Fig S1. Transparent gravity anomalies superimposed on Google Earth pictures reveal lack of associated landscape features. A) Release sites (red diamonds) and home directions (red arrows) within and behind the Boltishka gravity anomaly. The small city is Oleksandrivka, see also Fig S3. B) Overlap of Google Earth picture with gravimetric values (dG) of Boltishka anomaly. C) Overlap of Google Earth picture with horizontal gravity gradient corresponding to the rim of the gravity anomaly of Boltishka anomaly. See also Fig. s S2 – S6, and S8-S10). Note the lack of landscape features influencing flight directions of the pigeons. D) Google view of control site at Bogdanivka. There is also a small city in the neighborhood, and railways. E) Overlap of Google Earth picture with gravimetric values (dG) at Bogdanivka. F) Overlap of Google Earth picture with horizontal gravity gradient at control release site (see also Fig S5A). Google Earth Images from 2014 Digital Globe, 2014 CNES Astrium and 2014 Cnes Spot/Image.
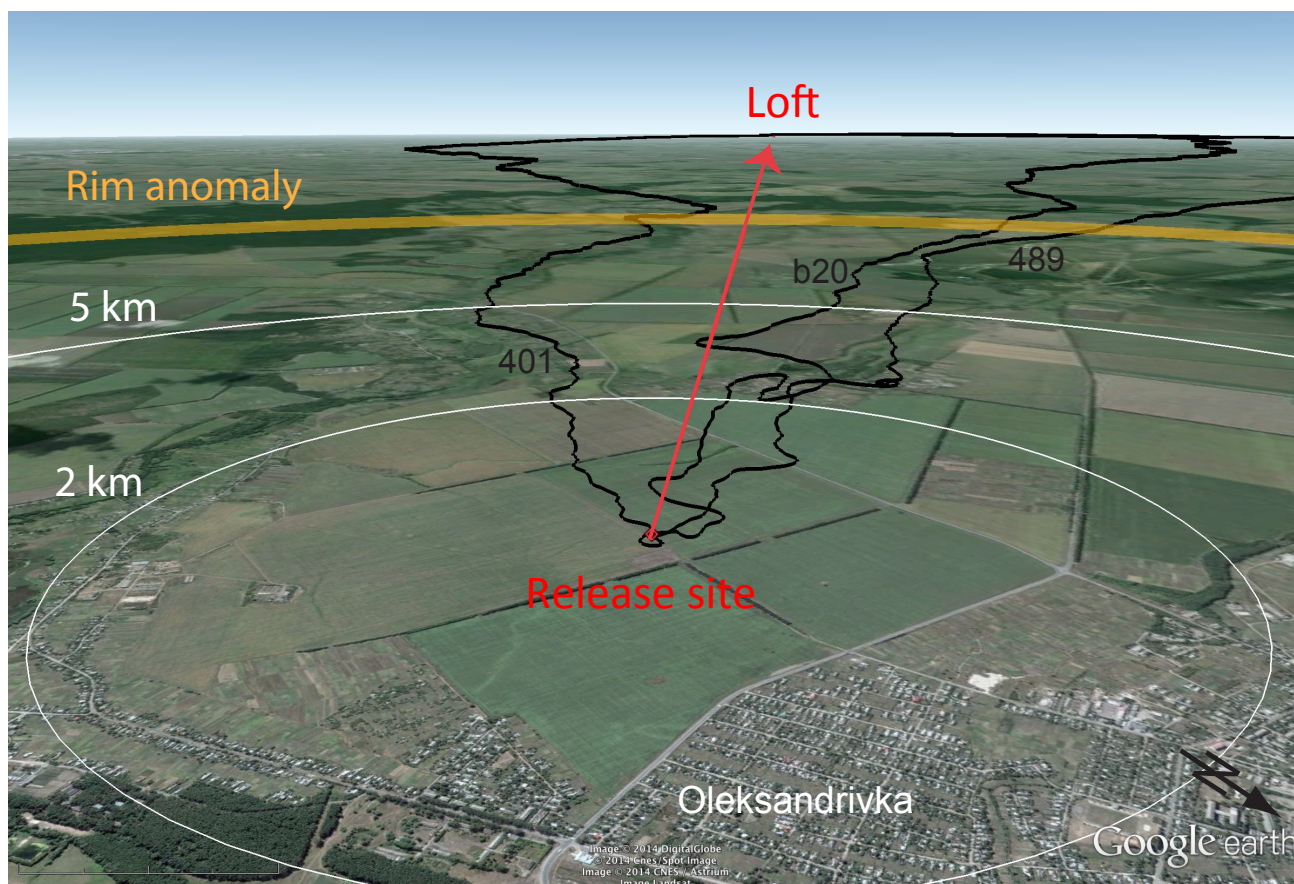
Fig S2. Large perspective view of Boltishka anomaly release site with three pigeon tracks. Orange line: approximate position of rim of gravity anomaly. Pigeon **401** follows the eastern of the two SW "exit channels" from the anomaly, pigeons **b20** and **323** follow the more western "exit channel". For details of tracks see also Fig. S5C (track 1 of **b20**), Fig. S6A (track 2 of **323**) and Fig. S8A (**401**). Picture provided by Google Earth Pro, Image 2014 Digital Globe, 2014 Cnes/SpotImage, Image 2014 CNES/ Astrium an, dImage Landsat.
