ATMOSPHERIC ROTORS INDUCED BY STABLY STRATIFIED FLOWS OVER MOUNTAINS

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Motivation

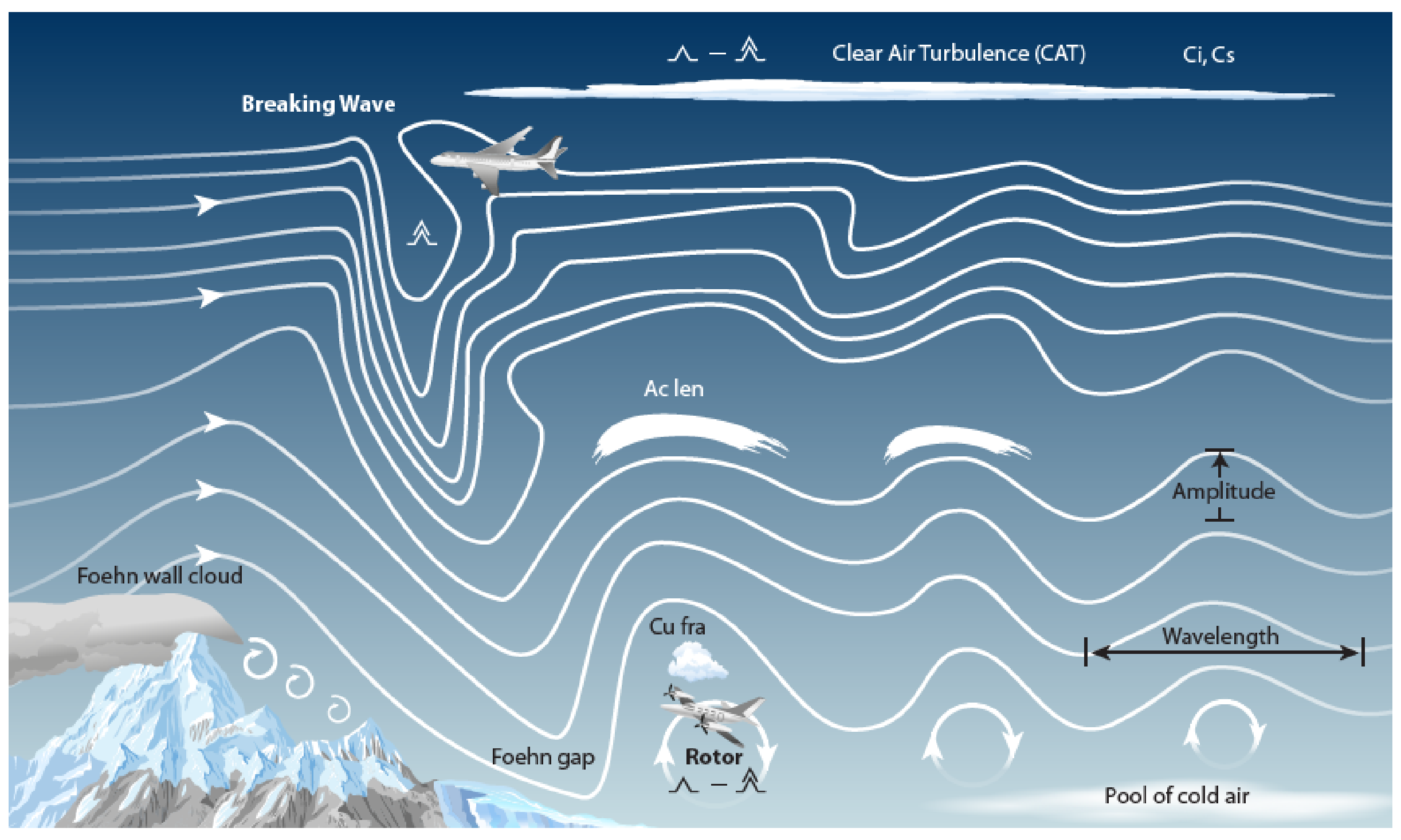

Figure 1: *Schematic of mountain waves and rotors. © Mountain Wave Project*

Atmospheric rotors form in the lower part of mountain lee waves (Figs. 1, 2). They have been investigated by field observations (Figs. 2, 8) like in T-REX (Grubisic et al., 2008) or by numerical simulations (e.g. *Vosper, 2004; Doyle and Durran, 2007*). The major finding of recent numerical simulations that an elevated inversion above the mountain greatly supports the rotor formation motivated our experimental work (Knigge et al., 2010) because this kind of stratification profile has not been used very often in laboratory experiments. A large-eddy simulation (LES) of one rotor case observed in the laboratory experiments was performed to compare the numerical results with those of the laboratory. Furthermore the LES provides high-resolution flow fields in time and space showing the threedimensional turbulent stucture of the rotor flow.

Figure 2: Rotor cloud observed during the T-TEX field campaign. The strong updraft into the rotor is indicated by dust lifted from the ground. © BADC NERC

Meteorological conditions and configuration

- The 2D numerical simulations by Vosper 2004 showed, that rotor formation depends on the non dimensional mountain height *H/z_i* and the inversion Froude number F_i defined as:

$$F_i = \frac{U}{\sqrt{(g\frac{\Delta\rho}{\rho_0} z_i)}} \quad \text{or} \quad F_i = \frac{U}{\sqrt{(g\frac{\Delta\theta}{\theta_0} z_i)}}$$

- The configuration of Vosper is shown in Fig. 3
- In the laboratory the setup shown in Fig. 3 is also used but with stratified density profile
- The experiments and the LES were run for the same values of $F_i = 0.9$ and $H/z_i = 1.1$

