Orographic Banner Clouds

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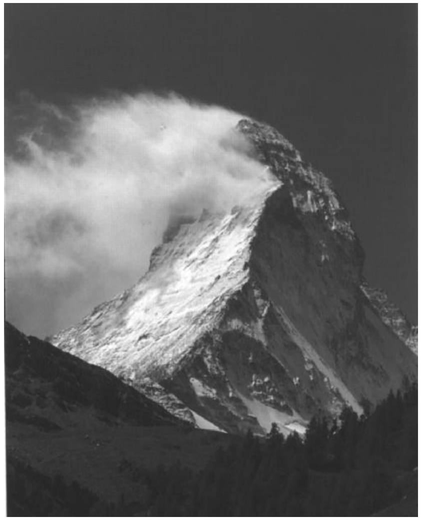
Occurrence:

Banner clouds are observed at steep 3D mountain summits or on quasi 2D mountain ridges

Characteristic property:

The cloud exists only in the leeward side
The windward side is cloud free

Rysy, Poland



Matterhorn, Switzerland

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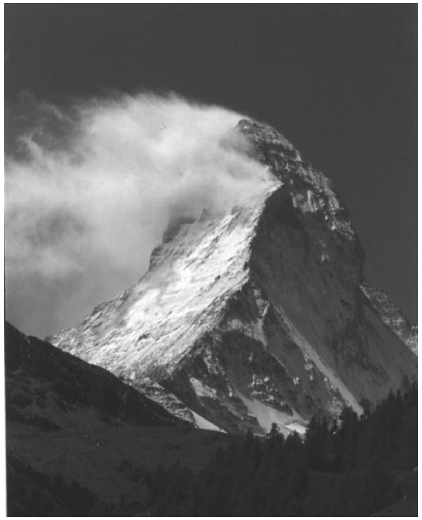
Outline

- Definition of the banner cloud
- Mechanism of formation
- Previous work / Simulations with EULAG
- Sensitivity on the thermodynamic conditions
- Summary

Definition

- Quasi stationary phenomenon
- Lifetime up to several hours
- Strong turbulence
- Conic shape, strongest vertical extent close to the obstacle
- Typical horizontal scale about 1 km
- Frequent occurrence
  (2-3 times per month at mount Zugspitze)



Matterhorn, Switzerland

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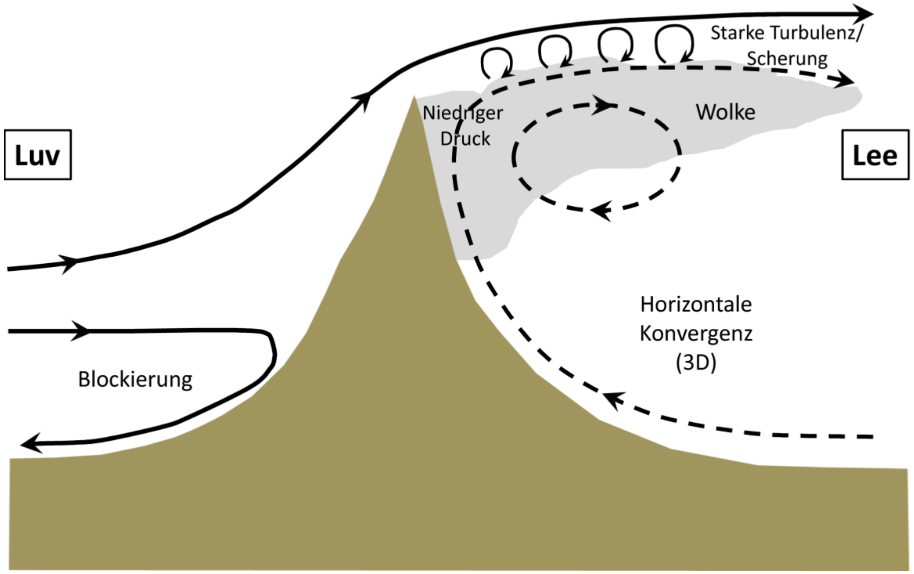
Mechanism behind

1. Bernoulli-Theory: Formation due to reduction of pressure (adiabatic expansion) in the area of strong acceleration close to the summit

   (Beer, 1974)
2. Fog-mixing-Theory: The mixing of two differently saturated air masses with different temperatures and specific humidity (Humphreys, 1964)
3. Lee-rotor-Theory: The banner cloud is the visible result of forced ascent in the upwelling part of the lee rotor (Glickman, 2000)

