Numerical simulation of stably stratified atmospheric flow around isolated complex-shaped tall building

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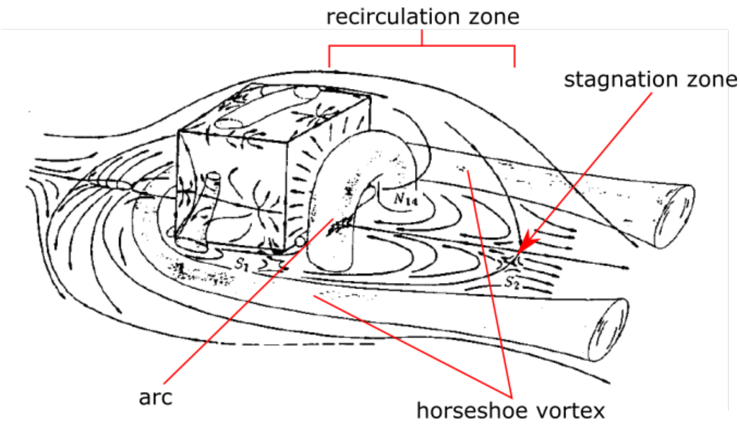
The current state of knowledge

- Flow around buildings is receiving more attention over time
- Numerous wind tunnel studies
- Increasing popularity of CFD
- Most simulations were focused on idealized flow around simplified buildings
- Very often steady state adiabatic flow
- Influence of stability is still poorly investigated but it is attracting more and more attention

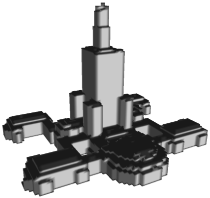
The significance of stability

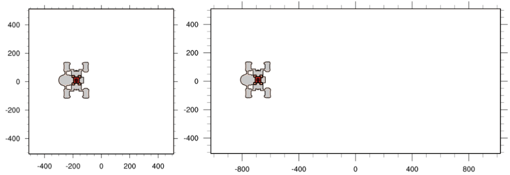
- Mechanically generated turbulence reduces the role of buoyancy effects
- Buoyancy may affect the flow itself

Flow structures
Hussein & Martinuzzi 1996



Computational domain





Model setup

- EULAG code
- Cartiesian coordinate frame with its X axis oriented parallel to the symmetry plane of buiding
- Wind direction along X axis
- Two computational domains: one for high Froude number 256^3, and second for low Froude numbers $256 \times 256 \times 512$
- $4 \times 4 \times 2m$ resolution
- Constant temperature gradients
- Wind speed at lowest model level was set to $3m/s$ with $0.002s^{-1}$ vertical gradient
- Boussinesq approximation
- Immersed Boundary method to represent the building

