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Probable trajectories associated with the transport of *Ochlerotatus albifasciatus* during a strong wind event in Buenos Aires city (Argentina)

R. Bejarán,[a]* S. Fischer,[b,c] A. De Garin[a†] and N. Schweigmann[b,c]

[a] *Departamento de Ciencias de la Atmósfera y los Océanos, Universidad de Buenos Aires, Argentina*

[b] *Grupo de Estudio de Mosquitos, Departamento de Ecología, Genética y Evolución-Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Argentina*

[c] *Consejo Nacional de Investigaciones, Científicas y Técnicas, Argentina*

ABSTRACT: Because of its capacity to infect human beings and domestic animals with a number of different viruses, the study of the mosquito *Ochlerotatus albifasciatus* (Macquart, 1938, (Diptera: Culicidae)) assumes great importance from the point of view of sanitation. It is a well-known fact that the abundance of this species peaks after drought periods in the provinces of Buenos Aires and Cordoba. This article aims at explaining the presence of the high abundance of adult *O. albifasciatus* in Buenos Aires city in February 2005. As no breeding immatures were recorded during the previous weeks, the most likely hypothesis was that mosquitoes entered the city from breeding sites located in the outskirts. Wind observations, the existing knowledge on this species biology, atmospheric dynamic models, and meteorological data were used to support this hypothesis and identify the sources.

Mass transport of these individuals was apparently the consequence of a convective process. It was demonstrated that the occurrence of a convective process transported air masses from the periphery towards the City of Buenos Aires. Air-parcel trajectories, Ezeiza radar images, and the flood zones observed in satellite images indicated that the source was located in the lowlands of Ezeiza in the Rio Matanza basin, some 50 km to the southwest of the City. The evidence suggests that *O. albifasciatus* is transported by wind, and the trajectory models are a very useful tool to locate the sources of proliferation of these insects. Copyright © 2008 Royal Meteorological Society

KEY WORDS wind; dispersal; Buenos Aires; *Ochlerotatus albifasciatus*; trajectory model

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1. Introduction

Long distance movements of insects have been widely studied and they usually occur immediately after the synchronized emergence of adults (Johnson, 1969; Service, 1997). Independent of the involved transport mechanism, these phenomena have ecological consequences such as population redistribution (Woiwood *et al.*, 2001). It has been discussed whether this kind of transport is adaptive or accidental. An evident advantage is the exchange of genes among populations, which increases the diversity of the genetic pool, and consequently the species' fitness. On the other hand, wind-assisted transport has a cost, as it is unlikely that all transported individuals will find a favourable place for reproduction (Service, 1997).

In the case of mosquitoes, it has been proposed to speak of 'dispersion' instead of 'migration', as there is no evidence of a periodical phenomenon by which individuals and/or their offspring return to the original location in the next season, or of a determined behaviour towards being transported by wind (Service, 1997). There are many examples of mosquitoes transported by wind over long distances (Johnson, 1969; Service, 1997). Among those mentioned in literature, some correspond to the genus *Ochlerotatus* (formerly called *Aedes*, Reinert, 2000) as for instance *O. taeniorhynchus*, *O. sollicitans* and *O. squamiger*.

O. albifasciatus is a neotropical floodwater mosquito, whose distribution extends from the south of Brazil and Bolivia to Tierra del Fuego (Bachmann and Bejarano, 1960; Prosen *et al.*, 1960; Forattini, 1965). This species is one of the most annoying in the region because of its insistent attacks on humans and domestic animals (Prosen *et al.*, 1960), causing diseases and substantial economic losses (Ludueña Almeida, 1994). It is also a cause of concern from the point of view of sanitation, as this species has been involved in the transmission of the western equine encephalitis virus (Mitchell *et al.*, 1987; Avilés *et al.*, 1990).

In Buenos Aires, throughout most of the year, a rainfall threshold of 10 mm is enough to trigger the development

* Correspondence to: R. Bejarán, Departamento de Ciencias de la Atmósfera y los Océanos, Universidad de Buenos Aires, Argentina. E-mail: bejaran@at.fcen.uba.ar

† We are extremely sorry to report the death of this author in December 2007 – Editor.

