

Title: GPS telemetry reveals changes in the movement patterns of a cinereous vulture (*Aegypius monachus*) flying over an active war zone

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Abstract

Armed conflicts have devastating effects over wildlife populations and ecosystems, yet their impacts on wildlife behavior remains understudied. In this study we summarized behavioral changes that occurred in a Cinereous Vulture (*Aegypius monachus*) which made three flights over active war zones in Northern and Eastern Ukraine during spring 2022.

As the individual approached the frontline its movements became more directional, with step lengths increasing progressively and turning angles becoming narrower. However, this only happened during the first flight, while changes were less marked in the two subsequent flights. Conversely, flying height did not show any change in any of the three flights.

The first and third flight, when the individual moved eastward towards more disturbed areas, happened under strong Western winds. This indicates that the individual could have been displaced by wind over active war zones, which would have otherwise avoided. Once there, the individual could have maximised wind support to evade disturbance.

Our findings, although based on data from only one individual, suggest that large soaring birds might be displaced by strong winds to active war zones, at least when flying in unfamiliar environments. Then, they might adapt their movement strategy reactively, by optimizing wind support, to escape these areas.

47 **Introduction**

48 Armed conflicts are well-known for their devastating consequences for wildlife and the
49 environment (Hanson et al., 2018). Conflicts and their large-scale use of explosives increase
50 wildlife mortality and produce large-scale damages to ecosystems (Wirtu and Abdela, 2015).
51 Moreover, in war zones, difficult economic conditions, coupled with increased armed violence,
52 often increase wildlife persecution (Bauer et al., 2022), poaching (Braga-Pereira et al., 2020;
53 Daskin and Pringle, 2018; Loucks et al., 2009; Mendiratta et al., 2021) and the unregulated
54 exploitation of natural resources (e.g. illegal logging, Daiyoub et al., 2023; Waśniewski et al.,
55 2026). The long time required by societies to fully recover from the social and economic
56 consequences of armed conflicts also makes these damages particularly long-lasting and hard to
57 remediate (Krampe et al., 2025).

58 Armed conflicts also have an undeniable influence on animal behavior and physiology. As
59 confirmed by many studies carried out on fireworks during holidays, explosions increase stress
60 in mammals and birds, sometimes with fatal consequences (Larkin et al., 1996; Bateman et al.,
61 2023). Moreover, contemporary warfare entails the mass use of Unmanned Aerial Vehicles
62 (UAVs), whose role as a source of disturbance for wildlife is increasingly being proven (Afridi et
63 al., 2025; Brissonne-Curadeau et al., 2024). Empirical research shows that armed conflicts alter
64 wildlife avoidance of humans (Gnanapragasam et al., 2021), activity rhythms (Kudrenko et al.,
65 2026) and feeding behavior (Yirga et al., 2025), with potential long-term consequences over
66 fitness. With respect to animal movement, explosions and shots can make individuals flush or
67 move away (Stalmaster and Kaiser, 1997; Hoekstra et al., 2023), with increased energetic costs
68 due to movement and stress (Kölzsch et al., 2022; Wascher et al., 2022) and a higher risk of
69 traumatic injuries (Petrov et al., 2026).

Widespread disturbance caused by explosions in active war zones, can be particularly problematic for diurnal raptors. These species typically move across the landscape through energetically-efficient routes, detected from specific landscape cues (Eisaguirre et al., 2020; Scacco et al., 2019). Whenever disturbance displaces large raptors from such optimal movement routes, these suffer from higher energetic costs (Bounas et al., 2026) and can experience a higher mortality (Oppel et al., 2015). Yet available evidence of the impact of armed conflicts over the behavior of raptors remains extremely limited. To the best of our knowledge, only Russell et al. (2024) showed that the Russo-Ukrainian war altered the migration route of Greater Spotted Eagles (*Aquila clanga*), while Literák et al. (2025) speculated that the same conflict could have led a Steppe Buzzard (*Buteo vulpinus*) to shift its summer range. This gap is caused by the widespread use of GPS jamming or spoofing in war zones (Gradev et al., 2026; Jiguet et al., 2025), which often compromises the quality of satellite telemetry data, and by difficulties in retrieving data from the field, whenever these cannot be transmitted remotely. There is therefore an urgent need to gather as much evidence as possible about changes in the movement patterns of raptors in active war zones, even from a few individuals, to gain further insights on the nature and magnitude of these changes.

As many raptors have an extremely developed eyesight that allows them to detect objects from great distances (Jackson et al., 2008; Cortés-Avizanda et al., 2014), in principle they could spot UAVs and explosions from dozens of kilometers. This possibility could be further strengthened by the capacity of birds to hear explosions from great distances (Duttenhefner and Klug, 2024). Raptors could therefore adapt their movements proactively to active war zones, by changing them in advance through disturbance cues. Proactive strategies include macro-avoidance of entire high-risk areas, or meso-avoidance on the vertical plane, with animals reaching safe flying

heights. Alternatively, it is possible for raptors to behave reactively, by adapting their movement in response to disturbance over short spatial scales, once in proximity or inside of an active conflict zone, and by changing their movements on the horizontal plane (see the Methods). In this study we gave a small contribution to address this knowledge gap, by providing insights on the movement of a Cinereous Vulture (*Aegypius monachus*), which flew over Ukraine at the onset of the Russo-Ukrainian war in spring 2022. Our findings emphasize marked changes in movement patterns, which became considerably more directional as the individual approached the front line, and the potential role of strong winds over vulture displacement in dangerous areas.

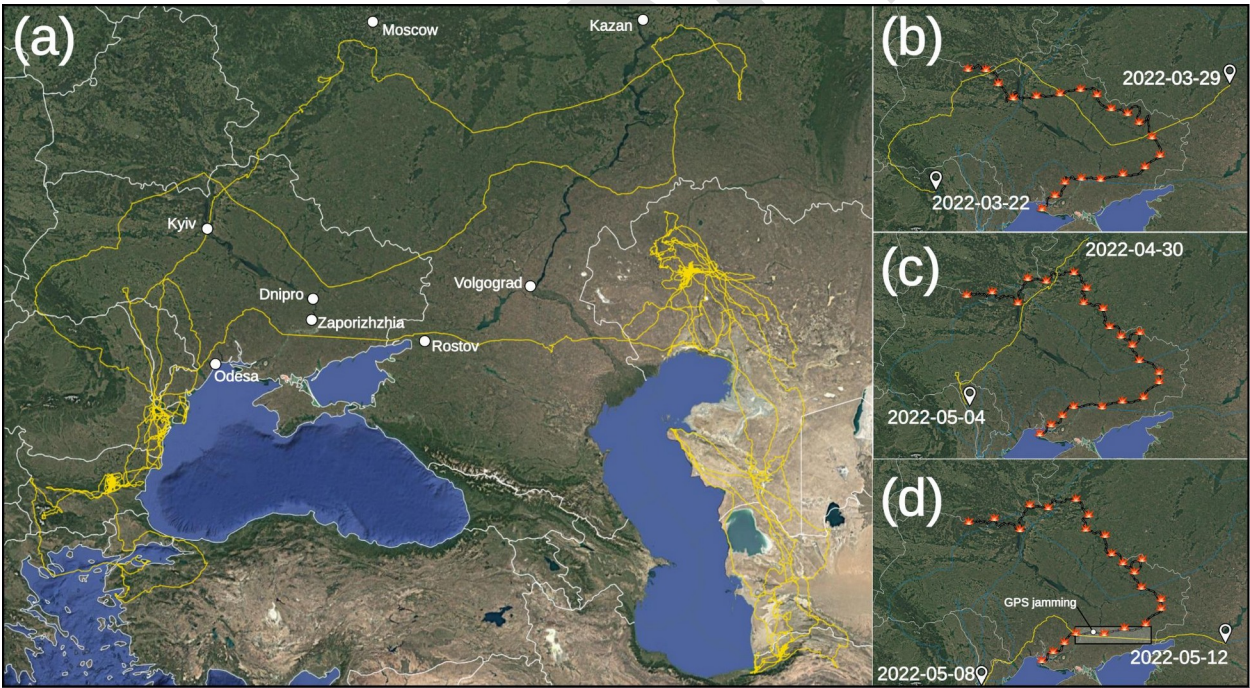


Fig. 1 Overview of the movements of A1 - DJURANLYI (a), as well as the first (b), second (c) and third (d) flight across Ukraine. The front line is represented in panels (b), (c), and (d)

