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Downburst outflow reconstruction by wind profile measurements

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ABSTRACT: When a downburst is measured by means of an anemometric station or vertical wind profiler, the observed flow field is most of the time the superposition of the downburst outflow induced by the thunderstorm-generated downdraft that spreads out after touchdown and some additional environmental flow field. In particular, two different environmental flow fields can affect downdraft and downburst outflow: the advective motion of the storm cloud affects the downdraft while it moves downward, determining a translation with respect to the ground that appears like an inclined downdraft axis; the flow within the boundary layer interacts with the downburst partially destroying the radial symmetry of the outflow. A procedure is presented to separate the contribution of these environmental flows from downburst outflows measured by means of wind vertical profilers in order to study the actual kinematic characteristics of the outflows. Assuming a Galilean transformation between time and space, time series of wind velocity measured at different heights above ground are transformed into flow trajectories on bi-dimensional *xz*-planes, which allow to represent visually the structure of downbursts.

KEYWORDS: downburst outflow, storm motion, boundary layer flow, LiDAR measurements

1 INTRODUCTION

At the author's knowledge, the concept of spatially stationary or travelling downburst was firstly introduced by Byers & Braham[1] (1949), who mentioned that when a storm is moving slowly the outflow of downdrafts is radial, whereas in fast-moving storms the outflow is not symmetric and the downstream flow is substantially higher than in the upstream side. This concept was later replicated by Fujita[2] (1985), who distinguished between the axisymmetric starburst outflow with an annular ring of high winds produced by stationary microbursts when no environmental flow is present and the elliptic shape of the outflow with higher wind speeds in the front-side when the microburst is travelling. Figure 1 shows Fig. 5.2 reported in Chapter Five of Fujita (1985), where this concept is explained.

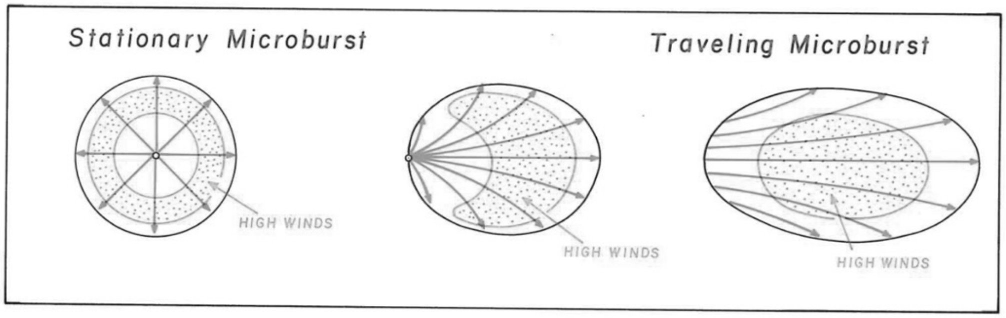

Figure 1. The variation of microburst outflows for different microburst travelling speed (from stationary to the left, to slowly and fast travelling to the right) as depicted by Fujita[2] (1985).

According to Byers & Braham[1] (1949) as well as Fujita[2] (1985), a downburst is referred to as travelling when the parent storm cloud is moving with respect to the ground, so that the downburst itself determines a downward horizontal momentum flux from aloft toward the atmospheric boundary layer. These authors clearly related the inclination of downdraft axis to the storm motion, but non-vertical downdrafts are sometimes related to different causes in the literature. For example, Hjelmfelt[3] (1988), analyzing the downbursts measured during JAWS Project in Colorado, related the downdraft axis inclination to the vertical wind shear below the cloud base rather than to the storm motion. Figure 2 reproduces Fig. 18 reported by Hjelmfelt[3] (1988), where the author discusses this topic.

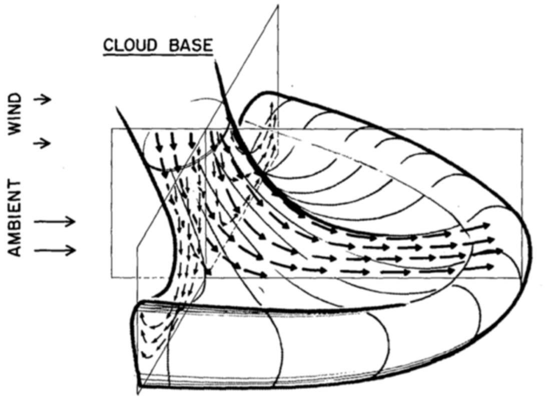

Figure 2. Three-dimensional representation of a microburst as reported by Hjelmfelt[3] (1988), showing that the downdraft axis inclination is related to the ambient wind below the parent cloud base.

