Exercise 2: Neutrally Stratified Boundary Layer

PALM group

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Please choose domain size, grid size and time to be simulated appropriately.

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- Is it really a large-eddy simulation, i.e., are the subgrid-scale fluxes much smaller than the resolved-scale fluxes?
- How do the turbulence spectra of u, v, w along x and along y look like?
  Can you identify the inertial subrange?

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  - Output of vertical profile data generated by the 1D-model is controlled by parameter `dt_pr_1d`. It is in ASCII-format and it is written into a separate file. You can include the profiles of the 1D-model, which are used to initialize the 3D-model, in the standard profile data output of the 3D-model (which is controlled by parameter `data_output_pr`) by adding a `'#'` sign to the respective output quantity, e.g. `data_output_pr = '#u'`.
  - For the 1D-model, please set `mixing_length_1d = 'blackadar'` and `dissipation_1d = 'detering'` in order to get a correct mean boundary layer wind profile. The default settings of these parameters would switch the turbulence parameterization of the 1D-model to the SGS-parameterization of the 3D-LES-model, which represents only the SGS-parts of turbulence. However, for this exercise the 1D-model has to parameterize all scales of turbulence (i.e., it should be used as a RANS-model).

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- **Stationary state:**
  - You probably will find it difficult to get the mean flow to a stationary state (for the 1D-model as well as for the 3D-model. Can you identify the mechanism responsible for this? Try parameters `damp_level_1d` (for the 1D-model) and `rayleigh_damping_factor` (for the 3D-model; this is a `inipar`-parameter!) to overcome this problem.

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  - You can switch on a Galilei-transformation in order to save CPU-time (see parameter galilei_transformation).

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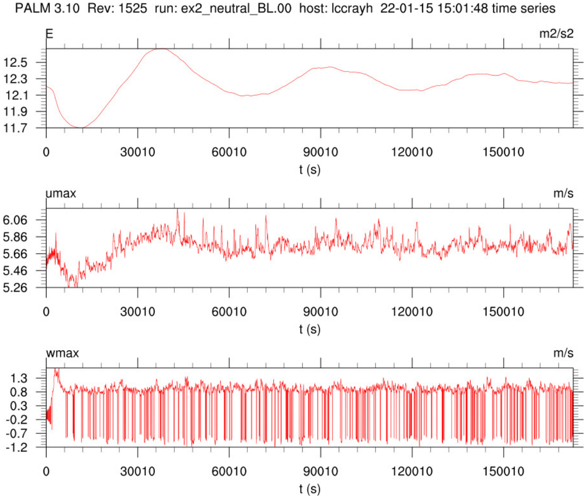
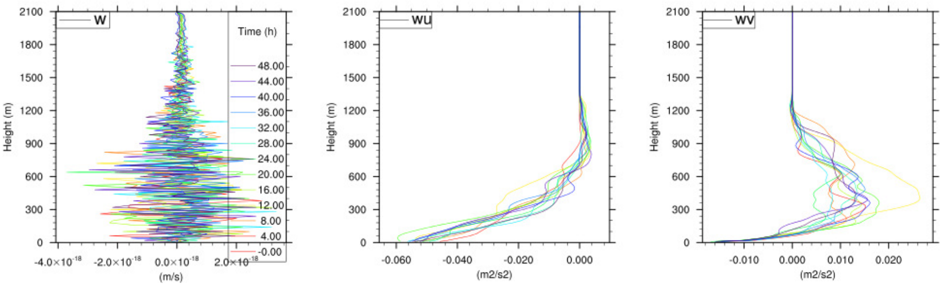
  - Spectra output is controlled by parameters `data_output_sp`, `dt_dosp`, etc. These package-parameters have to be given in a separate NAMELIST-block which has to follow the `d3par`-block:
    ```
    &d3par end_time = ... /
    &spectra_par data_output_sp = ... /
    ```