108 **Methods**

109 **Data collection**

110 Our data collection is based on “A1 - DJURANLYI”, a male individual of Cinereous Vulture
111 that was released in Bulgaria, at the Simite Kamani, on 2021-03-10. A1 - DJURANLYI was in
112 its second year of age when released, having been recovered in Spain, then used for restocking
113 within the Bright Future for Black Vulture LIFE14 NAT/BG/649
114 (<https://vulturesback.greenbalkans.org/>, Ivanov et al., 2022). Within the Bright Future for Black
115 Vulture, individuals were marked according to NAMEPROCEDURE and then equipped with
116 GPS/GMS transmitters (Ornitela, Ot-50 , weight – 50 gr), following procedures authorized by
117 the Bulgarian ministry for the environment. Tags were programmed to collect GPS locations
118 from dawn to dusk, and for A1 - DJURANLYI they collected a total of 43,206 GPS locations
119 (Fig. 1). In its first year after release, A1 - DJURANLYI initially remained mostly around the
120 release site, then progressively increased its movements across Bulgaria, Romania, Greece,
121 Türkiye and Moldova, in line with the long-distance post-release movements of Cinereous
122 Vultures (Rousteau et al., 2023).

123 From 2022-03-22 to 2022-03-28, A1 - DJURANLYI engaged in first a long range movement
124 from the Zakarpattia to the Zhytomyr Oblast in Ukraine, then into Belarus, then across Eastern
125 Ukraine, finally entering the Voronezh Oblast in Russia. During this flight the individual crossed
126 active war zones, subjected to shellings and drone attacks, particularly around Kiev (Fig. 2).

127 After this first flight, A1 - DJURANLYI moved North-East, up to the Republic of Bashkortostan
128 (2022-04-17) and then back to the surroundings of Moscow (Fig. 1). Then, A1 - DJURANLYI
129 moved south and crossed against Ukraine, from the Chernihiv to the Vinnytsia Oblast, and then

to Moldova, between 2022-04-30 to 2022-05-03. This second flight happened further away from the front line, due to the concentration of battles in Eastern Ukraine (Fig. 3).

A1 - DJURANLYI finally engaged in another flight over Ukraine, between 2022-05-08 and 2022-05-12, from the Odessa Oblast to the Donetsk Oblast. GPS locations were however subjected to jamming, on 2022-05-11 when the A1 - DJURANLYI crossed the most active section of the front line on the Zaporizhzhia Oblast (Fig. 4).

After this last flight over Ukraine, A1 - DJURANLYI reached Kazakhstan on 2022-05-16 and since then moved between Kazakhstan, Uzbekistan, Turkmenistan and Iran, where it died on 2023-01-04 from lead poisoning and or depredation by Golden Jackal (*Canis aureus*) (Ivanov et al., 2024; Fig. 1).

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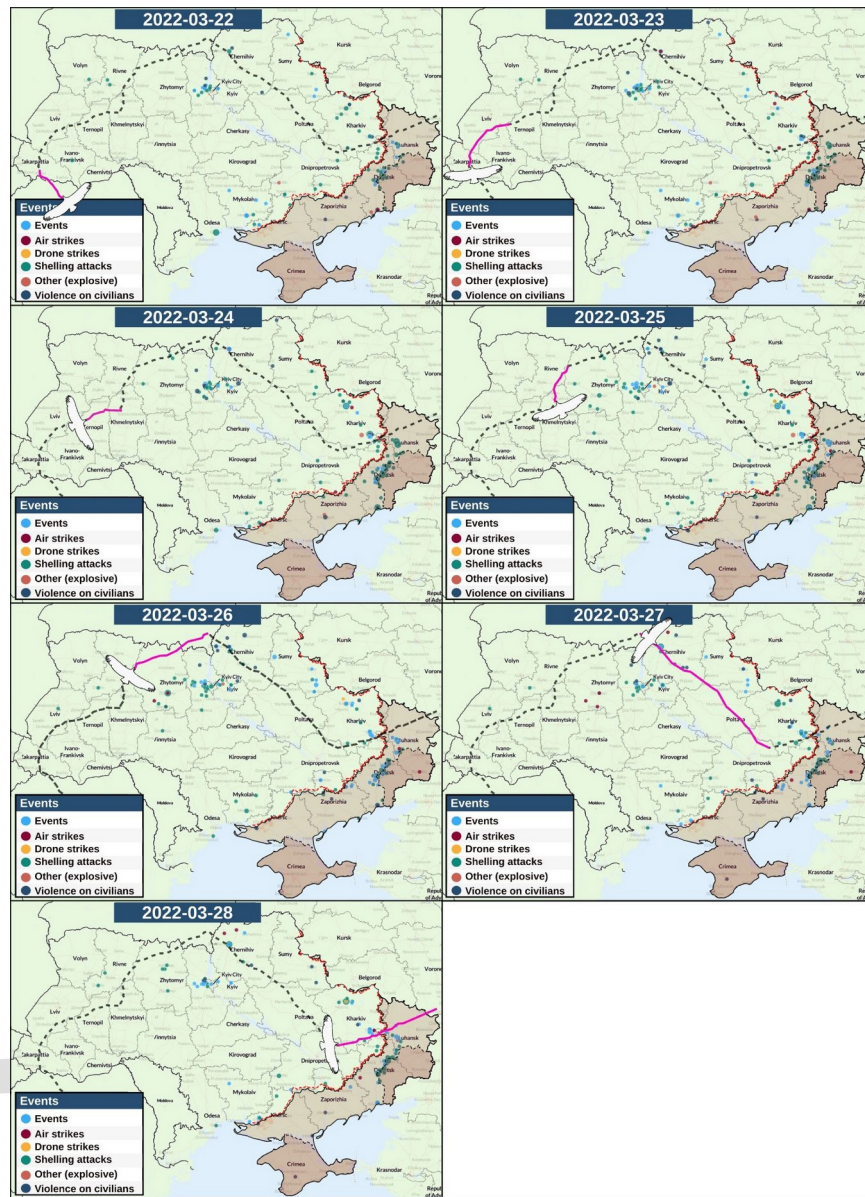


Fig. 2 Overview of daily movements of A1 - DJURANLYI, during its first flight across Ukraine, with respect to the active war zone. Maps have been downloaded from ACLED (<https://acleddata.com/monitor/ukraine-conflict-monitor>)

