The baroclinic instability of an initially stratified fluid layer

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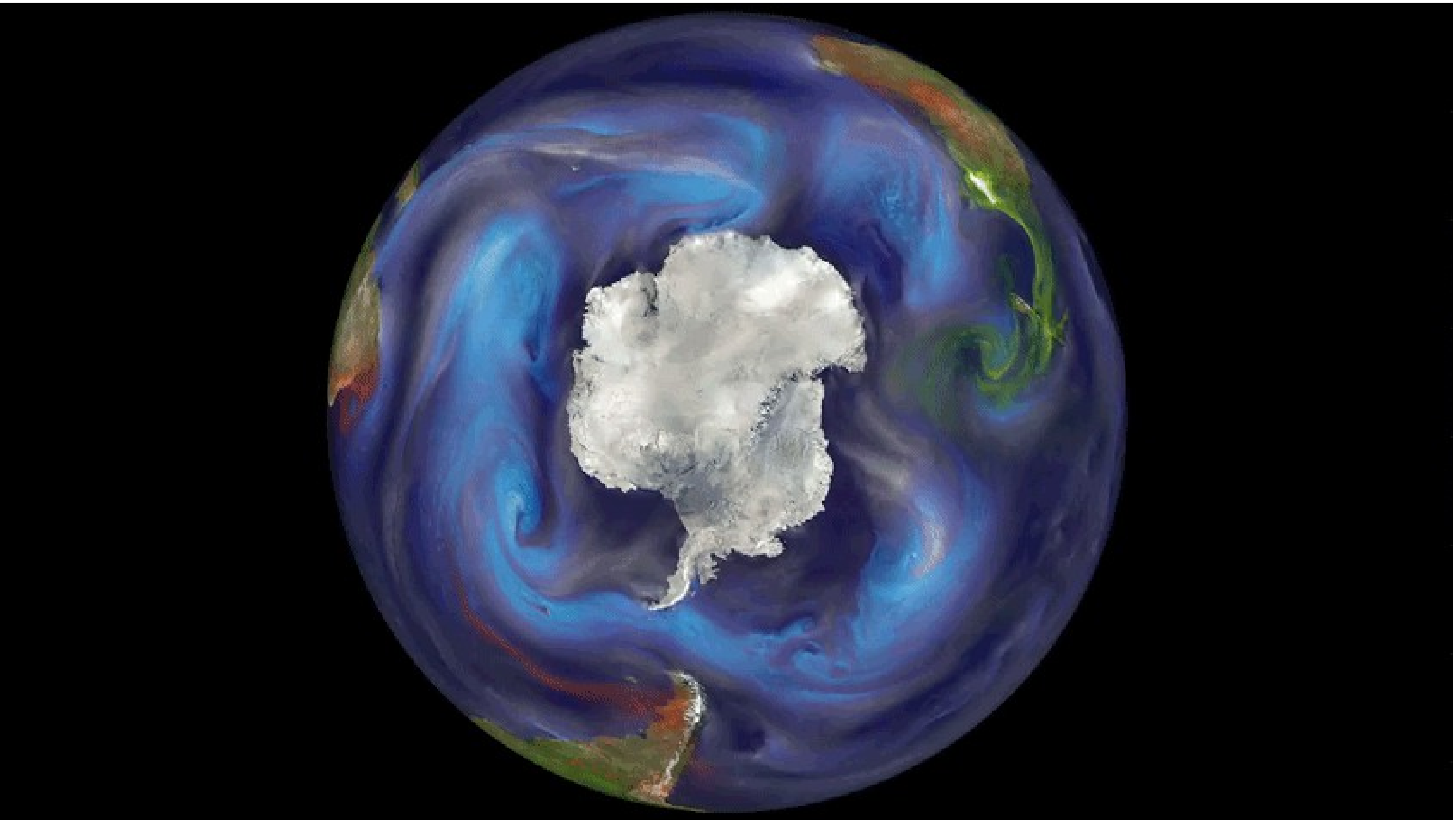
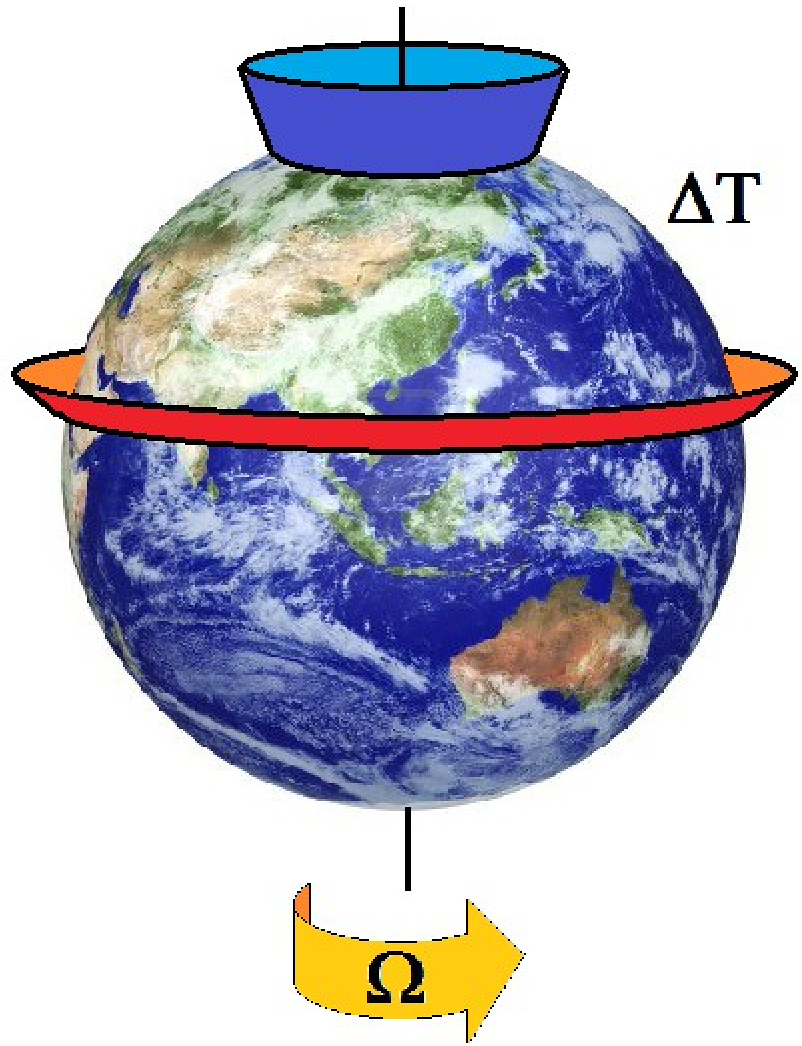
General motivation



Credit NASA: Aerosol transport patterns from the GOES-5 satellite data.
…: http://gmao.gsfc.nasa.gov/research/aerosol/

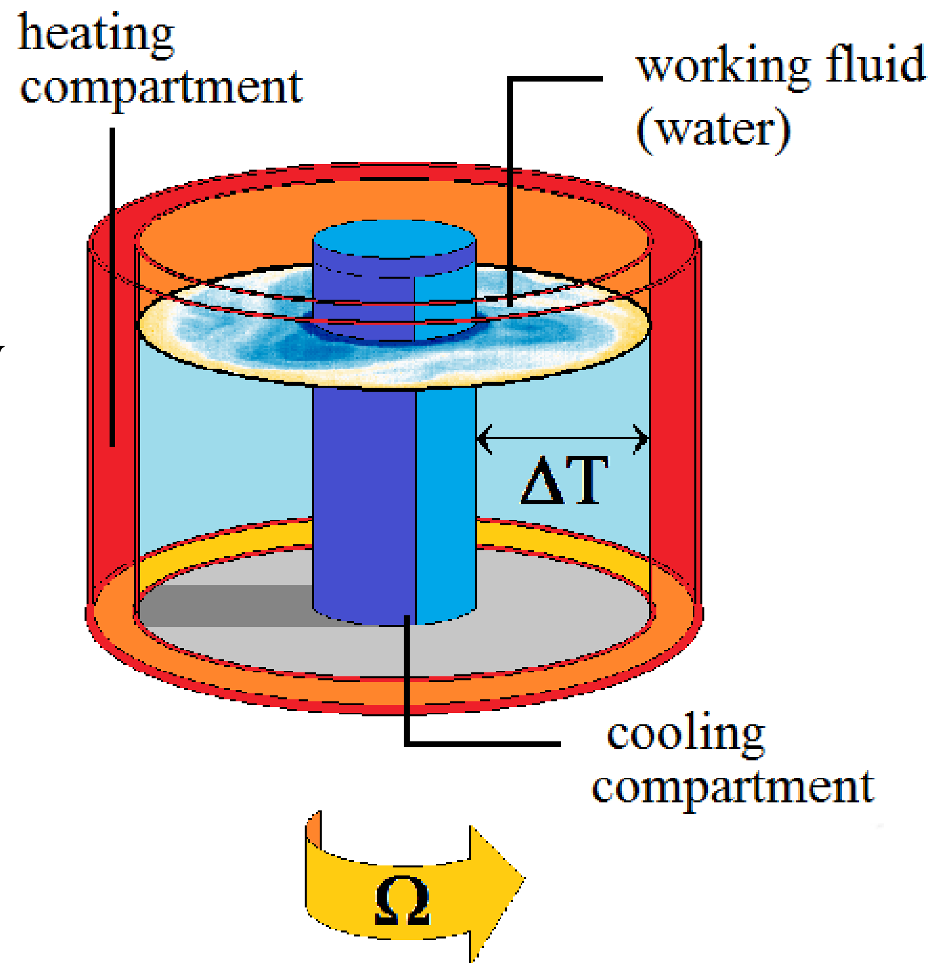
A minimal model of weather-like dynamics