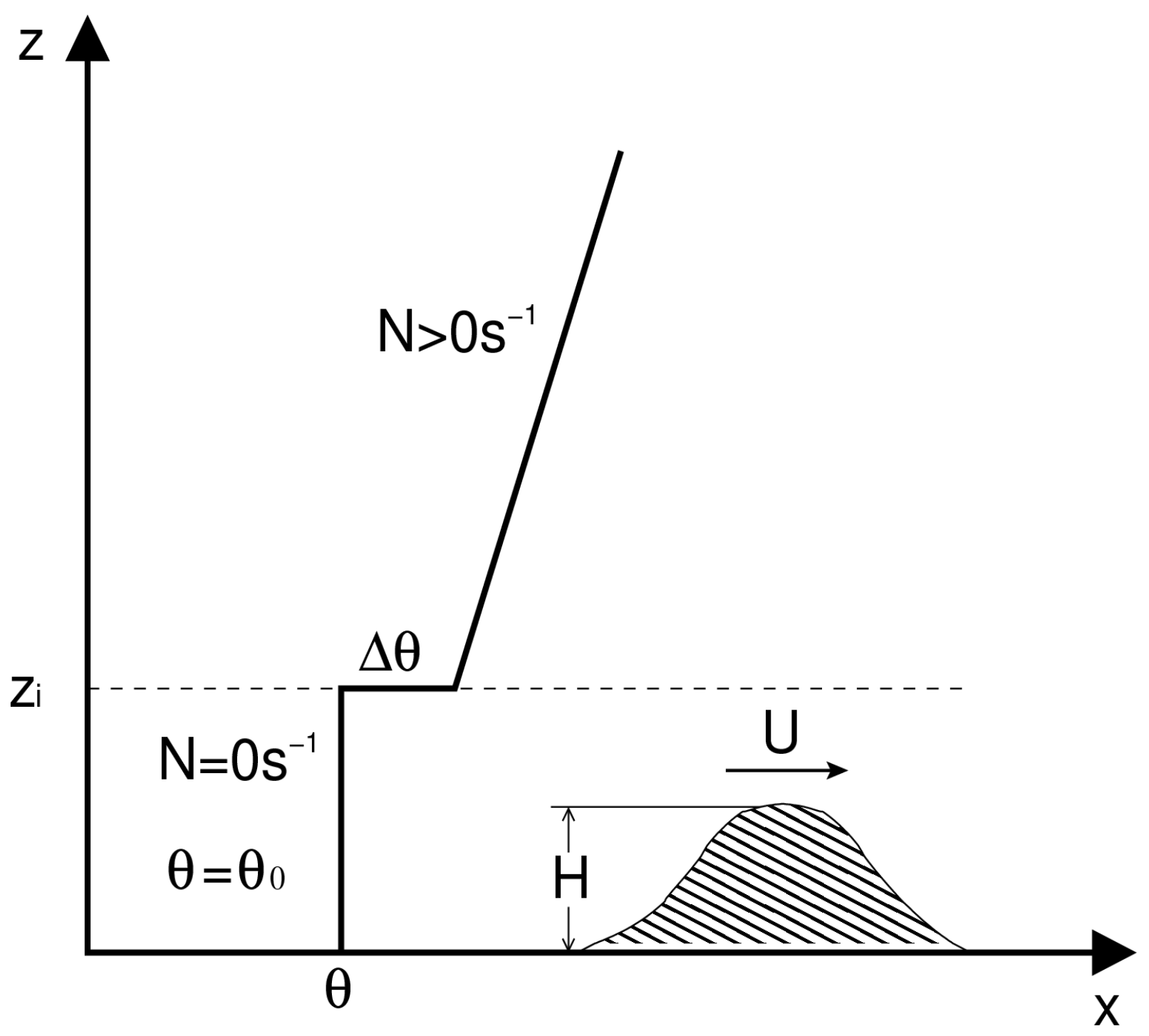

Figure 3: *Principle configuration for numerical simulations. Θ : potential temperature, N : Brunt-Vaisala frequency.*

Laboratory experiments:

- Towing tank of Météo-France in Toulouse
- Size: 22 m length, 3 m width and 1m heigth
- Obstacle: Bell-shaped with 13 cm height, 250 cm width and 124 cm length

Large-eddy simulation:

- LES model PALM of the Institute of Meteorology and Climatology at the Leibniz Universität Hannover (Raasch and Schröter, 2001)
- Domaine size: 28 km height, 30 km width and 144 km length
- Grid size: N_x x N_y x N_z = 9600 x 2048 x 214
- Obstacle: As in the laboratory but 480 m height, 14.6 km width and 4.6 km length

Results

Laboratory experiment

- The flow phenomana were observed by video and streakline photographs for visual inspection and with PIV for quantitative dertermination of the flow field
- The smooth flow in the lee wave and the rotor underneath the first wave crest can clearly be seen in Fig. 4
- A larger part of the flow could be made visible by the LES as shown in Fig. 5
- Fig. 6 shows normalised fields of the horizontal velocity and the vorticity obtained by PIV. These results can be compared to the results from the LES in Fig. 7