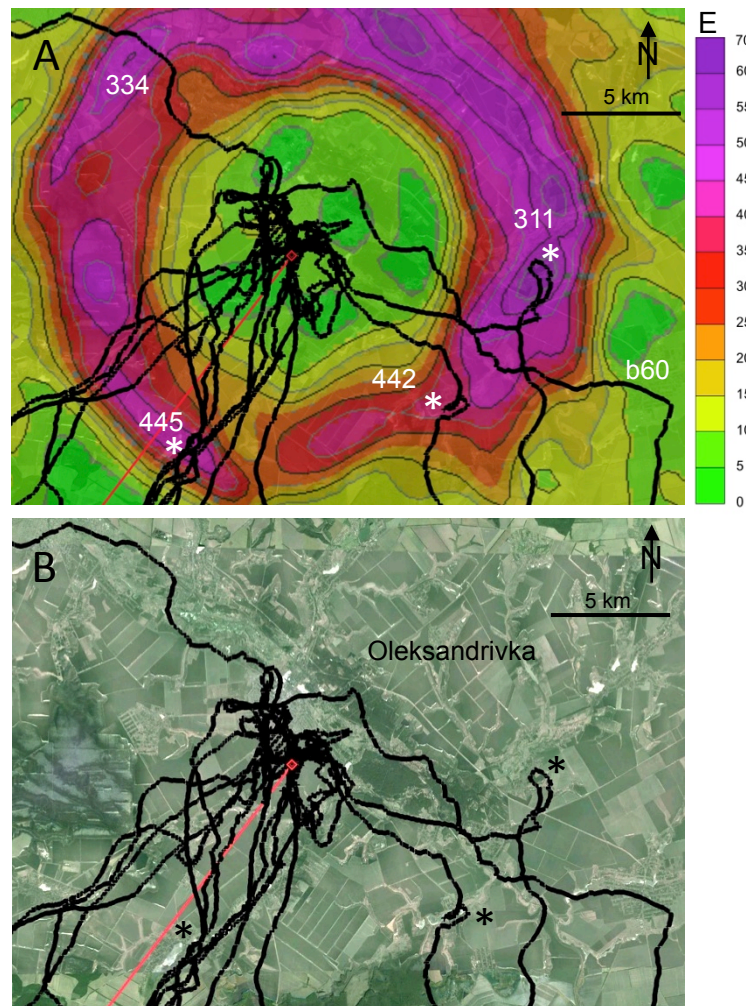
Fig. S3. Flight tracks of pigeons released from the center of the anomaly and flying across the rim of the anomaly. A) Upon approaching the rim of the anomaly with stronger horizontal gradients (yellow to purple), most pigeons changed course to cross the anomaly. Well oriented birds made minor changes, their tracks converging towards the home direction, ineffective homers (see Fig. S5B) showed more distinct directional changes, sometimes with circling. B) Satellite view of the release region indicating lack of prominent landscape features guiding pigeons. Asterisks: pigeons showing circling at sites of maximal gravity gradients. White numbers refer to individual pigeons. Red lines indicates the beeline between release site and loft. Color scale/isolines: horizontal gravity gradient in eotvos = E. . Google Earth Images from 2014 Digital Globe, 2014 CNES Astrium and 2014 Cnes Spot/Image.
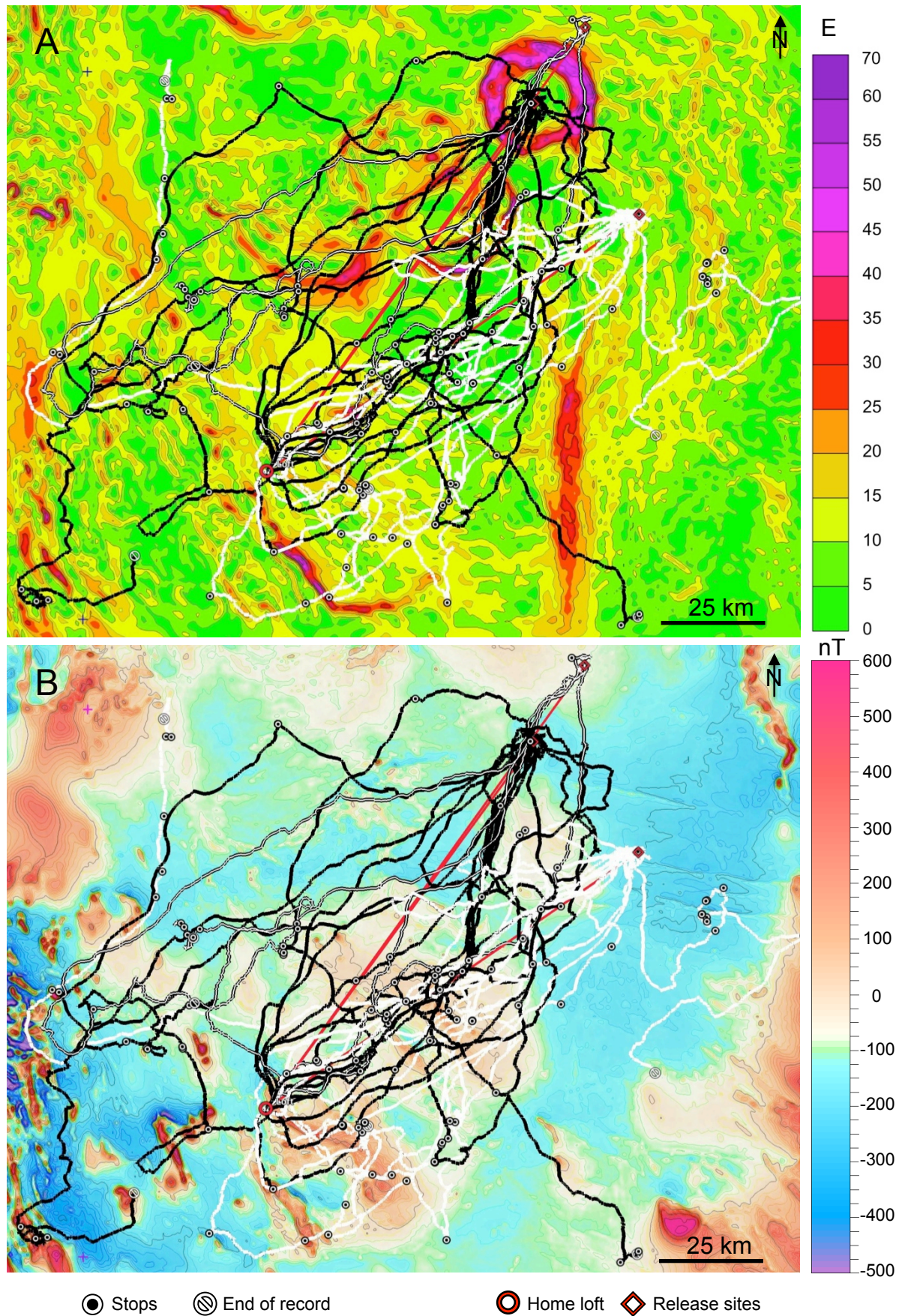
Fig S4. Overview of all GPS tracks on magnetic and gravity anomaly maps. A) Gravity anomaly map (1:50'000) showing the distribution of gravity anomalies according to gradients in their border zones – the steeper the gradient (E), the darker the color. Color scale/isolines: horizontal gravity gradient in eotvos = E. B) Geomagnetic variation across the entire track region, nT = nanotesla. White tracks: control releases; black tracks, releases from center of Boltishka anomaly; black-white tracks: releases behind gravity anomaly. Red lines: beelines between release site and home loft. The westernmost turning points are shown in detail in Fig. S12.
