Dataset description

# Turbulent Ekman flow with cubic small-scale surface roughness ($Re_D = 1000$, $Ri = 0$)

Direct numerical simulation – Set-up and vertical profiles

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## 1 Metadata



**Collection** This dataset is part of the collection *Turbulent wall-bounded flow*[3].

The collection is freely available and hosted by Refubium, the institutional repository of Freie Universität Berlin.

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**HPC systems** The data was generated under the project `TrainABL` on the supercomputer `HAWK` at Höchstleistungsrechenzentrum Stuttgart (HLRS, in Germany).

**Code** The data was generated by the tool-suite for turbulence simulation tLab[4].

## 2 The dataset

### 2.1 Contents

The dataset files, collectively named with grid information and the date of creation of the data on the High-Performance Computing (HPC) system. Each file of the collection contains time-series of statistical data for flow and scalar variables in a self-documented netCDF format and a namelist with the file name dns.ini, which is a plain text file holding the configuration of the tLab code (for documentation, please refer to the open-source code available under `github.com/turbulencia/tlab`). In the case of heterogeneous surface conditions, an additional netCDF file is provided that describes the geometry of the surface roughness.

### 2.2 Physical case

This dataset contains 4 simulation cases (`ID: s, r1, r2, r3`), with a similar computational grid, domain size and driven by the same large-scale forcing, but differ in the surface condition. Case `s` has a smooth surface and the rough cases `r1, r2, r3` feature each $56^2$ square

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blocks on the lower domain boundary with a uniform height and width distribution. The mean height of the roughness elements increases from case `r1` via `r2` to `r3`. These simulation cases, conducted with a Reynolds number of $Re_D = 1000$ ($Re_D = DG/\nu$, with the laminar Ekman-layer depth $D = \sqrt{2\nu/f}$, Coriolis parameter $f$, geostrophic wind $G$ and the kinematic viscosity $\nu$), corresponding to a friction Reynolds number $Re_\tau$ of 1408 for the smooth case `s`, delves into the study of the turbulent flow with small-scale surface roughness. Utilizing a computational grid measuring 3072 x 656 x 3072 collocation points with a spatial resolution of 2.3 x 1.0 x 2.3 wall units (smooth case), the domain size is scaled to $L_x = L_z = 0.27\ \Lambda$, where $\Lambda = G/f$ is the Rossby radius.

## 2.3 Variable information

The statistical data is available in self-documented netCDF format, and it contains a wide array of parameters, encompassing vertical profiles of velocity and scalar variables (temperature/buoyancy as active and for some cases also passive scalars), scalar and momentum budget terms, as well as statistical moments up to the fourth order of velocities, scalars, and derivatives. These parameters provide a comprehensive perspective on Ekman flow dynamics. They are organized into distinct groups. Within the subsequent table, you will find numerous variables grouped together, accompanied by their descriptions and associated equations.
In order to fully describe the geometry of the surface roughness, there are horizontal domain slices for each of the rough cases (`r1, r2, r3`) in netCDF format, that describe the positions and heights of the roughness elements in grid points.