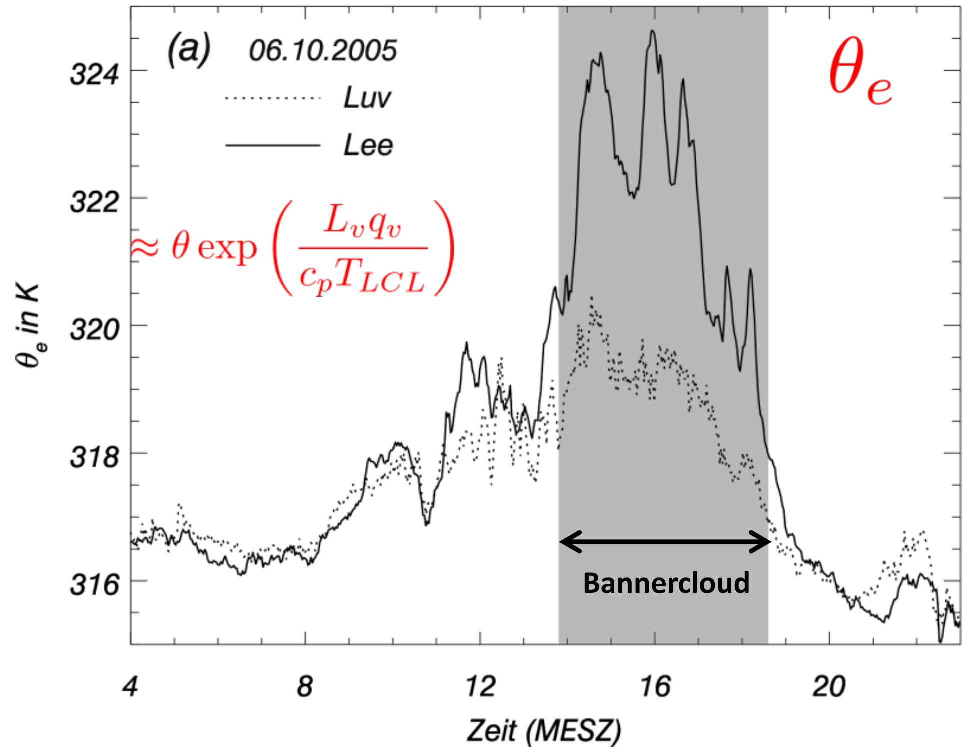


Meteorological conditions

Leeward air is 3-4K warmer and 40-70% more humid then the cloud free air on the windward side.

i.e. locally very strong instable stratification;

even so the appearance of the cloud is stable and persistent



Messungen am Zugspitzgrat (2005)

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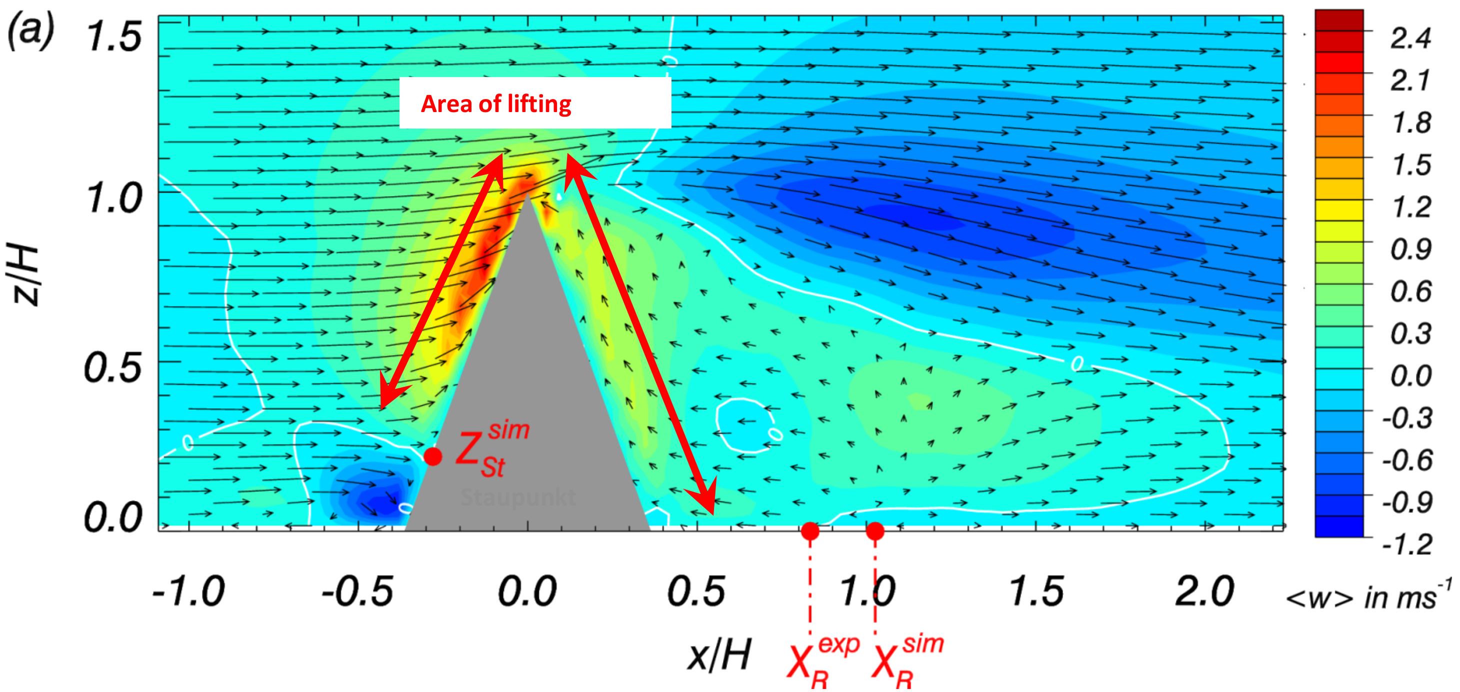
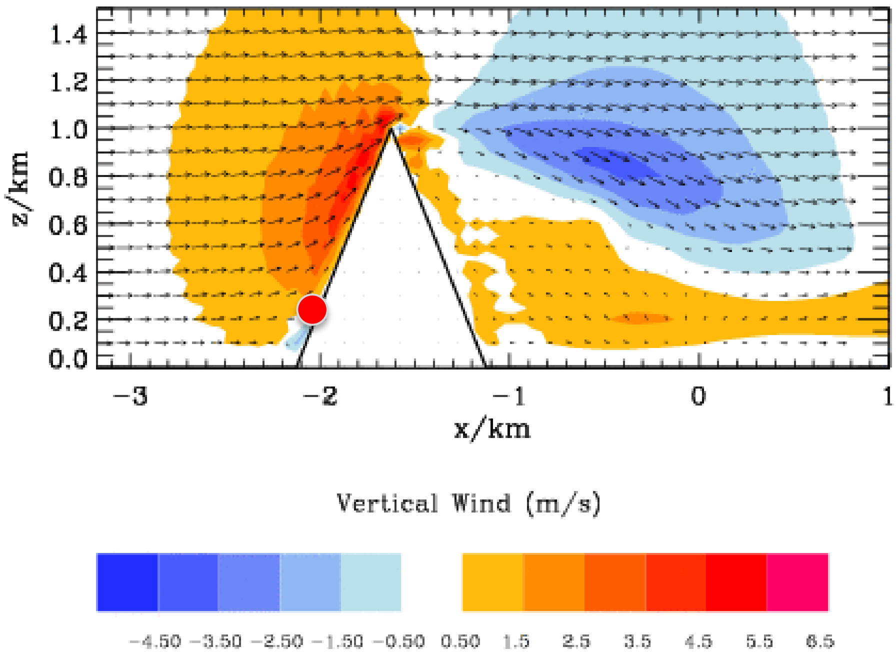
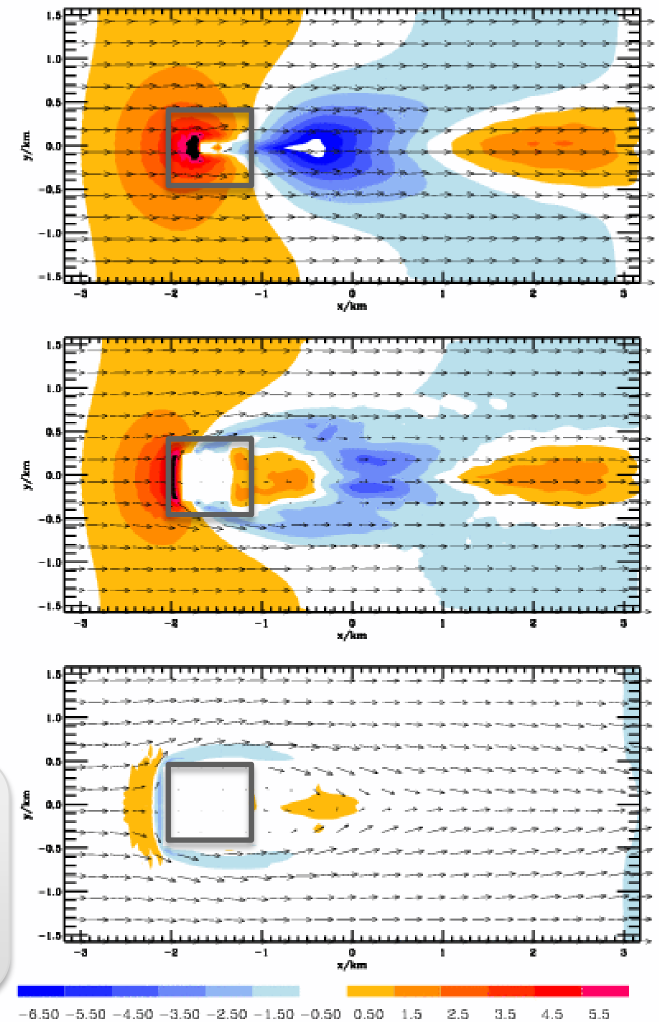
Previous work



