DECAYING GRID TURBULENCE IN A ROTATING STRATIFIED FLUID

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Collaborations:

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Reference: Praud, Sommeria, Fincham (2006), *J. Fluid Mech.* **547**

Existence of 2D turbulence

- Confined layers:

e.g. soap films, 2D dynamics +Rayleigh friction

- External force +confinement:

MHD, rotation, stratification

- External force in homogeneous case:

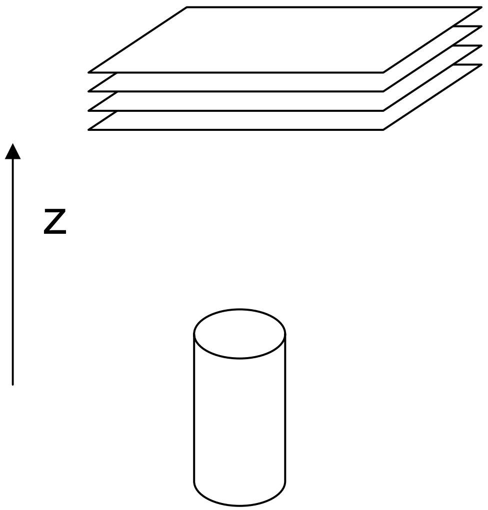
-stratification alone -> 3D dynamics

-rotation alone -> long axial scales ->confinement

-rotation + stratification -> geostrophic turbulence (Charney 1971)

Antagonistic effects

stratification



Froude number:
$Fr = U/(NL)$

$N^2 = -g(d\rho/\rho dz)$

rotation

Rossby number:
$Ro = U/(fL)$

$f = 2\Omega$

Quasi-geostrophic model

Charney (1971)

$Fr << 1$

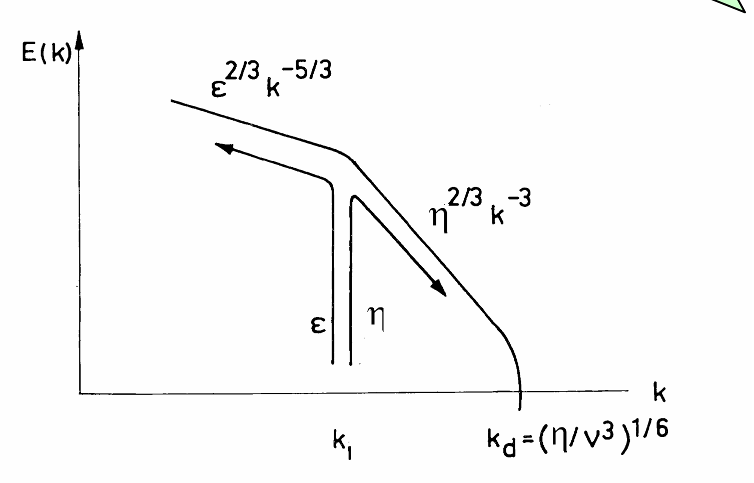
$Ro << 1$

Non-divergent horizontal flow

At each z, $PV = -\Delta_h \psi - (N/f)^2 \partial^2 \psi / \partial z^2$

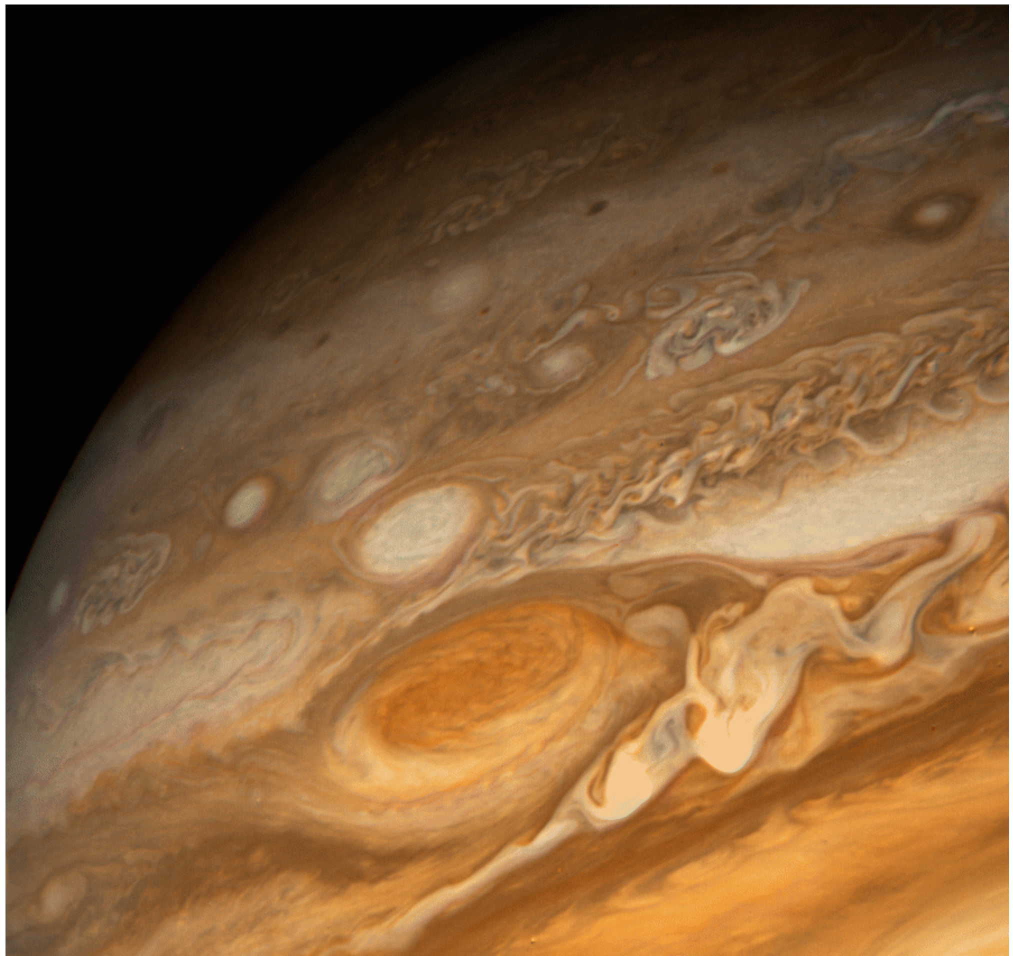
Formal analogy with two dimensional turbulence (conservation of PV)