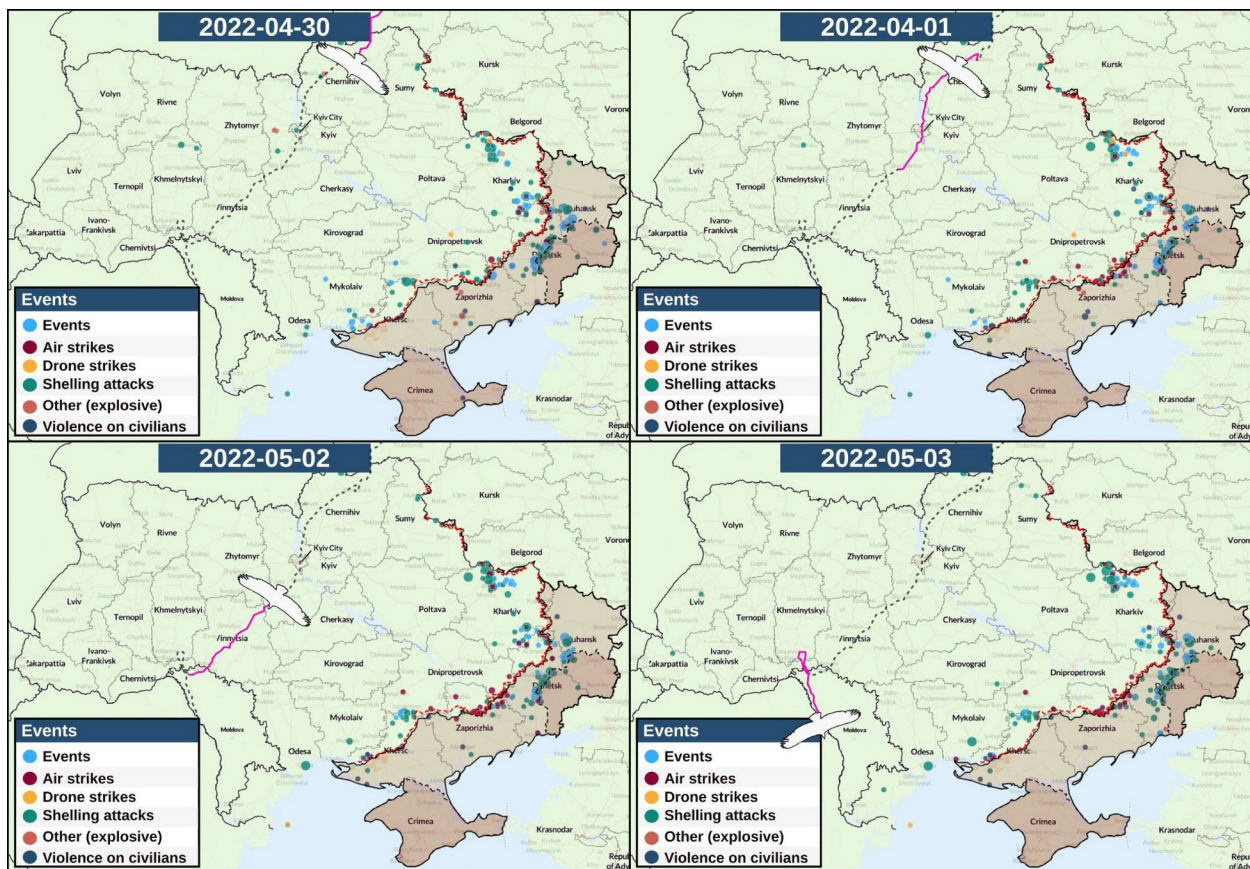


Fig. 3. Overview of daily movements of A1 - DJURANLYI, during its second flight across Ukraine, with respect to the active war zone. Maps have been downloaded from ACLED (<https://acleddata.com/monitor/ukraine-conflict-monitor>)

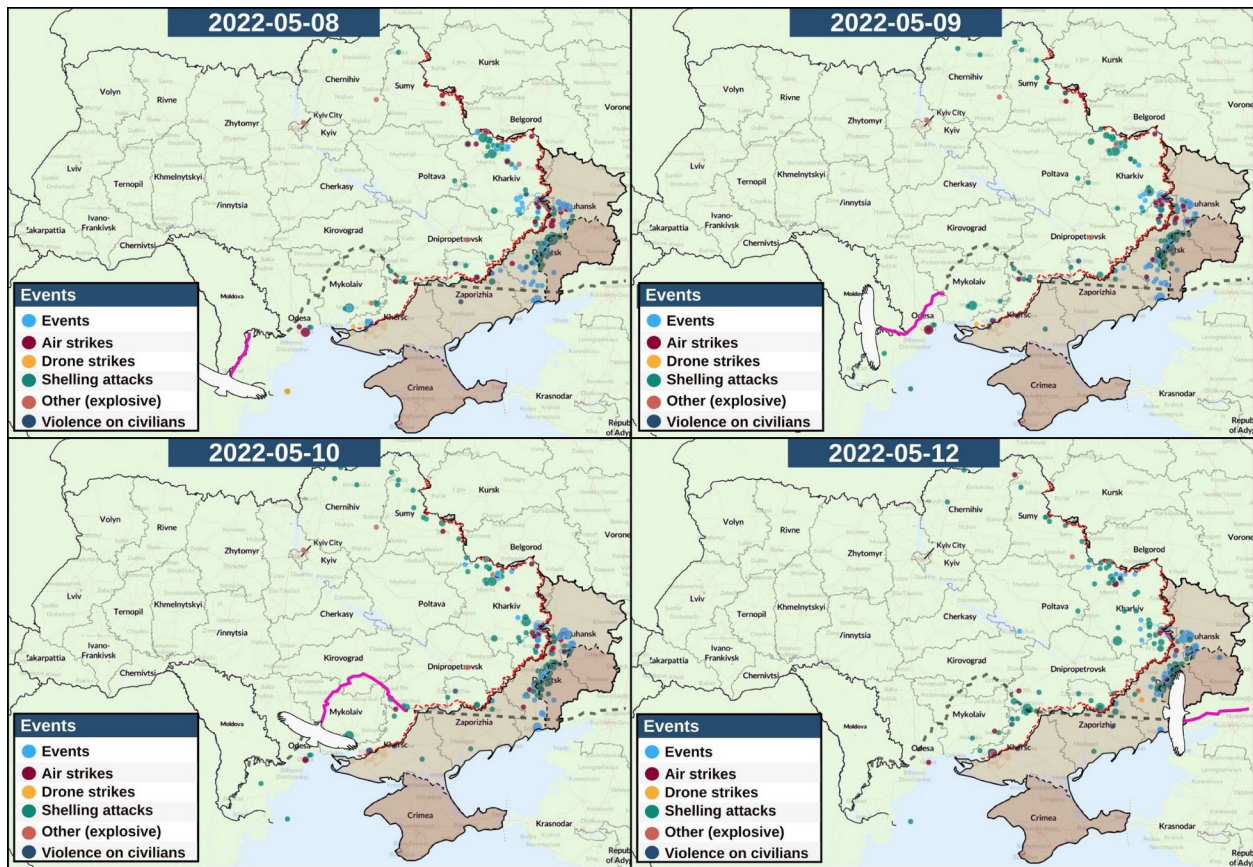


Fig. 4. Overview of daily movements of A1 - DJURANLYI, during its third flight across Ukraine, with respect to the active war zone. The movement track from 2022-05-11 is not displayed, due to the occurrence of GPS jamming. Maps have been downloaded from ACLED (<https://acleddata.com/monitor/ukraine-conflict-monitor>)

Data pre-processing

We subset the complete dataset, to obtain only GPS locations relative to those days when A1 - DJURANLYI crossed Ukraine: from 2022-03-22 to 2022-03-28 (first flight), from 2022-04-30 to 2022-05-03 (second flight) and from 2022-05-08 to 2022-05-12 (third flight, Fig. 1 - Fig. 4). We then removed GPS locations with HDOP ≥ 3 . As we were interested in changes relative to movement patterns, we graphically explored the data to remove GPS observations associated with the animal being stationary (e.g. perching on a tree), and retained only those associated with

a clear movement trajectory. Stationary locations referred to the individual stopping for more than 1 hour in a radius of 300-500 m. These were mostly concentrated early in the morning and in the afternoon, when A1 - DJURANLYI stopped moving and rested on vegetation or on the ground.

