

**Supplementary material**

## Appendix 1. Flight Itineraries

**Table A1. Flight Itineraries for April 2016 - September 2017.** nw= northward, sw=southward.

	2016	2017
<b>Northward migration</b>		
Total distance (km)	6404	4459
Total duration (h)	107	69
Number of migratory flights	3	2
nw departure from Wadden Sea	17 May	11 May
nw arrival in Iceland	18 May	12 May
nw departure round trip	30 May	-
nw arrival back on Iceland	31 May	-
nw departure from Iceland	4 June	30 May
nw arrival on Ellesmere	6 June	1 June
nw flight distance from Wadden Sea to Iceland (km)	2141	1990
Flight duration (h)	31	27
nw round trip (km)	1859	-
Fight duration (h)	39	-
<b>nw crossing of the Greenland Icecap</b>		
nw flight distance from Iceland to Ellesmere island (km)	2404	2469
Flight duration (h)	37	41
length of orthodrome route (km)	2269	2093
mean deviation from location to orthodrome route (km)	50 +/- 36	212 +/- 192
length of loxodrome route (km)	2365	2129
Bearing (degrees from north)	305	329
mean deviation from location to loxodrome route (km)	143 +/-101	142 +/- 136
Conclusion	GC	NS
	t = -4.8057, df = 37.342, p-value = 2.519e-05	t = 0.99243, df = 18.011, p-value = 0.3341
<b>Breeding season</b>		
start incubation	8 June	3 June
end incubation	26 June	>29 June

**Southward migration**

Total distance (km)	4091	4422
Total duration (h)	60	68+39+29
Number of migratory flights	1	3

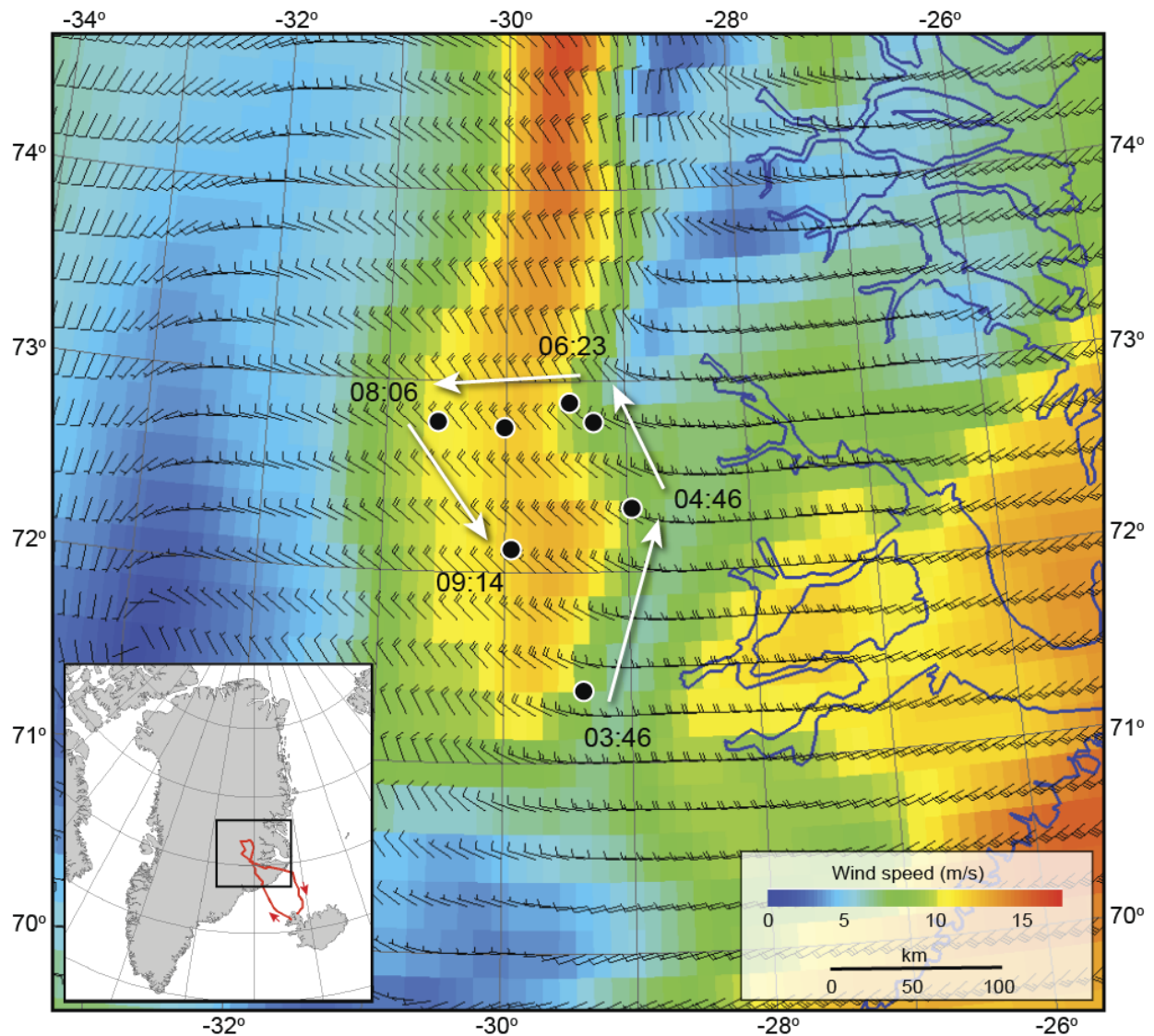
sw departure from Ellesmere island	12 July	29 July
sw arrival Scotland	-	1 August
sw departure Scotland	-	6 August
sw arrival Sylt	-	7 August
sw departure Sylt	-	13 August
sw arrival in Wadden Sea	15 July	14 August