Non dissipative dynamics

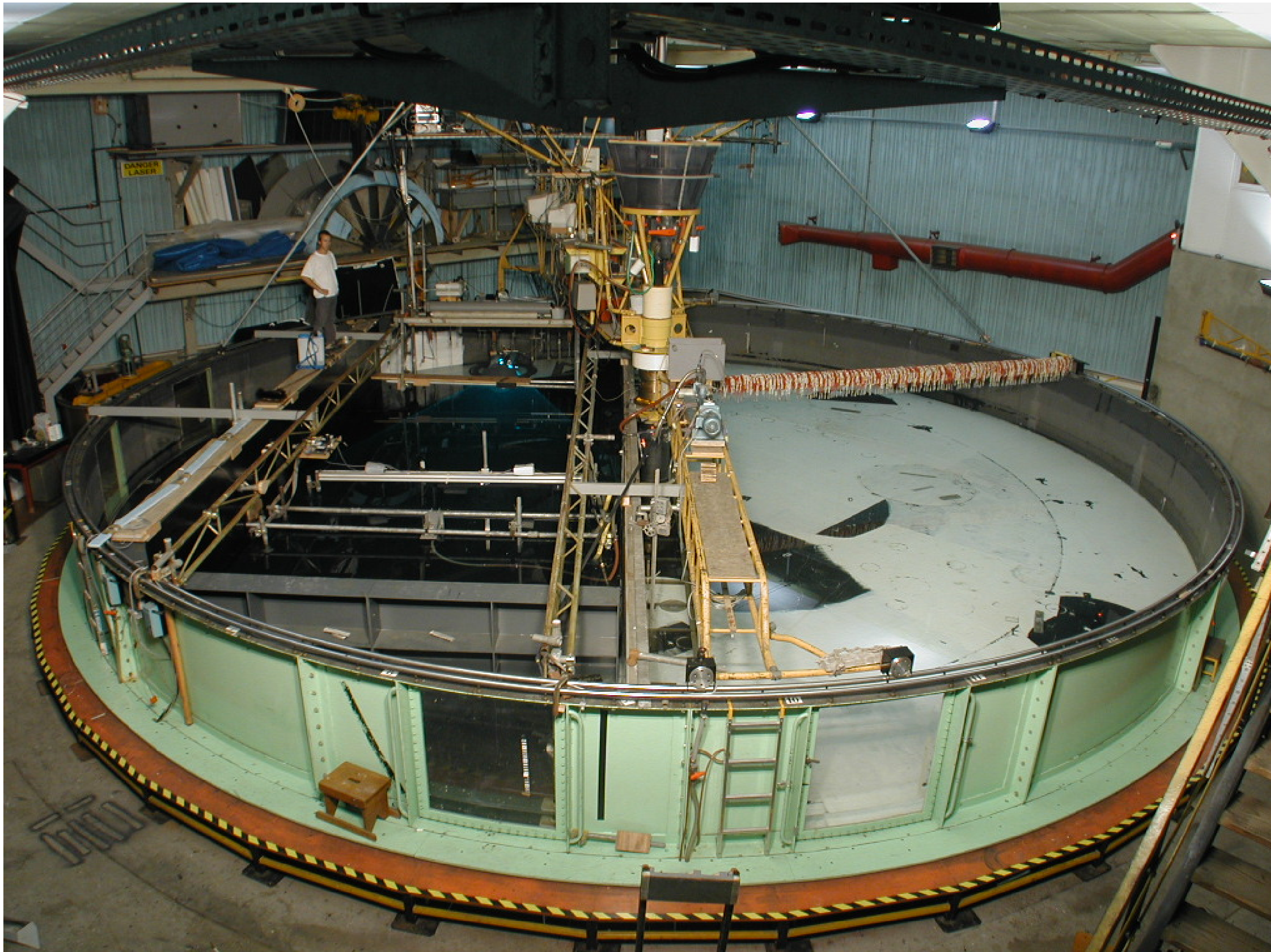


Emergence of coherent structures

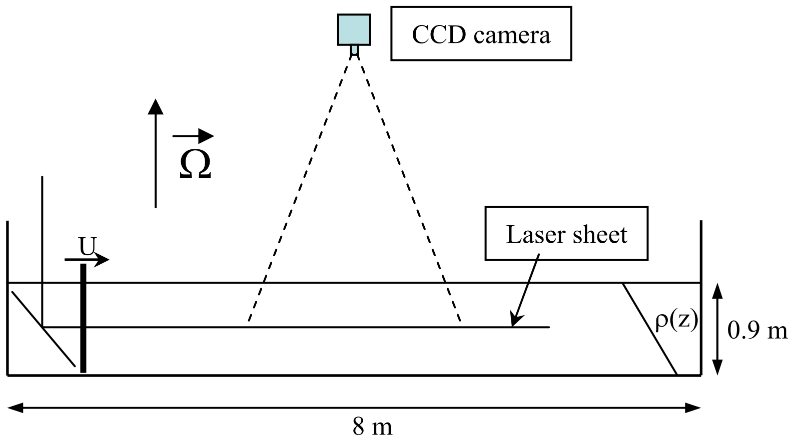
Jupiter atmosphere

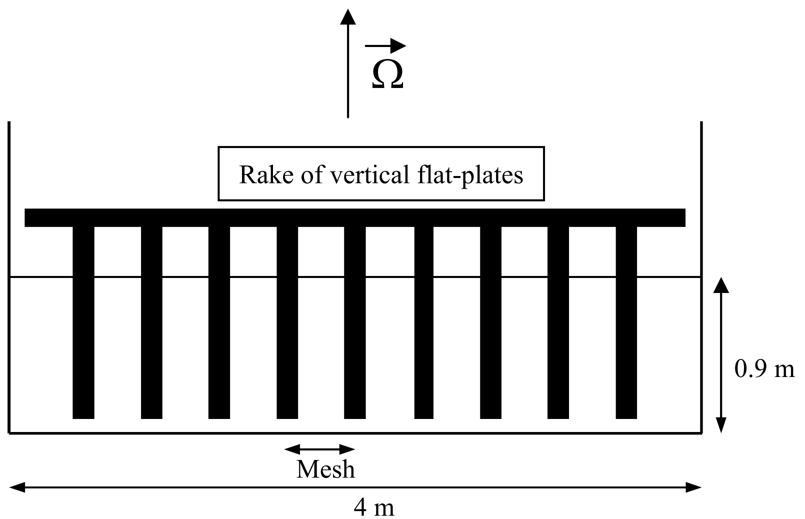


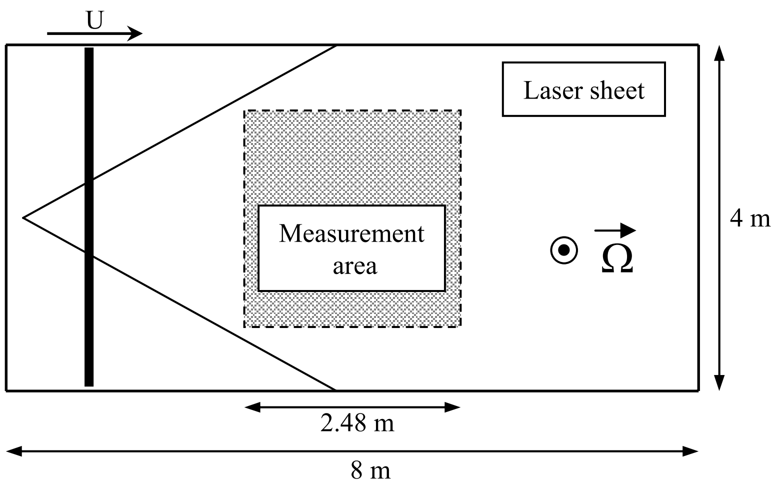
Coriolis rotating platform



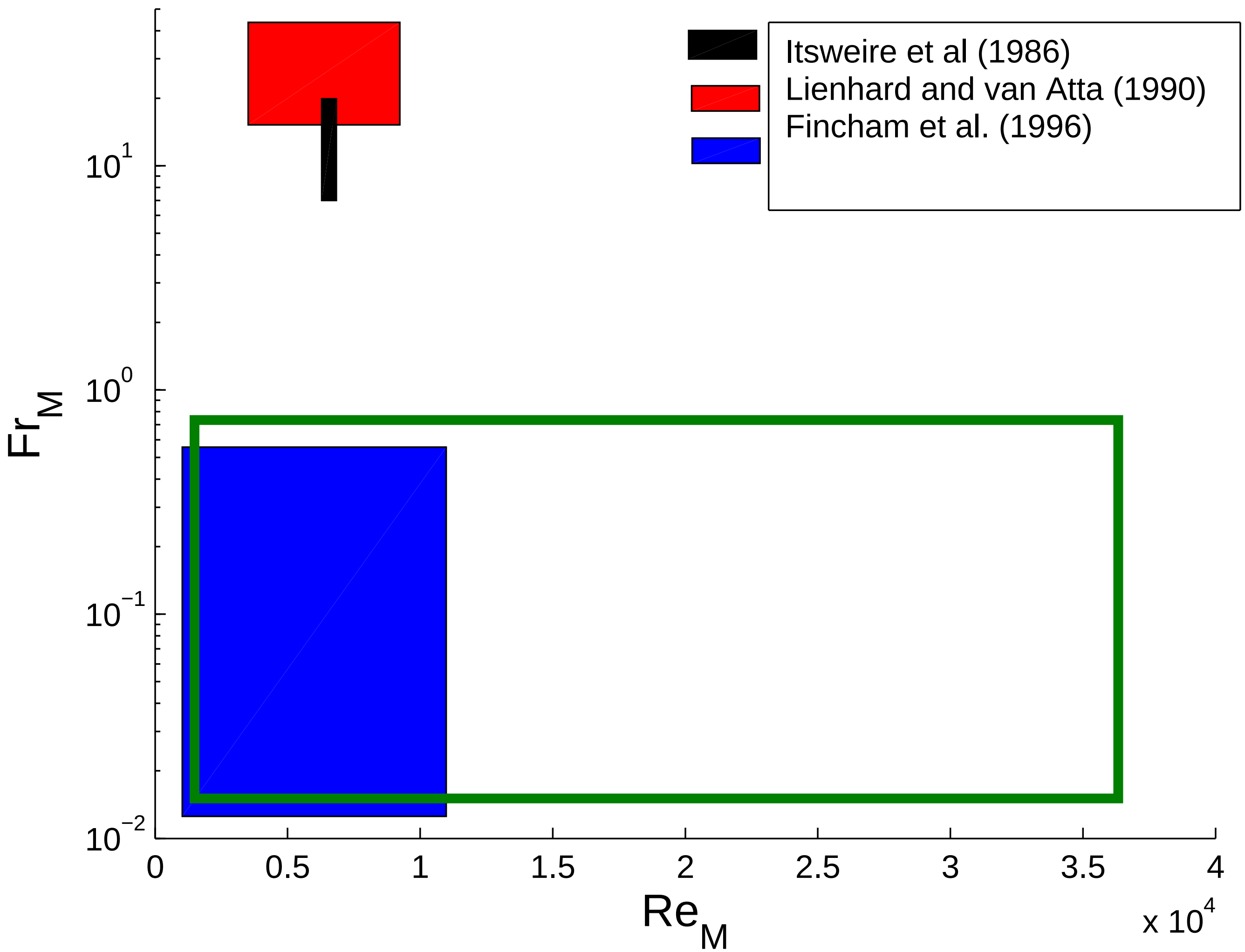
Grid turbulence



