Dynamics of Banner Clouds
Idealized LES Studies

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JG|U

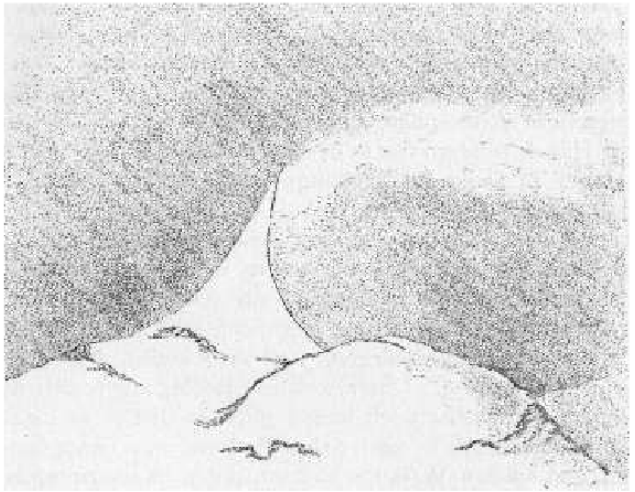
Definition
(Schween et al. 2007)

- Cloud is in fixed relation to mountain and only on leeward side
- Cloud is not composed of blown off snow crystals
- Cloud is persistent
- Cloud is not primarily convective

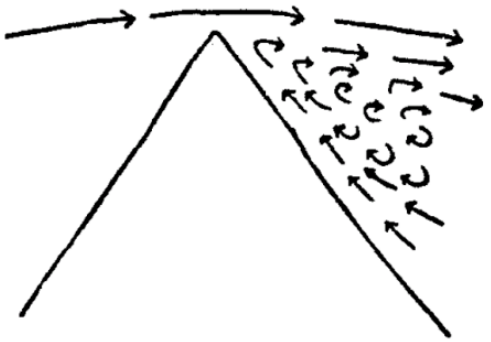
Scientific Questions

Historic Formation Hypothesis

- Bernoulli effect (Humphreys 1964, Beer 1974)
- Mixing fog (Humphreys 1964, Geerts 1992)
- Lee vortex (Hann 1896, Douglas 1928)



(Hann 1896)



(Douglas 1928)

Scientific Questions

Sensitivity

- Stability
- Wind speed
- Mountain shape

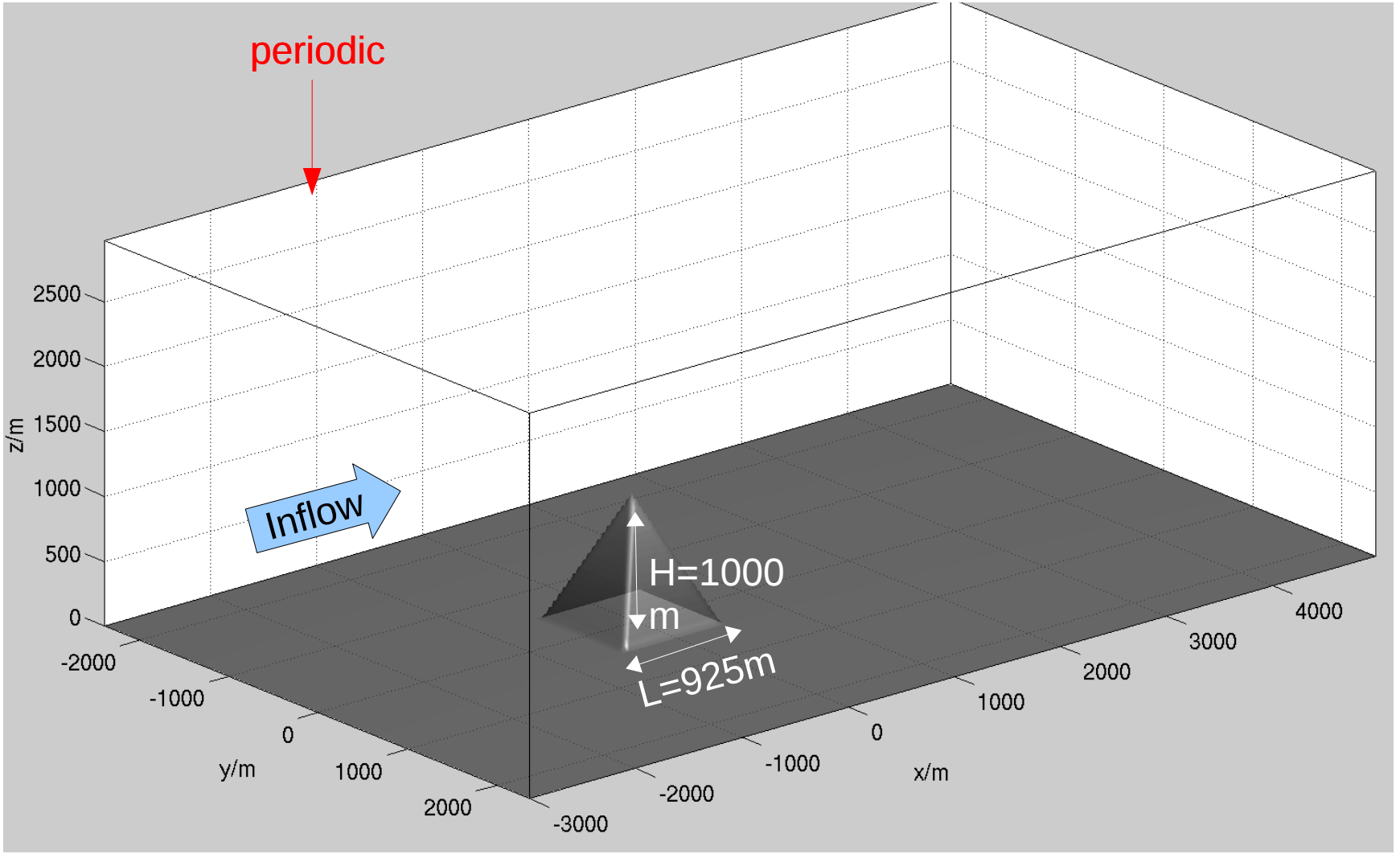
Model Version

- LES version
- TKE subgrid scale model
- Ogura and Philipps background state
- Dry version

Model Setup

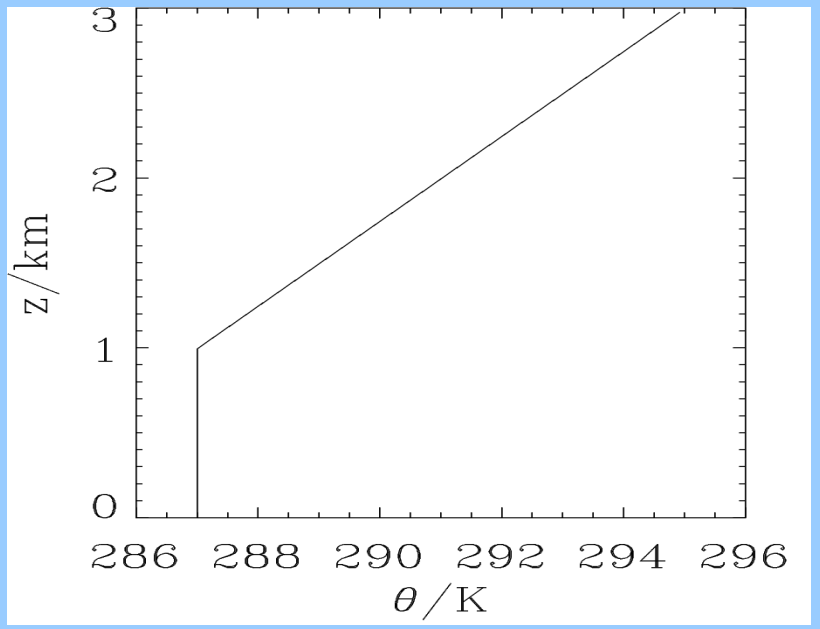
- $\Delta x = \Delta y = 25\text{m}$
- Δt between 0.5s and 2s
- Δz stretched between 10m and 100m
- 320 x 192 x 120 gridpoints
- Immersed orography
- Periodic in y-direction
- Sponge layer at upper boundary

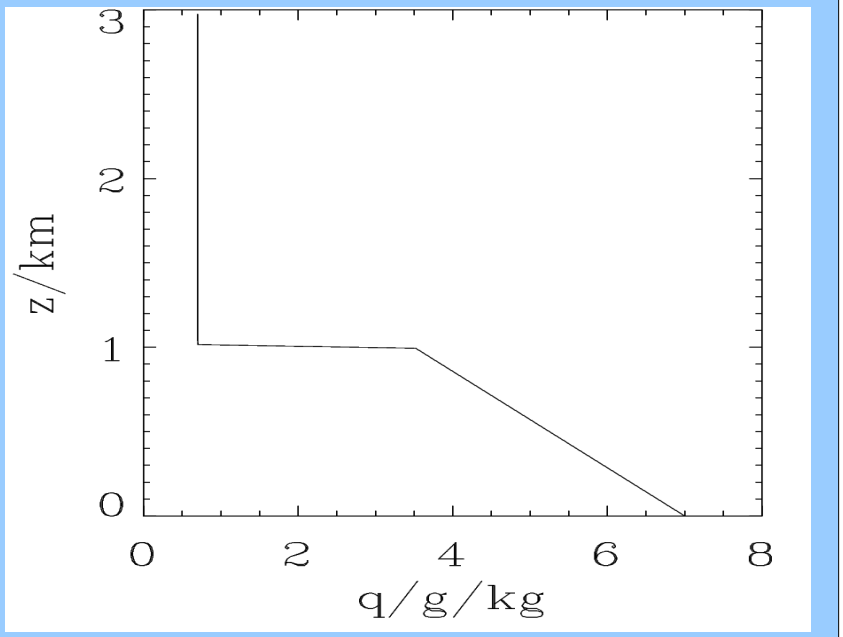
Model Setup


periodic
Inflow
H=1000
m
L=925m
z/m
2500
2000
1500
1000
500
0
-2000
-1000
0
1000
2000
y/m
-3000
-2000
-1000
0
1000
2000
3000
4000
x/m

