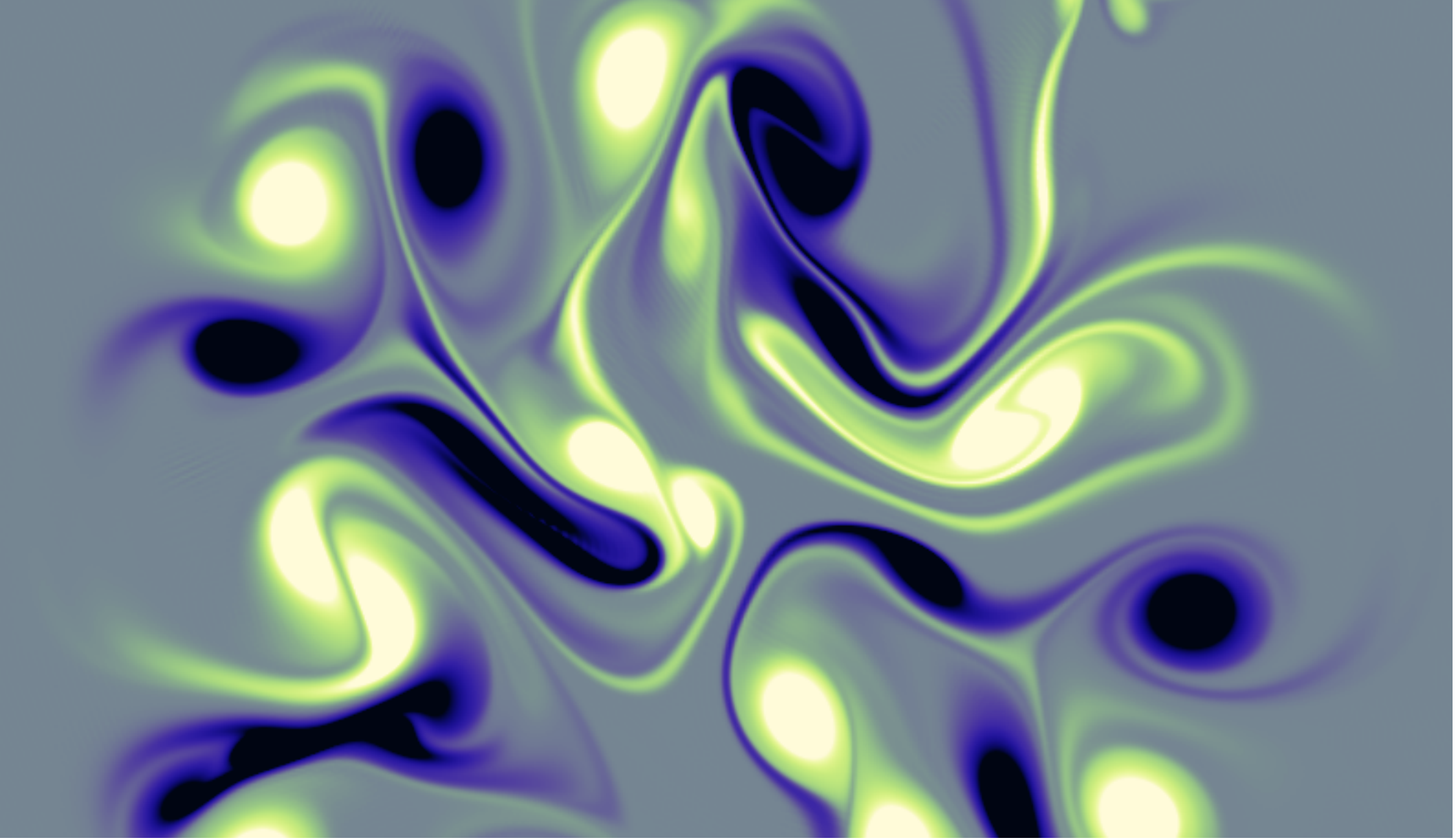
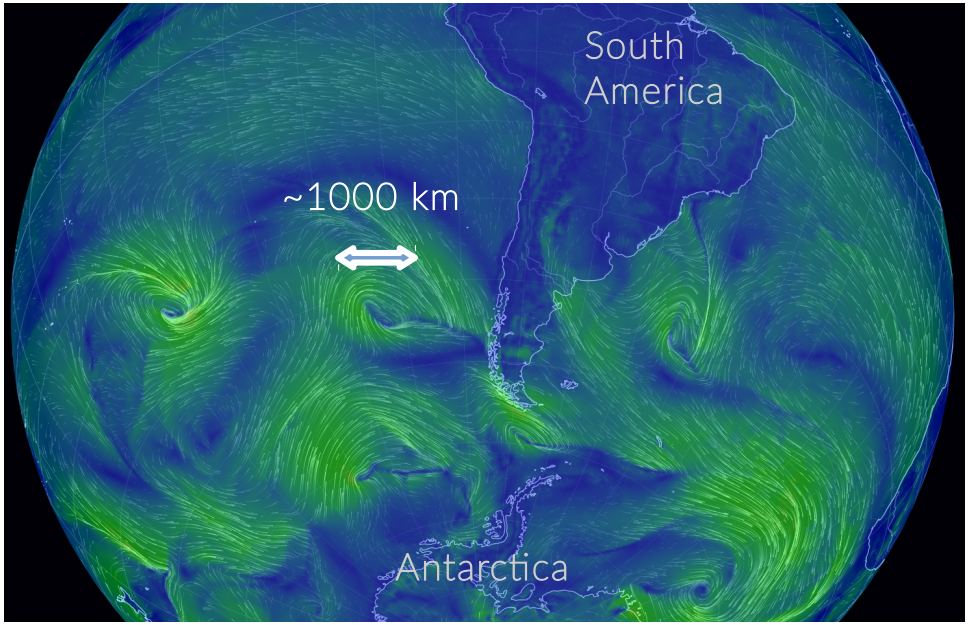


Upward and downward transfer of energy in rotating stratified flows

E. Horne, M. Hussein, J-M. Chomaz, P. Billant. Ladhyx, Paris. APS DFD 2019.

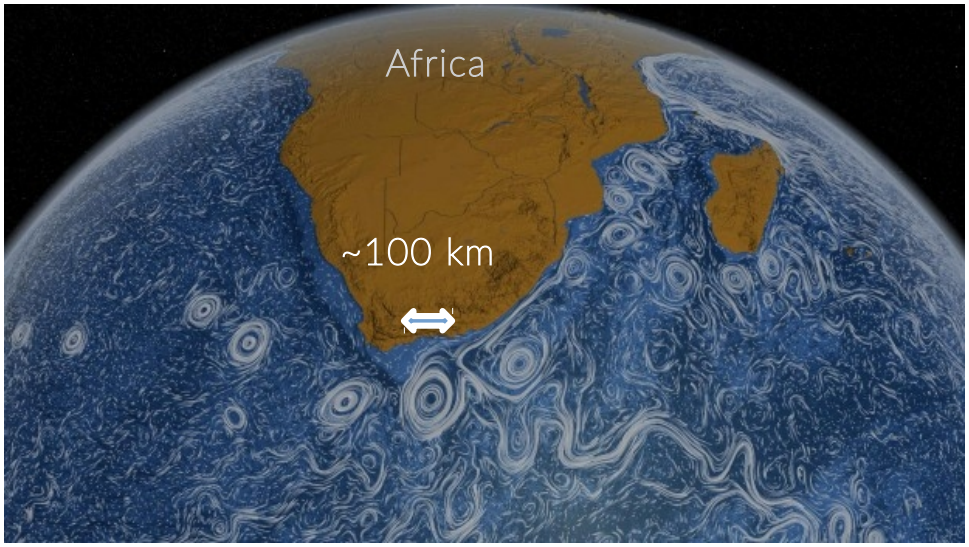
Geophysical stratified and rotating turbulence

Atmosphere



Wind direction and intensity at the southern hemisphere. Source: Earth nullschool.