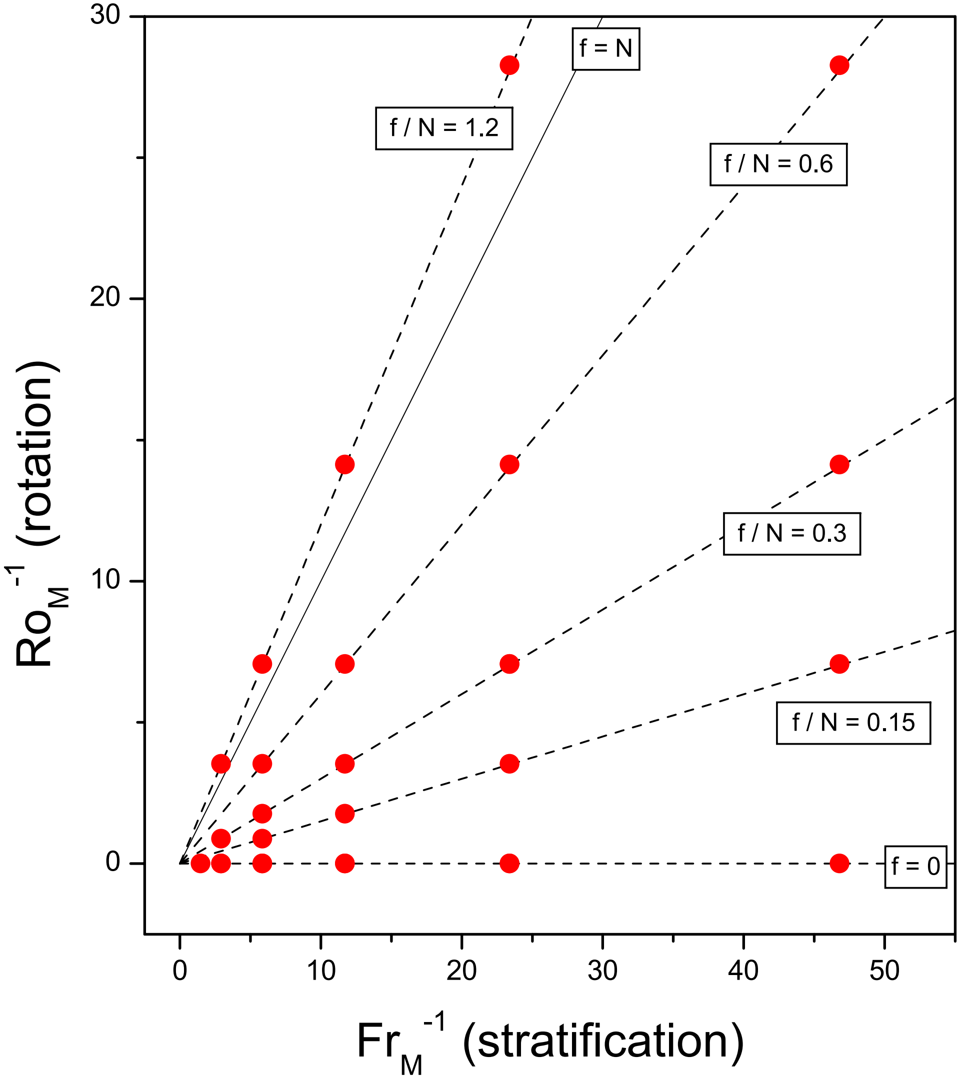




Experimental parameters (no rotation)



Experimental parameters



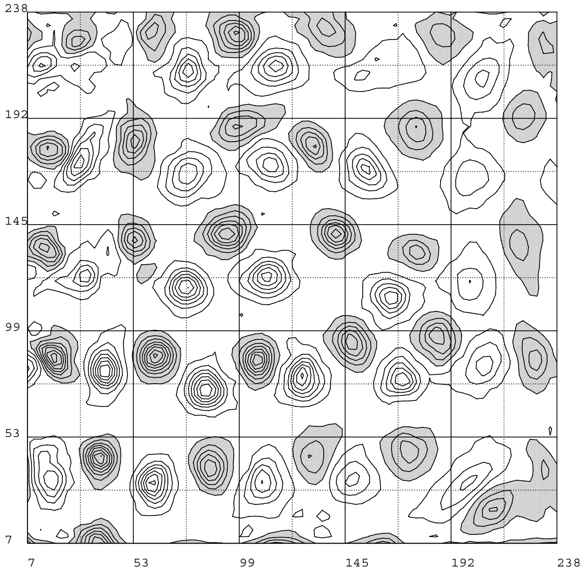
$2250 < Re_M < 36000$

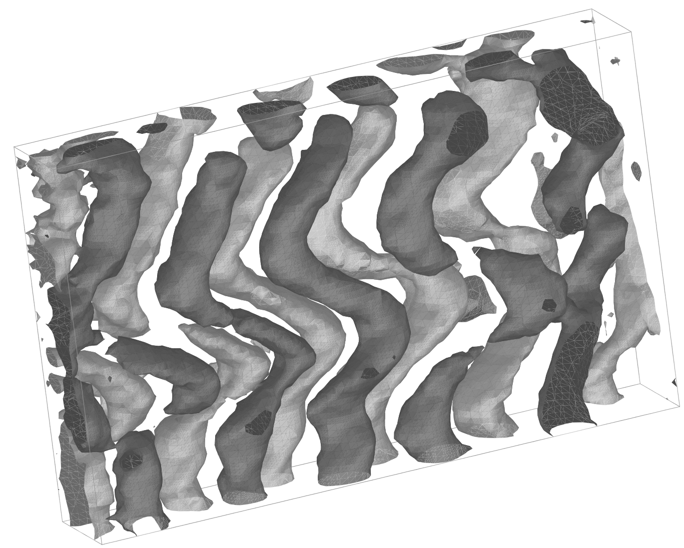
$0.04 < Ro_M < 1.13$

$0.02 < Fr_M < 0.34$

$Re \sim Re_M/5$
$Ro^{-1} \sim 10 Ro_M^{-1}$
$Fr^{-1} \sim 10\, Fr_M^{-1}$

Initial instability
(no rotation)

