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SUSTAINED FAST TRAVEL BY A GRAY-HEADED ALBATROSS (*THALASSARCHE CHRYSOSTOMA*) RIDING AN ANTARCTIC STORM

Paulo Catry,[1] Richard A. Phillips, and John P. Croxall

British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, United Kingdom

Abstract.—A Gray-headed Albatross (*Thalassarche chrysostoma*) was recorded traveling, in the course of a foraging trip, at a minimum average ground speed of >110 km h^{-1} for ~9 h with virtually no rest. After taking into account the sinuosity of albatross flight, actual mean ground speed was predicted to be ≥127 km h^{-1}, achieved in association with high tailwinds during an Antarctic storm. Despite its high speed and the storminess of the sea, the albatross still managed to successfully locate and capture prey at a rate comparable to that achieved under less extreme conditions. This individual's performance suggests that albatrosses have the capacity to maintain positive energy budgets while quickly covering long distances and taking advantage of the strong winds that are frequent in the Southern Ocean. *Received 3 November 2003, accepted 13 May 2004.*

Resumen.—Se registró un albatros *Thalassarche chrysostoma* viajando en el curso de un desplazamiento de forrajeo a una velocidad con respecto al suelo mínima promedio de más de 110 km h^{-1} durante ~9 h virtualmente sin descanso. Luego de tener en cuenta la sinuosidad del vuelo del albatros, se predijo que la velocidad promedio con respecto al suelo sería de 127 km h^{-1}, alcanzada en asociación con vientos de cola de altitud durante una tormenta del Antártico. A pesar de su alta velocidad y de la tormenta, el albatros aún logró encontrar y capturar exitosamente presas a una tasa comparable a aquella alcanzada bajo condiciones menos extremas. El desempeño de este individuo sugiere que los albatros tienen la capacidad de mantener presupuestos energéticos positivos mientras cubren grandes distancias rápidamente y aprovechan los vientos fuertes que se presentan con frecuencia en el Océano Sur.

As a group, birds are unique, in that many species regularly travel long distances at comparatively high speeds, to take advantage of favorable conditions in widely separated areas. Recent developments in tracking technologies have allowed a progressively greater appreciation of (1) how remarkable such performances are, (2) their constraints and limits, and (3) associated implications for the evolution of migration and life-history strategies (e.g. Spear and Ainley 1997, Berthold 2001, Hedenström 2002). Recent studies of large albatrosses have highlighted an outstanding ability to cover vast areas of the ocean at low energetic cost and at considerable speed (Weimerskirch et al. 2000, 2002). We document what may be the fastest medium- to long-distance travel bout ever recorded for a bird and show that extreme speeds (in this case, by a small albatross species) can be achieved without compromising the capacity for successful foraging while in transit.

[1]Present address: Unidade de Investigação em Eco-Etologia, Instituto Superior de Psicologia Aplicada, Rua Jardim do Tabaco 44, 1149-041 Lisbon, Portugal. E-mail: paulo.catry@netc.pt

Methods

Observations described here were made during a study of foraging behavior of Gray-headed Albatrosses (*Thalassarche chrysostoma*) nesting on Bird Island, South Georgia (54°00′S, 38°03′W; Fig. 1), in February and March 2003. Four Gray-headed Albatrosses were captured, just after feeding their chicks and before they departed to sea, and fitted with several devices to study their movements and behavior. Satellite transmitters (PTT 100; Microwave Telemetry, Columbia, Maryland) weighing 30 g were attached with adhesive tape to the mantle feathers (see Wilson et al. [2002], Phillips et al. [2003], and Catry et al. [2004] for more details on the devices and their attachment and success). Global positioning system (GPS) locations were provided by the Argos satellite system (CLS Argos, Toulouse, France). Birds were also fitted with wet–dry activity data-loggers (Francis Scientific Instruments, Cambridge, United Kingdom) that recorded, every 10 s, whether they were on the sea or in flight. Data-loggers were attached to a plastic band fitted to the tarsus (total mass, including band, 23 g). In addition, birds were fitted with stomach-temperature loggers (Earth and Ocean Technologies, Kiel, Germany) that weighed 42 g (including the anchoring spring) and incorporated a temperature sensor with a relative resolution of 0.1°C, inside a cylindrical titanium housing 99 mm tall and 19 mm in diameter. The anchoring spring hinders the regurgitation of the probe while the bird is at sea (see Wilson and Kierspel 1998 for more details). Loggers record temperature changes in the proventriculus, allowing the researcher to link sudden drops in temperature to ingestion of cold prey (Wilson et al. 1992). Housings were specifically designed to be large enough to sample and integrate the temperature over most of the stomach volume and not become covered by food after ingestion of only a few prey (Wilson et al. 1995). Stomach temperature was recorded and logged every 20 s.

