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# Bird-borne satellite transmitters: current limitations and future prospects

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**Abstract** — The paper provides a brief account on satellite tracking, a new promising method for studying bird migration and orientation. This method is based on two Tyros-N satellites which receive and locate the signals emitted by bird-borne transmitters. The literature on this topic is still very limited, due to the fact that this technique, which is only a few years old, has not yet left the pionieristic phase. However, technical problems concerning the weight of transmitters - and their short operative lifetime - which presently pose severe limits to experimentation, will supposedly be overcome soon by the progress of technology. New generations of transmitters, and possibly other satellite systems equipped with more advanced onboard instruments, will certainly provide relevant information on the many challenging questions related to avian migration and navigation which cannot be answered by conventional methods. Preliminary results from a satellite tracking experiment on migrating Brent Geese, recently run by the research team which the author belongs to, are briefly reported. Despite the limited operative lifetime of transmitters, this method allowed us to reconstruct a large portion of the geese' flight paths from their main staging sites in Iceland to the breeding grounds on Canadian arctic islands, and also to investigate the experimental birds' orientational strategies.

## Introduction

In the last few decades, new techniques for studying bird migration have been added to traditional methods; data achieved by conventional techniques, such as ringing activity and visual observations of migrating birds, have been complemented by a wealth of new and fruitful results produced by ceilometers, radars, radio transmitters and other instruments originally devised for quite different aims. Potential possibilities offered by these new methods had not yet been fully exploited when the attention of students of bird migration was attracted to artificial satellites orbiting around our planet. Animal satellite-tracking cannot be considered a new procedure, as the first successful attempts to track large mammals date back to the early 1970s; only in recent years, however, satellite transmitters have become sufficiently small and light to be carried by large birds. The present paper aims to offer a brief review of the main results achieved so far by using this promising and fascinating technique. A preliminary report will also be given on the investigation that is currently being carried out by the reseach team which the author belongs to.

## The Argos system and transmitters

Geographical coordinates of animals equipped with appropriate transmitters can be regularly localized by satellites which have been provided with specific onboard instruments. The commercial system presently used for animal tracking by satellite is the result of a co-operation between the Centre National d' Etudes Spatiales (CNES, France), the National Aeronautics & Space Administration (NASA, USA) and the National Oceanic & Atmospheric Administration (NOAA, USA). ARGOS is the name of this FrenchAmerican system, with headquarters in Toulouse, France; other commercial satellite systems will certainly be available in the near future (further details and references in Nowak and Berthold 1991).

The ARGOS space segment consists of two NOAA Tyros-N satellites with polar low-altitude orbits (830 and 870 km), each equipped with onboard location systems which record and process messages transmitted by platform transmitter terminals (PTTs) from the earth's surface. The onboard data collection systems may also be used for obtaining telemetry data (physiological and environmental information) from remote locations. The geographical position of each platform, and thus the

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locations of the animal which has been equipped with a PTT, is determined by measuring the Doppler effect on the frequency of incoming messages. Data are then transmitted from the satellite to one of the telemetry ground stations, from where the information is retransmitted to the ARGOS data processing center, in Toulouse. There the results are made available to the users within 2-6 hours from the receipt of signals.

As far as the performance of the system, the number of possible locations per day varies according to the latitude of the animal-borne transmitter (the ARGOS service guarantees a minimum of six locations per day). The minimum number is obtained close to the Equator, whereas more frequent locations (up to 28 per day) can be achieved at higher latitudes. Location accuracy varies according to circumstances: sources of errors may be related to such factors as altitude and speed of the animal-borne transmitter. The PTT is considered to be stationary at the ground level at the moment of the transmission; in these conditions, location accuracy is usually within 1 to 2 km. Fast movements or high altitudes, as those which characterize bird migration, can result in errors which however lie within an acceptable range.

The first successful attempts to track by satellite the flight paths of migrating birds were reported by Strikwerda *et al.* (1986), who used a 170 g transmitter devised by the Applied Physics Laboratory of the Johns Hopkins University in Laurel, Maryland, USA. Better levels of miniaturisation of the transmitters were subsequently achieved in Japan by Toyo Communication Equipment Co., and by other companies in Great Britain and in the USA (for further details and references on the ARGOS system and transmitters see Nowak and Berthold 1991).

