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Migration of a Peregrine Falcon *Falco peregrinus* over water in the vicinity of a hurricane

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Peregrine Falcons *Falco peregrinus* migrating over the Gulf of Mexico have limited perching opportunities and can encounter weather that impedes southward movement. In 1998 we tracked via satellite a migrating second-year female Peregrine during 79 days from Assateague Island, Virginia, USA, to inland Venezuela, and related its movement to local weather conditions, especially during its crossing of the Gulf where it encountered weather affected by Hurricane Mitch. We document Peregrine migration in extreme weather conditions and highlight the importance of tailwinds and updraughts, especially during the water crossing – even for a Peregrine, which is not adapted for soaring flight. Analyses of the large pool of data from migrating Peregrines fitted with satellite-received transmitters in relation to weather are lacking.

Peregrine Falcons *Falco peregrinus* that summer at high (> 50°N) latitudes are migratory and many factors are likely to affect their migration, including prey availability (Alerstam 1990), geography, landscape (Kerlinger 1989) and weather (Ferguson & Ferguson 1922, Richardson 1990). Water bodies, such as the Gulf of Mexico, can be an impediment, especially to migration by soaring raptors (McRae 1985, Kerlinger 1989). However, despite their being less reliant on soaring and able to hunt and feed on the wing, weather may also affect the willingness of Peregrines to make water crossings (Slack & Slack 1981).

Peregrine migration through the east coast of North America occurs mostly in September and October (see Zalles & Bildstein 2000) and their progress throughout autumn migration is linked to tail winds (Young, unpublished data). For Peregrines, which are strong, active fliers on migration (though they do soar), whether or not a water body is a barrier to migration may vary with weather conditions. Satellite tracking data (Seegar, unpublished data) and the distribution of known concentration points of migrating raptors in spring and autumn (Zalles & Bildstein 2000) suggest that the Gulf of Mexico is a greater barrier to migrating Peregrines in the spring than in the autumn. In some cases Peregrines cannot overcome adverse weather conditions while over open water and perish, or if lucky land on a boat or oil platform (Byers 1957, Russell 2001).

We used data from a single, autumn-migrating female Peregrine (Seegar *et al* 2003) and concentrated on its crossing of the Gulf of Mexico, where this bird encountered Hurricane Mitch and responded both to its approach and passing. We report this example of migration in the face of extreme weather conditions as a way of framing the variables that affected this Peregrine's migration over the Gulf, where it had no local terrestrial refuge for waiting out the storm.

METHODS

A second-year female Peregrine was captured on migration at Assateague Island, VA, USA, on 13 October 1998 and fitted with a satellite-received transmitter (PTT) operating on a duty cycle of eight hours on and 22 hours off, then tracked using the Argos system of satellites (see Fuller *et al* 1998, McGrady *et al* 2002). Seegar *et al* (2003) published a popular account of this bird's movements. We used location estimates of Location Class (LC) 0–3 to map the movement of this bird and relate it to weather conditions.

Location Classes are nominal accuracies assigned to each location estimate by the Argos system, and are derived from the signal characteristics, number of transmissions, agreement of location estimates between transmissions, and number of satellites to detect the transmissions. Nominally, LC 3 location estimates are accurate to < 300 m and LC 0 locations > 2 km. There is also a potential for inaccuracies in the estimated timing of departures and arrivals: although the locations of the Peregrine were nominally accurate to < 5 km, the bird may have moved from or landed at a stationary point during a time when the PTT was not transmitting.

The location and rate of movement of weather fronts was extrapolated from weather stations and maps of clouds. Weather data used in this study included surface wind speed and direction, atmospheric pressure at sea level, and surface

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air temperature on a 2.5° latitude–longitude grid extracted from the National Centers for Environmental Prediction (NCEP) Global Reanalysis data set (Kalnay *et al* 1996) and official National Weather Service (NWS) surface weather maps obtained from the National Climatic Data Center. The latter include plotted surface observations, contours of sea-level pressure, and analysed frontal positions. Hurricane position fixes every six hours were obtained from the official best-track data set (HURDAT, Jarvinen *et al* 1984) of the National Oceanic and Atmospheric Administration's Hurricane Research Division.