Data from stomach loggers were analyzed using the program FEEDINT (Jensen Software Systems, Laboe, Germany), following Wilson et al. (1992, 1995). Calibrations to allow estimation of mass of ingested prey items were performed on three temporarily captive Gray-headed Albatrosses on Bird Island (Catry et al. 2004). Captive birds were fed several meals of varying mass and composition. Effects on profiles of variation in stomach temperature were assessed quantitatively, so that a relationship between stomach-temperature drop and meal mass could be established.

The subject female Gray-headed Albatross ("233-O") departed for the foraging trip documented here on 25 February 2003 at 1754 hours GMT. At time of deployment, the combined weight of devices (plus adhesive tape) represented 3.8% of the bird's body mass of 3.05 kg. When calculating travel speed between two locations, we took into account the amount of time spent by the bird on the sea surface, as recorded by the wet–dry activity logger. Distances between locations referred to in the text or used in velocity calculations are great-circle distances.

Results and Discussion

During the 14-day trip, bird 233-O foraged mostly in pelagic waters west of South Georgia and later in shelf and shelf-slope waters adjacent to the South Shetland Islands (about 61–62°S, 55–63°W). On 10 March, it started moving back toward the breeding colony. On 11 March, at ~0900 hours, 233-O began directed travel toward South Georgia, riding the north edge of a deep depression centered east of the South Orkneys, at about 60°00′S, 40°00′W (weather data from European Center for Medium-Range Weather Forecasts [ECMWF]; see Acknowledgments). Satellite transmissions indicated that the bird returned to its colony around 1830–1900 hours on the same day. Ten Argos positions were obtained between 0941 and 1809 hours during the travel bout (Fig. 1). From available weather charts, it was apparent that 233-O experienced consistent tail winds with an estimated speed of 70–80 km h^{-1} (ECMWF data and G. Marshall pers. comm.).

Very high apparent travel speeds can result from inaccurate Argos locations. When estimating velocity, we used the approach proposed by Hays et al. (2001) to deal with that problem. Following their recommendations, we (1) inspected the data to assess whether high apparent speeds resulted from one or more particular locations that might have a large error associated with them; (2) calculated flight speeds over long distances to minimize effects of location errors; and (3) estimated the magnitude of errors associated with high-quality locations, using our own field data. In fact, all data available to us were consistent with fast (>100 km h^{-1}) travel, and the exclusion of one or several locations from the data had no effect on the overall result (Table 1). The slowest recorded speed between any 2 of the 10 Argos locations was 97 km h^{-1}. All except one of the other 44 possible measurements of speed (i.e. all possible combinations of the 10 locations) were >100 km h^{-1}. On the basis of preliminary analyses of data from albatrosses known to be at the colony, we estimate that Argos class-1 locations (LC 1) have a mean ± SD error of 1.19 ± 1.25 km (range = 0.12–8.89 km, n = 267 locations; British Antarctic Survey unpubl. data). Consideration of just the two LC 1 locations (numbers 155 and 160) indicates a flight speed (116 km h^{-1} over a distance of 393 km) that is entirely consistent with the remaining data (Table 1).

Apparent velocity between the first and last locations was 115 km h^{-1} over a great-circle distance of 934 km (Table 1). During that period, 233-O landed on the sea surface on nine occasions, for 2.2 min on average (range = 0.2–6.5 min; sum = 20 min). Because it was flying under similar conditions for some time before and after the period considered here, we estimate that 233-O covered a distance of >1,000 km in <10 h.