- A large variety of the typical atmospheric phenomena of the mid-latitudes are primarily driven by two factors only.
- ***Rotation + meridional temperature difference ≈ weather***

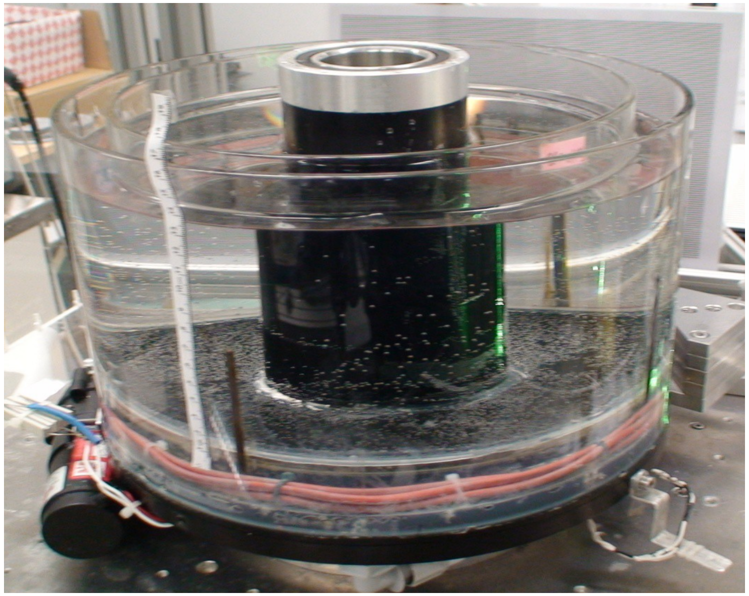


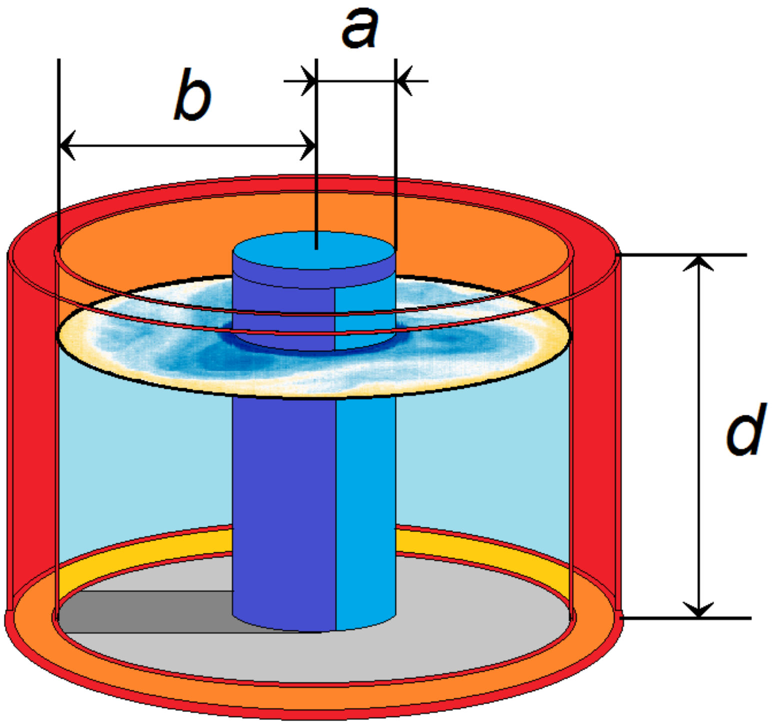
A minimal model of weather-like dynamics

Laboratory experiments
On the baroclinic instability



CoGeoF1 plateform
Brandenburg University of Technology (BTU) Cottbus





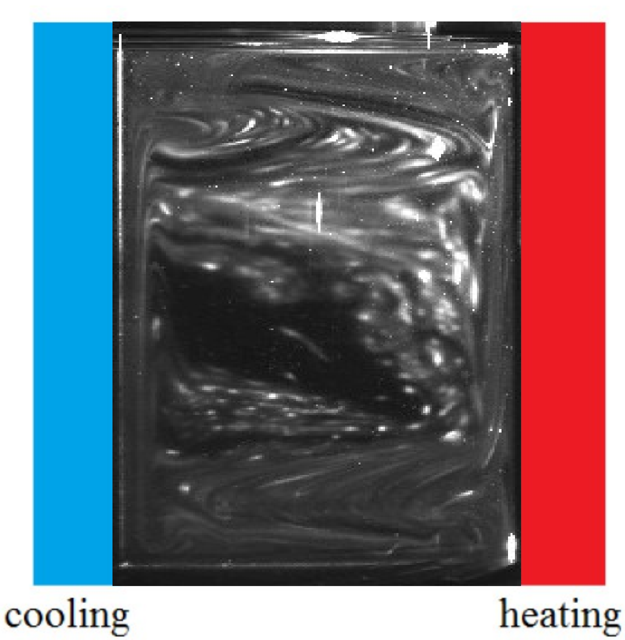
<u>Geometric parameters:</u>

a = 45 mm

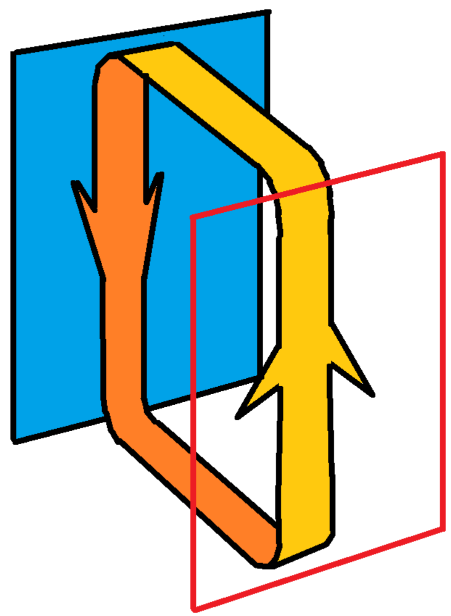
b = 120 mm

d = 135 mm

Basics: baroclinic instability



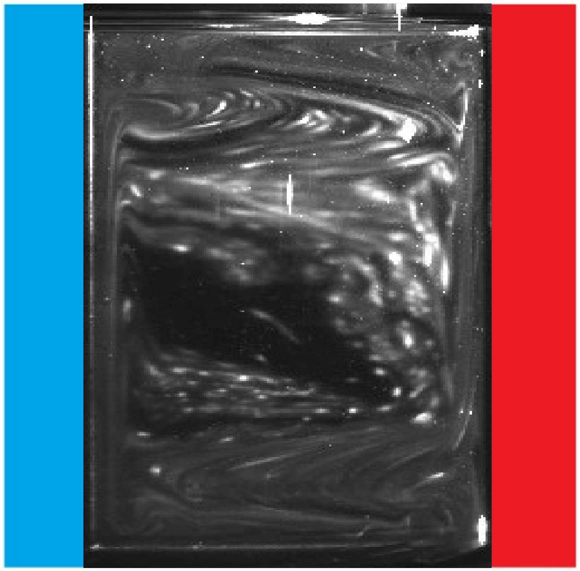
No Rotation



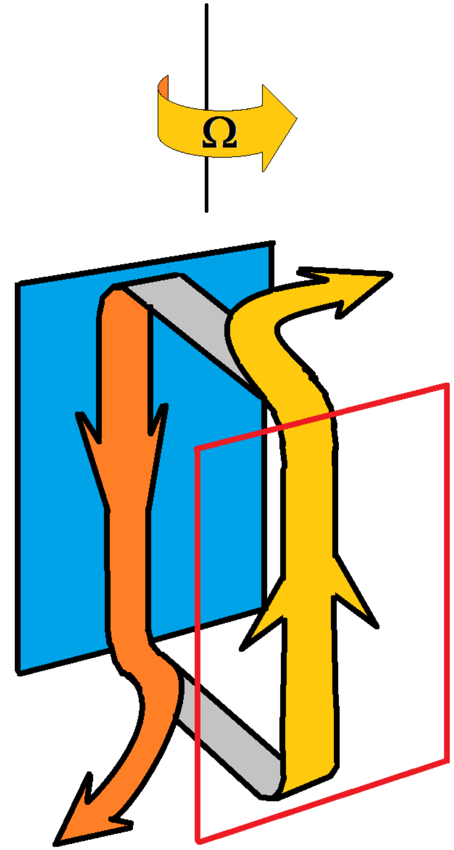
"Sideways convection" – no threshold in ΔT
(i.e. No 'critical Rayleigh number')