Reinert, D., and V. Wirth, 2008

Simulations with EULAG

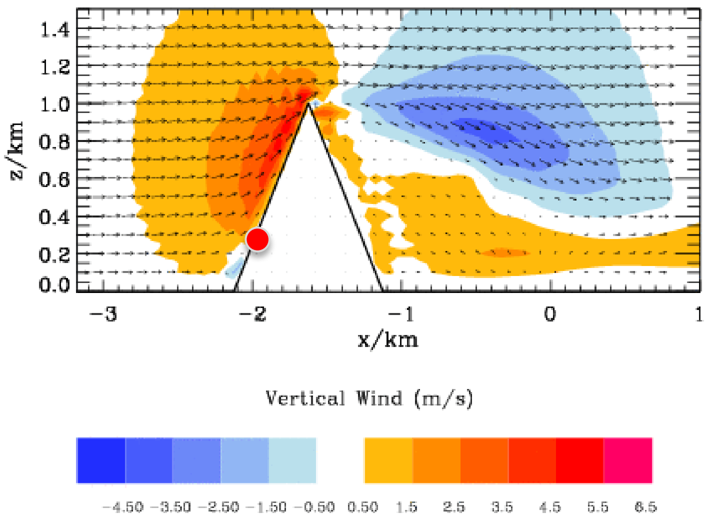




- Significant ascent in the lee
- Strong asymmetry between windward and leeward flow field
- Larger vertical extent of ascending region in the lee ward side

That supports the lee rotor theory

In order to gain information about the needed thermodynamic profiles lagrangian information is important



