Three-Dimensional Temperature and Wind Profiles Obtained Using UAV-Based Acoustic Atmospheric Tomography

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Abstract

The natural sound generated by an unmanned aerial vehicle is used in conjunction with tomography to remotely sense atmospheric temperature and wind profiles simultaneously. Sound fields recorded onboard the aircraft and by an array of microphones on the ground are compared and converted to sound speed estimates for the ray paths intersecting the intervening medium. Tomographic inversion is then used to transform these sound speed values into vertical cross-sections and 3D volumes of virtual temperature and wind vectors, which enables the atmosphere to be visualised and monitored over time up to altitudes of 1,200m and over baselines of up to 600m. This paper reports on results from two short campaigns during which 2D and 3D profiles of wind and temperature obtained in this way were compared to: measurements taken by co-located mid-range Doppler SODAR and LIDAR; and temperature measurements made by instruments carried by unmanned aircraft flying through the intervening atmosphere. Large eddy simulation of daytime atmospheric boundary layers were also used to examine the anticipated performance of the instruments and the nature of any errors. The observations obtained using all systems are shown to correspond closely.

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Concept: The natural sound of an unmanned aerial vehicle (UAV) is used in conjunction with tomography to obtain 3D atmospheric temperature and wind fields. Sound fields are recorded onboard the aircraft and by an array of microphones on the ground. These are compared and converted to accurate sound speed estimates for ray paths intersecting the intervening medium. Real time kinematic carrier phase differential global positioning system navigation and bespoke signal processing algorithms are required to exploit key aspects of the UAV's natural acoustic signature in order to achieve the necessary timing accuracy for propagation delay estimation (< 0.1ms) [Rogers & Finn, 2017]. Regularised tomographic inversion then transforms the measured sound speed values into continuous, high resolution 2 or 3D profiles of temperature and wind, which enables the atmosphere to be visualised and monitored over time [Finn & Rogers, 2016a]. Altitudes of up to 1,200m have been demonstrated; and the technique is extensible to both concurrent air and water body observations [Finn & Rogers, 2016b] and to measurement using multiple UAVs [Finn et al, 2016c].

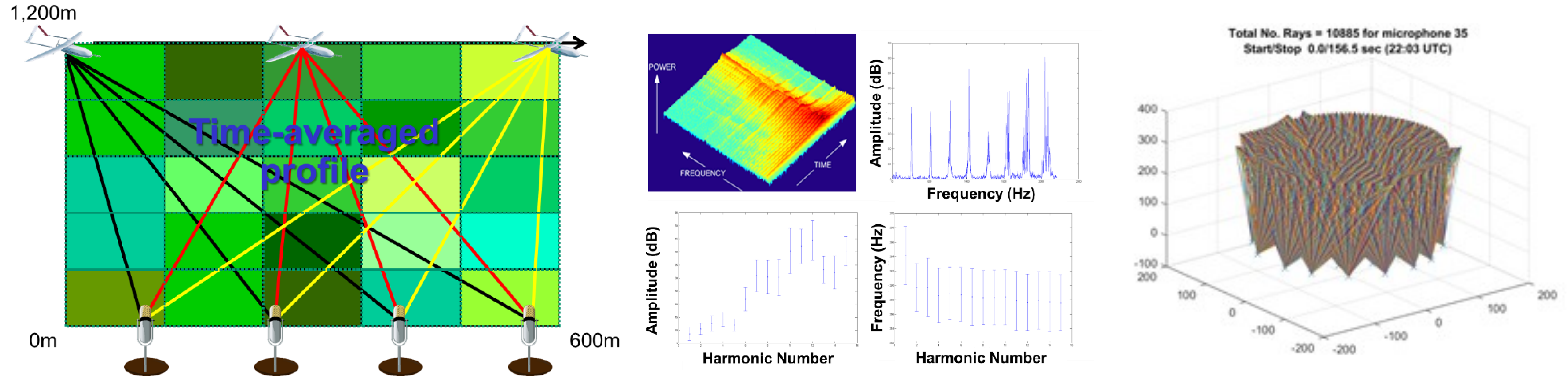

Figure 1: (left) Concept of UAV-Based AAT, (central) spectral properties of the UAV that enable AAT to work and (right) ray path intersections taken from