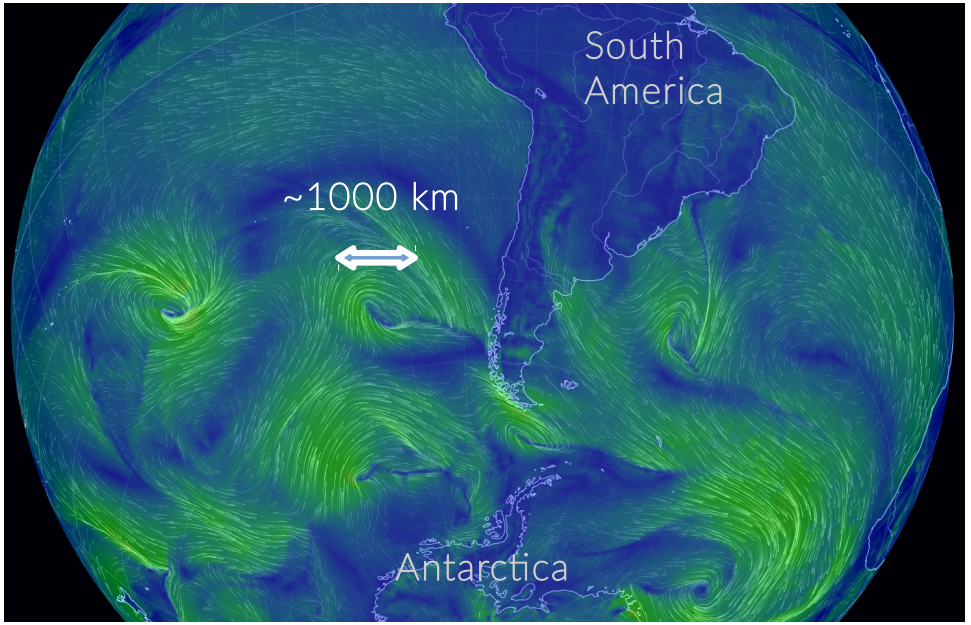
Ocean



Ocean surface currents at the south of South Africa. Source: Nasa Goddard.

Geophysical stratified and rotating turbulence

Atmosphere



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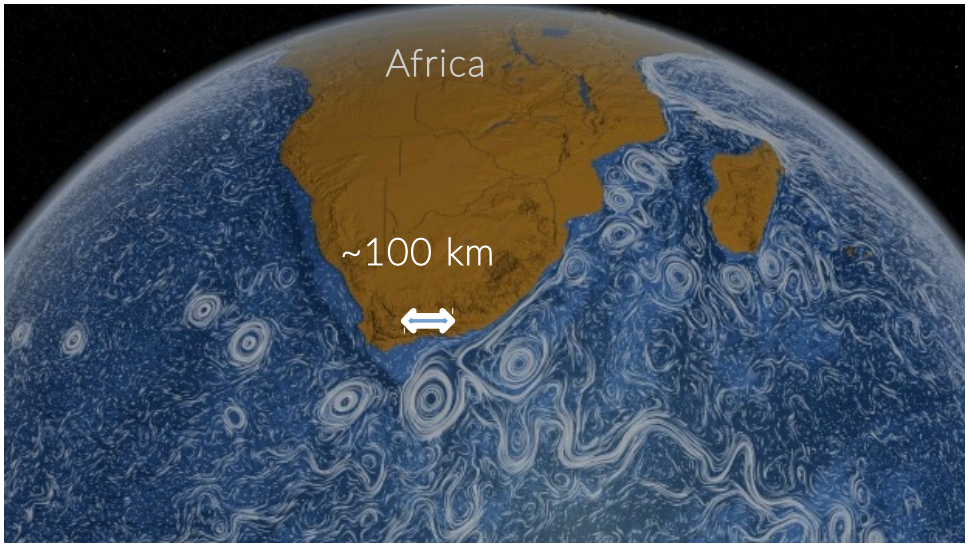

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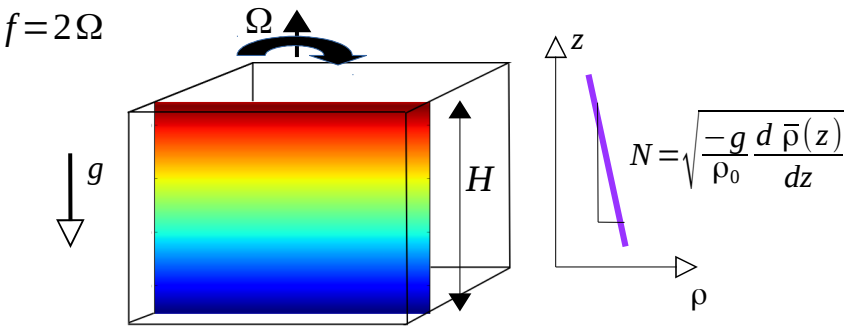
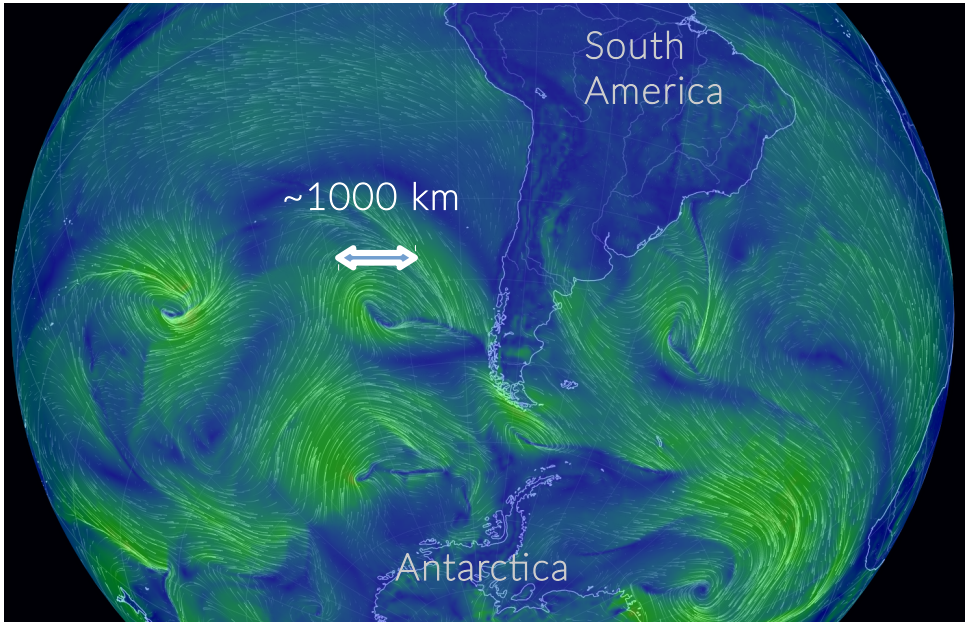


Geophysical stratified and rotating turbulence

Atmosphere



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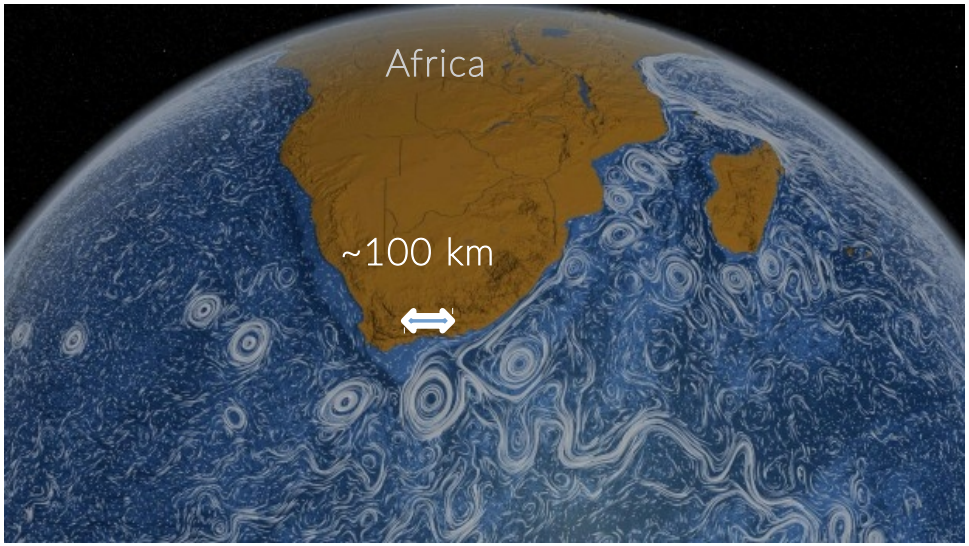


Ocean surface currents at the south of South Africa. Source: Nasa Goddard.