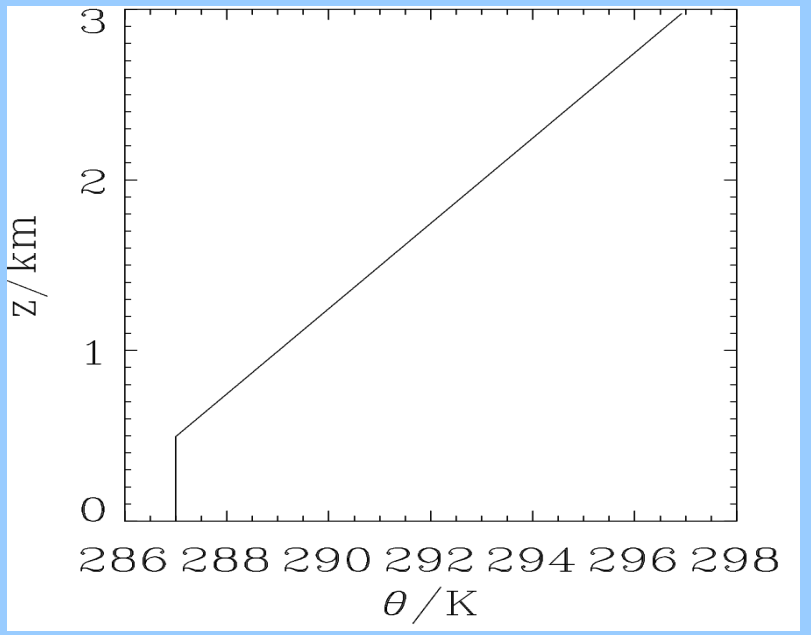
Inflow Profiles

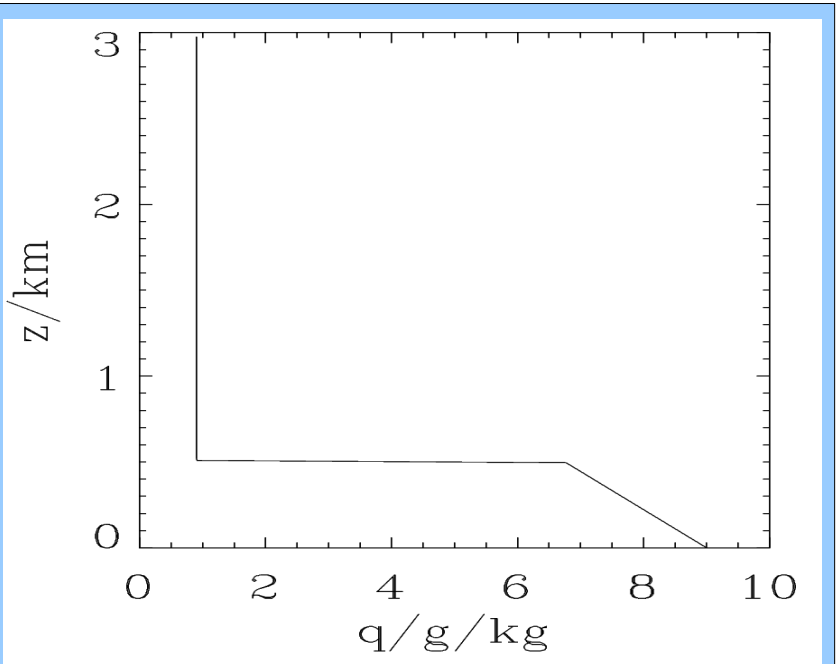
Deep boundary layer





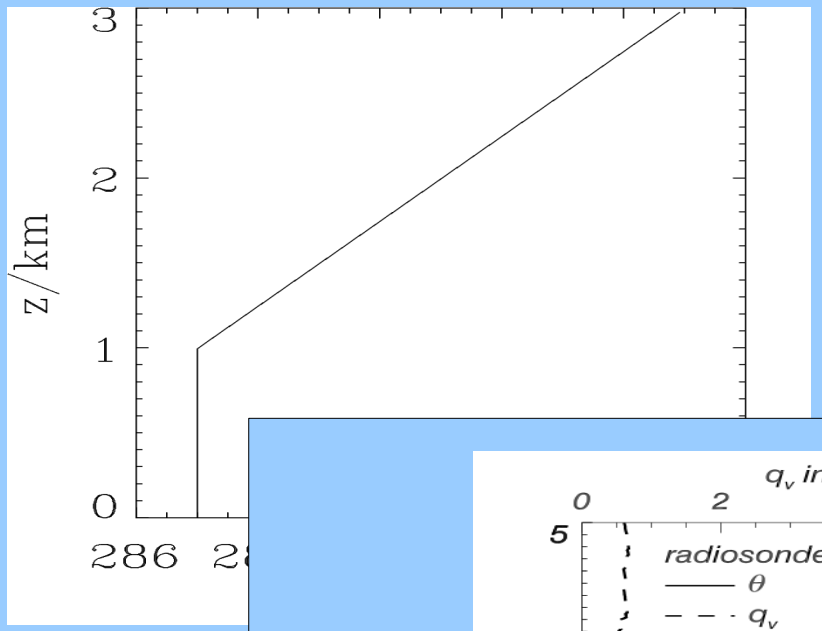
Shallow boundary layer

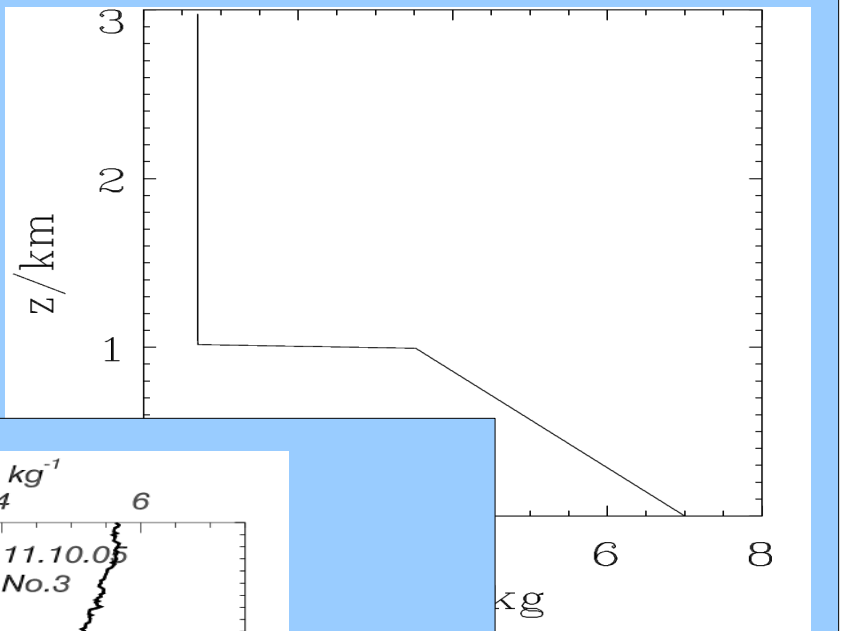




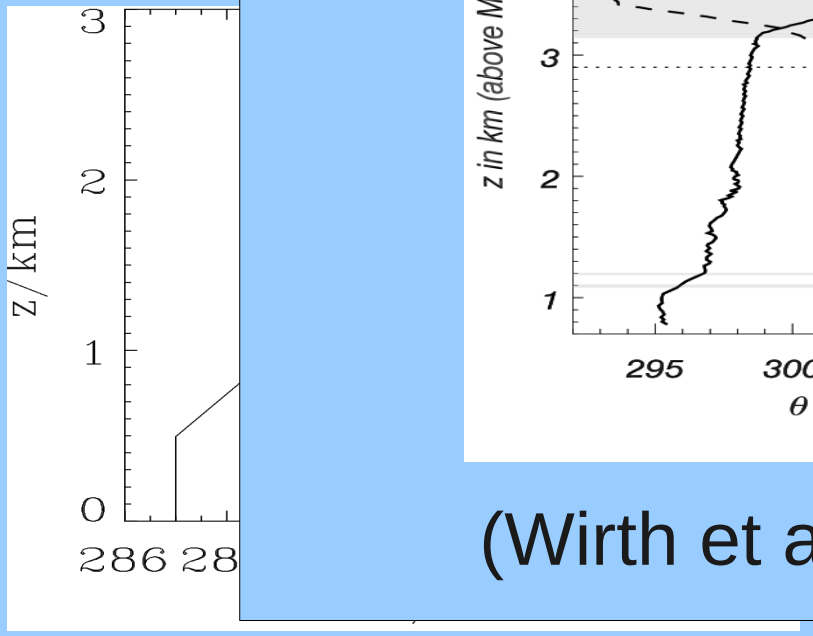
Inflow Profiles

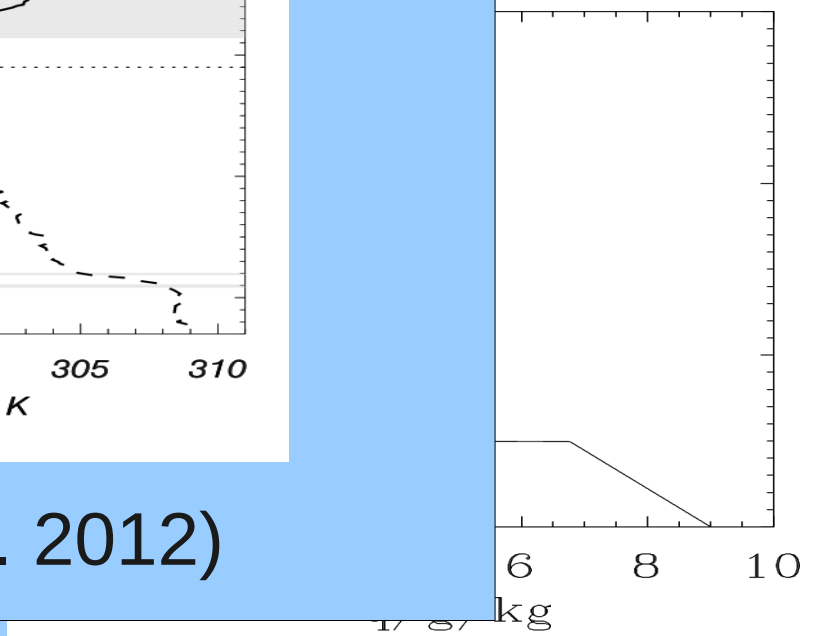
Deep Boundary Layer

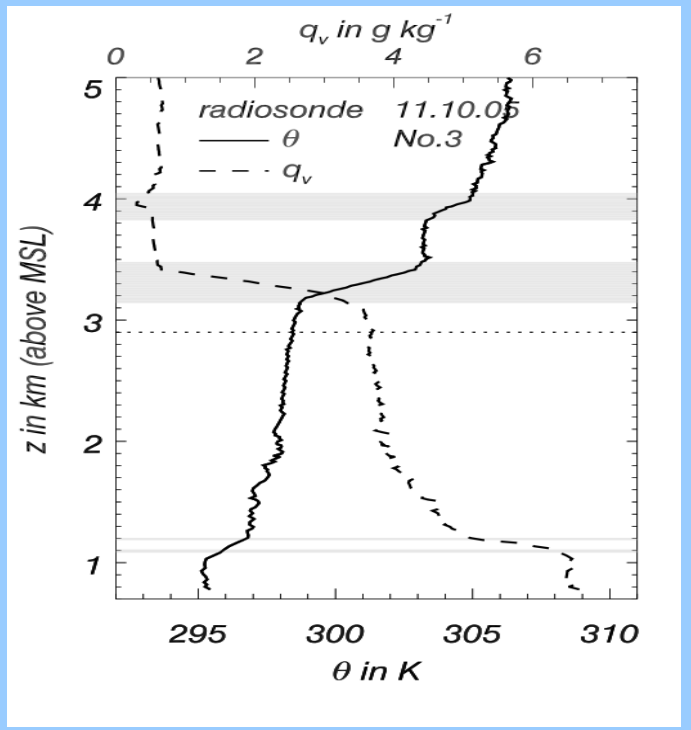




Shallow Boundary Layer



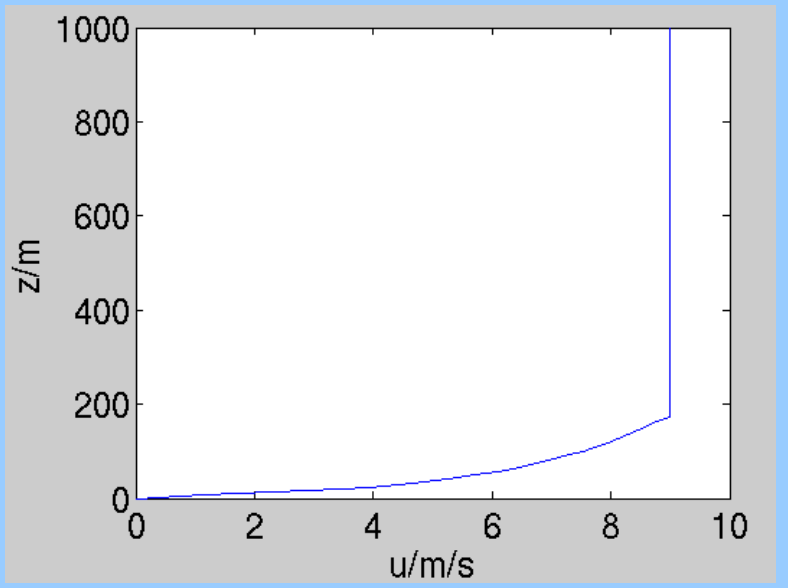




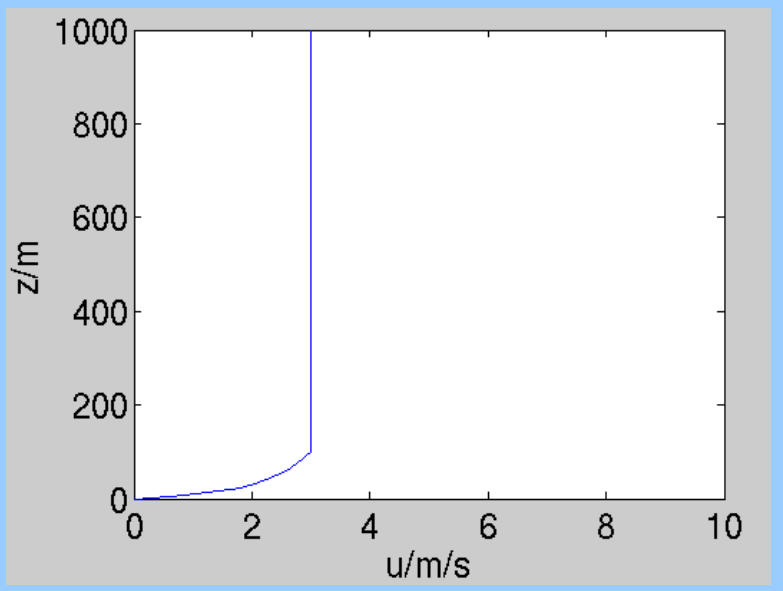
(Wirth et al. 2012)

