GRID RESOLUTION DEPENDENCY OF LAND SURFACE HETEROGENEITY EFFECTS ON BOUNDARY-LAYER STRUCTURE

2022-05-23 | STEFAN POLL[1,2,3], PRABHAKAR SHRESTHA[1], CLEMENS SIMMER[1,4]

1 INSTITUTE FOR GEOSCIENCE, SECTION METEOROLOGY, UNIVERSITY OF BONN, BONN, GERMANY
2 INSTITUTE OF BIO- AND GEOSCIENCES AGROSPHERE (IBG-3), RESEARCH CENTRE JÜLICH, JÜLICH, GERMANY
3 SDL TERRESTRIAL SYSTEMS, JÜLICH SUPERCOMPUTING CENTRE, RESEARCH CENTRE JÜLICH, JÜLICH, GERMANY
4 CENTRE FOR HIGH-PERFORMANCE SCIENTIFIC COMPUTING IN TERRESTRIAL SYSTEMS,GEOVERBUND ABC/J, JÜLICH, GERMANY

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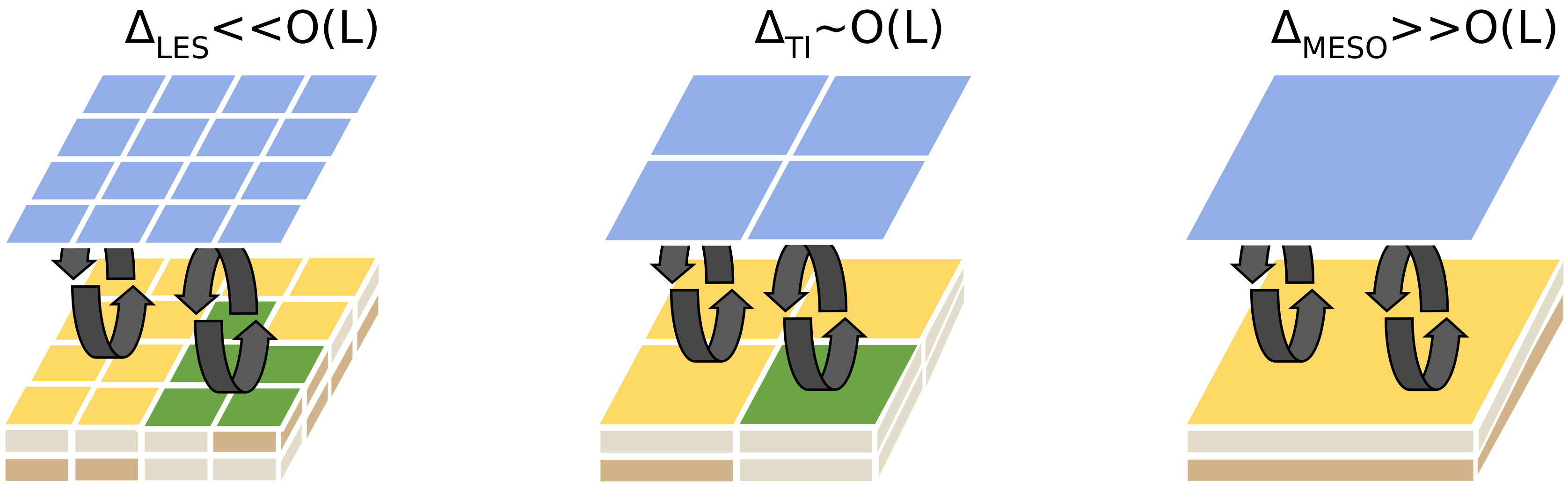
BACKGROUND

Land Surface Heterogeneity at TERRA INCOGNITA

Ever increasing computational resources Davies et al., 2005; Stevens et al., 2020

⇨ Grid scale approaches length scale of largest PBL eddies Wyngaard, 2004



L ~ 1km

Research Question:
What is the grid-resolution dependency of dynamical effects caused by land surface heterogeneity on the atmospheric boundary layer evolution?

EXPERIMENT SETUP

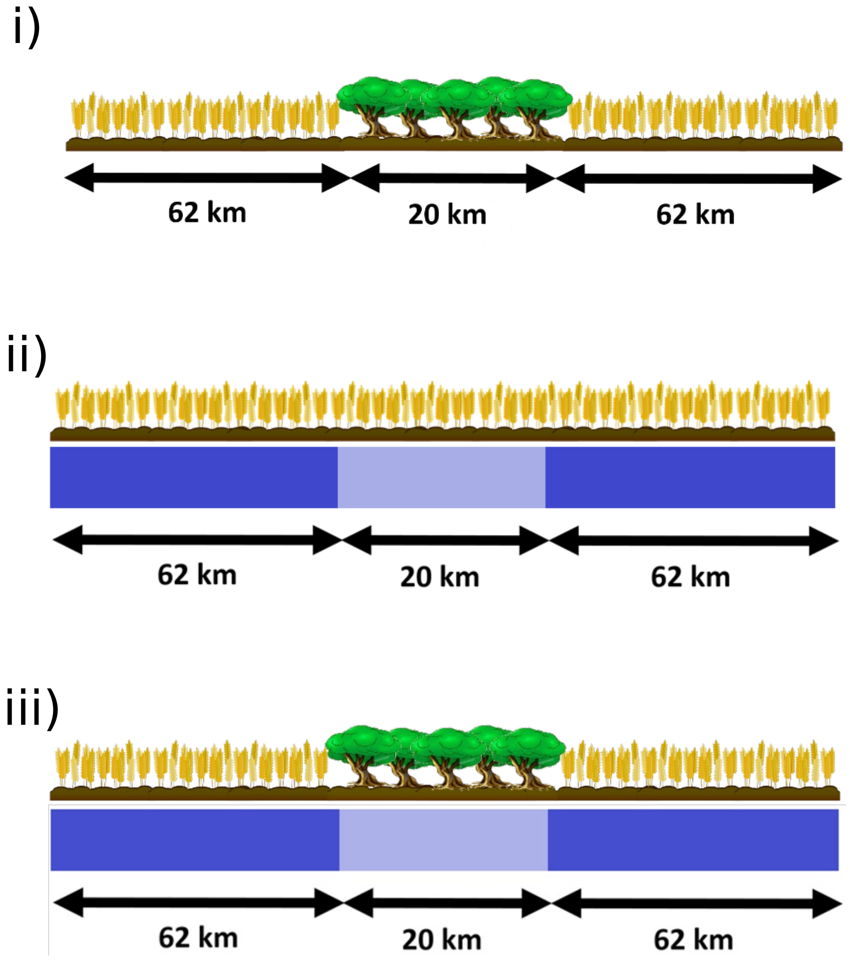
Idealized strip-like land-surface heterogeneity

