

Supplementary material

Appendix 1

1. Preliminary steps to check for errors in twilight events and calibration

We performed a preliminary step using a **provisional** sun elevation angle (SEA) of -6 to generate geographical positions and visually define **provisional** last and first positions on land (i.e. before and after migratory flight). Then, we manually checked for errors on twilight events during migratory periods and corrected them when necessary (Figure A1). To calculate the final SEA, we ran the *loessFilter* function ($k=2$) and used the Hill-Ekstrom calibration (Lisovski et al. 2012) for the period from 3 days after arrival to wintering areas (usually on first half of August) until 23 November (i.e. ~2 months after autumn equinox). SEAs ranged from -6 to -4.7.

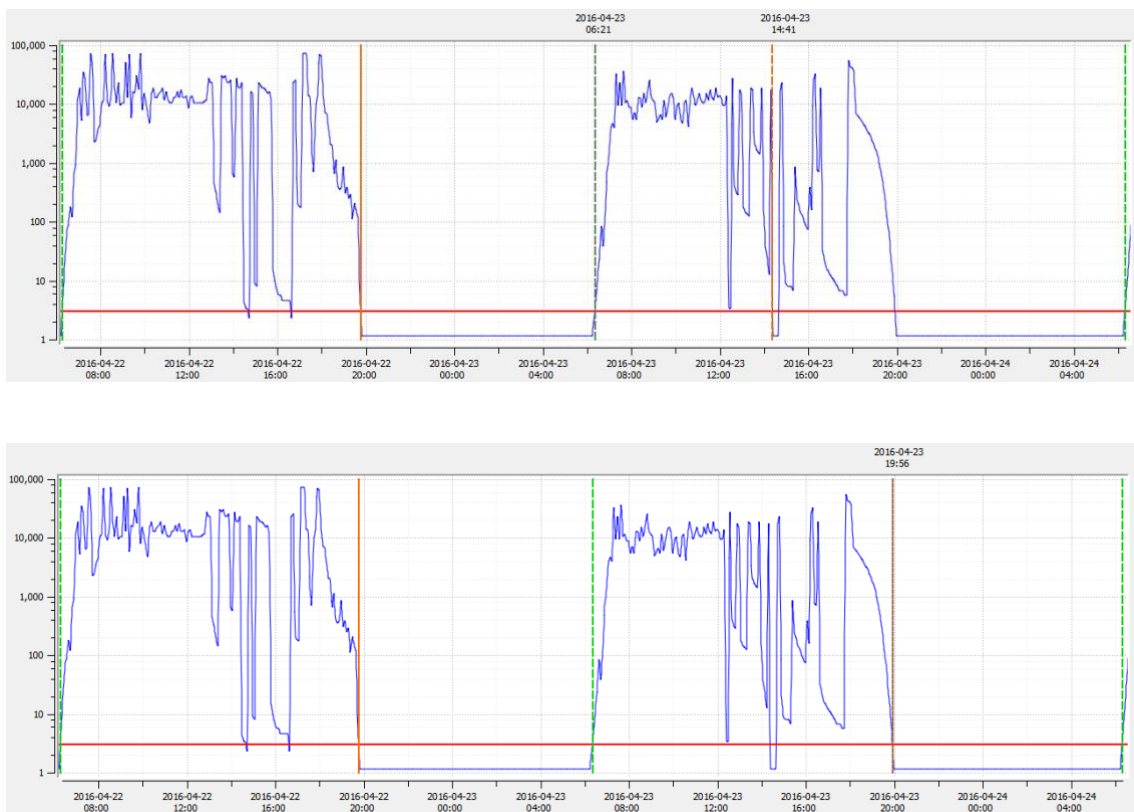


Figure A1. Example of visual adjustment of twilight events during migratory periods; in this case, on 23 April 2016 an incorrect sunset was defined at 14:41 (top) and was moved to 19:56 (bottom).

2. *Determining timing of events through conductivity, wet contacts and temperature*

We expected temperature to be different at both ends of the migration of Icelandic Whimbrels (Iceland and West Africa) and that behaviour would also differ, with the use of saline water and tidal habitats in West Africa but not on the breeding grounds in Iceland. Assuming that during migration (a) conductivity and (b) wet contacts are likely to be zero, as no water is touching the device pins (albeit dirt such as mud might cause conductivity and/or wet readings), (c) thermal amplitude ($t_{\max}-t_{\min}$) is likely to be low because the bird is in a relatively homogenous environment and performing the same behaviour and that (d) the overall pattern of variation on these parameters are likely to be distinct when in migratory flight or not, we visually inspected the profiles of minimum temperature, thermal amplitude, conductivity and wet contacts in a window of 48h around the *tFirst* time (i.e. the early twilight time that define the position; Figure A2) of the last and first positions on land (start and end of migration, respectively). In these periods we searched for one or more of the following: (a) sudden change (drop or increase) in conductivity, (b) in wet contacts, (c) in thermal amplitude and/or (d) in minimum temperature; the change in the overall pattern of these parameters before departure and after arrival was then used to define the departure and arrival timings (Figure A2).