## Vertical profiles flow

| | | |
|---|---|---|
| **Mean** | | |
| rR | density (RA) | $\overline{\rho}$ |
| rU | u, x-component of the velocity (RA) | $\overline{u}$ |
| rV | v, y-component of the velocity (RA) | $\overline{v}$ |
| rW | w, z-component of the velocity (RA) | $\overline{w}$ |
| rP | $\pi$ dynamic, reduced pressure (RA) | $\overline{\pi}$ |
| rT | $T$, caloric temperature (RA) | $\overline{T}$ |
| re | $e$, internal energy (RA) | $\overline{e}$ |
| rh | $h$, enthalpy (RA) | $\overline{e+(\Gamma_0-1)Ma^2\frac{p}{\rho}}$ |
| rs | $s$, entropy (RA) | $\overline{s}$ |
| rB | $B$, buoyancy (RA) | $\overline{B}$ |
| fU | u, x-component of the velocity (FA) | $\langle u\rangle$ |
| fV | v, y-component of the velocity (FA) | $\langle v\rangle$ |
| fW | w, z-component of the velocity (FA) | $\langle w\rangle$ |
| fT | $T$, caloric Temperature (FA) | $\langle T\rangle$ |
| fe | $e$, internal energy (FA) | $\langle e\rangle$ |
| fh | $h$, enthalpy (FA) | $\left\langle e+(\Gamma_0-1)Ma^2\frac{p}{\rho}\right\rangle$ |
| fs | $s$, entropy (FA) | $\langle s\rangle$ |
| **Fluctuations** | | |
| Tke | turbulence kinetic energy | $\overline{\frac{1}{2}u_i'u_i'}$ |
| Rxx | Reynolds stress $R_{11}$ | $\overline{u'u'}$ |
| Ryy | Reynolds stress $R_{22}$ | $\overline{v'v'}$ |
| Rzz | Reynolds stress $R_{33}$ | $\overline{w'w'}$ |
| Rxy | Reynolds stress $R_{12}$ | $\overline{u'v'}$ |
| Rxz | Reynolds stress $R_{13}$ | $\overline{u'w'}$ |
| Ryz | Reynolds stress $R_{23}$ | $\overline{v'w'}$ |
| rP2 | pressure fluctuation (RA) | $\overline{\pi'\pi'}$ |
| rR2 | density fluctuation (RA) | $\overline{\rho'\rho'}$ |
| rT2 | temperature fluctuation (RA) | $\overline{T'T'}$ |
| fT2 | temperature fluctuation (FA) | $\langle T'T'\rangle$ |
| re2 | internal energy fluctuation (RA) | $\overline{e'e'}$ |
| fe2 | internal energy fluctuation (FA) | $\langle e'e'\rangle$ |
| rh2 | enthalpy fluctuation (RA) | $\overline{h'h'}$ |
| fh2 | enthalpy fluctuation (FA) | $\langle h'h'\rangle$ |
| rs2 | entropy fluctuation (RA) | $\overline{s's'}$ |
| fs2 | entropy fluctuation (FA) | $\langle s's'\rangle$ |
| **DerivativeFluctuations** | | |
| U_y1 | | $\overline{\partial_y u}$ |
| V_y1 | | $\overline{\partial_y v}$ |
| W_y1 | | $\overline{\partial_y w}$ |
| U_ii2 | | |
| U_x2 | | $\overline{(\partial_x u')^2}$ |
| U_y2 | | $\overline{(\partial_y u')^2}$ |
| U_z2 | | $\overline{(\partial_z u')^2}$ |
| V_x2 | | $\overline{(\partial_x v')^2}$ |
| V_y2 | | $\overline{(\partial_y v')^2}$ |
| V_z2 | | $\overline{(\partial_z v')^2}$ |
| W_x2 | | $\overline{(\partial_x w')^2}$ |
| W_y2 | | $\overline{(\partial_y w')^2}$ |
| W_z2 | | $\overline{(\partial_z w')^2}$ |
| U_x3 | | $\overline{(\partial_x u')^3}$ |
| U_y3 | | $\overline{(\partial_y u')^3}$ |