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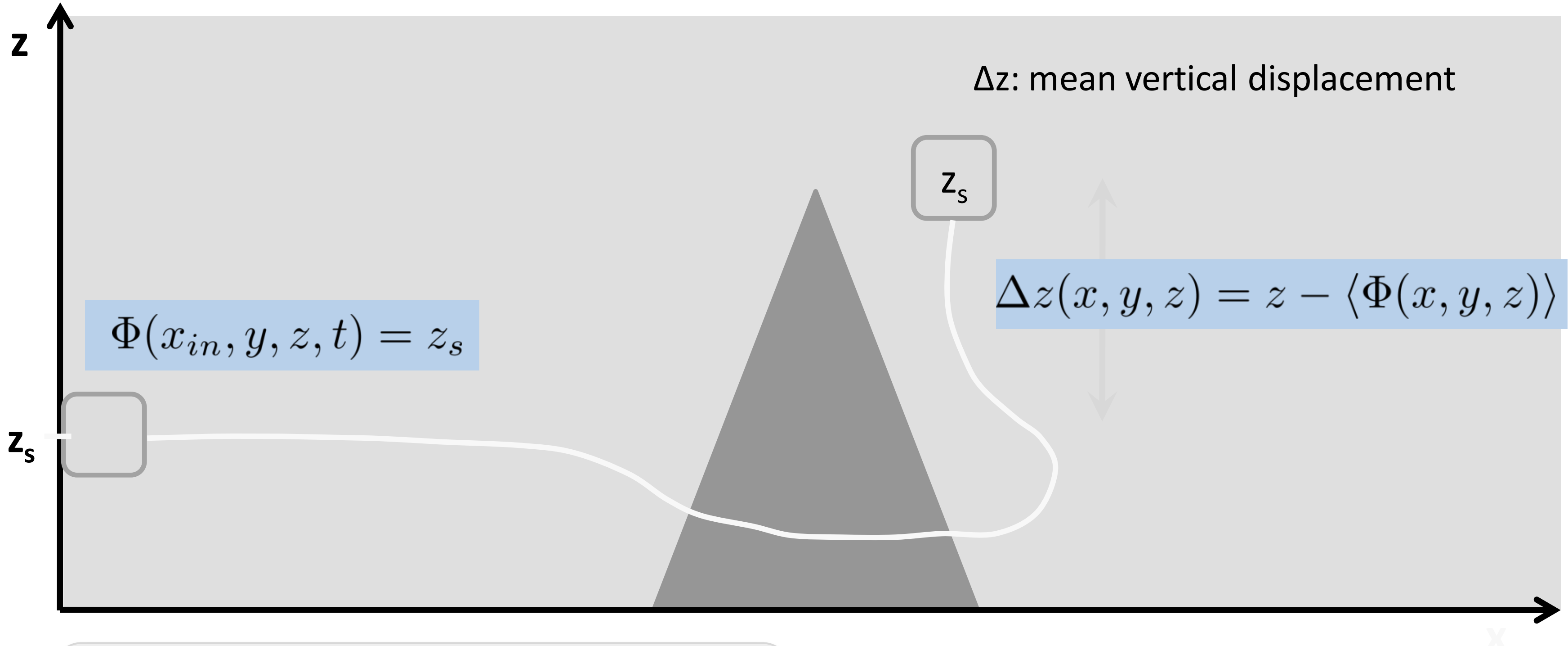
Initializing of a passive tracer



Advection of a passive tracer
Initialized by its altitude at t_0

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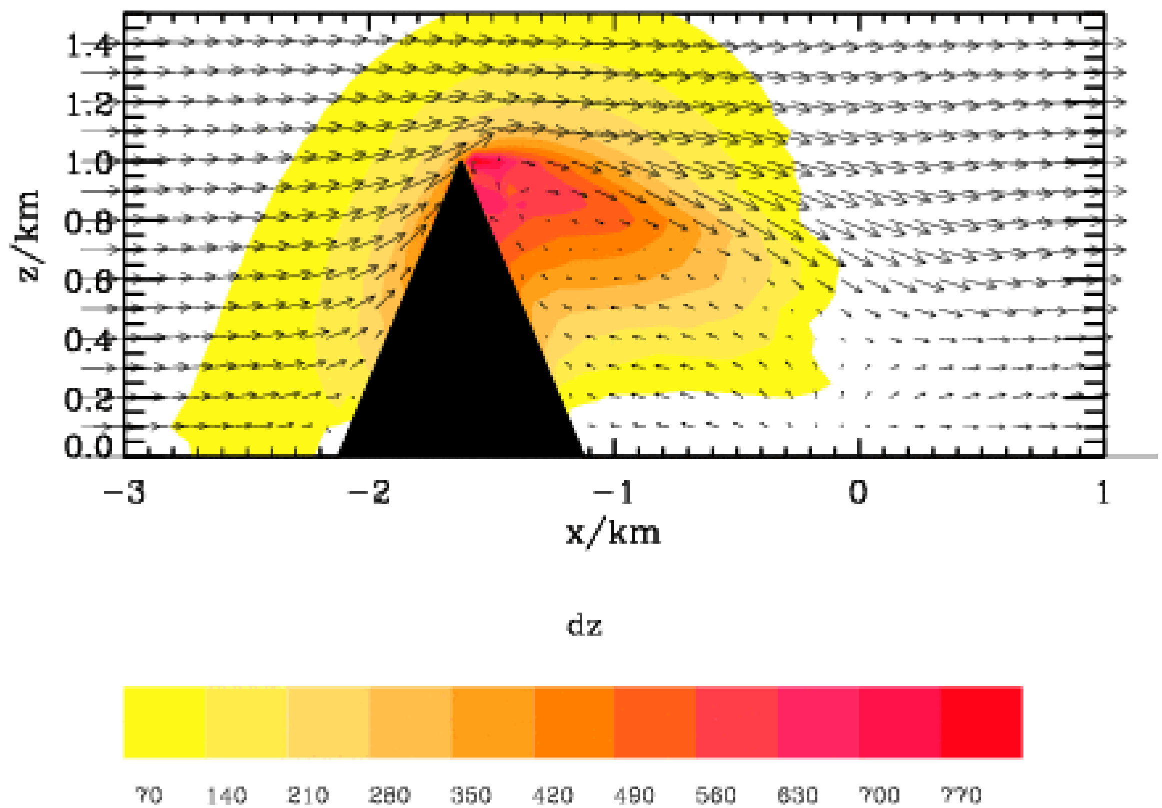
Mean vertical displacement, m

Strong windward leeward asymmetry

Strongest positive vertical displacement in in lee

⇒Different air masses or additional sources of humidity are not necessary



Similarity of the tracer field to the banner cloud

Thermodynamic conditions

	Thermodynamic Properties	Dynamic Properties
	LCL(z_s) Vertical profile of the Lifting Condensation Level as a function of starting height z_s.	Vertical profile of the mean maximum height of air parcels in the very near of the leeward/windward side as a function of the starting height z_s.
	1 profile	1 profile for the leeward and 1 profile for the windward side

Conditions:

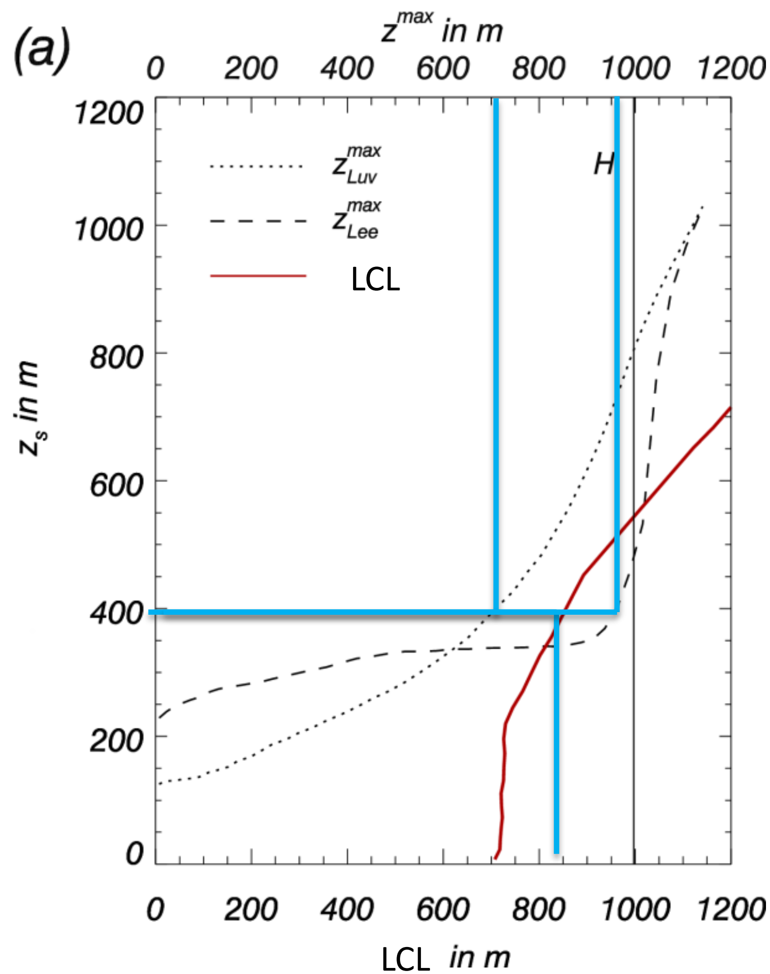
$$\text{I} \quad \exists\, z_s, \quad \text{with LCL}(z_s) \leq H$$
$$\text{II} \quad \exists\, z_s, \quad \text{with LCL}(z_s) \leq z_{Lee}^{max}(z_s)$$
$$\text{III} \quad \forall\, z_s, \quad \text{LCL}(z_s) > z_{Luv}^{max}(z_s)$$

- Diagram shows Situation that fulfills the conditions
- Implications for the profiles of θ, q_v, θ_e
  - LCL-Profile cannot be constant in height; needs to increase with height

$$\frac{\mathrm{d}q_v}{\mathrm{d}z} < 0 \ \text{ und/oder } \ \frac{\mathrm{d}\theta}{\mathrm{d}z} > 0 \ \text{ für } \ z < H$$

  - Very favorable are the situations with:

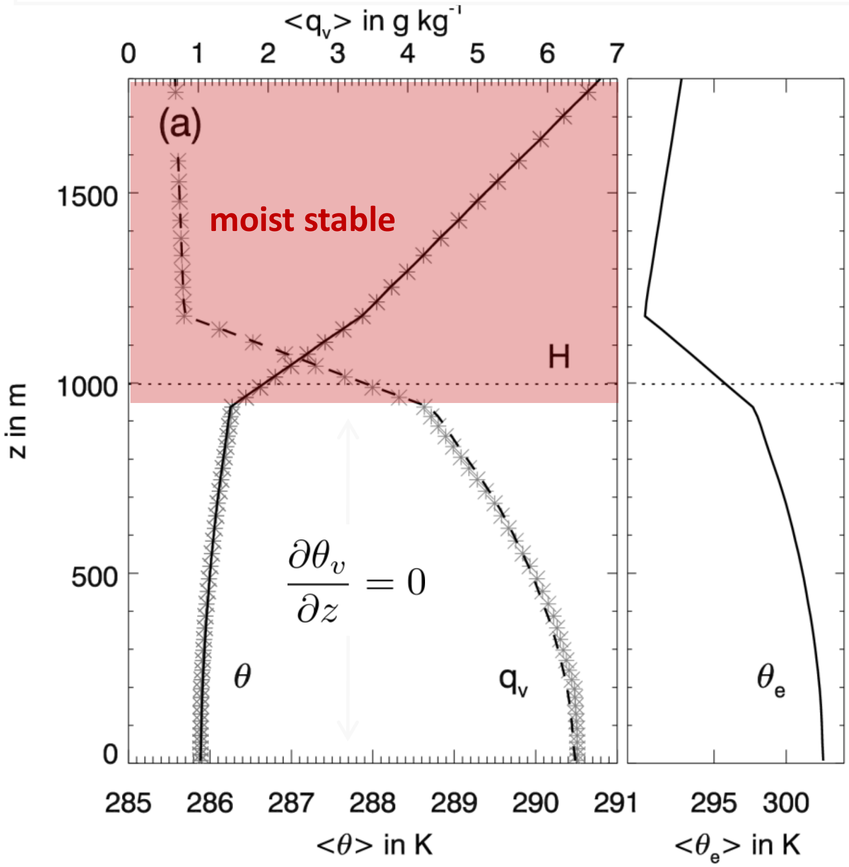
$$\frac{\mathrm{d}\theta_e}{\mathrm{d}z} < 0 \ \text{ für } \ z < H$$