For each daily movement trajectory then we calculated step length, expressed as the Euclidean distance between two consecutive GPS locations, and turning angles between consecutive steps. We did not calculate step length and turning angles between consecutive GPS locations collected on two consecutive days, as tags were programmed not to collect locations at night. We found no anomalies in GPS length and turning angles, which respected the characteristic shape of a “copula”, with longer steps being associated with smaller turning angles.

We calculated flying heights by calculating the difference between values provided by the altimeter and the Amazon AWS DEM, with a 250m resolution. Considering that some of the fly heights were negative, after a graphical inspection of their distribution (see Fig. S1 in Appendix 1), we decided to remove these values and also positive fly heights within 60 meters from the ground. Moreover, due to clear evidence of GPS interference, we decided to exclude GPS locations, collected on 2022-05-11, corresponding to the individual flying over the Zaporizhzhia Oblast.

Then, for each GPS location, we calculated its distance from the front line, estimated from official Wikipedia maps about the war and official ACLED maps (<https://acleddata.com/monitor/ukraine-conflict-monitor>, see Appendix 2). We used two different front lines for the first and the other two flights, due to the different geographical distribution of battles between March 2022 and April-May 2022 (Fig. 2 - Fig. 4). The distance from the front line was then used as a proxy for increased disturbance associated with the war zone, as most

strikes and explosions in 2022 were concentrated around it (Fig. 2 - Fig. 4). However, it should be kept in mind that the front line had a dynamic nature, with some explosions occurring even dozens of kilometers from it. Moreover, the individual could have been exposed to some disturbance, even at a great distance from the front-line, for example due to UAVs. Therefore, the distance from the front line should be interpreted as a relative index of increased disturbance due to the active war zone.

To account for wind conditions during flight, which can occasionally displace vultures (Cerri et al., 2026; Cortés-Avizanda and Tavecchia, 2021) we downloaded the u- and v- component of the wind from the ECMWF reanalysis dataset (<https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels?tab=overview>). Wind components had a resolution of 1 hour and approx. 30 km and were downloaded for the pressure level of 950hPa, corresponding to the height of most GPS locations.

Hypotheses

Considering that A1 - DJURANLYI flew directly over an active war zone, characterized by a considerable amount of disturbance due to explosions and the presence of UAVs, we tested for two different movement tactics.

In case that the individual adopted a proactive approach, by hearing explosions or seeing UAVs from distance, we predicted it to increase its fly height when approaching the front line. Once at a safe height of thousands of metres, the individual would have maintained the same levels of step lengths and turning angles. This hypothesis is motivated by the considerable flying height of thousands of meters at which vultures can fly and by the fact that large birds are known to increase their flying height to avoid disturbances (Khosravifard et al., 2020; Kimani et al., 2025;

Johnston et al., 2014), including explosions (Kölzsch et al., 2023). Reaching a safe flying height of a few thousand metres would have allowed our individual to avoid explosions as well as quadcopters and smaller drones, which generally fly within 1,500 m from the ground (<https://www.military-hub.com/how-high-do-military-drones-fly-uav-altitude-by-type/>).

Therefore, in case of a proactive approach our prediction (Hypothesis 1, H_1) was that the individual did not change its step length and turning angles, but increased its flying height.

In case of a reactive approach, with the individual only perceiving disturbance sources from relatively close distance (e.g. a few kilometers or hundreds of meters), we predicted its step length and turning angles to change as it approached the front line. Namely, an animal trying to evade the active war zone as soon as possible probably moves directionally, with turning angles showing decreasing levels of heterogeneity and step lengths an increasing size. However, as moving in a vertical direction is more complex than moving horizontally, from a biomechanical viewpoint, due to the need of locating and using updrafts, the continuous disturbance would prevent the individual from engaging in complex soaring by using thermals and updraft, producing no remarkable change in its flying height (H_2).

Despite integrated Step Selection Analysis (iSSA) can be used to quantify changes in step length and turning angles due to environmental covariates (Arce Guillen et al., 2025), we did not use this method to formally test for a differential use of wind support, with respect to the distance from the front line. This choice was motivated by a significant mismatch between the temporal/spatial resolution of our GPS locations, which at full charge were collected every 10 minutes and that of ECMWF data, which were collected every hour. Our interpretation of wind conditions and their potential influence over observed changes in the movements of A1-

DJURALNYI was therefore purely qualitative and future studies, based on multiple individuals, are needed to fully leverage on iSSA and study changes in animal behavior.

Statistical analyses

We tested these hypotheses by using Bayesian Generalized Additive Models (GAMs), fitted in STAN (Carpenter et al., 2017), through the brms package (Bürkner et al., 2017). Model selection was carried out by means of leave-one-out cross validation (Vehtari et al., 2017). We used Gaussian Processes (Wood et al., 2017) for modeling non-linear effects. Namely, we quantified the effect of distance from the front line, and the three flights, in three different models, predicting: *i*) the mean of step lengths, *ii*) the mean flying height and *iii*) the variance of turning angles.

For step lengths and flying heights we used a skewed Gaussian distribution, while for turning angles a von Mises distribution. For turning angles we used distributional models (Klein et al., 2024), quantifying changes in the precision (the inverse of the variance) of the response. For further information about the parameterization of distributions in brms, please see: https://cran.r-project.org/web/packages/brms/vignettes/brms_families.html#location-shift-models

Model covariates included the distance from the front line, as well as a categorical covariate indicating whether GPS locations belonged to the first, the second or the third time that the individual crossed the front line. We also added an interaction term to quantify differences in the effect of the distance from the front line, between the three flights. This accounted for the dynamic nature of the conflict, with the animal experiencing different intensity of the conflict from one crossing to another. A complete overview of model selection is provided in Appendix1.

Results

Overall, we retained a final dataset of 714 GPS locations, 648 of which also had complete values of flying height (588 ± 350.884 m, median $\pm$ sd). Locations were collected every 10 ± 0.13 minutes (median $\pm$ sd).

All our three models for step length, turning angles and flying height showed a good fit to the data (Fig. S2, Appendix 1). However, model selection for flying height did not identify any effect of the distance from the front line, simply remarking a difference in the overall flying height of the three flights (Fig. S3, Appendix 1).

Model selection indicated that precision in turning angles, the inverse of variance, decreased as GPS locations were further away from the front line (Table 1). In other words, as the animal moved towards the front line, variation between turning angles progressively diminished. However, this effect occurred only in the first and in the third flight, when A1 - DJURANLYI moved across highly disturbed sections of the frontline.

Table. 1. Overview of model coefficients for the Bayesian GAM predicting the variance in turning angles. Kappa refers to the precision, or the inverse of the variance.