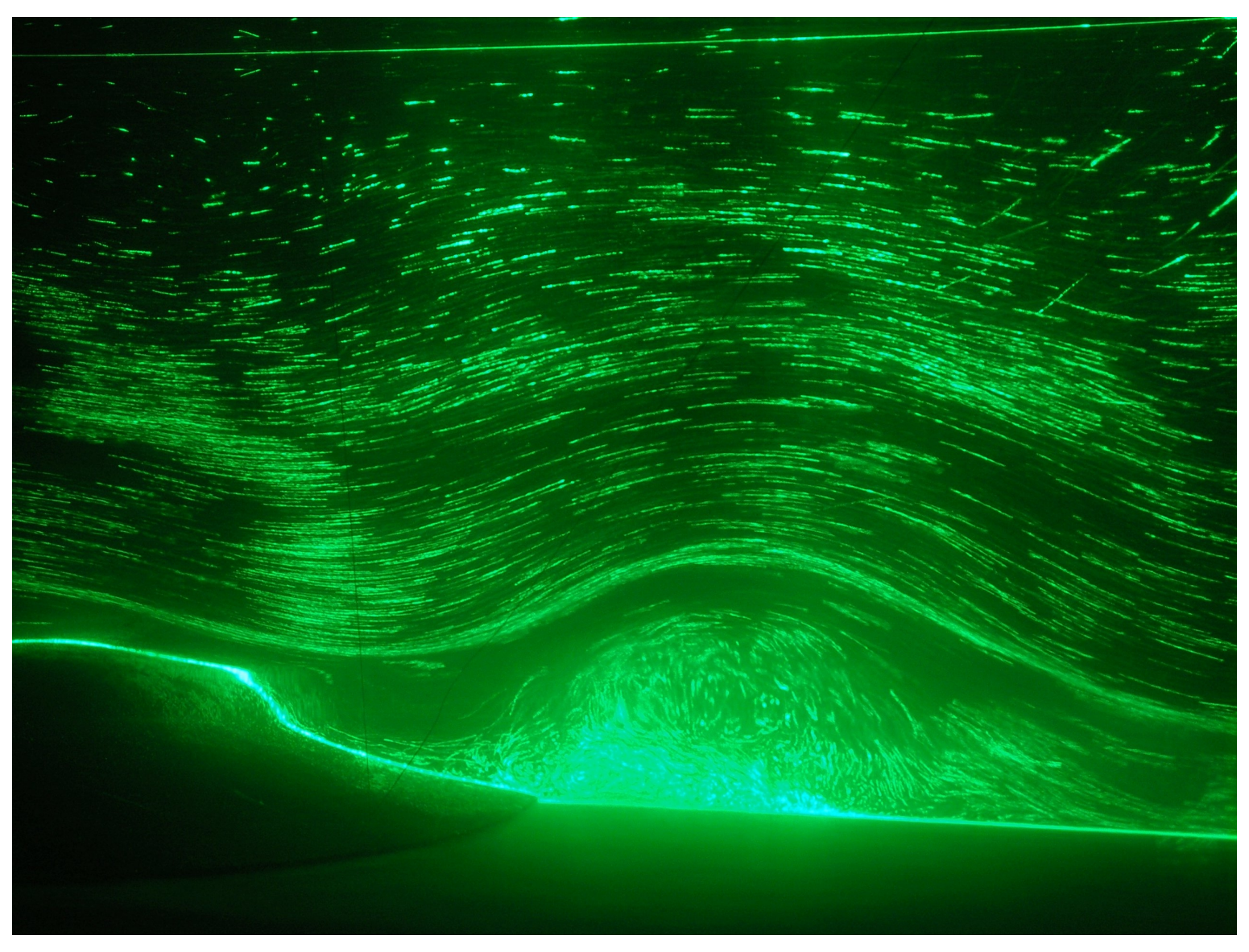

Figure 4: *Streaklines photograph showing part of the lee wave and rotor below the crest.Flow is from left to right*