Inflow Profiles

u_0=9m/s

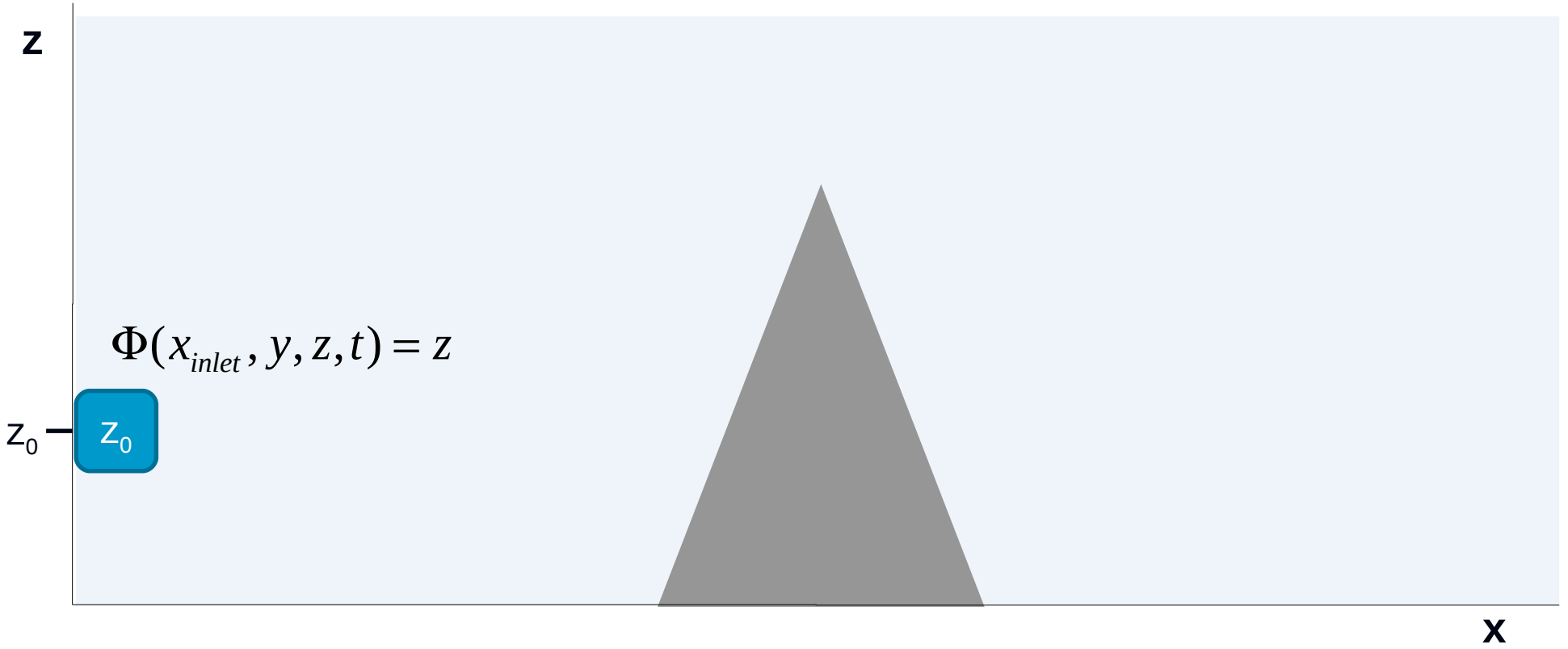


u_0=3m/s



Diagnostics

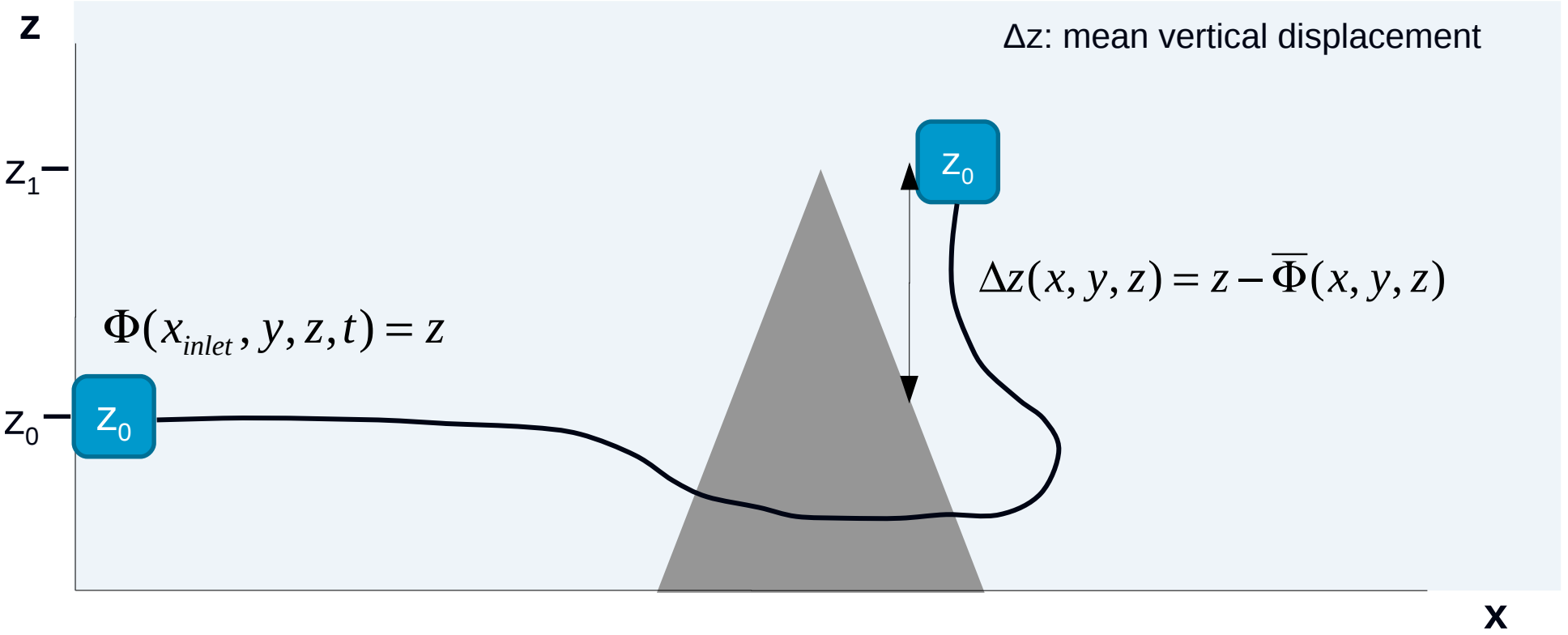
Advection of passive tracer Φ, satisfying $\frac{D\Phi}{Dt} = 0$



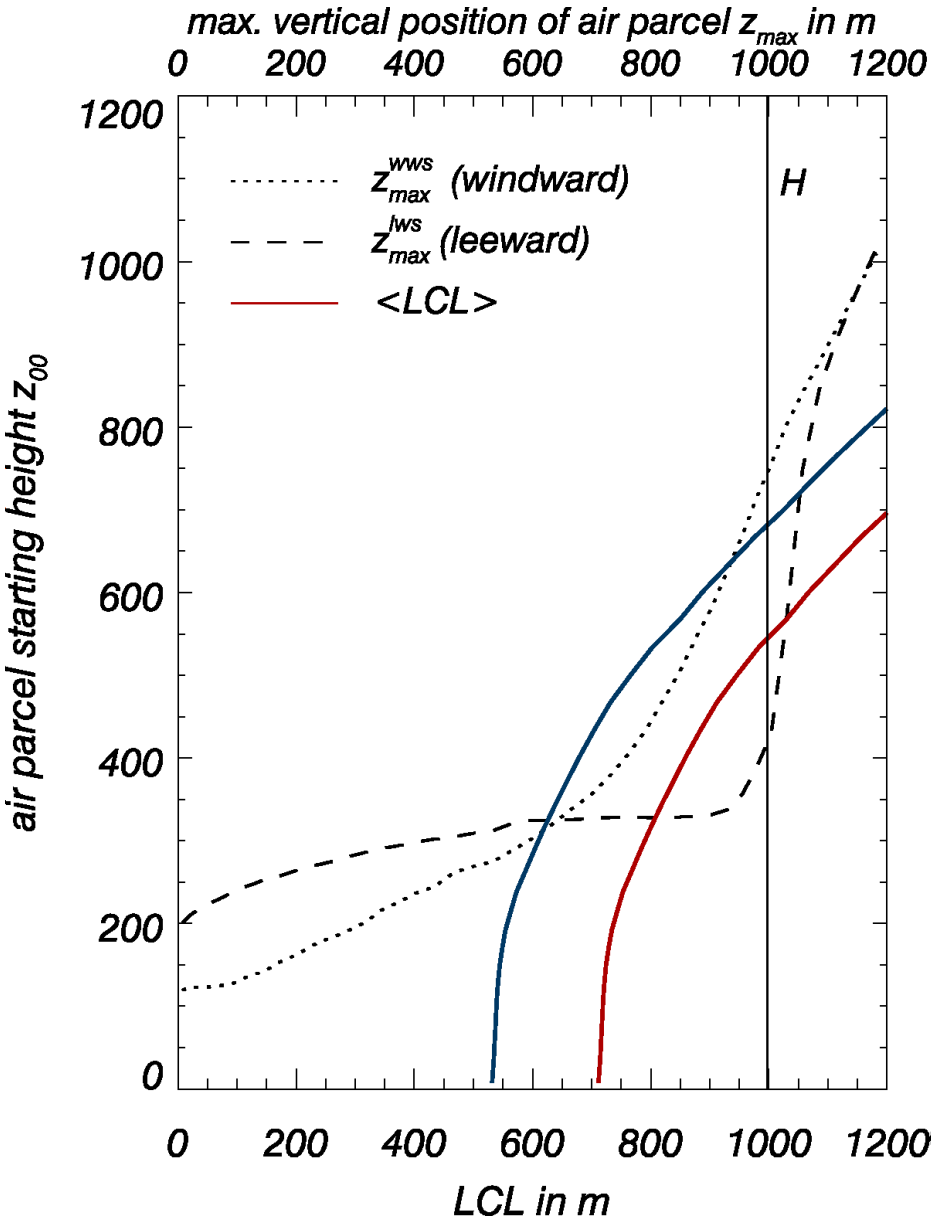
Diagnostics

Advection of passive tracer Φ, satisfying $\frac{D\Phi}{Dt} = 0$

Information about mean vertical displacement Δz of air masses on windward versus leeward side.

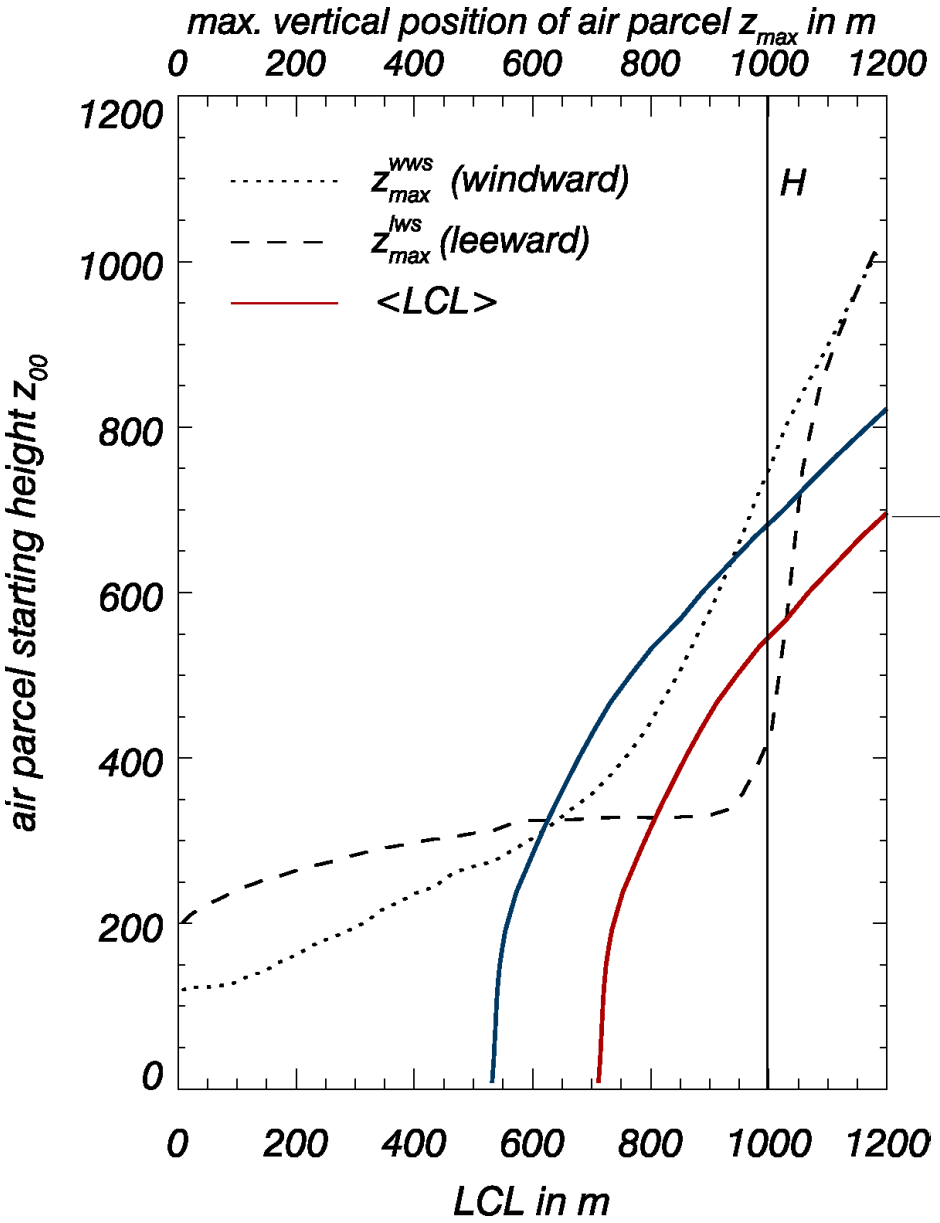


Diagnostics

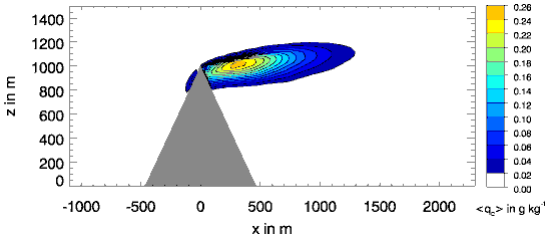


(Reinert 2010)