## Bird migration studies by satellite tracking

Due to the limits imposed by the weight of transmitters, only a few species of large birds have so far been subjected to satellite tracking experiments. Since 1984, when pilot studies of Strikwerda *et al.* (1986) on the Giant Petrel *(Macronectes giganteus)* and Trumpeter Swan *(Cignus buccinator)* were carried out, only a few papers have been published. Main papers regards five systematic groups: Sphenisciformes: *Aptenodytes patagonica, A. forsteri, Pygoscelis adeliae* (Freby *et al.* 1990, Ancel *et al.* 1992, Davis and Miller 1992); Procellariformes: *Diomedea exulans, Macronectes giganteus* (Strikwerda *et al.* 1986, Juventin and Weimerskirch 1990, Croxall 1990, Prince *et al.* 1992); Anseriformes: *Cignus c. columbianus, C. c. bewickii, C. c. jankowsky, C. buccinator* (Strikwerda *et al.* 1986, Nowak *et al.* 1990, Higuchi *et al.* 1991); Accipitriformes: *Haliaetus leucocephalus, Gyps fulvus* (Strikwerda *et al.* 1986, Berthold et al 1991); Ciconiiformes: *Ciconia ciconia* (Berthold *et al.* 1992).

It is expected that this short list of papers will dramatically lengthen in the near future due to the large number of the studies which are in progress on several species of Cranes in America and Asia, and of Accipitriformes in North America (see Nowak and Berthold 1991). Other interesting programs concern Magpie Geese in Australia *(Anseranas semipalmata,* Taplin 1992) and Hubara Bustards *(Chlamidotis undata)* in Saudi Arabia (Goriup 1990).

It is worth to point out that not all these investigations concern migratory behaviour; the fascinating study of Juventin and Weimerskirch (1990) on the Wandering Albatross *(Diomedea exulans)* at the Crozet archipelago in the Indian Ocean regards the foraging behaviour of breeding individuals. Nonetheless, the results were impressive indeed; the satellite tracking technique revealed that breeding Wandering Albatrosses accomplish extremely long foraging trips whose lenght may exceed 15.000 km - ten times longer than expected - and allowed to plot the birds' foraging routes with respect to winds, to pressure systems and other environmental factors.

## Migratory routes of the Light-bellied Brent Goose

Brent Geese *(Brenta bernicla hrota)* have recently been subjected to a fruitful satellite tracking study by an international research team composed by Swedish (S. Akesson, T. Alerstam, University of Lund), Icelandic (G.A. Gudmundsson, Icelandic Museum of Natural History, Reykjavik) and Italian researchers (F.Papi and the author of this article). Brent Geese are arctic migrants whose migratory pattern is particularly interesting due to severe environmental conditions at polar latitudes, such as pronounced seasonality and extreme weather systems; these are associated with factors which may make the known orientational mechanisms totally unreliable. Stars are in fact not visible during the spring migration period of Brent Geese in the Arctic region; steep inclination angles and weak horizontal field intensities, associated with frequent magnetic disturbances, may not supply birds with reliable geomagnetic orientational information. Moreover, fast longitudinal displacement, which arctic migrants are subjected to along this particular route, may not allow the time-compensated sun compass to reset in accordance with the local time (references in Alerstam *et al.* 1990).

Five Brent Geese were netted on 25 and 26 May 1992 in western Iceland, the most important staging site for this population during the spring migration between wintering quarters in western Europe and the breeding grounds on Canadian arctic islands. The birds were equipped with PTTs produced by Toyocom (Toyo Communication Equipment Co., Tokyo, Japan; series T 2038, weight: 57 g, expected operative lifetime: 30 days). Four of the transmitters were simply glued to the birds' backs, whereas one of the instruments was also harnessed by a thin teflon tubing (weight of the harness: 18 g). Soon after the manipulation the birds were released at the site where they had been captured. Unfortunately, the birds' trip took longer than expected, as they frequently rested at stop-over sites along the migratory path. Conversely, the operative life of transmitters was significantly shorter than expected, and we were thus not able to track the birds as far as their breeding grounds. The last signals from the transmitters were received from the eastern (two birds) and western (three birds) coast of Greenland. However, data achieved from bird-borne transmitters have allowed us to reconstruct the route of the five Brent Geese along a large portion of their migratory flights, including the Greenland Inlandice - a vast and inhospitable ice barrier which rises to an altitude of over 2500 m (Fig. 1). Satellite data show that the migratory paths were neither in agreement with a rhumbline or a great circle route between western Iceland and the expected final destination (for theoretical aspects, see Alerstam et al. 1990, Alerstam and Pettersson 1991), but followed a zigzagging course which appears as a strategy 'intended' to detain the birds in unfavourable environments (the open sea and Greenland ice-cap) as little as possible. Thus, the Denmark Strait between Greenland and Iceland was traversed in a direction which minimizes the length of the flight over the open sea; the southwestward