Any **temperature difference can initia the flow**

Baroclinic instability



cooling heating



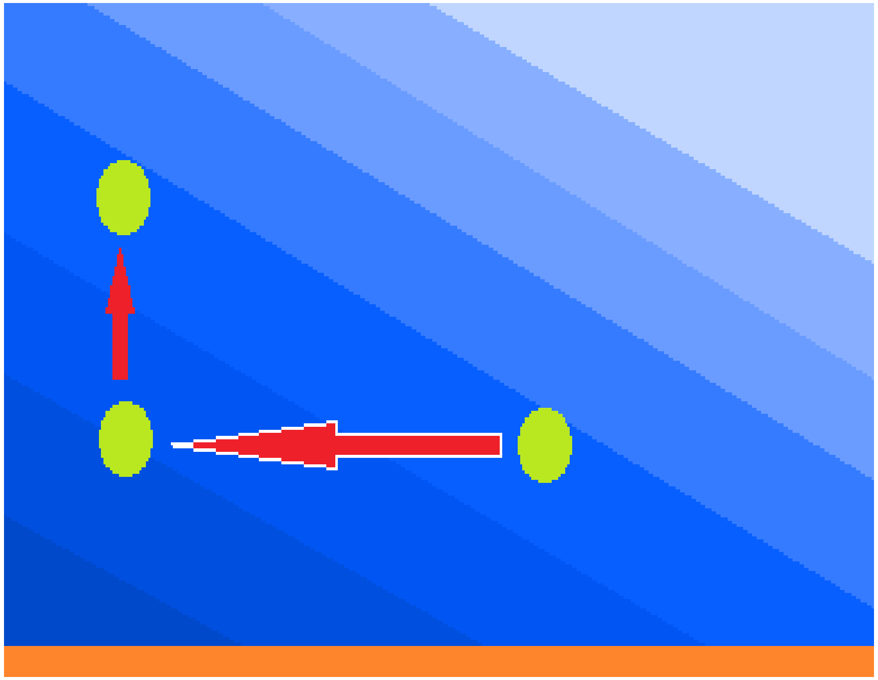
$$-2\Omega\vec{e_z} \times \vec{u}$$

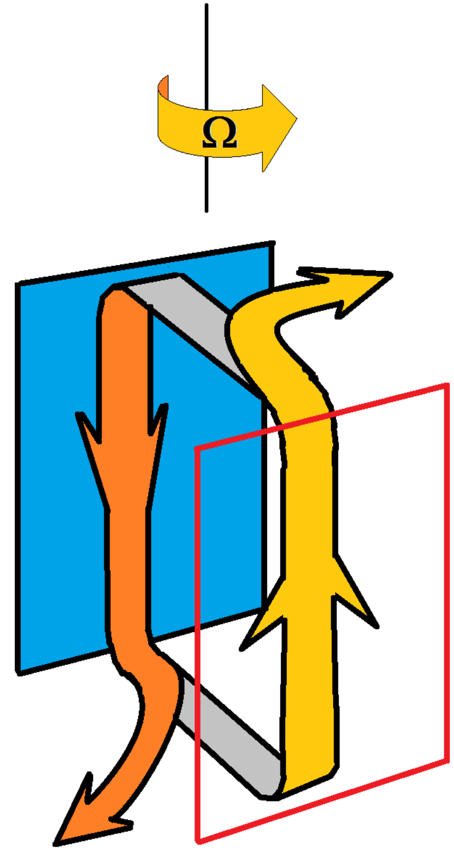
Rotation!

Zonal flow (thermal wind)

Geostrophic theory:
Tilted density surfaces

Baroclinic instability





Rotation!

Zonal flow
(thermal wind)

Geostrophic theory:
Tilted density surfaces

$$-2\Omega\vec{e_z} \times \vec{u}$$

INSTABILITY

Experimental baroclinic instability set-up mimics:
Convective cells, jets and zonal winds,
Rossby waves of planetary atmospheres

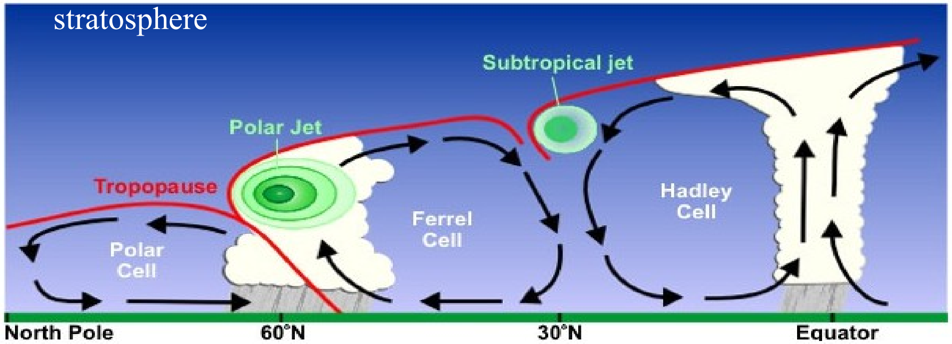
- control parameters:

  rotation rate, radial temperature difference

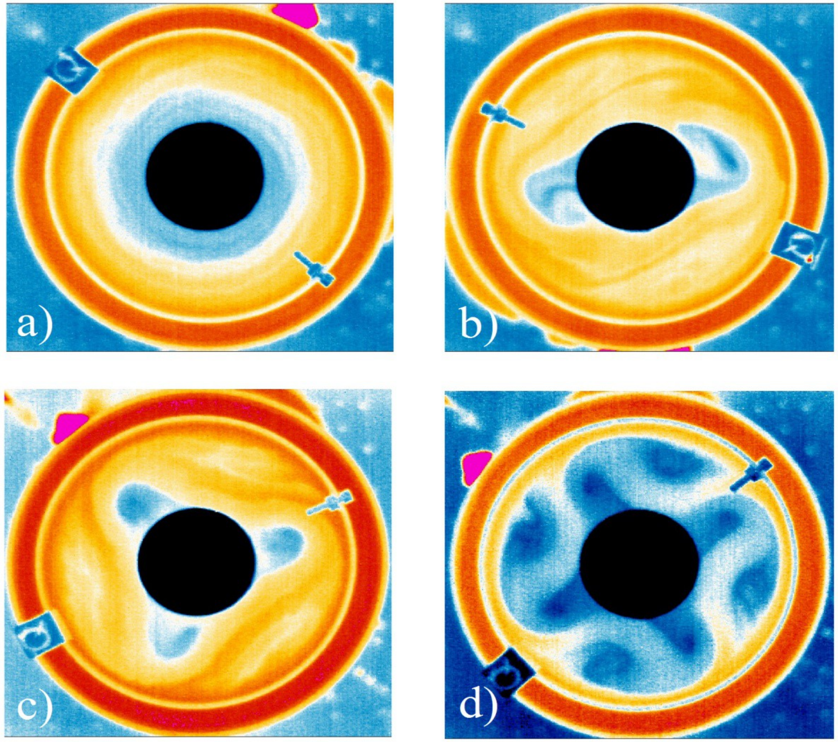
- Different planetary atmospheres can be modelled

  Venus: slow rotation, zonal flow

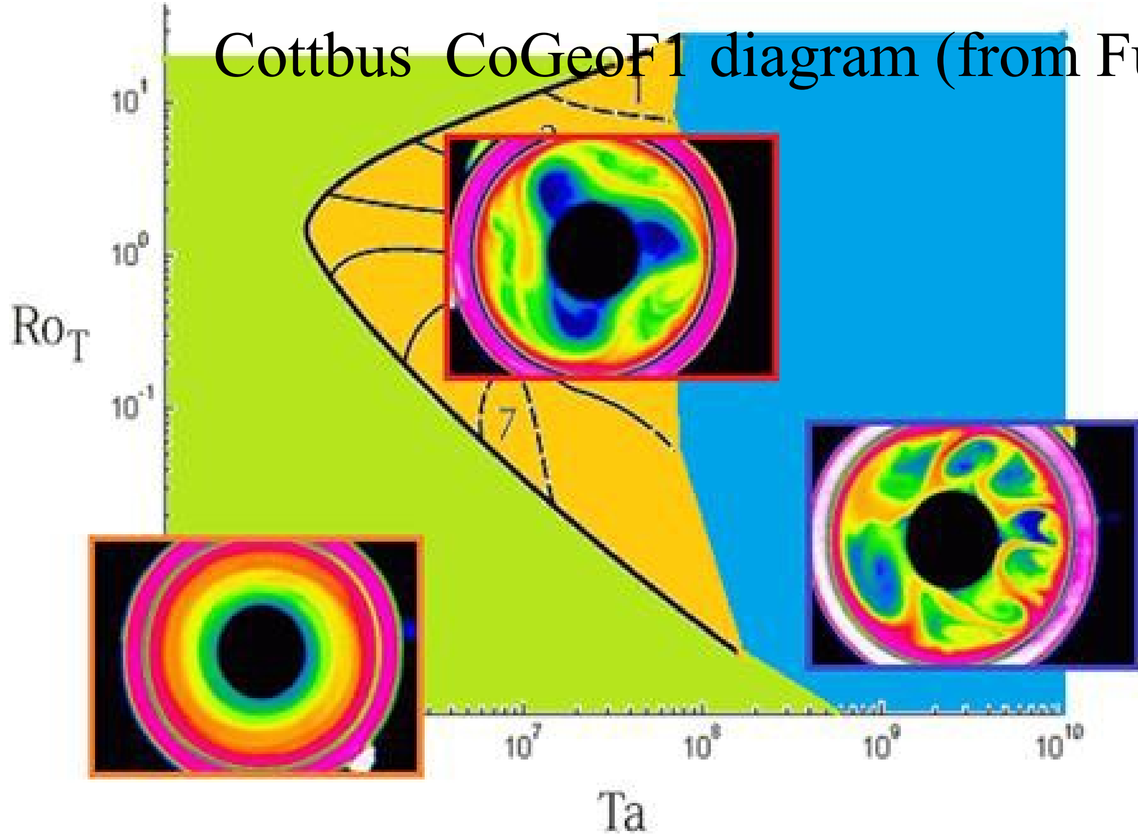
  Earth: fast rotation → Coriolis effect → vortices ("weather")