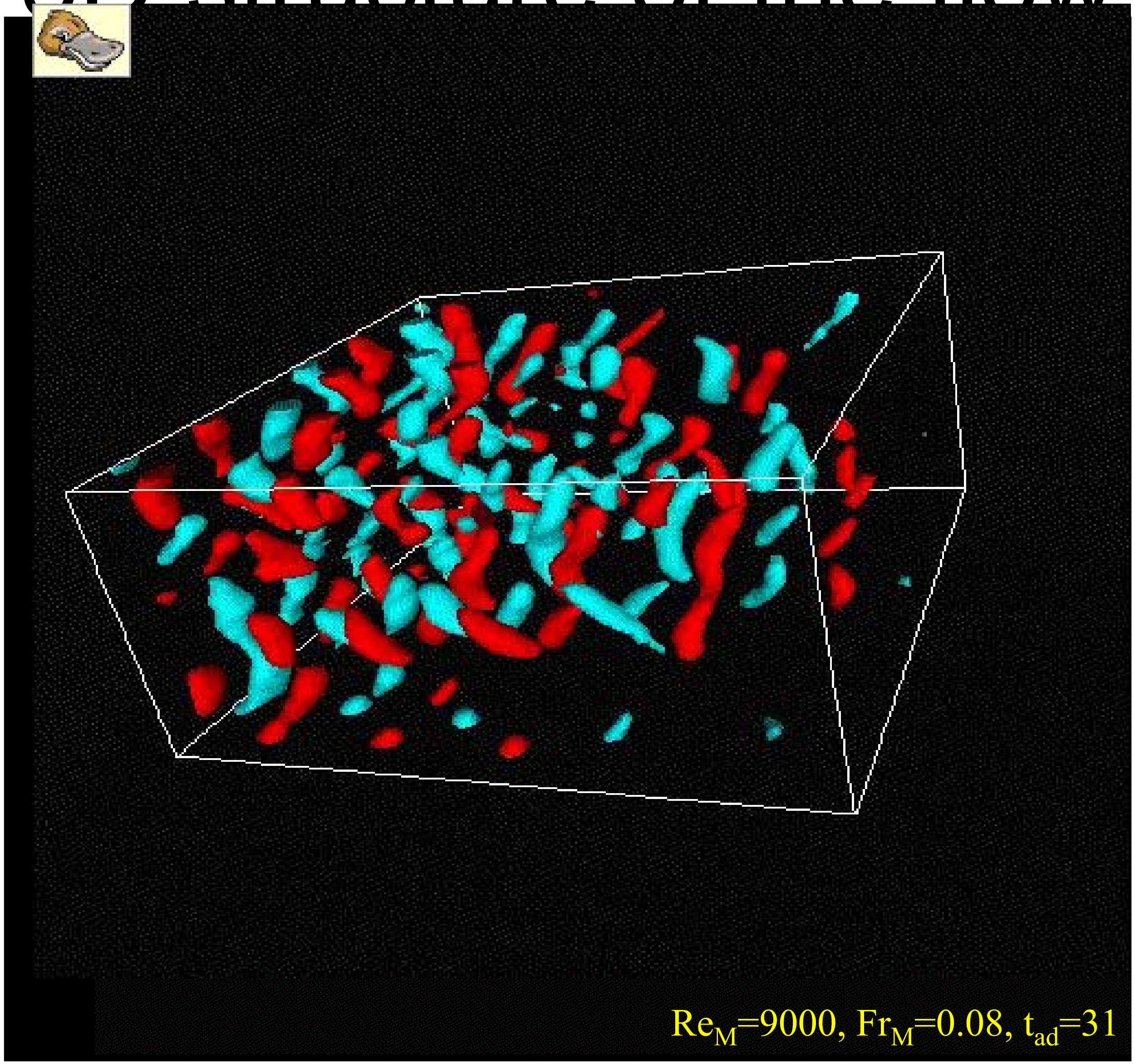




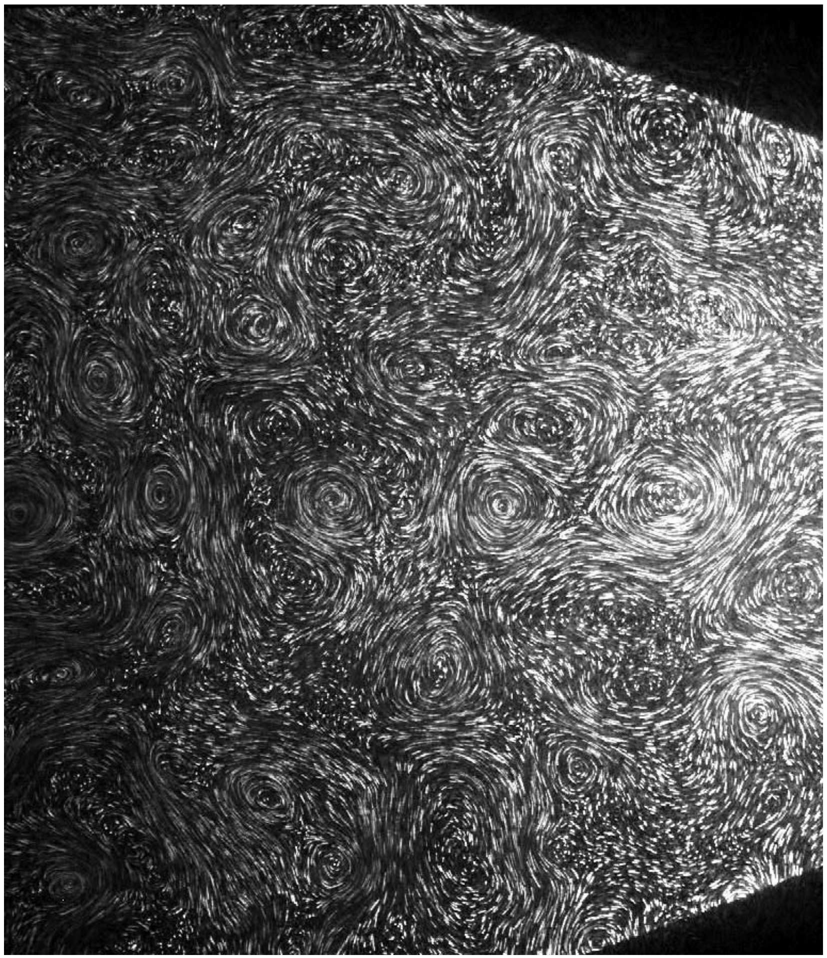
Zigzag instability

Vertical vorticity field:
Re=2250, Fr=0.02

3D structure of the flow



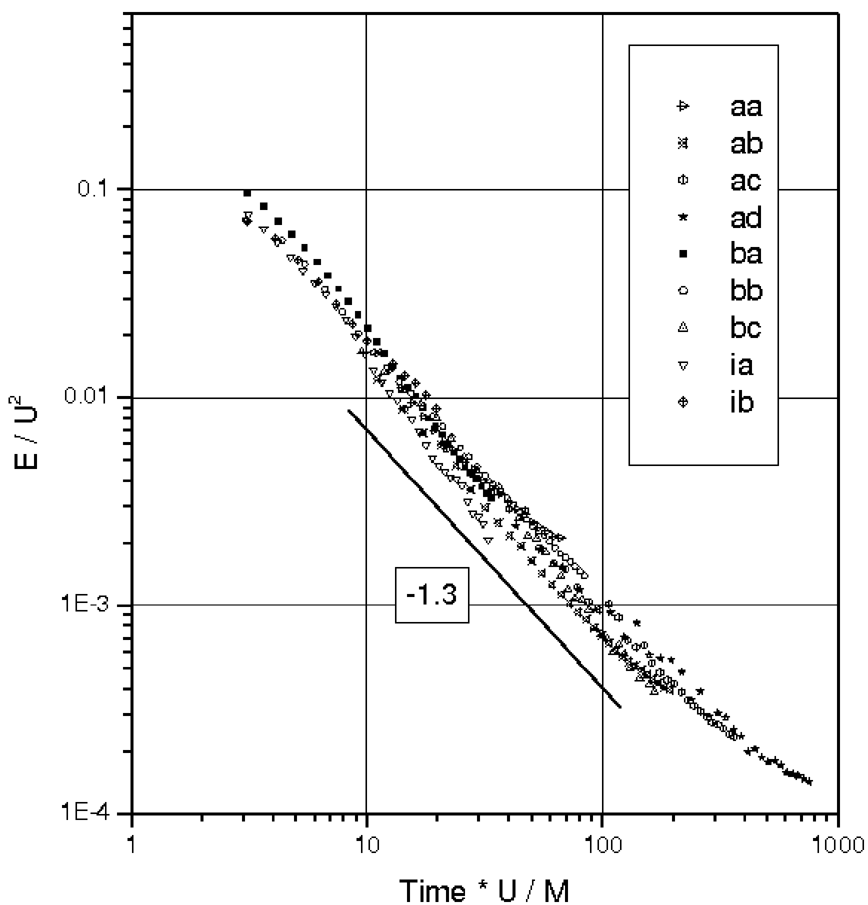
Steack photos (no rotation)



