MICROMETEOROLOGICAL OBSERVATION OF A DOWNBURST IN SOUTHERN FINLAND

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I. INTRODUCTION

On the afternoon of 3 July 2004, an area of scattered thunderstorms occurred in southern Finland. One of the convective cells produced a small downburst, known as a microburst, that was detected at the SMEAR II *(Measuring Forest Ecosystem – Atmosphere Relations)* field station in Hyytiälä, where a large array of micrometeorological instrumentation is operated continuously (Hari and Kulmala, 2005). Although much previous research has been performed on severe convective storms and microbursts, we are not aware of any other study that has presented high-frequency (>10 Hz) data from a microburst. Our observations are novel in that we are able to link the meteorological observations to measurements of turbulence characteristics, trace gas (water vapor, carbon dioxide, and ozone) concentrations, and aerosol particle concentrations before, during, and after the microburst. Thus, a microburst passing through a well-equipped observation site provides a unique opportunity to study high-resolution turbulence data, trace gas and total aerosol particle concentrations, and aerosol size spectra during an extreme weather event. Moreover, use of doppler radar data clarifies the larger mesoscale conditions associated with the microburst.

The main microburst damage track was around ten meters long and a couple of tens meters wide, and trees fell mostly to the southwest (FIG. 1). Based on the damage, the wind speed was estimated to be around 30 m s^{-1}, 10 m s^{-1} more than the measured wind-speed maxima.

II. MEASUREMENTS AND METHODS

The microburst occurred in Hyytiälä, Juupajoki, 210 km north of Helsinki (FIG. 2). The SMEAR II field station (61° 51'N, 24° 17'E, 181 m above sea level) is located close to the Hyytiälä Forestry Field Station. The forest damage site is about 200 m southwest from the measuring station (FIG. 1). The C-band weather radar used in the study is situated at Ikaalinen (61° 46'N, 23° 04'E, 154 m above sea level), 65 km west of Hyytiälä.

Data from three eddy covariance set-ups recording turbulence data were used. Two set-ups above canopy are at the same height of 23 m and are separated by a horizontal distance of 30 m. These are henceforth referred as locations A and B (FIG. 1). The third set-up is at sub-canopy, below the foliage at 3 m, about 20 m south from Location B.

At location A, wind speed and direction are measured at heights of 73.0 and 8.4 m with a 2-dimensional ultrasonic anemometer, whereas temperature is measured at heights of 67.2 m and 8.4 m and dew-point temperature at a height of 23 m. Carbon dioxide and water vapour concentrations are measured with a fast-response gas analyser. An ozone analyser and a Condensation Particle Counter were used to measure ozone and total particle concentrations, respectively. Aerosol particle size distribution is observed by means of twin Differential Mobility Particle Sizer system (Aalto et al., 2001), and ion size distribution is measured with a Balanced Scanning Mobility Analyzer.

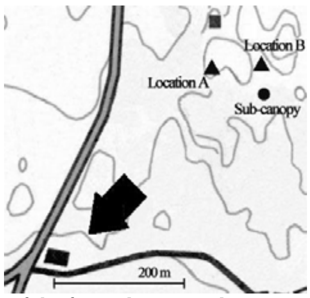


FIG. 1: Location of the forest damage and measuring locations. The black arrow shows the location of the damage site and the direction of fallen trees. The triangle represents the above-canopy locations A and B and the circle stands for sub-canopy measurements. The square represents the instrument cabin.

Detailed meteorological analysis was made during 1400–1430 EET (Eastern European Time, UTC+2) when the event was observed. Mean or instantaneous values for wind speed, wind direction and vertical wind speed in all locations are used. For gas and total aerosol particle concentrations, 15-second average values are analysed. The atmospheric spectra were calculated using a Fast Fourier Transform for 5- to 10-minute sections, after having been de-trended and Hamming windowed (Kaimal and Kristensen, 1991).

III. RESULTS AND DISCUSSION

On 3 July 2004, an elongated upper-level short-wave trough, extending from southern Norway to the Baltic countries, moved north (FIG. 2). In the afternoon, a warm front laid just west of Hyytiälä, and a cold front was about to arrive at the microburst area. The leading edge of a squall line was reaching Hyytiälä at 1330 EET. The radar reflectivity factor maximum was located in the middle of the line, contrary to many other mesoscale convective systems (e.g., Parker and Johnson, 2000). Typical radar signatures of downburst-producing convective systems (bow echo, rear-inflow jet, and rear-inflow notch) were observed just north of Hyytiälä preceding and at the time of the microburst (FIG. 3).

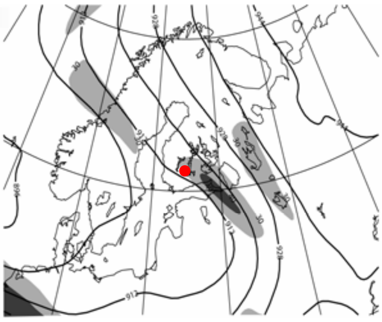


FIG. 2: 300 hPa model analysis from European Centre for Medium-Range Weather Forecasts at 0200 EET 3 July 2004: isohypses (solid lines every 80 dam) and isotachs (shaded every 10 m s^{-1} for speeds greater than 30 m s^{-1}). Red dot shows the location of Hyytiälä.

