Open ocean nocturnal insect migration in the Brazilian South Atlantic with comments on flight endurance

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Abstract

We report a nocturnal insect swarm observed aboard the oceanographic ship Cruzeiro do Sul of the Brazilian Navy, while conducting a survey of the Montague guyot (seamount), 389 km distant from the nearest land in the South Atlantic. The insects came from open sea towards the ship in all directions, attracted by powerful lighting of the deck. Except for one specimen, their provenance from another island or another ship were discarded. Most insects collided with the hull and fell into the ocean, but we managed to capture and determine seventeen (13 Hemiptera of a single species, three Lepidoptera and one Odonata). Considerations about the geographic origin and flight endurance of these insects are supported by the reconstruction of wind speed and direction provided by the crew of the ship and Hysplit modelling of air current trajectories.

Keywords

Aeshnidae, Dispersal, Migration, Nocturnal flight, Pentatomidae

Introduction

Insects, with more than one million species, represent two thirds of the total metazoan diversity (Zhang 2011, 2013). Undoubtedly the ability to fly is among the causal explanations of their evolutionary success (Grimaldi 2010). Indeed, winged insects alone correspond to 69% of all animal species and excluding vertebrates such as birds and bats are the only extant Arthropods using flapping wings for locomotion. One of their extraordinary capabilities is long-distance flight or migration, which is well-documented for several groups including dragonflies, locusts, and butterflies (*e.g.* Holzapfel & Harrell, 1968; May 2013, Chapman *et al.* 2015). Definitions of migration are numerous in the literature, but there is a reasonable agreement with Dingle's (2006: 214) concept of migratory behavior as "persistent and straightened-out movement effected by the animal's own locomotory exertions or by its active embarkation upon a vehicle". By vehicle the author means wind.

Night flight of insects has been less studied because it is more difficult to observe, but observations of it began as early as the 1930s by use of airborne traps (Glick, 1939). Progress in that direction, pioneered by Fowler & Lagrone (1968) was eventually made by deployment of entomological Radar, with which Riley (1975) found insects flying against the wind, while several recent studies have found such insects capable of active downwind flight (*e.g.* Reynolds *et al.* 2010a, 2010b, 2016 and references therein). There is mounting evidence for the geomagnetic orientation capabilities of various insects, which corroborates their flight capabilities in the dark and strengthens the hypothesis for active migration (*e.g.* Vácha, 1997; 2015; 2017).

The assemblage of Odonata, Hemiptera and Lepidoptera attracted to light and captured by us on a ship in open South Atlantic Ocean appeared so distant from the mainland, at a point where no islands are nearby. There were also no other ships in the vicinity, which could have been transporting the insects. This fact leads us to pose the same question as Reynolds *et al.* (2010a, 2010b): "*How do insects maintain wind-related orientation at altitudes of several hundreds of metres in the dark*?" Immediately questions arose as to how they arrived at such a distant point of open ocean. Could they have come as stowaways from Trindade island, the closest oceanic land mass in South Atlantic? What were the insects doing so far from land? Were they migrating *sensu* Dingle (2006) or were they accidentally dispersed to open ocean, victims of weather extremes? What was the minimal duration of their sustained flights?

In this paper we undertook, face to this nocturnal insect swarm, a study of the known natural distributions of the identified species, reconstruction of wind conditions preceding capture, their hypothetic flight paths and their probable source locations, and to estimate the duration of their sustained flights.

Material and Methods

Background. Of the Brazilian islands in the South Atlantic, only Trindade (Barth, 1958; Becker, 1998) and Fernando de Noronha (Alvarenga, 1962) have been surveyed by entomologists in the 1950s and 1960s. Insects registered on Trindade are mostly continental species with only 11 species of Lepidoptera, 8 of true bugs and 2 species of dragonflies. Of the latter, apparently only *Pantala flavescens* (Fabricius, 1798) a characteristically migrant species and well-known as successful in colonization (*e.g.* Santos, 1981; Mesquita & Matteo, 1991) survives at present.