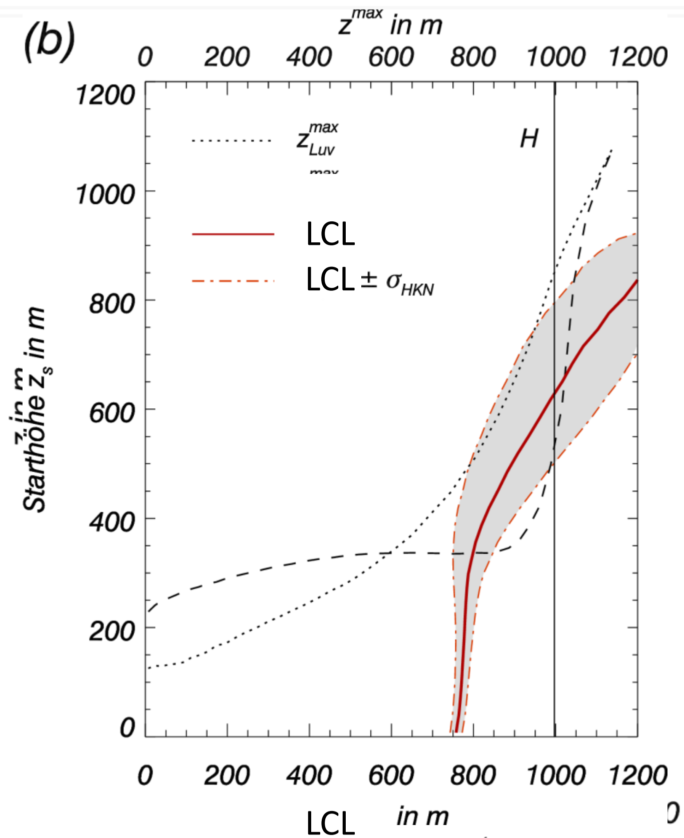
Initial conditions of the simulations

- Structure of the profiles motivated by measurements at mount Zugspitze during a banner cloud event
- Precise form was adapted to match the defined criterions

Mean environmental profiles for θ, q_v, θ_e



Satisfy the criterions



Simulated banner cloud

Unfortunately the banner cloud simulated by EULAG is still not available…

but coming soon

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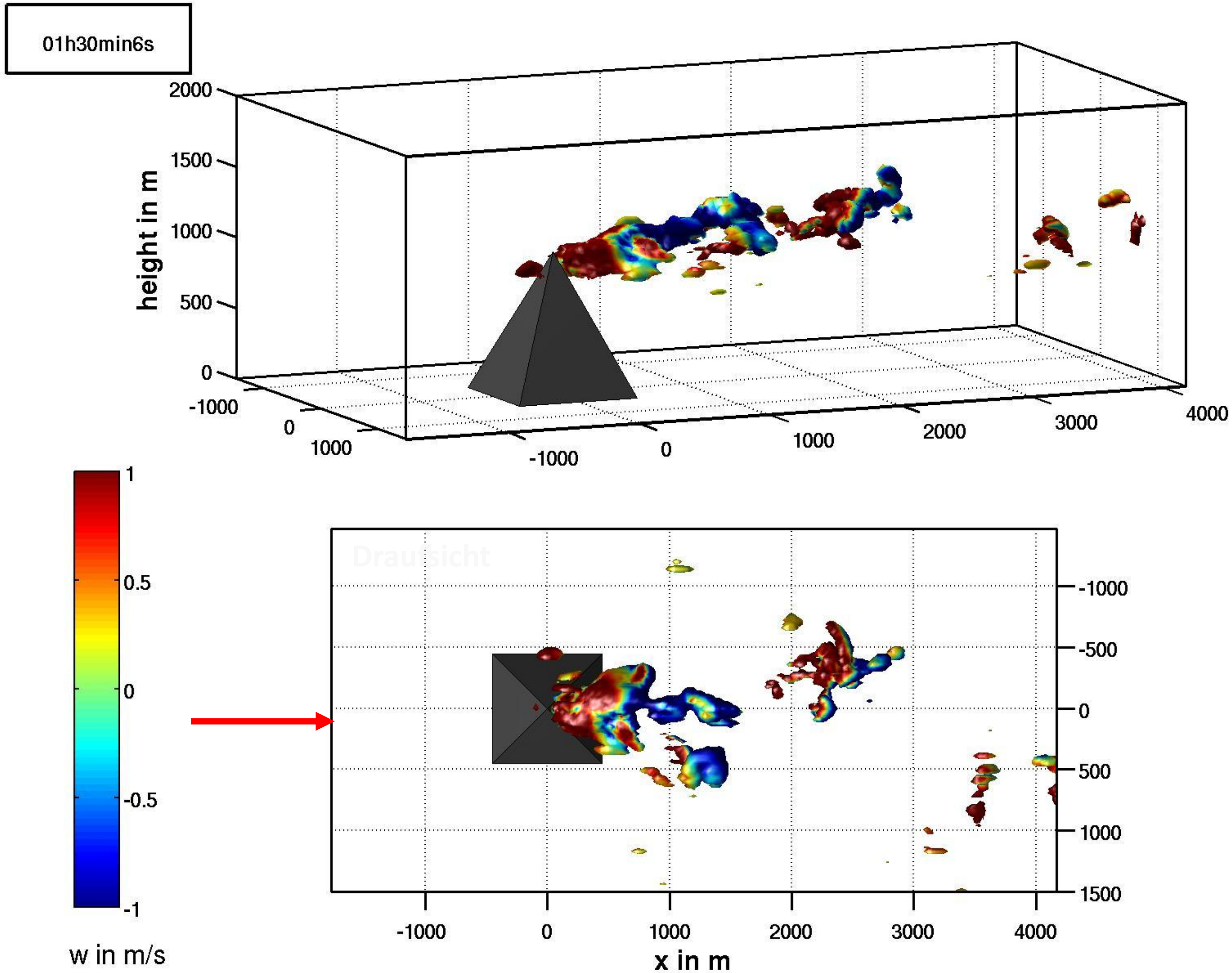
Simulated banner cloud of previous study