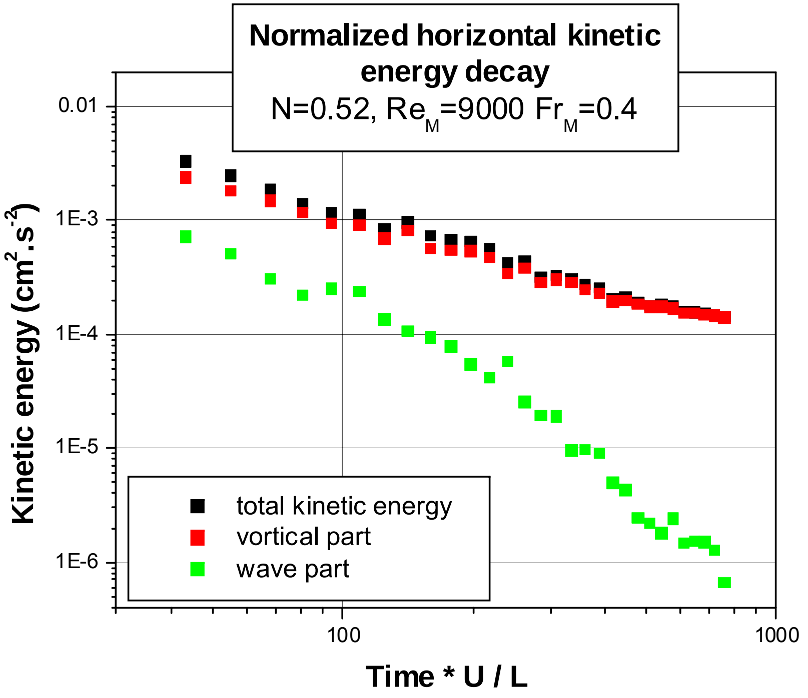
t=74 s

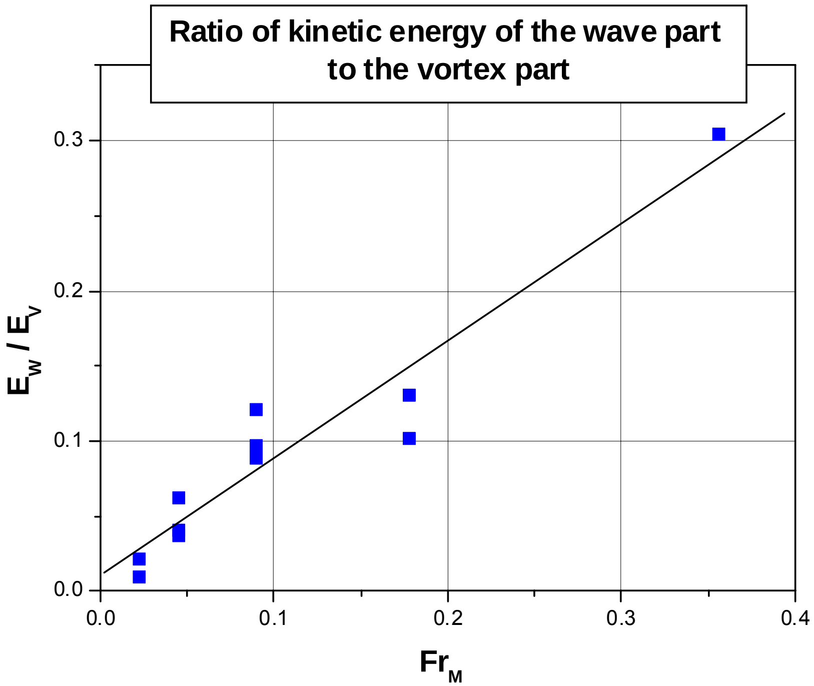
t=407s

Energy decay



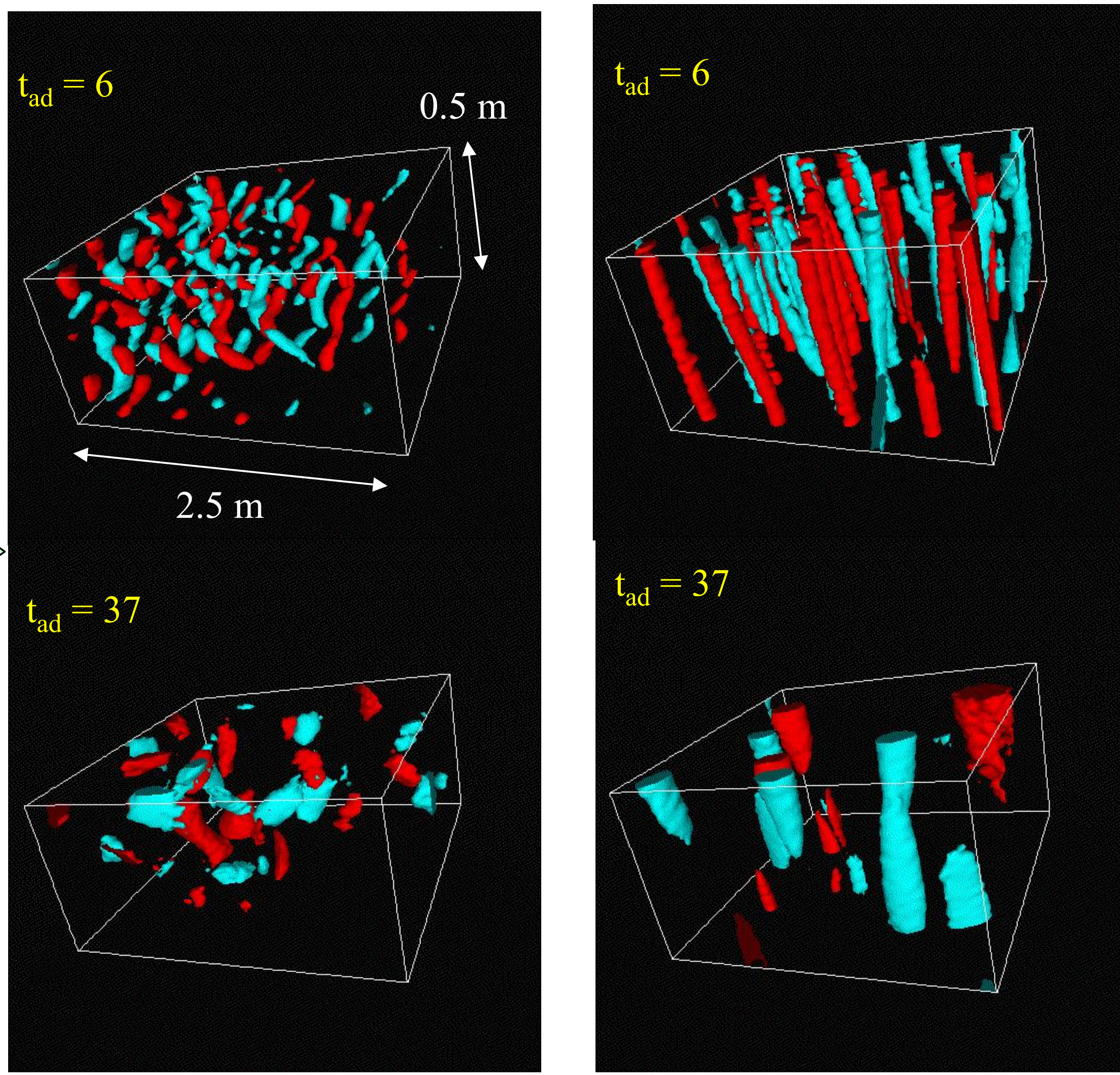
Vortex-wave separation





Influence of rotation

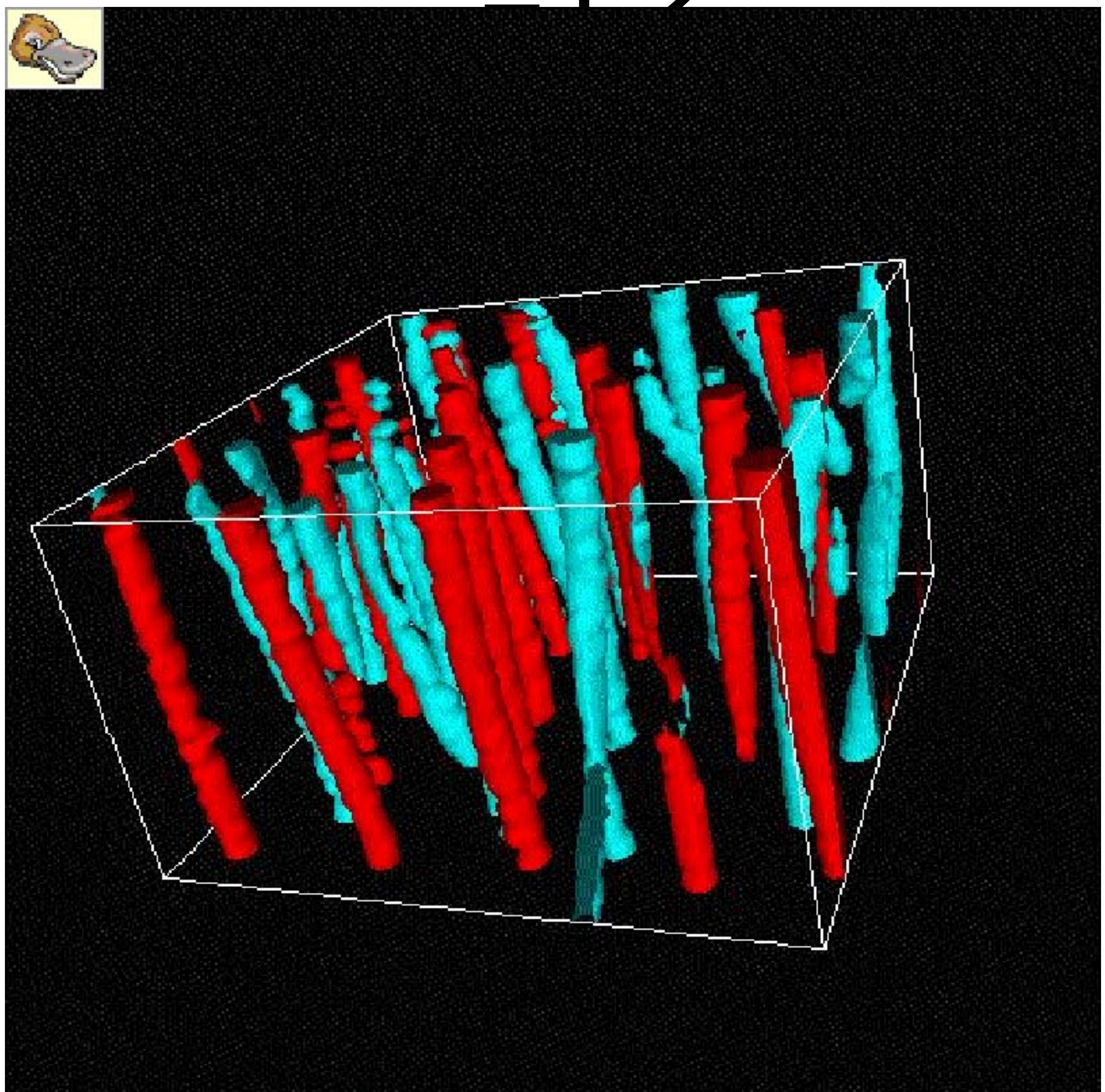
Re_M=4500
Fr_M=0.09



f = 0