Cases

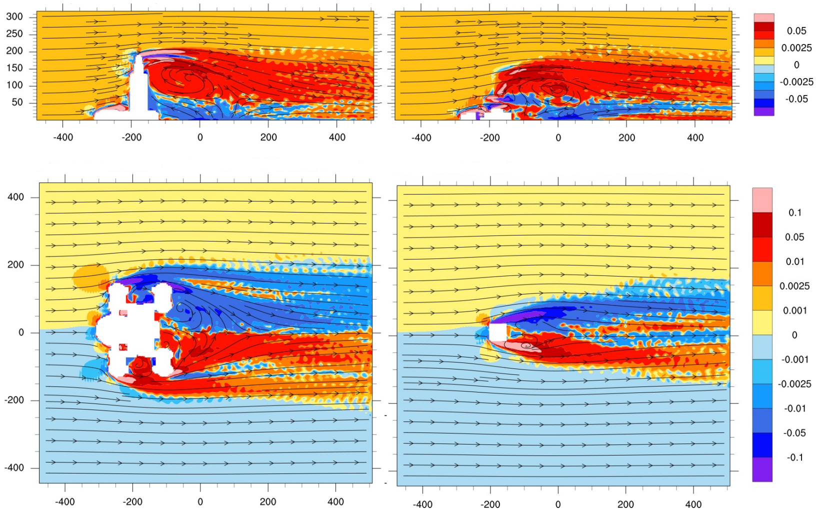
Case #	S $[1/m]$	$\partial\bar{\Theta}/\partial z$ $[K/m]$	N_{BV} $[1/s]$	Fr	λ_x $[m]$
1	$1 \cdot 10^{-6}$	$2.88 \cdot 10^{-4}$	0.0031	5	6015
2	$1 \cdot 10^{-5}$	$2.88 \cdot 10^{-3}$	0.0099	1.6	1902
3	$1.5 \cdot 10^{-5}$	$4.32 \cdot 10^{-3}$	0.0121	1.3	1553
4	$2 \cdot 10^{-5}$	$5.76 \cdot 10^{-3}$	0.0140	1.13	1345
5	$2.5 \cdot 10^{-5}$	$7.2 \cdot 10^{-3}$	0.0157	1.01	1203
6	$3 \cdot 10^{-5}$	$8.64 \cdot 10^{-3}$	0.0172	0.92	1098
7	$5 \cdot 10^{-5}$	$1.44 \cdot 10^{-2}$	0.0221	0.71	851
8	$7.5 \cdot 10^{-5}$	$2.16 \cdot 10^{-2}$	0.0271	0.58	695
9	$1 \cdot 10^{-4}$	$2.88 \cdot 10^{-2}$	0.0313	0.50	602
10	$1.25 \cdot 10^{-4}$	$3.6 \cdot 10^{-2}$	0.0350	0.45	538
11	$1.5 \cdot 10^{-4}$	$4.32 \cdot 10^{-2}$	0.0383	0.41	491
12	$1.75 \cdot 10^{-4}$	$5.04 \cdot 10^{-2}$	0.0414	0.38	455
13	$2 \cdot 10^{-4}$	$5.76 \cdot 10^{-2}$	0.0443	0.36	425

Boundary conditions

- Outflow boundaries in the lateral and streamwise direction were open
- Free-slip boundary condition at the ground
- Impermeable rigid boundary with a wave absorber at the top
- No-slip and partial-slip were also tested for comaprison