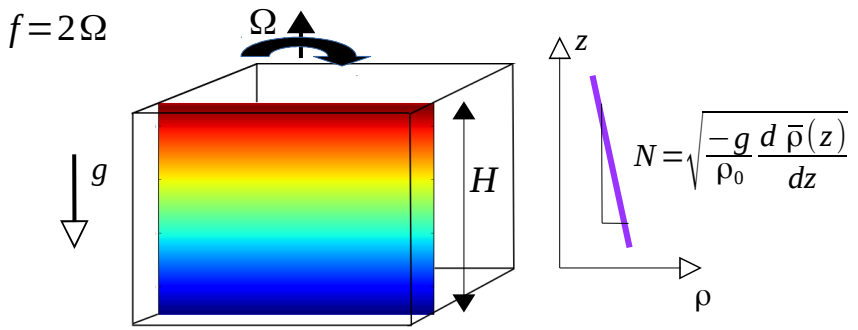
Baroclinic instability

Atmosphere

$$L_d = \frac{N\,H}{f} = \frac{10^{-2}\,10^{4}}{10^{-4}} = 1000\,km$$

Ocean

$$L_d = \frac{N\,H}{f} = \frac{10^{-2}\,10^{3}}{10^{-4}} = 100\,km$$



Large scale geophysical turbulence

Quasi-geostrophic balance

- Large scale turbulence is governed by the quasi-geostrophic balance.

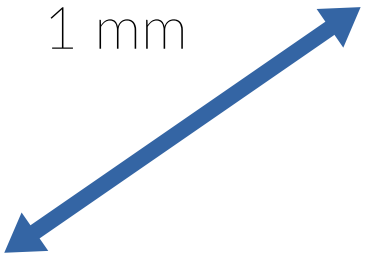
- Presents a quasi-two-dimensional type dynamics. Therefore upward cascade.

- With the exception of Eckman friction the energy has to be dissipated at small scales.

Large scale geophysical turbulence

Quasi-geostrophic balance

Dissipation occurs at the small scales



- Large scale turbulence is governed by the quasi-geostrophic balance.

- Presents a quasi-two-dimensional type dynamics. Therefore upward cascade.

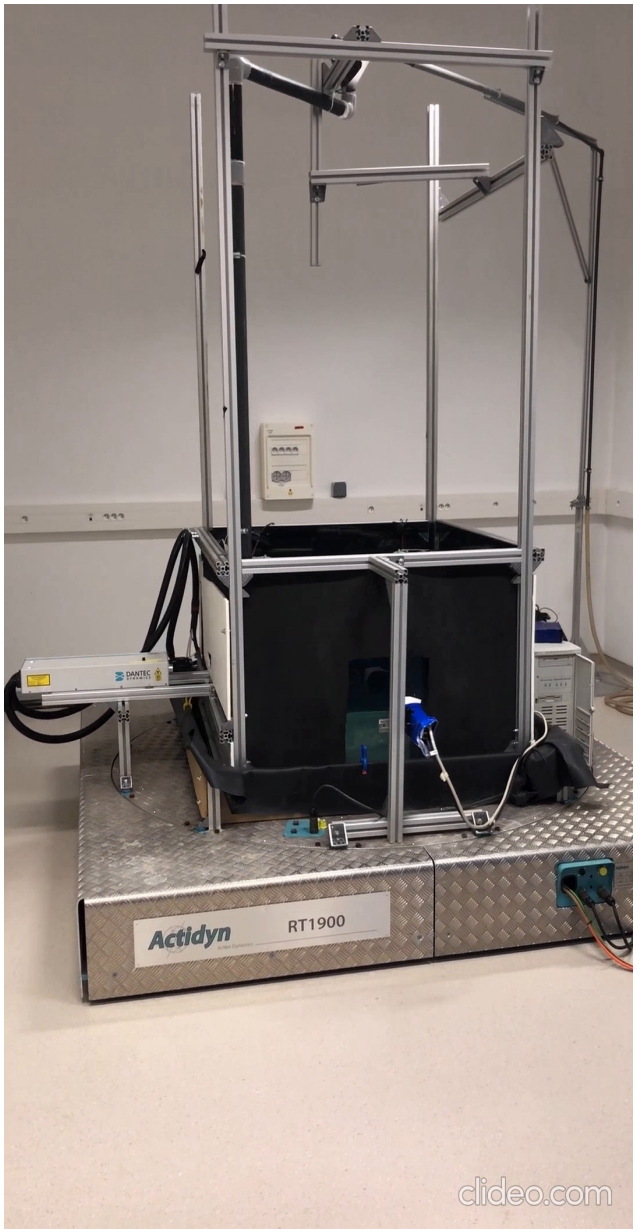
- With the exception of Eckman friction the energy has to be dissipated at small scales.

How is the energy transport to small scales?

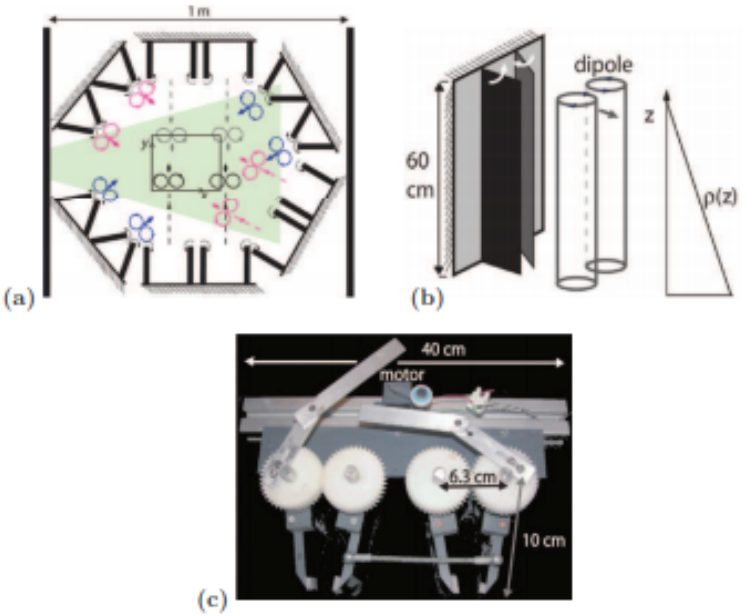
Pouquet & Marino. PRL. 2013.

Experimental setup

- Columnar vortex forcing
- Stratification: N~1.5 rad/s
- Rotation: 0.1- 5 tour/min
- PIV measurements



Columnar vortex forcing



Observations

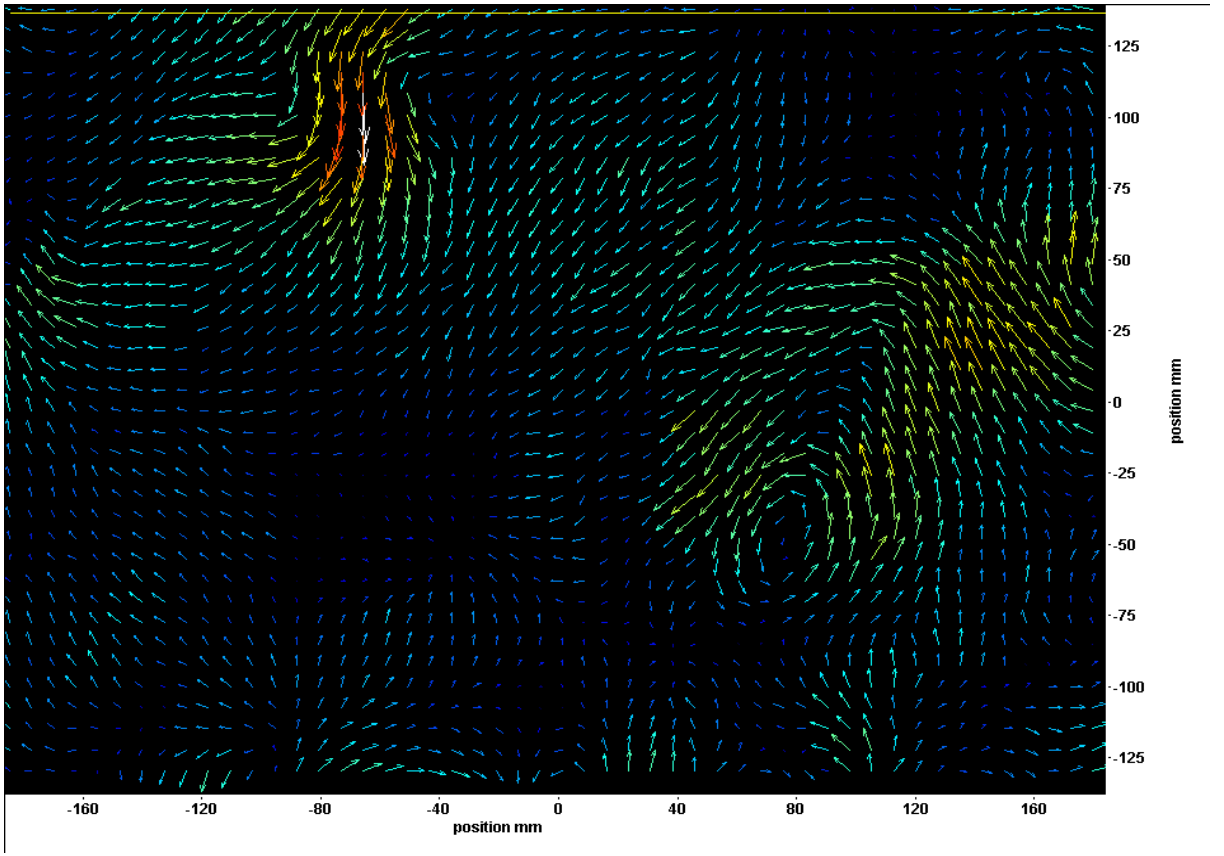
Top View

Dimensionless numbers explored;

