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Network analysis reveals patterns behind air safety events

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HIGHLIGHTS

- A complex network representation of air traffic is proposed.
- Aircraft are mapped into nodes, pairwise connected according to their distance.
- Resulting topologies are able to forecast the appearance of unsafe situations.

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ABSTRACT

Complex networks have been extensively used to study the topological and dynamical characteristics of transportation systems, although far less attention has been devoted to the analysis of specific problems arising in everyday operations. In this work, the use of a network representation is proposed for studying the appearance of Loss of Separation events, a kind of safety occurrence in which two aircraft violate the minimal separation while airborne. The topological analysis of networks representing the structure of traffic flows allows identifying situations in which the probability of appearance of such events is increased. Beyond these specific results, this work demonstrates the usefulness of the complex network approach in the analysis of operational patterns and occurrences.

1. Introduction

Complex networks [1–4] have extensively been used in the last decade as an instrument for modeling and analyzing complex systems, *i.e.* those systems composed of a large number of elements interacting in a non-linear way [5]. Among the large set of examples that can be found in the Literature [6], transportation systems have been the focus of numerous researches, the air transport being no exception—see, for instance, Refs. [7–9]. These studies can be categorized in two families, according to their main scope [10]: the characterization of the topology arising from direct connections between pairs of airports on one side, and the study of simple dynamical processes on top of the connection network, *e.g.* the appearance and propagation of congested states, on the other. A third family that has largely been neglected is the study of operational problems, that is, the use of complex networks as an instrument for the analysis of adverse situations that arise in the daily operation of the system. Notice that, on the contrary, this has extensively been done in other fields: in biomedicine, for instance, beyond the analysis of the topology created by interactions between genes, complex networks have been used to tackle specific problems, as detecting those genes responsible for different diseases [11,12].

In this work, complex networks are used to describe the status of the airspace when two aircraft are expected to cross close to each other, a situation known as *Loss of Separation* (LoS). Such events are of major importance in Air Traffic Management, as they may lead to serious accidents (*mid-air collisions*) when not correctly managed. In normal conditions,

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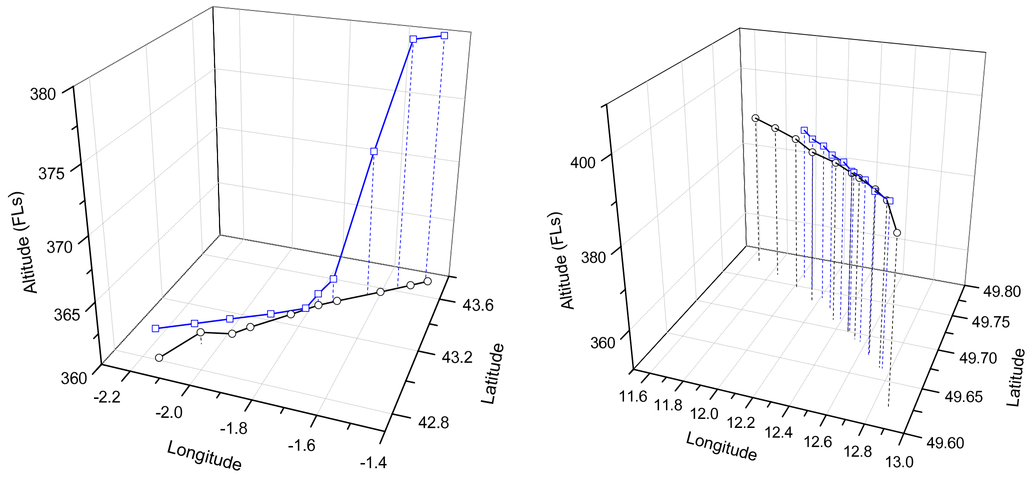

Fig. 1. *Example of safe and unsafe events:* left graph depicts the trajectories of two aircraft that were going to reach a *Loss of Separation* condition, but in which the intervention of the controller solved the conflict; notice how, between the third and four point (from left to right), the speed of the black aircraft was reduced, as indicated by the smaller length of the corresponding segment. Right graph depicts a similar situation where the LoS is not avoided. Both graphs have been constructed using radar recording of the 1st of March 2011. Longitudes and latitudes are expressed in degrees, while the altitude in *Flight Levels* (hundreds of feets).

two different barriers are acting to prevent such events [13]: first, the intervention of Air Traffic Controllers, whose mission is to guide the aircraft through optimal and safe trajectories, and second, different automatic tools, *e.g.* the *Traffic Collision Avoidance System*, which alert both the pilots and the controller of a potentially unsafe situation. In spite of this, and due to the high congestion of some airspaces, LoSs may still happen.

Two types of events are here considered: (i) those events that may have evolved in an incident, but were avoided by the intervention of pilots and controllers, and thus resulted in a *safe* situation; and (ii) those that actually ended up in a separation loss, *i.e.* in a (potentially) *unsafe* situation. Example of both types of events are represented in Fig. 1. In both cases, the two aircraft are expected to reach a close position in space at a given time. In Fig. 1 left, the black aircraft is slowed down between the third and fourth point of its trajectory, resulting in a safe distance with respect to the blue aircraft; on the other hand, Fig. 1 right reveals how the actuation of the controller is not enough to prevent an insufficient separation between the two vehicles. Using information about trajectories of all aircraft crossing the European airspace between March and December 2011, 100.032 events have been detected, 4.316 of which have been classified as *unsafe*—see Sections 2.1 and 2.2 for additional details.

The analysis of each one of these 100.032 events is performed by creating a network representation of the traffic in the region of interest. Trajectories of involved flights are *rewinded* 2 min back in time, in order to analyze the characteristics of the airspace that have led to the appearance of the event, and aircraft positions are mapped into a complex network following the method proposed in Fig. 2. Specifically, a node is associated to an aircraft when the latter lays within an *outer radius* centered in the safety event (blue dashed circle of Fig. 2); pairs of nodes are then connected whether their respective distance is lower than an *inner radius* (gray dashed circles of Fig. 2). Notice that such representation mimics the way Air Traffic Controllers manage aircraft: all flights within a given airspace are monitored, but special attention is devoted to those pairs whose distance falls below a given threshold [14].

In what follows one hypothesis will be tested, *i.e.* that an analysis of the topology of these networks may unveil information about the mechanisms behind the appearance of unsafe events. This is achieved by classifying events through standard data mining algorithms, using the topological metrics extracted from the networks as input parameters: a significantly high classification score implies that such network representations encode information able to forecast the appearance of unsafe situations. Beyond this specific aim, the work here presented aims at highlighting how complex networks can be used for the study of operational problems, a promising field that has not yet been tackled by means of statistical physics techniques.

2. Data preparation

2.1. Data set description

Trajectories data have been extracted from the *ALL_FT+* data set, collected by the EUROCONTROL PRISME group. It includes information about planned and executed trajectories for all flights crossing the European airspace, with a mean average resolution of 2 min. The data set covers the period from 1st March to the 31st December 2011, including a total of 10.3 million flights.