In the literature, a few models of downburst outflow include the effect of storm motion, like the one by Holmes and Oliver[4] (2000), but in the Author's knowledge none of them consider the possibility that the actual measured flow field, $\mathbf{V}$, could be the superposition of three contributions: the axisymmetric downburst outflow, $\mathbf{V}_O$; the storm motion, $\mathbf{V}_S$; the atmospheric boundary layer flow field, $\mathbf{V}_{BL}$

$$\mathbf{V} = \mathbf{V}_O + \mathbf{V}_S + \mathbf{V}_{BL} \tag{1}$$

In the present paper a downburst event measured by means of a vertical wind profiler in Livorno (Italy) is analyzed and a procedure is proposed to separate the three mentioned contributions from the overall flow field.

2 THE THUNDERSTORM EVENT ON 13 SEPTEMBER 2015 IN LIVORNO

2.1 *Weather scenario*

On 13 September 2015, in the morning, the extratropical cyclone Michael (according to naming convention adopted by the Institute of Meteorology of the Freie Universität Berlin, Berlin, Germany) was to the south of Ireland. Around midday, its warm front reached from south-west the coast of Tuscany and a squall line was over the area of Livorno City at about 1100 UTC. Figure 3 (left) shows the radar reflectivity over Livorno at the time that the squall line was approaching the coast. Figure 3 (right) shows the skewT-logP thermodynamic diagram calculated from GFS analyses at 1200 UTC over Livorno. It shows that within the layer between 800 and 300 hPa, which is roughly where thunderstorm clouds develop, the wind flow was around 15 m/s from west-south-west, while at the surface it was approximately 5 m/s from southeast. These values of the wind aloft and at the surface are not negligible in case of downburst occurrence and a microburst outflow would be probably affected by both storm motion and boundary layer flow through some kind of mutual interaction.

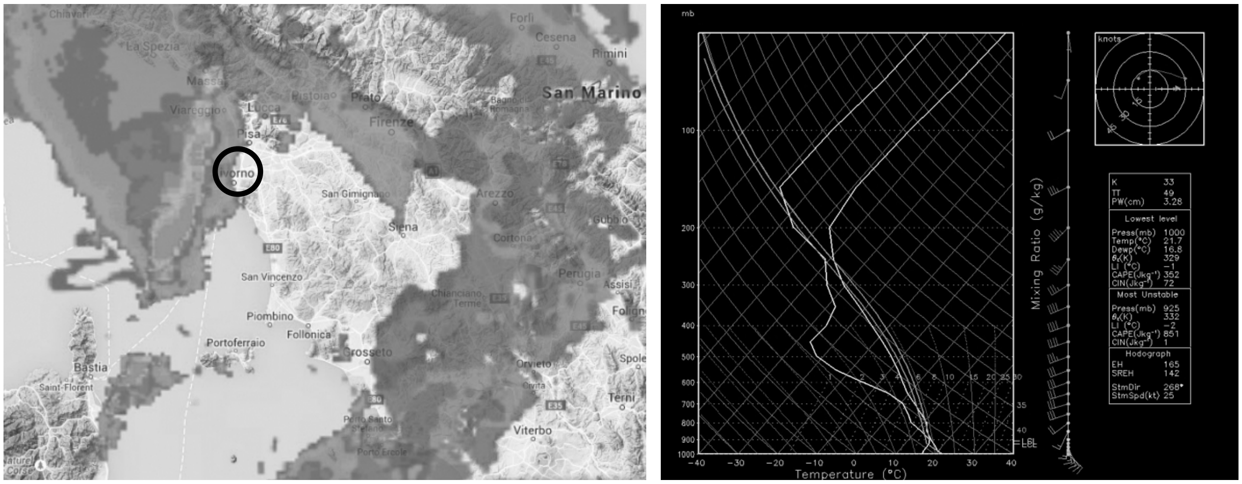

Figure 3. Radar reflectivity (left) over the northern Tyrrhenian Sea (Italy) and thermodynamic diagram over Livorno at 1200 UTC (data from GFS analysis).

2.2 *Separation of storm motion, boundary layer flow, and microburst outflow*

On 13 September 2015, a LiDAR wind profiler installed in the port area of Livorno, belonging to the "Wind and Ports" anemometric network (Solari[5] 2012), detected the passage of a microburst in the time interval between 1100 and 1145 UTC, with maximum measured wind speed values around 25 m/s. In order to remove storm motion and boundary layer flow from the recorded wind velocity time series, the overall velocity field has been assumed to result from a vector summation of the three contributions (see Eq. 1).