The dynamic soaring flight of albatrosses involves a zigzag movement at a small scale (~100 m) as the bird continuously adjusts for optimal use of the wind (Alerstam et al. 1993, Fritz et al. 2003). An index of the straightness of a flight path can be calculated by dividing the

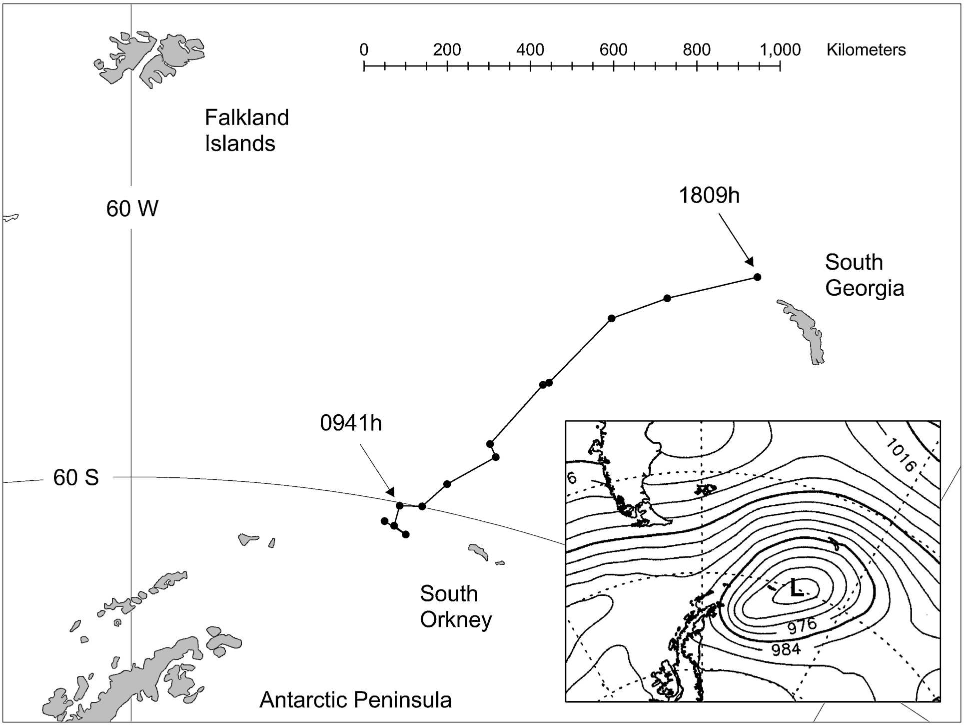

FIG. 1. Flight track of the female Gray-headed Albatross 233-O, on 11 March 2003, moving from the South Orkney region to the vicinity of Bird Island, South Georgia. Inset is the meteorological chart representing the weather situation at 1200 hours on the same day in the southwest Atlantic and showing a deep depression centered east of South Orkney. Note that winds blow clockwise around centers of depressions in the Southern Hemisphere.

straight-line distance between initial and final tracking position by the cumulative distance between all successive positions (an index of 1.0 is obtained when the movement occurs along a perfectly straight line). Such measurements for smaller albatrosses are available only at coarser scales, which tend to overestimate "real" straightness indices (Alerstam et al. 1993). Straightness indices have, however, been measured for Wandering Albatrosses (*Diomedea exulans*), using accurate GPS locations recorded at 1-s intervals, with the straightest movement recorded between two successive landings having an index value of 0.72 (Weimerskirch et al. 2002). Assuming a similar degree of sinuosity for Gray-headed Albatrosses, which seems reasonable given the general similarity of the flight patterns of large and small albatrosses (Pennycuick 1982), and assuming that sinuosity of movements at small scales are largely independent of wind strength and direction in relation to the flight path (Weimerskirch et al. 2002, Fritz et al. 2003), the mean speed of travel suggested for 233-O is 158 km h^{-1}. Even taking a very conservative approach and assuming a straightness index as high as 0.90 (incidentally, much less sinuous than the flight paths of Wandering Albatrosses), we estimate that 233-O maintained a mean ground speed of 127 km h^{-1} (= 35.3 m s^{-1}) for >8 h, with only brief stops for feeding and possibly resting. Instantaneous ground speeds of soaring albatrosses show large short-term variations as the bird turns and as it gains and loses altitude (Weimerskirch et al. 2002). Therefore, the peak instantaneous ground speeds of 233-O must have been considerably higher than 127 km h^{-1} during much of the flight. A maximum instantaneous ground speed of 135 km h^{-1} has been recorded for a Wandering Albatross (Weimerskirch et al. 2002), but our results suggest that 233-O was sometimes traveling considerably faster.

