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Wind parameters extraction from aircraft trajectories

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ABSTRACT

When supervising aircraft, air traffic controllers need to know the current wind magnitude and direction since they impact every flying vessel. The wind may accelerate or slow down an aircraft, depending on its relative direction to the wind. Considering several aircraft flying in the same geographical area, one can observe how the ground speed depends on the direction followed by the aircraft. If a sufficient amount of trajectory data is available, approximately sinusoidal shapes emerge when plotting the ground speeds. These patterns characterize the wind in the observed area. After visualizing this phenomenon on recorded radar data, we propose an analytical method based on a least squares approximation to retrieve the wind direction and magnitude from the trajectories of several aircraft flying in different directions. After some preliminary tests for which the use of the algorithm is discussed, we propose an interactive procedure to extract the wind from trajectory data. In this procedure, a human operator selects appropriate subsets of radar data, performs automatic and/or manual curve fitting to extract the wind, and validates the resulting wind estimates. The operators can also assess the wind stability in time, and validate or invalidate their previous choices concerning the time interval used to filter the input data.

The wind resulting from the least squares approximation is compared with two other sources – the wind data provided by Météo-France and the wind computed from on-board aircraft parameters – showing the good performance of our algorithm. The interactive procedure received positive feedback from air traffic controllers, which is reported in this paper.

1. Introduction

Aircraft fly through the air, and the air flows over the Earth's surface. This simple statement highlights the crucial need to know the winds aloft when one wants to navigate over the Earth's surface in a flying machine. Alternatively, one can also guess how the wind flows simply by observing the trajectories of aircraft relative to the ground. Interestingly enough, air traffic controllers already apply this idea in their everyday work. Experienced controllers can roughly estimate the wind force and direction by observing the aircraft trajectories, and comparing the ground speeds of aircraft flying in different directions: aircraft facing the wind have a lower ground speed than aircraft flying in the opposite direction. This basic idea is at the core of the interactive process proposed in this paper, which allows users to extract the wind direction and magnitude from aircraft radar tracks.

Air Traffic Controllers need accurate wind parameters to perform their activity efficiently. For instance, one can reduce the converging speed of two conflicting aircraft by turning one aircraft so that it will face the wind. The wind impact on aircraft ground speed is also used to slow down or speed up aircraft in order to respect a paced landing sequence, optimizing runway usage (i.e. one landing every 3 min). The wind parameters are also necessary to make reliable short/medium term trajectory predictions, so as to avoid trajectory conflicts. With the emergence of new operational concepts (SESAR Consortium, 2007; Swenson, Barhydt, & Landis, 2006) and automated tools for air traffic management, predicting aircraft trajectories with great accuracy has become more and more critical in recent years. For example, medium-term conflict detection and resolution is very sensitive to trajectory prediction uncertainties (Alliot, Durand, & Granger, 2001). In this context, it is crucial to forecast the wind with accuracy within a prediction window of 15–30 min, at any point in the airspace. The current meteorological forecasting models do not operate within such

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timeframes and the best alternative is most probably to use the current wind, assuming that it will remain constant during the time interval of the prediction.

Estimating the current wind numerically still remains a difficult problem, as wind measurements through sensors such as meteorological balloons or radar wind profilers are sparse in both space and time. These wind measurements must be processed by a numerical model and the meteorological wind, pressure, and temperature data is updated every N hours (3 h, usually).

In this paper, flying aircraft are used as passive wind sensors, with their positions and velocities measured through radar detection. These radar measurements are currently used for air traffic management purposes and are easily available to ground systems, in great quantities. When plotting the ground speed magnitude as a function of ground speed direction, for a number of aircraft, some roughly sinusoidal patterns emerge. These visual patterns are a straightforward result of the wind influence on aircraft trajectories (Fig. 1).

In the following, we propose an analytical method to extract the wind from these patterns, using a least squares regression. Instead of focusing on one or two aircraft as in Delahaye and Puechmorel (2009), the idea is to take advantage of the amount of data, and consider categories of aircraft with the same speed characteristics. The wind magnitude and direction is then approximated by applying a least squares method to selected radar tracks, considering all flights in the vicinity of the points where the wind is estimated. A simplified ground speed and wind model is used, neglecting the influence of lateral drift (the drift angle is the angle between the longitudinal axis of an aircraft and its path relative to the ground) on the along-track ground speed. With this approximation, which is justified for aircraft flying at high speeds, the number of unknown variables can be considerably reduced and the model can be linearized.