Idealized setup:

- ICON + TERRA-ML Zängl et al., 2015; Schrodin and Heise, 2001
- 1D PBL scheme (NWP – MY2.5) Mellor and Yamada, 1982; Raschendorfer, 2001
  [+ reference (Δ_x=50 m LES)] Dipankar et al., 2015
- 144 x 80 km², 3 hr simulation time
- Δ_x=300 to 4800 m
- Diurnal cycle mid-latitudes
- Atmospheric environments (cells | rolls)
  - Managed by soil moisture (S_r =0.3 | 0.6) and wind velocity (v_0 = 3 | 15 m/s)

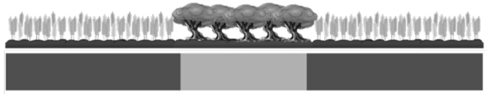
Land surface heterogeneity:

i) Forest patch with homogeneous soil
ii) Soil moisture patch with homogeneous land surface
iii) Soil moisture patch with forest surface



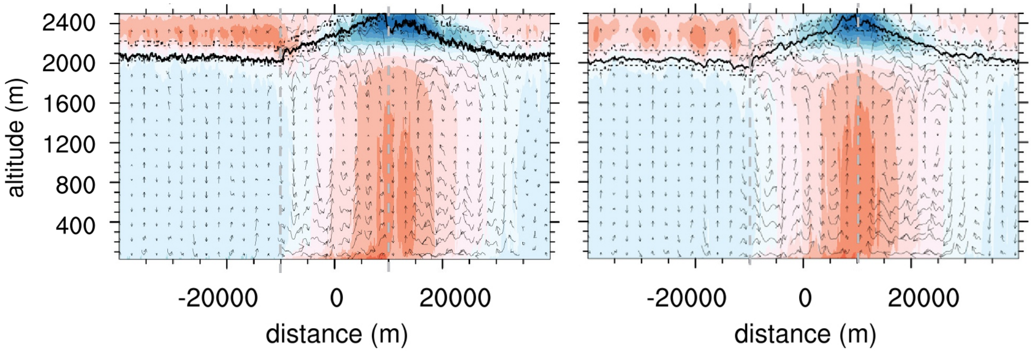
RESULTS

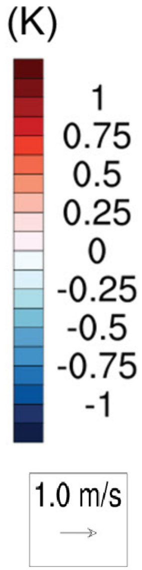
Atmospheric boundary layer structure