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of *O. albifasciatus* (Fischer *et al.*, 2002), while in the summer a minimum of 25–30 mm is necessary to allow *O. albifasciatus* to complete their immature development (Fontanarrosa *et al.*, 2000). Once the eggs have hatched, the development time of immature stages ranges from 6 days at 24 °C to 32 days at 13 °C (Ludueña Almeida and Gorla, 1995; Fontanarrosa *et al.*, 2000; Fava *et al.*, 2001; Campos and Sy, 2003). Great abundance peaks are the result of the synchronized emergence of adult floodwater mosquitoes (Horsfall, 1963).

Previous unpublished studies in 1999 in the City of Buenos Aires show the presence of adults in disproportioned abundance, as compared with the number of larvae in local breeding areas recorded during the preceding weeks. In 2005, during the afternoon–night of 9 February, an extremely high abundance of adult *O. albifasciatus* was observed in green areas and private dwellings (local newspaper articles). However, the survey of immature insects in the city did not reveal important larvae and/or adult presence of this species in the previous week (Sander *et al.*, 2005). These observations made it possible to infer that mosquitoes had been massively transported from neighbouring areas.

Studies on the movements of *O. albifasciatus* related to the wind mainly describe the activity of females searching for blood, which decreases with increased wind speed (Del Ponte and Blaksley, 1947; Hack *et al.*, 1978; Ludueña Almeida and Gorla, 1995). On the other hand, molecular studies have shown a considerable genetic homogeneity among different populations of this species, despite the environment diversity of the region under study (De Sousa *et al.*, 1996a,b). Although it has been suggested that wind could contribute to the passive dispersion of this species (Ludueña Almeida *et al.*, 2002), this phenomenon has not been documented. Teneral (not fully mature) or post-teneral dispersal (defined by Johnson, 1969, as an exodus made relatively soon after emergence, on the first flight or one of the very early flights) comparable with the observations for *O. taeniorhynchus* (Service, 1997) has not been suggested for *O. albifasciatus*. The movement of organisms through the air has been studied using different methods, for example by tracking their trajectory and dispersal range by means of more or less complicated models similar to those that originate from particle dispersion models.

Basically, there are two approaches to address wind dispersion when studying particles or organisms, i.e. Eulerian models, which consider a fixed set of coordinates, and the Lagrangian models, where the coordinate systems move with the average wind.

The first approach is the use of the plume models (Eulerian), which are based on the diffusion principle; the assumptions of these models are not complied within complex situations and are not adequate, for instance, in the case of convective updraughts. On the other hand, trajectory (Lagrangian) models are based on the statistical probability of particle displacement, with integration of their trajectories in small time intervals (Tackenberg, 2003). These models allow determining the direction of a given particle at a given moment (forward) or estimating its source (backward) (Draxler, 1992). These models were used to describe the dispersion of different kinds of organisms and their trajectories in time and space; e.g. seeds (Tackenberg, 2003), pollen (Gassmann and Perez, 2006), insects (Wood *et al.*, 2006), and particularly mosquitoes (Ritchie and Rochester, 2001).

HYSPLIT (HYbrid Single-particle Lagrange Integrated Trajectory, Draxler, 1992) is an air-parcel trajectory model which calculates concentration on a fixed grid, while trajectory calculations are made in a Lagrangian framework. The advantage consists of the use of gridded meteorological data over a map and it recalculates particle dispersion and transport coefficients at every time step, taking into account both the mean wind and the turbulence components.

This article aims at investigating conditions associated with the unforeseen appearance of large numbers of *O. albifasciatus* in Buenos Aires, and with contributing biological and meteorological evidence to explain the phenomenon. Thereafter, assuming the possibility of wind transport, backward simulation models were used to identify the possible source areas of these culicids.

2. Methodology

2.1. Study area

Buenos Aires (35 °S, 58 °W) is a metropolis with more than 11 million inhabitants. It is bounded by the River Plate to the northeast, and to the south and west by depressed, rather flat pampas of grasslands and wetlands with lands belonging to several river and stream basins (Matanza, Reconquista and Luján rivers) that are prone to flooding. Mosquito sources in the River Plate estuary, located to the east of the city, were excluded *a priori* from this study, since the landscape pattern contains no favourable habitats for this species.