**sw crossing of the Greenland Icecap**

sw flight distance from Ellesmere island to Iceland (km)	2141	1990
Flight duration (h)	33	33
length of orthodrome route (km)	2134	2099
mean deviation from location to orthodrome route (km)	57 +/- 44	66+/-61
length of loxodrome route (km)	2190	2148
Bearing	143	145
mean deviation from location to loxodrome route (km)	171 +/- 108	155 +/-118
Conclusion	GC	GC
	t = -5.0729, df = 34.584, p-value = 1.325e-05	t = -2.593, df = 20.978, p-value = 0.01698

---

## Appendix 2. Paula's circuitous flight over Greenland



**Figure A1. Paula's circuitous flight over Greenland during northward migration in 2016.**

Detailed wind conditions at the time when Paula made a circuitous flight over part of the mid-eastern portion of the Greenland Icecap, before turning back to Iceland. ERA5 wind speeds (700 mb) on May 31, 2016, at 06:00 UTC are color-shaded with wind-barbs denoting direction (Copernicus Climate Change Service, 2017, Unidata, 2020). Seven Argos tracking locations (black dots) obtained on May 31, 2016 are shown with generalized directional arrows and

timestamps (UTC). After flying ~580 km from Iceland, a zone of headwinds that Paula encountered may have contributed to her decision not to undertake the remaining flight across the largely inhospitable Greenland ice cap to Ellesmere Island.

## **References**

Copernicus Climate Change Service (C3S). 2017. ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate. Copernicus Climate Change Service Climate Data Store (CDS), *Accessed 8 April 2020*. <https://cds.climate.copernicus.eu/cdsapp#!/home>

Unidata. 2020. Integrated Data Viewer (IDV) version 5.7. Boulder, CO, USA UCAR/Unidata, *Accessed 8 April 2020*. <http://doi.org/10.5065/D6RN35XM>

### Appendix 3. Magnetic loxodrome

We obtained magnetic declination values at the departure locations and dates of the four migratory flights between Iceland and Ellesmere Island using the `magneticField()` function in the R package *oce* (Kelley and Richards 2019), which used the 12th generation International Geomagnetic Reference Field (IGRF, Thébault et al. 2015). For each migratory flight we adjusted Paula's initial geographic departure bearing by the magnetic declination at the departure location to establish the magnetic bearing at departure. We used the `destPointRhumb()` function in the *geosphere* package (Hijmans 2019) with the magnetic bearing to advance Paula's migration in 10 km intervals, adjusting the bearing at each interval by the change in declination. We tuned Paula's initial departure compass bearings to establish magnetic loxodromes that led to Paula's observed destinations. The tuned departure compass bearings in 2016 and 2017 were, respectively, 328° and 345° for the northbound migrations, and 121° and 124° for the southbound migrations.

#### References

Hijmans, R.J. 2019. *geosphere*: Spherical Trigonometry. R package version 1.5-10.

<https://CRAN.R-project.org/package=geosphere>.

Kelley, D., and Richards, C. 2019. *oce*: Analysis of Oceanographic Data. R package version 1.1-1.

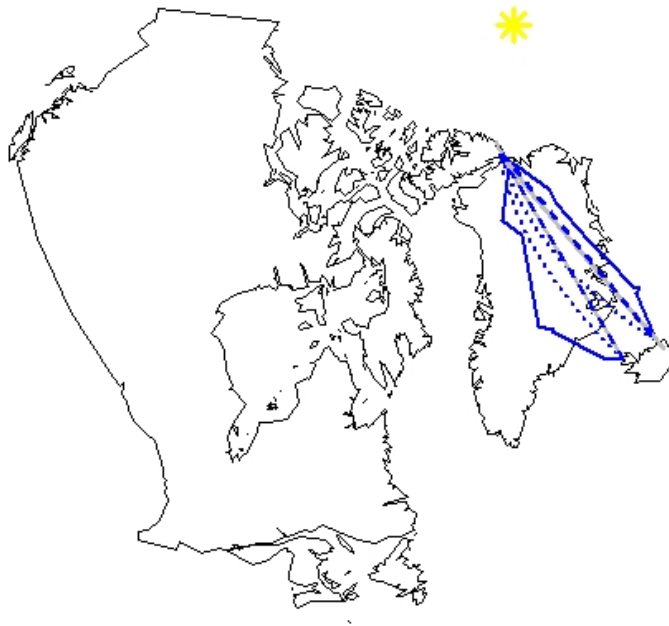
<https://CRAN.R-project.org/package=oce>.

Thébault, E., Finlay, C.C., Beggan, C.D., Alken, P., Aubert, J., Barrois, O., ... and Zvereva, T. 2015.

International Geomagnetic Reference Field: the 12th generation. – *Earth, Planets and Space* 67:79.



**Figure A2. 2016 Magnetic loxodromes.** Map of the northward and southward crossings of the Greenland Icecap in 2016 (solid lines) in relation to the orthodrome (dashed lines), the geographic loxodrome (dotted lines) and the magnetic loxodrome (solid grey lines) paths between Iceland and Ellesmere Island, shown in an Azimuthal Equidistant projection. The yellow asterisk shows the location of the magnetic North Pole in 2016 ( $194^{\circ}\text{N}$ , and  $86^{\circ}\text{E}$ ).



**Figure A3. 2017 Magnetic loxodromes.** Map of the northward and southward crossings of the Greenland Icecap in 2017 (solid lines) in relation to the orthodrome (dashed lines), the geographic loxodrome (dotted lines) and the magnetic loxodrome (solid grey lines) paths between Iceland and Ellesmere Island, shown in an Azimuthal Equidistant projection. The yellow asterisk shows the location of the magnetic North Pole in 2017 (187°N, 86°E).