t=3hr EXP iii)  v_0 = 3 m/s

LES Reference

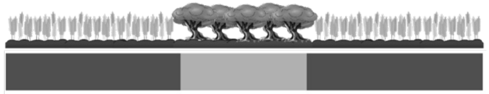
Δ_x=50 m Δ_x=300 m

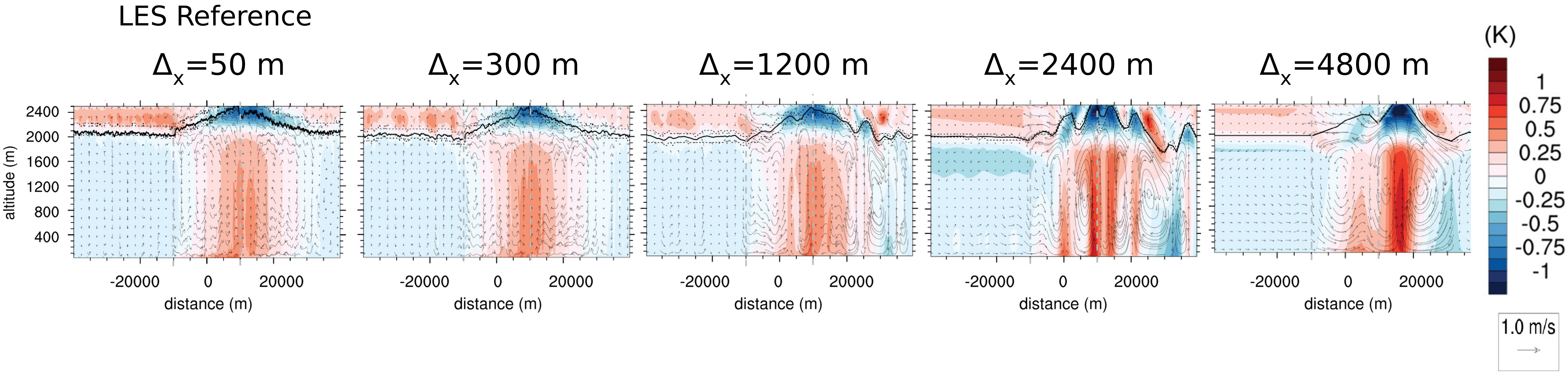




RESULTS

Atmospheric boundary layer structure

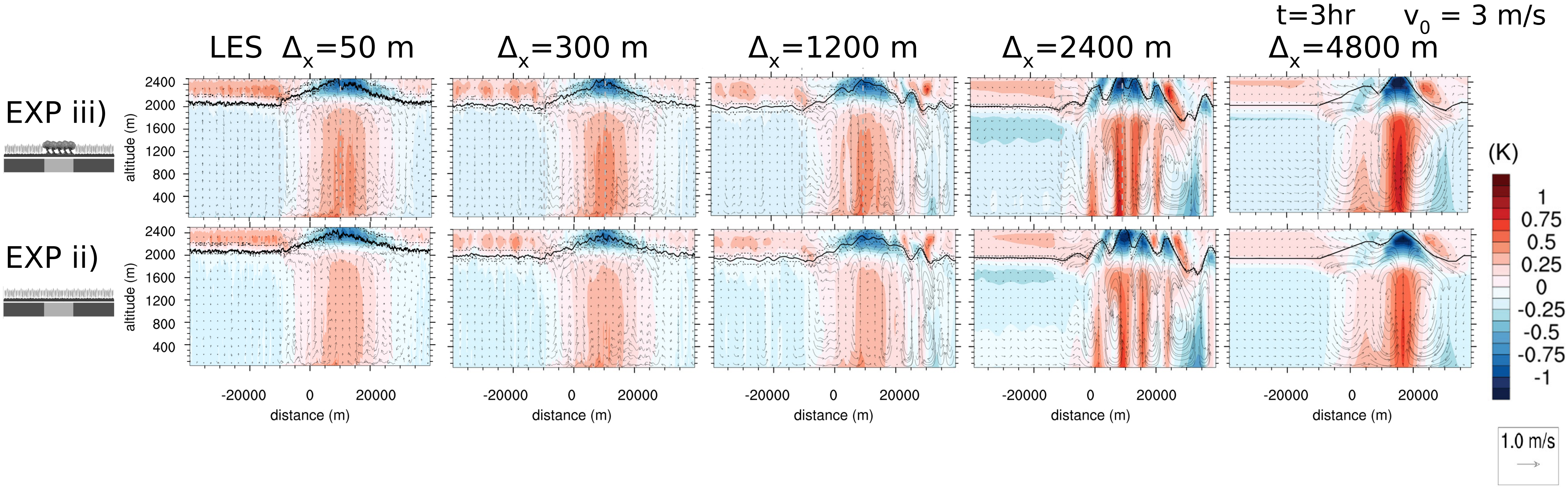
t=3hr EXP iii)  v_0 = 3 m/s



▼ Artificial circulations lead to exaggeration of land surface heterogeneity effects at km-scale simulation

RESULTS

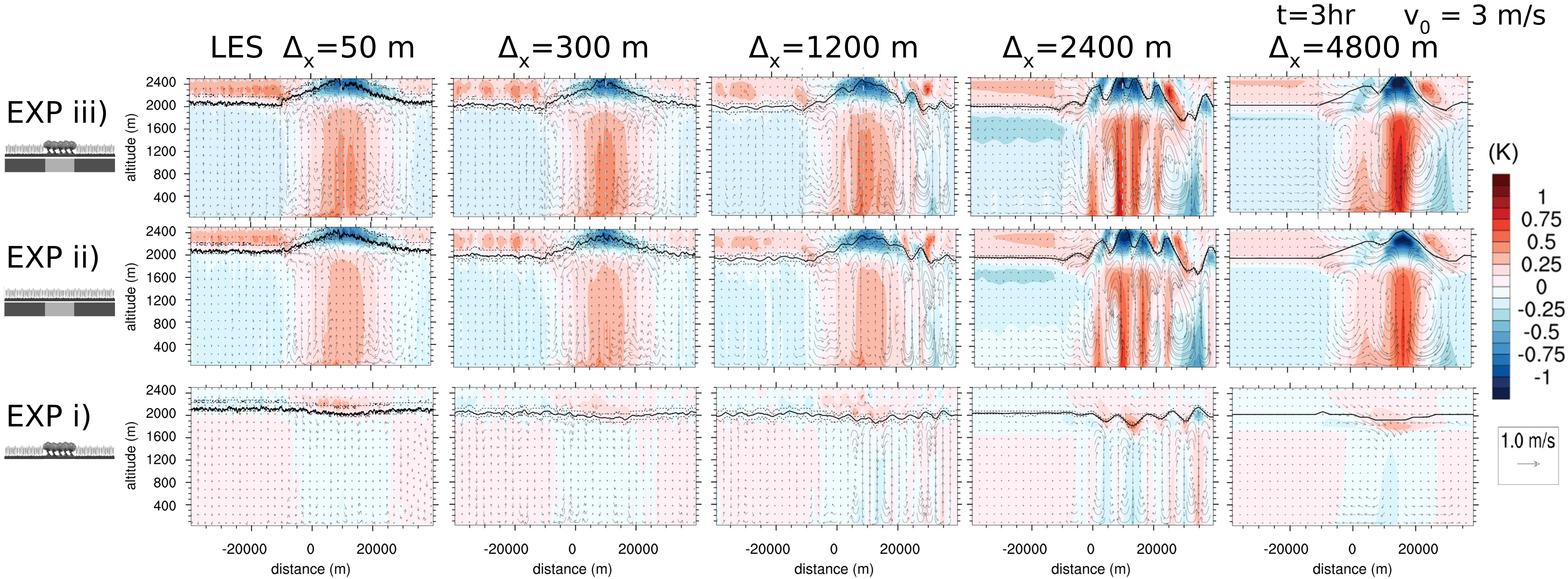
Thermal heterogeneity effects on boundary layer structure and its grid resolution dependency



- Exaggeration of land surface heterogeneity effects at km-scale simulation independent of thermal heterogeneity strength

RESULTS

Thermal heterogeneity effects on boundary layer structure and its grid resolution dependency