Insects endemic to Trindade are *Liagonum beckeri* Jeannel, 1961 (Coleoptera: Carabidae) and *Limonethe beckeri* Costa Lima & Guitton, 1961 (Hymenoptera: Ichneumonidae).

Study area and sampling. On May 28th, 2014, the ship Cruzeiro do Sul of the Brazilian Navy, on its way from the Archipelago of Trindade & Martin Vaz to the port of Rio de Janeiro, southeastern Brazil, stopped above the Montague seamount (20°21'57.60"S, 36°38'46.80"W), a guyot which is part of the Vitória-Trindade oceanic mountain chain (Fig. 1). From this point of open ocean, the distance to the nearest land in the continental Brazil is 389 km. The ship lowered a measuring apparatus into the water and the white walls of the hull and deck were illuminated by ca. 10,000 Watts of spotlights composed by incandescent (minority) white halogen bulbs (most) and several white fluorescent lights. The maneuver was executed starting 22:25h and 23:00h UTC. Shortly after the lights were turned on, insects were observed flying straight toward the ship from all directions, evidently attracted by the lighting. Most of them collided against the hull and fell into the ocean, but with help from crew and other researchers, two of us (NGS and RJVA) were able to capture most of those which landed on deck.

The specimens were preserved pinned or in envelopes and deposited in the Department of Entomology of the Museu Nacional (MNRJ), Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil. On 2 September of 2018 occurred one of the biggest tragedies for the research on natural history when the MNRJ burned on fire and almost all its heritage of 20 million of items was lost (see Zamudio *et al.* 2018), including the material reported here (Figs 2A–C). These specimens were determined by coauthors LAAS (Hemiptera), AS (Lepidoptera) and APP (Odonata). All material was collected in accordance with the Brazilian biodiversity policies, under Instituto Chico Mendes de Conservação da Biodiversidade - ICMBIO/SISBIO licenses numbers 25034-6 and 41194-4.

Analysis. The crew provided us with measurements of wind direction and intensity for a period of 21h prior to the capture event. This was essential to estimate the trajectory which a hovering insect could have performed during that time. The capture occurred on the night immediately preceding the new moon, hence the night was very dark, and our ship was the only light source in a vast region of open ocean. The air temperature measured on deck was 25.4 °C.

We first reconstructed changes in wind speed and direction using the ship' log data and calculated the trajectory an idle floating object would have had spanning 21h prior to capture. We calculated the distance to the closest coastal point in Brazil to our acquired GPS (WGS84) coordinates from the capture site.

Subsequently we reconstructed 24 Hysplit trajectories backward preceding capture by 34h and 48h and forward 180h toward the African coast (Stein *et al.* 2015; Rolph *et al.* 2017), not leading into account heading deviations by active flight of the insects. Hysplit settings used: *Backward trajectory direction; runtimes:; altitudinal range 10–3000 m asl.*

Results

Flight endurance. According to the trajectory reconstructions, the minimum flight time from the continent was 34h, when a single backward trajectory had its starting point on the coast between the Brazilian states of Espírito Santo and Bahia, 380 km from the point of capture (Fig. 3). With a 48h flight duration, three additional potential points of origin on the coast were reconstructed (Fig. 4). If the migration of the insects were to continue toward Africa from the point of capture, assisted by prevailing winds, another 180h of flight time would be needed, and the insects would need to gradually ascend to high altitudes accompanying the air currents (Fig. 5).

Insects at the open ocean. There are no Trindade endemics species among the insects we captured. Hemiptera were the most numerous, with 13 individuals of only one species, several of which emitted a strong odor resembling green apples, an odor still present in 2017, after three years of preservation. Three different species of Lepidoptera were distinct moths. A single very large dragonfly completes the list.

Odonata: Anisoptera: Aeshnidae

1. *Anax amazili* (Burmeister, 1839)
(Fig. 2A)

Material examined. One female (MNRJ ODO-0012).