Distances, bearing and the pace of the Peregrine's migration were measured within a GIS (ArcView 3.3, ESRI, Redlands, CA, USA). The NCEP gridded weather data were manipulated within Matlab (MathWorks, Natick, MA, USA) to prepare charts overlaying the position of the Peregrine and Hurricane Mitch upon a map of wind vectors. The frontal positions from the NWS surface maps were then added as an additional overlay using Photoshop (Adobe, San Jose, CA, USA). Matlab was used to produce maps of NCEP sea-level pressure and surface temperature fields as a means of verifying these frontal positions and other features of the NWS surface-weather maps. Time is in local time: Eastern Standard Time (EST) = GMT – 5 h, or Central Standard Time (CST) = GMT – 6 h. Sunrise in the Gulf at this time of year is around 0430–0530 and sunset is around 1830–1930. The potential inaccuracies in weather data and Peregrine location were small compared to the extent of migration and the size of the Gulf region.

RESULTS

This Peregrine was tracked for a total of 79 days in 1998, during which it crossed 28 degrees of latitude (Fig 1). A total of 105 locations of LC 0–3 quality were estimated, and these fell within 57 of a possible 64 transmission periods. The Peregrine's movement could be divided into six phases: 1) migration before embarking across the Gulf; 2) first attempt to migrate south over the Gulf; 3) retreat from the hurricane; 4) waiting for the hurricane to pass; 5) second attempt to migrate south over the Gulf, and 6) migration south over land in Central and South America. Phases 3 and 5 probably included times when the Peregrine was perched on a ship or oil platform. During phases 1–4 the hurricane was generally south of the falcon; during phases 5 and 6 it was to the east.

Phase 1

The Peregrine travelled approximately 1,650 km (c13 degrees of latitude) from where it was captured (13 October) on Assateague Island, VA, to the south coast of Florida,

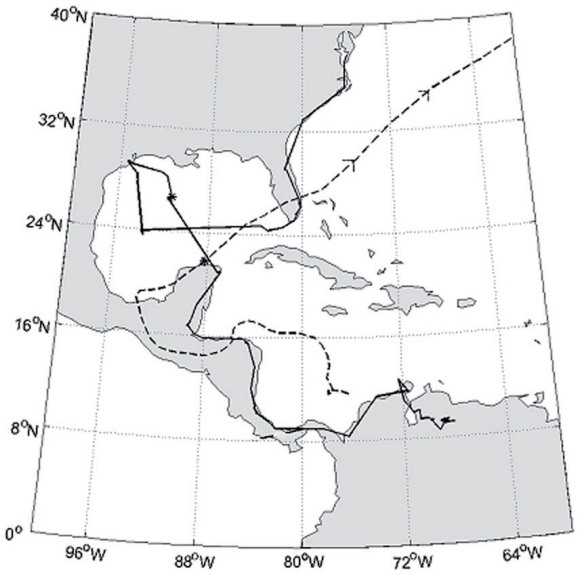

Figure 1. Migration track of a Peregrine Falcon (solid) and the track of Hurricane Mitch (dashed) during autumn 1998. The * symbols mark the positions of the falcon and hurricane at the time of their closest approach (~ 0600 CST 4 November 1998).

probably arriving on 19 October (approximate minimum mean migration rate = 264 km day^{-1}). The Peregrine moved at least 150 km each day despite variable weather conditions. It was recaptured on the Florida Keys and released (C. Lott, pers comm) on 20 October. It was on or near Saddlebunch Key (24.7°N 81.6°W) for at least all of 21 October and possibly 22 October. A cold front pushed slowly south across the Peregrine's position at about 1300 EST on 22 October.