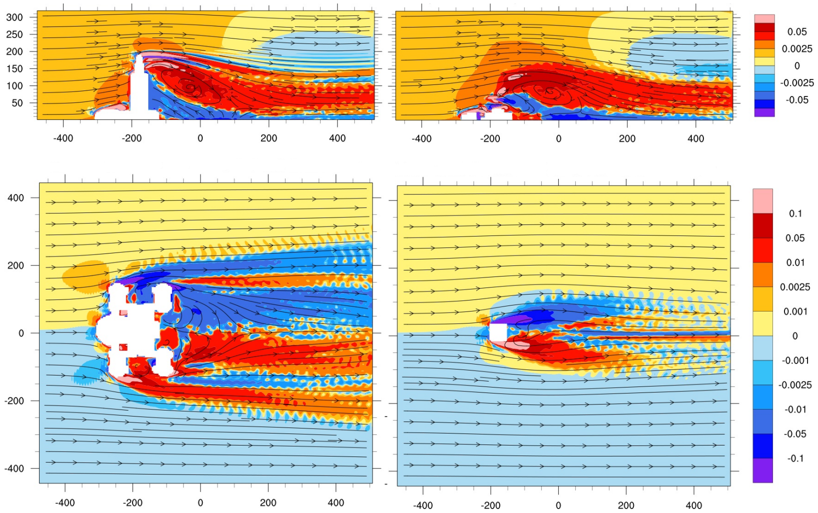
Neutral stratification

"Our way" vorticity components



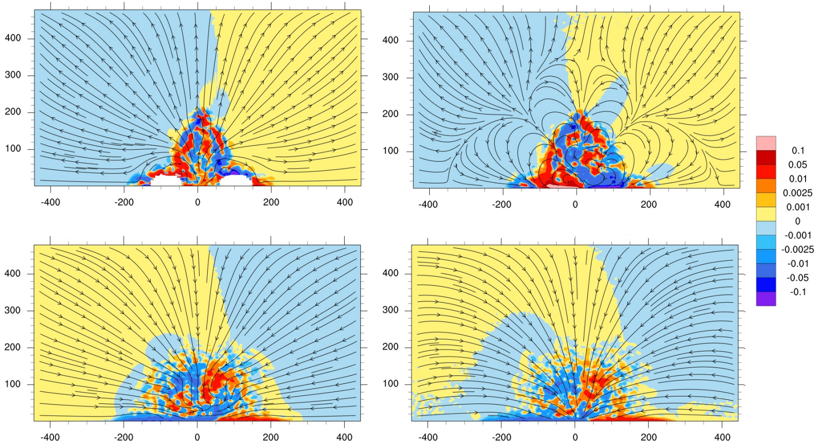
Stable stratification, $Fr = 0.92$

"Our way" vorticity component



Neutral stratification, YZ cross-section

"Our way" vorticity components at $x = -110m$, $x = -30m$, $x = 360m$, $x = 506m$



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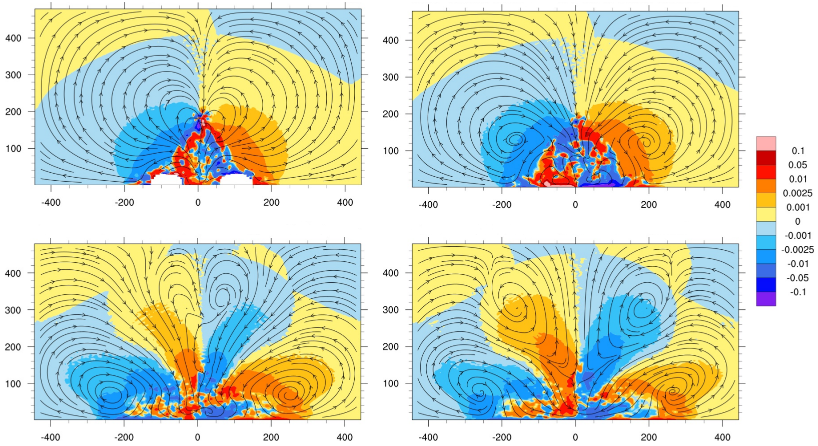
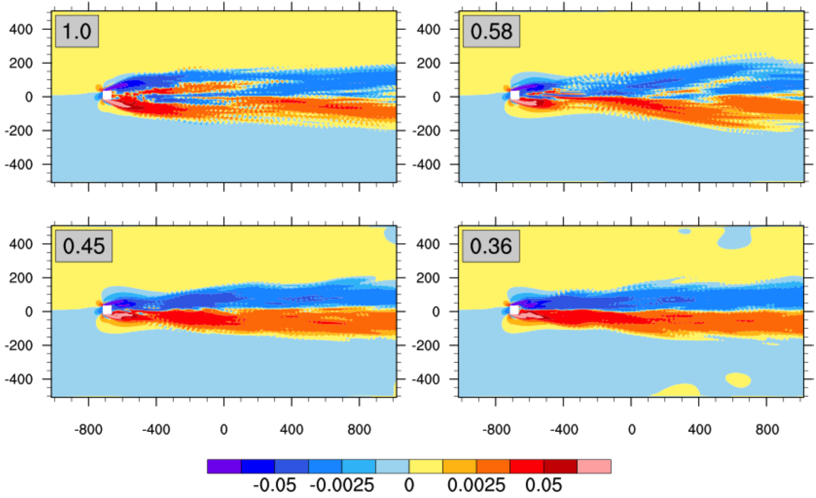