	Estimate	Lower bound of 95% CI	Upper bound of 95% CI
Intercept	0.88	0.75	1.01
Distance from the front line	-0.31	-0.46	-0.17
Second flight	-0.04	-0.25	0.17
Third flight	0.02	-0.23	0.26
Distance:second flight	0.45	0.23	0.68
Distance:third flight	0.13	-0.17	0.43

Finally, model selection for step lengths retained a best candidate model that accounted well for non-linear changes in step lengths (Fig. S4-S5, Appendix 1). The best candidate model indicated that step lengths decreased, as the animal moved further away from the front line. This also means that in the most disturbed areas of the war zone, around the front line, A1 - DJURANLYI moved faster. This pattern was observed for all the three flights, but was much clearer during the first one, when A1 - DJURANLYI flew over Northern Ukraine (Fig. 5).

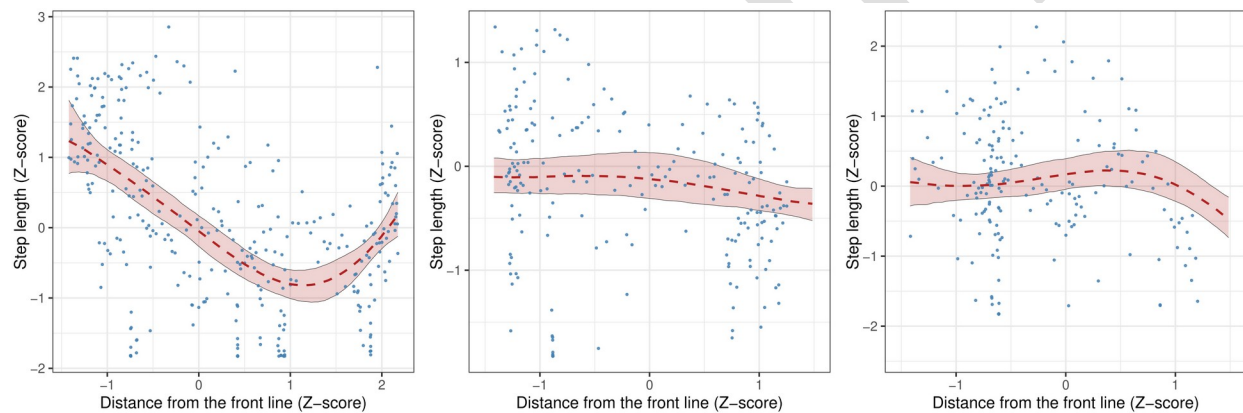


Fig. 5. Conditional effect plots, representing the effect of the distance from the front line, over the length of movement steps. Both variables have been converted to Z-scores, and are expressed as standard deviations from the mean. Plots refer to the first flight (left), the second (center) and the third (flight) over Ukraine.

Discussion

To the best of our knowledge, this is the only study, apart from Russel et al. (2024), to have properly quantified changes in the movement strategy of diurnal raptors flying over an active war zone. Although based only on the movements of a single Cinereous Vultures, we believe our findings to pinpoint two main issues which are useful from a conservation viewpoint.

313 The first one is the lack of any clear proactive strategy by our individual, which flew over
314 Ukraine on three separate occasions, crossing active war zones. On all three occasions,
315 particularly during the first and the last flight, A1 - DJURANLYI passed across areas with a high
316 number of explosions and UAVs, which should have been completely avoided. Even when
317 considering the possibility of avoidance on the vertical plane (H_1), we did not detect any
318 significant change in flying height. This indicates that the individual did not cross high-risk areas
319 at a safety height of thousands of metres, which would have allowed him to evade explosions
320 and smaller UAVs. While large raptors increase their flying height to surpass obstacles or avoid
321 static sources of disturbance (Khosravifard et al., 2020; Kimani et al., 2025; Johnston et al.,
322 2014), this approach is probably impossible to adopt whenever disturbance is dynamic and
323 widespread, like in a war zone. Vultures need to locate and use updrafts to increase their flying
324 height, a strategy which requires complex maneuvers (Harel et al., 2016), and which probably
325 becomes impossible when they are systematically disturbed by explosions and/or UAVs.

326 The lack of a proactive avoidance strategy, coupled with changes in step lengths and turning
327 angles around the front line, is particularly interesting when considered altogether with wind
328 conditions (Table 2). During its first flight, A1 - DJURANLYI flew across Western Ukraine, up
329 to the surroundings of the city of Równe, under relatively mild wind conditions. Then from the
330 26th to the 29th of March, Ukraine was subjected to strong Western winds, whose strength was
331 that of a “Near Gale”, according to the Beaufort scale
332 (<https://www.rmets.org/metmatters/beaufort-wind-scale>). Strong winds can displace vultures
333 over large distances (Cerri et al., 2026; Cortés-Avizanda and Tavecchia, 2021) and it is therefore
334 plausible that A1 - DJURANLYI was displaced up to the active war zone around the front line.
335 At this point it could have decided to escape disturbance by optimizing wind support, moving

eastwards up to the Voronezh Oblast. This would explain the joint pattern of step lengths and turning angles, which indicated highly directional and fast movement around the front line (H_2), which then disappeared once the animal was further away from danger.

Strong winds from West/South-West also characterized the third flight, where changes in step lengths and turning angles were however less pronounced. Indeed, it is possible for these patterns to have been partially smoothed by GPS jamming. In fact, data was missing for 2025-05-11, when the animal was flying over the front line between Nikopol' and Mariupol (Fig. 1, Fig. 4, Fig. 6). Indeed, when exploring step lengths before and after the front-line, we noticed an increase soon after the beginning of the front line, which at that time was around Nikopol' and a decrease only at 300 km from it (Fig. 6), only when the animal was already well inside the Russian Federation. The second flight over Ukraine might instead be explained with an attempt to go South, by using relatively mild Northern winds, as the areas of the Russian Federation visited in March and April 2022 were far Northern than the known range of the species (<https://datazone.birdlife.org/species/factsheet/cinereous-vulture-aegypius-monachus>).

Table. 2. Overview of daily wind strength (km/h) and wind direction (degrees North) during each one of the three flights over Ukraine made by A1 - DJURANLYI. Values for 2022-05-11 are missing, as there were no GPS locations.

Date	Flight over Ukraine	Wind strength (km/h, median $\pm$ sd)	Wind direction (degrees North, median $\pm$ sd)
2022-03-22	First	14.5 $\pm$ 6.83	40.6 $\pm$ 67.8
2022-03-23	First	7.74 $\pm$ 3.74	33.2 $\pm$ 160
2022-03-24	First	29.8 $\pm$ 6.69	331 $\pm$ 102
2022-03-25	First	9.99 $\pm$ 4.07	325. $\pm$ 142
2022-03-26	First	57.1 $\pm$ 5.12	273 $\pm$ 3.83

2022-03-27	First	56.9 ± 2.12	320 ± 3.31
2022-03-28	First	39.0 ± 3.51	279 ± 11.7
2022-04-30	Second	14.4 ± 1.41	336 ± 147
2022-05-01	Second	5.4 ± 2.35	48.7 ± 24.0
2022-05-02	Second	11.0 ± 2.75	155 ± 23.1
2022-05-03	Second	11.9 ± 1.38	198 ± 14.2
2022-05-08	Third	18.3 ± 3.62	125 ± 16.8
2022-05-09	Third	6.07 ± 6.14	306 ± 25.5
2022-05-10	Third	21.2 ± 3.79	329 ± 131
2022-05-12	Third	29.2 ± 5.00	273 ± 7.03

From a conservation viewpoint our results indicate that armed conflicts could be extremely problematic for vultures. Whenever individuals move around active conflict zones, for example during movements associated with dispersal, foraging or prospecting, strong winds can displace them over front lines spanning hundreds of kilometers. At that point, without being capable of reaching safe flying heights, due to continuous disturbance from explosions and UAVs, individuals could optimize wind support to escape from these areas, being displaced. While displacement and long-range movements are not unusual for these species and could potentially benefit isolated populations (Agudo et al., 2010), of course this can pose individuals in extremely dangerous contexts. Vultures crossing war zones could die because of the shock of explosions, or being accidentally targeted by UAVs or being mistaken for UAVs by defense forces, due to their size and shot down.