Reynolds: $Re = \frac{UL}{\nu} \approx 450$

Froude: $Fr = \frac{U}{LN} \approx 1$

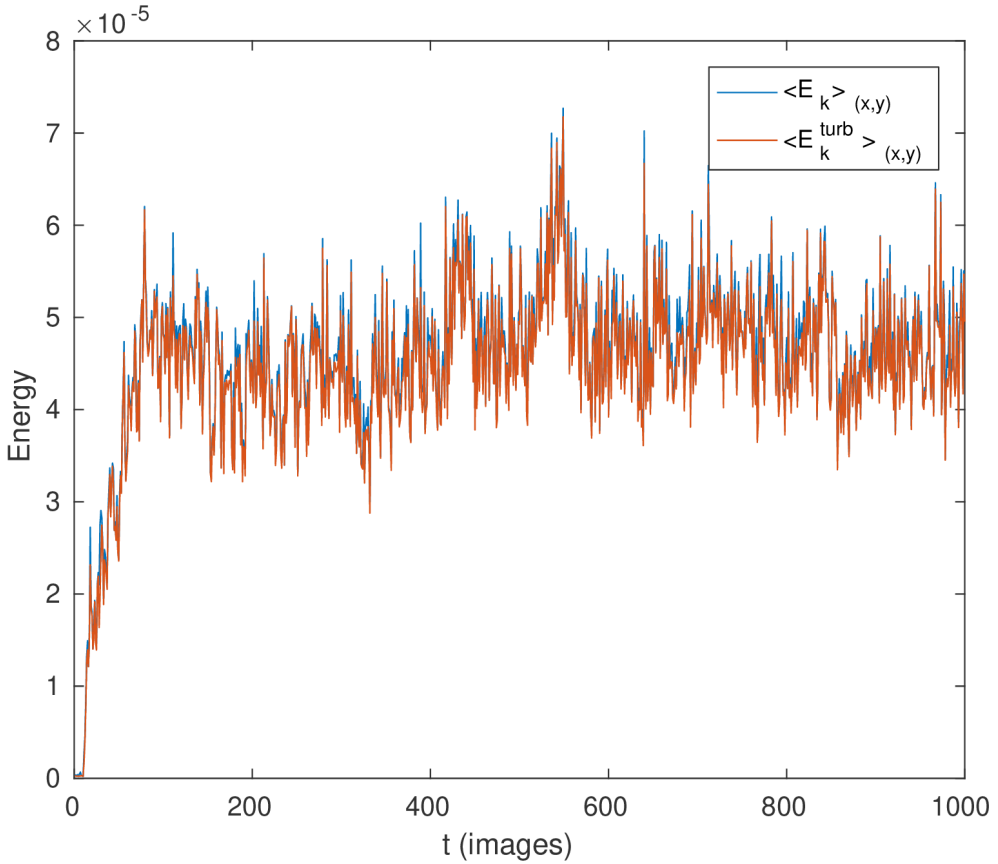
Rossby: $Ro = \frac{U}{Lf} = [6.6 - 66]$



N=1.4 rad/ s, Ω = 0.06 rad/s, N/f = 11.6

Velocity field and energy

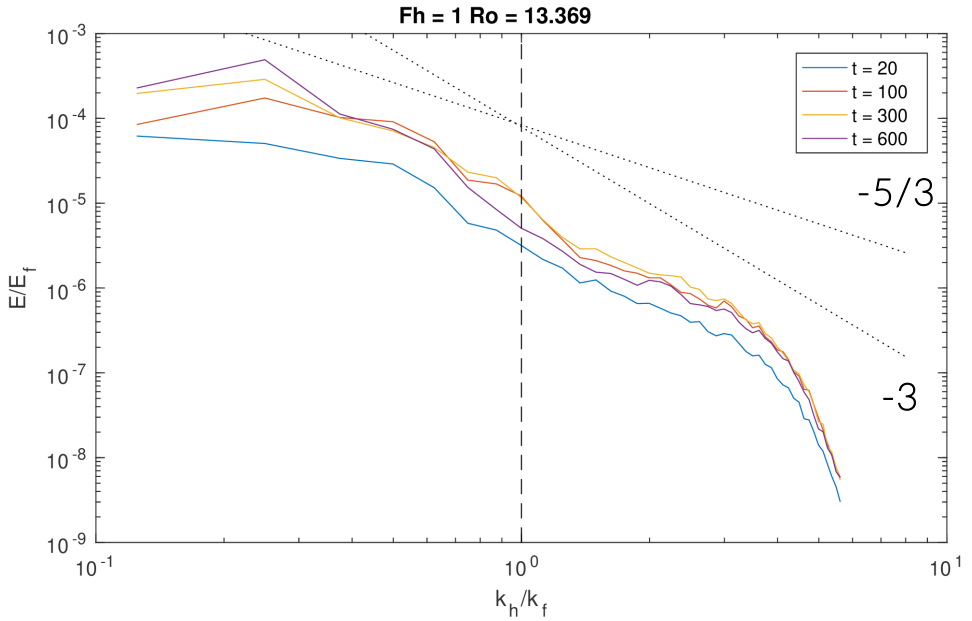
Spatial average of horizontal kinetic energy



N=1.4 rad/ s, Ω = 0.06 rad/s, N/f = 11.6

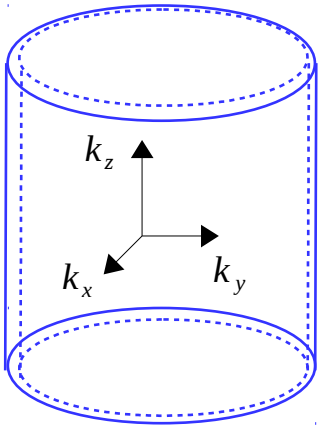
Starting from rest.

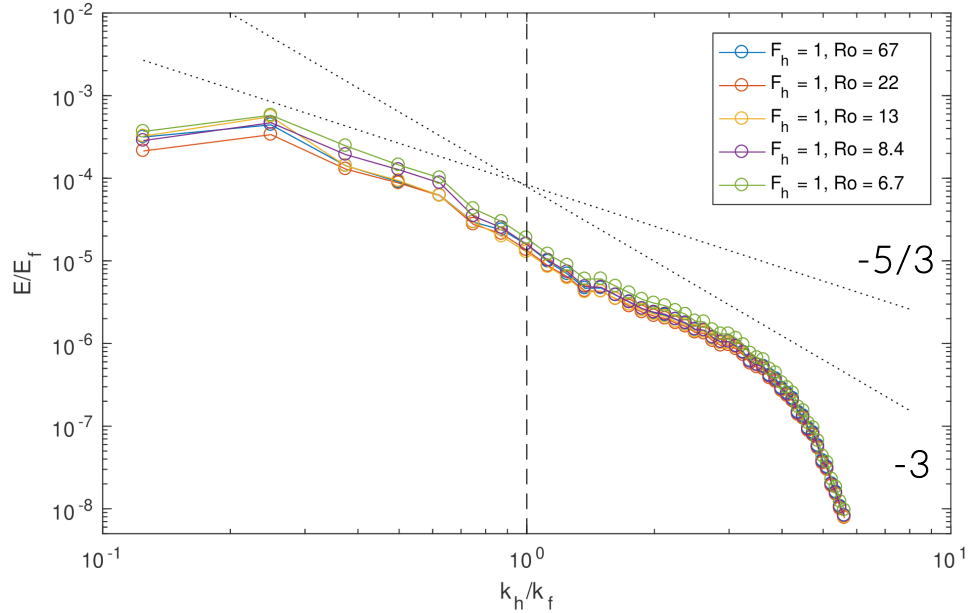
Spectral analysis



Evolution of Energy spectra:

- Increase of energy in the large scales





Energy spectra for several rotation

- Increase of energy in the large scales

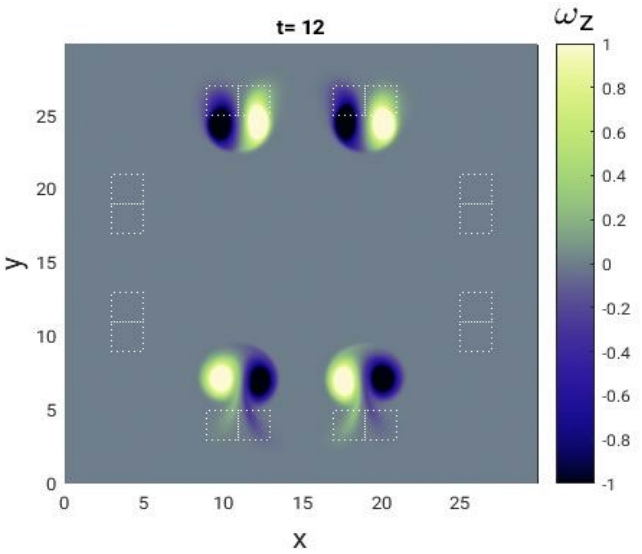
Stratified and rotating turbulence: Numerics

Navier-Stokes equation under Boussinesq approximation
in a rotating framework f and fixed buoyancy frequency N

Vortex dynamics

$$u_\theta(x,y,t)=\frac{\Gamma}{2\pi r}\left[1-\exp\left(\frac{-(x-x_c)-(y-y_c)}{a^2}\right)\right]$$