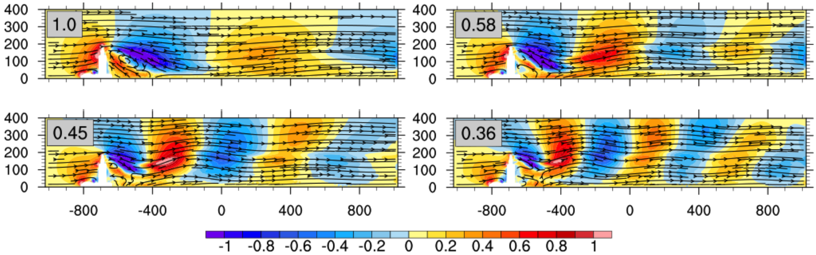
XY cross-section on $z = 100m$

Vertical vorticity component



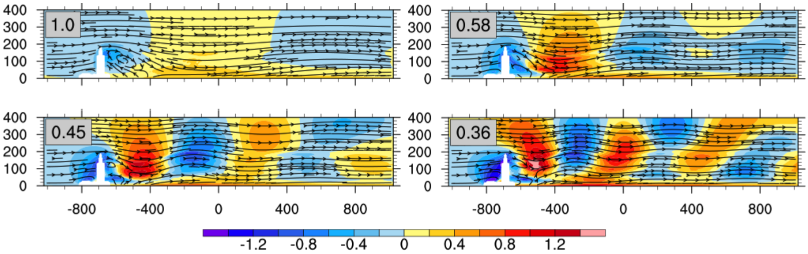
XZ cross-section

Vertical velocity



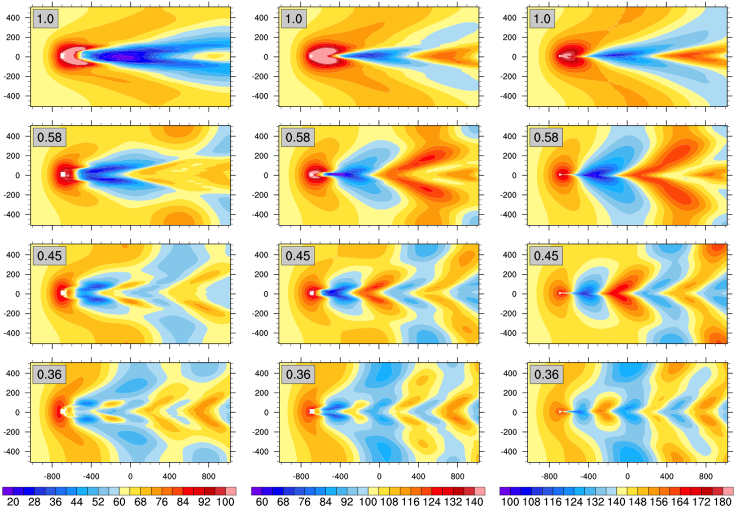
XZ cross-section

Potential temperature departure



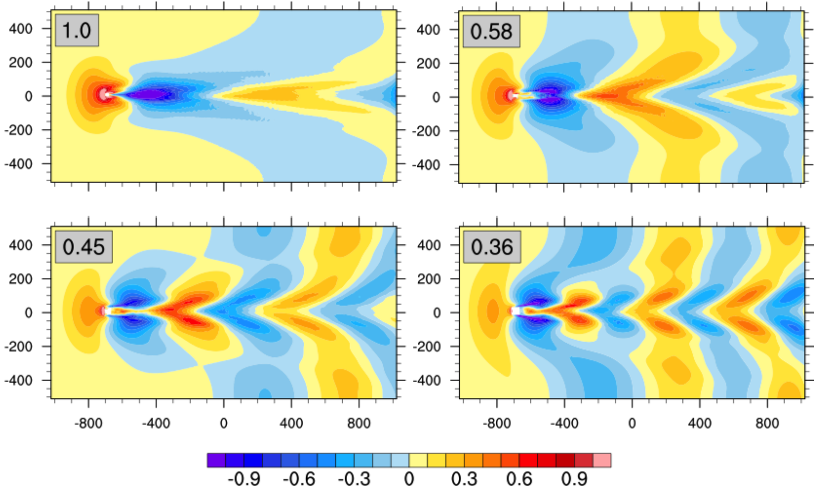
Isentropic surfaces

Respectively $\Theta = \Theta_e$ $(z = 60m)$, $(z = 100m)$, $(z = 140m)$



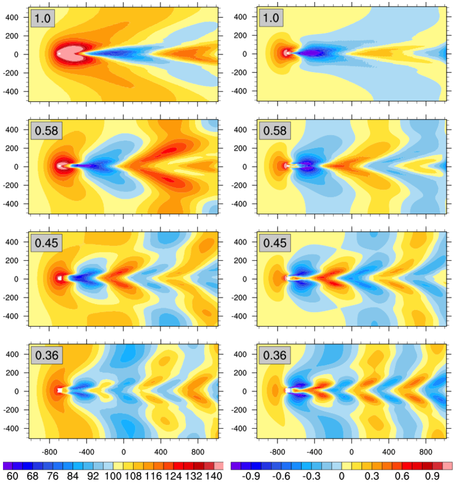
Vertical velocities

at isentropic surfaces at $\Theta = \Theta_e$ $(z = 100m)$

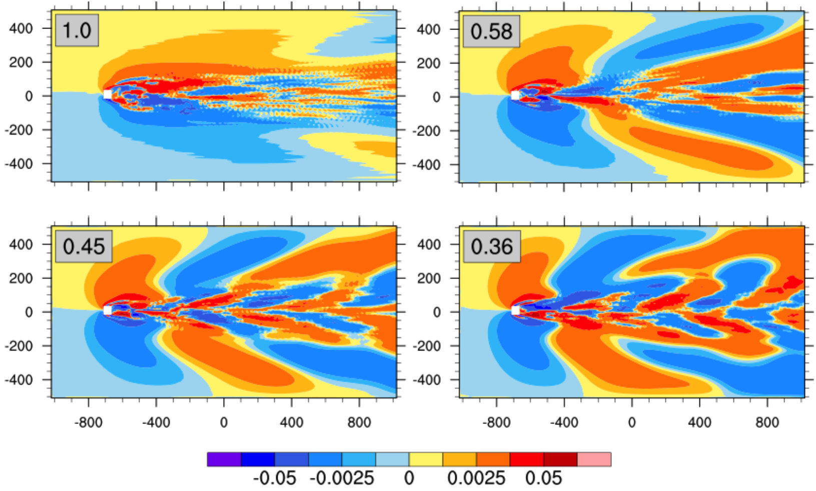