Diagnostics

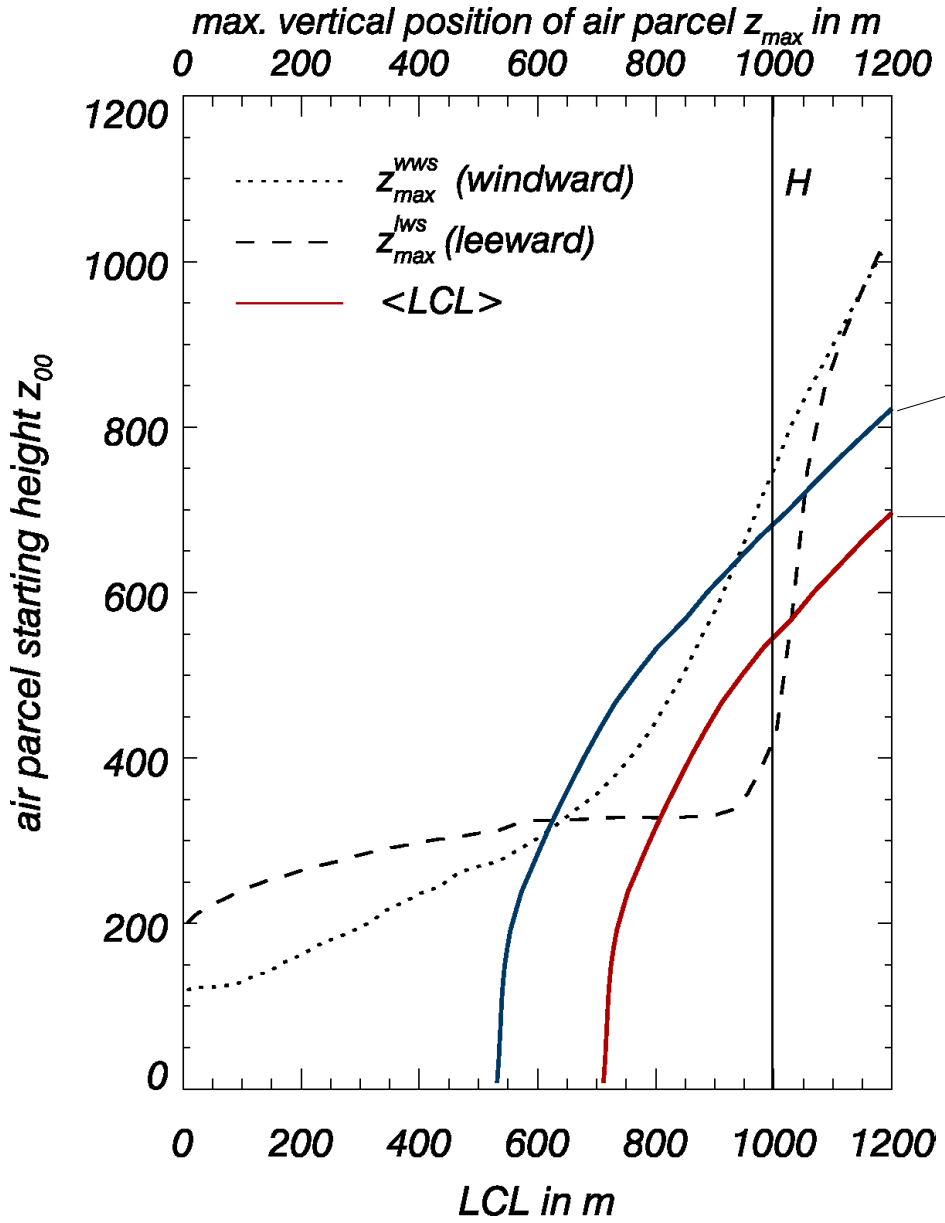


Banner cloud

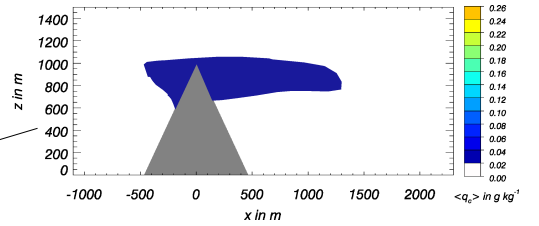


(Reinert 2010)

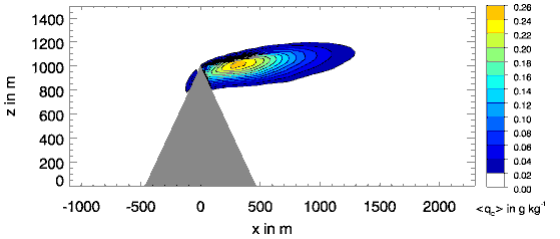
Diagnostics



No banner cloud
cloud on ww and lw side

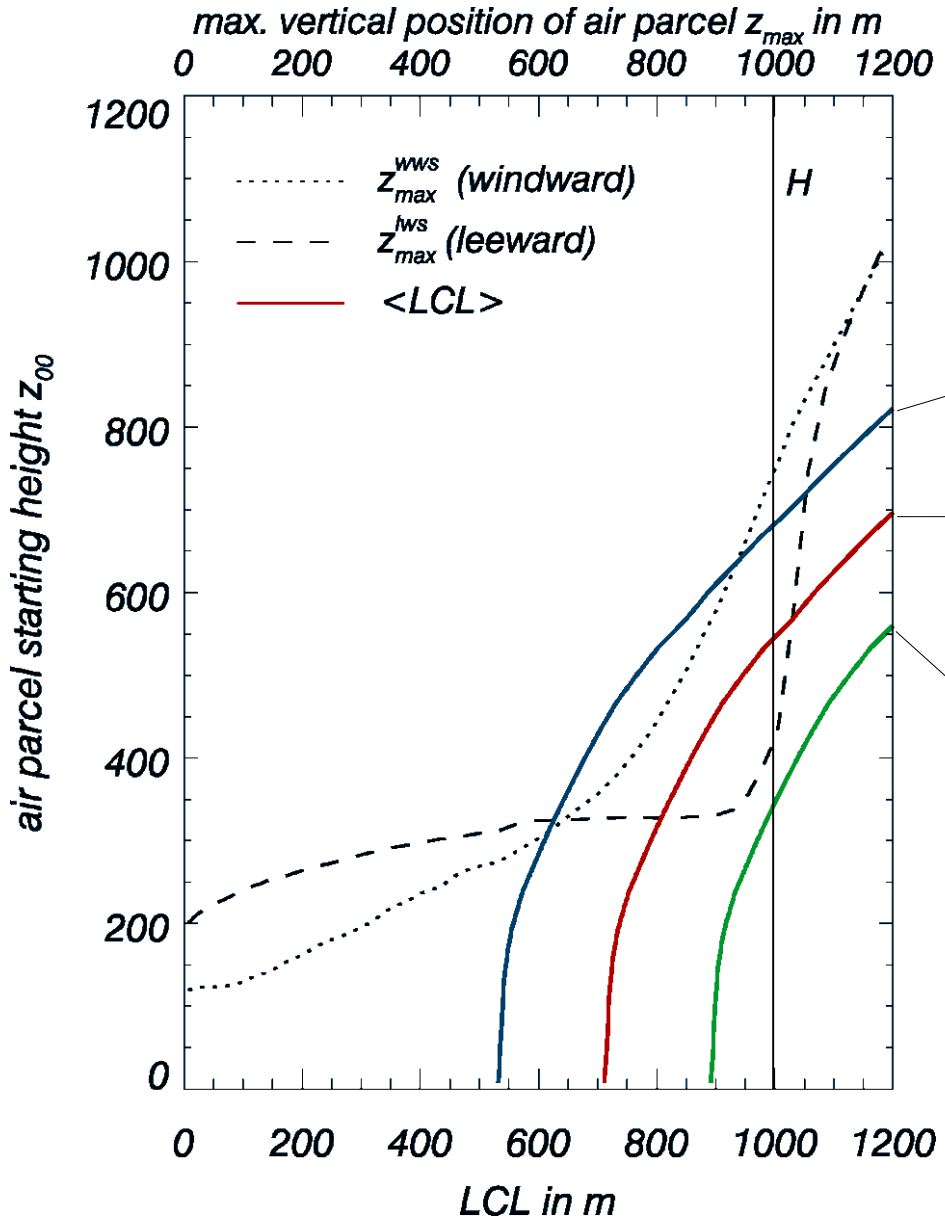


Banner cloud

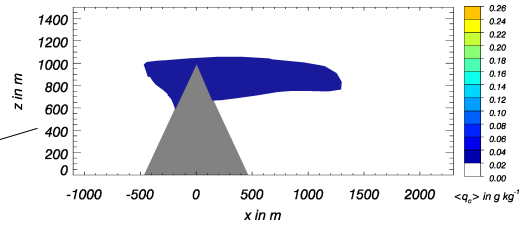


(Reinert 2010)

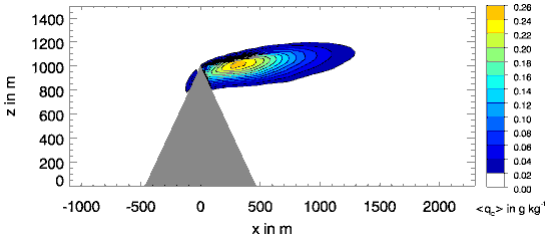
Diagnostics



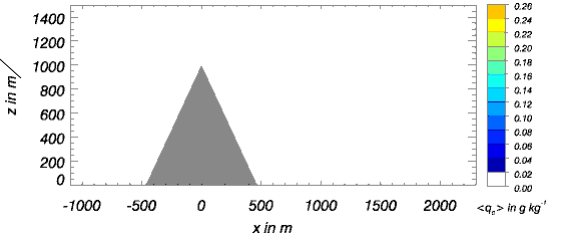
No banner cloud
cloud on ww and lw side



Banner cloud



No cloud



(Reinert 2010)