Field Trials: Short campaigns have been undertaken in which the wind vector and temperature estimates derived using UAV-based AAT have been compared to measurements taken by a co-located mid-range Doppler LIDAR, together with temperature sensors carried onboard the aircraft. The field trials were conducted at Saint Leonards, Victoria (Australia) during days with light-moderate winds (< 8m/s). An Aerosonde MK 4.7 UAV was repeatedly flown over an array of 35 microphones. Baselines of up to 600m and inter-sensor separation distances for the microphones of 25 - 50m were used. All were positioned approximately 1m above a flat grassy surface (the grass was about 3-4cm long). The maximum height of the UAV was 1,200m, although it was readily tracked at ranges exceeding 2km.

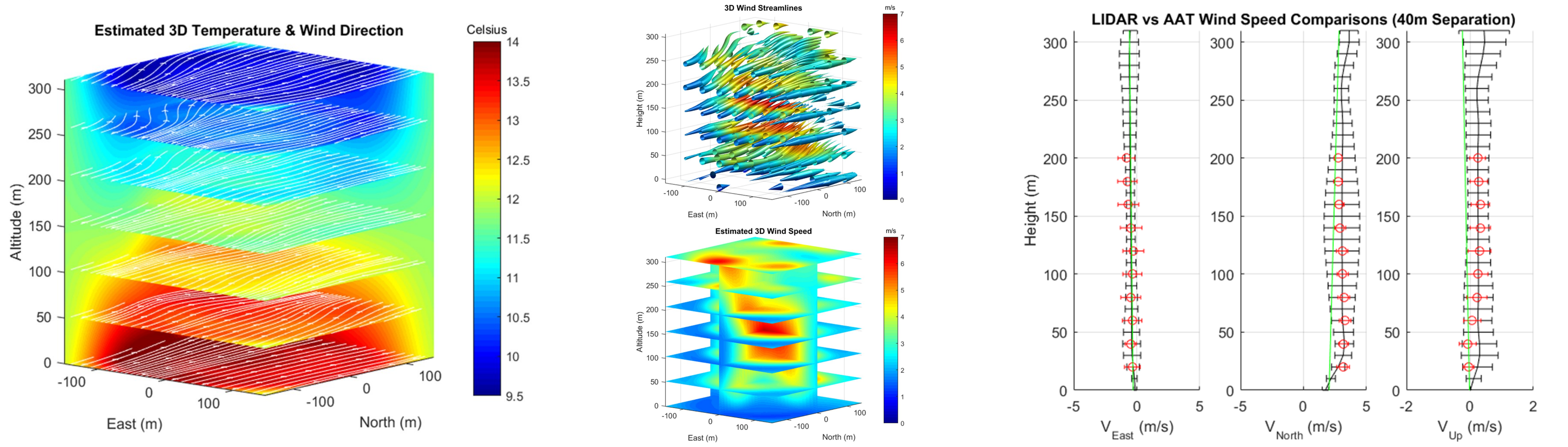

Figure 3: Typical 3D profile of temperature and wind direction fields (left), wind divergence and speed profiles (centre top & bottom, respectively) and comparisons to a LIDAR co-located with the microphone array (right). The LIDAR (red circles) was only able to observe between altitudes of 20m and 200m, whereas the UAV-based AAT (continuous black line) was able to observe between 0 and 1,200m. The error bars for the AAT are shown as horizontal black bars (the green line may be ignored). Analysis of the data set from the 3-day campaign suggests close correspondence between the techniques, with < 0.2m/s bias and < 0.4m/s (1σ) standard deviation in the horizontal axes and < 0.1m/s bias and < 0.1m/s (1σ) standard deviation in the vertical. Temperature estimates correspond to near co-temporal UAV observations to better than 0.3°C

