Experiments in *geostrophic* and *zonostrophic* turbulence [G/ZT]

Peter L Read (University of Oxford, UK)

Boris Galperin (Univ. of South Florida, USA)

- What is G/ZT?
- Why is it important?
- Experimental requirements
- Advantages of low viscosity?

What is G/ZT?

- Turbulent flows driven by mechanical or buoyancy forces in the presence of rapid rotation
- Rapid rotation imparts ‘stiffness’ and coherence parallel to rotation axis
  - Taylor-Proudman theorem $(2\Omega.\nabla)\mathbf{u} \approx 0$
- Flows are highly anisotropic and quasi-2D
- Conservation of energy AND enstrophy in inertial ranges

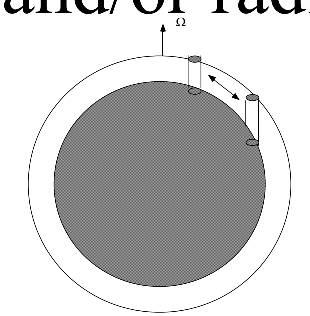
  $\Rightarrow$ Upscale energy cascade

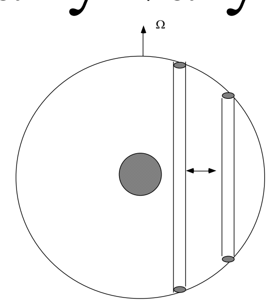
  $\Rightarrow$ Downscale enstrophy cascade?
- Spherical curvature and/or radially-varying topography

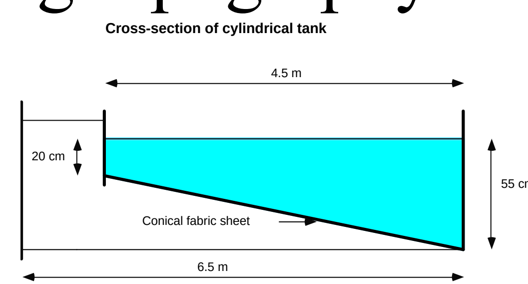
  $\Rightarrow$ Extra anisotropy

  $\Rightarrow$ Zonal jets…..

$$\beta = \frac{2\Omega}{H}\frac{\partial H}{\partial r}$$





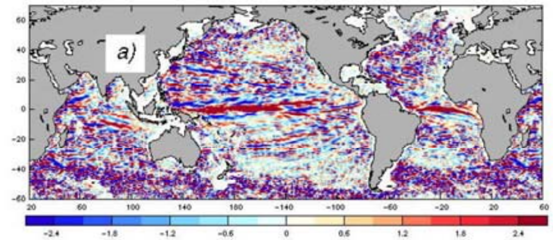


Why is G/ZT important?

- Paradigm for large-scale circulation in planetary atmospheres and oceans (inc. Earth)
  - Transport of heat, momentum, vorticity, chemical constituents
  - Climate
  - Predictability and weather forecasting

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

- Zonostrophic flow (with sphericity or topography)
  - Non-local energy 'cascade'
  - Zonal banding in gas giant planets (Jupiter, Saturn….)?
  - Zonal banding and currents in the open oceans?



- Paradigm for flows in turbomachinery and rotating systems in engineering
  - Aircraft engine efficiency and performance
  - Mixing and stirring in chemical engineering….etc.

- Isomorphic with certain forms of MHD turbulence in plasmas
  - Plasma technology and energy generation
  - Astrophysical plasmas

Experimental requirements

Parameter	Defn	Desired	To date	Jupiter
Rossby No.	$U/\square\Omega L$	$< 10^{-2}$	10^{-2}	$< 10^{-2}$
Burger number	N^2H^2/Ω^2L^2 $[N^2 = -g(\partial\rho/\partial z)/\rho]$	$< 10^{-3}$	10^{-3}	3×10^{-5}
Ekman number	$\nu/\Omega H^2$	$< 10^{-6}$	10^{-5}	$< 10^{-12}$..?
Reynolds number	UL/ν	$> 10^4$	~500	$> 10^{14}$..?
Beta parameter	$\beta L^2/U$	>> 30	~400	> 100
Zonostrophy parameter	$\beta U \tau_E^2$ $[\tau_E = H/\sqrt{\nu\Omega}]$	$>> 10^3$	200-800	$> 10^{12}$

Red parameters -> affected/limited by fluid viscosity

Advantages of a low viscosity fluid

- Very small dissipative scales
- Broad and well developed inertial ranges
  - Both energy AND enstrophy cascades?
  - Zonostrophic anisotropies…?
- Ability to achieve geophysically realistic/relevant parameter ranges and degree of nonlinearity
- Would allow rigorous tests of scaling predictions much more conclusively than possible hitherto
  - even on largest scales with 'normal' fluids
  - cf Coriolis facility, Grenoble (France)