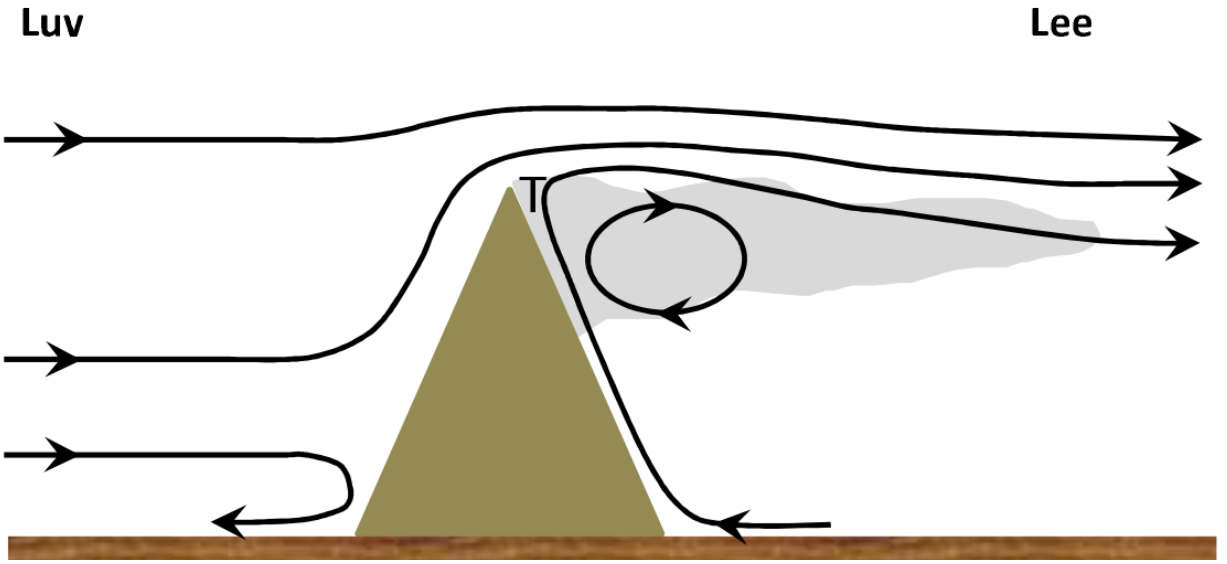
Diagnostics

Turbulent fluxes of passive tracers calculated online

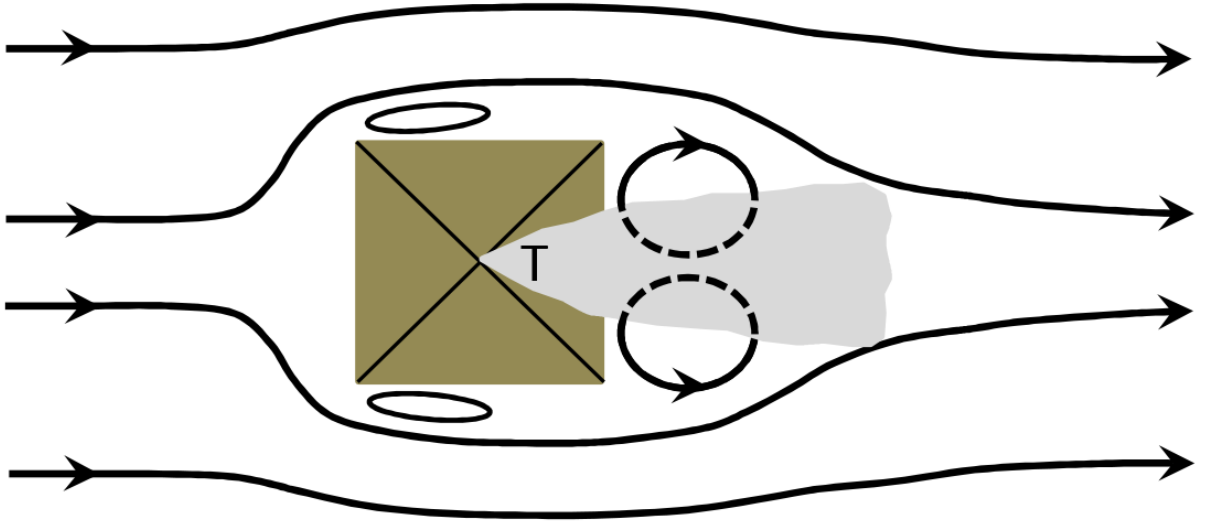
$$\frac{\bar{D}\overline{\psi}}{Dt} = -\frac{1}{\rho_0}\nabla \cdot (\rho_0 \overline{\psi' \mathbf{u}'}) =: S_{\psi,\mathrm{eff}}$$