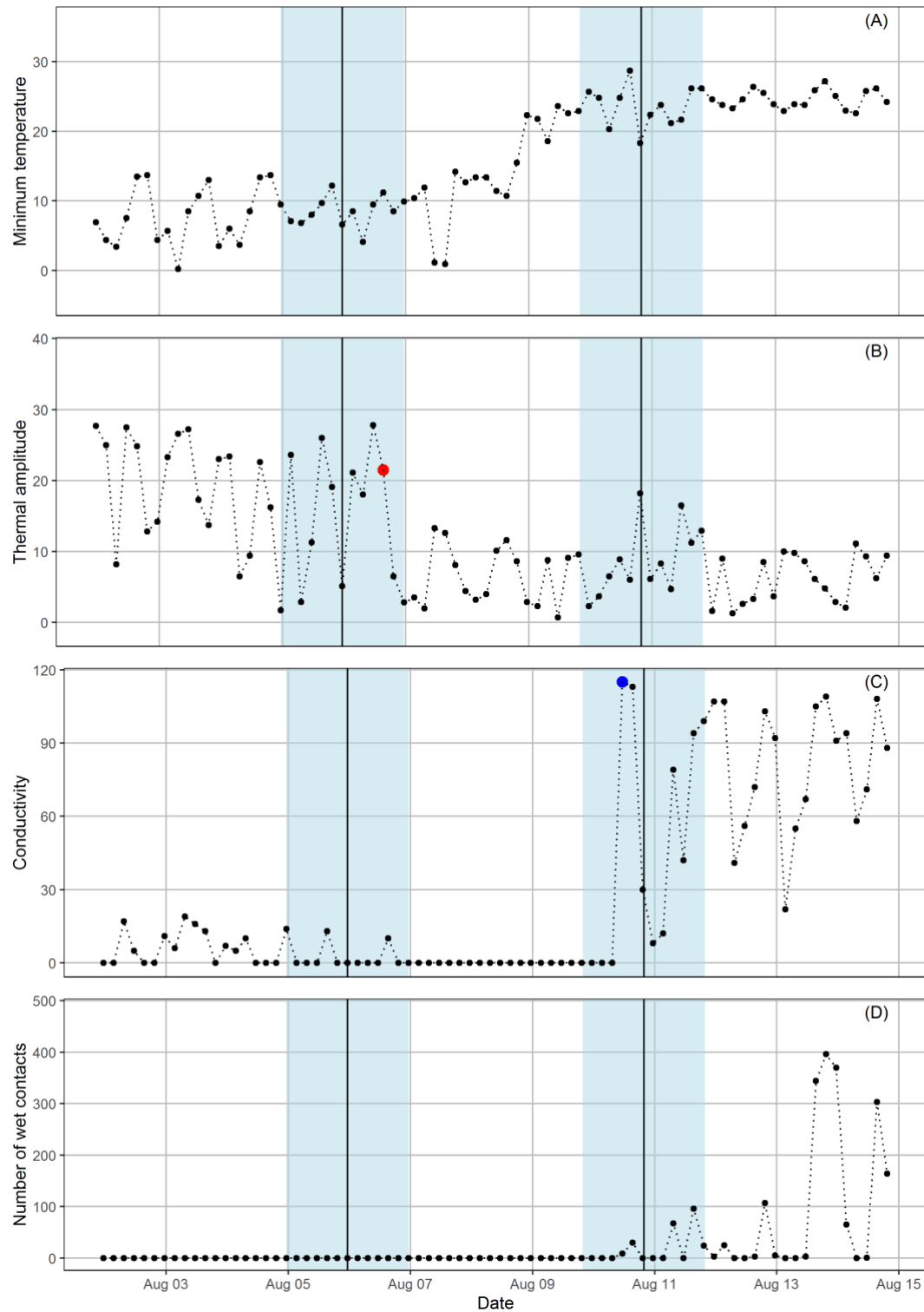


Figure A2. Example of timings fine-tuning through conductivity, wets and temperature data. Black vertical lines represent t_{First} (time of last and first geographical positions on land) and the shaded light blue areas a 48h window around it, where departure and arrival timings were searched for based on (A) minimum temperature, (B) thermal amplitude, (C) conductivity and

(D) wet contacts. Red and blue circles represent the time assumed for the last (departure) and first (arrival) positions on autumn migration, respectively.