Typical air speed of small albatrosses flying with a tail wind is 32 ± 14 km h^{-1}, that speed

Table 1. Apparent velocities of travel by a Gray-headed Albatross (233-O) between 10 Argos locations (154 through 163; see text), obtained between 0941 and 1809 hours, on 11 March 2003. Note that within each set of five measurements, each velocity estimate is entirely independent. Measurements in different sets, though not independent, are never repeated. Velocity estimates are corrected for time spent on the sea surface and assume travel in a straight (great-circle) line between locations.

Pair of locations	Quality (location class[a])	Great-circle distance (km)	Velocity (km h^{-1})
154, 155	0, 1	50.4	137.2
156, 157	0, 0	123.8	98.9
158, 159	0, 0	175.3	112.1
160, 161	1, B	196.5	128.3
162, 163	0, B	200.8	127.8
154, 156	0, 0	116.1	168.2
155, 157	1, 0	197.1	122.8
158, 161	0, B	384.6	119.0
159, 162	0, 0	331.6	112.8
160, 163	1, B	509.7	116.6
154, 163	0, B	934.0	115.1
155, 162	1, 0	708.9	114.8
156, 161	0, B	515.2	112.4
158, 160	0, 1	188.1	110.6
157, 159	0, 0	190.6	114.8
Median of medians per set			119.0

[a]Argos assigns a quality index, termed "location class" (LC), to each location. By decreasing order of quality, the index can take the values or codes 3, 2, 1, 0, A, and B. See Hays et al. (2001) for a detailed evaluation of errors associated with measurements in each LC.

being relatively constant with increasing wind force (Spear and Ainley 1997). Adding a mean (tail) wind speed of 70–80 km h^{-1} (see above) to that value gives ground-speed values around (but slightly lower than) the ones reported for 233-O. Note that Spear and Ainley (1997) used a correction factor based on a straightness index (from Alerstam et al. 1993) that is likely to be considerably over-estimated; hence, their air-speed estimates are probably conservative, which may partly explain why our observations suggest a ground speed, during the fast travel-bout discussed here, slightly higher than the sum of typical albatross air speeds and estimated tail-wind speed.

Several models of optimal speed on foraging flights have assumed that searching becomes progressively less efficient with increasing ground speed (e.g. Pyke 1981, Houston 1986, Alerstam et al. 1993). Analysis of stomach temperature records indicates that, on 11 March, 233-O ingested 11 prey items or meals representing an estimated total of 792 g of food. Four of those items or meals (total 484 g) were ingested between 0941 and 1809 hours, during the bout of rapid travel toward the colony. The total food ingested during that particular day (792 g) compares with a mean daily intake of 793 g (range = 209–1,709 g) by the same individual during the previous 13 days. Even considering the several possible sources of error when estimating meal masses from temperature data (e.g. Wilson et al. 1995, Ancel et al. 1997), it is clear that the foraging performance of 233-O was unimpaired by her rapid travel speed. It is remarkable that such performance was achieved under storm conditions, undoubtedly involving rough seas and salt spray, which likely affected visibility and prey detection. Thus, our results suggest that models of foraging behavior should not necessarily assume a sharp decrease in prey-detection ability with increasing speeds, at least in large petrels and albatrosses.

Flight costs are known to be low, as compared with costs of other at-sea activities in albatrosses (e.g. Bevan et al. 1995), particularly when the bird is traveling with following winds (Weimerskirch et al. 2000). We would not, therefore, expect the energy consumption of 233-O, during its prolonged flight, to have been higher than the average on a standard day at sea. Gray-headed Albatrosses need to consume ~775 g of food, on a diet of standard composition, to meet their daily energy requirements when foraging (Costa and Prince 1987, Huin and Prince 1997). Thus, our calculations of daily food intake seem reasonable. Under the conditions reported here, "storm riding" can evidently be an extremely fast and efficient means of travel for albatrosses: 233-O covered 1,000 km in <10 h, while probably maintaining a positive net energy-balance, thanks to the capture of several prey *en route*.

Fast travel by albatrosses under favorable weather conditions is probably not exceptional, but rather a typical part of their foraging and migration strategies (e.g. Stahl and Sagar 2000, Weimerskirch et al. 2002). Murray et al. (2003) have shown how albatrosses can use weather systems to travel long distances, even against the regionally prevailing direction of air flow. Data presented here not only highlight the capacity for exceptionally rapid flight by small albatrosses under favorable conditions, but also show, for the first time, that such travel is not incompatible with successful foraging.

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