| U_z3 | | $\overline{(\partial_z u')^3}$ |
| V_x3 | | $\overline{(\partial_x v')^3}$ |
| V_y3 | | $\overline{(\partial_y v')^3}$ |
| V_z3 | | $\overline{(\partial_z v')^3}$ |
| W_x3 | | $\overline{(\partial_x w')^3}$ |
| W_y3 | | $\overline{(\partial_y w')^3}$ |
| W_z3 | | $\overline{(\partial_z w')^3}$ |
| U_x4 | | $\overline{(\partial_x u')^4}$ |
| U_y4 | | $\overline{(\partial_y u')^4}$ |
| U_z4 | | $\overline{(\partial_z u')^4}$ |
| V_x4 | | $\overline{(\partial_x v')^4}$ |
| V_y4 | | $\overline{(\partial_y v')^4}$ |
| V_z4 | | $\overline{(\partial_z v')^4}$ |
| W_x4 | | $\overline{(\partial_x w')^4}$ |
| W_y4 | | $\overline{(\partial_y w')^4}$ |
| W_z4 | | $\overline{(\partial_z w')^4}$ |
| **Vorticity** | | |
| Wx | vorticity (x-component) | $\overline{\partial_z v-\partial_y w}$ |
| Wy | vorticity (y-component) | $\overline{\partial_x w-\partial_z u}$ |
| Wz | vorticity (z-component) | $\overline{\partial_y u-\partial_x v}$ |
| Wx2 | fluctuation of x-Vorticity | $\overline{\partial_z v'-\partial_y w'}$ |
| Wy2 | fluctuation of y-Vorticity | $\overline{\partial_x w'-\partial_z u'}$ |
| Wz2 | fluctuation of z-Vorticity | $\overline{\partial_y u'-\partial_x v'}$ |
| **RxxBudget** | | |
| Rxx_t | time-rate of change of $R_{11}$ | $\overline{\partial_t R_{11}}$ |
| Bxx | buoyancy production | $2b_x\overline{u'B'}$ |
| Cxx | advection in y-direction | $-\overline{v}\ \partial_y\overline{u'u'}$ |
| Pxx | shear-production | $-2\ \overline{u'v'}\ \partial_y\overline{u}$ |
| Exx | viscous dissipation | |
| PIxx | pressure-velocity correlation $\Pi_{11}$ | $2\ \overline{u'p'}$ |
| Fxx | Coriolis production | $2f_y\overline{u'w'}$ |
| Txxy_y | divergence of $T_{112}$ turbulent transport | $\partial_y R_{112}$ |
| Txxy | vertical transport $T_{112}$ | $\overline{u'u'v'}-2\nu\overline{\partial_y(u-\langle u\rangle)}$ |
| Gxx | pressure variable-density term | 0 |
| Dxx | viscous variable-density term | |
| **RyyBudget** | | |
| Ryy_t | time-rate of change of $R_{22}$ | $\overline{\partial_t R_{22}}$ |
| Byy | buoyancy production of Ryy | $2b_y\overline{v'B'}$ |
| Cyy | advection in y-direction | $\overline{v}\ \partial_y\overline{v'v'}$ |
| Pyy | shear production | $-2\overline{v'v'}\partial_y\overline{v}$ |
| Eyy | viscous dissipation | |
| PIyy | pressure–velocity correlation $\Pi_{22}$ | $2\overline{v'p'}$ |
| Fyy | Coriolis production | 0 |
| Tyyy_y | divergence of $T_{222}$ turbulent transport | $\partial_y R_{222}$ |
| Tyyy | vertical transport $T_{222}$ | $\overline{v'v'v'}+2\overline{v'p'}-2\nu\overline{(\partial_y v)(v-\langle v\rangle)}$ |
| Gyy | pressure variable-density term | $2(\overline{v}-\langle v\rangle)\partial_y\overline{p}$ |
| Dyy | viscous variable-density term | |
| **RzzBudget** | | |