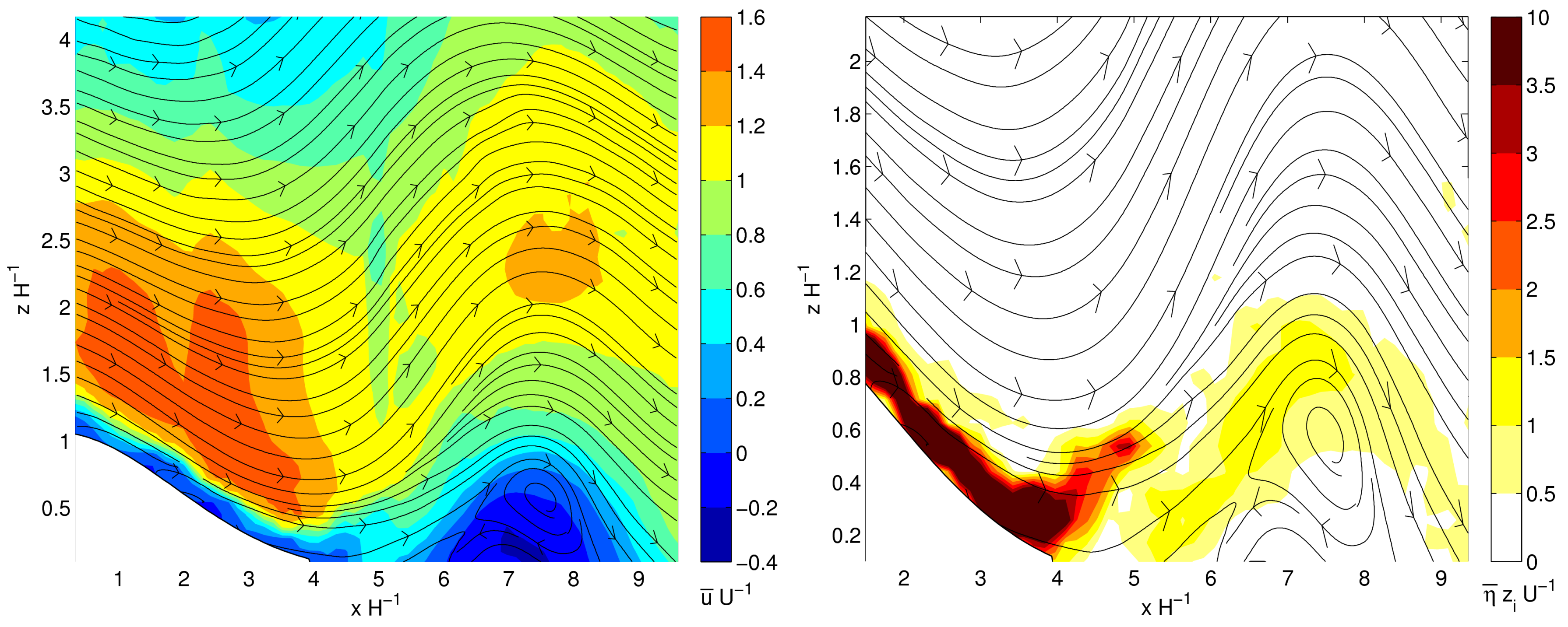

Figure 6: *Time-averaged results from the PIV measurements. Left: Streamlines (arrows indicating flow direction) and time averaged horizontal velocity field (coloured), right: close up showing the streamlines and the normalised vorticity component parallel to the obstacle.*