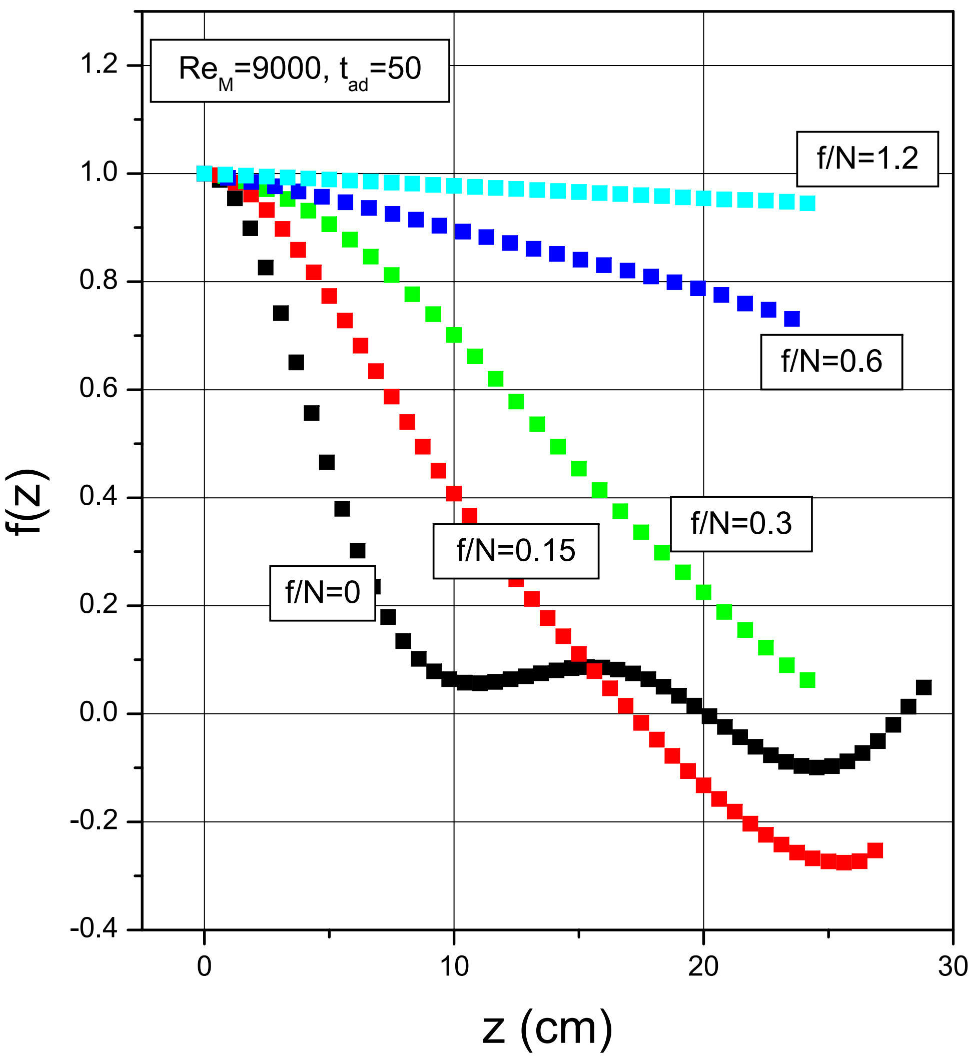
f / N = 1.2

Strong rotation f / N =1.2



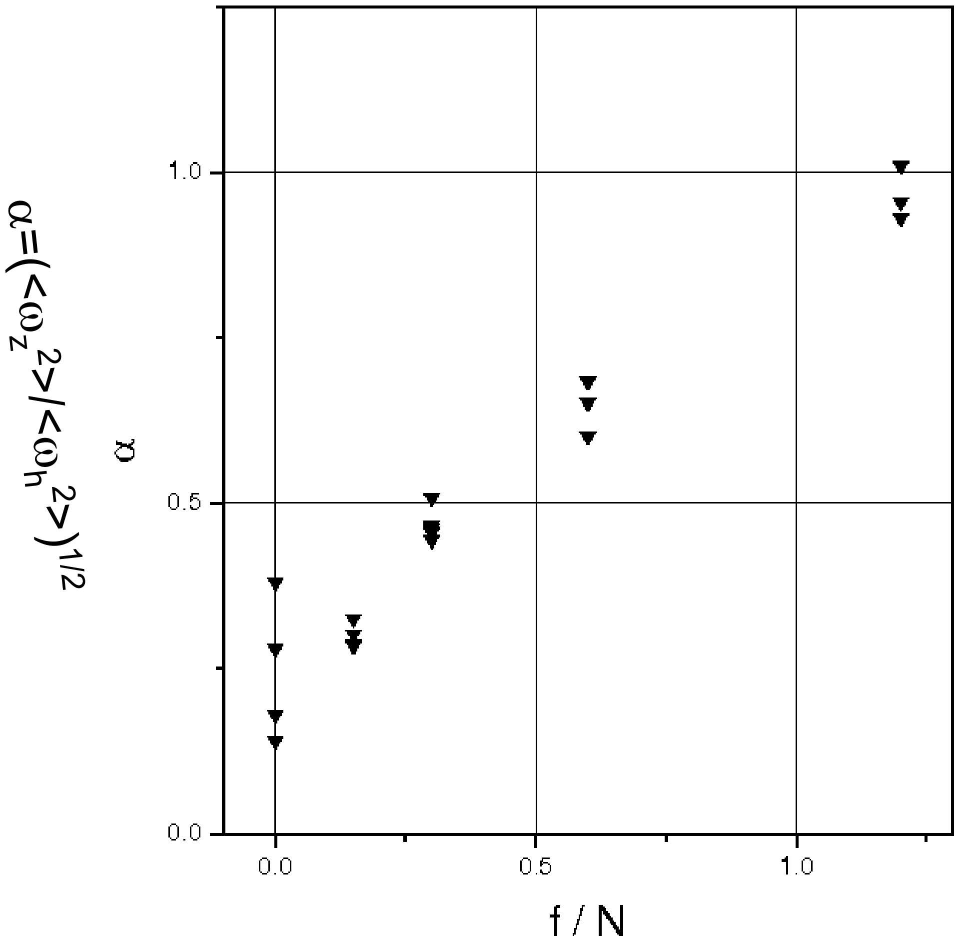
Vertical correlation

Vertical correlation function



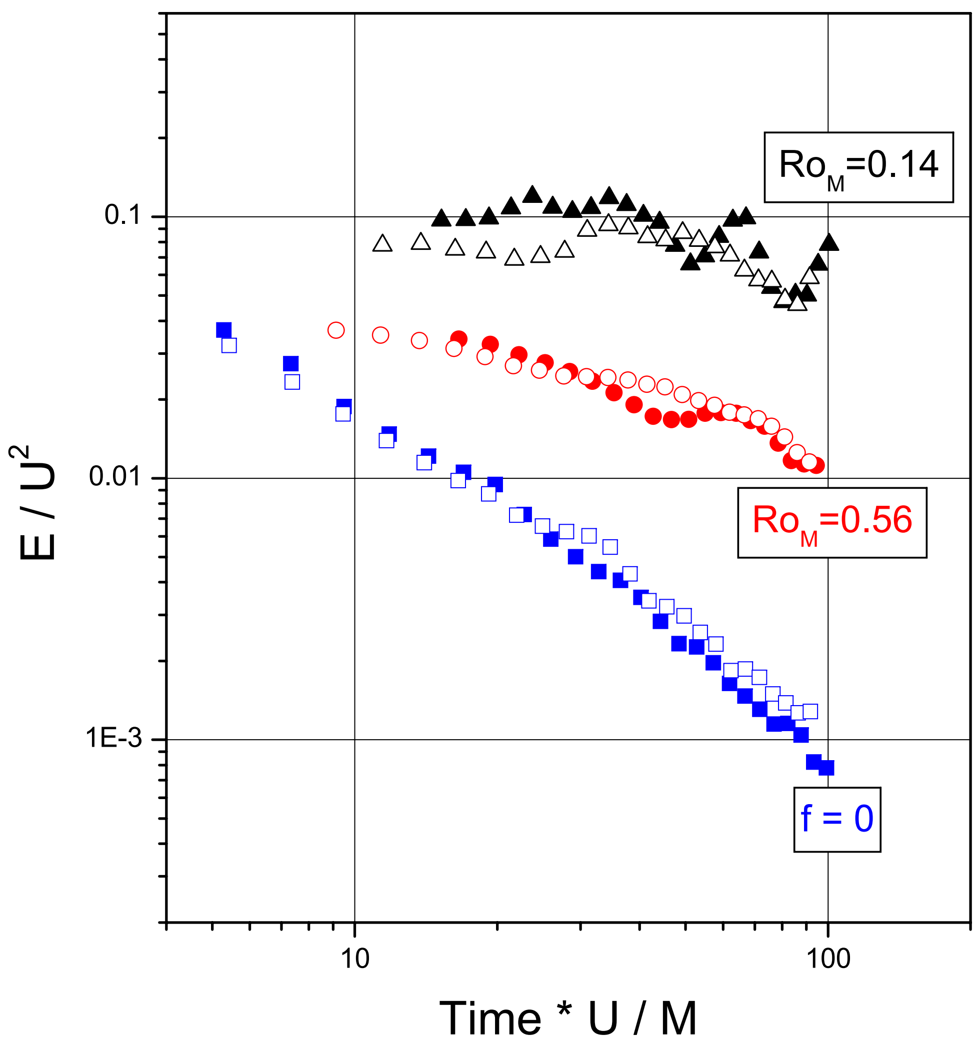
- The vertical scale increases with f/N
- Geostrophic adjustment of the vortices