Iso-surface of the specific cloud water content q_c, colors show the instantaneous vertical velocities



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Sensitivity of the cloud on the LCL profile

Conditions:

I	$\exists\, z_s,$	with LCL$(z_s) \leq H$
II	$\exists\, z_s,$	with LCL$(z_s) \leq z_{Lee}^{max}(z_s)$
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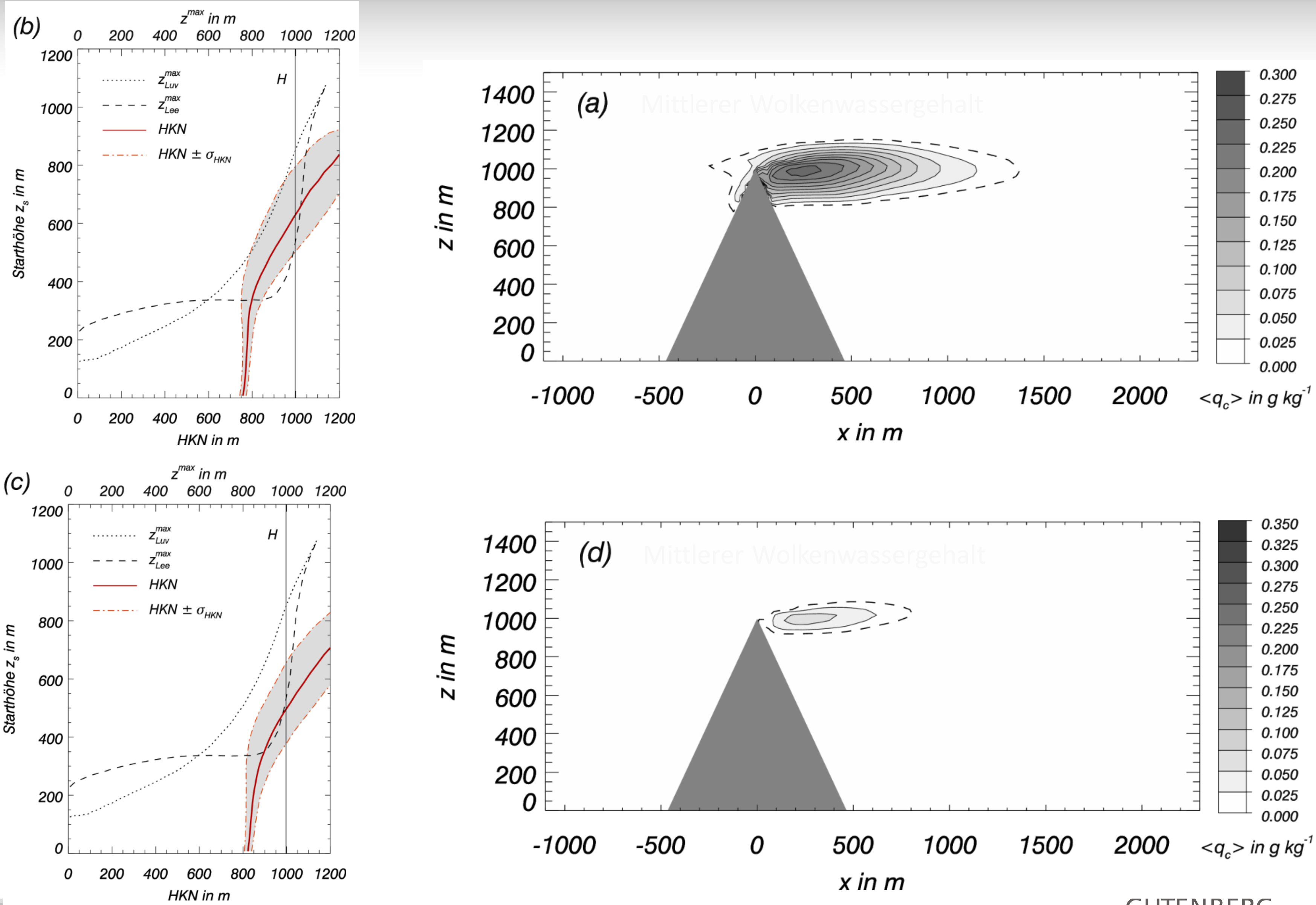
Sensitivity of the cloud on the LCL profile



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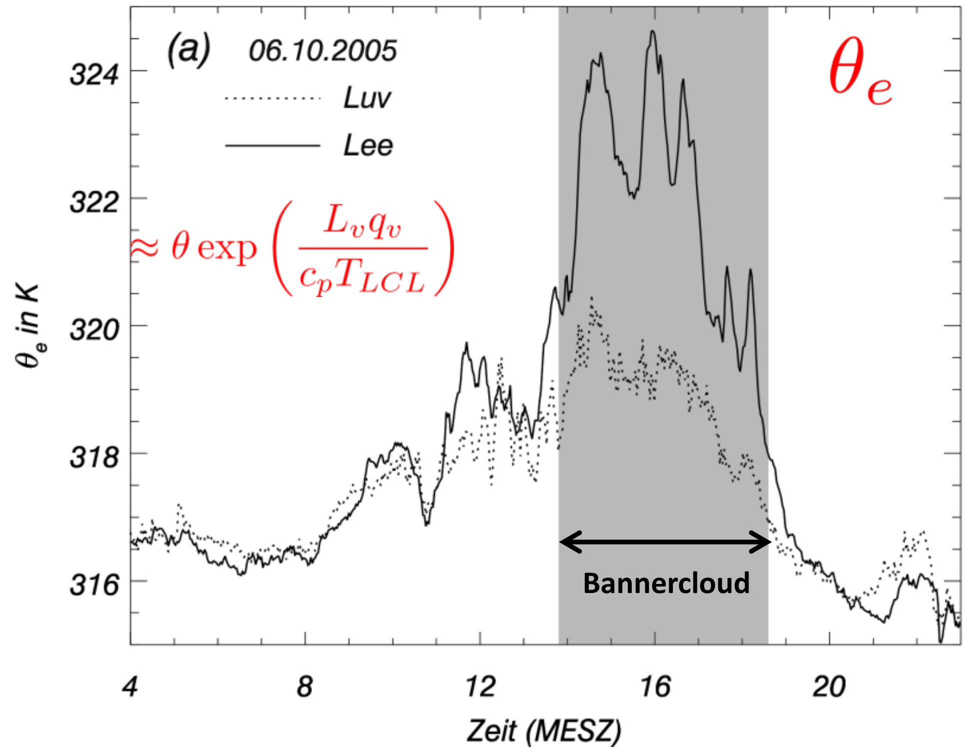
Simulation compared to measurements

