LES For Beginners

palm group

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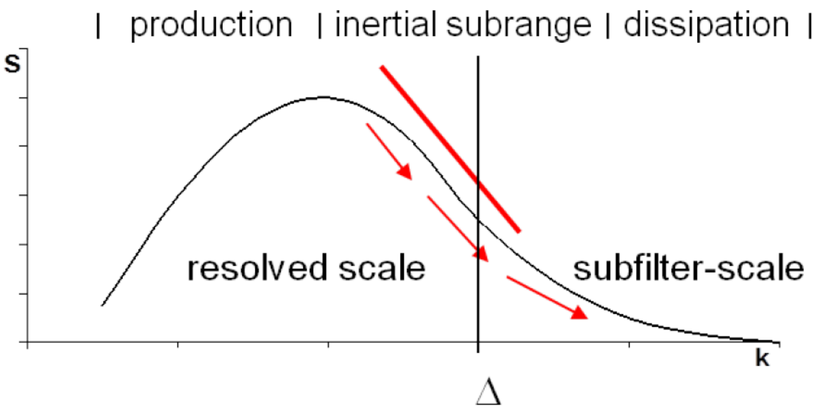
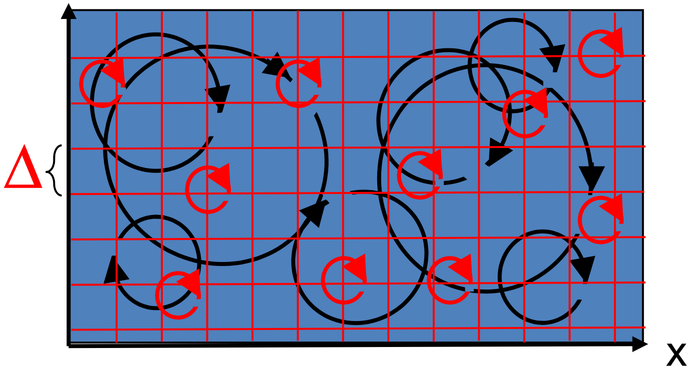
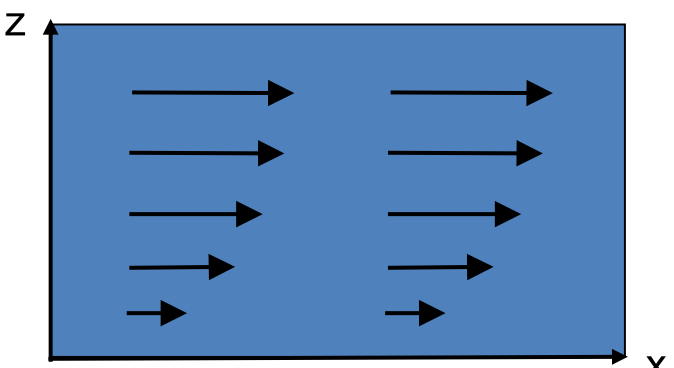
LES in a nutshell