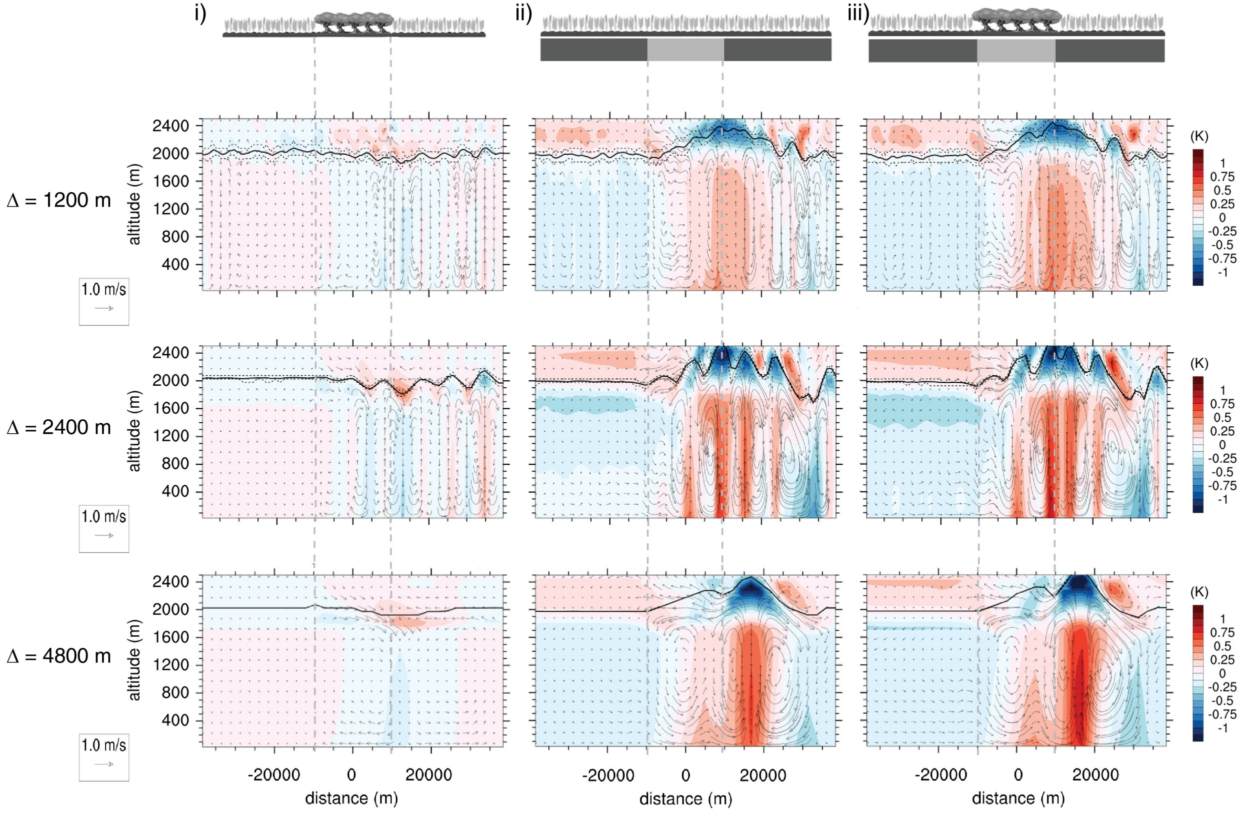
▼ Exaggeration of land surface heterogeneity effects at km-scale simulation independent of thermal heterogeneity strength

RESULTS

Tuning of PBL scheme with l_∞

t=3hr

homogeneous l_∞



$$l_\infty = f\left(\frac{\Delta x}{z_i}, \Delta H, v_x\right)$$

l_∞ as function of

- Ratio grid spacing / PBL height
- Thermal heterogeneity
- Background wind speed

RESULTS

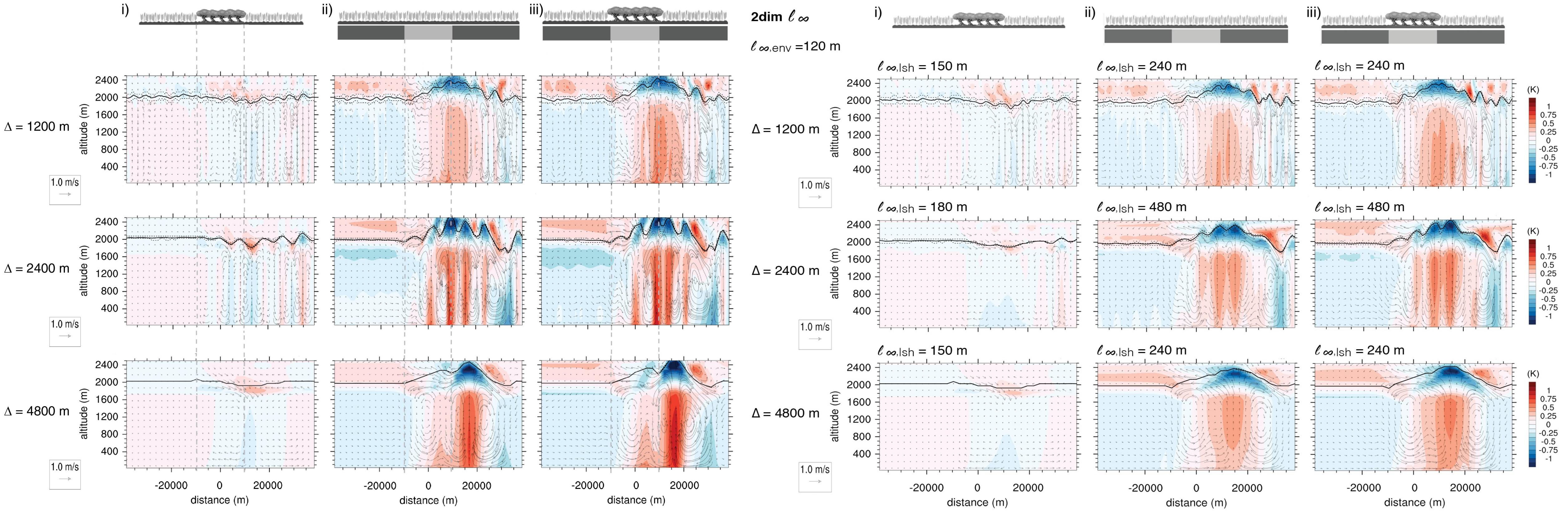
Tuning of PBL scheme with l_∞

$$l_\infty = f\left(\frac{\Delta x}{z_i}, \Delta H, v_x\right)$$

t=3hr

homogeneous l_∞

2-dimensional l_∞



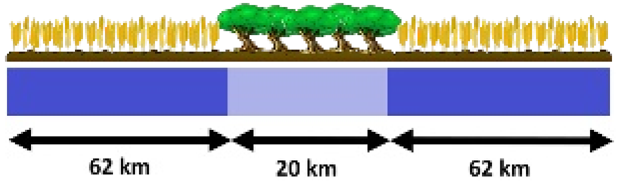
▼ Boundary-layer tuning reduces this effect and leads to improvement of boundary layer states