Remarks. Species of *Anax* are known as migratory, spending many weeks in migration routes undertaking distinct behaviors such as foraging (cf., May 2013). *Anax amazili* is a New World species widespread along the entire American continent occurring from the USA (Needham *et al.*, 2000), through central America and the Caribbean Islands (Calvert, 1905) to southern Argentina (von Ellenrieder & Muzón 2008). It also occurs as a resident species in the Pacific archipelago of Galápagos about of 1,000 km from the coast (Calvert, 1905, Peck, 1992). The site of capture was about 380 km from Brazilian cost and almost 800 km west of the closest archipelago, Trindade & Martin Vaz, from which only two different Odonata were recorded to date (MNRJ): *Pantala flavescens* and *Rhionaeschna* sp. (see Santos, 1981). the pantropical Libellulidae glider *Pantala flavescens* in the best-known migrant dragonfly species (Samways & Osborn 1998), for which the early expectations of this species forming a global panmictic population were recently supported (Troast *et al.* 2016). However, if there is a regular migration route among these land masses is an open question.

Hemiptera: Heteroptera: Pentatomidae

2. ***Alcaeorrhynchus grandis*** (Dallas, 1851)
(Figs 2B–C)

Material examined. 12 specimens, 4 males, 8 females, including one *in copula*. Many more were seen drowning alongside the deck.

Remarks. Recorded from Brazil, Colombia, Mexico, and the southern United States (Ribeiro *et al.*, 2010); Argentina, Bolivia, Cuba, Ecuador, Paraguay and the Galapagos (Dellapé *et al.* 2003). In Brazil there are collections from Bahia: (*sine loco*); Goiás: (Capada dos Veadeiros); Minas Gerais: (Belo Horizonte – sucking a caterpillar); Mato Grosso: (*sine loco*); Espírito Santo (20 º 40´S 40 º 30´W); Rio de Janeiro: Angra dos Reis; Petrópolis; Rio de Janeiro (Copacabana; Quinta da Boa Vista); Serra dos Órgãos; Paraná: (*sine loco*); Santa Catarina: (*sine loco*); São Paulo: (*sine loco*) (MNRJ collection); Pará (Ribeiro *et al.* 2010); Rio Grande do Sul (Dellapé *et al.* 2003; Magistrali *et al.* 2014).

This stink bug was considered an introduced or invasive species in the oceanic archipelago of Galápagos, Ecuador where it was first recorded in 1937 and was argued to have arrived by passive transport through plants on Floreana Island (Peck *et al.*, 1998), distant just over one thousand kilometers from continental South America. Our observation of this species in open ocean provides support to a distinct hypothesis whereby active migration is a suitable explanation for the occurrence of this insect in the Galapagos. To support this, however, these events should be dated by means of populational and migratory studies and modelling of air currents.

Lepidoptera: Erebidae

3. *Eudocima procus* (Cramer, 1777)

Material examined. one male/female

Remarks. Originally described from Surinam (Zaspel & Branham, 2008), this species has a widespread distribution in Neotropics (Zilli & Hogenes 2002); in Brazil, it occurs at least in the states of Santa Catarina and Rio Grande do Sul (material previously deposited in MNRJ).

4. *Mocis repanda* (Fabricius, 1794)

Material examined. one specimen.

Remarks. Widespread in South America: Argentina, Bolivia, Brazil, El Salvador, Colombia, Guyana, Mexico, Nicaragua, Surinam, Venezuela, West Indies (Muthaiyan, 2009). Also found in Central America and the Caribbean, including Cuba, the Dominican Republic, Guadeloupe, Martinique, Guatemala, Jamaica, Puerto Rico and Saint Thomas; Strays can be found in the United States, up to southern Texas as well as subtropical Africa south of the Sahara, including the islands of the Indian Ocean.

5. Undetermined species (damaged specimen)

Material examined. one specimen.