The rain pattern in the region is moderate all through the year, with an accumulated total of 1100 mm. In summer, there are frequent convective storms with strong winds and even powerful thunderstorms. Annual average temperature is 16.5 °C, with warm summers (24 °C) and moderate winters (10 °C). In the city of Buenos Aires, there are 1685 green hectares, part of them being areas prone to floods. After heavy rainfall, a large number of temporary puddles form, which are potential breeding sites for *O. albifasciatus*. The presence of mosquitoes in these temporary puddles is periodically monitored by a Governmental Programme, while those in the Greater Buenos Aires are not monitored.

2.2. Information sources and analysis of data

To determine the date of egg eclosion, rainfall records from the meteorological station at Ezeiza airport (SMN-National Meteorological Service) were used. The time of development for immature forms and probable emergence of the *O. albifasciatus* adults was estimated

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using mean daily temperature records from the same station and pre-existing models on development times related to temperature in the city of Buenos Aires, in the Province of Buenos Aires, and in the Province of Córdoba (Fontanarrosa *et al.*, 2000; Fava *et al.*, 2001; Campos and Sy, 2003). In addition, observations of the gender composition and behaviour of the adults found in the city on the day after the episode under study were taken into account.

The synoptic situation causing the storm on 9 February 2005 was analysed on the basis of meteorological data and satellite and radar images from the National Meteorological Service. To identify the potential areas of origin, a backward air-parcel trajectory model (HYSPLIT, NOAA and Australia Meteorological Agency) was applied over a mosaic of geo-referenced satellite images. In this case, the meteorological data used for the trajectory model were FNL data for 9 February 2005 provided by the NCEP GDAS (Global Data Assimilation System) available at ftp://www.arl.noaa.gov/pub/archives/fnl/. The grid has spatial resolution of $0.5 \times 0.5°$ and time intervals of 6 h (0000, 0600, 1200, 1800 UTC). The model was run for 14 h at 1-h time steps, simulating the arrival of mosquitoes to Aeroparque – the airport in the city of Buenos Aires (34°34′S, 58°25′W) – from 1300 UTC (9 February) to 0200 UTC (10 February).

3. Results

During the first 3 weeks of the month before the mass ingress of mosquitoes in Buenos Aires (9 February), there was scarce rainfall (Figure 1) and the first significant event for the appearance of water puddles occurred from 29 to 31 January with accumulated rainfall of 114 mm.

The mean temperature from the time of these rainfall-events up to the moment of the invasion was 21.3 °C. Estimated time from immature development to the emergence of adults for this temperature is 8–9 days (Fontanarrosa *et al.*, 2000) and the most probable moment for the emergence was between 7 and 8 February. On the following day, there was a low-pressure system over the centre of the Province of Buenos Aires with warm temperatures and high humidity (Figure 1).

The 1445 UTC satellite image showed a developing convective system located approximately 400 km to the southwest of the city. This cloud system moved causing rainfall in several localities near the area under study (not shown). In the afternoon, the atmospheric pressure in Ezeiza dropped to 1009 hPa. The sky was clear and dewpoint temperature was very high (24 °C). At 1800 UTC, the Doppler radar detected an echo of approximately 45 dbz located some 100 km to the southwest of Buenos Aires, rapidly moving to the northeast and intensifying until 2046 UTC.

In Ezeiza, between 2024 and 2100 UTC, gusts of up to 28 m s^{-1} (Figure 2) were recorded, which reached the city of Buenos Aires 45 min later. After the passage of the weather system, calm conditions were restored. After 2300 UTC, a high abundance of *O. albifasciatus* was found in several public spaces and in downtown private dwelling patios. Also mass ingress of mosquitoes was noted through open windows of apartments at various storeys, for instance 40 m above ground level. Among the specimens found, there were both males and females. On the following day, females were not actively searching for blood.

Of the 14 runs of the parcel-trajectory model HYSPLIT, those from 1300 to 2100 UTC showed a similar wind speed and direction pattern (Figure 3). From 2200 UTC, there were significant changes in wind direction, prevailing from the south-southwest.