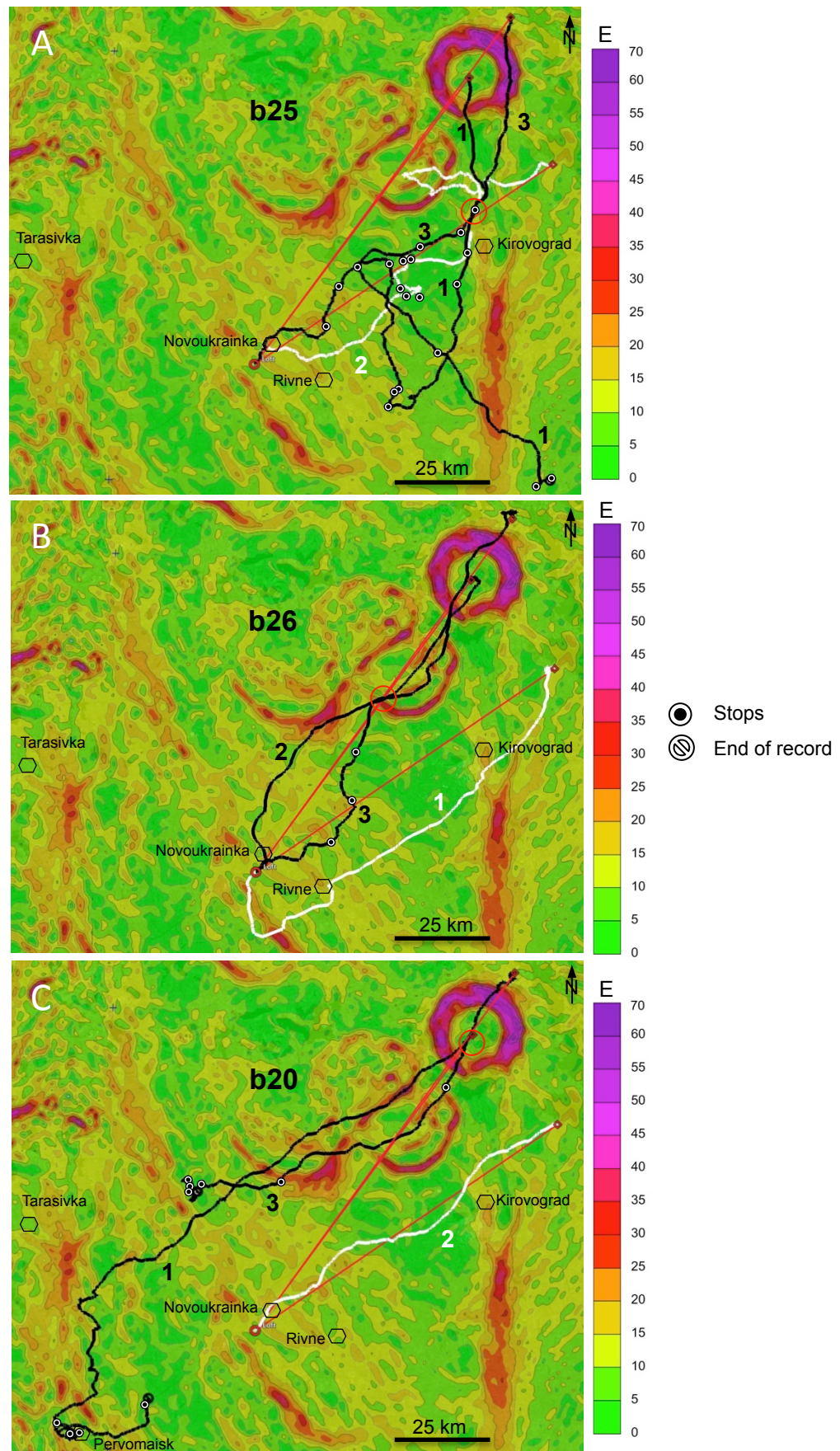
Fig S5. GPS tracks of pigeons that were released 3 times each, one track from the control site (white numbers), one track from the center of the anomaly, and one from behind the anomaly (black numbers). A) Pigeon **b25** did not return the same day from the center of the anomaly (1), showed very inefficient homing from the control site after hitting a gravity anomaly (2), and, after release behind the anomaly (3) deviated from the beeline along the rim of the anomaly, following mostly landscape guidelines afterwards. B) Pigeon **b26** was an efficient homer yet changing course three times after encountering gravity or gravitomagnetic anomalies. C) Pigeon **b20**, a fast flyer, showed perfect homing from the control site (2), but when crossing the second gravity anomaly it always deviated westwards and got lost for some days (1,3). Red circles, common flight paths; Color scale/isolines: horizontal gravity gradient in eotvos = E.