Discussion

One of the most interesting questions about insects flying over open ocean on a moonless night at such a large distance from land is whether they (and which ones) were flying in a chosen direction or changed directions responding to changing environmental factors, *e.g.*, geomagnetic cues (Vácha 1997; 2015); the time-compensated sun-compass (Reppert, Gegear & Merlin, 2011; Guerra *et al.*, 2014) or the wind cues described by Reynolds *et al.* (2010a; 2010b; 2016). How, if at all, did our sampled insects orient themselves before they were attracted to and flew actively towards the ship's lights at night?

The fact that hundreds of insects actively pursued the ship in the dark of a moonless night suggests that light is a stronger cue to them than the wind characteristics proposed by Reynolds *et al.* (2010a, 2010b).

Geijskes (1968) considered the dragonfly *Anax amazili* as having predominantly crepuscular behavior and sometimes being attracted by light at night. However, this species presents a more complex behavior than previous expected. In Rio Grande do Sul State at latitude of 30° south, it has been collected in light traps, and observed foraging and ovipositing in with small open swamp areas at noon (APP, unpublished). Our data shows that while migrating, this species is also capable of night flight. However, if this species was truly migrating, where was it heading? After all, the known distribution includes neither Africa nor the islands in the South Atlantic.

Glick (1939) did not register any Odonata flying at night. To 14 individuals of the related *Anax junius* (Drury, 1773), Wikelski *et al.* (2006) attached miniaturized radio transmitters and followed them during migration for up to 12 days, using receiver–equipped airplanes and ground teams. They found an average net advance of 11.9 +- 2.8 km/day, exclusively during the day time. Hence our record of *Anax amazili* migrating during the night might well be the first ever.

Of the species captured by us, the moths *Mocis repanda*, and *Eudocima procus* were also collected in Santa Catarina and Rio Grande do Sul (SpeciesLink, 2017). *Mocis repanda* was registered as the most abundant moth on island in 1957 (Barth, 1958), and probably persisted there in the 1960s (Becker, 1998). *Mocis repanda* is a widespread species considered a pest of various grasses including corn.

The remaining identified insect species occur in Brazil, some also extending to countries north and south, but none to Africa. Combining the ranges of distribution with reconstructions of wind speed and direction during the days preceding capture, it is hence reasonable to suppose all captured insects began their flight in Brazil, somewhere on the coast between Espírito Santo and Bahia.

Hence there is a remote chance this species could have come aboard the ship from that island (either flying or stowed in cargo), hitched a ride aboard, flown out to sea prior to capture, and then returned toward the suddenly illuminated ship from open ocean. Even based on the observed event that favoring the hypothesis of active flight hundreds of kilometers from closer land mass at least for these moths, we not discarded that already were on the ship and started to flight after ships' lights turned on.

Insects flying at night often align their flight paths with the wind (Riley, 1975; Reynolds *et al.* 2010a; 2010b; 2016). Whether the insect's bodies are heading upwind or downwind during such aligned night flights probably depends on the wind speed and has been subject to some debate. Several studies indicate the insects increment their self-propelled velocities by actively travelling downwind (Reynolds *et al.* 2010a; 2010b; 2016) even though Riley (1975) observed the contrary. In the Northern Hemisphere, Hu *et al.* (2016) found that the insects tend to fly slightly to the right in relation to the wind axis and aligned themselves with the flow direction with greater accuracy with increasing flight altitude.

Monarch butterflies can fly in still air at average speeds of 37.5 km/h and probably up to 50 km/h, and they usually fly close to the ground, but have been registered at altitudes of ca. 3,500 m asl.; and have been known to fly more than 600km over water non-stop in 16 hours (Poirier, 1995). Even though Monarchs are considered day butterflies, a part of that 16h flight would obviously happen in the dark. On the other hand, the three Lepidoptera we captured were noctuid moths. Open ocean night flight seems to be a novelty for the captured dragonfly and the stink-bug species.