TOP View



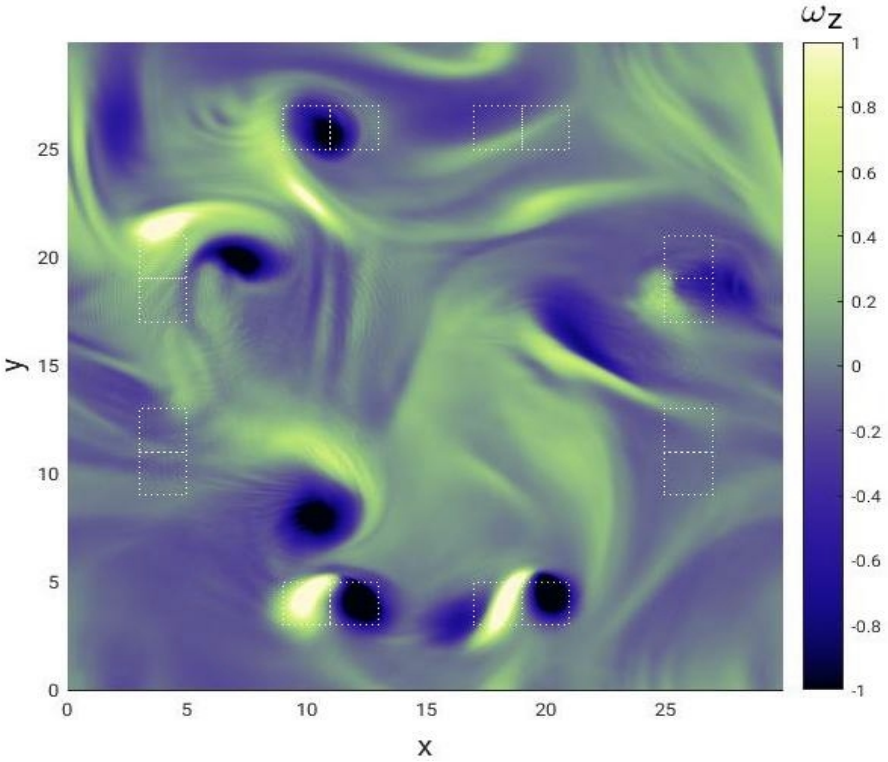
Forcing time: 0.5 s U=1

Forcing dipole period: 7 s L=1

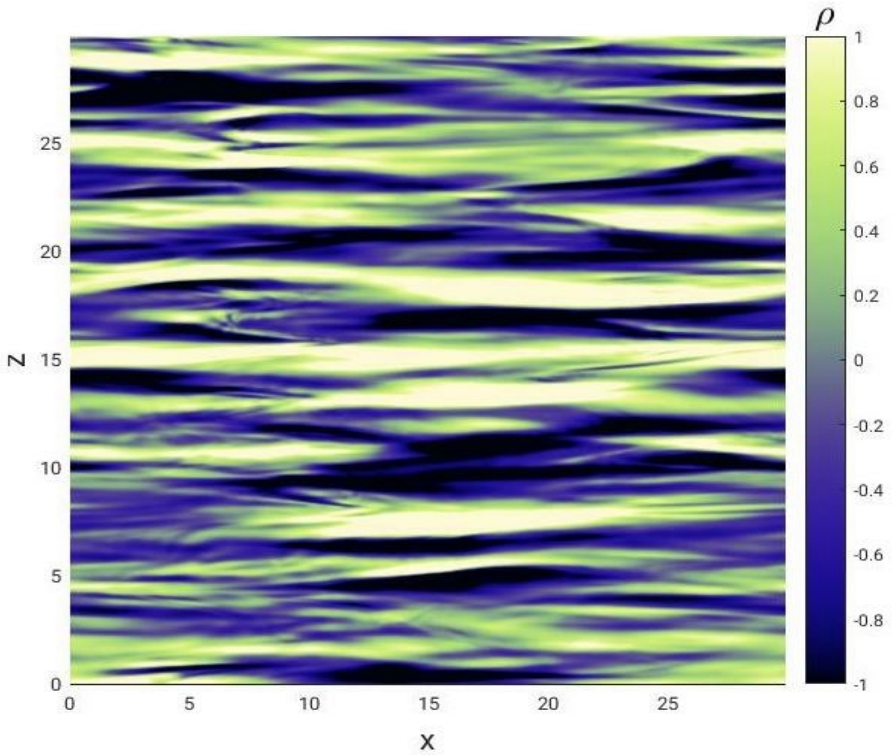
Full forcing period: 28 s

Numerical observations

TOP View



Vertical Cut

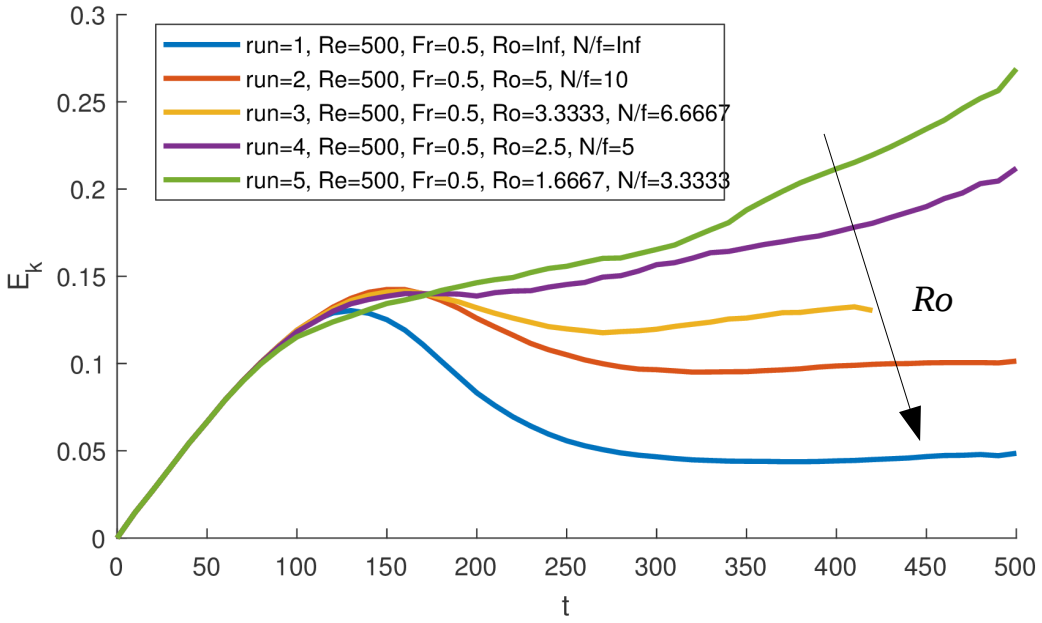


Associated lengthscales: $L_v \propto L_h \frac{f}{N}$

Re=1600 , Fr=0.25, Ro=3.3
dimensions=512^3

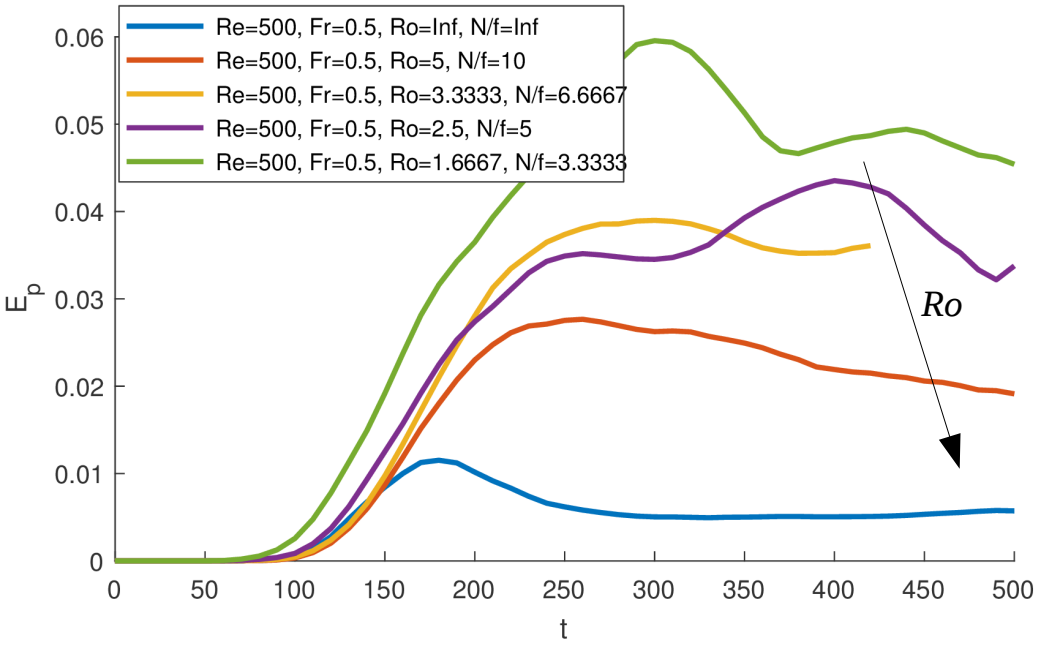
Energy and rotation

Kinetic Energy



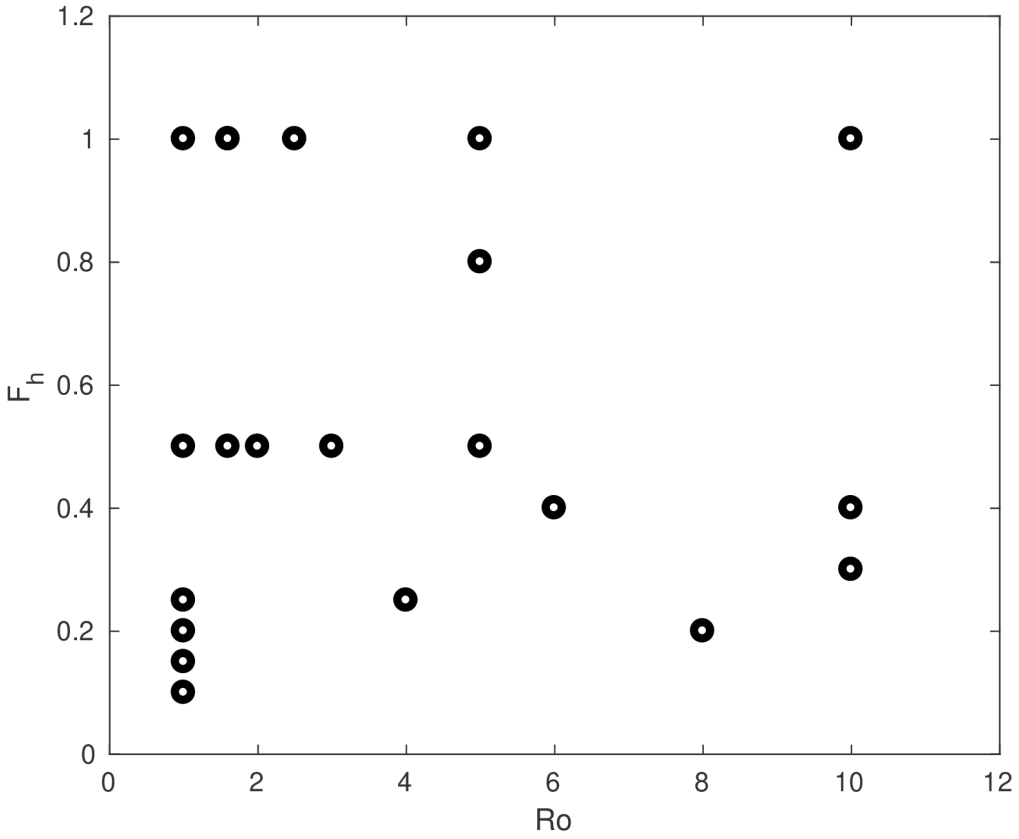
The rate of increase of the kinetic energy is larger for faster rotation

Potential Energy



The potential energy increases as the rotation is faster

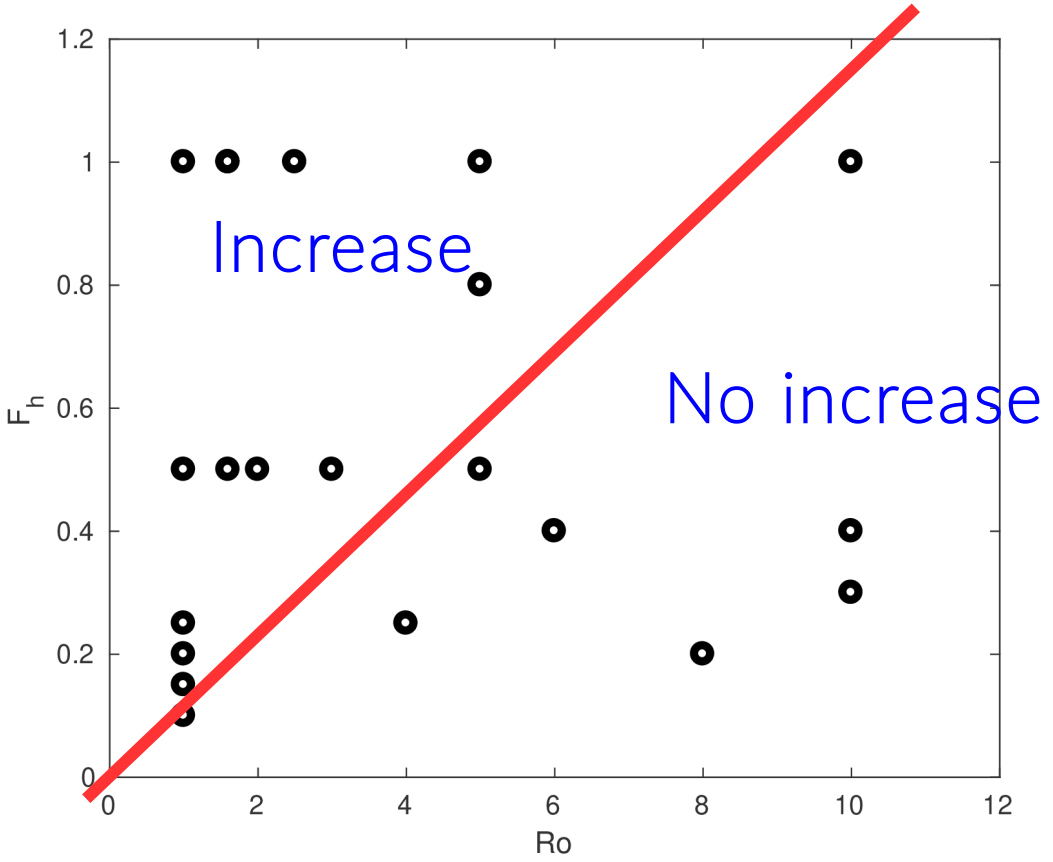
Inverse and direct cascade



DNS parameter space, Re =[500- 4600]