The trajectories consistent with the time when the first mosquitoes were detected in the city correspond to the period between 2200 UTC (9 February) and 0000 UTC (10 February) (Figure 3). This area included the basin and the alluvial plain of the Matanza River in Ezeiza.

4. Discussion

This study was possible because natural conditions allowed isolating the phenomenon under study: a drought period, followed by a well defined rainfall event, and the

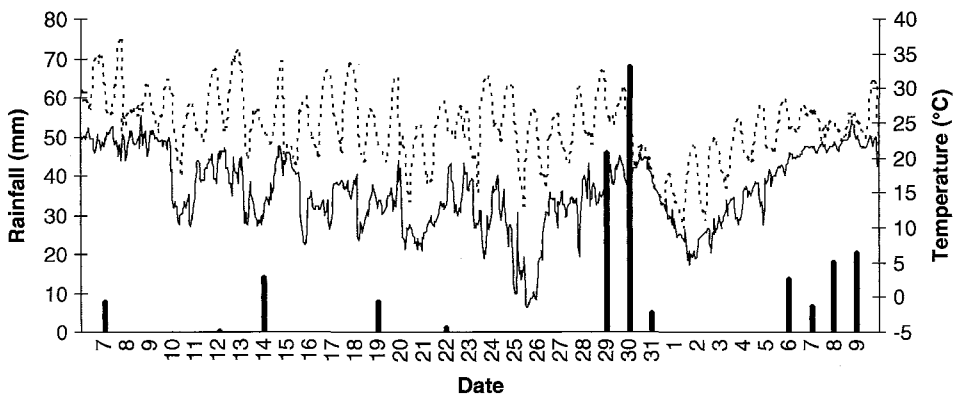

Figure 1. Daily cumulative rainfall (bars), hourly temperature (dashed line), and dewpoint temperature (solid line) in Ezeiza from 7 January to 10 February 2005.

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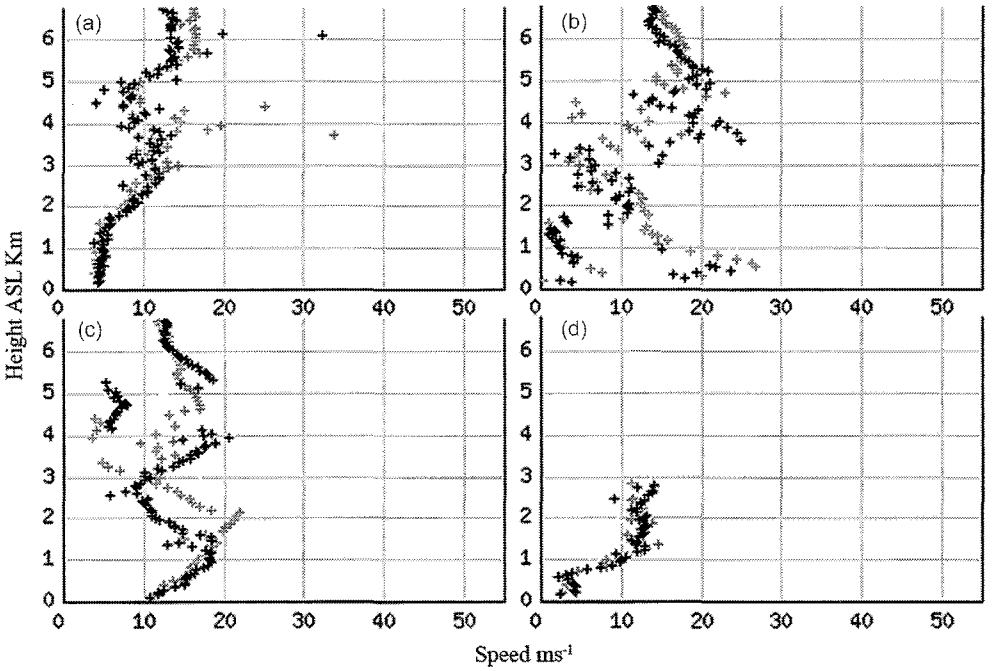

Figure 2. Vertical section of wind speed. (a) 2024 UTC, (b) 2036 UTC, (c) 2048 UTC, (d) 2300 UTC.