Credit : wikipedia



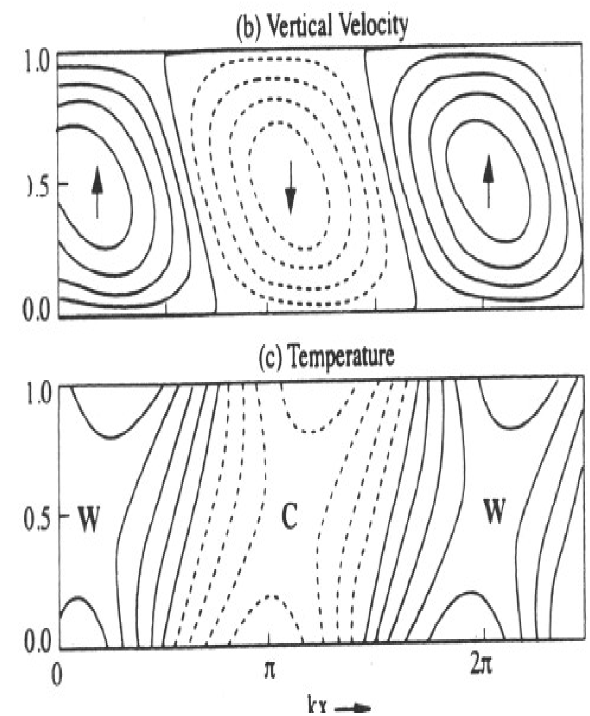
Cottbus CoGeoF1 diagram (from Fultz):

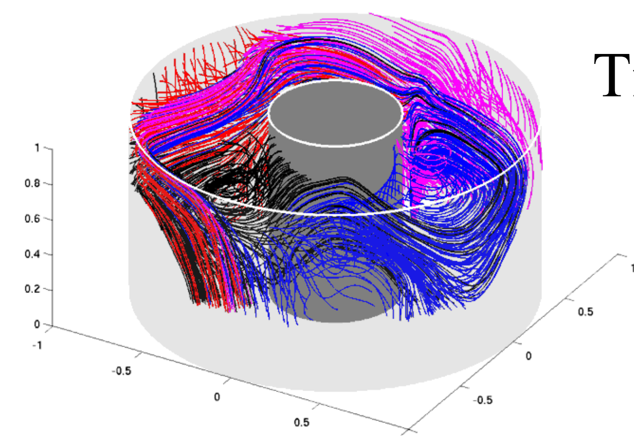


$$Ta = \frac{4 \cdot \Omega^2 \cdot (b-a)^5}{\nu^2 \cdot d}$$

$$Ro = \frac{g \cdot d \cdot \alpha \Delta T}{\Omega^2 \cdot (b-a)^2}$$

Tilted columnar vortices





3D flow field from simultaneous PIV
ermography observations

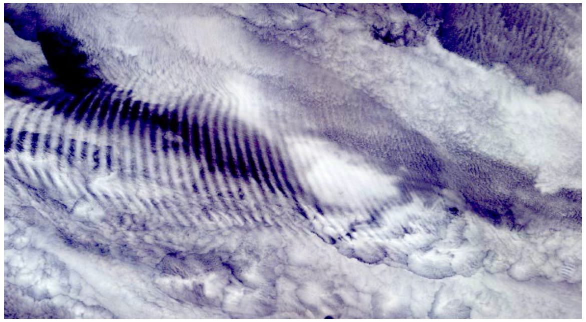
Credit : www.atmosp.physics.utoronto.ca

Can we add a stratosphere ?

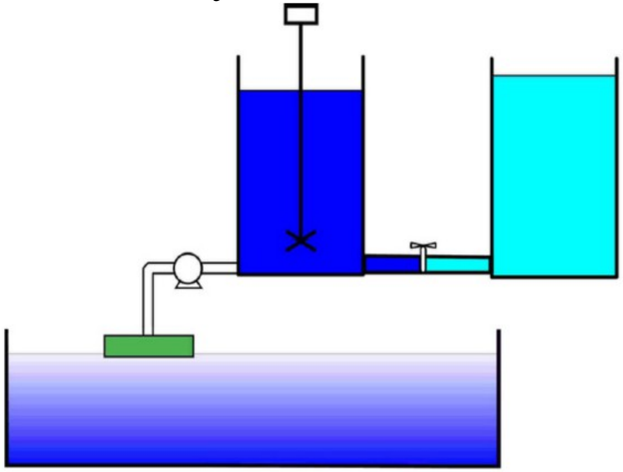
- To get the « right » horizontal stress free Boundary Condition
- To generate « pancake » vortices in rotating and stratied flows : Jupiter Great Red Spot

Credit:NASA

- To excite Gravity Waves from eventual unbalanced dynamics



Credit:http://www.planetpals.com

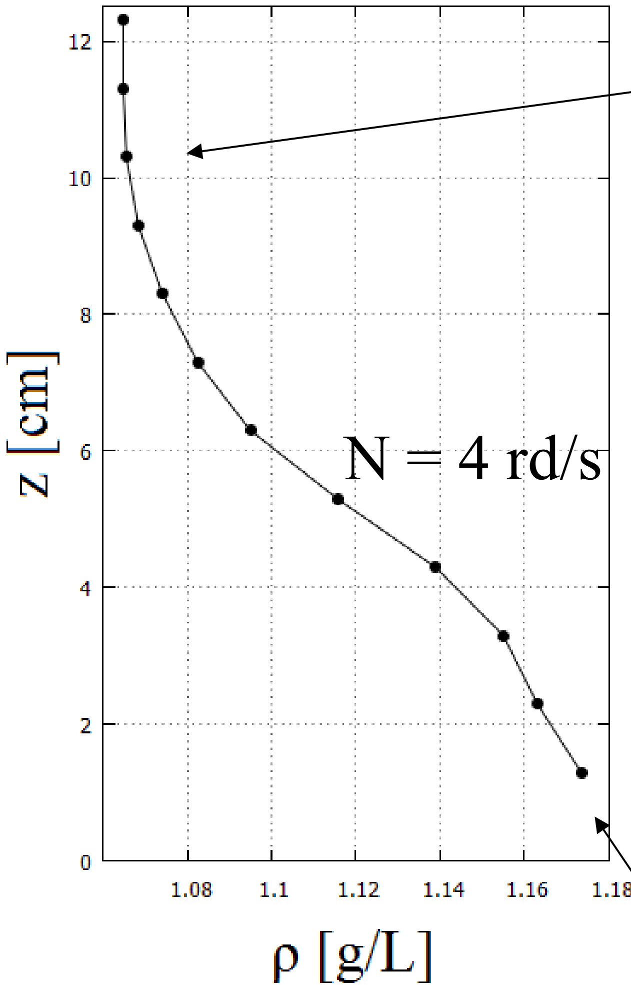


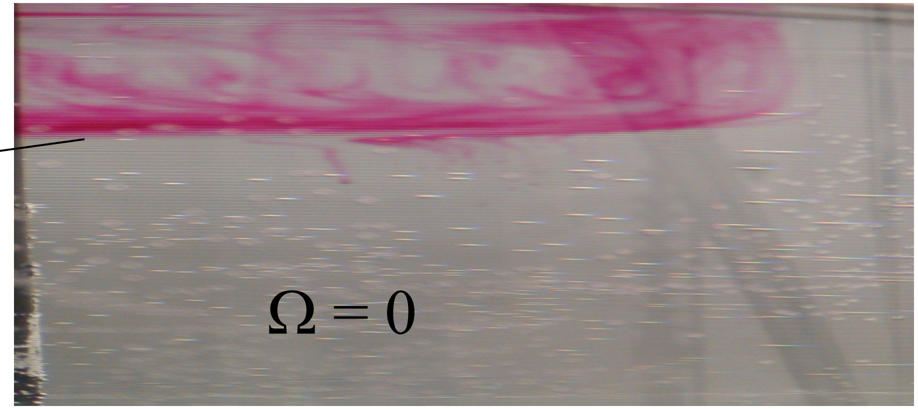
→ The baroclinic instability of an initially stratified fluid layer :

The BAROSTRAT Instability

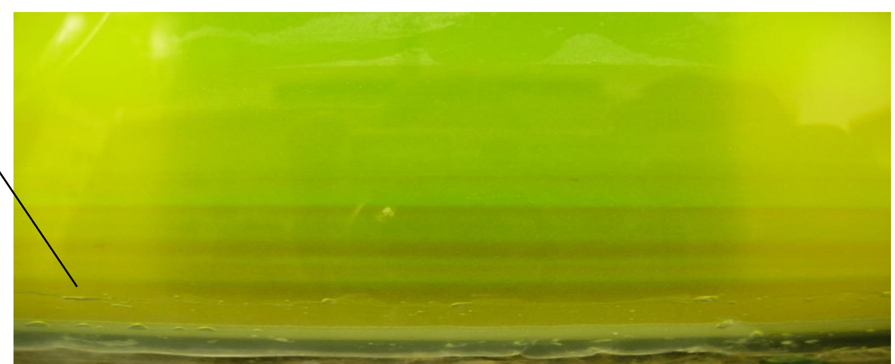
Salinity stratification:
"Double-bucket" method

Stratification will oppose to convection !