Flow around a Pyramid

Schematic flow in the symmetry xz-plane

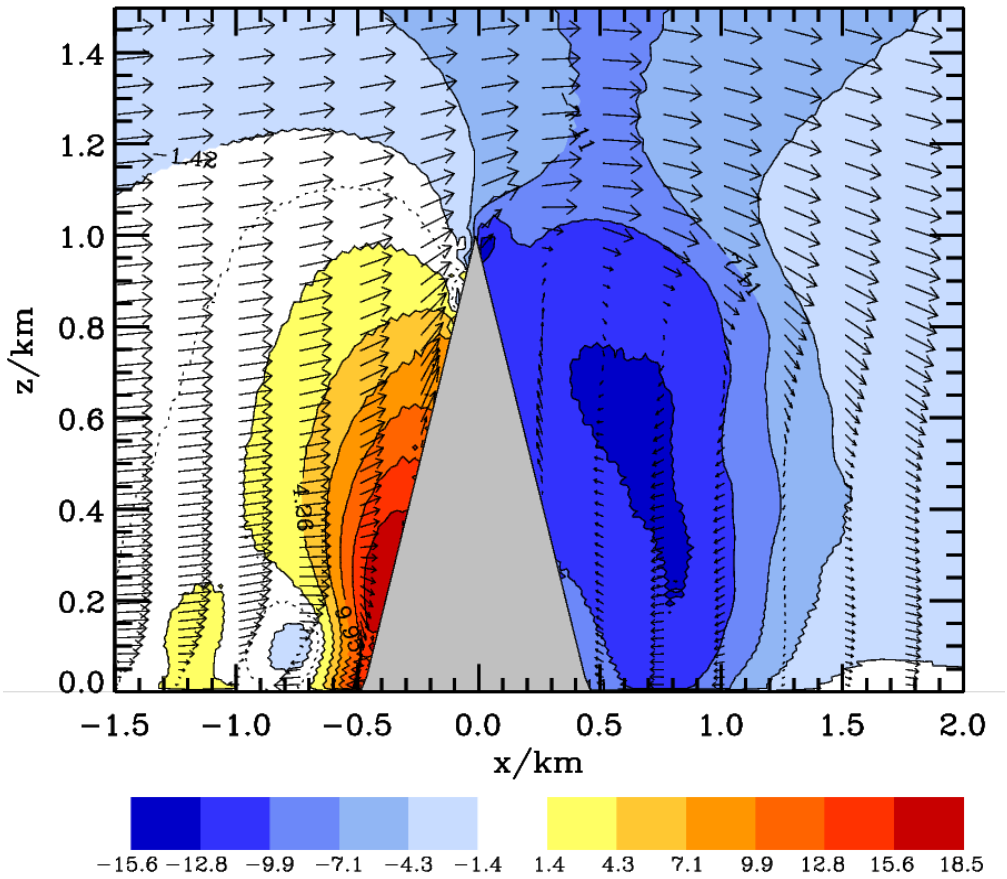


Schematic flow in a xy-plane near the ground



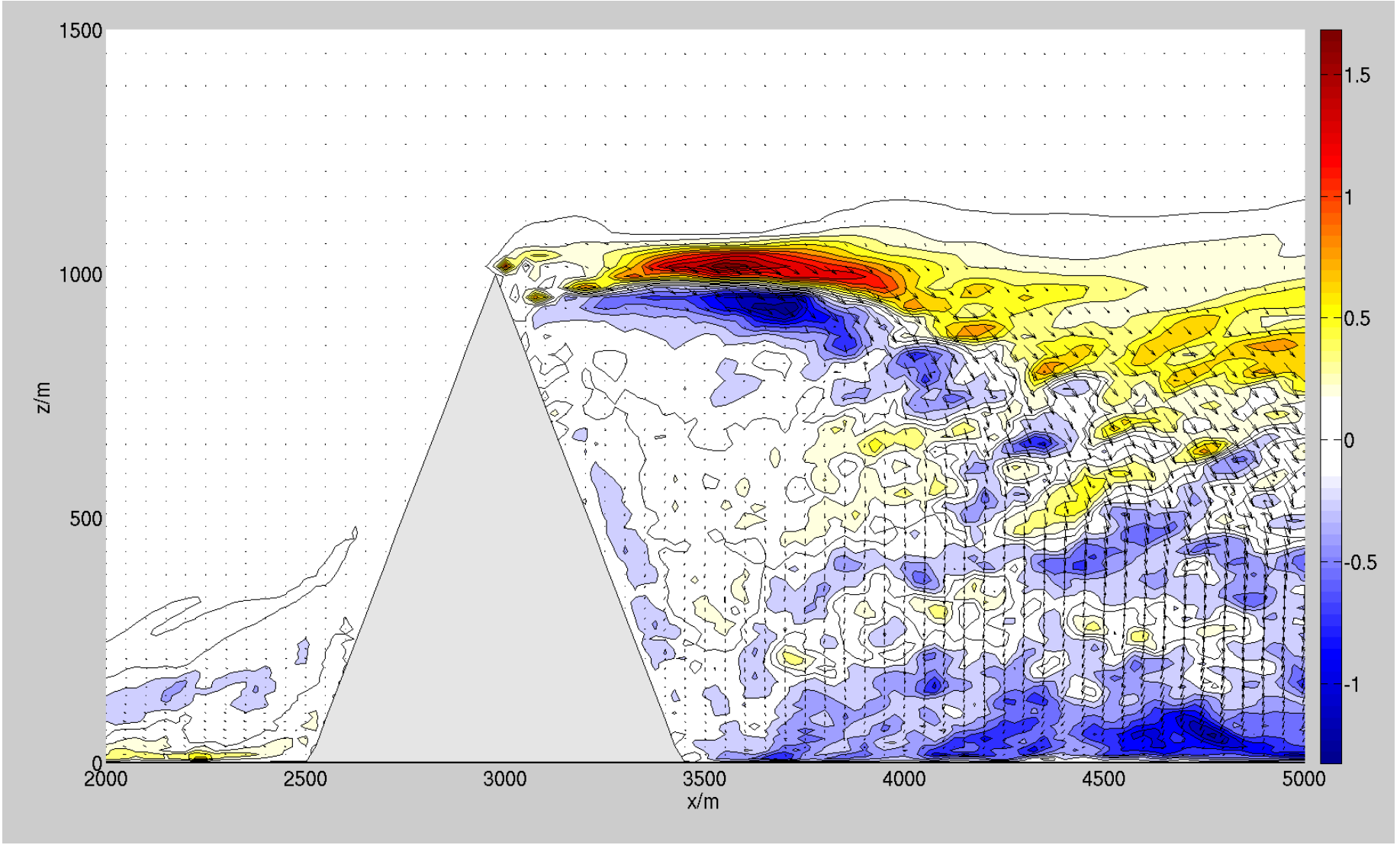
Hypothesis: Bernoulli effect

Perturbation pressure in Pa



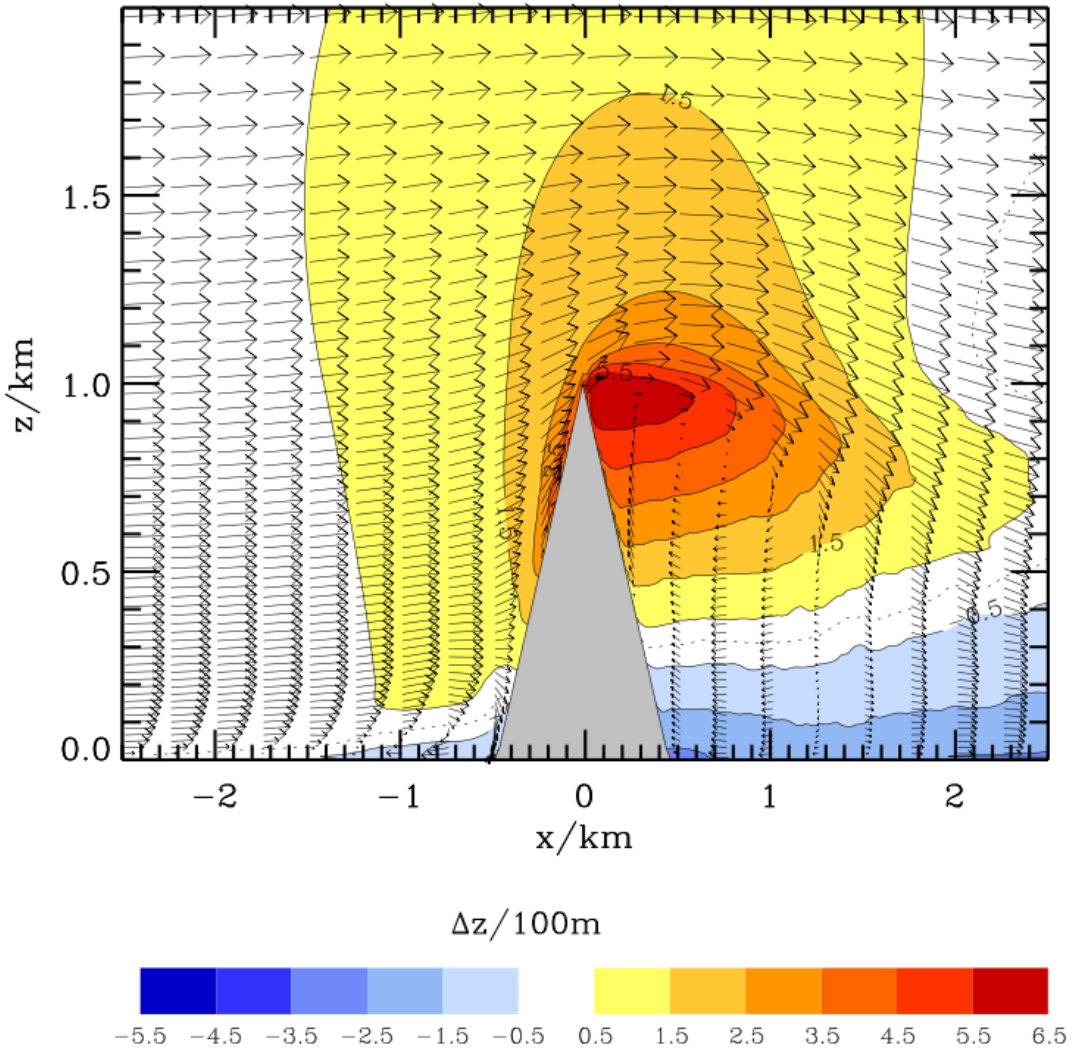
Hypothesis: Mixing Fog

Divergence of turbulent height tracer flux



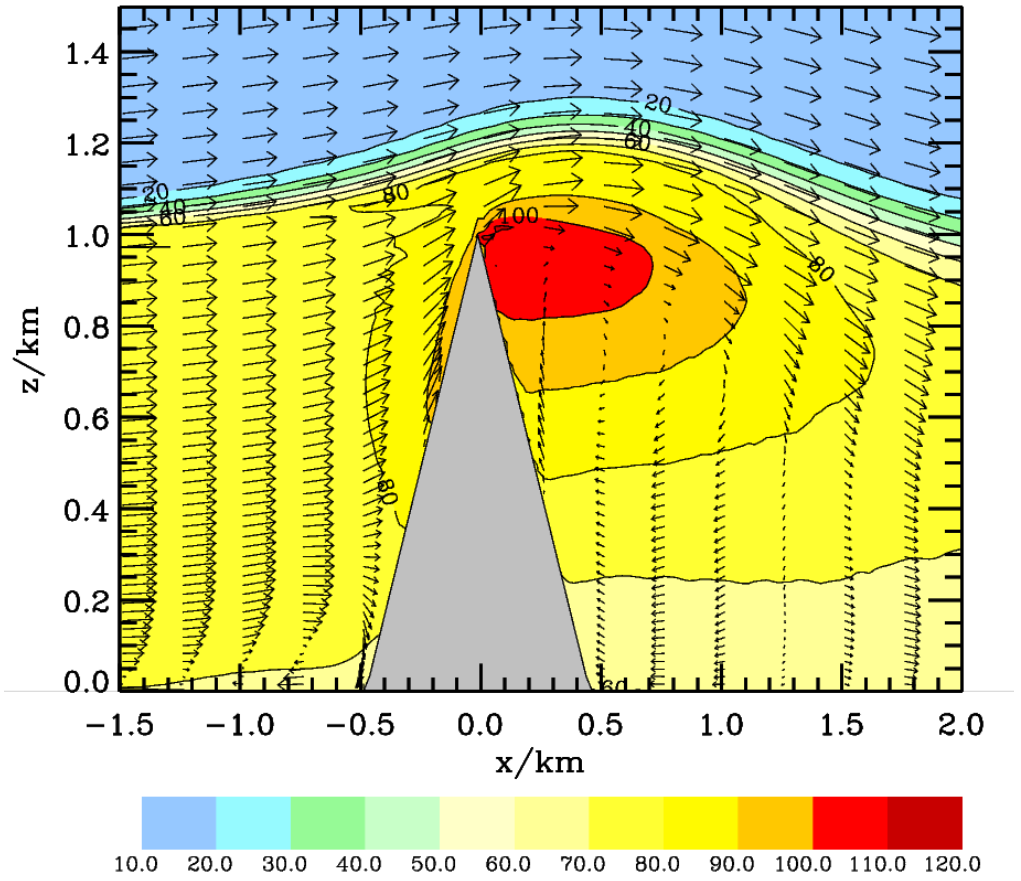
Hypothesis: Lee vortex

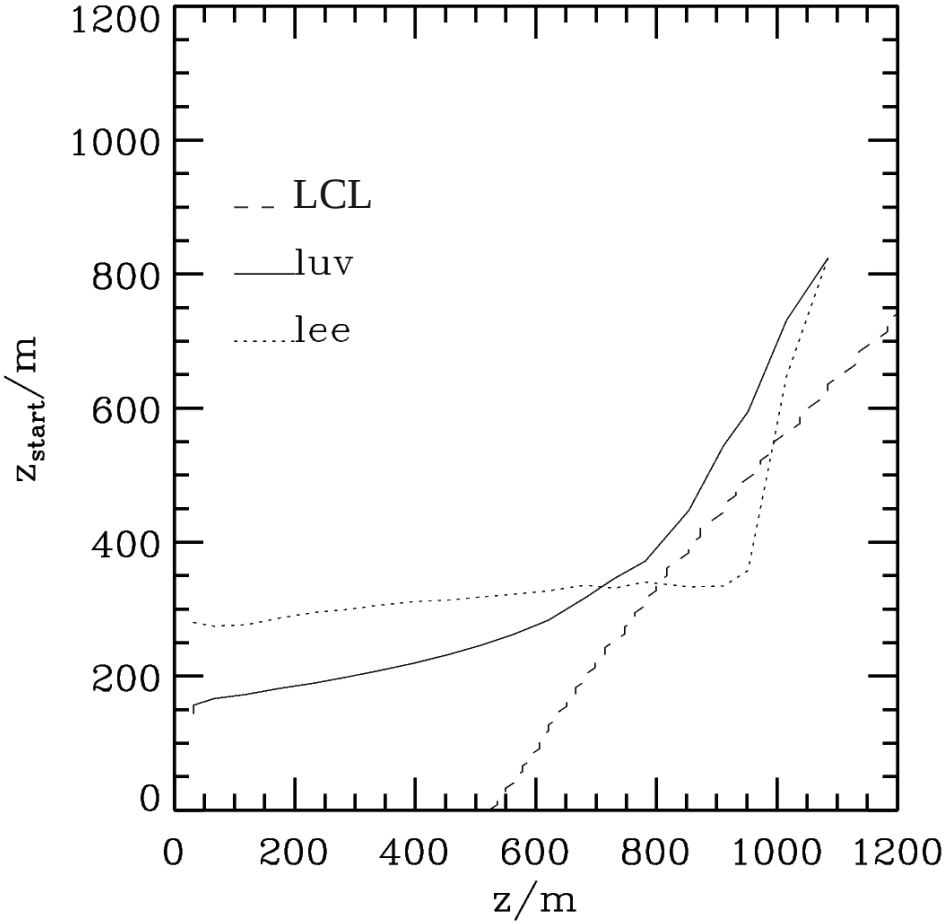
Vertical displacement Δz in 100m



Hypothesis: All together

Relative humidity calculated with tracer Ψ

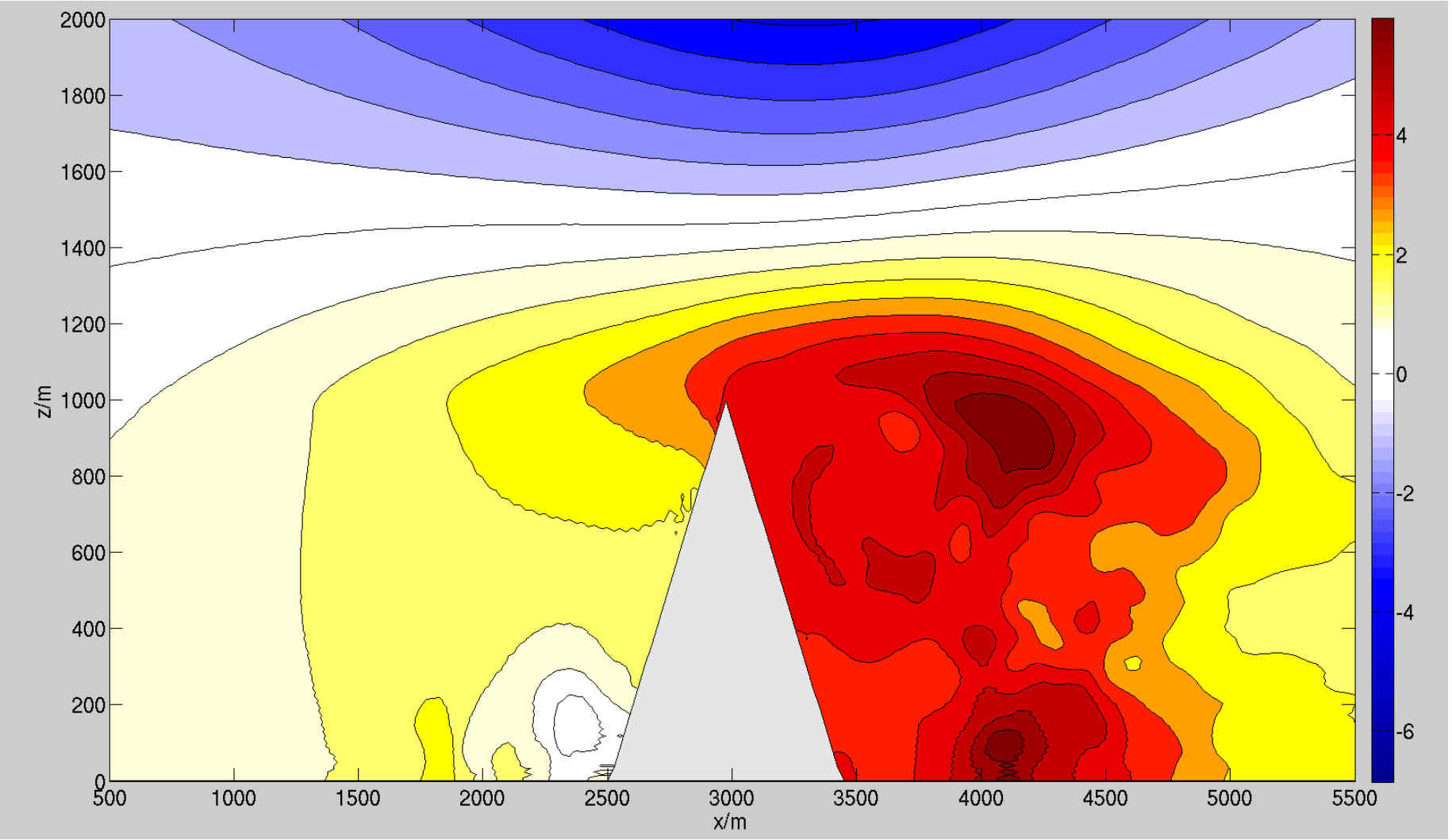




q(z=0)=7g/kg

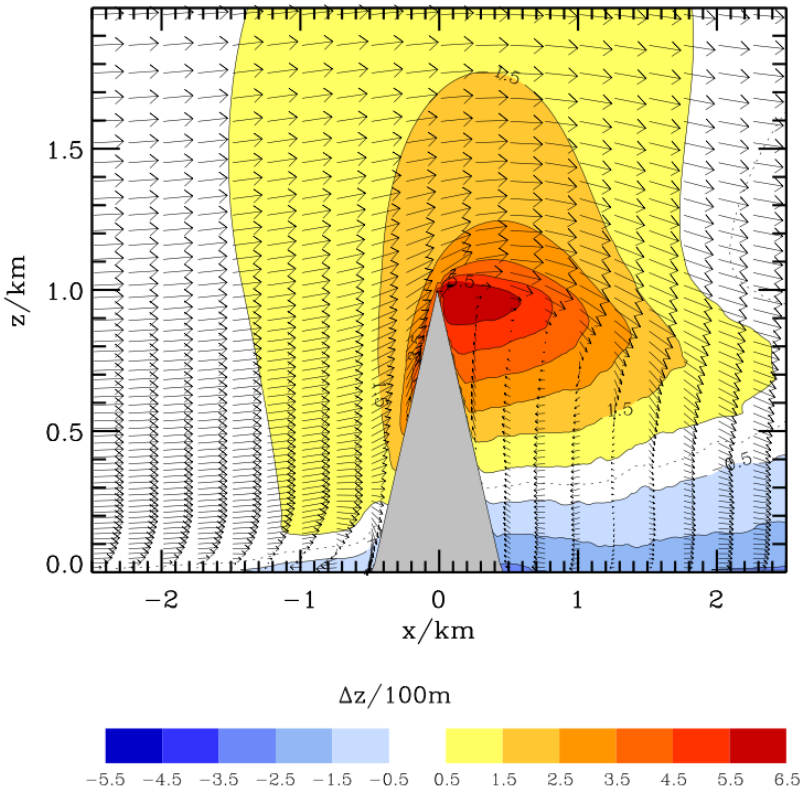
Sensitivity: Stability