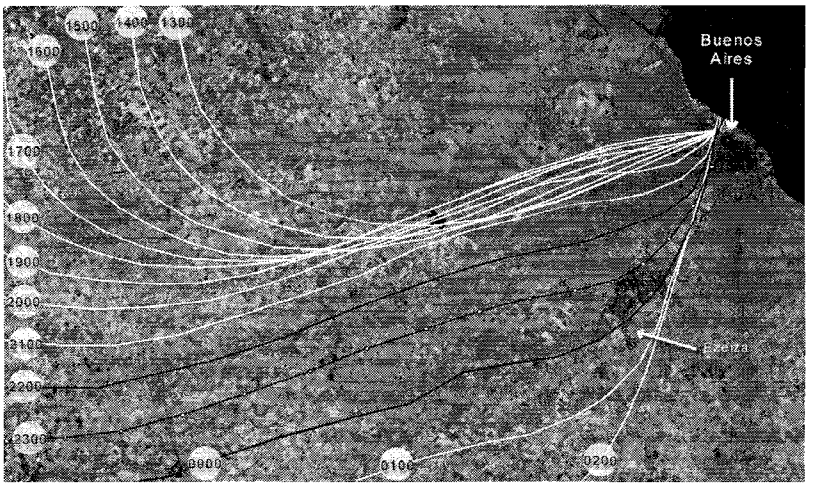

Figure 3. Sequence of particle trajectory lines HYSPLYT (backward) from 1300 UTC 9 February to 0200 UTC 10 February 2005.

existence of a monitoring system for culicids in the city and a meteorological monitoring system in the area.

The sudden presence of large numbers of *O. albifasciatus* 10–11 days after the flooding caused by abundant rainfall in late January is consistent with the observations known for floodwater mosquito (Horsfall, 1963) and for this species, in particular, when flooding occurs after drought periods (Ludueña Almeida and Gorla, 1995; Fontanarrosa *et al.*, 2000; Gleiser *et al.*, 2000). The extended drought period could have favoured the hatching of a larger number of eggs. Experimental studies have found that after drought periods the proportion of eggs of *O. albifasciatus* that hatch with the first flood increases (Campos and Sy, 2006).

Rainfall during the last two days of January 2005 in the area was above the typical accumulated amount for January (National Meteorological Service), probably forming a significant number of temporary puddles. It has been suggested that the number of emergent adults of this species is directly proportional to the flooded area (Ludueña Almeida, 1994; Gleiser *et al.*, 1997). However, in Buenos Aires, the unforeseen and generalized presence of a large number of adult mosquitoes (noted by inhabitants and the press) could not be explained by the scarce immature forms observed in the urban puddles (Sander *et al.*, 2005), indicating that the main breeding grounds were likely to be located outside the city. The low abundance of immature stages of *O. albifasciatus* in Buenos Aires city during the summer has been observed in previous studies, and possible explanations are excessively high temperatures in the shallow urban pools, and a low survival of eggs from the previous seasons. The presence

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of this species in autumn and winter poses the possibility of yearly fall recolonization, either by the remaining egg-bank or the dispersion of adults from adjacent areas (Fischer *et al.*, 2002). The present article contributes to evidence of the latter option.

Some evidence suggests that the adults detected after the storm were recently emerged:

(1) the most probable rainfall event triggering larval development occurred 10 days before the abrupt increase of abundance, (2) the estimated emergence date was coincident with the mass detection of adults in the city, and (3) the presence of specimens of both genders, along with the fact that the females were not biting. The last point would also indicate that these mosquitoes were not surviving specimens from the previous weeks, and that this was not an active female-dispersion mechanism, which normally happens inversely to wind speed in *O. albifasciatus* (Hack *et al.*, 1978) but a mass transport of teneral or post-teneral individuals from their breeding grounds.