If Monarch butterflies could cover the expanse of ca. 400 km from the continent to the capture site in just under 11 hours of sustained flight, it is quite possible that other insects could reach the site in comparable speeds, and that migration across the entire Atlantic between South America and Africa could be achieved in 3.6 days in still weather. If winds are factored into the equation. the migration could potentially be much slower or much faster.

Even though some insects have been observed to rest on the surface of a calm ocean and resume flight (Walker, 1931 and references therein), the ocean conditions during our capture were 3 on the Beaufort scale – hardly considered calm.

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Figures and captions

Figure 1. Part of South Atlantic Ocean depicting the location of Southern Brazil, Montague seamount (site of anchorage of the hidrooceanographic ship Cruzeiro do Sul of the Brazilian Navy, 20°21'57.60"S, 36°38'46.80"W) and Trindade Island. Abbreviations for the Brazilian States: ES: Espírito Santo; RJ: Rio de Janeiro. Map data: Google, image Landsat/Copernicus, SIO, NOAA, U.S. Navy, NGA, GEBCO.

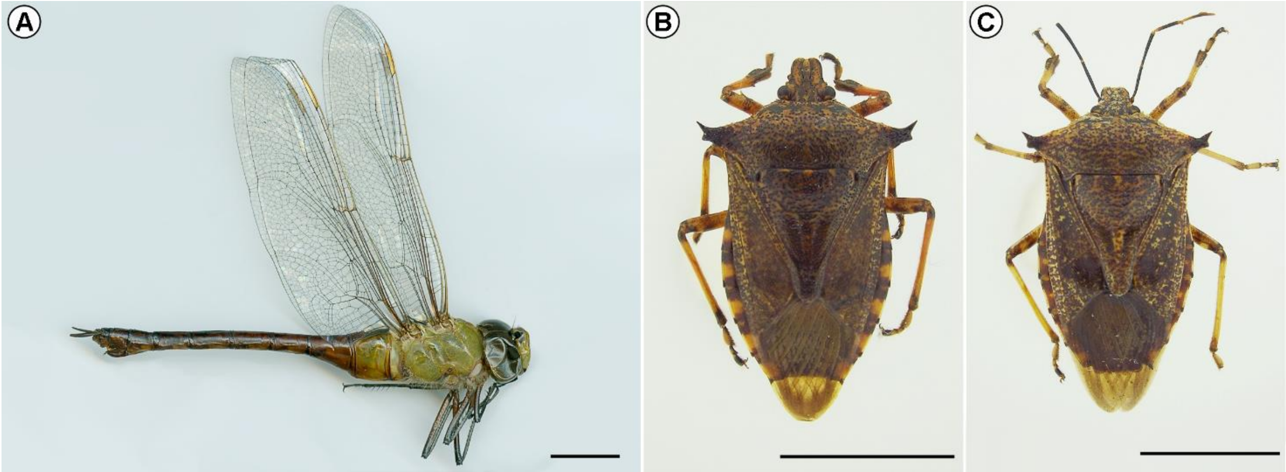


Figure 2. Habitus of insects collected at South Atlantic, Montague seamount aboard the hidrooceanographic ship Cruzeiro do Sul of the Brazilian Navy 20°21'57.60"S, 36°38'46.80"W) during a nocturnal swarm flight. A. female of *Anax amazili* (Burmeister, 1839) in lateral view, B–C. male (B) and female (C) of *Alcaeorrhynchus grandis* (Dallas, 1851) in dorsal view. Scale bar = 10 mm. Photos credit: Ângelo P. Pinto.