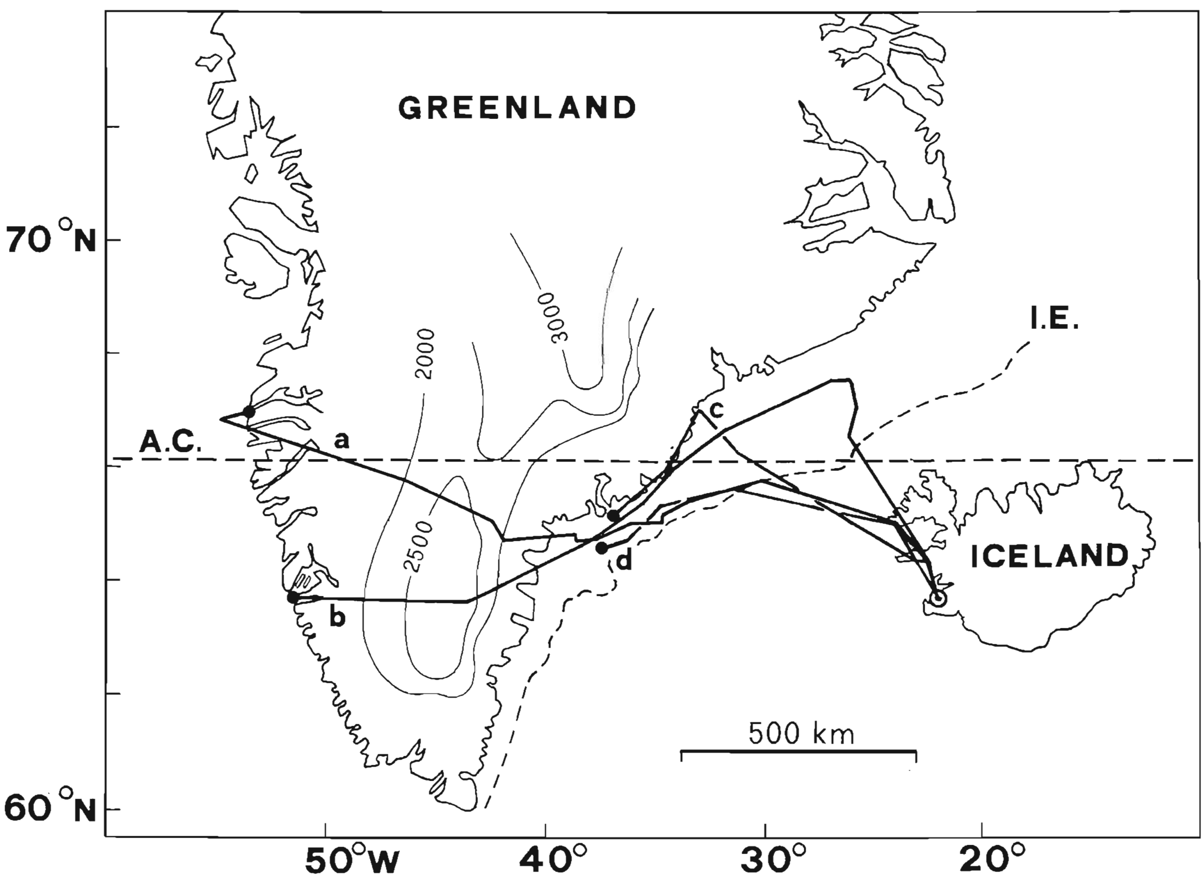


Fig. 1. The routes of five migrating Brent Geese between the capture site near to Reykjavik (circle) to the sites where transmitters sent the last signals (black dots) are shown. Only four routes are presented because two of the geese - a pair (male and female) of adult birds - flew together along the same path (a). Route b was flown by a young male, whereas c and d belong to two adult males. A.C. and I.E. = Arctic Circle and pack-ice edge.

flight along the eastern coast of Greenland, on the other hand, shortened the distance to the western coast across the Inlandice (Fig. 1). The cumulative distance flown by the birds (three individuals and a pair) ranged between 917 and 2420 km.

New satellite tracking experiments, using transmitters with longer lifetime, will be run in the future in the attempt to track migrating Brent geese as far as their breeding grounds in northern Canada.