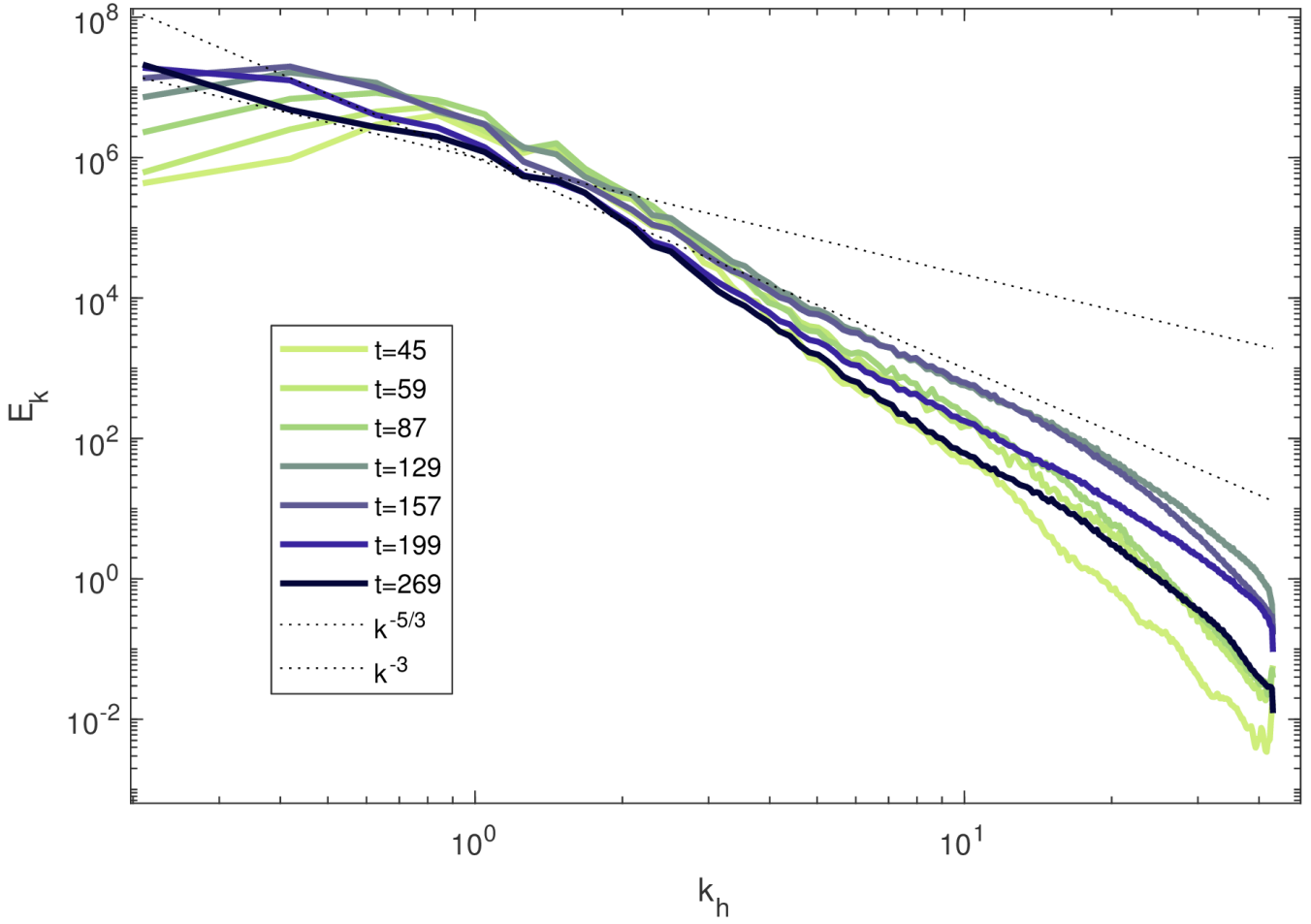
Inverse and direct cascade

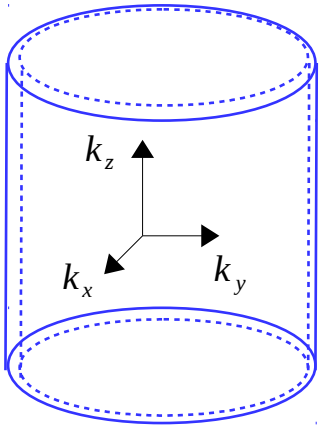
N/f ~ 8



DNS parameter space, Re =[500- 4600]