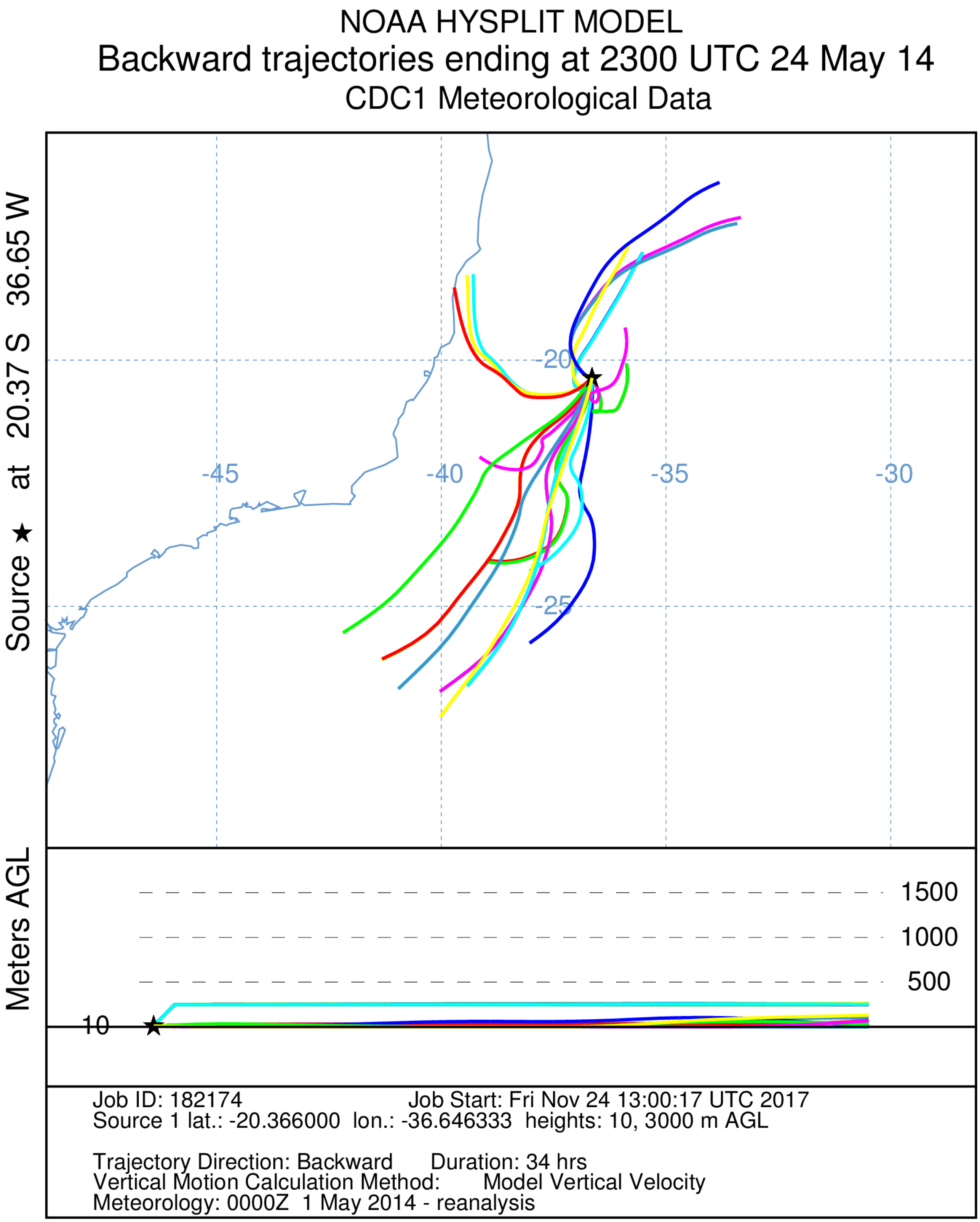