Phase 2

The Peregrine started to migrate again on 23 October, heading west past the Dry Tortugas (24.6°N 82.3°W) and most of the way westward across the Gulf of Mexico (bearing = 263°). The stationary front began to move south again in mid phase (c 2100 CST, 23 October) and faded by the end of this phase (c 0600 CST, 24 October). There were northeast winds to the north of the front converging with weak easterlies to the south of the front (Fig 2). Thus, a Peregrine leaving the Keys behind the front would have experienced brisk tailwinds on a course to Cuba or Yucatan until reaching the front and then encountered weak quartering tailwinds. The dissipation of the western end of the front would have left the Peregrine over the open Gulf of Mexico with weakening updraughts, but still strong tailwinds for a westward course. The Peregrine reached its open Gulf resting point (1,230 km from Saddlebunch Key, 23.5°N 93.5°W) most probably on 24 October. The minimum speed for this leg was 35 km h^{-1}, about the

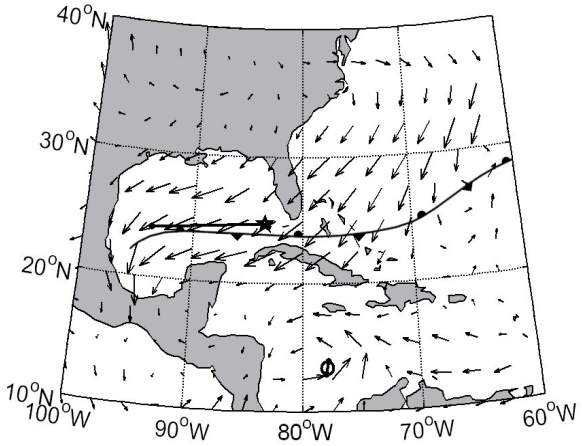

Figure 2. Peregrine track between locations bracketing 1800 CST on 23 October 1998 (phase 2) overlain on maps of the NCEP reanalysis wind vectors, and the NWS frontal position (thick black line with frontal symbols). The star marks the Peregrine fix closest to the map time (0.65 h prior to map time), while the dots mark the preceding fix and the subsequent fix. Only the latter is visible, as the former is overlain by the star. An open circle (map time) and two dots are used for the three six-hourly hurricane position fixes, all of which are located near 13°N 78°W.

speed of the tailwind north of the front. At this point the Peregrine appeared to stop for about 1.7 h, presumably perching on a ship.

Phase 3

Between 25 and 27 October the Peregrine moved NNW (bearing = 347°) towards Galveston Bay at a speed of about 16.5 km h^{-1}, presumably on a ship. During this time the bird would have been moving across a brisk wind (c 35 km h^{-1}).

Phase 4

The Peregrine settled for about four days on the Brazos River estuary (c 29.1°N 95.2°W), just west of Galveston.

Phase 5

On 2 or 3 November the Peregrine left the mainland and headed SE (bearing = 109°), when a cold front crossed its location and favourable winds ensued. It may have been that departure from the mainland was aided by a ship because the minimum speed of this movement was 10 km h^{-1}. Its path then swung south, and on 4 November it settled for at least 2.7 h on an apparently stationary perch at approximately 26.5°N 91.6°W, some 445 km SE from the Brazos River estuary and some 300 km SSW from the nearest land.

At this point the weather and updraught patterns near the Peregrine's location were likely to have been complex as the polar front and the spiralling convective bands of the hurricane interacted. NWS maps (Figs 3, 4 & 5) show

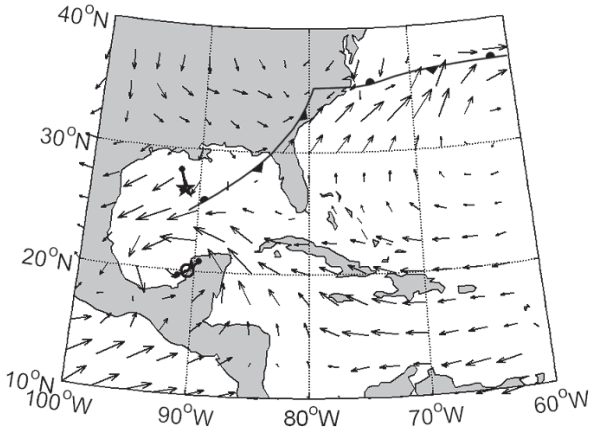

Figure 3. As in Fig 2, but for 1800 CST on 3 November 1998 (phase 5). The circled Peregrine fix was 11 h after map time. The front to the south of the plotted Peregrine positions is a cold front starting to go stationary. The hurricane moved northeast along the coast of Yucatan.