Large-eddy simulation

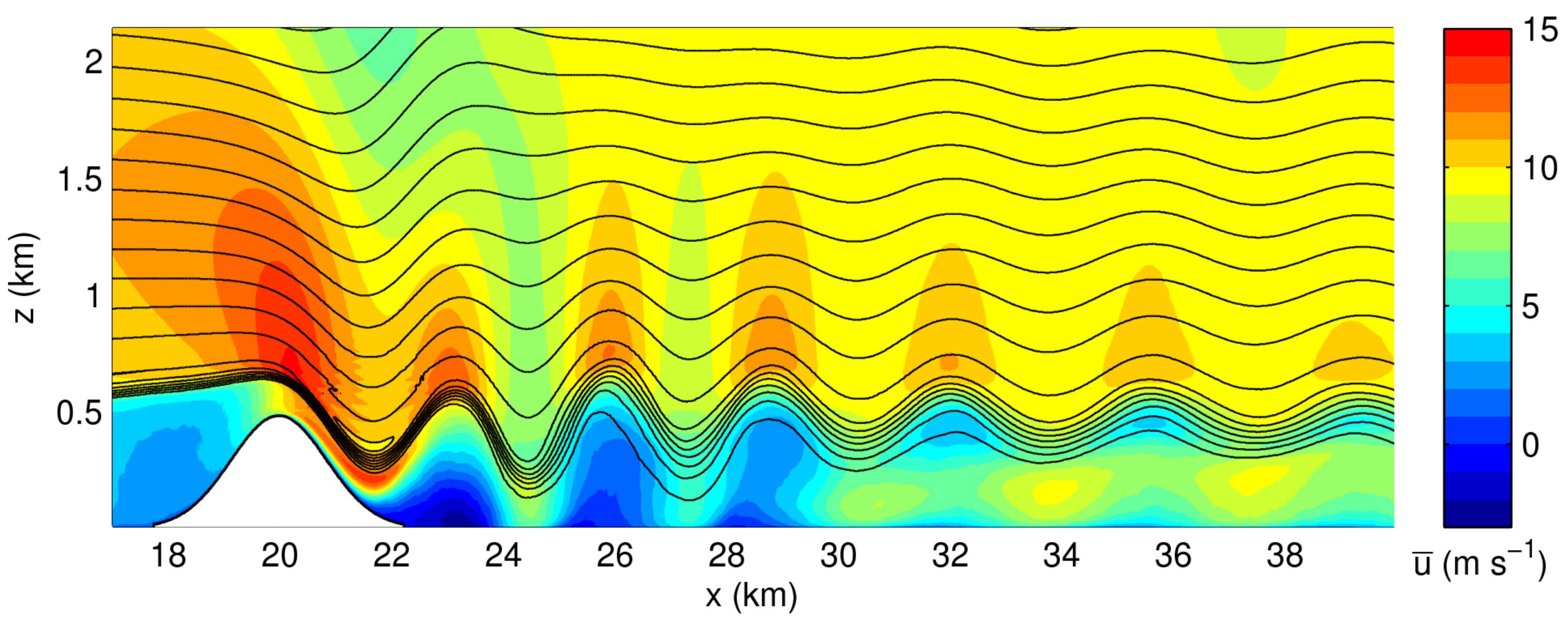

Figure 5: *Lee wave and rotor flow from the LES. Time-averaged quantities shown are the potential temperature (line contours, interval 1K) and the horizontal velocity field (coloured).*