| Rzz_t | time-rate of change of $R_{33}$ | $\overline{\partial_t R_{33}}$ |
| Bzz | buoyancy production | $2b_z\overline{w'B'}$ |
| Czz | advection in y-direction | $-\overline{v}\ \partial_y\ \overline{w'w'}$ |
| Pzz | shear production | $-2\overline{v'w'}\partial_y\ \overline{w}$ |
| Ezz | viscous dissipation | |
| PIzz | pressure–velocity correlation $\Pi_{33}$ | $2\overline{w'p'}$ |
| Fzz | Coriolis production of Rzz | $-2f_y\overline{u'w'}$ |
| Tzzy_y | divergence of $T_{332}$ turbulent transport | $\partial_y R_{332}$ |
| Tzzy | vertical transport $T_{332}$ | $\overline{w'w'v'}-2\nu\overline{(\partial_y w)(w-\langle w\rangle)}$ |
| Gzz | pressure variable-density term | 0 |
| Dzz | viscous variable-density term | |
| **RxyBudget** | | |
| Rxy_t | time-rate of change of $R_{12}$ | $\overline{\partial_t R_{12}}$ |
| Bxy | buoyancy production | $b_x\overline{u'B'}+b_y\overline{v'B'}$ |
| Cxy | advection in y-direction | $-\overline{v}\partial_y\overline{u'v'}$ |
| Pxy | shear production | $-\overline{u'v'}\partial_y\overline{v}-\overline{v'v'}\ \partial_y\overline{u}$ |
| Exy | viscous dissipation | |
| PIxy | pressure-velocity correlation $\Pi_{12}$ | $\overline{p'\,(\partial_y u-\partial_x v)}$ |
| Fxy | Coriolis production of Rxy | $f_y\overline{v'w'}$ |
| Txyy_y | divergence of $T_{122}$ turbulent transport | $\partial_y R_{122}$ |
| Txyy | vertical transport $T_{122}$ | $\overline{u'v'v'}+\overline{u'p'}$ |
| Gxy | pressure variable-density term | $(\overline{u}-\langle u\rangle)\partial_y\overline{p}$ |
| Dxy | viscous variable-density term | |
| **RxzBudget** | | |
| Rxz_t | time-rate of change of $R_{13}$ | $\overline{\partial_t R_{13}}$ |
| Bxz | buoyancy production | $b_x\overline{u'B'}+b_z\overline{u'B'}$ |
| Cxz | advection in y-direction | $-\overline{v}\ \partial_y\overline{u'w'}$ |
| Pxz | shear production | $-\overline{u'w'}\ \partial_y\ \overline{w}-\overline{v'w'}\ \partial_y\overline{u}$ |
| Exz | viscous dissipation | |
| PIxz | pressure–velocity correlation $\Pi_{13}$ | $\overline{p'\,(\partial_z u-\partial_x w)}$ |
| Fxz | Coriolis production | $f_y(\overline{w'w'-u'u'})$ |
| Txzy_y | divergence of $T_{132}$ turbulent transport | $\partial_y R_{132}$ |
| Txzy | vertical transport $T_{132}$ | $\overline{u'w'v'}$ |
| Gxz | pressure variable-density term | 0 |
| Dxz | viscous variable-density term | |
| **RyzBudget** | | |
| Ryz_t | time-rate of change of $R_{23}$ | $\overline{\partial_t R_{23}}$ |
| Byz | buoyancy production | $b_y\overline{v'B'}+b_z\overline{w'B'}$ |
| Cyz | advection in y-direction | $-\overline{v}\partial_y\overline{v'w'}$ |
| Pyz | shear production | $-\overline{v'v'}\ \partial_y\ \overline{w}-\overline{v'w'}\ \partial_y\overline{v}$ |
| Eyz | viscous dissipation | |