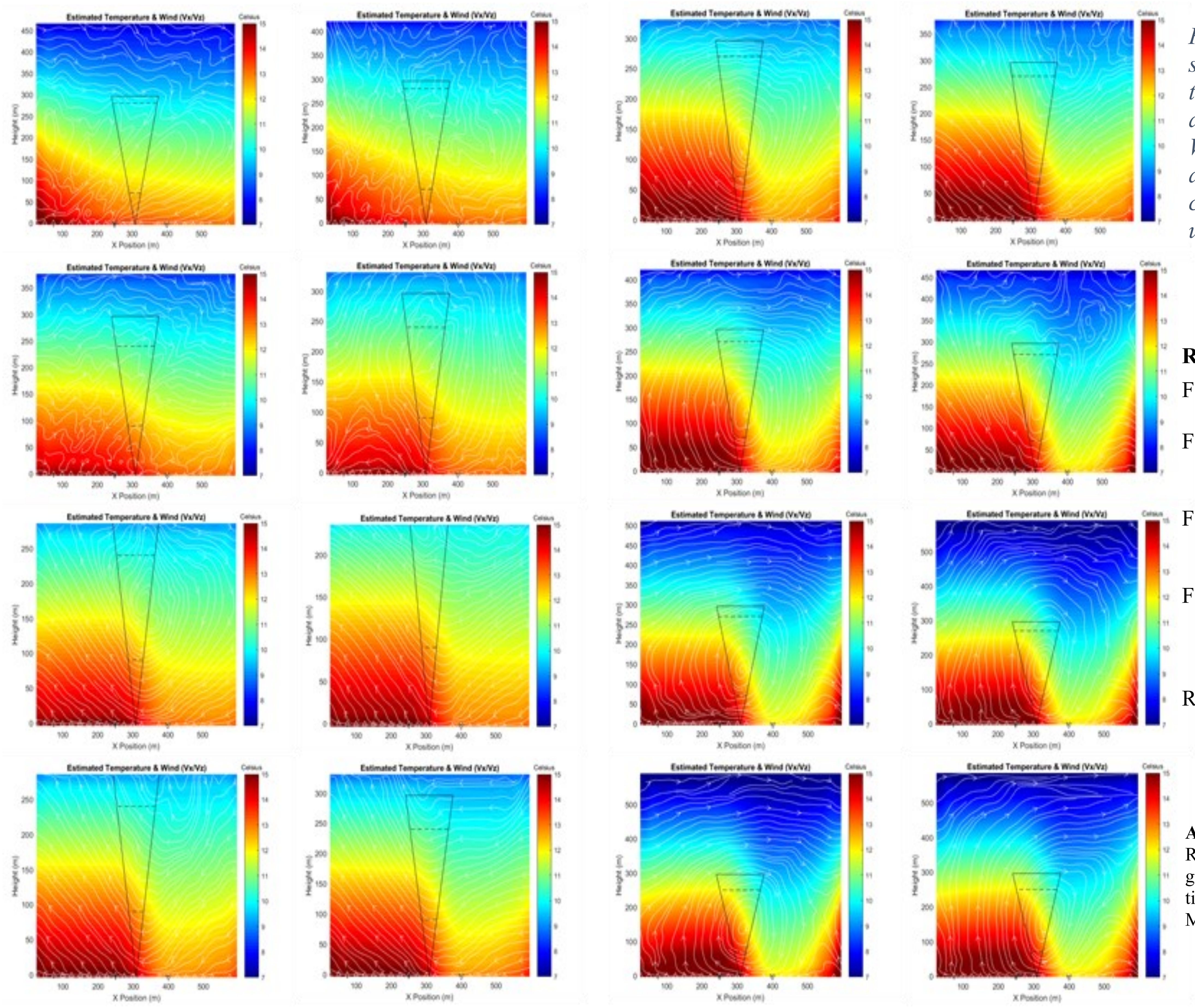

Figure 6: A sequence of 2D slices of temperature and wind velocity observed 100 sec apart over a period of 30 mins showing the development of a thermal near some buildings and a parking area near the origin of the x-axis. The thermal locally disrupts a breeze from the East (+ve x = West). Wind is shown as a set of white streamlines, temperature is coded in accordance with the scale on the right. The image sequence runs: column 1, row 1; column 2, row 1; column 1, row 2; column 2, row 2 … column 2, row 4; column 3, row 1; column 4, row 1 … column 4, row 4.

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