Firstly, the boundary layer flow velocity, $\mathbf{V}_{BL}$, is evaluated as the velocity measured before the microburst occurrence, which was equal to 6.4 m/s from 155.3°. According to the vector summation assumption mentioned above, the boundary layer flow is then removed from measurements and the resulting velocity is the microburst outflow plus storm motion, $\mathbf{V}_O + \mathbf{V}_S = \mathbf{V} - \mathbf{V}_{BL}$. This resulting velocity corresponds to the wind field depicted in the picture to the right of Figure 1.

Secondly, the along-wind and transversal components of the velocity field $\mathbf{V}_O + \mathbf{V}_S$, referred to as (u_1, u_2), are calculated by means of a matrix rotation obtained according to a principal component analysis. The time-averaged value of the along-wind component, $\overline{u_1}$, is assumed to be equal to the storm motion, $\mathbf{V}_S = (\overline{u_1}, 0{,}0)$, so that the microburst outflow is reconstructed removing it. The final vector field of the microburst outflow is therefore $\mathbf{V}_O = (u_1 - \overline{u_1}, u_2, u_3)$, where u_3 is the vertical component.

2.3 *Results and conclusions*

Figure 4 (above) shows vectors (u_1, u_3),, which represent the summation of $\mathbf{V}_O + \mathbf{V}_S$, on the *xz*-plane, where x is the along-wind direction and z is along the vertical. Figure 4 (below) shows vectors $(u_1 - \overline{u_1}, u_3)$, that correspond to $\mathbf{V}_O$ only. The comparison between these two pictures allows to quantify the role of storm motion in increasing the flow intensity at the ground caused by the additional horizontal momentum flux from the wind aloft.

In the final paper, more details about the procedure shortly described in section 2.2 will be added as well as the results from other case studies.

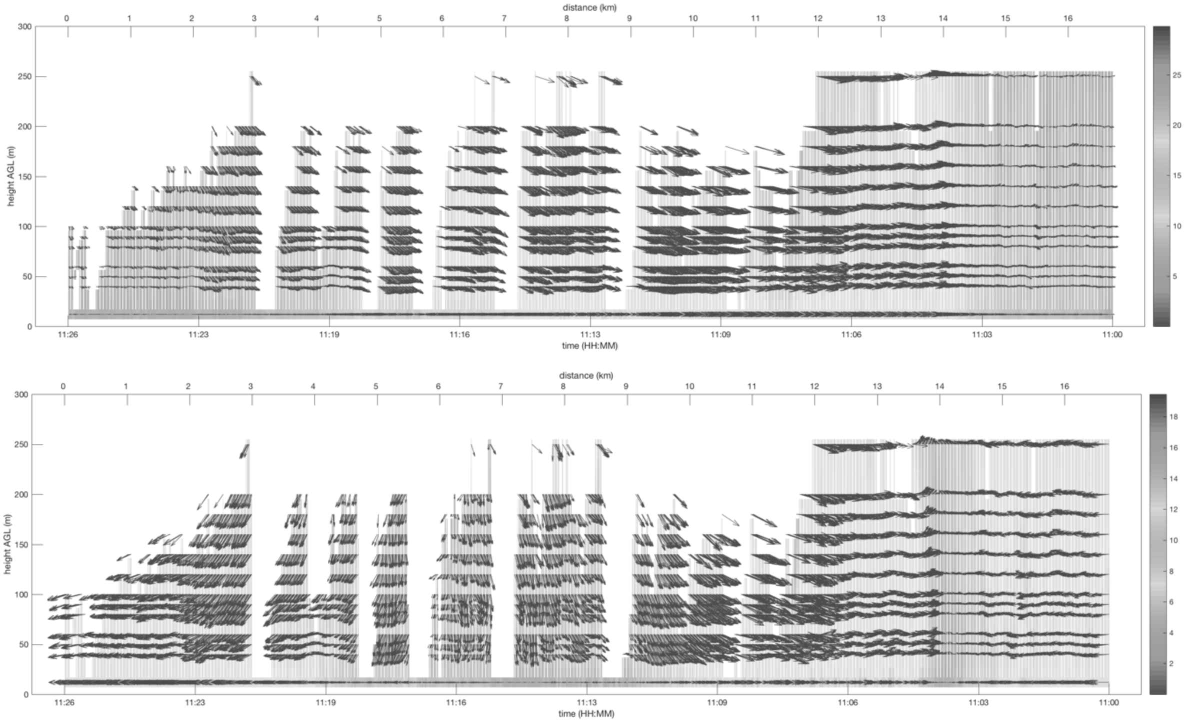

Figure 4. Vector fields $\mathbf{V}_O + \mathbf{V}_S$ (above) and $\mathbf{V}_O$ (below) projected on *xz*-planes.

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