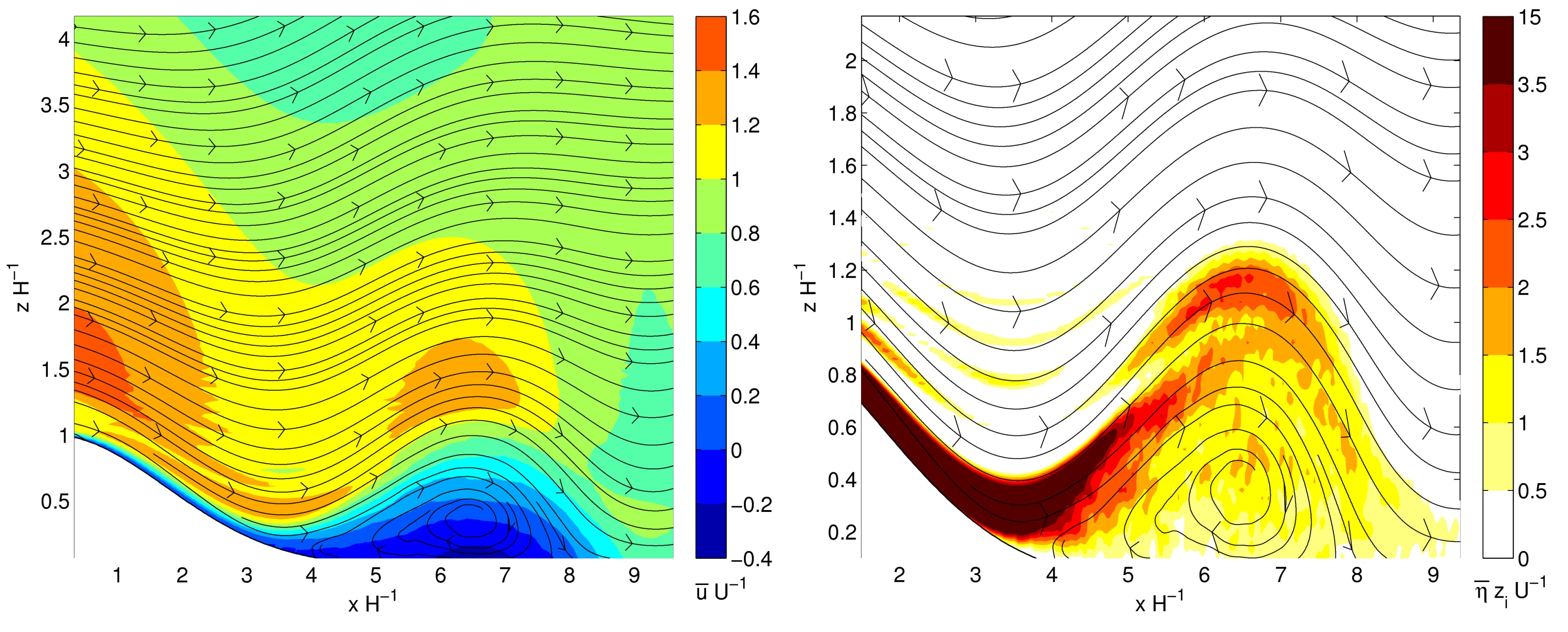

Figure 7: *As Fig. 4 but showing results of the large-eddy simulation.*

References

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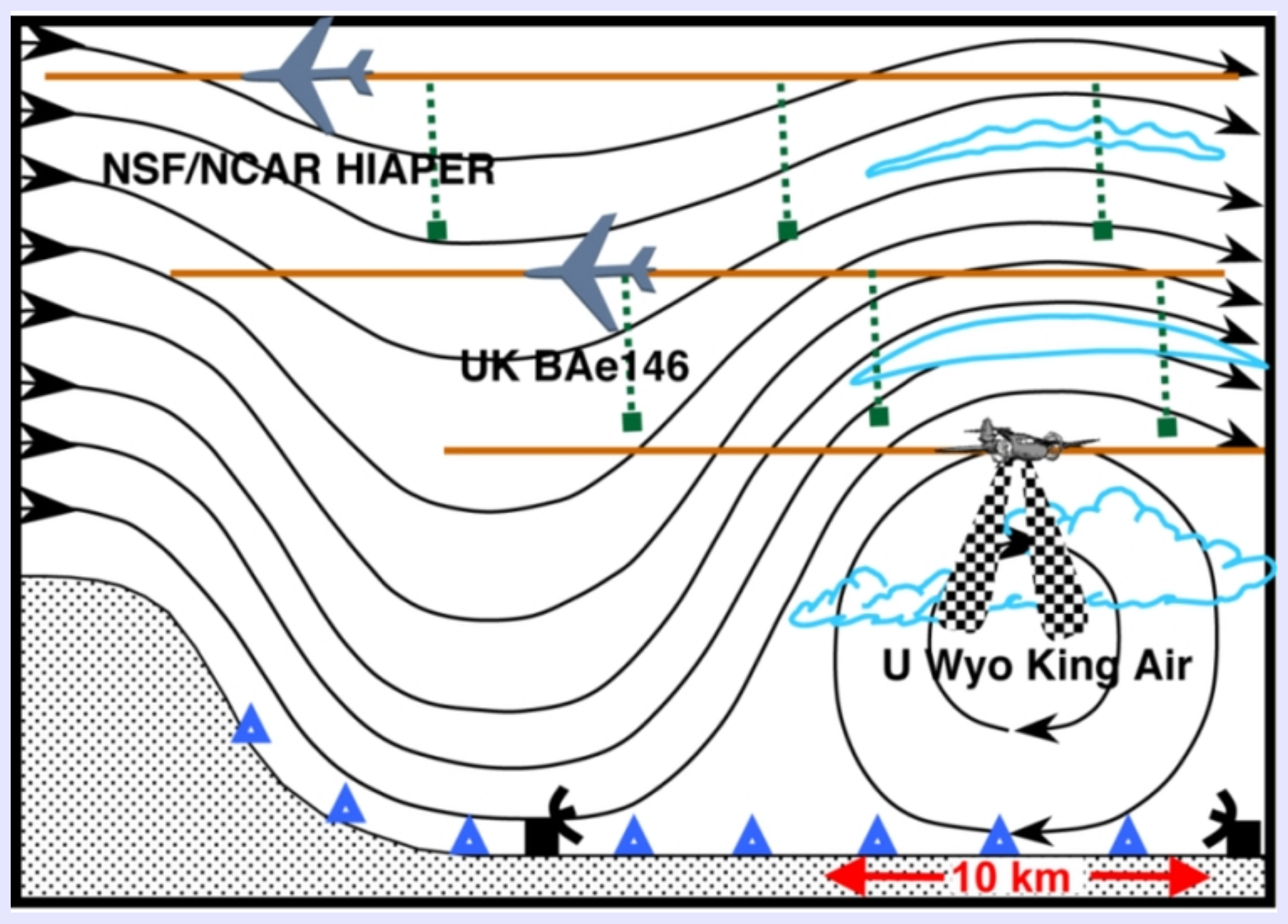

Figure 8: *Schematic of the Terrain-induced Rotor EXperiment (T-REX) at Owens Valley, Sierra Nevada. © EOL UCAR*

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