LES: volume average

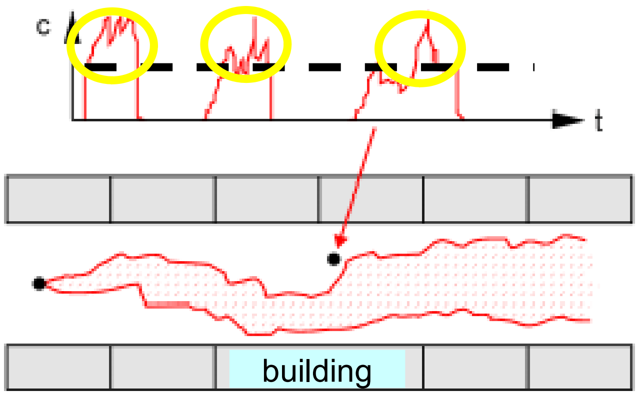


RANS, k-ε: ensemble average

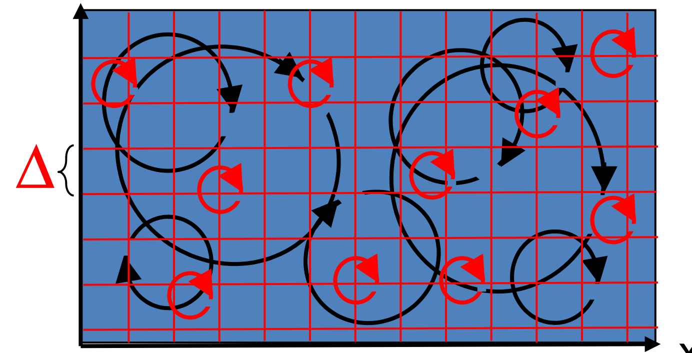
LES For Beginners

LES in a nutshell

local concentration time series



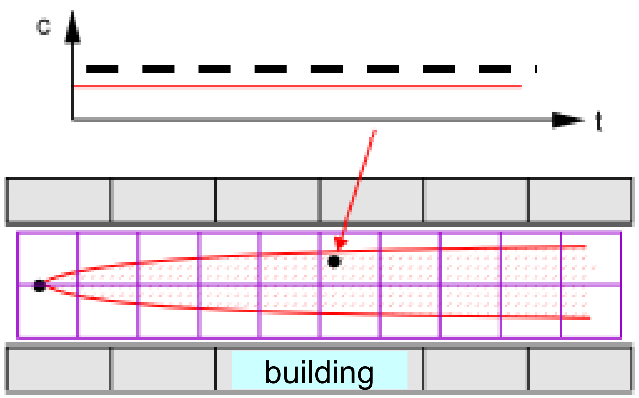
fluctuations
(**u**, c)



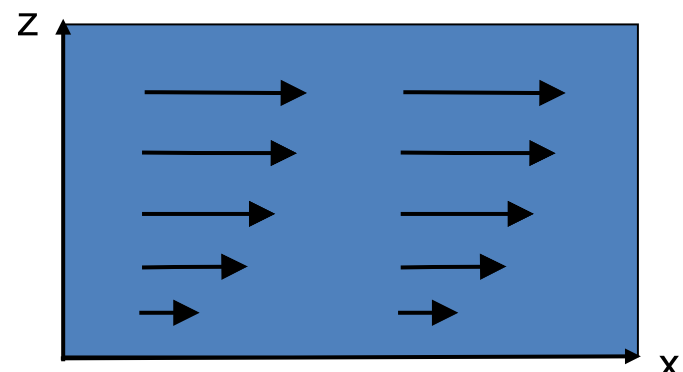
LES: volume average

- - - - critical concentration level

local concentration time series



smooth result



RANS, k-ε: ensemble average

after Schatzmann and Leitl (2001)

Important points for carrying out simulations (I)

Carrying out LES requires several important points to be taken care off!

- **Domain size**
  - Must be large enough to capture all relevant scales of turbulence. It should contain several of the largest structures (for possible interactions among them, and for sufficient statistics). → **carry out sensitivity study**
- **Grid spacing**
  - Must be fine enough to resolve most of the turbulent transport (explicit transport >> subgrid-scale transport, E_{SGS} < (<<) $E_{resolved}$).
    → check profiles of resolved-scale and subgrid-scale fluxes
  - Results should not depend on the grid spacing. → **carry out sensitivity study**
- **Horizontal boundary conditions**
  - The inflow/outflow boundaries must not effect the flow turbulence, therefore cyclic boundary conditions are used in most cases.
  - In case of Dirichlet conditions at inflow boundaries, a turbulence signal has to be added at the inflow.

Important points for carrying out simulations (II)