| PIyz | pressure–velocity correlation $\Pi_{23}$ | $\overline{p'\,(\partial_z v-\partial_y w)}$ |
| Fyz | Coriolis production | $-f_y\overline{u'v'}$ |
| Tyzy_y | turbulent transport divergence | $\partial_y R_{232}$ |
| Tyzy | vertical transport $T_{232}$ | $\overline{v'w'v'}+\overline{w'p'}$ |
| Gyz | pressure variable-density term | $(\overline{w}-\langle w\rangle)\partial_y\overline{p}$ |
| Dyz | viscous variable-density term | |
| **TkeBudget** | | |
| Tke_t | time-rate of change of Tke | $\overline{\partial_t\frac{1}{2}R_{ii}}$ |
| Tke | turbulence kinetic energy | $\frac{1}{2}R_{ii}$ |
| Buo | buoyancy production of Tke | $\frac{1}{2}B_{ii}$ |
| Con | advection in y-direction | $\frac{1}{2}C_{ii}$ |
| Prd | shear production | $\frac{1}{2}P_{ii}$ |
| Eps | dissipation | $\frac{1}{2}E_{ii}$ |
| Pi | pressure–velocity correlation | $\frac{1}{2}\Pi_{ii}$ |
| Trp | sum of transport terms | $\frac{1}{2}T_{ii2}$ |
| Trp1 | transport due to triple correlation terms | $\overline{u_i'u_i'v'}$ |
| Trp2 | transport by pressure–velocity correlation | $2\overline{v'p'}$ |
| Trp3 | viscous transport | $-2\nu\overline{(\partial_y u_i)(u_i-\langle u_i\rangle)}$ |
| Trp1_y | divergence of triple correlations | $\partial_y\overline{u_i'u_i'v'}$ |
| Trp2_y | divergence of pressure–velocity correltion | $2\partial_y\overline{v'p'}$ |
| Trp3_y | divergence of viscous transport | $-2\nu\partial_y\overline{(\partial_y u_i)(u_i-\langle u_i\rangle)}$ |
| G | pressure variable-density term | $\frac{1}{2}G_{ii}$ |
| D | viscous variable-density term | $\frac{1}{2}D_{ii}$ |
| Phi | mean viscous dissipation rate | |
| UgradP | | $\overline{u_i\partial_{x_i}p}$ |
| **HigherOrder** | | |
| rU3 | | |
| rU4 | | |
| rV3 | | |
| rV4 | | |
| rW3 | | |
| rW4 | | |
| **Acoustics** | | |
| gamma | | |
| C2 | | |
| Rho_ac | | |
| Rho_en | | |
| T_ac | | |
| T_en | | |
| M_t | | |
| rRP | | |
| rRT | | |
| **RhoBudget** | | |
| RhoFluxX | | |
| RhoFluxY | | |
| RhoFluxZ | | |
| RhoDil1 | | |
| RhoDil2 | | |
| RhoTrp | | |
| RhoProd | | |
| RhoConv | | $-\overline{v}\partial_y\overline{\rho'\rho'}$ |
| **Stratification** | | |
| Pot | potential energy | |
| rRref | background density profile | |
| rTref | background temperature profile | |
| BuoyFreq_fr | buoyancy frequency | |
| BuoyFreq_eq | buoyancy frequency | |
| LapseRate_fr | lapse rate | |
| LapseRate_eq | lapse rate | |
| PotTemp | | |
| PotTemp_v | | |
| SaturationPressure | | |
| rPref | background pressure profile | |
| RelativeHumidity | | |
| Dewpoint | dewpoint temperature | |
| LapseRate_dew | | |
| **Roughness** | | |
| eps_0 | fluid fraction (grid-based approach) | |
| eps_1 | solid fraction (grid-based approach) | |
| eps_f | fluid fraction (volume-based approach) | |
| eps_s | solid fraction (volume-based approach) | |