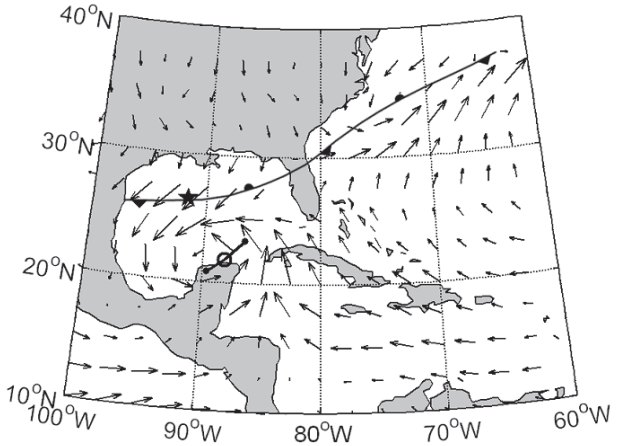

Figure 4. As in Fig 2, but for 0600 CST on 4 November 1998 (phase 5). The circled Peregrine fix was 0.65 h after map time. The front had retrogressed to the Peregrine's position as a warm front. The hurricane continued moving northeast, leaving Yucatan on its way toward Florida.

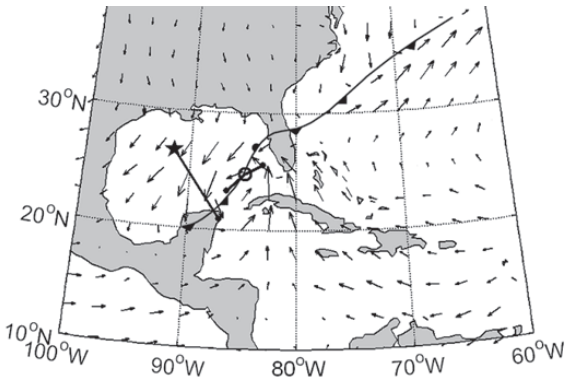

Figure 5. As in Fig 2, but for 1800 CST on 5 November 1998 (phase 5). The circled Peregrine fix was 9.6 h before map time. The front was again pushing south as a cold front that wraps around the hurricane. The hurricane continued moving northeast across the Gulf of Mexico, now entwined with the front.

the front shifting northwest then displacing southeast to merge with the hurricane. The front crossed the Peregrine's position at 2000 CST (as darkness fell), and the bird remained there at least until 0800 CST, when it initiated its flight to the Yucatan Peninsula using either the frontal updraught or the postfrontal tailwind and convective updraughts. The Peregrine was first recorded on the Yucatan Peninsula at 1243 CST, slightly inland from Cancún at 20.9°N, 87.1°W.

Phase 6

Once on the Yucatan, the Peregrine appeared to pause for at least 1.7 h, then moved to low lands around Bahía Chetumal on the east coast of the Yucatan at approximately 21.0°N 86.9°W. It then made relatively slow (*c* 85 km day^{-1}) but steady progress to approximately 9.2°N 68.8° W (near Villa Bruzual, Venezuela) on 7 December, where it apparently wintered. Weather along the flight track during this period was benign, alternating between northeasterly trade winds and the somewhat weaker northerly surges. The apparent wintering area was in the Orinoco Basin in an area of intensive agriculture, including rice cultivation. The last location was received on 31 December 1998.