SUMMARY AND CONCLUSION

RQ: What is the grid-resolution dependency of dynamical effects caused by land surface heterogeneity on the atmospheric boundary layer evolution?

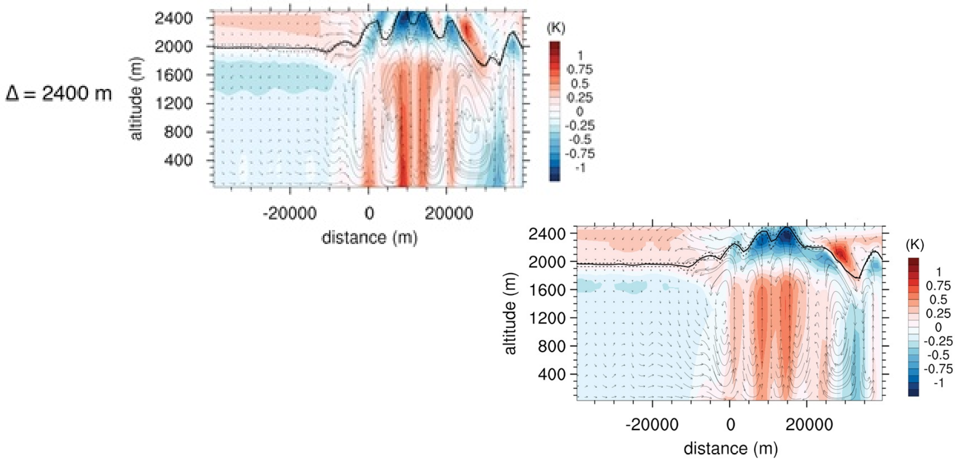
Background and Setup:

- Grid spacing approaches size of PBL eddies
- Idealized simulation with strip-wise land surface heterogeneity



Results:

- Exaggeration of land surface heterogeneity effects at km-scale simulation
- Improvement of boundary layer states due to boundary layer tuning



Poll et al. (2021), Grid Resolution Dependency of Land Surface Heterogeneity Effects on Boundary Layer Structure, QJRMS, https://doi.org/10.1002/qj.4196

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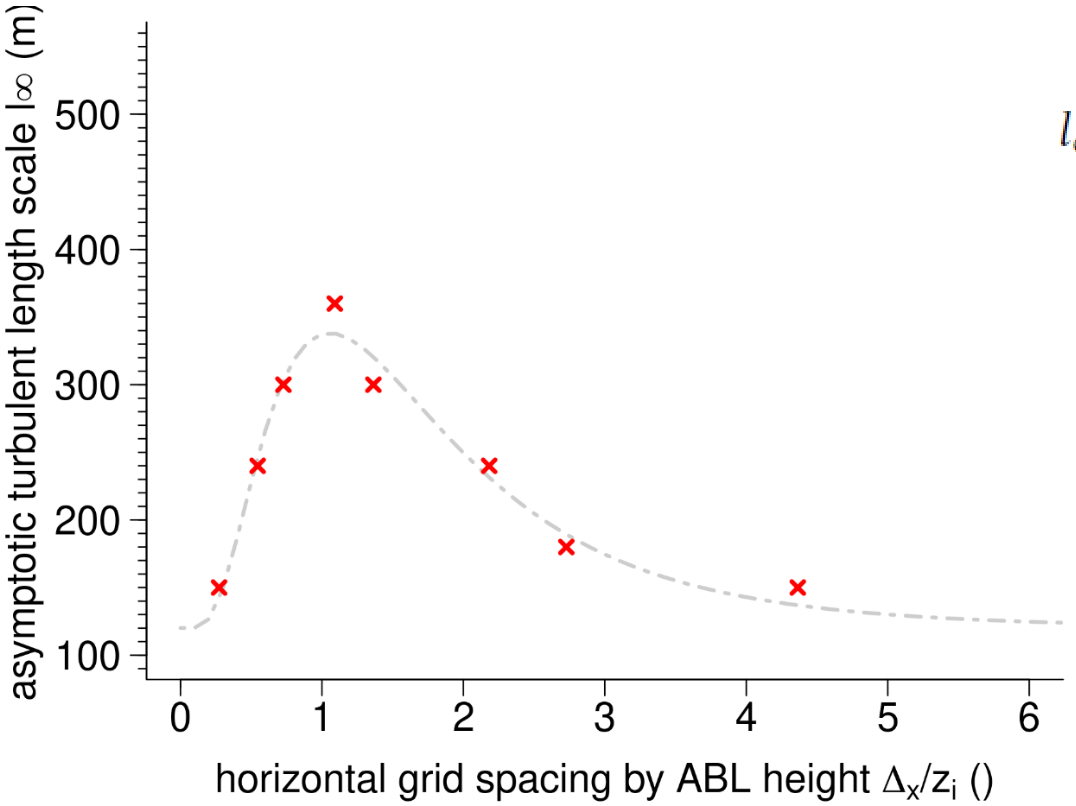
RESULTS