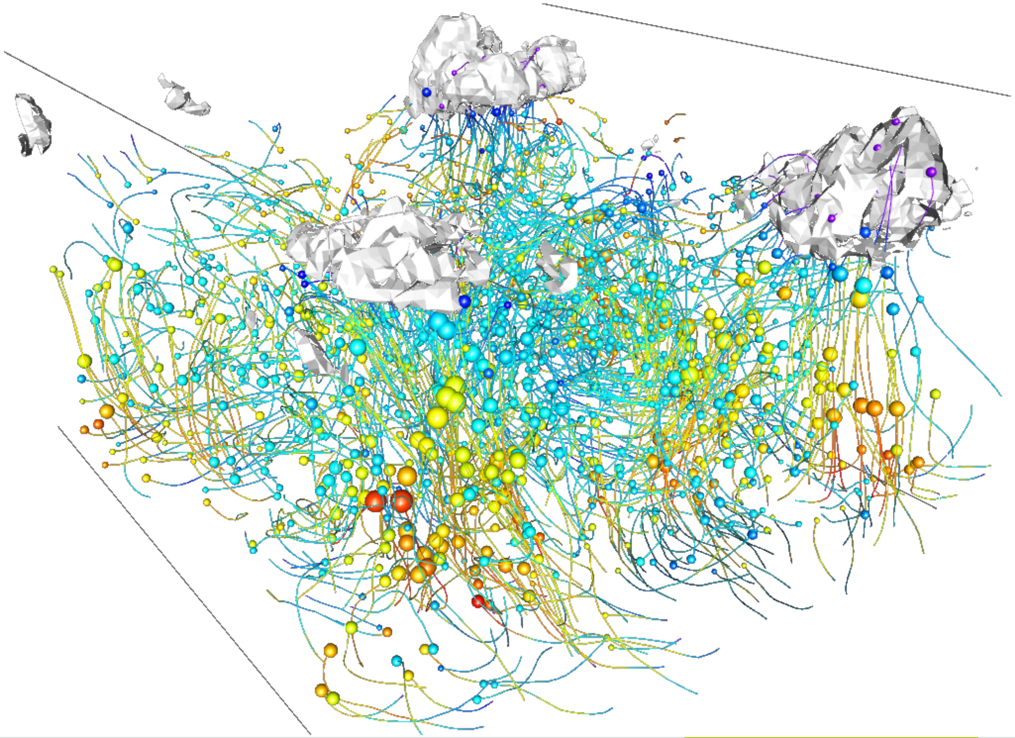
- **Simulation time**
  - Simulations have to be run for a long time to reach a (quasi-) stationary state and stable statistics, both for mean flow **AND** turbulence. There will always be a spinup time for turbulence at the beginning.
    → check the time series of velocity components or resolved-scale TKE
  - In case of horizontally homogeneous initial and boundary conditions, the onset of turbulence has to be triggered by imposing random disturbances to the flow. Otherwise, there may be no turbulence!
- **Data analysis**
  - Results during the spinup of turbulence should not be used for analysis. Data analysis should start only after onset of turbulence and after the mean flow has reached a (quasi-) stationary state.
  - Getting correct mean flow profiles often requires additional temporal averaging of the data (e.g., over the eddy-turnover timescale in the convective boundary layer). Turbulence statistics might be poor if averaging is insufficient.

simple LES for a homogeneous CBL

Setup:

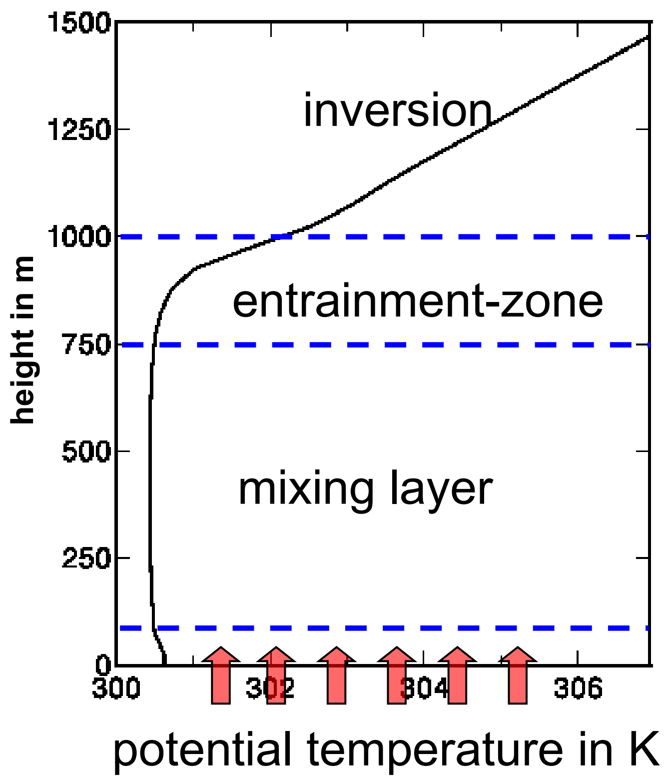
homogeneously heated surface,
temperature inversion at z = 800 m,
domain size: 2 * 2 km², Δ = 50 m
cyclic horizontal boundary conditions

