Dataset description

Turbulent Ekman flow ($Re_D = 1000$, $Ri = 0$)

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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[4] `github.com/turbulencia/tlab`

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 ν), corresponding to a friction Reynolds number Re_τ 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	π 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 Π_{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 Π_{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 Π_{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 Π_{12}	$\overline{p'\left(\partial_y u-\partial_x v\right)}$
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 Π_{13}	$\overline{p'\left(\partial_z u-\partial_x w\right)}$
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 Π_{23}	$\overline{p'\left(\partial_z v-\partial_y w\right)}$
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	$\partial_y(\mathrm{Tssy1} + \mathrm{Tssy2})$
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	$\partial_y(\mathrm{Tsuy1} + \mathrm{Tsuy2})$
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	$\partial_y(\mathrm{Tsvy1} + \mathrm{Tsvy2} + \mathrm{Tsvy3})$
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	$\partial_y(\mathrm{Tswy1} + \mathrm{Tswy2})$
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