Parameterization for PBL tuning

- PBL tuning considering strength, width and location of thermal heterogeneity



$$l_\infty = f\left(\frac{\Delta x}{z_i}, \Delta H, v_x\right)$$

1) Ratio grid spacing / PBL height
2) Thermal heterogeneity
3) Background wind speed

$$l_{\infty,lsh}(\Delta x/z_i, \Delta H, v_x) = \max\left[(a\,\Delta H\, v_x + b\,\Delta H) * n_{l_\infty}(\Delta x/z_i\colon \mu, \sigma) + l_{\infty,env},\ l_{\infty,env}\right]$$

$$w_x(l_\infty) = \left(1 + c\, v_x^2\right) * \Delta L$$

$$s_x(l_\infty) = d * v_x$$

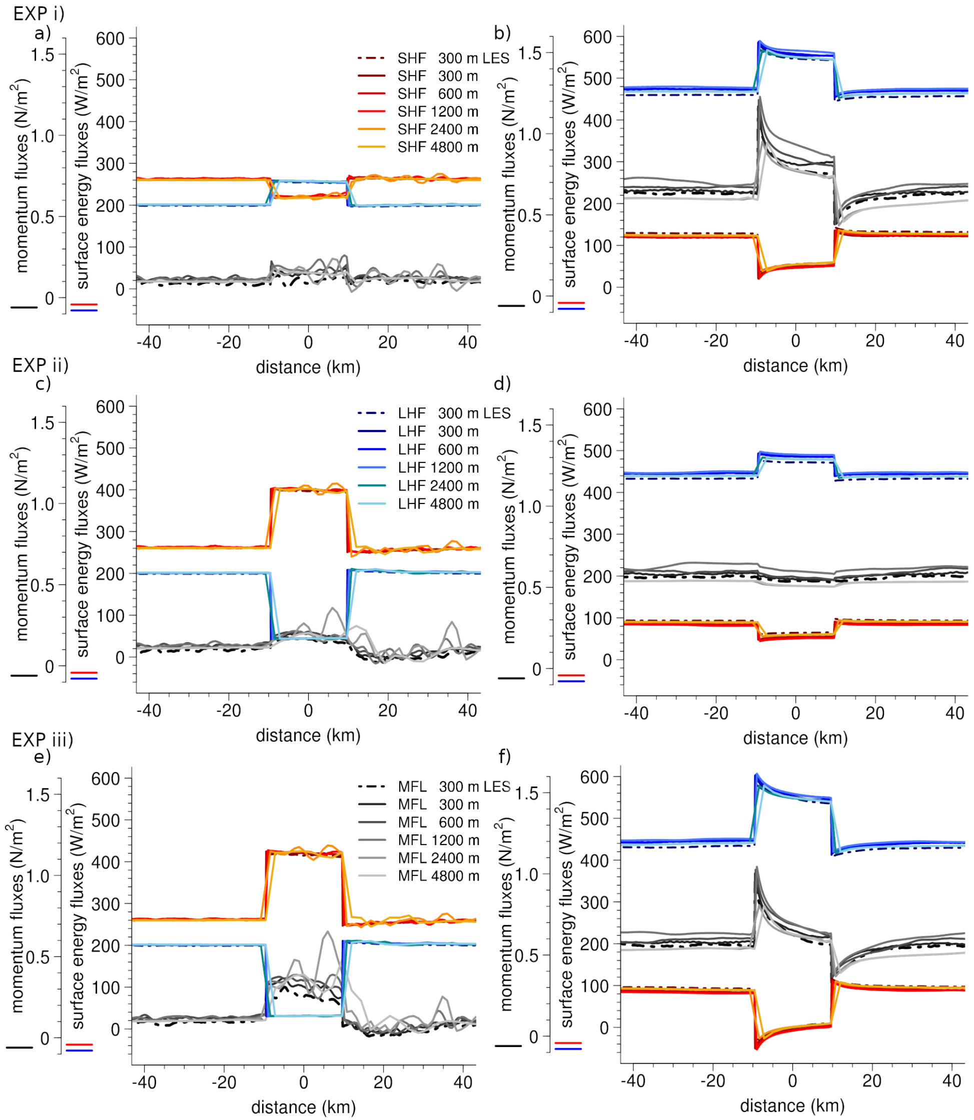
$$a = -0.987,\ b = 5.924,\ \mu = 0.447\quad \sigma = 0.629$$

$$d = 0.02,\quad e = 3200$$

RESULTS

Surface Energy Fluxes

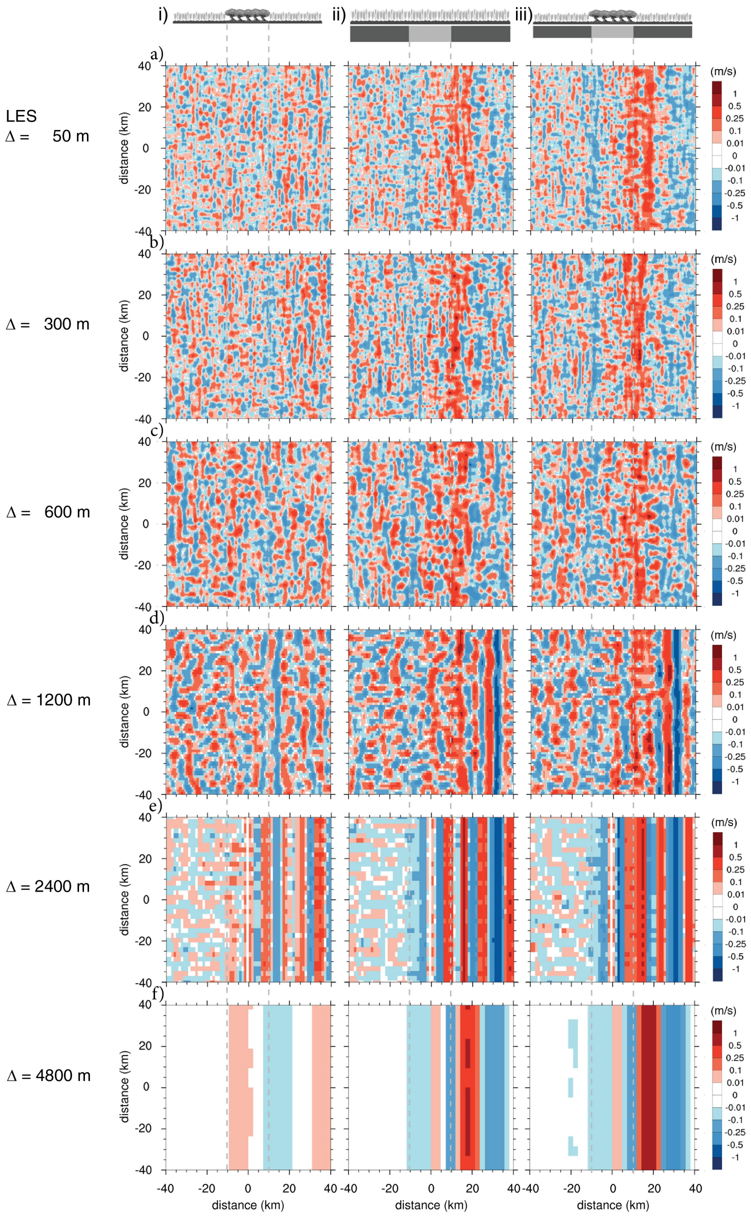
- Surface energy fluxes of the experiments for two atmospheric conditions.