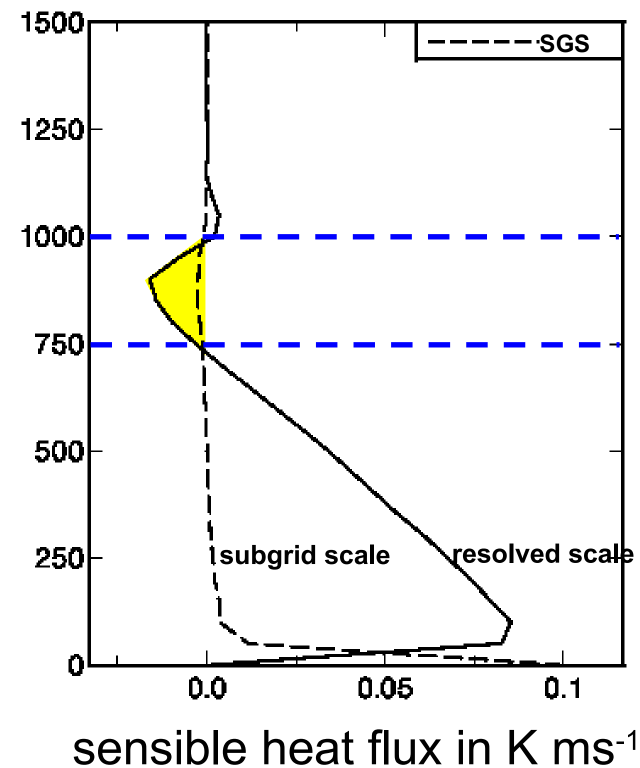
- particles = passive tracers
- colour ~ buoyancy: ↑ ↓
- diameter ~ |vertical velocity|
- (isosurface = cumulus cloud)



simple LES for a homogeneous CBL, example output (I)

- **Mean state profiles**
  - Data horizontally averaged over the whole model domain
  - Meaningful for horizontally homogeneous cases only





How to calculate turbulence quantities from LES data? (I)

- **LES distinguishes between *resolved-scale* and *subgrid-scale* quantities**
  - Turbulent fluctuations are in general defined as the deviation from a mean state $\langle \phi \rangle$. The mean can be, e.g., a spatial or a temporal mean.
  - Prognostic (volume averaged) quantities in LES contain both the mean flow **and** the resolved-scale turbulence: $\overline{\phi} = \langle \overline{\phi} \rangle + \overline{\phi}*$
  - Resolved-scale turbulence quantities have to be calculated from the resolved-scale prognostic quantities.
  - Some subgrid-scale quantities (mainly the SGS-fluxes) can be calculated directly (but most of them are unknown!).

How to calculate turbulence quantities from LES data? (II)

- **Example: calculating the turbulent transport (turbulent momentum flux)**
  - Resolved-scale transport includes transport by mean flow and transport by resolved-scale turbulence:

$$\frac{\partial \overline{u}_i}{\partial t} = \ldots - \frac{\partial \overline{u}_k \overline{u}_i}{\partial x_k} \ldots - \frac{\partial \overline{u_k' u_i'}}{\partial x_k}$$

resolved-scale transport

subgrid-scale transport

  - In case of horizontal homogeneity:

$$\overline{u}_i = \langle \overline{u}_i \rangle + \overline{u}_i^*$$

deviation with respect to horizontal average = resolved-scale turbulence

horizontal average (varies with z)