Finally, although optimizing wind support, it is possible that vultures still resort to flapped flight to evade war zones, suffering major energetic costs (Duriez et al., 2014). Future studies based on

370 accelerometers and well-calibrated machine learning algorithms for behavioral states (Vaadia et
371 al., 2025) should quantify the extent to which vultures resort to flapped flight, when moving in
372 active war zones. Understanding this point would be crucial to better understand the
373 bioenergetics costs of flying in these dangerous environments.

374 Another important gap that needs to be addressed is to understand the extent to which the
375 disturbance caused by active war zones can disrupt collective movement strategies (Berdahl et
376 al., 2018). Many soaring birds rely on conspecifics for navigating the landscape, an aspect
377 which, in synergy with individual flight experience, can significantly improve their flight
378 performances (Brønnvik et al., 2024; Sassi et al., 2024; Williams et al. 2018). Under continuous
379 disturbance, these groups might be disrupted, with a decrease in movement efficiency. Future
380 studies, based on the simultaneous analysis of the movement tracks of multiple individuals,
381 should address this gap.

382 Considering the high number of armed conflicts around the world, some of which occur in areas
383 that are important for the conservation of terrestrial vertebrates, or that are migratory bottlenecks
384 (e.g., the Levantine; e.g. the Strait of Hormuz; e.g. Sudan; e.g. the Strait of Bab-al-Mandeib) we
385 encourage further research about animal movement in war zones. While the availability of
386 satellite telemetry data is certainly curtailed by GPS jamming or spoofing, as well as by risks
387 associated with retrieving location and accelerometer data from the field, we believe the
388 increasing availability of biologging data and accurate data on conflicts (e.g. ACLED,
389 <https://acleddata.com/>) to open considerable possibilities for participatory research. This would
390 allow researchers to better understand the decision-making of animals moving in active war
391 zones and therefore some of the ecological, physiological and behavioral mechanisms, through

which these impact on the well-being and fitness of wildlife, ultimately posing a challenge for their conservation.

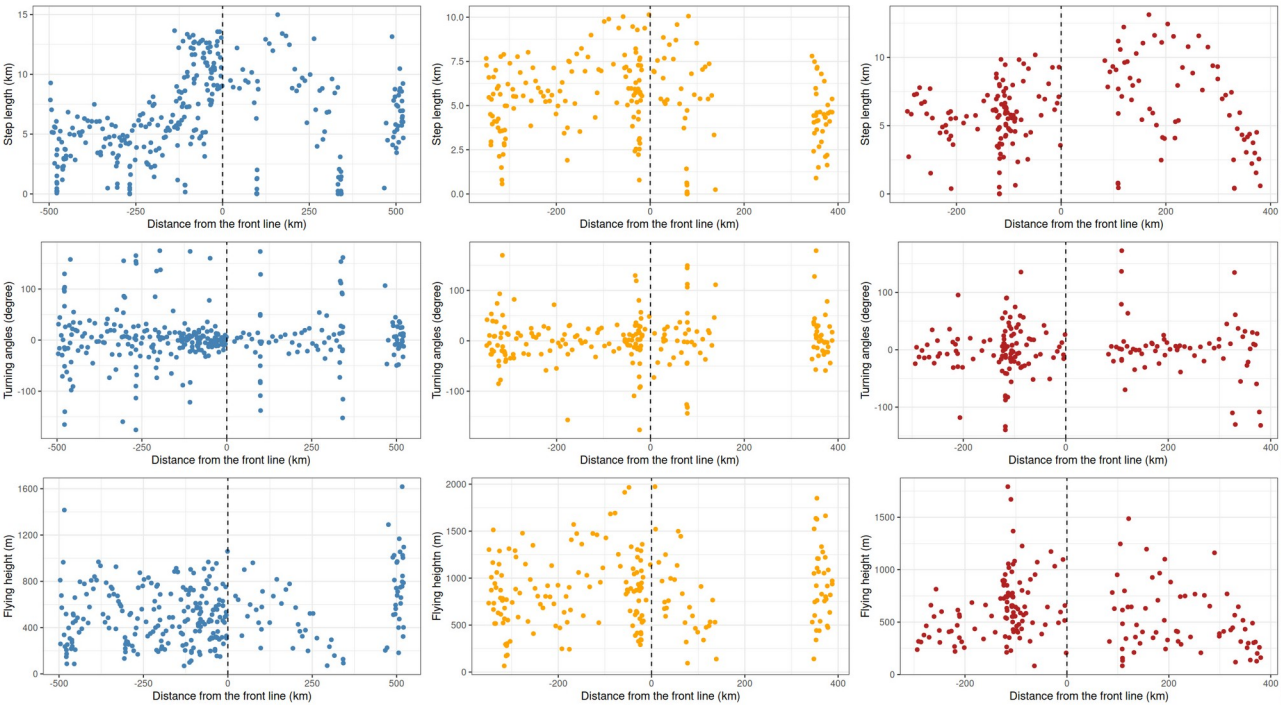


Fig. 6. Scatter plot representing the step lengths (top row), turning angles (middle row) and flying height (bottom row), with respect to their distance from the front line. Values on the left of the vertical line refer to GPS locations before the animal reaches the front line, while values on the right refer to GPS locations once the individual has crossed it. Values refer to the first flight over Ukraine (left column), as well as to the second (center column) and third flight (right column)

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Data availability statement

The reproducible data and software code are available on CodeBerg: https://codeberg.org/jacopocerri/Vulture_Ukraine as well as on GitHub: <https://github.com/JacopoCerri7/VulturesUkraine>

Conflict of interest

The authors declare no conflict of interest

Author contribution (CRediT)

Conceptualization: JC; Methodology: JC; Software: JC; Validation: JC, HP, CC, GG; Formal analysis: JC; Investigation: JC, HP, CC, GG; Resources: JC, HP, CC, GG; Data Curation: HP, CC; Writing - Original Draft: JC; Writing - Review & Editing: JC, HP, CC, GG; Visualization: JC, HP, CC, GG; Supervision: JC, GG; Project administration: JC, GG; Funding acquisition: JC, HP, CC, GG

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Appendix 1 - Overview of data processing and model selection

