ECOLOGY

GPS Tracking of Foraging Albatrosses

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Developments in satellite telemetry have recently allowed considerable progress in the study of long-range movements of large animals in the wild (*1*), but the study of the detailed patterns of their foraging behavior on a small to medium scale is not possible because of the imprecision of satellite telemetry systems (*2*). We used a miniaturized Global Position System (GPS) that recorded geographic position at 1-s intervals (*3*) to examine the exact flight pattern and foraging behavior of free-ranging wandering albatrosses (*Diomedea exulans*).

We deployed GPS loggers on breeding birds (*3*) either starting a long foraging trip in ocenic waters during the incubation period or searching for food close to the colony during the chick brooding period (Fig. 1, A and B, respectively). The distribution of ground speeds measured between 924,712 GPS locations was bimodal, with speeds varying from 0 to 9 km hour^{-1} (average = 2.6 ± 0.7 km hour^{-1}) indicating that birds were sitting on the water (59.5% of foraging time) and speeds ranging between 18 and 135 km hour^{-1} (average = 54.5 ± 4.5 km hour^{-1}) when birds are in flight. When in flight, birds frequently attained (8.2% of time) ground speeds higher than 85 km hour^{-1}, the maximum travel speed predicted for wandering albatrosses (*4*, *5*). Small-scale flight paths show typical zigzag patterns with continuous changes in flight speed according to the position of the bird with respect to wind (Fig. 1C).

Because they rely extensively on wind conditions to reduce flight costs (*4–6*), wandering albatrosses have to adjust their searching behavior according to wind conditions, but at the same time they must adjust their foraging movements to increase the probability of encountering prey. The zigzagging small-scale movements added to the larger scale changes in overall direction affect overall the sinuosity of the track. The straightness index of the path, as measured by the ratio of straight-line distance between the initial and final positions of two consecutive landings relative to the actual path (*7*), was on average 0.512 (range = 0.72 to 0.280, with 1.0 being a straight-line course). The ratio was not affected by wind direction with respect to overall route direction because birds always have a zigzagging flight when they move with head, cross, or tail winds [$F(_{2,15}) = 0.893$, $P = 0.429$]. Predators foraging in a heterogeneous environment are expected to adjust their search pattern (e.g., the straightness of their route, the flight speed, and/or turning rate) to increase the probability of encountering prey (*8*), but this prediction is generally impossible to test on marine animals. We tested whether birds modified the straightness of their movements according to the season or the marine habitat visited. The straightness index of the track was lower during the brooding period (0.41 ± 0.1), when birds are searching for food close to the colonies (*9*), compared with the incubation period (0.588 ± 0.09; Kruskal-Wallis, $U = 4.0$, $P = 0.028$), when birds are only moving away from the shelf area during the first day of foraging. The difference was only due to the higher sinuosity of tracks during brooding over the shelf break (0.294 ± 0.084), where birds are known to catch most prey (*9*), compared with when birds were over the shelf itself (0.693 ± 0.182; Wilcoxon paired test, $Z = 2.42$, $P = 0.015$) or over oceanic waters (0.648 ± 0.09). Thus, birds increase the sinuosity of their flight only over a specific area, the edge of the peri-insular shelf.