Pressure difference *stable* minus *neutral* in Pa

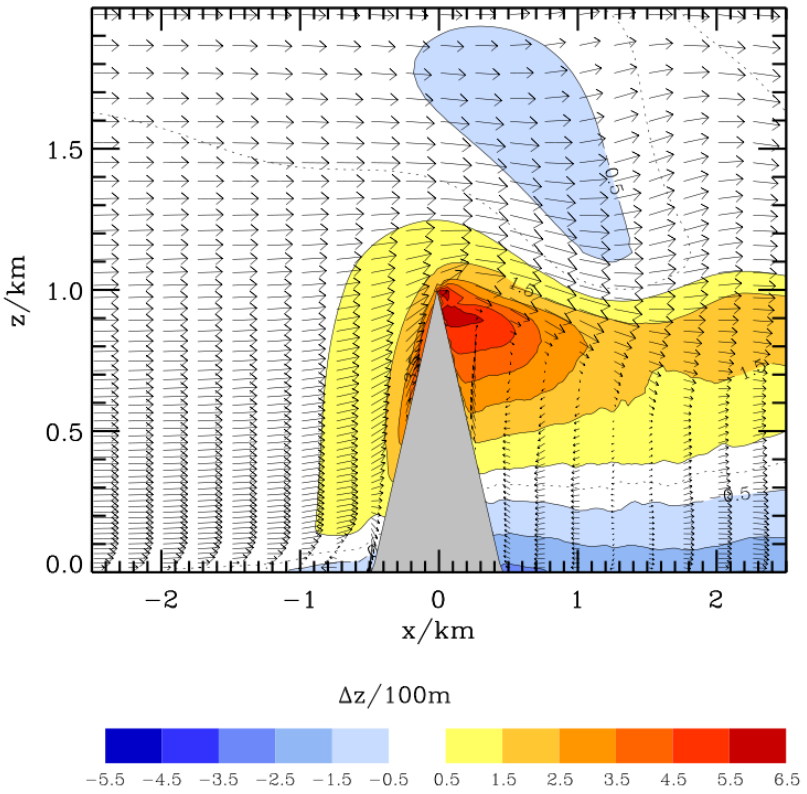


Sensitivity: Windspeed in deep boundary layer

Vertical displacement Δz in 100m



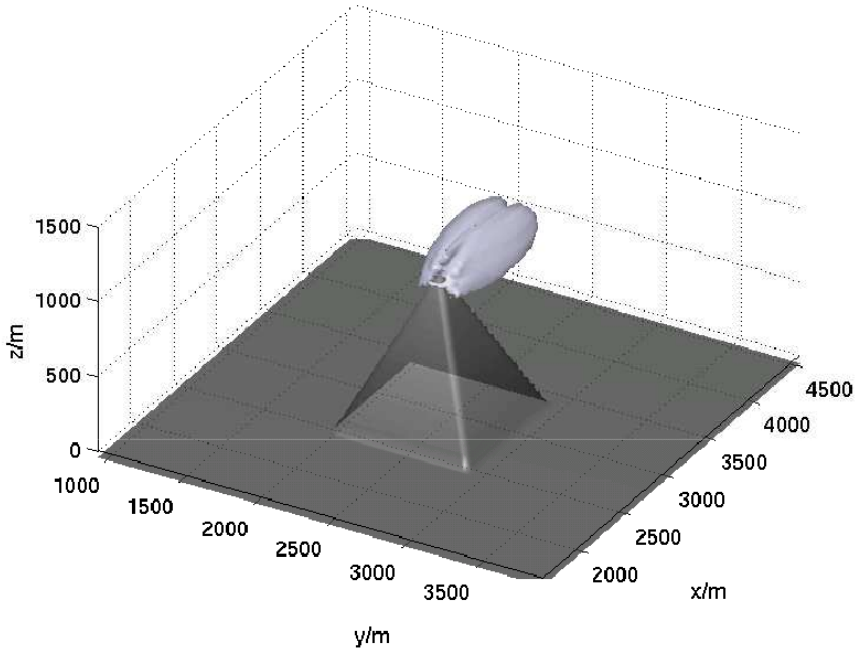
u_0=9m/s



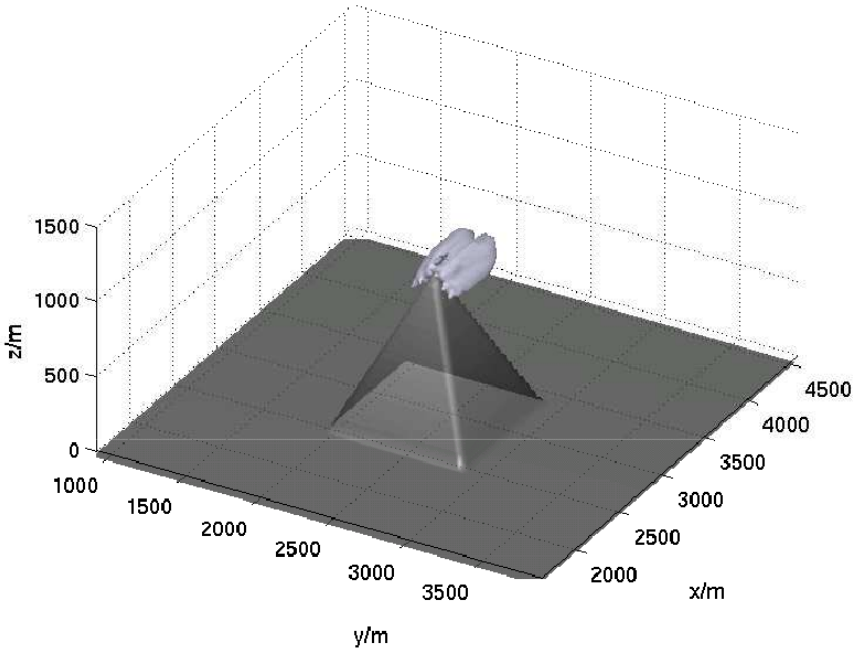
u_0=3m/s

Sensitivity: Wind speed in deep boundary layer

100% relative humidity surface



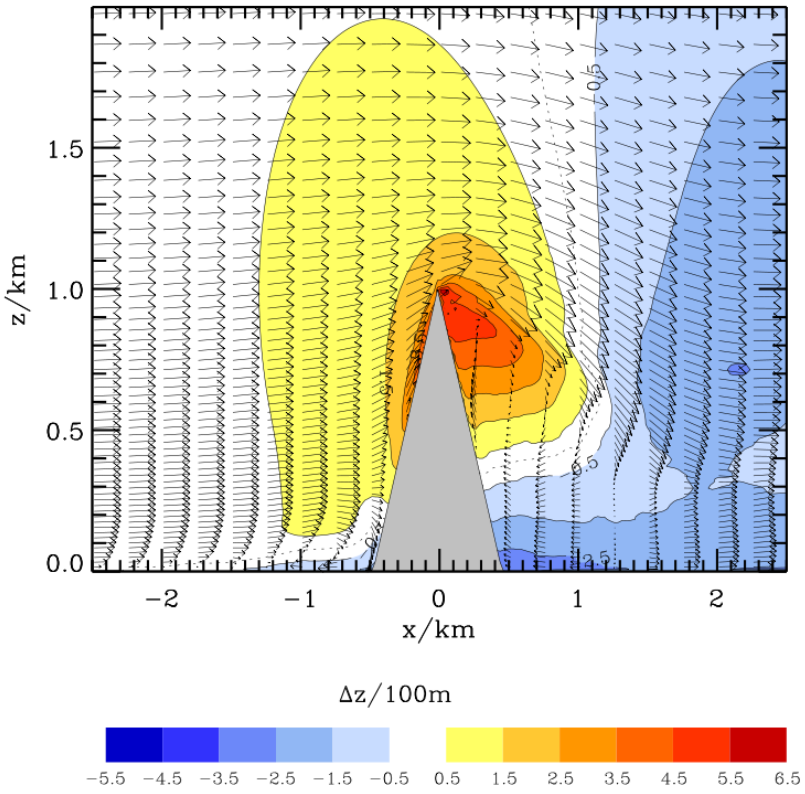
u_0=9m/s



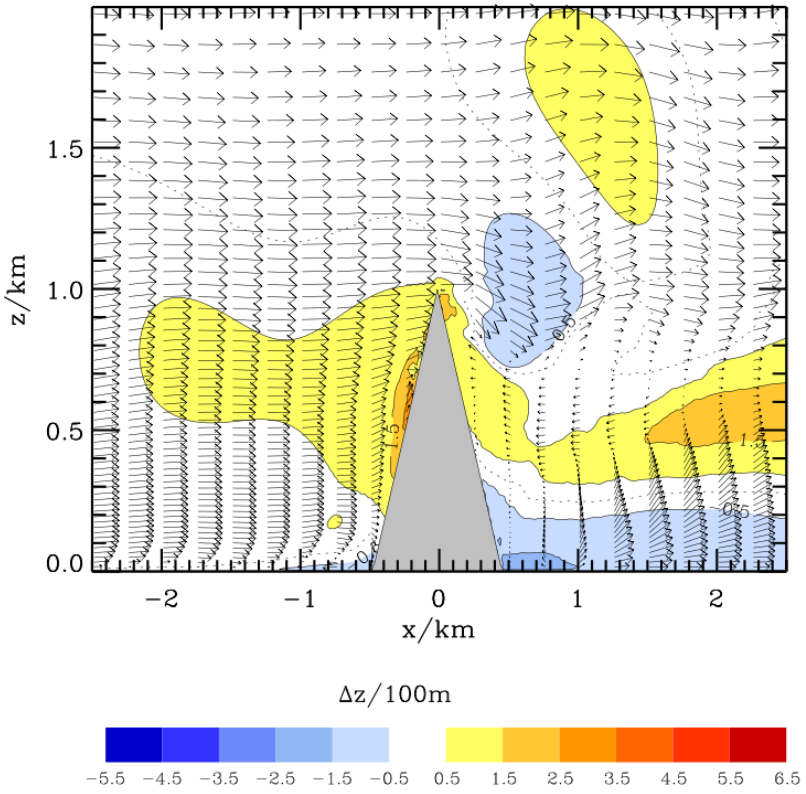
u_0=3m/s

Sensitivity: Wind speed in shallow boundary layer

Vertical displacement Δz in 100m

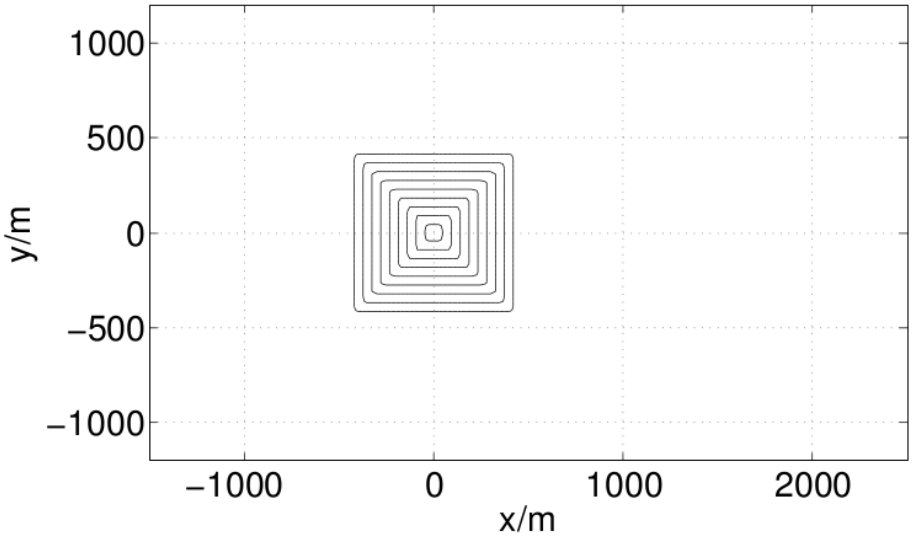


u_0=9m/s

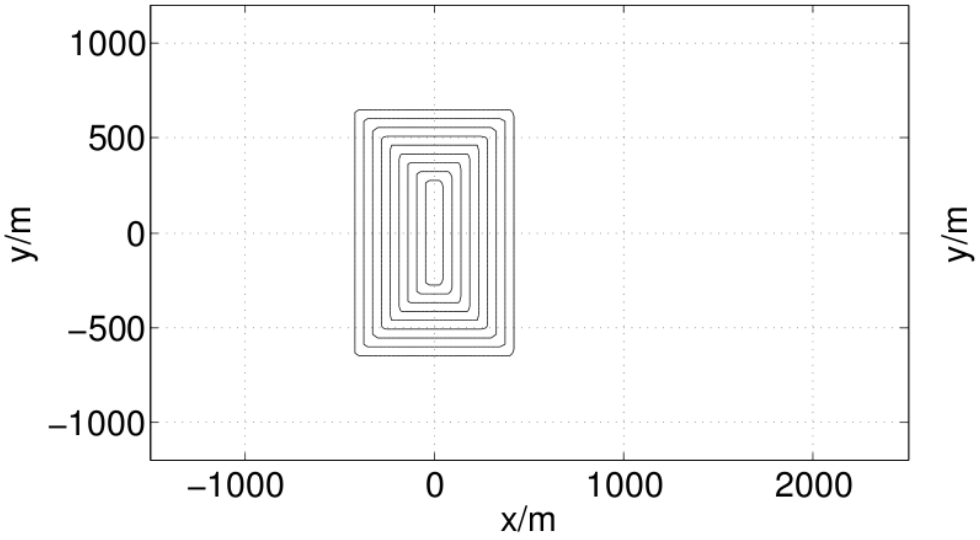


u_0=3m/s

Sensitivity: Mountain shape



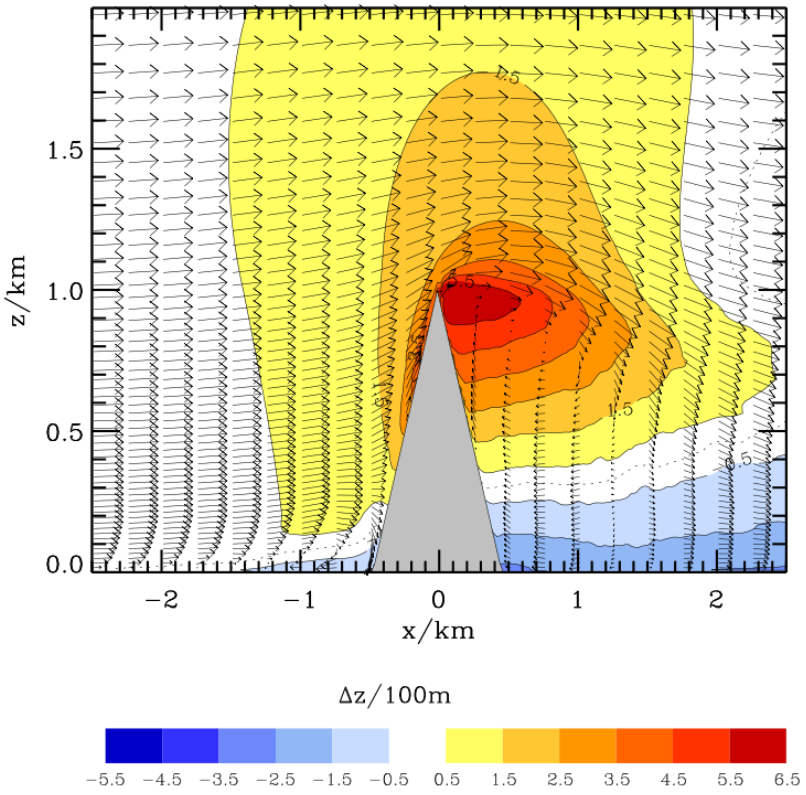
Pyramid