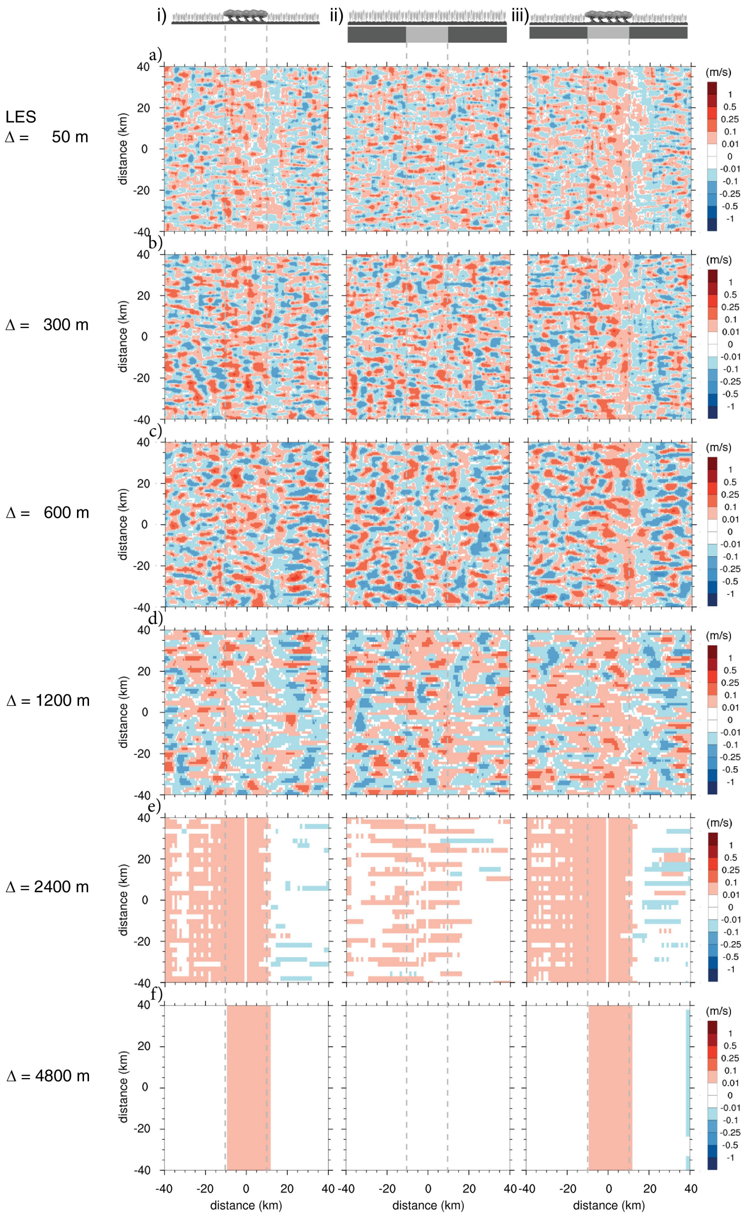


RESULTS

Vertical Velocity at zi/2

- Spatially filter is applied

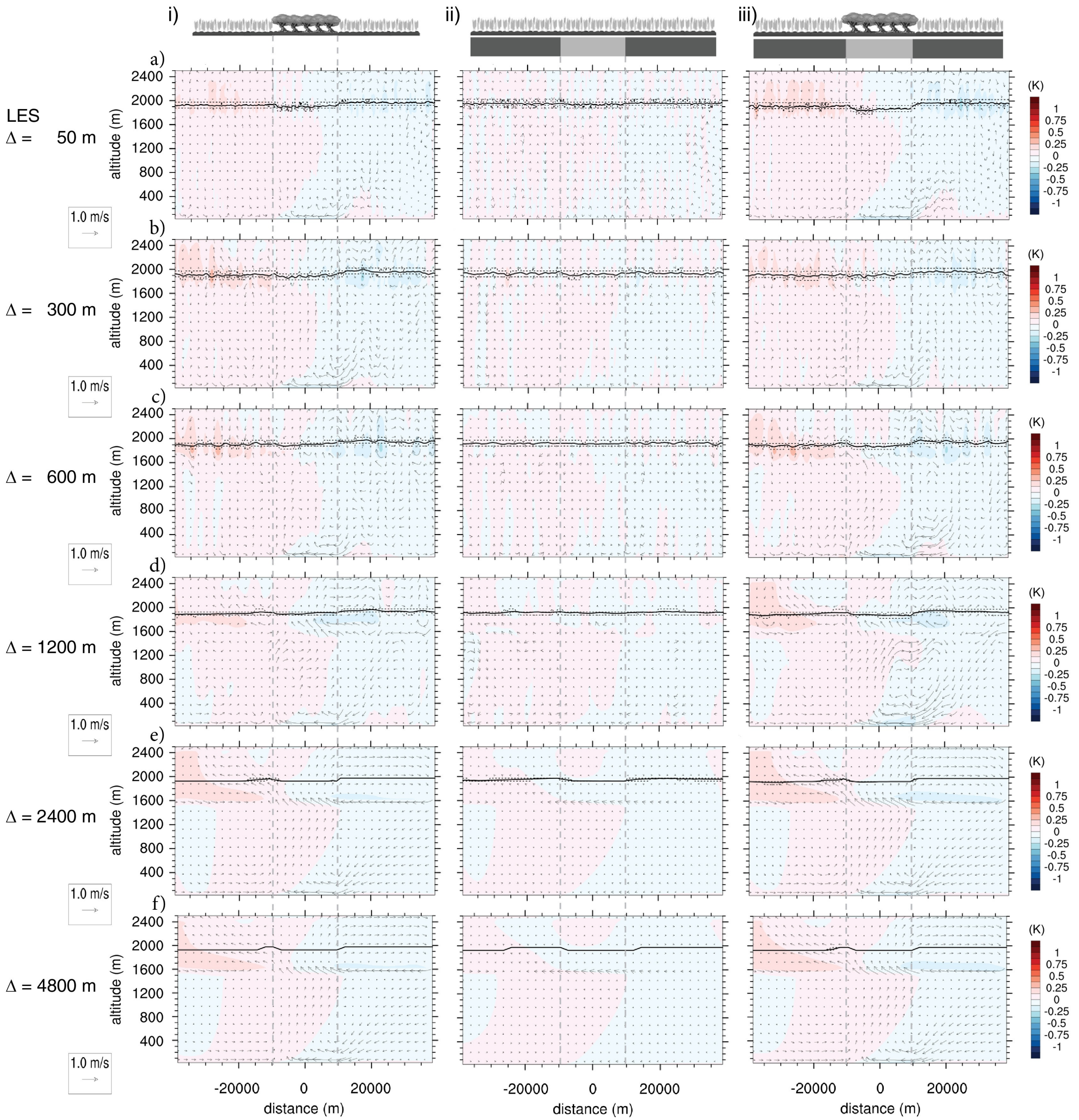




RESULTS

Atmospheric boundary layer response