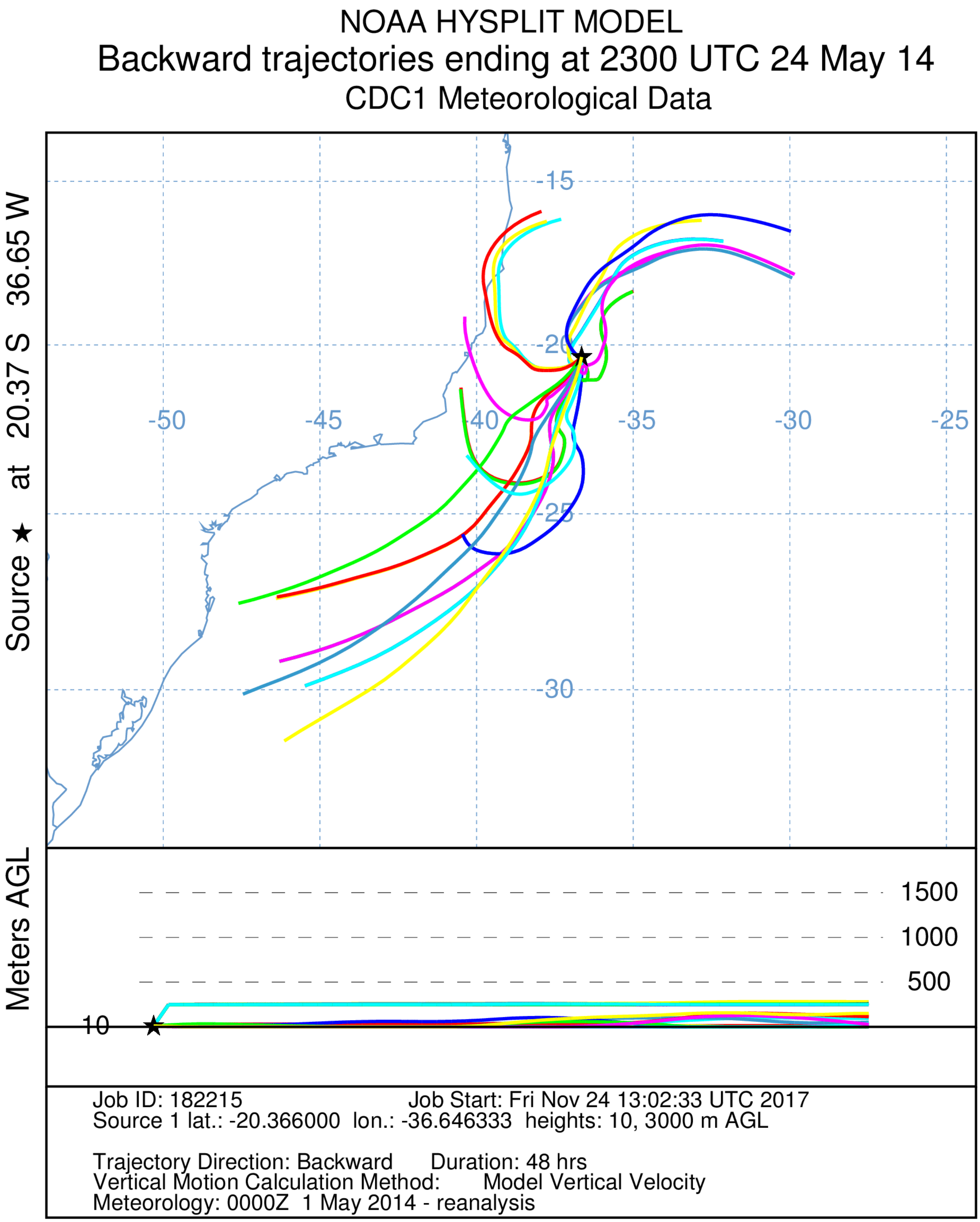