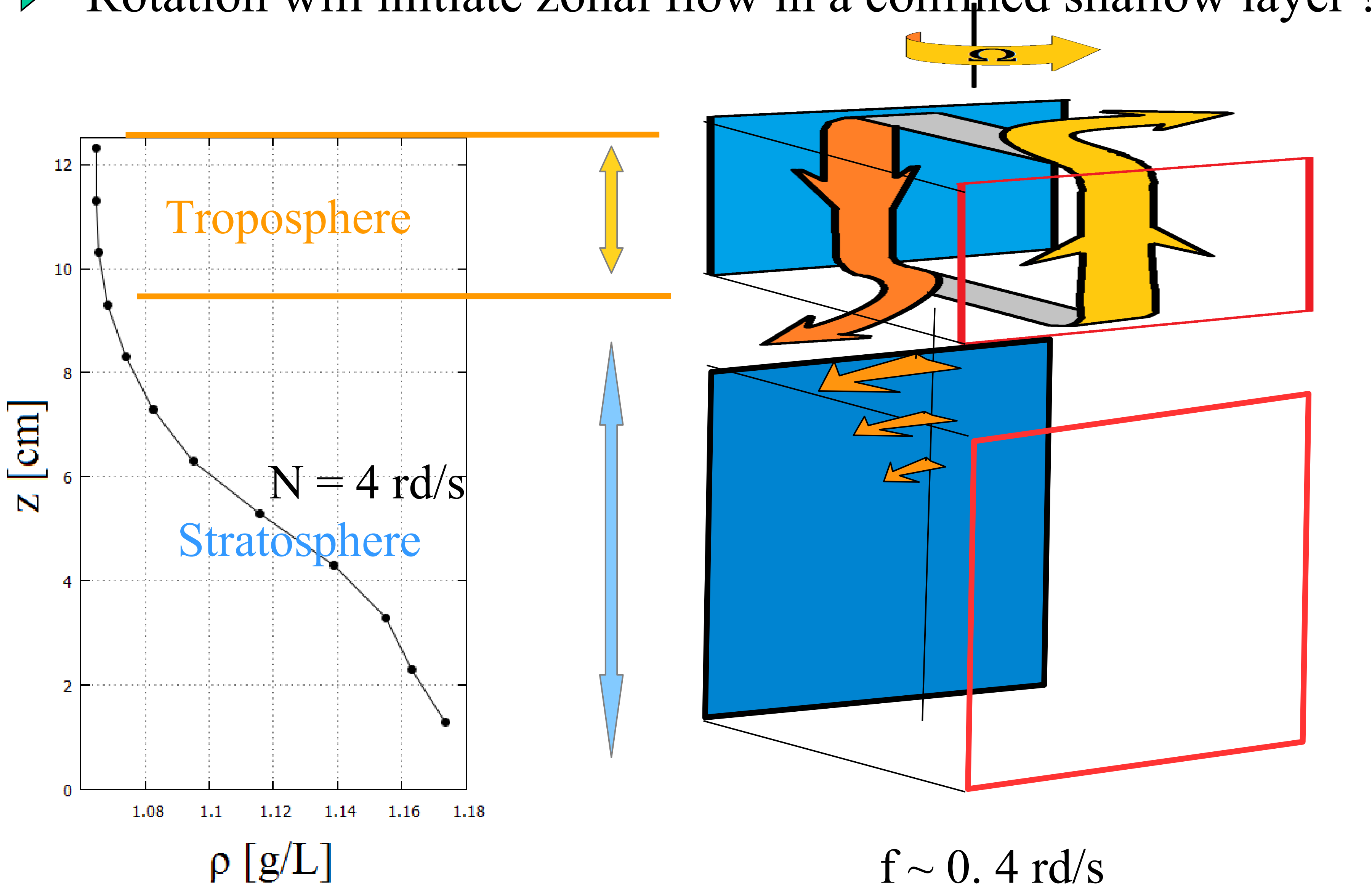


Above a temperature threshold, convection confined in weakly stratified shallow layers (Lee, Kang, Son 1999)



Double diffusive staircase cells at bottom

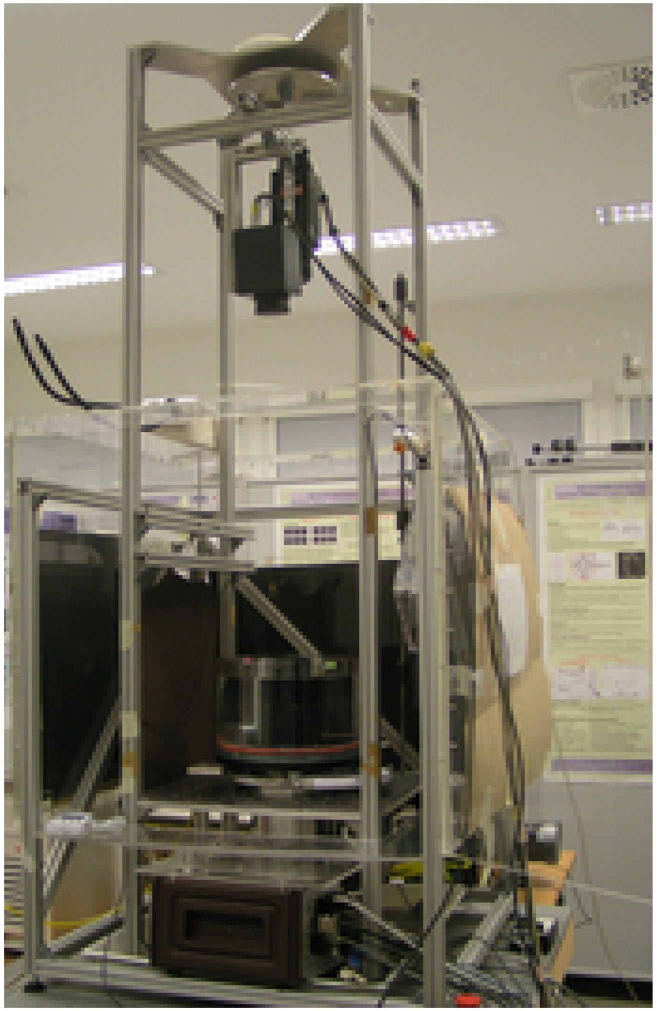
Rotation will initiate zonal flow in a confined shallow layer !