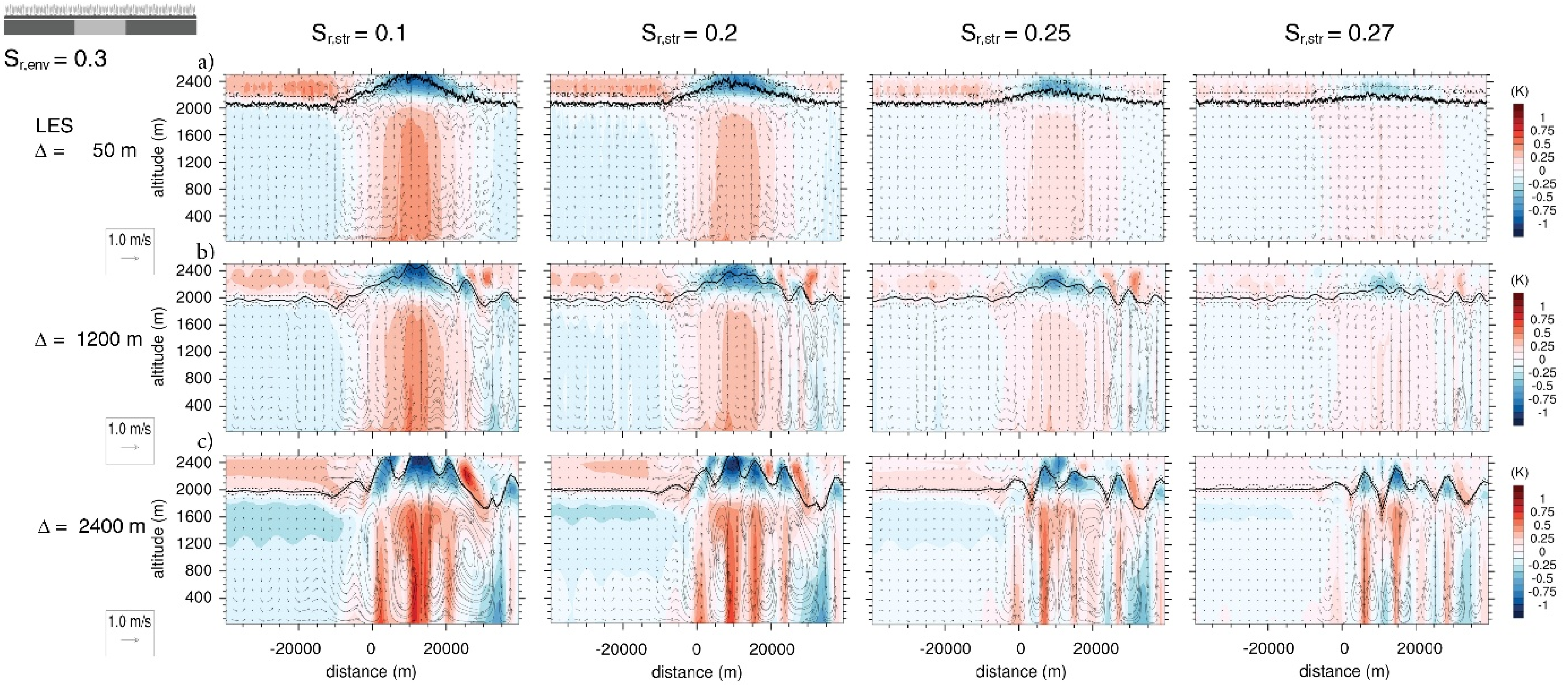
- V0= 15 m/s



RESULTS

Atmospheric boundary layer response

- V0= 3 m/s



RESULTS

Atmospheric boundary layer response

- Sr_env= 0.3; Sr_str=0.2