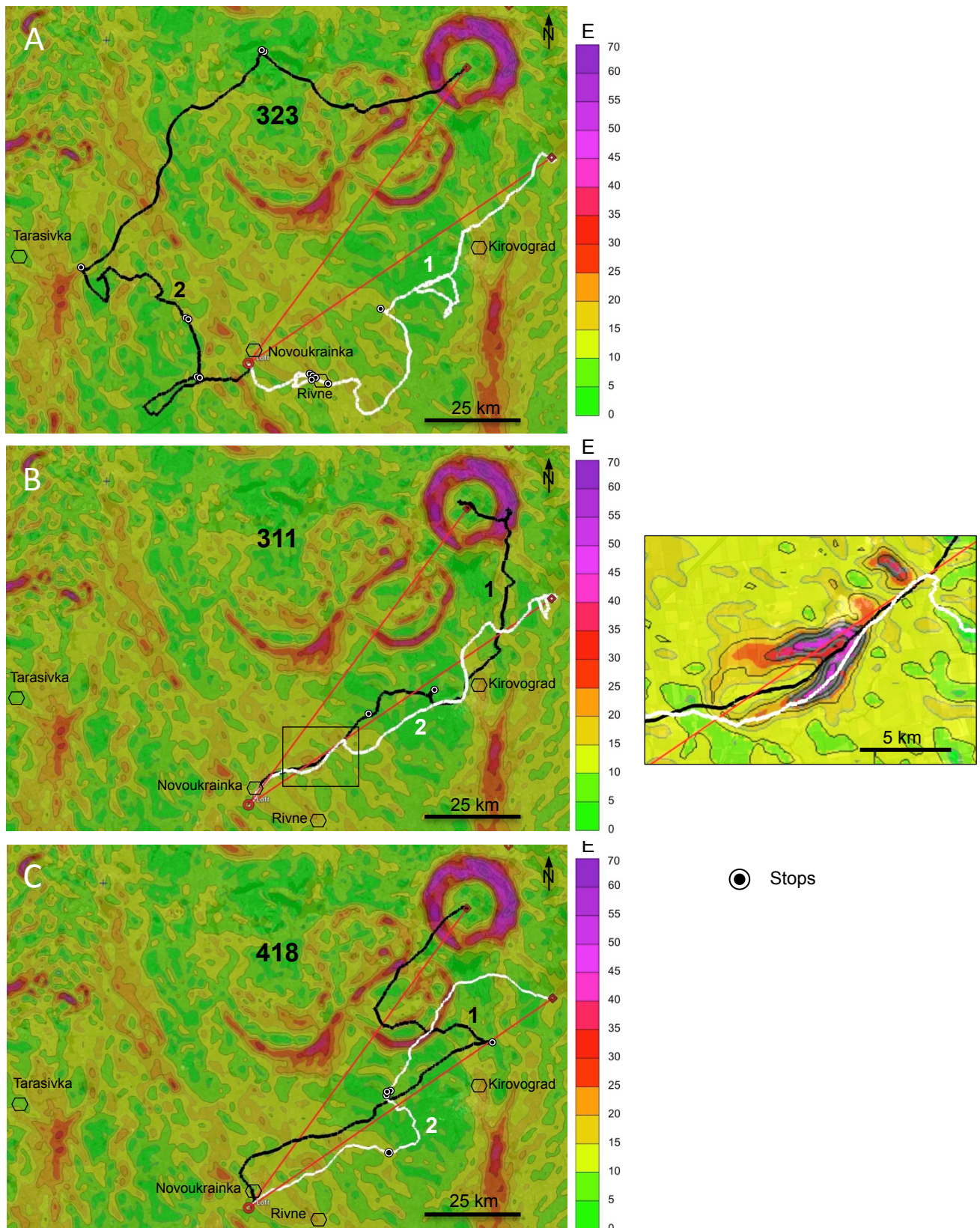
Fig S6. GPS tracks of pigeons that were released twice, one track from the control site (white numbers), one track from the center of the anomaly (black numbers). A) Pigeon **323** deviated from the beeline southwards and appeared disoriented at the gravity and magnetic anomaly at Rivne (1). After passing the rim of the Boltishka anomaly it deviated westwards flying a large detour (2). B) Pigeon **311** changed course in the rim of the Boltishka anomaly , but showed a relatively efficient flight path from the control site (2). Inset: aligning to a small gravity anomaly located on the beeline (scale 1:50'000). C) Pigeon **418** changed course when encountering gravity anomalies, both from the Boltishka anomaly (1) and from the control site (2). Red lines: beelines from release site to loft. Color scale/isolines: horizontal gravity gradient in eotvos = E.
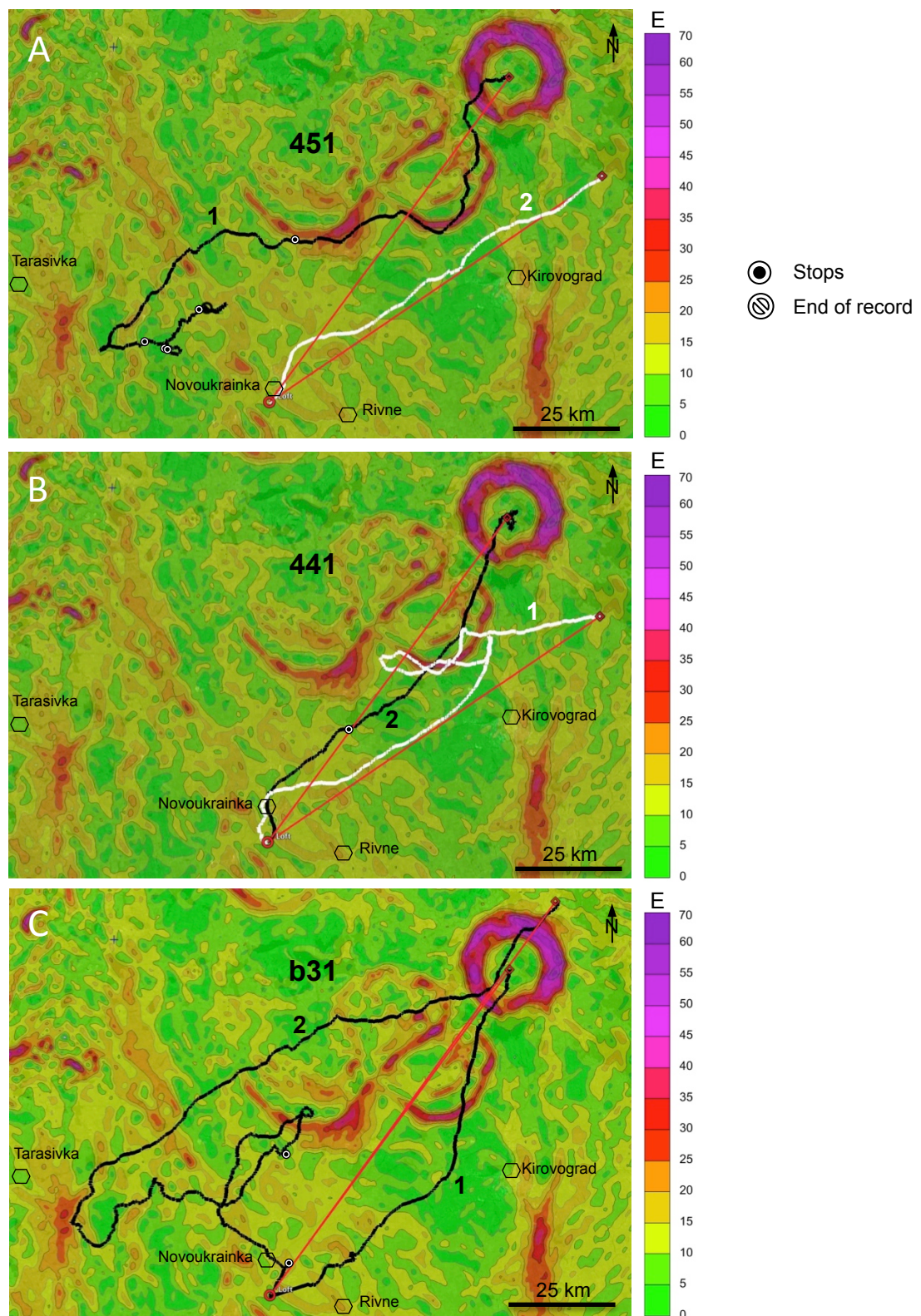
Fig S7. GPS tracks of pigeons that were released twice, one track from the control site (white numbers), one track from the center of the anomaly or from behind (black numbers). A) Pigeon **451**: After passing the rim of the Boltishka anomaly it deviated southwards and followed the contours of two gravity anomalies, getting lost for two days after stopping 30 km from the loft (1) but showed perfect homing from the control site (2). B) Pigeon **441** changed course after flying into a gravity anomaly, but corrected perfectly homewards after having left the anomaly (1). From the Boltishka anomaly, it showed efficient homing showing only small corrections while crossing the second anomaly (2). C) Pigeon **b31** homed well from the center of the Boltishka anomaly, showing a minor