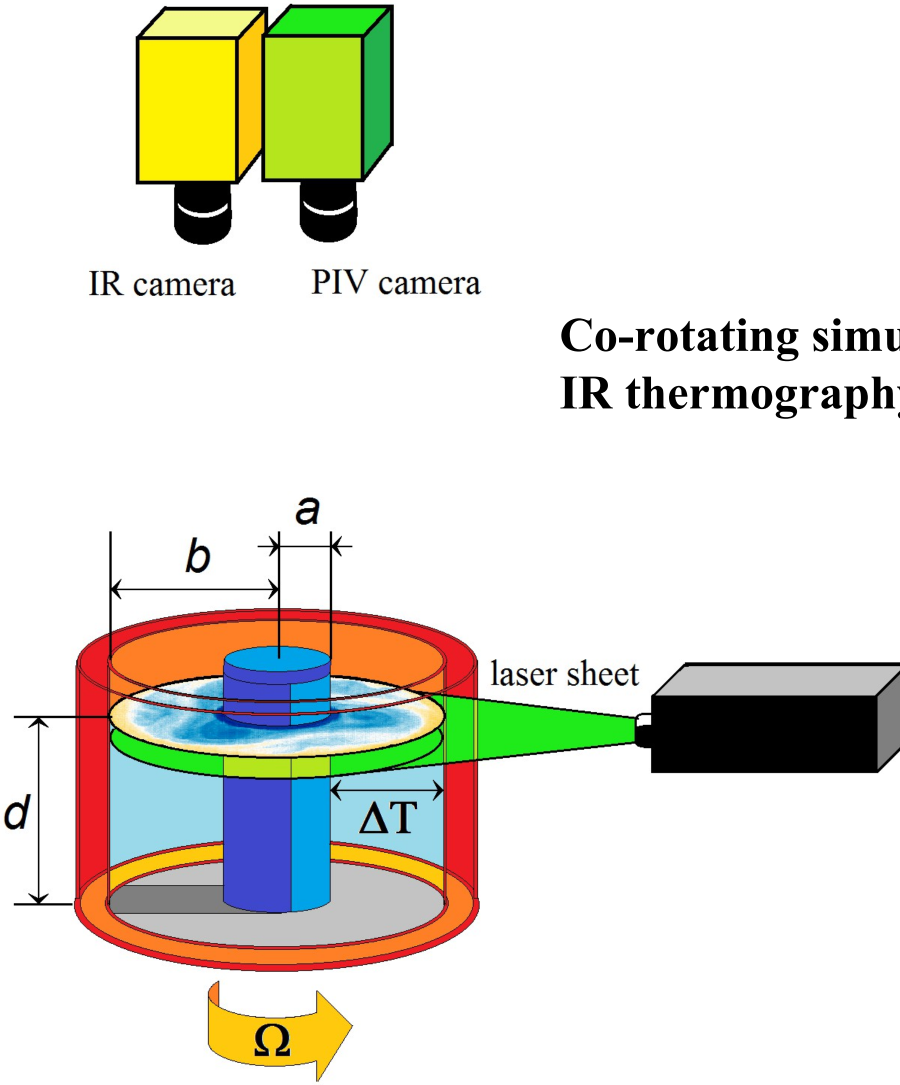


Above a critical Ω : Baroclinic Instability in a shallow layer

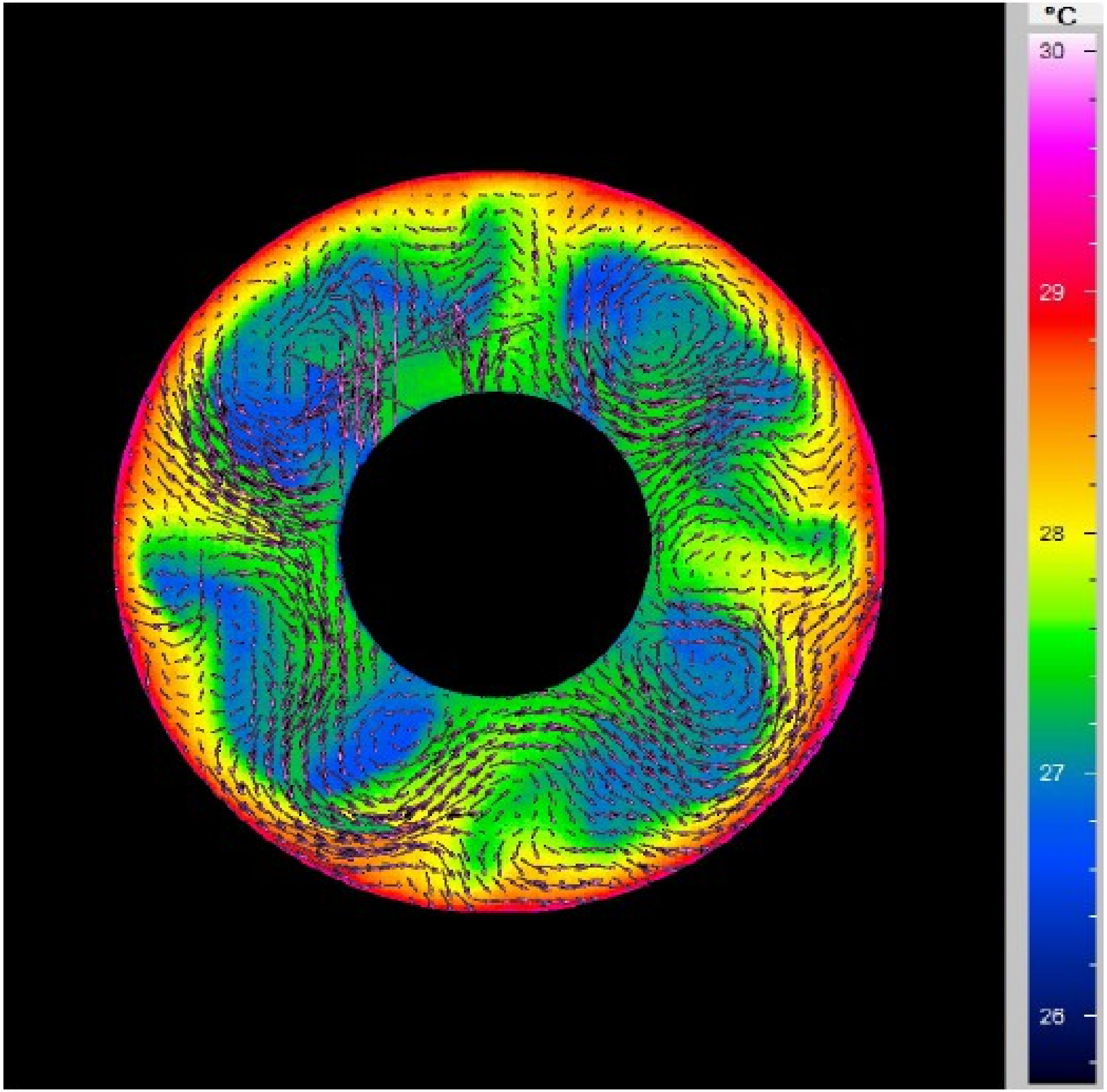
ve a stratified layer

Measurement techniques



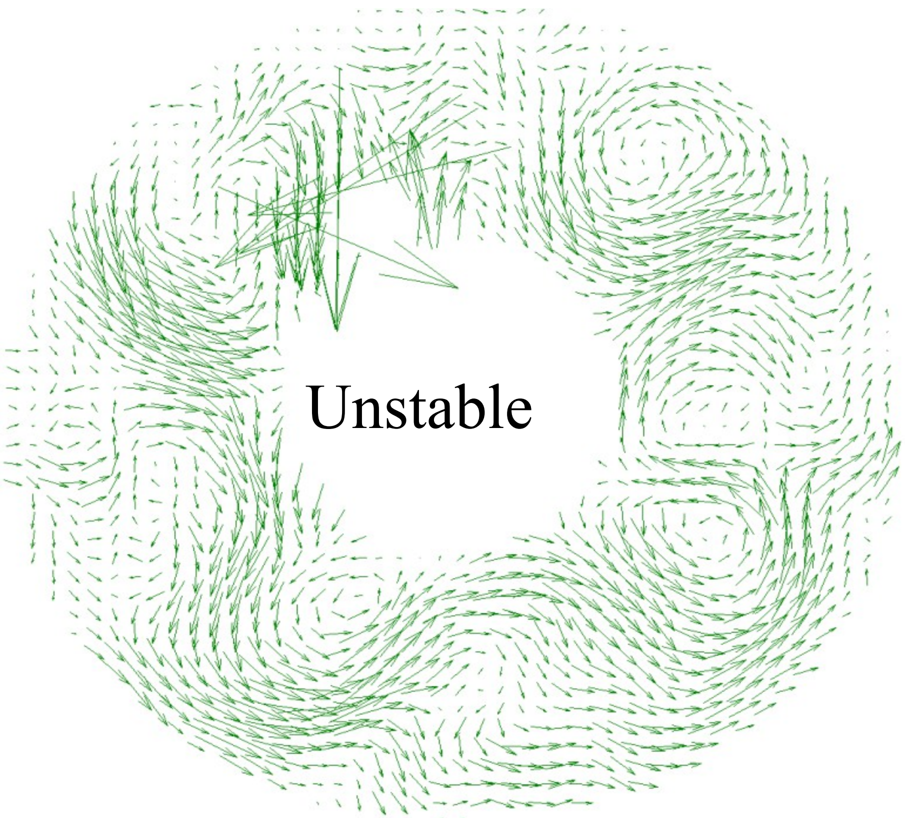


Co-rotating simultaneous IR thermography and PIV

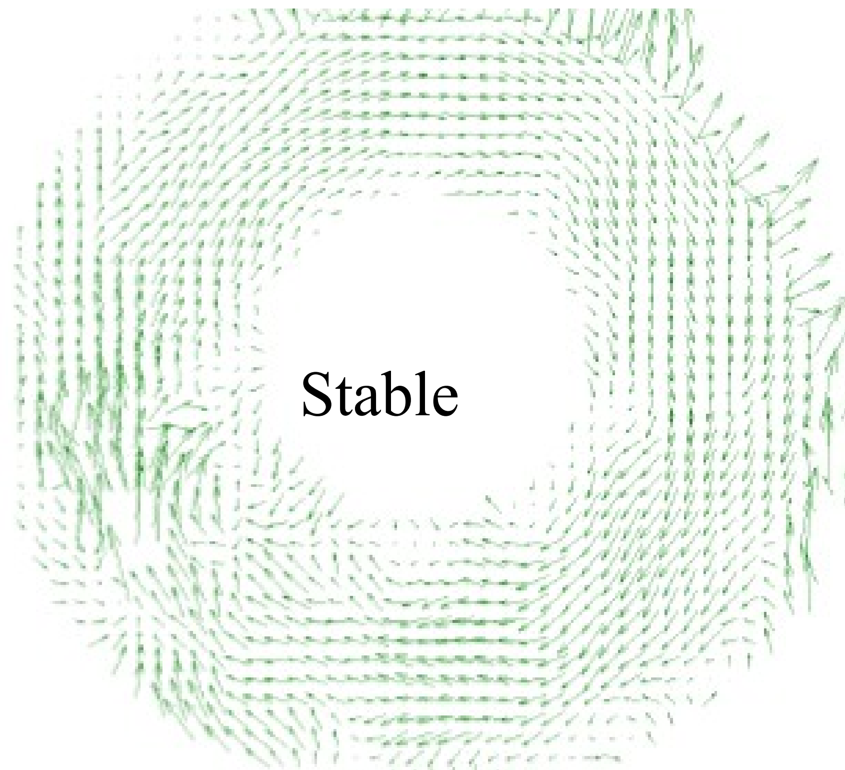


$\Delta T = 6$ K
$\Omega = 2.7$ rpm

PIV field near surface

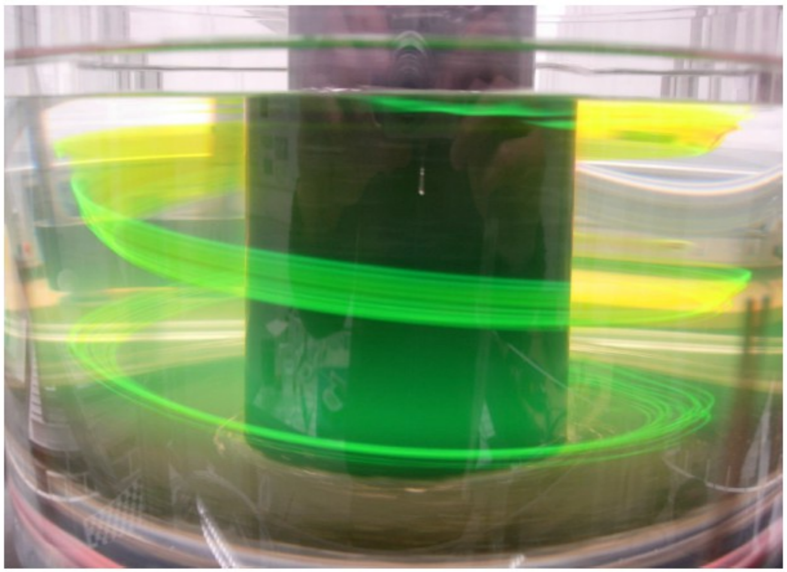


PIV field near bottom

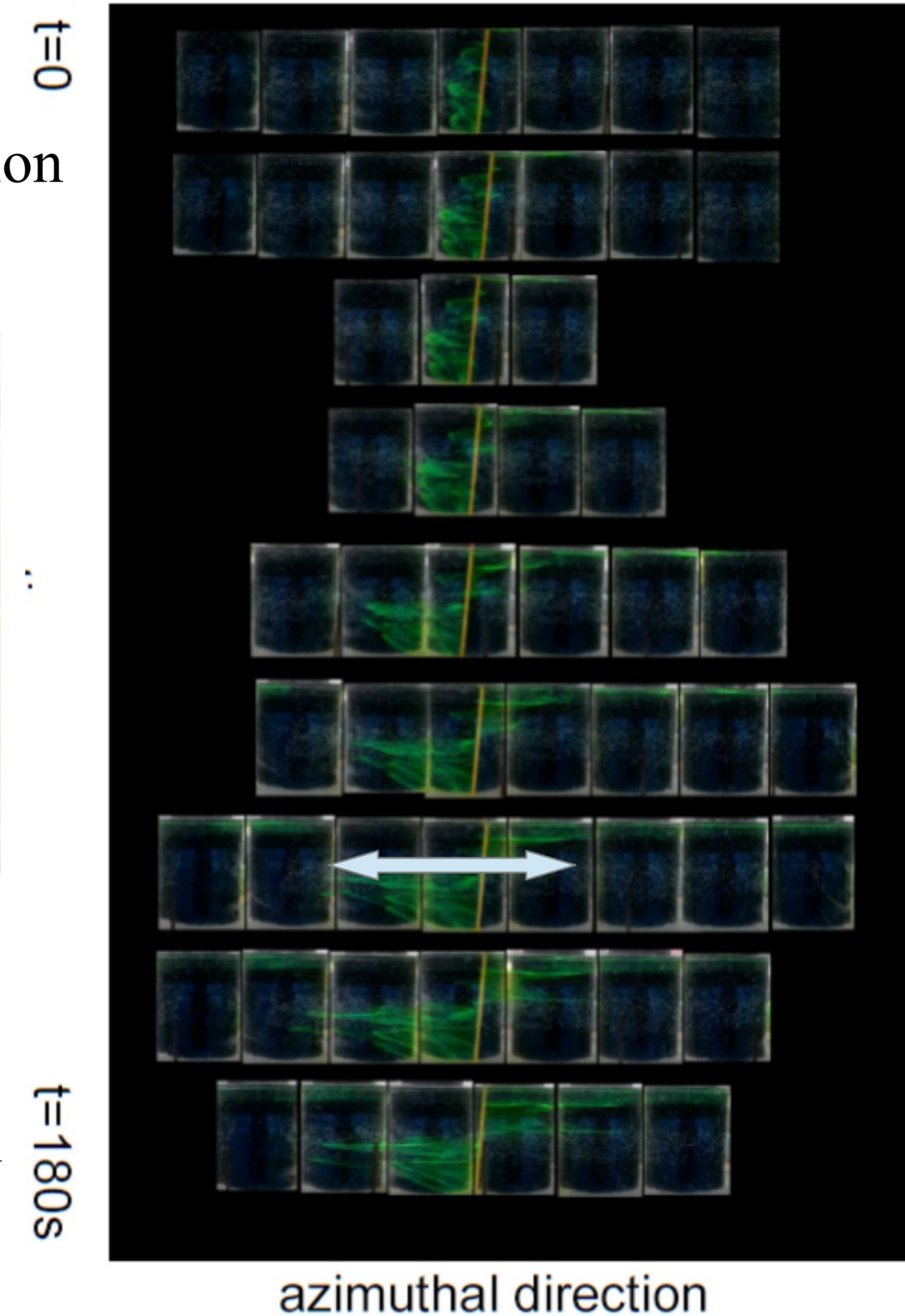