## Satellite tracking technique: current limitations and future prospects

Satellite tracking experiments on birds are still in a pionieristic phase due to severe limitations imposed by the current technology. The transmitters, in fact, are still too heavy, and can therefore only be used to study large birds. Their weight, associated with non-aerodinamic shape, may influence the behaviour of the birds by increasing the number and/or length of stops during the migratory flight. Wind tunnel studies on birds equipped with conventional radio transmitters have suggested that the weight and shape of transmitters and harness may have little effect on flight dynamic of some bird species, whereas in other cases a drastic impairment has been reported (Gessaman and Nagy 1988, Pennycuick *et al.* 1988, Walsberg 1990).

Another negative aspect of the presently available transmitters is the short operative lifetime; as the batteries constitute most of the transmitters' weight, the decrease in size and weight has mainly been obtained by reduction of batteries thereby reducing the transmitters' lifetime. A promising solution of this problem may be the use of light solar cells, which will hopefully be produced in the near future (some pilot attempts have already been carried out by Stikwerda and his coworkers in 1986), and by devising a new generation of light transmitters endowed with longer operative lifetime. Light transmitters will certainly be available quite soon, considering the rapid advances in electronic technology. Tokyo Communication Equipment Co. (Tokyo, Japan) has recently announced that a 20 g transmitter - produced by large-scale integration of the electronic components and a ultra-light power supply - will soon be put to the market (Tsutsumi 1992).

Despite the above mentioned limitations (which also include a low number of locations per day, and the high cost of transmitters and their management by the ARGOS system), bird satellite tracking is a technique which has opened a wealth of new possibilities in bird migration and orientation studies. When this method will emerge from the current pionieristic phase, it can certainly provide relevant information on many fascinating problems related to avian migration strategies and orientation mechanisms which cannot be solved by any of the conventional methods. Satellite tracking may allow researchers to reconstruct a detailed "ecodiagram" (or "Ökodiagramme des Zugablaufs", according to Nowak and Berthold 1987, Berthold *et al.* 1992) of the migratory journey of individual birds. This ecodiagram can supply important information on the migratory course with respect to weather systems and relevant topographical features, flight speed, the pattern of stop over sites and the length of resting periods. In addition, it may provide a significant basis for conservation measures in favour of endangered species.

Satellite tracking will certainly turn out to be a powerful method to investigate orientation mechanisms of birds and to provide an answer to the many questions related to this fascinating, and still obscure aspect of avian migration.

These and other crucial questions may be answered not only by simply running satellite tracking observations, but also by subjecting birds, equipped with satellite transmitters, to experimental manipulations. An interesting prospect, for example, is the possibility to carry out long-distance displacement experiments of breeding and migrating individuals in order to investigate their navigational ability. This would allow us to verify whether olfactory cues, which the navigational performance of homing pigeons is based on (references in Papi 1991), and which seem to play a role in the homing process of the Swift (*Apus apus:* Fiaschi *et al.* 1974) and Starling (*Sturnus vulgaris:* Wallraff and Hund, 1982), are also an important component of other bird species' navigational system.

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**Riassunto** — Viene descritta brevemente la tecnica di rilevamento via satellite: un nuovo e promettente metodo di studio delle migrazioni e delle capacità di orientamento degli uccelli. Il sistema si basa su due satelliti Tyros-N che ricevono e ritrasmettono a stazioni di rilevamento a terra i segnali emessi da speciali trasmettitori applicati agli uccelli. La letteratura in questo campo è ancora molto limitata in quanto questa tecnica, introdotta solo pochi anni fa nella ricerca ornitologica, non è ancora uscita dalla iniziale fase pionieristica; infatti, il peso e la forma dei trasmettitori, unitamente alla loro breve vita operativa, impongono severi limiti alla sperimentazione. È probabile tuttavia che il progresso della tecnologia produca entro breve tempo nuove generazioni di trasmettitori e nuovi sistemi di rilevamento basati su satelliti dotati di una strumentazione piú efficiente,

che saranno certamente in grado di fornire importanti informazioni sui molti lati oscuri presentati dalle migrazioni degli uccelli che non possono essere chiariti usando metodi di studio convenzionali.
Un esperimento di rilevamento delle rotte migratorie dell'oca colombaccio via satellite è stato recentemente compiuto dal gruppo di ricerca cui l'autore appartiene; nonostante la breve vita operativa dei trasmettitori, questo metodo ha permesso di tracciare un esteso segmento della rotta degli uccelli e di investigare sulle loro strategie di orientamento nel corso della migrazione primaverile dalle aree di foraggiamento in Islanda occidentale ai quartieri di riproduzione nelle isole artiche del Canada.

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