deviation in the second anomaly. When released behind the Boltishka anomaly, it changed twice course westwards while crossing it, flew then WSW and then SW till meeting the Tarasivka anomaly where it reversed direction towards another gravity anomaly after which it reversed again to reach the loft after 344 km of flight. Red lines: beelines from release site to loft. Color scale/isolines: horizontal gravity gradient in eotvos= E.
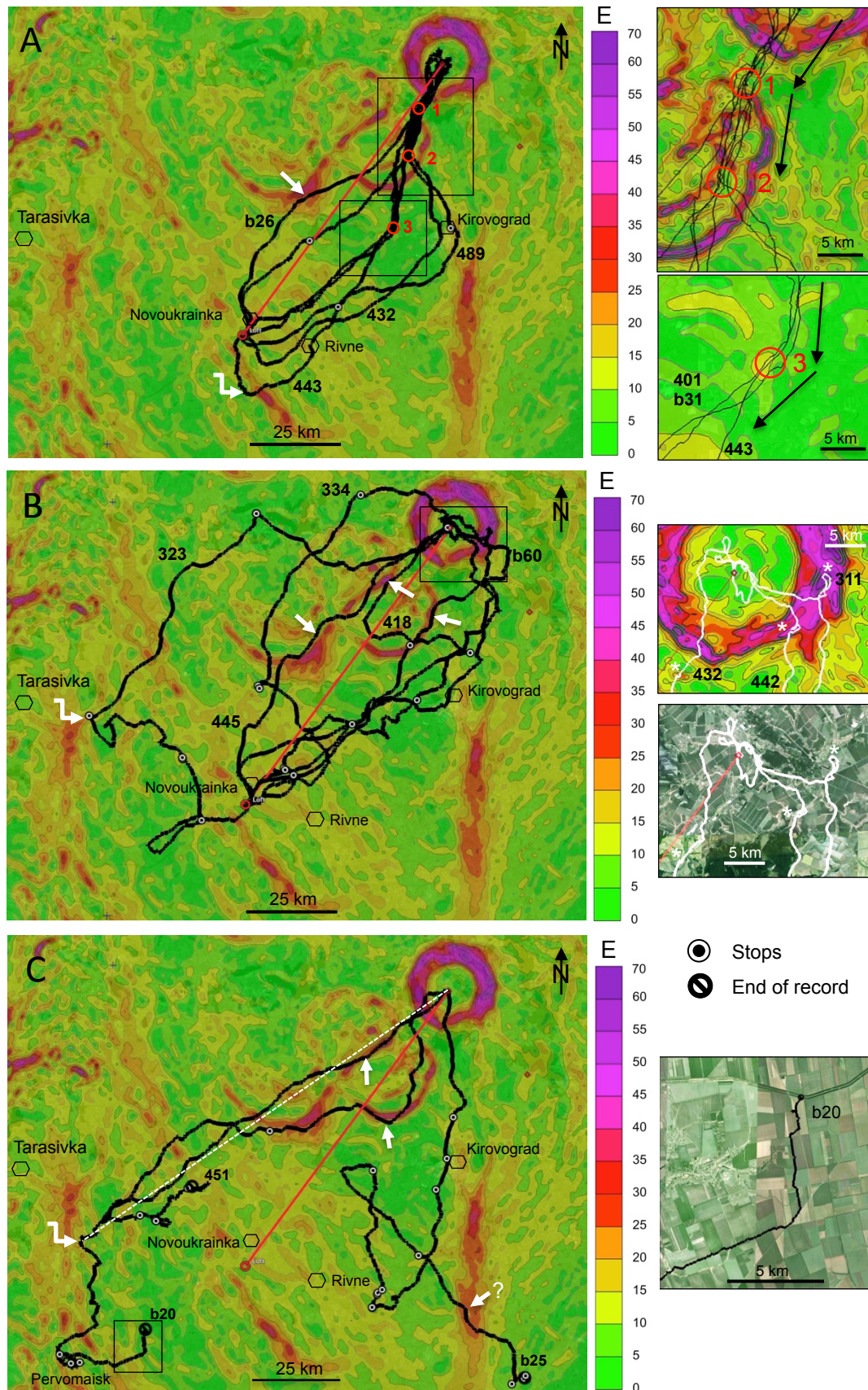
Fig. S8. Pigeon tracks from center of gravity anomaly grouped according to performance. A) Efficient homers (7 tracks). These fast and initially well-directed pigeons change flight paths upon hitting the next anomaly (red circle 1) and disperse after passing more anomalies (red circle 2). Three birds fly a common route at different days (red circle 3). B) Inefficient homers (7 tracks) change frequently their flight direction according to both gravity and topographic cues. Inlets show tracks of 3 pigeons circling over peaks of gravity anomalies (asterisks) with no obvious topographic cues. C) Poor homers (3 tracks) choosing wrong directions. **Pigeon b25** adopted a wrong direction after crossing the rim of the circular anomaly, **pigeon 451** appeared to be misrouted by gravity anomalies. **Pigeon b20** maintained an increasingly deviating compass direction (dotted white line) for 120 km, its last leg of 20 km showing a road-following strategy (Inset). White arrows: alignment of flight to gravity anomalies; white angular arrows: sharp turns associated with gravity anomalies in last flight segments. Color scale/isolines: horizontal gravity gradient in eotvos = E. Google Earth Images from 2014 Digital Globe, 2014 CNES Astrium and 2014 Cnes Spot/Image.