3. Details on defining migratory tracks and speeds

On the winter quarters, the first and last positions on land, i.e. at the end of autumn migration and start of spring migration respectively, did not always coincide with the overall mean wintering position (average location of all points recorded during the period spent in Africa; also referred as 'winter location' henceforward). This was expected due to geolocation precision (ca. 200km; Phillips et al. 2004, Shaffer et al. 2005, Fudickar et al. 2012) and Whimbrel's behaviour (e.g. spending high tide within mangroves, sitting or roosting with the leg with geolocator tucked in the body feathers, causing shading and potentially affecting sunrise and sunset estimate). Such differences were on average 329 ± 192 km (range 40-683; n=29) for autumn (excluding geolocator U190, see below) and 385 ± 238 km (range 81-1064; n=26) for spring. All these discrepancies were analysed to investigate the possibility of a small staging event before completion of autumn migration. When there was no evidence (by checking temperature, conductivity and wet profiles) of a stationary period on these discrepancies we considered that this position represented arrival to winter location and therefore assumed that autumn migration had been completed. Departure location for spring migration was defined the as winter location but on five cases initial movement southwards was observed at spring departure. We considered this was unlikely and due to geolocation precision errors through shading and assumed migration from the first position on the track northwards. The final part of autumn migration recorded by geolocator U190 indicated a very fast flight up to the equator followed by a return movement to the wintering location (coast of Guinea). We assumed such movement to be a measurement error and excluded it from speed and distance calculations, thus considering migration only up to the first position closer to the winter location.

Appendix 2

1. Flight model

In order to calculate migration costs, data on wing span, wing area, body mass prior to migration, fat fraction and muscle fraction are required. All these were recorded from Whimbrels in Iceland (Table A1). The sex of each individual was determined through behavioural observations (2 individuals), following Katrínardóttir et al. (2013) equation (15 individuals) and the molecular procedure described therein (4 individuals, plus 6 whose partner was molecularly sexed). For each individual, the wing span was measured to the nearest mm with a tape measure, the right wing traced and the area calculated following Pennycuick (2008). Muscle fraction was measured from two dead individuals found fresh in Iceland. Fat fraction was estimated as the fraction lost by the heaviest individual in the population flying in the model until reaching the body mass of the lightest (i.e. with no fuel reserves, Pennycuick 2008). The body mass of the heaviest bird was measured just prior departure from Iceland, on 17 August and the lightest upon arrival, on 8 May. Models were produced in Flight (ver. 1.25, Pennycuick 2008) with default parameters described by Pennycuick and Battley (2003), except air density that at start was at 0m and cruising altitude was set for 1500m.

Table A1. Parameters of Icelandic Whimbrels used in Flight 1.25 to estimate flight costs during migration.

	Females	n	Males	n
Wing span (m)	0.877	14	0.861	13
Wing area (m ²)	0.088	14	0.083	13
Body mass (kg)	0.601	1	0.601	1
Fat fraction	0.371	-	0.371	-
Muscle fraction	0.18	2	0.18	2
Cruising altitude	1500	-	1500	-

Table A4. Model results testing differences in (A) migration duration and (B) migration speed between seasons and sexes, considering a fuel deposition rate of 3% of lean body mass; estimates for sex are of male in relation to female, for season is of spring in relation to autumn and for stopover duration is the expected in relation to recorded duration.

	n	Fixed effects					Random effects			
			Estimate	SE	df	t	p	Variance	SD	
(A) Migration duration	56	Intercept	35.844	1.57	20.6	22.89	<0.001	individual	7.31	2.70
		season	9.0698	1.61	33.3	5.651	<0.001	Residual	11.75	3.43
		sex	1.2495	1.92	22.03	0.651	0.5220			
		season*sex	-0.9615	1.96	33.2	-0.49	0.628			
(B) Migration speed	56	Intercept	166.2090	2.68	25.8	61.996	<0.001	individual	2.68	1.64
		season	-25.3630	3.96	40.7	-6.413	<0.001	Residual	72.26	8.50
		sex	-2.3940	3.36	29.3	-0.713	0.4810			
		season*sex	6.5660	4.84	40.34	1.355	0.1830			

References

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