Time series of TKE, umax and wmax

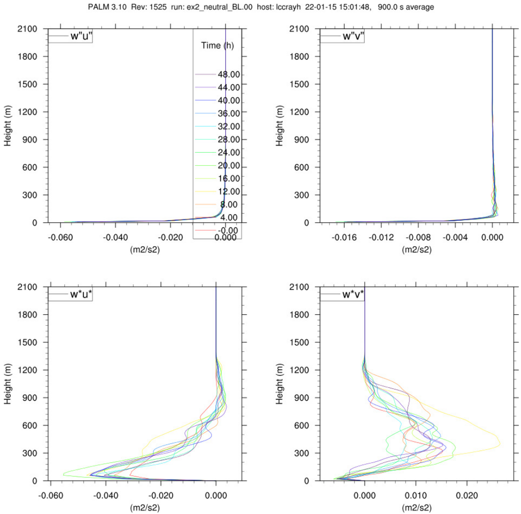


Vertical profiles of $\overline{w}$, $\overline{wu}$, $\overline{wv}$

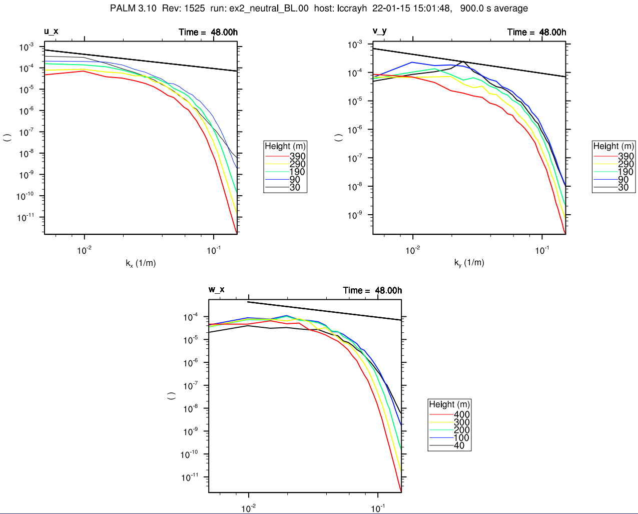
PALM 3.10 Rev: 1525 run: ex2_neutral_BL.00 host: lccrayh 22-01-15 15:01:48, 900.0 s average



Vertical profiles of $\overline{w'u'}$, $\overline{w'v'}$, $\overline{w``u''}$ and $\overline{w``v''}$



Spectra of *u*, *v* and *w*



Answers to question I

How long do you have to simulate until turbulence / mean flow become stationary?

- As can be seen in frame 6, a simulation time of about 48 h should at least be taken to obtain a roughly constant kinetic energy.
- The time series of E shows an oscillation with a period of roughly 14 h. This can be attributed to the inertial oscillation affecting the air parcels due to the Coriolis force. This oscillation is damped with time.
- umax and wmax do not change much in time after the spin-up time of roughly 6 h.

Answers to question II

How do the horizontally and temporally averaged vertical velocity and momentum flux profiles look like?

- The profiles are shown in frame 7. The horizontally averaged vertical velocity is practically zero as the usage of incompressible equations together with cyclic boundary conditions (horizontal homogeneity) suggest.
- wu an wv decrease with height since friction decelerates the flow at the surface. Due to the turning of the wind vector with height (Ekman spiral), the meridional velocity component is non-zero evoking also a non-zero vertical momentum flux of the v-velocity component.
- The non-convergence of the single profiles can be attributed to the inertial oscillation.

Answers to question III

Is it really a large-eddy simulation?

- Frame 8 shows sub-grid and resolved momentum flux profiles.
- The simulation is an LES since resolved momentum fluxes are the dominant components to the total flux except for the near vicinity of the surface where the unresolved, sub-grid fluxes dominate.

Answers to question IV

Can you identify the inertial subrange?

- In PALM, the spectral density is normalized by means of the variance and additionally multiplied by the wave number. Thus, the spectral density appearing on the ordinate of the plots in frame 9 is dimensionless.
- The spectra show a maximum spectral density for small wave numbers. Thus, the largest eddies contain the highest variance (or turbulence kinetic energy, TKE). For higher wave numbers the inertial subrange follows where the spectra follow a -2/3 slope in the plot (indicated by a black line). There, the variance follows the energy cascade where larger eddies break-up into smaller eddies. For the highest wave numbers, the spectra depart from the -2/3 slope indicating that dissipation takes place.
- The spectra also show that the production range is not well developed (very flat maxima). This suggests that the modeling domain might be too small to capture relevant larger scales.