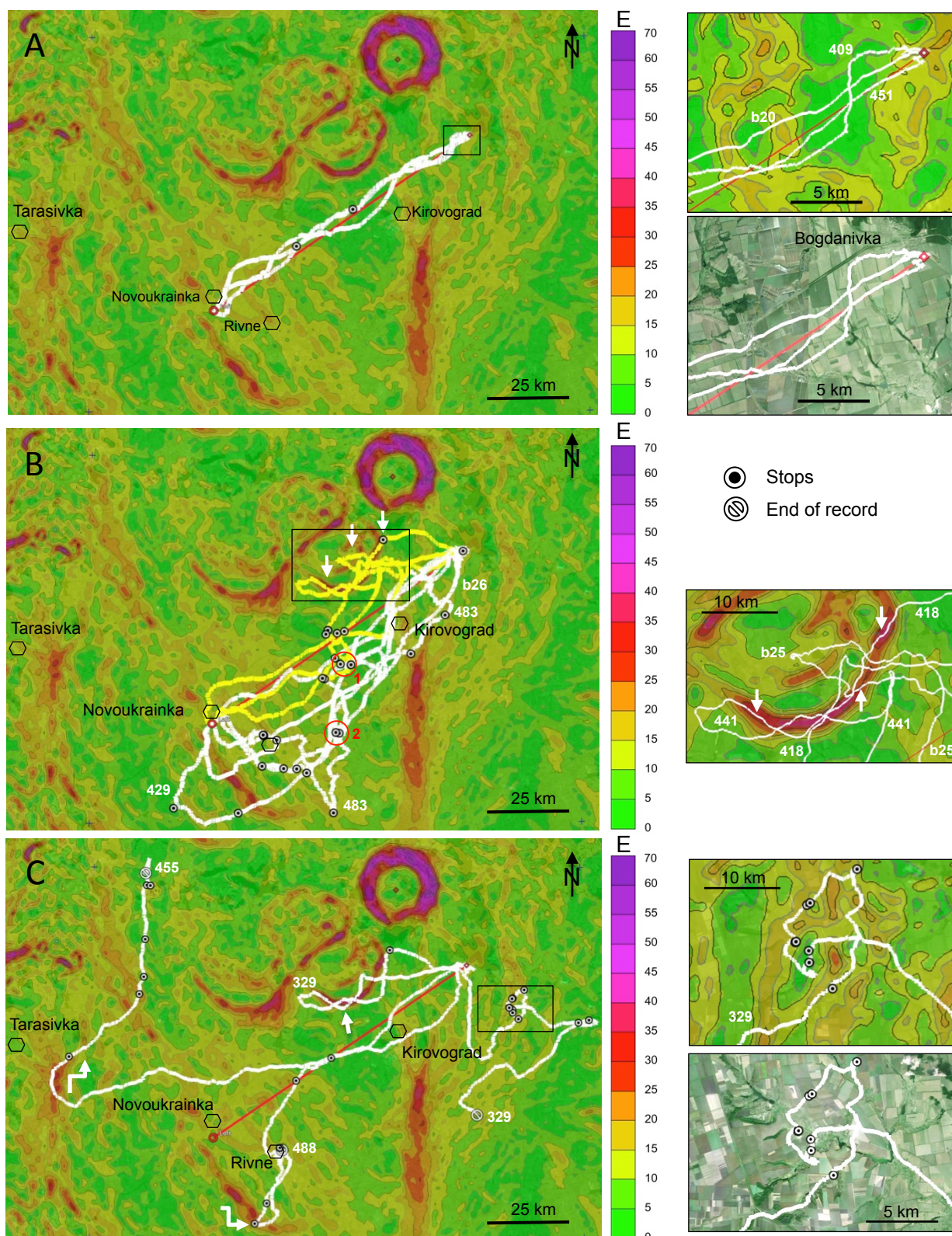
Fig. S9. Pigeon tracks from the control site, grouped according to performance. A) Efficient homers (3 tracks) flew fast and remained aligned to the beeline from release site to loft (pigeons **b20**, **409**, **451**) . Insets show that the release site was located on a moderate gravity anomaly unrelated to topography. B) Inefficient homers (9 tracks) either departed westwards (yellow tracks**, b25**, **418**, **441**), hitting a gravity anomaly associated with dramatic changes in flight direction (Inset), or they departed from the bee-line to the south, often following shallow valleys and small lakes, changing their flight direction according to both gravity and topographic cues, interspersing many stops. Red circle: convergence site of 4 tracks from the same day. C) Late homers (3 tracks) choosing wrong directions. Pigeon **329** flew first westwards, met a gravity anomaly, returned to the release site and then took a disoriented course with many stops inside a maze of small gravity anomalies (Inset). Pigeon **488** was initially well directed and deviated later from the home direction following a river system, continuing southward and, after having met a gravity anomaly, returning to the end-of-record point at Rivne, site of a combined gravitomagnetic anomaly. Pigeon **455** departed southwards, corrected towards home but maintained a deviating flight course for 100 km until hitting a gravity anomaly near Tarasivka, where it turned northwest and north till the end of record. White arrows: alignment of flight to gravity anomalies; white angular arrows: sharp turns associated with gravity anomalies in last flight segments. Red lines: beelines from release site to loft. Color scale/isolines: horizontal gravity gradient in eotvos = E. Google Earth Images from 2014 Digital Globe, 2014 CNES Astrium and 2014 Cnes Spot/Image.