Isentropic surface's elevations and vertical velocities

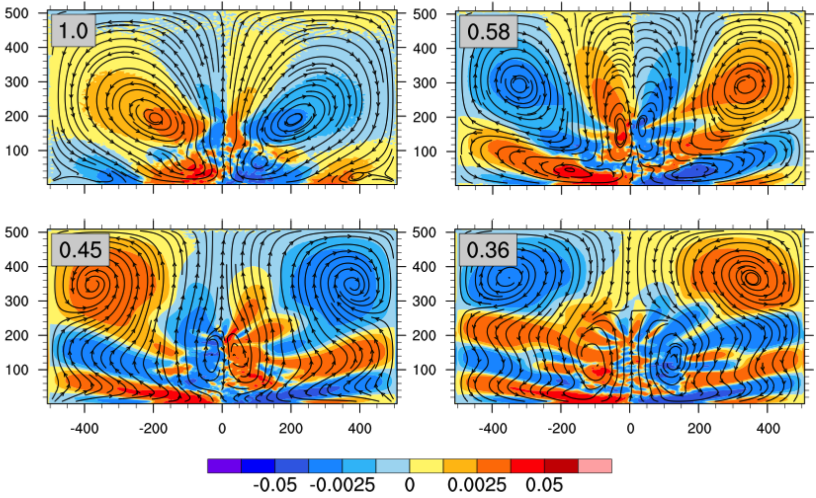
at $\Theta = \Theta_e$ $(z = 100m)$



Streamwise X vorticity component
at $z = 100m$

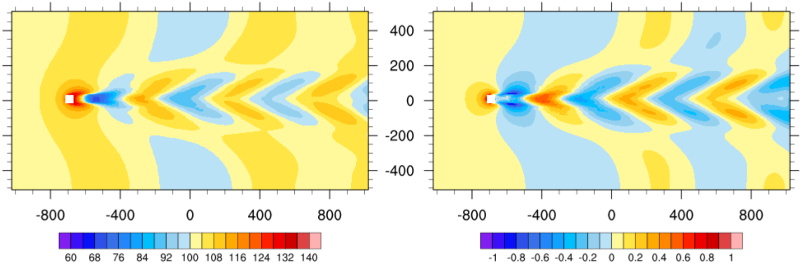


Streamwise X vorticity component
at $x = 576m$



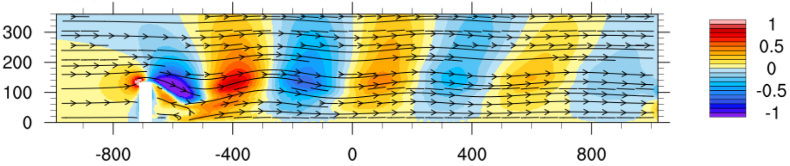
Cuboidal building, $Fr = 0.36$

Elevation of isentropic surface and vertical velocity at $\Theta = \Theta_e$ $(z = 100)$



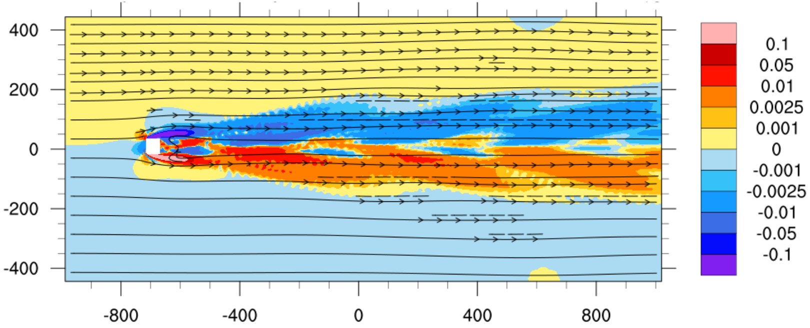
Cuboidal building, $Fr = 0.36$

Vertical velocity at $\Theta = \Theta_e$ $(z = 100)$