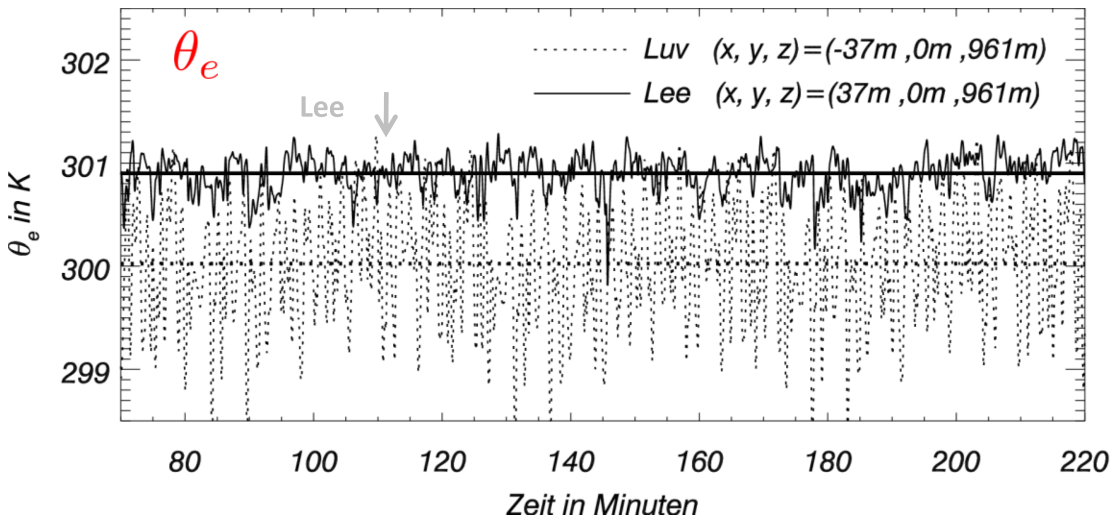
Typical observation for banner clouds:
higher values for T, q_{tot} (and so θ_e) in the lee

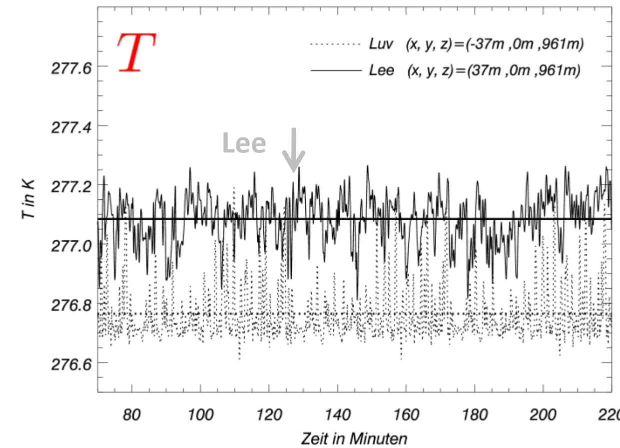


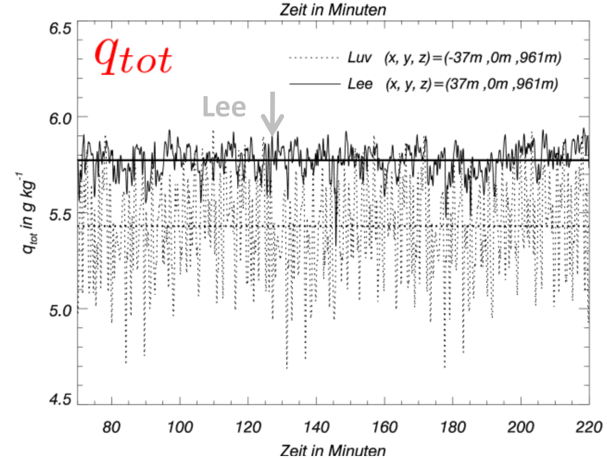
Messungen am Zugspitzgrat (2005)

Simulation compared to measurements

Time series of θ_e, q_{tot}, T for simulated Banner cloud







Higher values of T, q_{tot} (θ_e) in the leeward side in the simulation. This is the result of the differential lifting and the gradients in the imposed profiles of T and q_{tot}

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Summary

- Recent research of our group strengthened the lee-rotor-theory as the mechanism behind the formation of the banner cloud.

  (dynamic phenomenon)
- The thermodynamic conditions had been identified for the case of a steep pyramidical shaped mountain
- EULAG reproduced some of the results of previous simulations that give confidence if the previous results

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Outlook

After the successful simulation of the banner cloud with EULAG the next steps will be

- Investigation of the banner clouds on quasi 2D mountain ridges (like mount Zugspitze)
- Use of real topography
- Use of trajectories instead of the passive tracer
- Investigations on the sensitivity of the static stability of the Flow. Is there a regime

  $a < Fr < b$ beyond the banner cloud cannot occur (e.g. due to the missing lee rotor)

Thank you