Zonal flow only

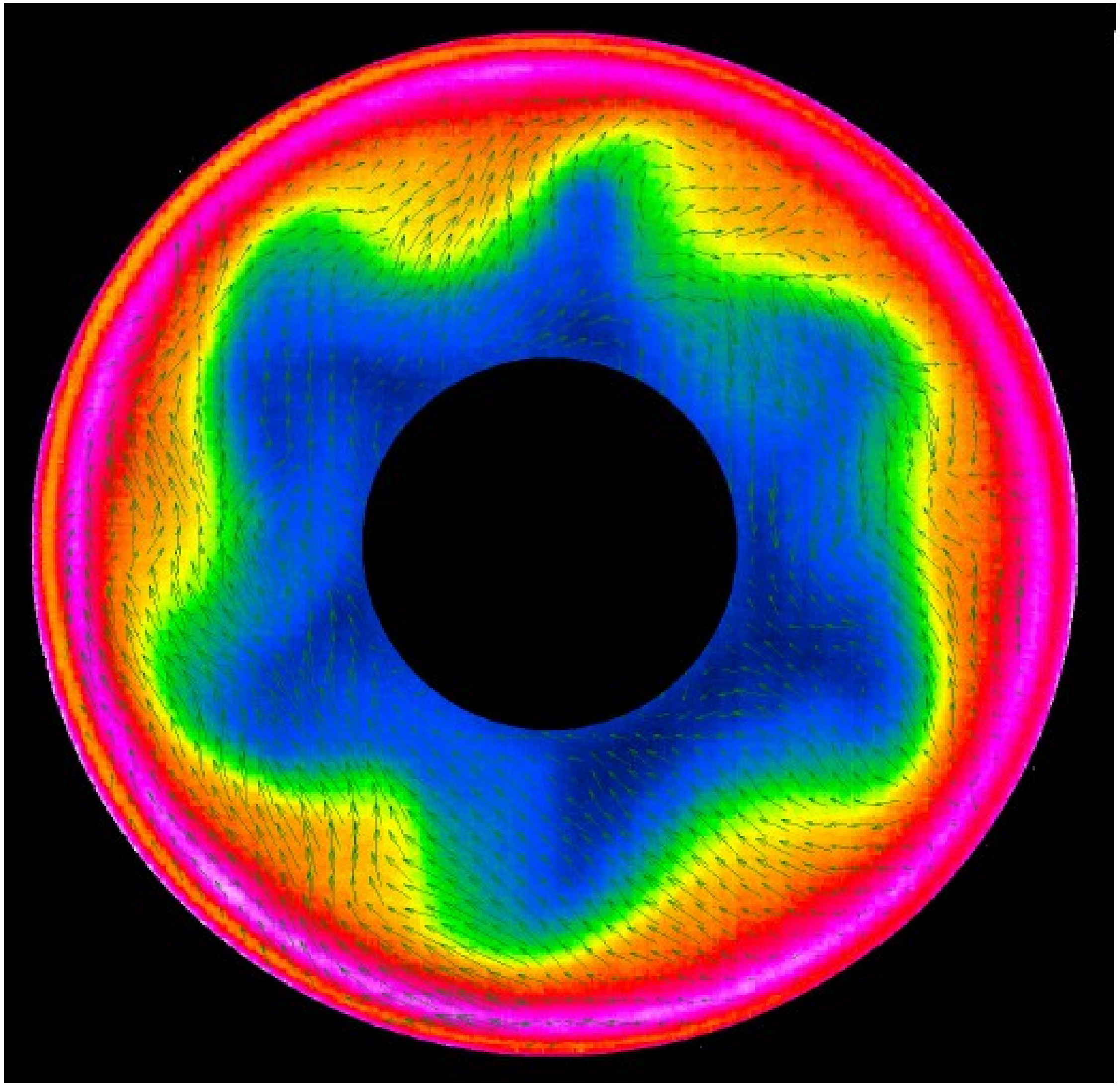
Fluoresceine visualization of thermal wind



Note the stretching of dye filaments between top and bottom of the convective cell



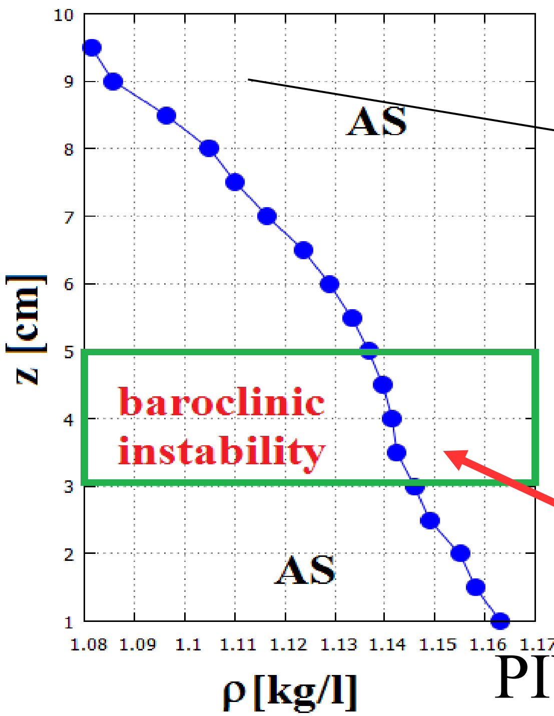
Sucking top mixed layer : decreases its thickness and changes azimuthal wave number

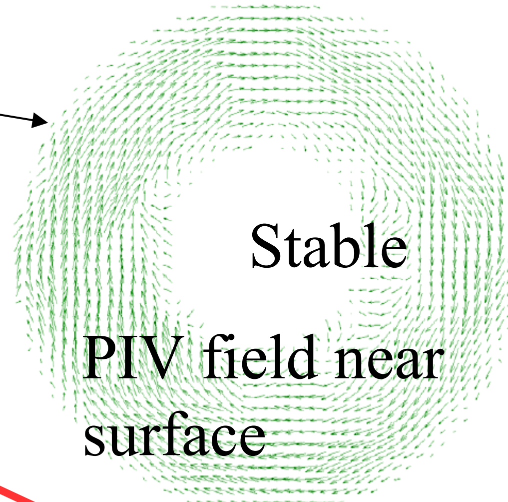


ΔT = 6 K
Ω = 1.7 rpm

A combined thermographic/PIV image (surface temperature + PIV data from h = 12 cm)