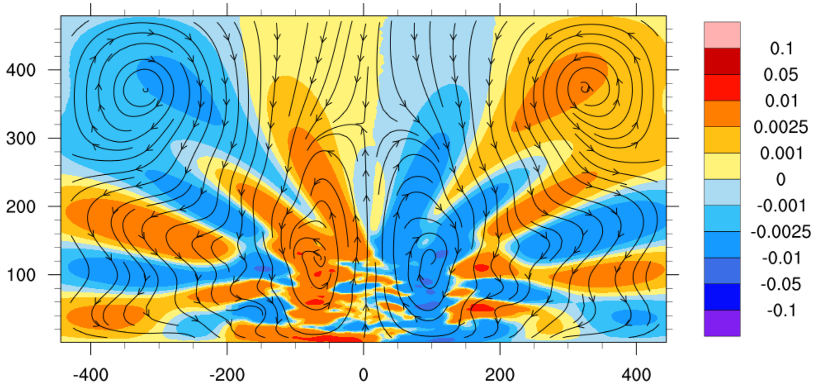


Streamwise X vorticity component

at $z = 100m$



Streamwise X vorticity component
at $x = 576m$



Conclusions

- Flow structures at low Froude numbers are more complex
- There is a close link between V-shaped waveforms filling the wake and vortices spreading out from the centerline of the wake
- With Froude number decreasing, gravity waves become shorter and more vortices appear.
- Wave motion becomes apparent when $Fr < 1$
- Similar flow structures can be found in cases with simplified buildings