Aspect ratio



Inhibition of the energy decay

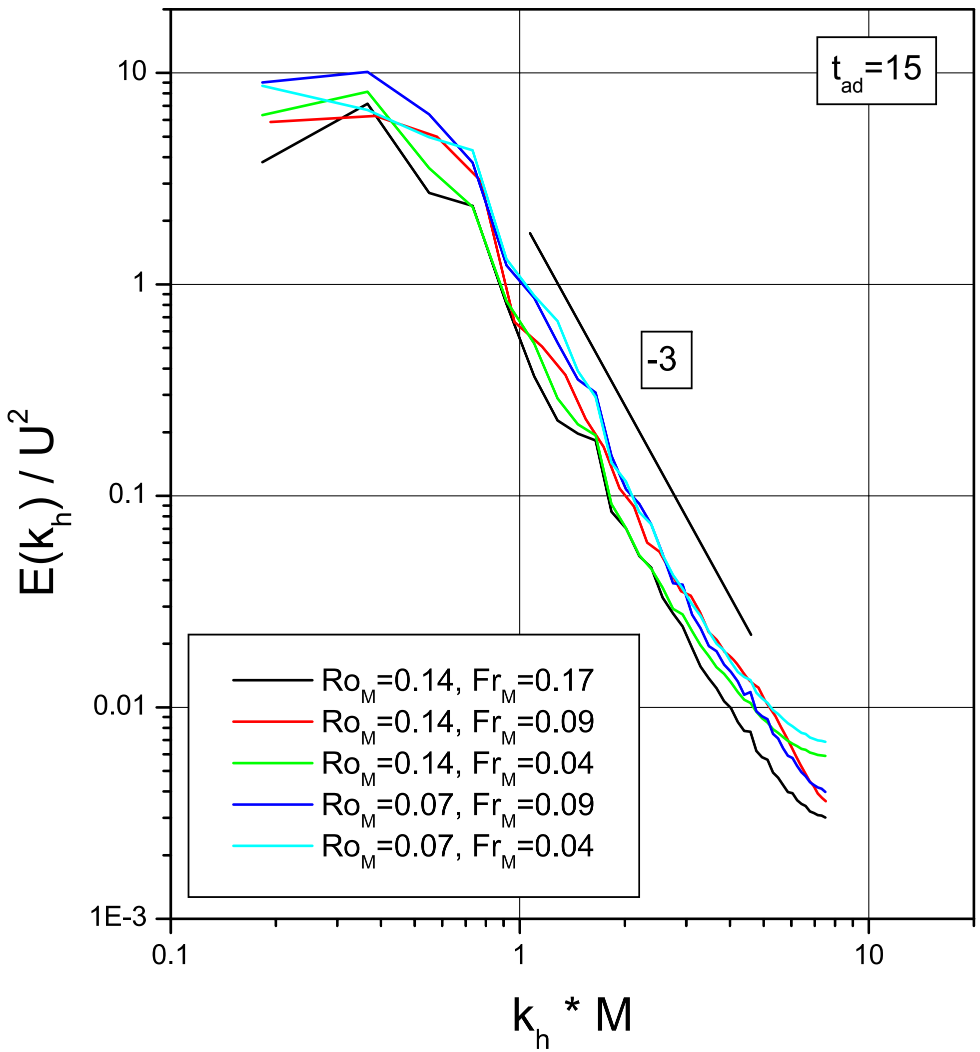
Kinetic energy decay



- Inhibition of the kinetic energy decay with rotation
- Conservation for Ro < 0.2
- Little influence of stratification

Energy spectra

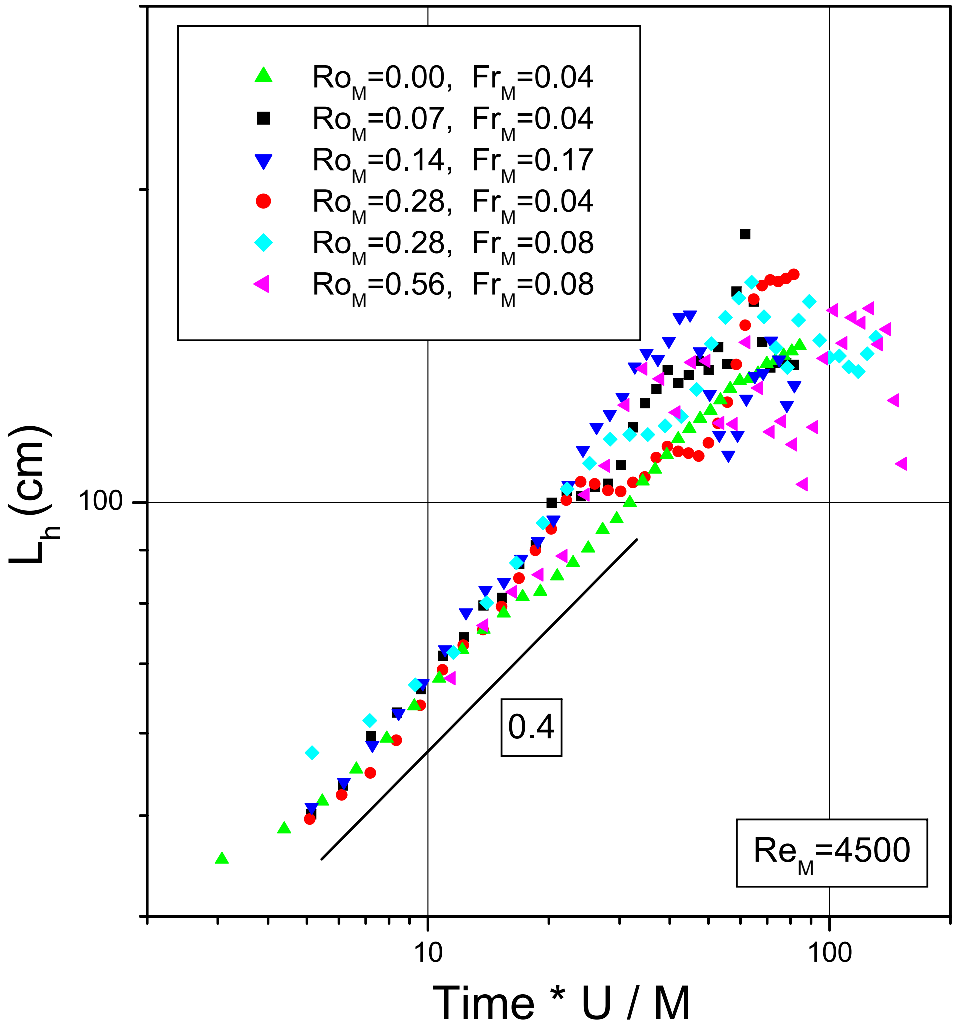
Horizontal energy spectra



- k_h^{-3} energy spectra in agreement with Charney's predictions
- The flow dynamics is quasi-geostrophic

Horizontal length scale

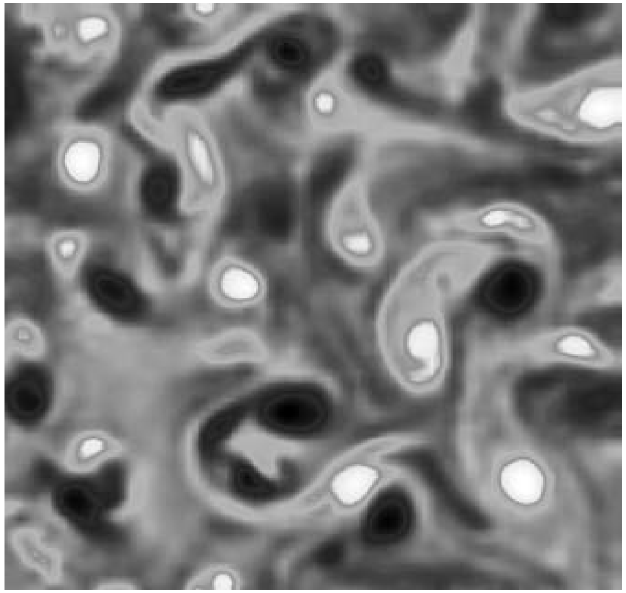
Horizontal integral scale L_h

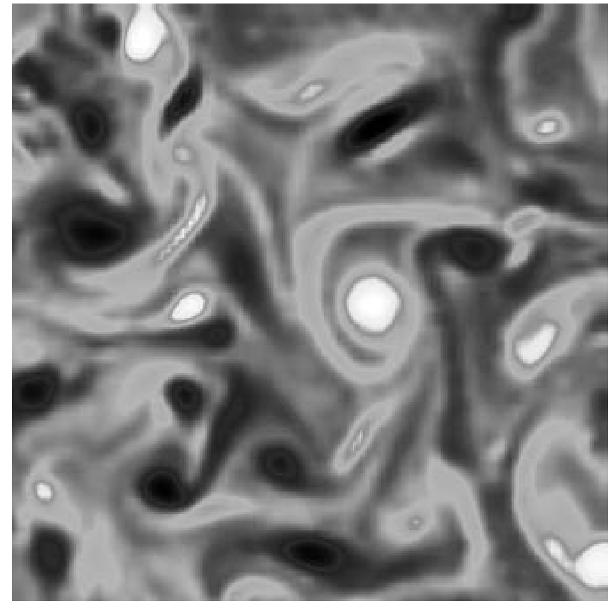


- Very little influence of rotation and stratification on the horizontal length scale