We also propose an interactive semi-automatic process, where the least squares computation is driven by the user who selects the input data and validates the results through a visual interface.

The remainder of the paper is organized as follows: Section 2 details the related works on trajectory exploration and wind extraction, while Section 3 introduces the principles of wind extraction from a dataset of aircraft trajectories. The dataset itself is described in Section 4. The issues that were raised during some preliminary tests of the automatic extraction method are detailed in Section 5. The interactive extraction procedure mixing the least squares algorithm and user filtering and adjustments is presented in Section 6. Section 7 shows how the wind dynamics can be extracted and displayed in order to help the user to select time windows when filtering the data. Finally, in Section 8, we visually compare our results with Météo-France data. We also discuss the confidence intervals of the least squares method and give some numerical results on the comparison with the Météo-France wind data and the wind computed from downlinked aircraft data. Section 9 concludes the paper and gives some perspectives about further improvements and possible applications of our method.

2. Related work

2.1. Trajectory exploration

The data-flow model in Card, Mackinlay, and Schneiderman (1999) is widely used to perform data exploration. In this paper, we also use this data flow model to transform raw data (i.e. aircraft records) into visualization with a sequence of transformation steps.

There is a rich bibliography on trajectory analysis in information visualization, in particular on direct manipulation to filter and extract relevant aircraft information (Hurter, Tissoires, & Conversy, 2009; Hurter, Ersoy, & Telea, 2011), density map computation to discover boat trajectory interactions (Scheepens et al., 2011), aircraft trajectory schematization (Hurter, Serrurier, Alonso, Tabart, & Vinot, 2010), trajectory bundling (Hurter, Ersoy, & Telea, 2013), Visual Analytics (Andrienko & Andrienko, 2013), knowledge discovery in databases (Giannotti, Giannotti, & Pedreschi, 2008; Andrienko & Andrienko, 2005), geocomputations (Laube, 2009), moving object databases (Güting & Schneider, 2005), and detection of landing areas (Andrienko, Andrienko, Hurter, Rinzivillo, & Wrobel, 2012). However, none of these previous works tried to extract wind parameters from trajectories.

2.2. Wind extraction

De Haan and Stoffelen De Haan and Stoffelen (2012) show that high resolution wind and temperature observations can be obtained using on-board measurements made by aircraft and transmitted through the data-link capabilities of the Enhanced Mode-S radars (these data will be detailed in the following). They also show how these measurements can be used as input to

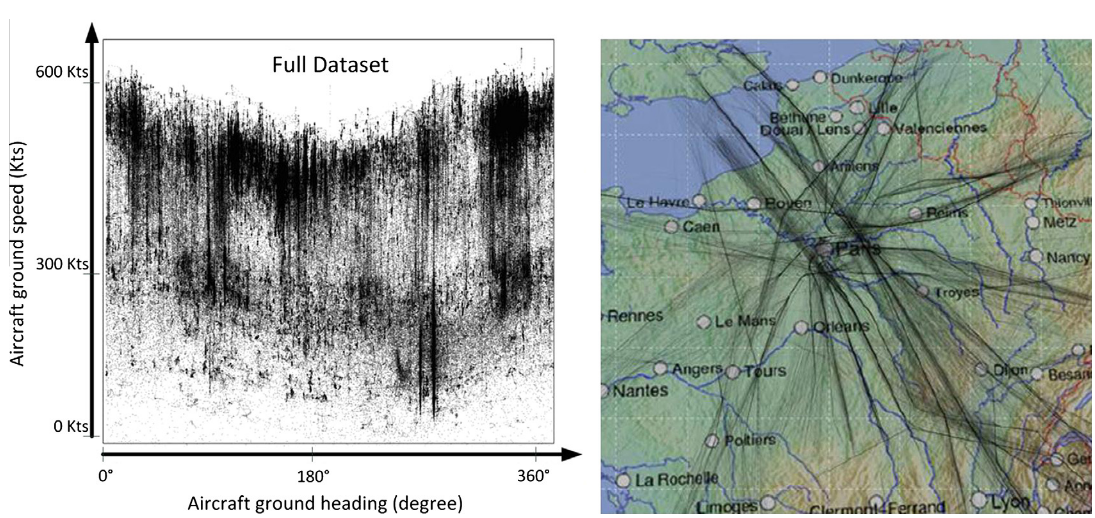

Fig. 1. right "Top view", one day of recorded aircraft trajectories over Paris area. Left "wind view", scatterplot with aircraft headings, and their corresponding ground speeds. Sinus shapes emerge which show the wind influence on aircraft ground speed.