Dataset description

Turbulent Ekman flow under stable stratification

Set-up and vertical profiles for $Re_D = 1000$

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1 Metadata

Collection This data set is part of the collection *Turbulent wall-bounded flow*[2].

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 `hku24` on the supercomputer `JUGENE` at John-von-Neumann Institute for Computing (NIC) at Forschungszentrum Jülich (Germany).

Code The data was generated by the tool-suite for turbulence simulation tLab[3]

Related Publications

10.1007/s10546-014-9941-3
10.1017/jfm.2016.534
10.1175/JAS-D-21-0053.1
10.48550/arXiv.2110.02253
10.1017/jfm.2018.693
10.1007/978-3-319-29130-7_34

2 The dataset

2.1 Contents

The dataset files are 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 a namelist file (dns.ini), which is a plain text file holding the configuration of the tLab code for the respective case (for documentation, please refer to Open-source code available under github.com/turbulencia/tlab).

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[2] `refubium.fu-berlin.de/handle/fub188/42710`
[3] `github.com/turbulencia/tlab`

2.2 Physical case

This dataset contains statistics of resolved-turbulence simulation for turbulent Ekman flow, the flow over a flat rotating plate. The five simulation cases differ by the strength of stable density stratification imposed as a Dirichlet boundary condition at the surface and quantified in the non-dimensional formulation as Froude and Richardson numbers (cf. Tab. 1). Here, cases are labelled by their Froude numbers as `fr02, fr05, fr07, fr09, fr18`.

The physical case is characterized by four parameters: geostrophic wind vector $\vec{G}$, the fluid kinematic viscosity ν, the Coriolis parameter f, and the buoyancy difference B_0 between the wall and free stream (the molecular Prandtl number equals one, i.e. the kinematic diffusivity equals the viscosity). The rossby radius $\Lambda = G/f$ is the length scale implied for this choice of parameters. We let $G \equiv \left|\vec{G}\right|$ and align the coordinate direction O_x with $\vec{G}$. The flow is then governed by two dimensionless groups; we choose the Reynolds number Re, the Froude number Fr, and give the bulk Richardson number Ri_B (which is a scaled version of the inverse Froude number) for completeness:

$$Re_\Lambda = \frac{G\Lambda}{\nu} \quad , \quad Fr_\Lambda = \frac{G^2}{B_0\Lambda} \quad \text{and} \quad Ri_{B\text{neutral}} = \frac{B_0\delta_\text{neutral}}{G^2}. \tag{1}$$

Here the bulk Richardson number is evaluated based on the boundary layer thickness of the neutrally stratified case such that it does not evolve over the course of simulation. The choice of $Re_\Lambda = 5 \times 10^5$ corresponds to an Ekman-based Reynolds-number of 1000 and a friction Reynolds number $Re_\tau \approx 1400$ for the neutrally stratified case. All simulations utilize a computational grid of 3072 x 512 x 6144 collocation points with a spatial resolution of approximately 4.1 × 4.1 × 1.05 wall units. The horizontal domain size in terms of the Rossby radius $L_x = L_y = 1.08\ \Lambda$.

case identifier	`fr18`	`fr09`	`fr07`	`fr05`	`fr02`
Re_Λ			5×10^5		
Fr_Λ	0.1825	0.0913	0.0684	0.0456	0.0228
$Ri_{B\text{neutral}}$	0.29	0.58	0.77	1.16	2.32
t_start/f	9.76	12.59	16.40	19.29	23.32
t_end/f	12.89	16.40	19.29	21.23	26.63
$\Delta(t/f)$	3.13	3.81	2.90	1.94	3.31
#iterations	20 400	25 500	20 200	13 950	25 200

Table 1: Simulations used. t_start/f is the time in inertial periods over which the initial condition of the flow is exposed to stable stratification. $\Delta(t/f) = (t_\text{end} - t_\text{start})/f$ is the duration of the simulation and #iterations is the number of Runge–Kutta time-integration steps used for integration of the problem over the respective time span.

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.

	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	
VarDilatation	Variance of Dilatation	$\overline{(\partial_{x_i}u_i-\partial_y\overline{v})^2}$
VarUx		$\overline{(\partial_x u')^2}$
VarUy		$\overline{(\partial_y u')^2}$
VarUz		$\overline{(\partial_z u')^2}$
VarVx		$\overline{(\partial_x v')^2}$
VarVy		$\overline{(\partial_y v')^2}$
VarVz		$\overline{(\partial_z v')^2}$
VarWx		$\overline{(\partial_x w')^2}$
VarWy		$\overline{(\partial_y w')^2}$
VarWz		$\overline{(\partial_z w')^2}$
SkewUx		
SkewUy		
SkewUz		
SkewVx		
SkewVy		
SkewVz		
SkewWx		
SkewWy		
SkewWz		
FlatUx		
FlatUy		
FlatUz		
FlatVx		
FlatVy		
FlatVz		
FlatWx		
FlatWy		
FlatWz		
	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	$\overline{\partial_x w'-\partial_z x'}$
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	
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}	$\overline{p'\,(\partial_y u-\partial_x v)}$
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 Π_{13}	$\overline{p'\,(\partial_z u-\partial_x w)}$
Fxz	Coriolis production	$f_y(\overline{w'w'}-\overline{u'u'})$
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}	$\overline{p'\,(\partial_z v-\partial_y w)}$
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	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		$\overline{u_i\partial_{x_i}p}$
	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	
BuoyFreq_fr	buoyancy frequency	
BuoyFreq_eq	buoyancy frequency	
LapseRate_fr	lapse rate	
LapseRate_eq	lapse rate	
SaturationPressure		
RelativeHumidity		
Source		
rSb		
PotTemp_fr		
PotTemp_eq		
rP0		
rPmod		
Ri_f		
Ri_g		
	Scales	
Eta	Kolmogorov Scale	
LambdaUx	Taylor micro-scale in x-direction	
LambdaVy	Taylor micro-scale in y-direction	
LambdaWz	Taylor micro-scale in z-direction	
ReLambdaUx	Taylor-Reynolds number in x-direction	
ReLambdaVy	Taylor-Reynolds number in y-direction	
ReLambdaWz	Taylor-Reynolds number in z-direction	
ReLambdaIso	Taylor-Reynolds number	
	TurbDiffusivities	
EddyDiff	turbulent eddy diffusivity (for scalar)	
EddyVisc	turbulent eddy viscosity (for momentum)	
TurbPrandtl	turbulent Prandtl number	
	ShearThicknesses	
Delta_m		
Delta_m_p		
Delta_w		
	MixingThicknesses	
Delta_hb01		
Delta_ht01		
Delta_h01		
Delta_hb25		
Delta_ht25		
Delta_h25		
	FrictionTerms	
FrictionVelocity	magnitude of surface shear stress	$u_\star$
FrictionThickness	height-scale related to surface friction	$u_\star/f$
FrictionAngle	angle α of negative surface shear stress with the x-axis	