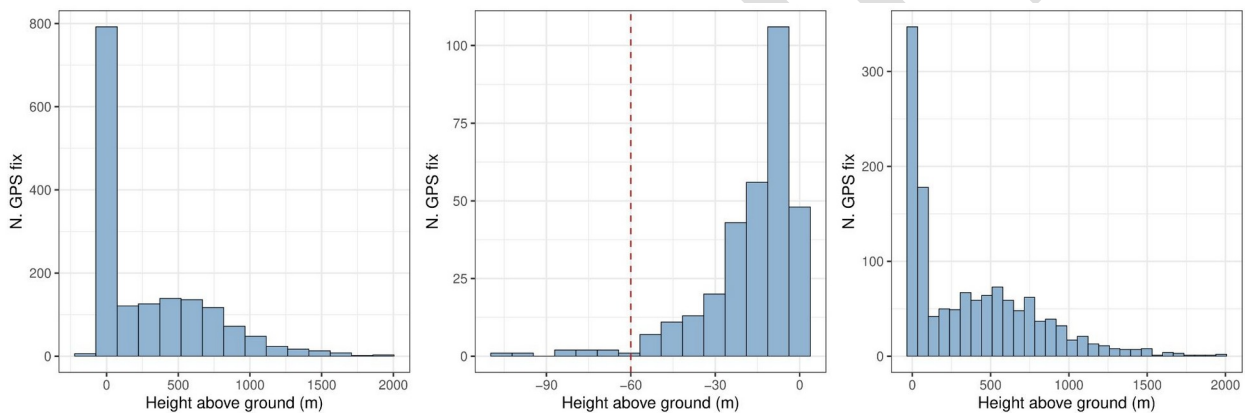
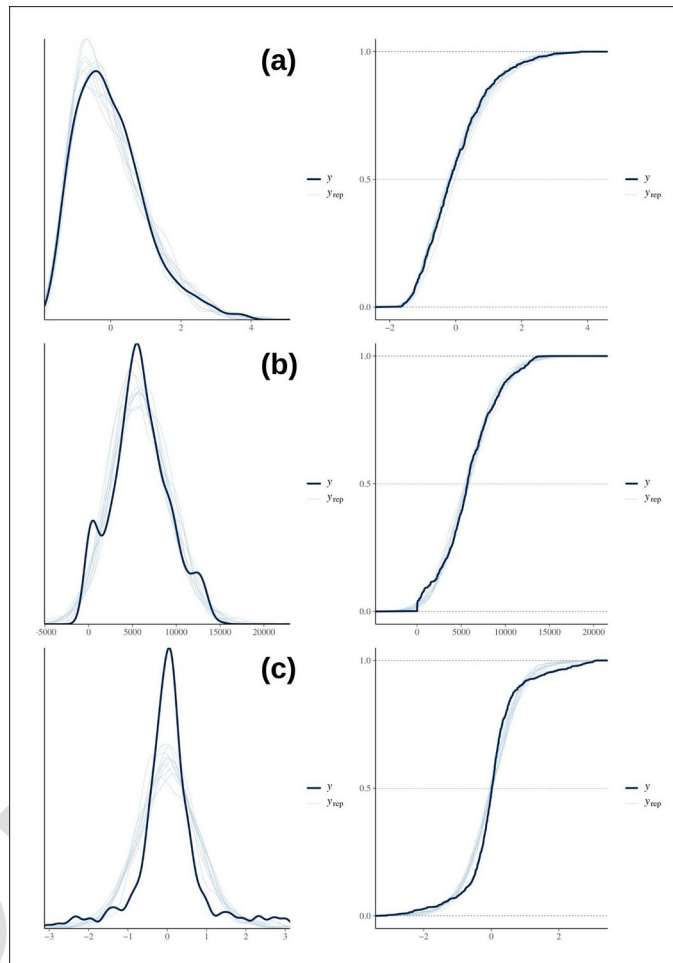


Fig. S1. Frequency of the flying height of GPS fix from the original movement track (a), then of fix with a negative flying height, indicating that vertical errors could be up to approx. 60m (b). Finally, overview of flying height after the removal of GPS fix with a flying height within 60 m from the ground.

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596 Fig. S2. Posterior predictive density plots for the model for flying heights (a), step lengths (b)

597 and turning angles. For further information on how to interpret them, please see:

598 https://paulbuerkner.com/brms/reference/pp_check.brmsfit.html

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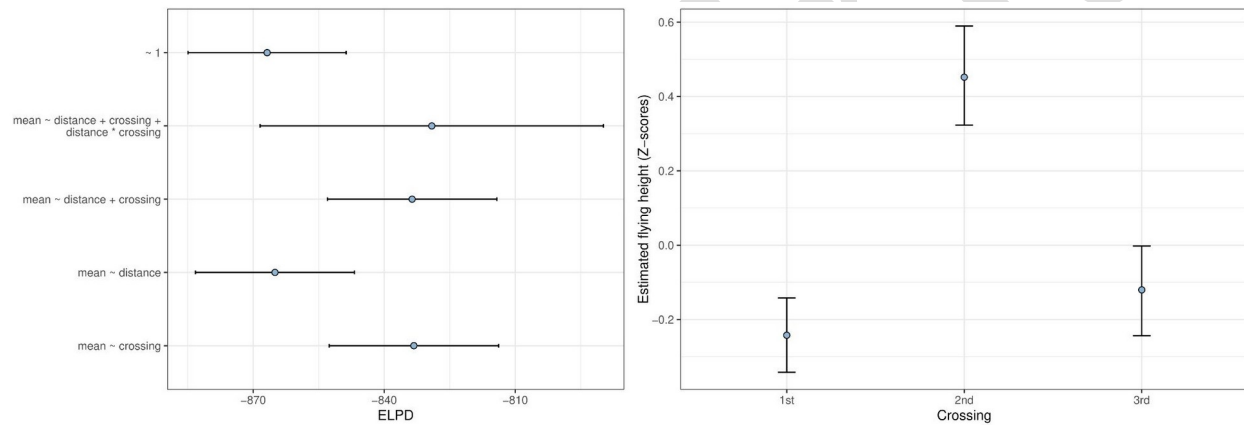
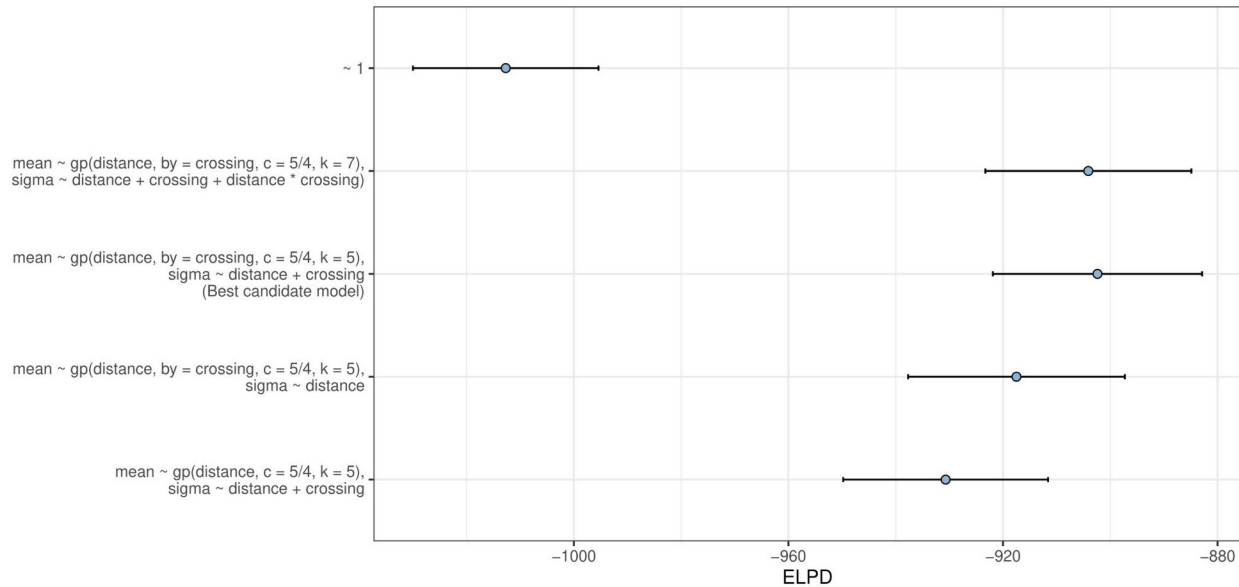


Fig. S3. Left: Expected Log-Pointwise Density of different models for flying height (for further information see, <https://users.aalto.fi/~ave/CV-FAQ.html>), indicating differences in model performances. The variable named “distance” corresponds to the distance from the front line, while the variable “crossing” to the flight over Ukraine. Right: overview of estimated flying height between the three flights over Ukraine.