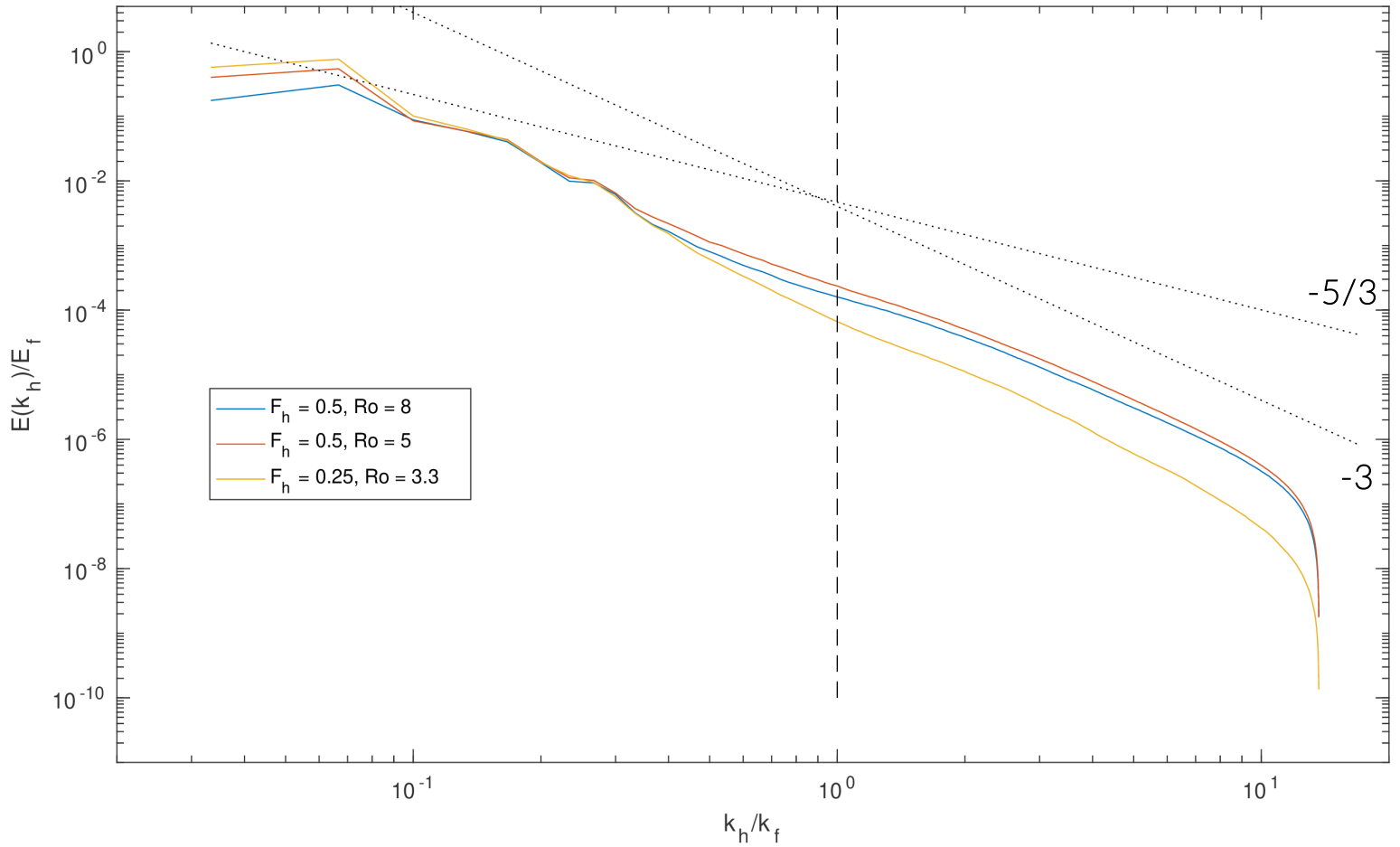
Energy spectrum evolution

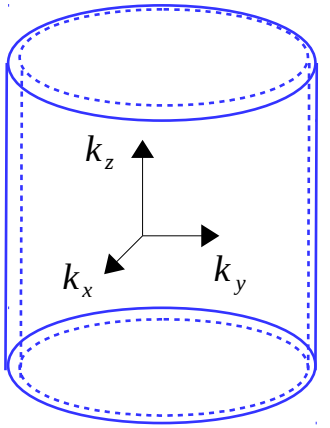




Re=1600 , Fr=0.25, Ro=3.3
dimensions=512^3

Energy spectrum evolution

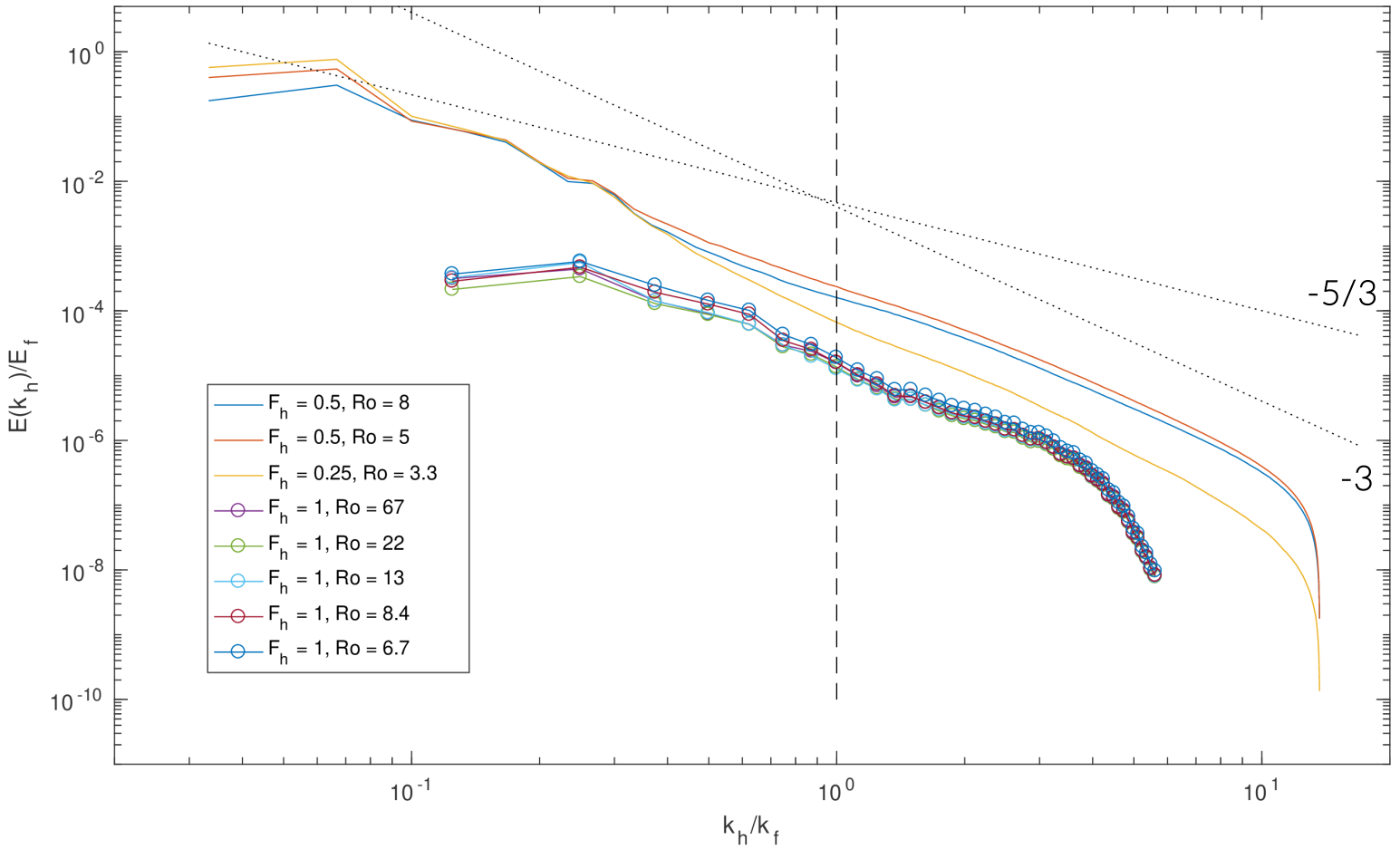


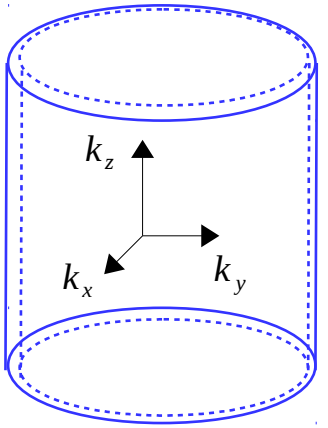


Re=4600

dimensions=1024^2 x 512

Energy spectrum evolution





Re=4600

dimensions=1024^2 x 512

Thank you for your attention

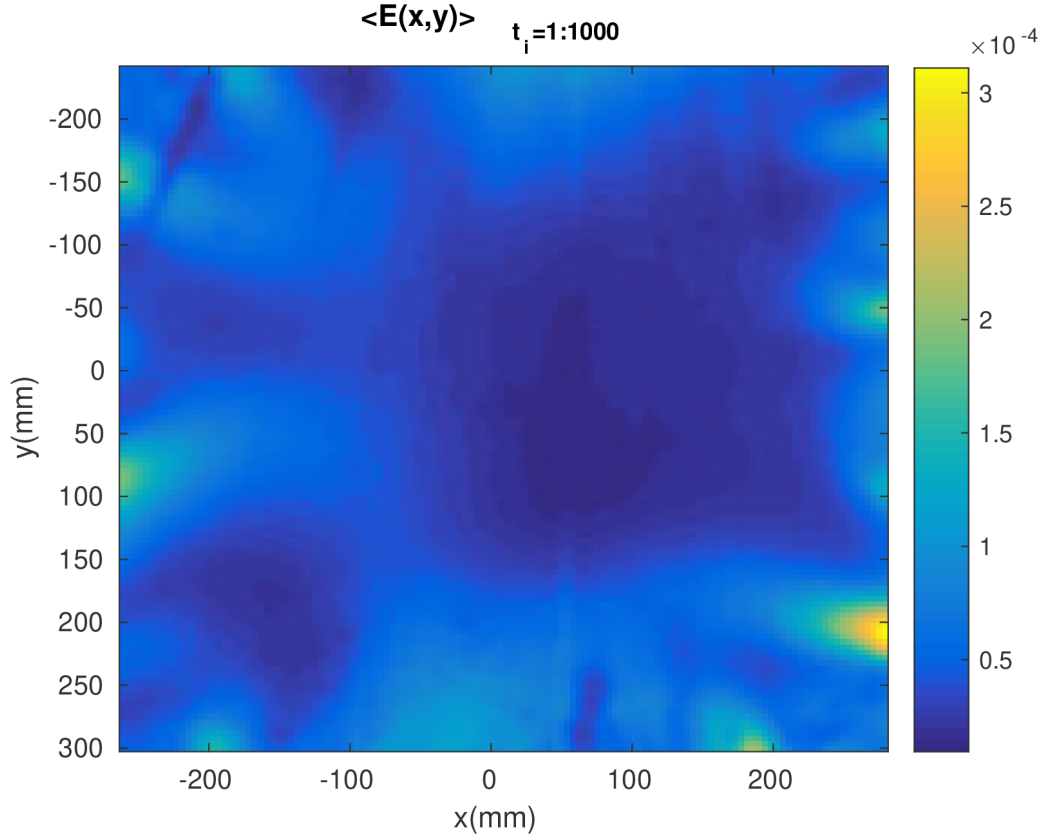
- We observed an increase of the kinetic energy associated to large scales for decreasing Ro number for experiments.

- DNS indicate that the increase of the energy at large scales depends on the ratio N/f.

- Perspectives: Study relation between critical value of N/f and forcing.

- Study response to the change of configuration of the array.

Stratified and rotating turbulence



Stratified and rotating turbulence