## Vertical profiles scalar

| | | |
|---|---|---|
| **Mean** | | |
| rS | scalar (RA) | $\overline{s}$ |
| rQ | scalar source (RA) | |
| rS_y | y-derivative of scalar (RA) | $\overline{\partial_y s}$ |
| fS | scalar (FA) | $\langle s\rangle$ |
| fS_y | y-derivative of scalar (FA) | $\langle \partial_y s\rangle$ |
| fQ | scalar source (FA) | |
| **Fluctuations** | | |
| Rsu | covariance $R_{su}$ (of scalar $s$ and velocity $u$) | $\overline{s'u'}$ |
| Rsv | covariance $R_{sv}$ (of scalar $s$ and velocity $v$) | $\overline{s'v'}$ |
| Rsw | covariance $R_{sw}$ (of scalar $s$ and velocity $w$) | $\overline{s'w'}$ |
| rS2 | scalar variance $R_{ss}$ (RA) | $\overline{s's'}$ |
| rS3 | | $\overline{s's's'}$ |
| rS4 | | $\overline{s's's's'}$ |
| fS2 | scalar variance (FA) | $\langle s's'\rangle$ |
| fS3 | | $\langle s's's'\rangle$ |
| fS4 | | $\langle s's's's'\rangle$ |
| **DerivativeFluctuations** | | |
| S_x2 | | $\overline{(\partial_x s')^2}$ |
| S_y2 | | $\overline{(\partial_y s')^2}$ |
| S_z2 | | $\overline{(\partial_z s')^2}$ |
| S_x3 | | $\overline{(\partial_x s')^3}$ |
| S_y3 | | $\overline{(\partial_y s')^3}$ |
| S_z3 | | $\overline{(\partial_z s')^3}$ |
| S_x4 | | $\overline{(\partial_x s')^4}$ |
| S_y4 | | $\overline{(\partial_y s')^4}$ |
| S_z4 | | $\overline{(\partial_z s')^4}$ |
| **RssBudget** | | |
| Rss_t | time-rate of change of $R_{ss}$ | $\overline{\partial_t R_{ss}}$ |
| Css | advection in y-direction | $-\langle v\rangle\ \partial_y\overline{s's'}$ |
| Pss | gradient production | $-2\overline{s'v'}\partial_y\langle s\rangle$ |
| Ess | molecular dissipation | |
| Tssy1 | turbulent transport due to triple correlation | $\overline{s's'v'}$ |
| Tssy2 | transport | $-2\kappa_d\overline{s'\partial_y s'}$ |
| Tssy_y | turbulent transport | $\partial_y(\text{Tssy1}+\text{Tssy2})$ |
| Dss | diffusion variable-density term | |
| Qss | source | |
| **RsuBudget** | | |
| Rsu_t | time-rate of change of $R_{su}$ | $\overline{\partial_t R_{su}}$ |
| Csu | advection in y-direction | $-\langle v\rangle\ \partial_y\overline{s'u'}$ |
| Psu | shear and gradient production | $-\overline{s'v'}\partial_y\langle u\rangle\ -\overline{u'v'}\partial_y\langle s\rangle$ |
| Esu | molecular dissipation | |
| PIsu | pressure redistribution | $\overline{p'\partial_x s'}$ |
| Tsuy1 | turbulent transport due to triple correlation | $\overline{s'u'v'}$ |
| Tsuy2 | transport | |
| Tsuy_y | turbulent transport | $\partial_y(\text{Tsuy1}+\text{Tsuy2})$ |
| Dsu | diffusion variable-density term | |
| Gsu | pressure-flux | 0 |
| Bsu | buoyant production | 0 |
| Fsu | Coriolis production | $f_y\overline{s'w'}$ |
| Qsu | source | |
| **RsvBudget** | | |
| Rsv_t | time-rate of change of $R_{sv}$ | $\overline{\partial_t R_{sv}}$ |
| Csv | advection in y-direction | $-\langle v\rangle\ \partial_y\overline{s'v'}$ |
| Psv | shear and gradient production | $-\overline{s'v'}\partial_y\langle v\rangle\ -\overline{v'v'}\partial_y\langle s\rangle$ |
| Esv | molecular dissipation | |
| PIsv | pressure redistribution | $\overline{p'\partial_y s'}$ |
| Tsvy1 | turbulent transport due to triple correlation | $\overline{s'v'v'}$ |
| Tsvy2 | transport | |
| Tsvy3 | transport | $\overline{p's'}$ |
| Tsvy_y | turbulent transport | $\partial_y(\text{Tsvy1}+\text{Tsvy2}+\text{Tsvy3})$ |
| Dsv | diffusion variable-density term | |
| Gsv | pressure-flux | $\overline{s'\partial_y p'}$ |
| Bsv | buoyant production | $\overline{\rho b's'}$ |
| Fsv | Coriolis production | 0 |
| Qsv | source | |
| **RswBudget** | | |
| Rsw_t | time-rate of change of $R_{sw}$ | $\overline{\partial_t R_{sw}}$ |
| Csw | advection in y-direction | $-\langle v\rangle\ \partial_y\overline{s'w'}$ |
| Psw | shear and gradient production | $-\overline{s'v'}\partial_y\langle w\rangle\ -\overline{v'w'}\partial_y\langle s\rangle$ |
| Esw | molecular dissipation | |
| PIsw | pressure redistribution | $\overline{p'\partial_z s'}$ |
| Tswy1 | turbulent transport due to triple correlation | $\overline{s'v'w'}$ |
| Tswy2 | transport | |
| Tswy_y | turbulent transport | $\partial_y(\text{Tswy1}+\text{Tswy2})$ |
| Dsw | diffusion variable-density term | |
| Gsw | pressure-flux | 0 |
| Bsw | buoyant production | 0 |
| Fsw | Coriolis production | $-f_y\overline{s'u'}$ |
| Qsw | source | |
| **CrossScalars** | | |
| Cs1 | | |
| Css1 | | |
| **Roughness** | | |
| Sbcs | scalar boundary values applied on solids | |
| eps_0 | fluid fraction (grid-based approach) | |
| eps_1 | solid fraction (grid-based approach) | |
| eps_f | fluid fraction (volume-based approach) | |
| eps_s | solid fraction (volume-based approach) | |

| Horizontal distribution of roughness elements | |
|---|---|

| HorizontalSlice | |
|---|---|
| eps2d | horizontal (x,z) distribution of roughness heights of the elements in grid points |