The most likely hypothesis is that the large number of recently emerged mosquitoes was transported from the puddles near Ezeiza to Buenos Aires city along with the warm surface air mass they were in. Transport was aided by the significant vertical development of cumulonimbus-type storm clouds (Figure 4(a)–(d)). The strong cool descending flows – probably downbursts – began to move horizontally on reaching the surface, causing strong gusts and forcing warm surface air masses to rise (Figure 4(c), (e)). The warm air mass so raised, together with the mosquitoes, moved toward the city of Buenos Aires, as shown by the trajectory model. Mosquitoes recovered flying capacity at the declining stage of convection (Figure 4(d)), when the descending flow lost intensity. In addition, mechanical and thermal friction caused by the urban effect may have contributed to slowing down the air mass containing the mosquitoes. The fact that winds from rural zones become weaker in urban areas is well known (Bornstein and Johnson, 1977).

Three independent sets of evidence allow identification of the possible mosquito source area. First, the plume generated by the particle trajectories arriving in Buenos Aires between 2200 UTC (9 February) to 0000 UTC (10 February) by means of the HYSPLIT model, indicating air mass movement from the south-southwest of Buenos Aires. Second, within the area defined by this model, there are flood areas belonging to the Matanza River basin, near Ezeiza. With poor runoff, the Ezeiza lowland landscape is an undulating terrain that is prone to flooding and well known for the proliferation of mosquitoes. Third, the meteorological and radar records showed that maximum intensity winds started near Ezeiza and moved towards the city of Buenos Aires.

It was observed that post-teneral adults of other floodwater mosquitoes, such as *O. taeniorhynchus,* move upwards to be carried by wind when the density of immature forms is high in the breeding areas (Haeger, 1960). No evidence of such behaviour is documented for *O. albifasciatus.* However, independent of the original cause for dispersion, the genetic homogeneity at regional level noted in the Province of Cordoba (De Sousa *et al.*, 1996a) can be explained by phenomena similar to the one studied here.

The information provided by the mosquito monitoring program in Buenos Aires city, together with the atmospheric conditions recorded prior to and during the studied event allowed to describe for the first time the possible factors involved in the transport of *O. albifasciatus.* If climate change trends in this area imply an increase in rainfall and turbulence, this phenomenon may be expected to occur much more frequently. In this scenario, dispersion should be taken into account when developing models that predict population abundance of this mosquito species.

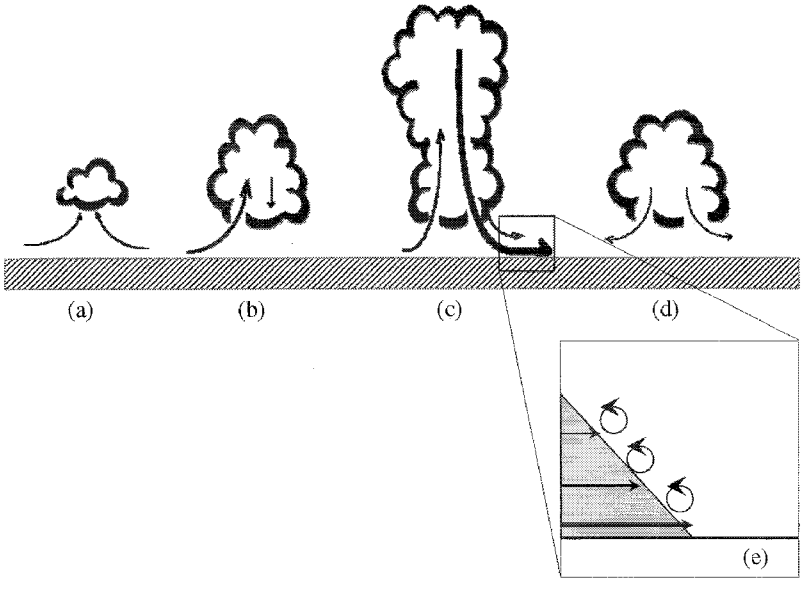

Figure 4. Schematic stages of a convective cloud cycle (a) generation, (b) development, (c) maturity, and (d) declination. (e) Detail of the sinking air mass of (c), showing the downdraught effect of a convective cloud near the surface (white area: warm air mass, grey area: cold air mass).

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