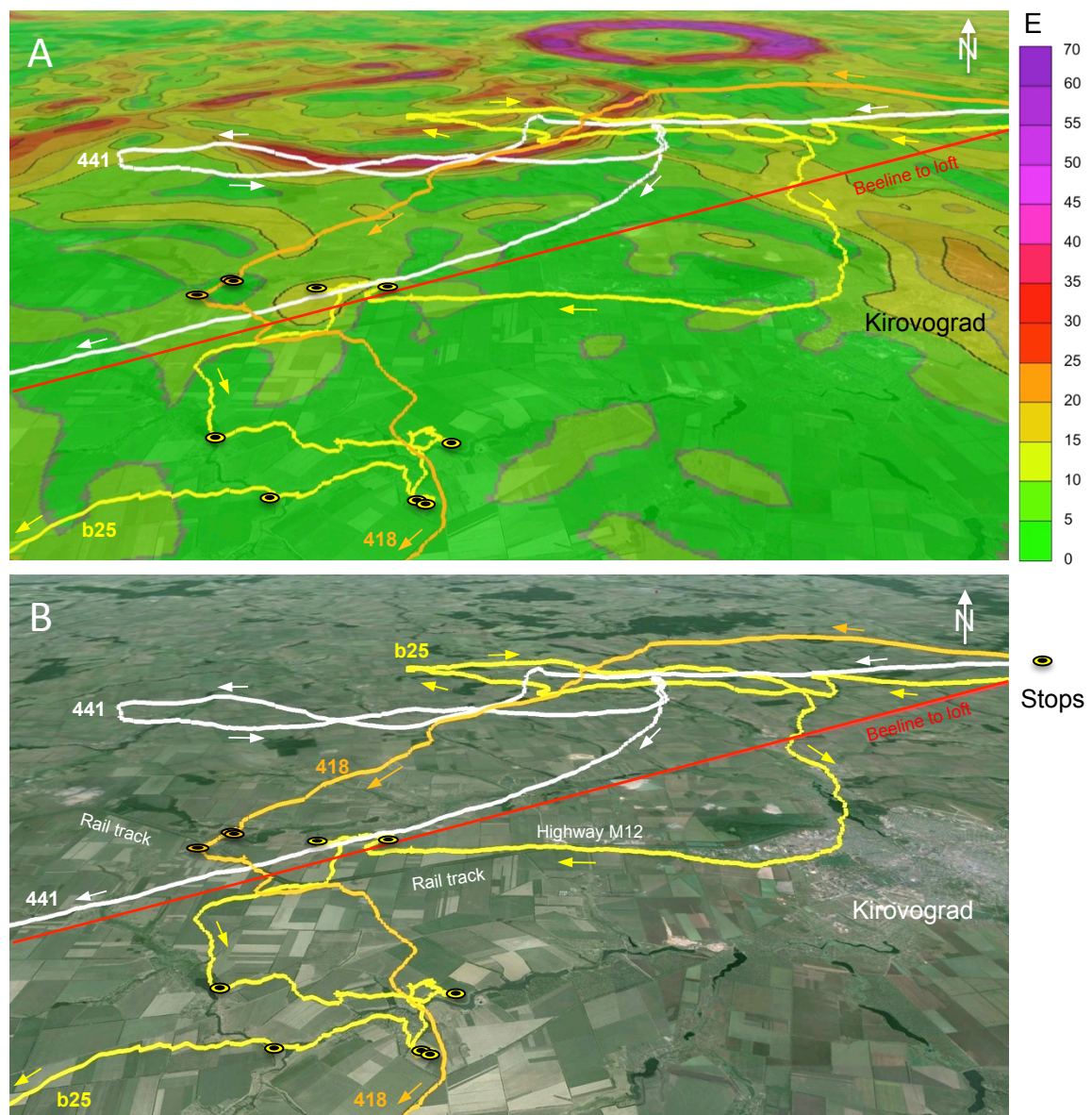
Fig S10. Alignment of 3 tracks of control pigeons first to gravity anomalies and then to landscape cues. A) Perspective view of gravity anomalies without topographic cues, north of the beeline (in red). Pigeons tracks changed without apparent reactions to landscape features. B). Tracks of the same pigeons after having passed the anomaly zones. Pigeon **b25** (yellow) followed rivers and partially the highway M12. Pigeon **418** (orange) changed flight course by 90° after meeting highway M12 which it followed before taking gradually a homeward course that frequently joined shallow river valleys. Pigeon **441** (white) took, after returning from the anomaly, a hairpin turn and then a course gradually aligning to the beeline, which it continued without further topography-induced deflections. Arrows: direction of flight. Color scale/isolines: horizontal gravity gradient in eotvos = E. Images from Digital Globe 2014,

Fig S11. Examples of flight strategies in pigeon 411. A) After start, precise following of a railway track running parallel to the bee-line to the loft. B) In-between segment of the home flight, the pigeon maintaining a compass direction ignoring guiding landmarks. C) Last leg of flight showing a compromise between home direction (white line from last stop to loft) and adherence to visual guidelines. Bottom of picture: pigeon 411 joining a river valley, afterwards flight along canopies lining agricultural fields, the bird taking 90° turns to the left and re-aligning by 90° towards the actual home direction. Last segment: aligning to bee-line in familiar territory. Google Earth Images from 2014 Digital Globe, 2014 CNES Astrium and 2014 Cnes Spot/Image.