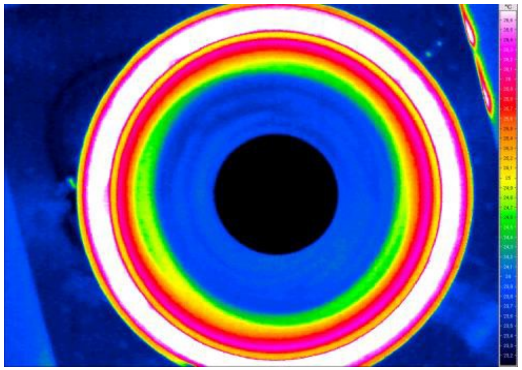
Sucking out completely top mixed layer on a vertical Density profile with a zero gradient inner layer





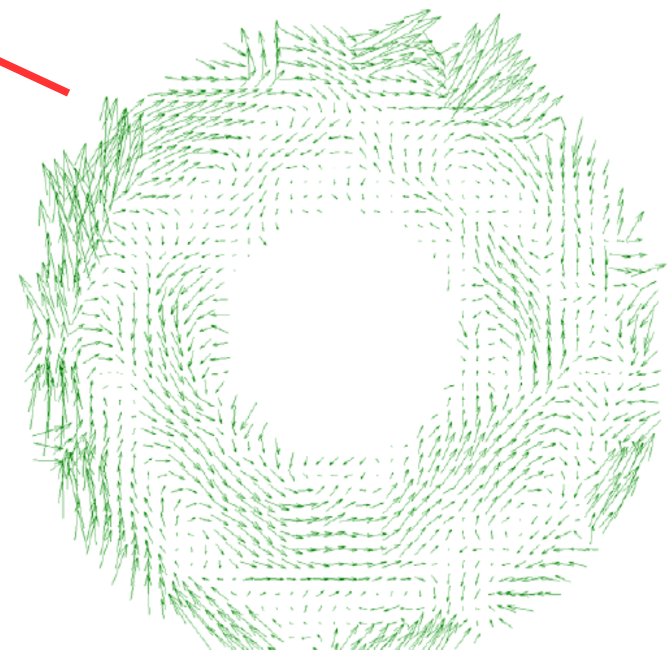
Stable

PIV field near surface



Infrared surface image

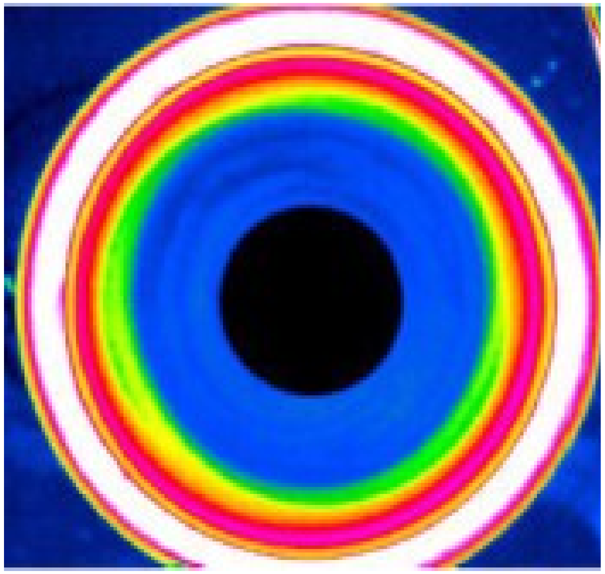
PIV field in inner layer

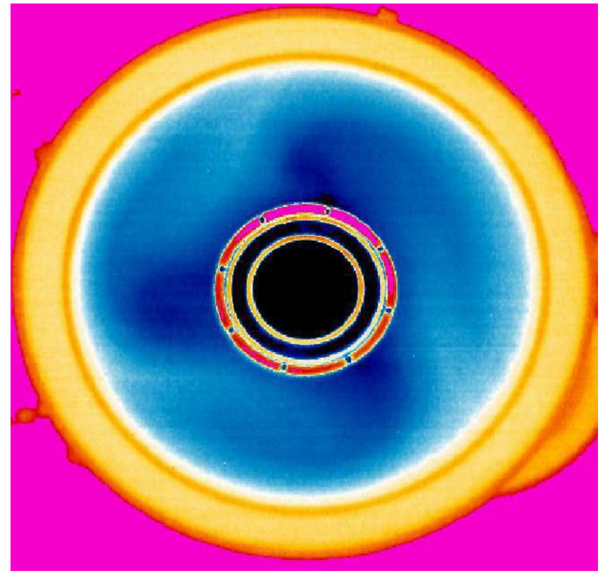


Unstable in a confined inner layer :
Chain of pancake vortices between two stratified regions

Zoology of different patterns of the « Barostrat intability »

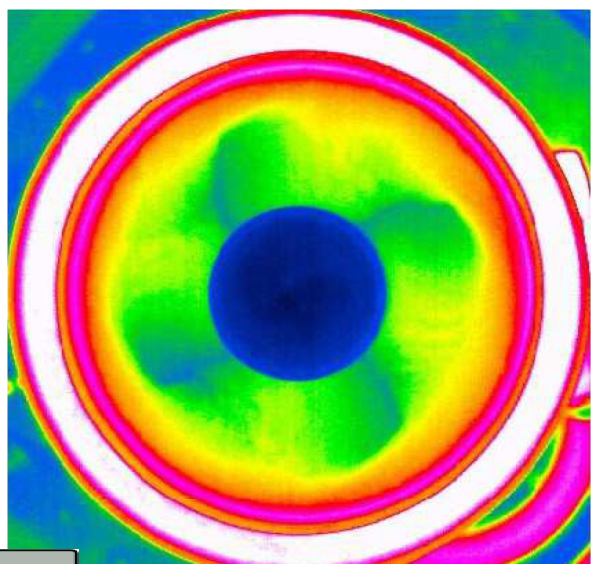
m = 0

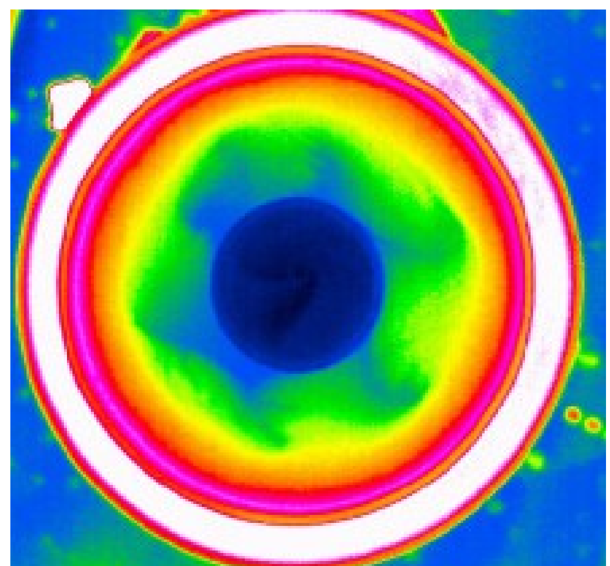




m = 3

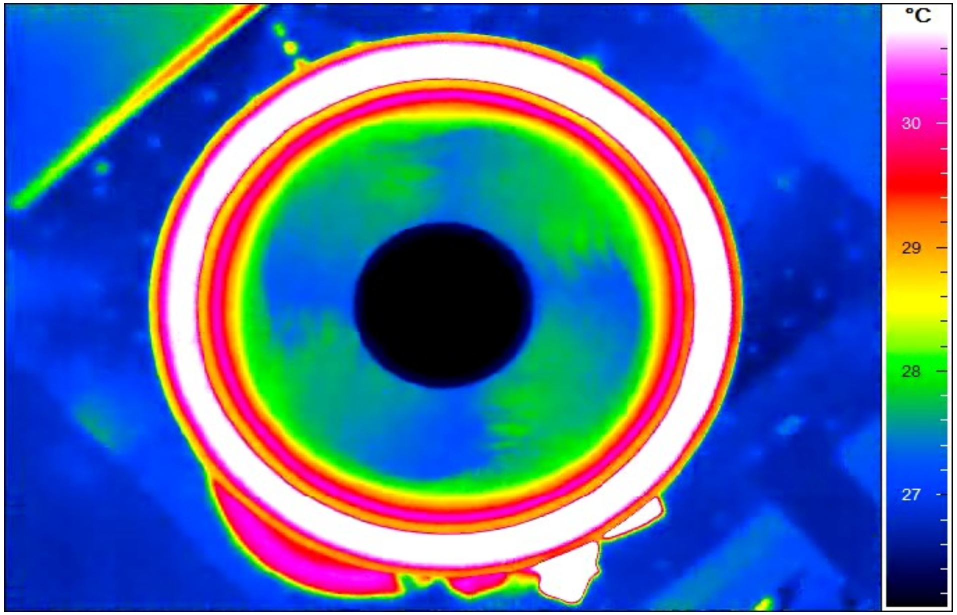
m =4



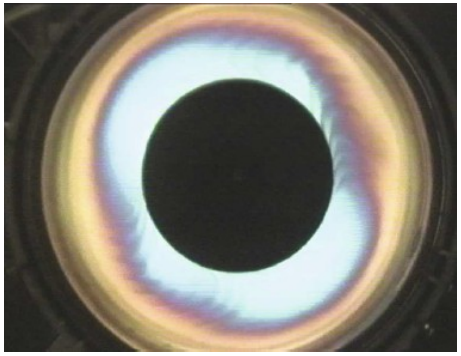


m = 6

Study unbalanced dynamics
(spontaneous emission of internal waves)



$$\Delta T \approx 6.5 \text{ K}$$
$$\Omega = 2.5 \text{ rpm}$$



Waves *have been observed in a 2 immiscible fluid layers experiment (Williams, Haine, Read, 2008)*