In the United States, where the majority of the bow echoes move to the east or southeast, the most severe wind damage is observed north or northwest (left) of the bow echo apex in close association with mesovortices (e.g., Wheatley et al., 2006). Interestingly, the 3 July 2004 microburst occurred about 10 km left of the apex. Examination of the Ikaalinen radar radial velocities at 1415 EET (FIG. 3) showed a couplet of inbound and outbound velocities, with the northern flank of the possible vortex traveling over Hyytiälä at the time of the microburst. The individual convective cells were moving to the west or west-southwest.

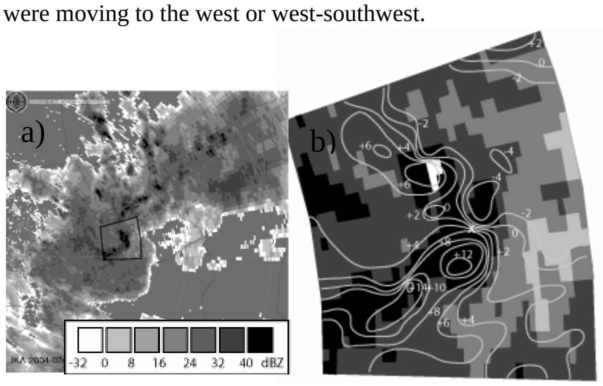
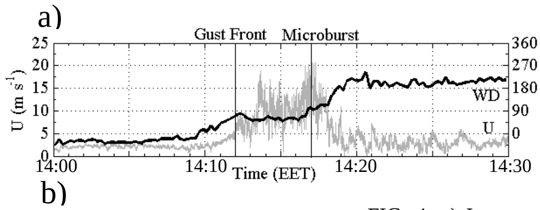


FIG. 3: a) Radar reflectivity factor (dB*Z*, shaded) from Ikaalinen radar at 1415 EET with inset box, b) inset location from a) showing 1415 EET storm-relative radial velocity field (white solid lines every 2 m s^{-1}, positive values away from radar) overlain on radar reflectivity factor (dB*Z*, shaded), and the location of the wind damage area marked with white X.

At the SMEAR II station, the horizontal and vertical wind speed, wind direction, temperature and pressure showed the typical behaviour of a thunderstorm outflow (Mueller and Carbone, 1987). The gust front caused the wind to increase and temperature to drop around 1412 EET (FIG. 4). An increased number of ultra-fine particles were measured during the gust front. Carbon dioxide concentrations increased due to the stronger turbulent mixing associated with the gust front, and water-vapour and particle concentrations decreased due to the cold downdrafts and rain (FIG. 5). Strong peaks at horizontal wind speeds (21 to 22 m s^{-1} above the canopy and 9 m s^{-1} at sub-canopy) and periods of downward vertical motion occurred five minutes after the arrival of the gust front (FIG. 4). Simultaneously, temperature, dew-point temperature, water vapour and pressure increased, suggesting a strong microburst. During the seven-minute windy period, the vertical wind speed at location A experienced maxima of upward and downward flow (10 and 15 m s^{-1}, respectively), comparable with other microburst studies (Hjelmfelt et al., 1989).



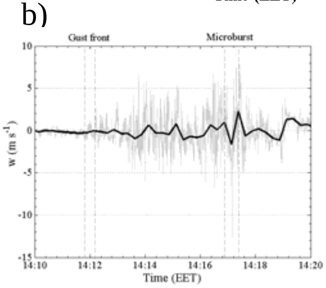


FIG. 4: a) Instantaneous wind speed (thin gray line) and 15-second average wind direction (thick black line) measured at location A. b) Instantaneous (gray line) and 15-second average (black line) vertical wind speed at location A.

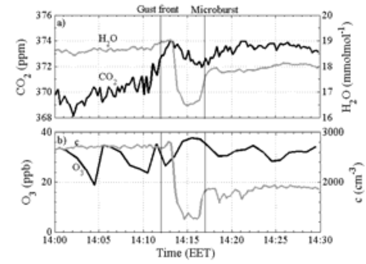


FIG. 5: Time series at location A for 1400–1430 EET: a) 15-second average carbon dioxide (in black) and water vapour (in gray) concentrations, and b) 1-minute average ozone (in black) and 15-second average total particle (in gray) concentrations.

The turbulence spectra of horizontal and vertical wind speed showed typical model spectral behaviour before, during and after the microburst (not shown). The *w* spectra followed the –2/3 power law better than the u_{rot} spectra at the inertial subrange. TKE had maxima during the microburst (1416–1418 EET), but the values were higher around the measured wind speed maxima (1417 EET) indicating the front and rear flanks of the strongest downward motion.

IV. REFERENCES

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