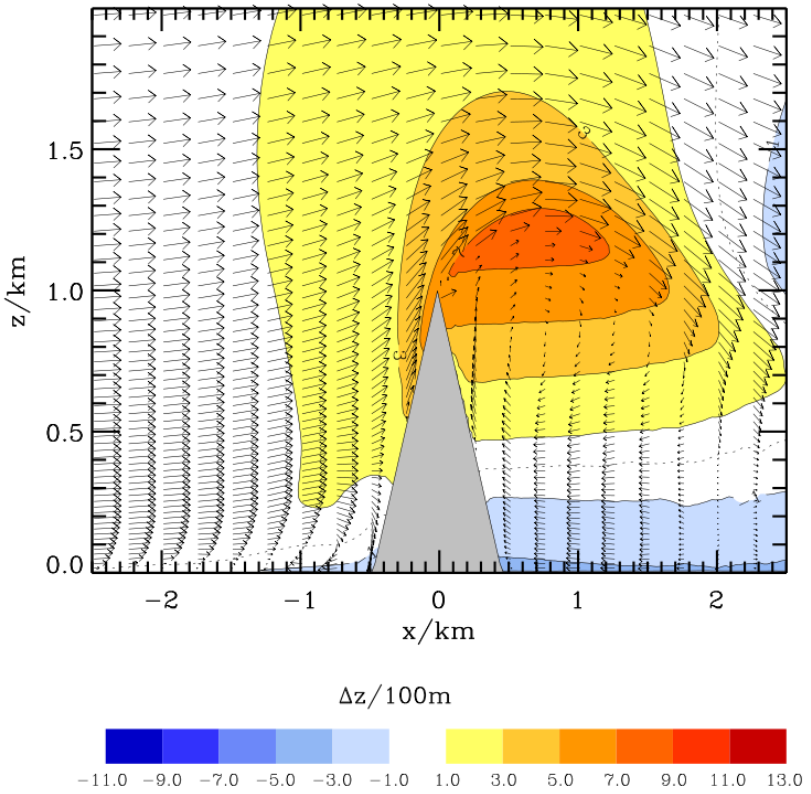
Ridge

Sensitivity: Ridge in deep boundary layer

Vertical displacement Δz in 100m



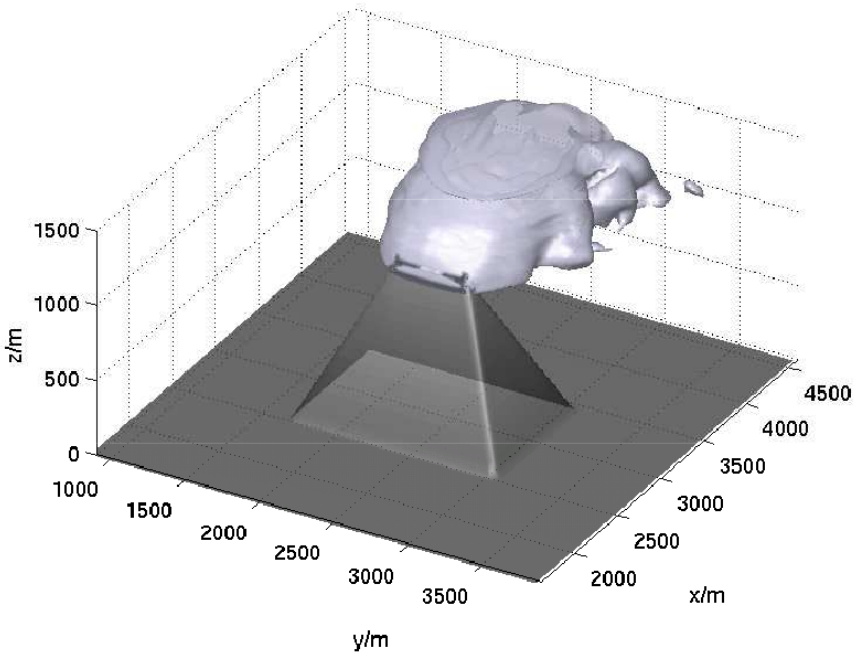
Pyramid



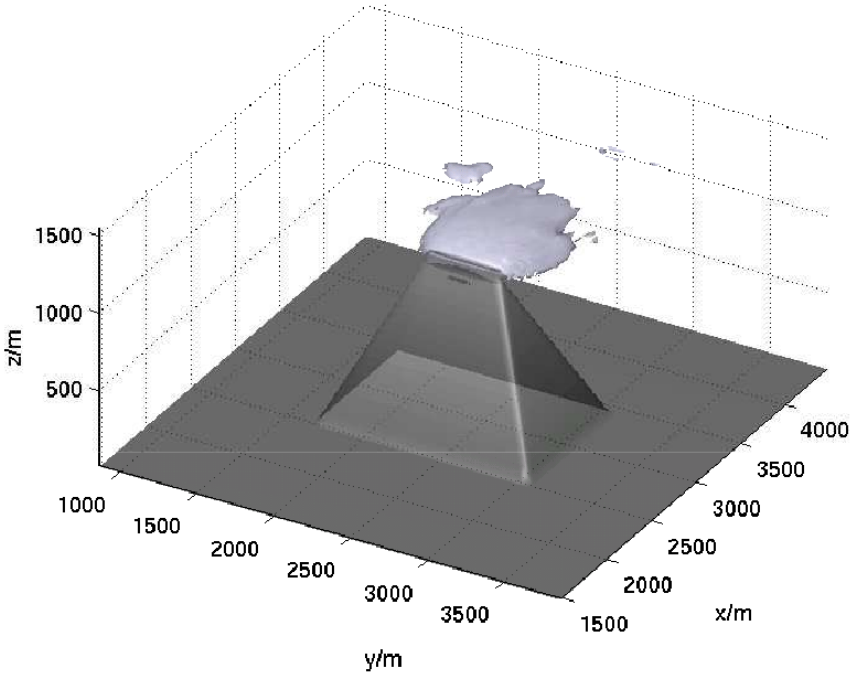
Ridge

Sensitivity: Ridge in deep boundary layer

100% relative humidity surface snapshot



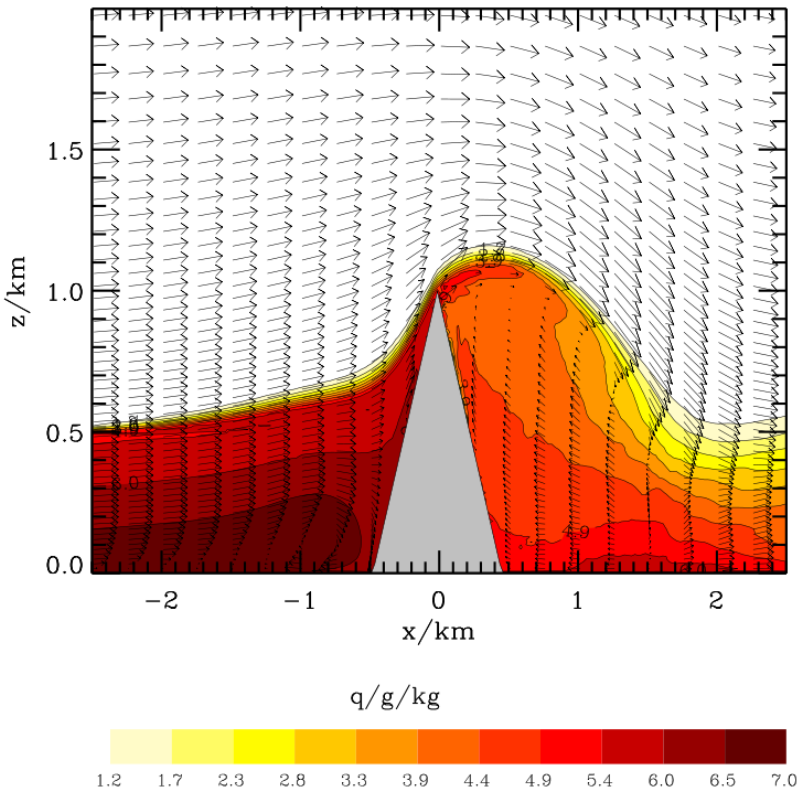
u_0=9m/s



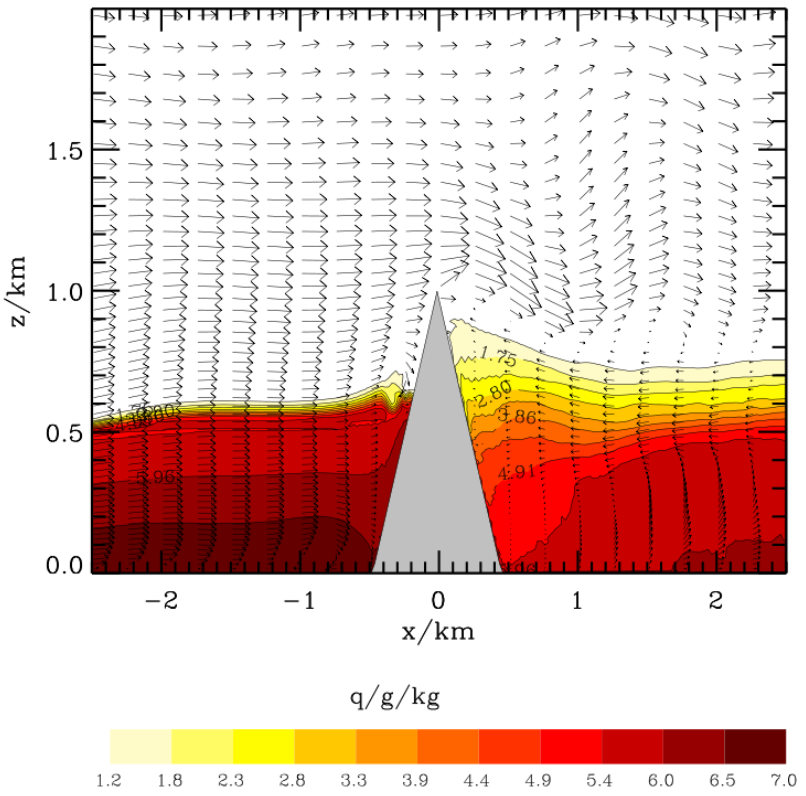
u_0=3m/s

Sensitivity: Ridge in shallow boundary layer

Specific humidity tracer



u_0=9m/s



u_0=3m/s

Conclusions

- Lee rotor is most important formation mechanism
- Banner cloud may be explained by dry dynamics
- Sensitivity on wind speed only in shallow boundary layer
- Pyramid more favorable to formation than ridge