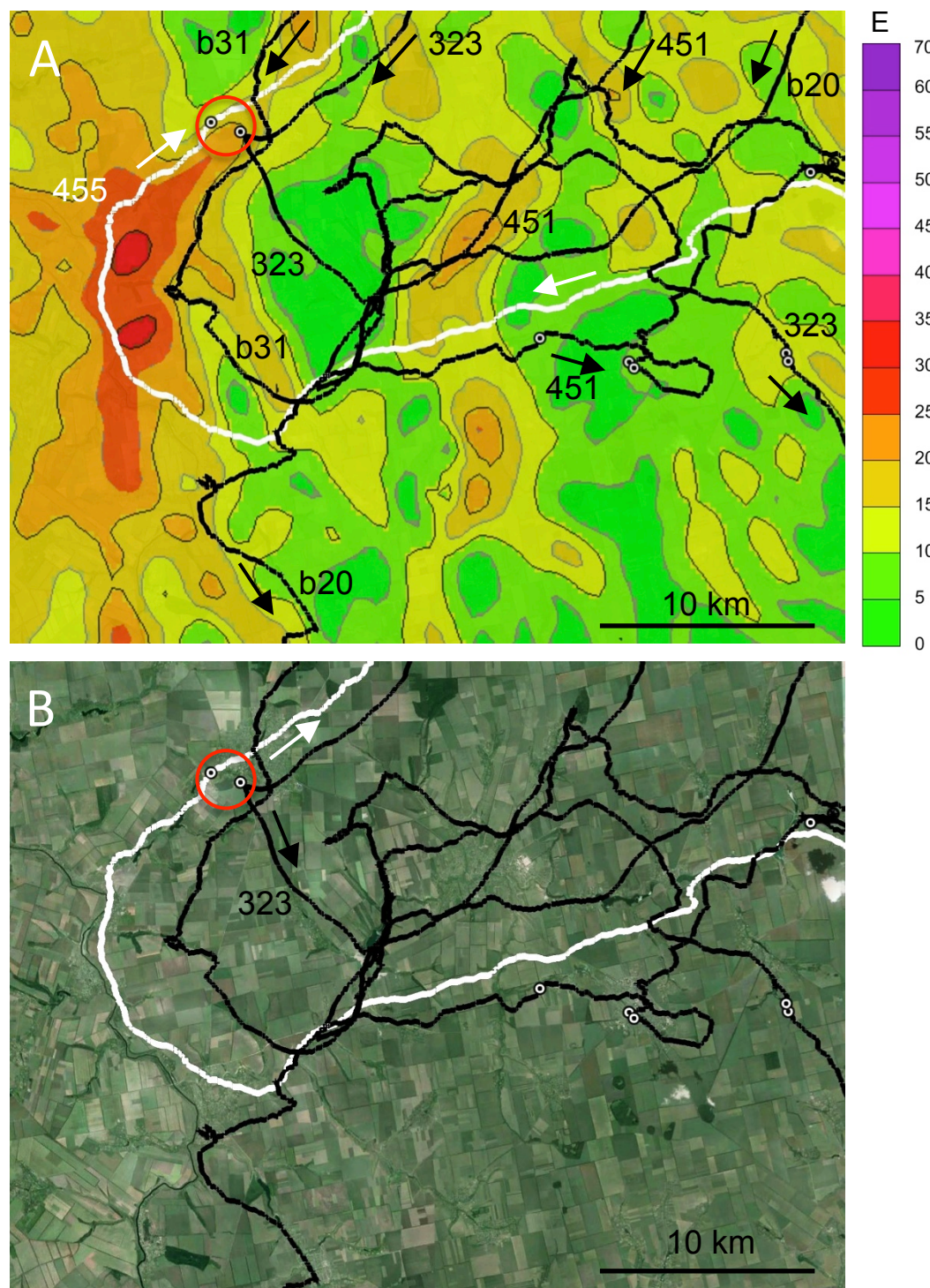
Fig S12. Westernmost turning point of errant pigeons at the Tarasivka gravity anomaly (see also Fig. S4 for a general overview). A) Tracks of 3 pigeons released from the center of the Boltishka anomaly (**b20**, **323**, **451**), from behind the Boltishka anomaly (**b31**) and from the control site (**455**). B) Satellite view of same tracks. Note that the three pigeons arriving from Boltishka (black tracks) arrived from NNW and reversed the flight direction eastwards after some erratic flight patterns, pigeon **b20** turning southwards along the gravity anomaly. Pigeon **455** was released at the control site and arrived from West to turn NE. Red circles denote two sites were two pigeons rested, 1.5 km apart. Yet pigeon **455** departed towards NE, pigeon **323** towards SE. Color scale/isolines: horizontal gravity gradient in eotvos = E. Google Earth Images from 2014 Digital Globe, 2014 CNES Astrium and 2014 Cnes Spot/Image.

Table S1. Number of released and lost pigeons

Date	Anomaly			Control site			Moon	Wind speed	Cloud cover	Temp.	% loss/day	Pigeons	
	released	back	lost	released	back	lost						Boltishka anomaly	Control site (Bogdanivka)
26.7.	5	4*	1	5	3	2	22.1% d	none	clear	20°	30.0%	**311**,442,**451,** 348*	329, **441**, 455
29.7.	2	2	0	3	3	0	new moon	N 10 km/h	clear	17°	0.0%	**b25**,b60	**b20**, **b26**
12.8.	6	5	1	6	4	2	full moon	NW 15 km/h	60-80%	14°	25.0%	**b20**,**b26**,**b31**,**441**,445	**311**, 409, **451**, **b25**
24.8.	8	6	2	8	5	3	27.7% d	none	clear	15°	31.3%	334,401,**418**,432,443,489	**323**,411,429,483,488
28.8	5	1	4	5	1	4	new moon	none	clear	12°	80.0%	**323**	**418**
29.8.	5	4	1				new moon	none	clear	12°	20.0%	**b26,b20,b25,b31** (behind anomaly only)	
Totals	31	22	9	27	16	11					34.5%		

d = decreasing moon
N = north
NW = northwest

bold print: 2-3 tracks
plain text: one return only
* pigeon back with no GPS record