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622 Fig. S4. Left: Expected Log-Pointwise Density of different models for step lengths (for further
623 information see, <https://users.aalto.fi/~ave/CV-FAQ.html>), indicating differences in model
624 performances. The variable named “distance” correspond to the distance from the front line,
625 while the variable “crossing” to the flight over Ukraine. The term “gp” refers to Gaussian
626 process, while the term “sigma” to the shape parameter of the skewed Gaussian distribution (see
627 https://paulbuerkner.com/brms/articles/brms_distreg.html).

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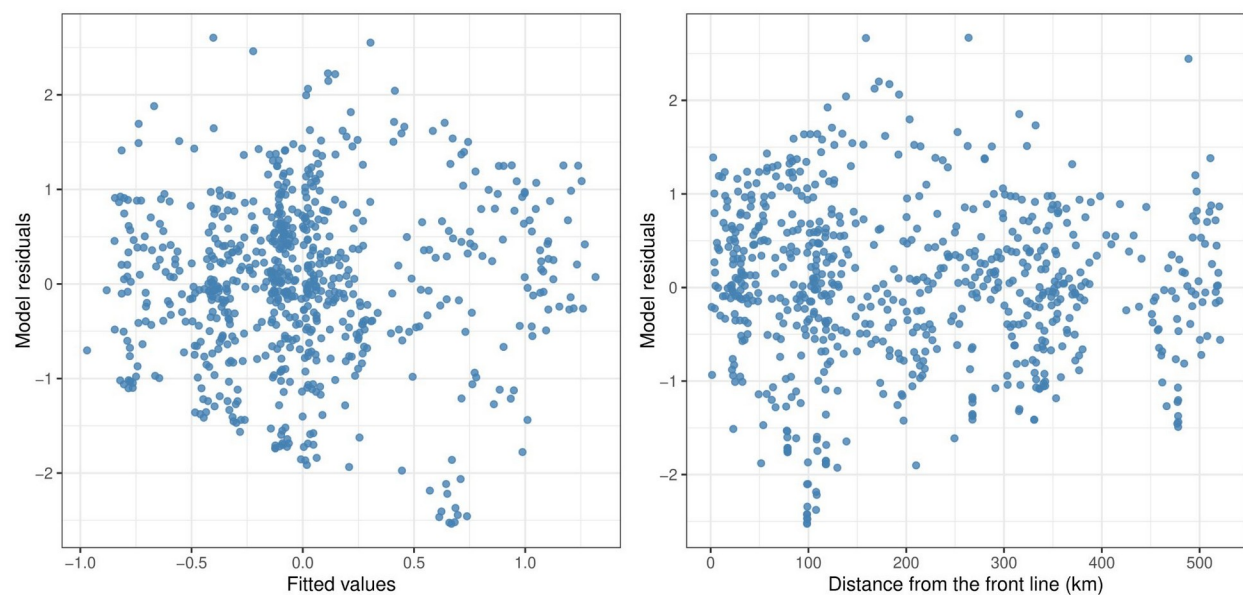


Fig. S5. Overview of model residuals (Z-score). Left: residuals versus fitted values, Right: residuals versus the distance from the front line.

Appendix 2 - Overview of the evolution of the war zone through time

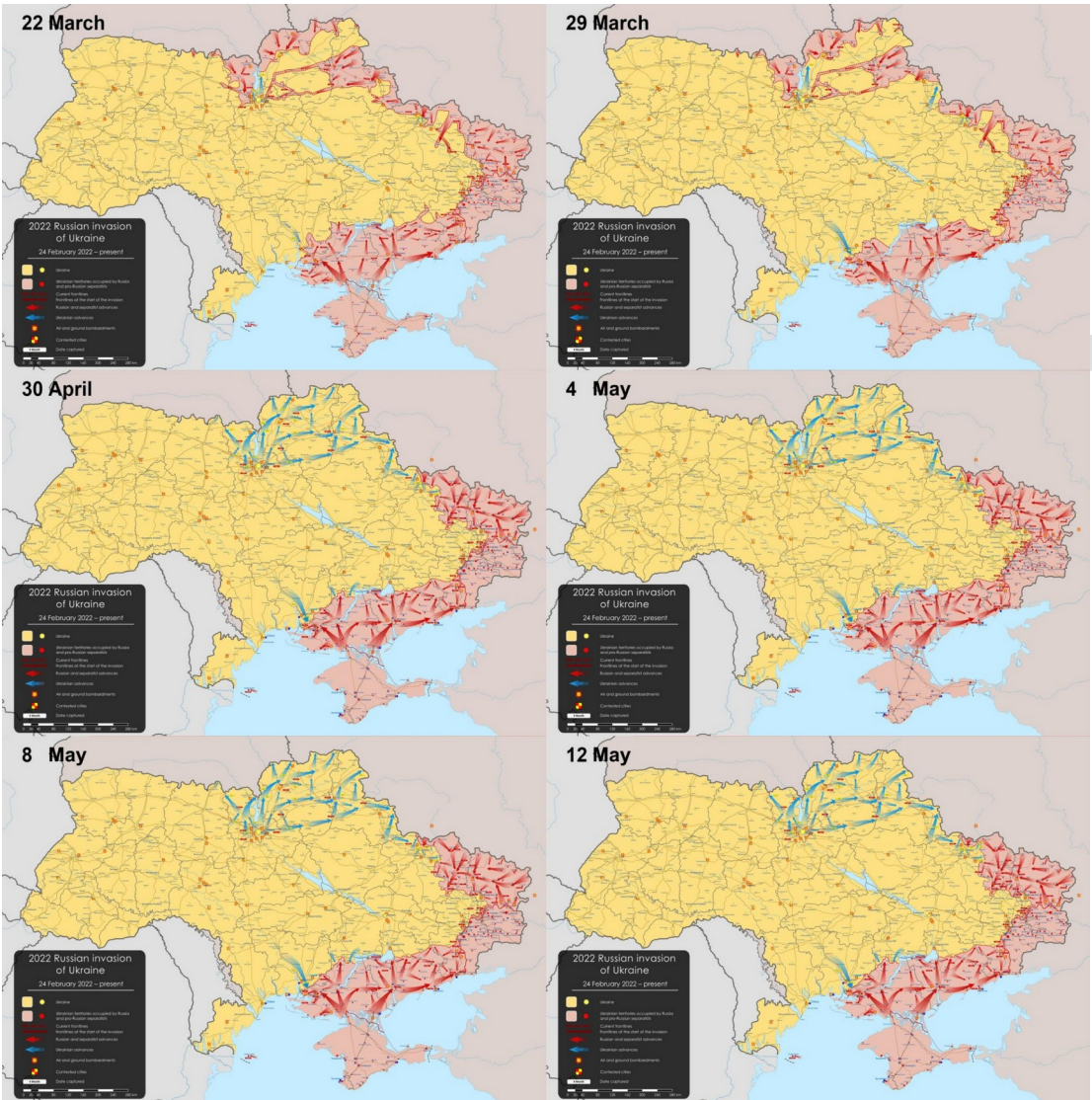


Fig. S6. Overview of the spatial distribution of the active war zone, according to Wikipedia (https://en.wikipedia.org/wiki/Russo-Ukrainian_war#/media/File:2022_Russian_Invasion_of_Ukraine_animated.gif)

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