DISCUSSION

Phases 1 and 6 were completely (or nearly so) over land and the weather during those periods seemed to be less of a determinant of whether and how far the Peregrine would migrate. The Peregrine made the phase 2, 4 and 5 (southerly) water crossings either on cold fronts (or stalling cold fronts) or in the cold air outbreaks immediately behind these. Phase 2 ended when the Peregrine ran off the western (dissipating) end of the front. Phase 4 began as a pure cold front, but developed into one with enhanced tailwinds caused by its merging with Hurricane Mitch. Phase 3, the move northward, was made across a brisk wind, probably on a ship.

Prior to each over-water leg, the bird waited while the winds opposed southward flight and launched on over-water legs whenever a cold front passed, bringing updraughts and a northerly wind component. This contrasts with McRae (1985) who stated that falcons will make water crossings in any weather, though her data were from direct observations at short crossings where a falcon at high altitude could see the other side.

The movements by this Peregrine suggest three preferred courses of action:

a) If on a southward-tending coast, migrate along it no matter what the wind direction. This may have been violated when good migrating conditions pushed the falcon over water, especially during daylight.

b) If facing a water crossing, wait until there is a brisk northerly component to the wind and updraughts are available, then migrate. (It is not possible to separate these two weather factors since they occur together in the autumn over the Gulf of Mexico).

c) If facing a water crossing during opposing winds, find a suitable place to wait until weather better for migration arrives.

G. Holroyd (pers comm) tracked another falcon in autumn 1997 via satellite from its breeding area in central Canada, and it, too, encountered Hurricane Mitch. That bird made two attempts to cross from Haiti to Venezuela, apparently perishing on the second when it may have encountered head winds of *c* 160 km hr^{-1}.

Peregrine migration has been examined in relation to weather (*eg* Ward & Berry 1972, Titus *et al* 1988) but these studies have considered the volume of migrants seen at concentration points and not the movements of individuals. Whereas movements of soaring raptors seem closely linked to cold fronts and northwest winds, information on Peregrines is less consistent. Kerlinger (1989) and Allen *et al* (1996) found that counts of autumn-migrating Peregrines in eastern North America were associated with cold fronts, and Slack & Slack (1981) suggest that the bearing of flight by Peregrines and whether they departed over water depended on local weather – both of which are features of the migration we describe. However, Dekker (1979) states that Peregrines will migrate in a variety of conditions, even against headwinds, and the only weather variable that Titus *et al* (1988) could relate to numbers of migrating Peregrines was low barometric pressure (cold fronts are characterised by high pressure). This study showed that this Peregrine was likely to have used updraughts and tailwinds to help its migration and that these influenced its bearing, especially over water, and probably its willingness to embark on migration over water. The overall pattern of movement of Peregrines across the Gulf in autumn may be linked to such weather. In turn, the reason why there appears to be no great movement of Peregrines across the Gulf during spring (Fuller *et al* 1998) may be because they do not have such favourable weather conditions. The speed of migration that we were able to calculate appeared related to wind speed – a finding similar to that of Cochran & Applegate (1986). The use of boats (*eg* Byers 1957, Craddock & Carlson 1970) and oil platforms (Russell 2001) by Peregrines is well known, but, because the timing of transmissions could affect our ability to detect short (mid Gulf) stopovers, we may have underestimated their use by this Peregrine.

The data reported here are from a single bird confronted by extreme weather while on migration, so the extent to which the data and its preferences for migration under

different weather conditions are representative of other Peregrines in similar conditions, or in milder weather, is not known. Data analysed by Fuller *et al* (1998) are only a portion of a larger pool of data from satellite-tracked migrating Peregrines in existence, but there have been few other detailed analyses. It is likely that much can be learned from analyses of a large number of tracked Peregrines. However, most data are for southbound birds, and data from northbound birds are mostly from birds that winter on the mainland. It would be interesting to look at how Peregrines that winter on Caribbean islands cope with making the northbound water crossing. Of course, all birds summering in Greenland have to cross a water barrier, the Davis Strait, on their way north in the spring, though ice probably provides perching possibilities (Mosbech *et al* 2000).

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