instantaneous value

$$\overline{u}_i^* = \overline{u}_i - \langle \overline{u}_i \rangle$$

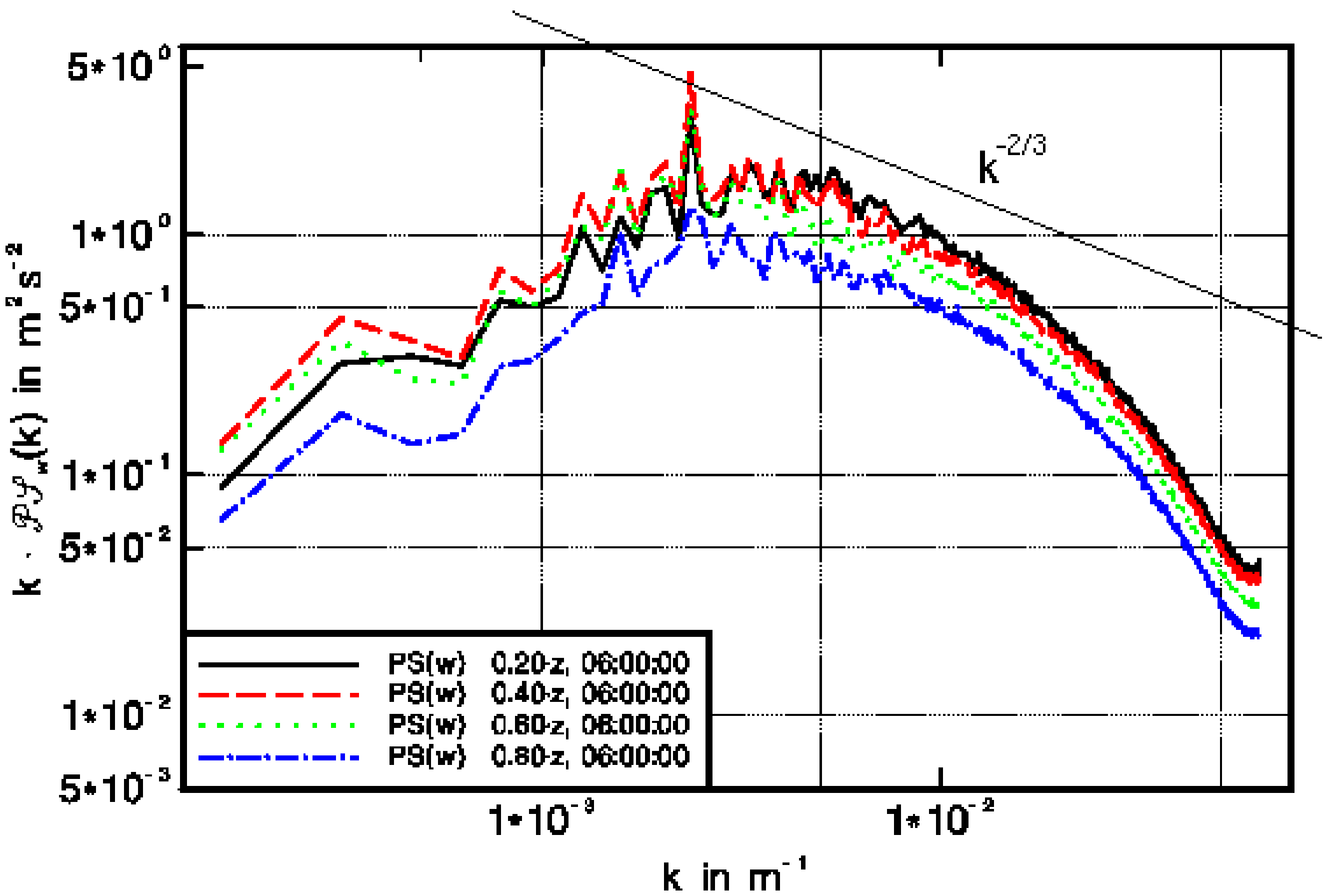
  - Resolved-scale **turbulent** transport: $\langle \overline{u}_k^* \overline{u}_i^* \rangle$

spatial eddy-correlation (EC) method

How to calculate turbulence quantities from LES data? (III)

- **Spatial eddy-correlation method**
  - **Advantage:** Can be calculated at any time step from the instantaneous data (they are all resident in the memory).
  - Uncertainty of turbulence quantities can be improved by enlarging the data set.
    - enlarged domain size (requires horizontally homogeneous conditions)
    - additional temporal average (requires turbulence to be in a stationary state)
    - ensemble runs (if non-homogeneous and non-stationary)
  - In LES models (like PALM) many of the resolved-scale turbulence quantities (turbulent fluxes, variances, higher order moments) are calculated online (during the simulation) and output as vertical profiles.
    Calculation in a post-processing step would result in excessive data output.
  - **Attention:** Spatial EC method only works under condition of a **horizontally homogeneous mean flow**! See lecture *topography* for how to handle horizontally inhomogeneous flow conditions using the temporal EC method.

simple LES for a homogeneous CBL, example output (II)



power spectrum of vertical velocity