Figure 3. backward reconstruction 34h Hysplit model of wind vectors leading toward capture point. Note single vector originated on the coast of the states of Espírito Santo and Bahia.



397 Figure 4. Backward reconstruction 48h Hysplit model of wind vectors leading toward capture point. Note three
398 vectors originated on the coast of Espírito Santo and Bahia.

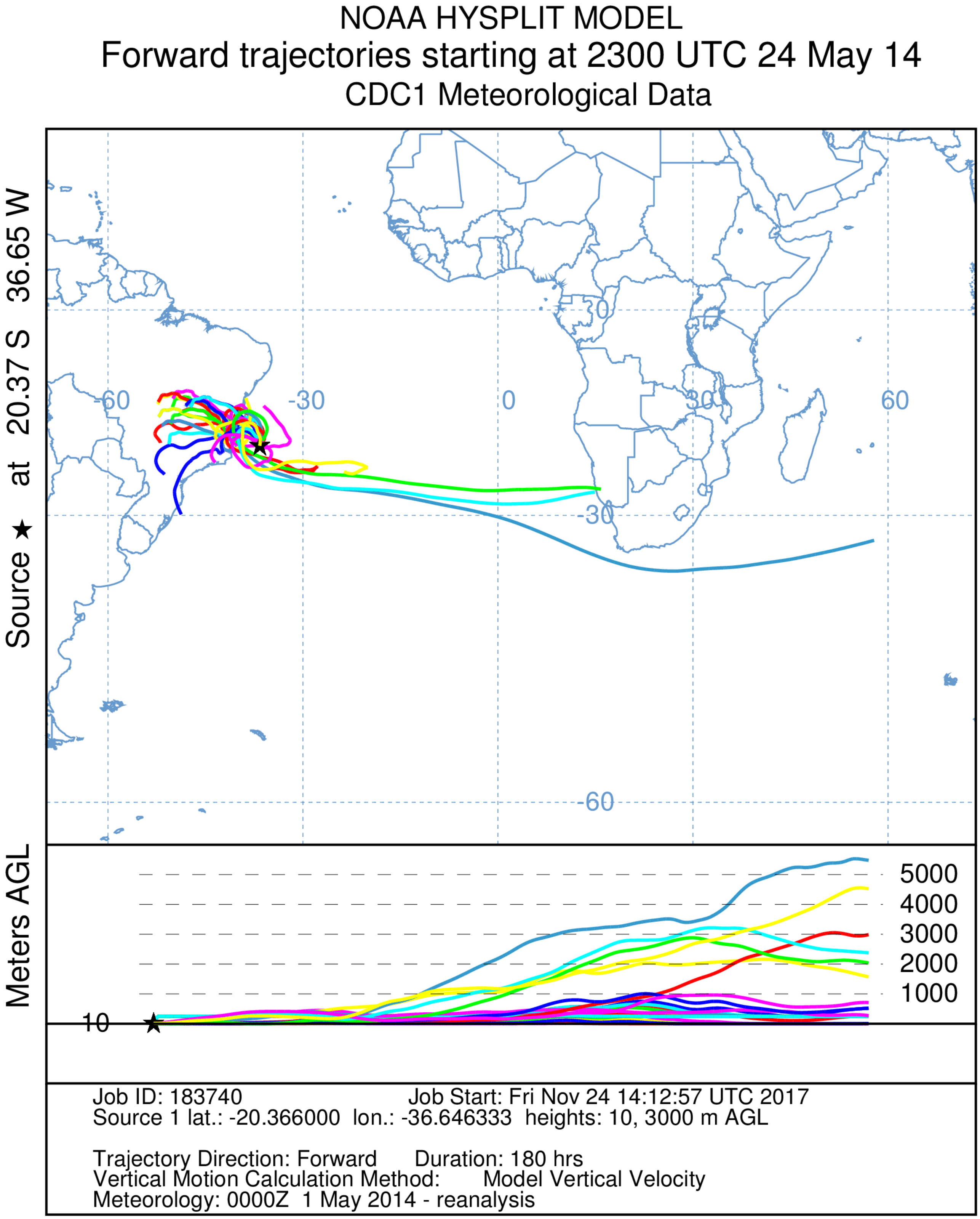


Figure 5. Forward reconstruction 180h Hysplit model of wind vectors leading from capture point. Note two vectors arriving in Namibia on the African coast.