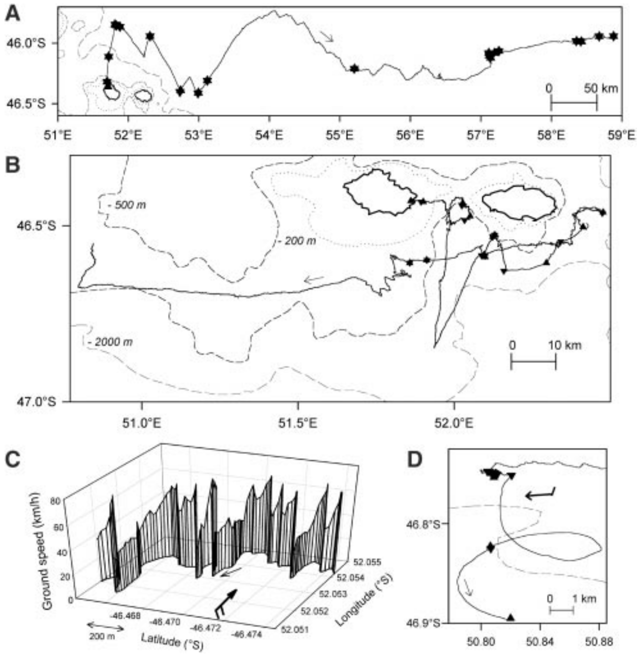

Fig. 1. Movements of wandering albatrosses moving from Possession Island, Crozet Archipelago: (**A**) over oceanic waters during the incubation period and (**B**) during the brooding period in the vicinity of the island. Part of tracks showing (**C**) the movement in relation to ground speed and (**D**) the drifting movement of a bird over the shelf break. Upward triangles indicate take-offs and downward triangles landings on water, the stars are conjunctions of landings and take-offs, and large bold arrows represent the wind direction and speed. Dashed lines indicate bathymetric contours; the shelf area is considered at depths shallower than –500 m, the shelf edge at depths between –500 and –2000 m, and oceanic waters over waters deeper than –2000 m.

When foraging, birds landed regularly on the sea surface (Fig. 1, A and B), on average every 1.8 ± 0.9 hours, and drifted when sitting on the water. The overall direction of the drift was partly due to wind direction, but marine currents also played an important role. Several birds spent long periods drifting over the shelf break region, and the trajectory of the drift over this area was not straight as might be expected if birds were transported by a unidirectional currents or by wind as occurs in oceanic waters. In contrast, the drift tracks showed a smooth looping movement, indicating the presence of medium-scale turbulence such as small gyres (Fig. 1D). These looping movements only occurred over the Crozet shelf break. In these gyres, probably associated with upwelling movements often present on shelf breaks, prey are probably pushed to the surface and become concentrated and accessible to surface feeding in a restricted and predictable area.

References and Notes

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Supplementary Material

Methods: The study was carried out in January to April 2001, on the Crozet Islands. We used a fully self-contained GPS-MS1 receiver with an onboard non-volatile memory that stores up to 100,000 positions. Details of the GPS are given by I. Steiner et al. [Physiol. Behavior 71, 1-8 (2000)]. The GPS used has a circular error probability of 4 m for horizontal position. Accuracy for altitude was lower and was not used, especially because albatrosses rarely fly over the sea at altitudes higher than 20 m. The GPS devices, weighing 105 g (1-1.3% of birds mass) including batteries and waterproof packaging, were taped to back feathers on the bird leaving the nest after a change over by its partner. Eight GPS units were deployed during the incubation period (average trip duration 8.26 ± 1.88 days) and nine units were deployed during brooding (trip duration 2.99 ± 1.42 days). Wind speed and wind directions were derived from meteorological models that estimated twice daily the wind strength and direction from NOAA/NESDIS, based on near real-time data collected by NASA/JPL's SeaWinds Scatterometer aboard the QuikSCAT satellite. Wind direction was mainly from the west. In order to acquire the precise movements of birds compared to obtaining movements over longer periods with lower resolution, the loggers were programmed to run in continuous mode by measuring one fix every second for a period of 27.7 hours from the time the GPS was started before the memory was full. This study was supported by Institut Français pour la Recherche et la Technologie Polaire and by a grant from Swiss National Science Foundation SNF 31-58822.99. We thank G. Merlet for help with the packaging of the GPS, Ralf Lashefski-Sievers (GFT) for help with the GPS, Armel and Charles for help in the field, and Scott Shaffer and Yves Cherel for helpful comments on earlier drafts of the manuscript.

Additional legend to Fig. 1. In (A), the movement of a male was recorded for 20.2 hours at sea with the bird spending 68.8% of its time in flight and covering a total distance of 1014 km (i.e., 996 km in flight and the rest drifting). The average flight speed was 71.6 km hour-1 and the overall straightness ratio of the track between two landings was 0.63. In (B), a female's movement was recorded for 23.4 hours at sea during which she spent 38.9% in flight, flew a total distance of 625 km (i.e., 580 km in flight and the rest drifting on the water), traveled at an average flight speed of 63.7 km hour-1, and had a straightness ratio of 0.36. (C) Smaller scale part of a flight bout with cross-head winds; ground speeds progressively decreased when birds soar against the wind or with side winds, while speeds increased abruptly after birds has oriented from a head to tail wind. (D) Drifting movement on the sea surface after landing over the shelf edge.