Emergence of vortices

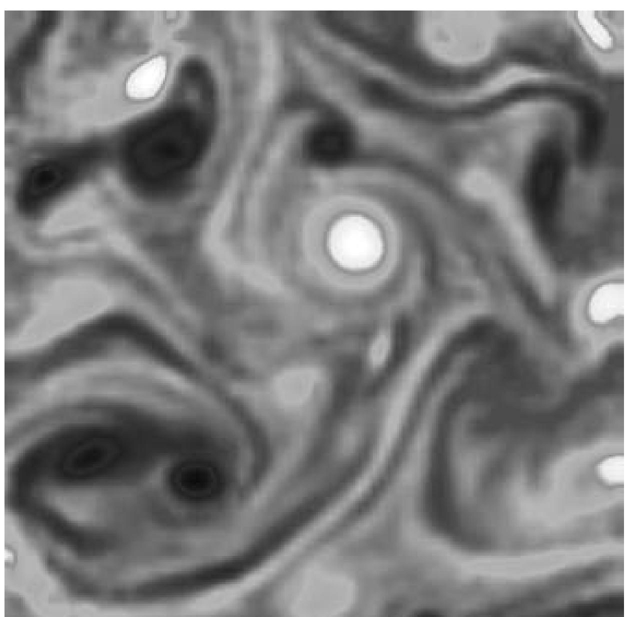
t=377 s

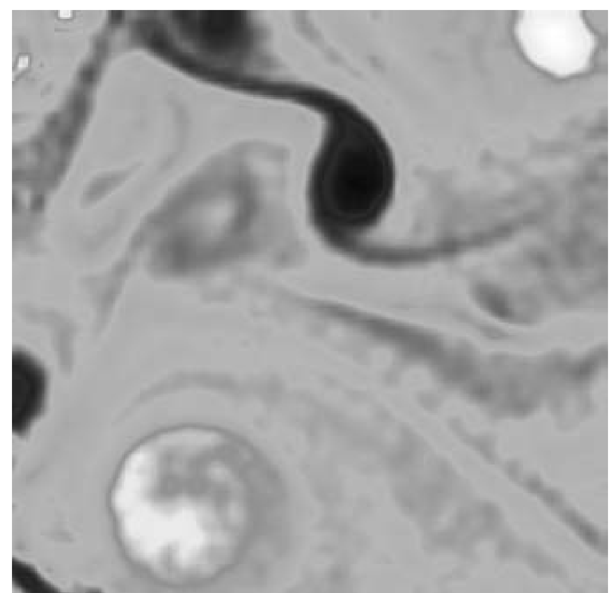




t=619 s

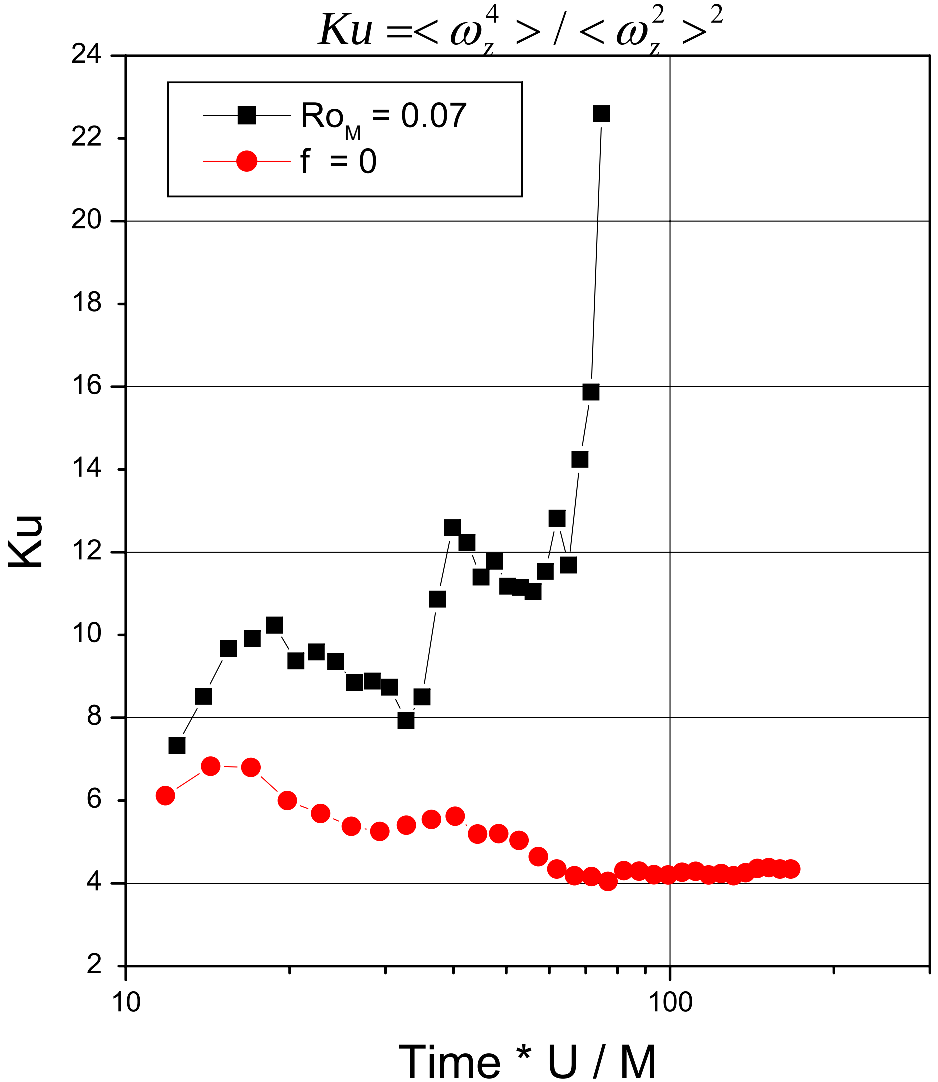
t=915 s





t=3000 s

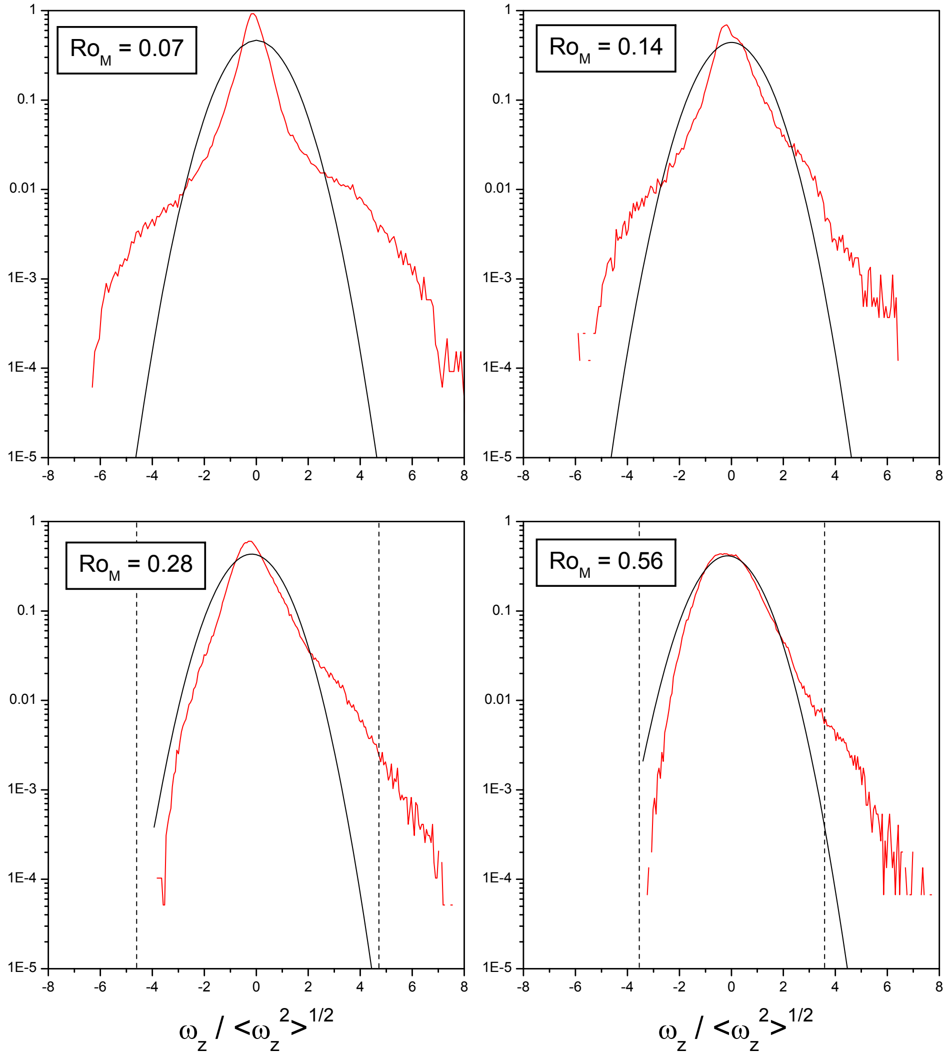
Intermittency



- Strong intermittency for Ro < 0.2
- Quasi Gaussian distribution in absence of rotation

Intermittency and symmetry

P.D.F. of vertical vorticity



- Intermittency and symmetry for $Ro_M < 0.2$
- Domination of cyclones for $Ro_M > 0.2$
- Anticyclones limited by Ro=1

Conclusions

- Stratified turbulence without rotation has a 3D dynamics (strong decay)
- Stratified turbulence submitted to strong rotation (Ro < 0.2) has a quasi-geostrophic dynamics (Charney 1971):
  - Energy conservation
  - Energy spectra in k^{-3}
  - Formation of isolated vortices (symmetry cyclone-anticyclone)

  (similar to 2D turbulence, but with a z dependency)
- For a moderate rotation (Ro close to 1): departure from quasi-geostrophic model:
  - Suppression of anticyclonic vortices such that $\omega/f < -1$
  - Other possible ageostrophic effects: front formation, wave generation?