GeoFlow Experiment - From Numerical Simulation to Experimental Data Evaluation Numerical and Experimental Alignment

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Geophysical Flow Simulation
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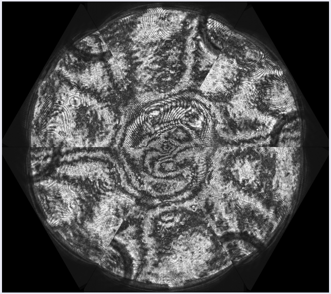
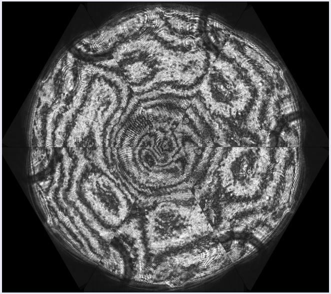
Patterns of convection in the rapid rotation regime: Alignment of convective cells at the tangent cylinder

$Ra_{centr} = 8.87 \cdot 10^4$
$Ta = 8.59 \cdot 10^6$

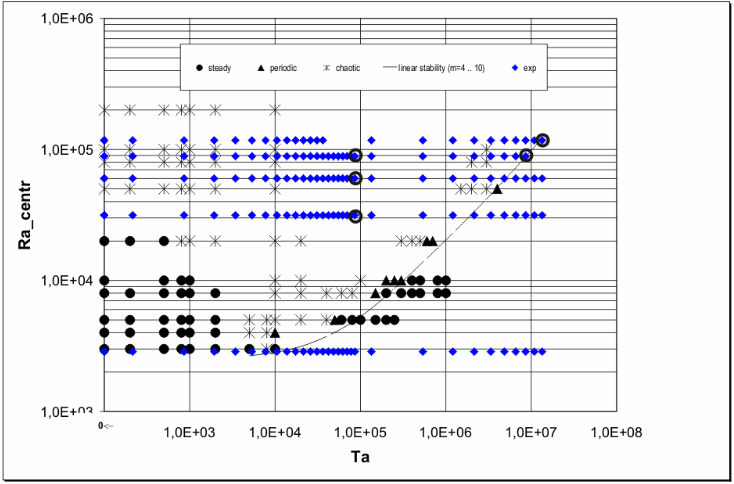


$Ra_{centr} = 1.17 \cdot 10^5$
$Ta = 1.34 \cdot 10^7$



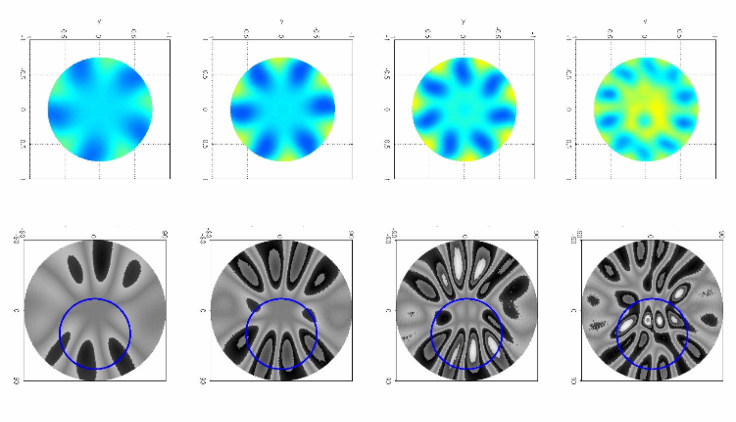
'columnar cells'

Dynamics of GeoFlow: stability diagram
. . . with specific selection for first evaluation



Increase of mode number m with increasing of parameter set:
$m = 5 \rightarrow 6 \rightarrow 7 \rightarrow 10$
$(Ra_{centr}, Ta) = (8 \cdot 10^3, 1 \cdot 10^6) \rightarrow (1 \cdot 10^4, 1 \cdot 10^6) \rightarrow (2 \cdot 10^4, 2 \cdot 10^6) \rightarrow (5 \cdot 10^4, 4 \cdot 10^6)$

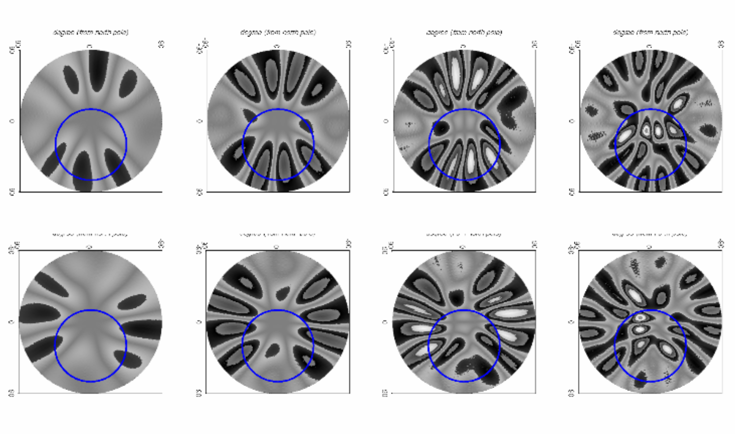
visualization of temperature field with view at the top of the sphere, i.e. the middle of the image is the 'polar' region.



interferogram scaled to $\Delta T = 10\ K$ with blue circle marking observation window, i.e. the top of a single image captures polar region

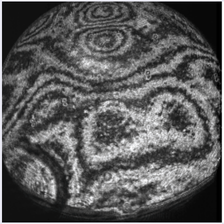
Increase of mode number m with increasing of parameter set:
$m = 5 \longrightarrow 6 \longrightarrow 7 \longrightarrow 10$
$(Ra_{centr}, Ta) = (8 \cdot 10^3, 1 \cdot 10^6) \longrightarrow (1 \cdot 10^4, 1 \cdot 10^6) \longrightarrow (2 \cdot 10^4, 2 \cdot 10^6) \longrightarrow (5 \cdot 10^4, 4 \cdot 10^6)$

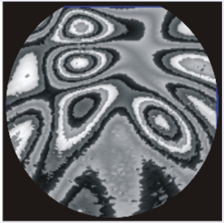
Wollaston shearing interferometry I

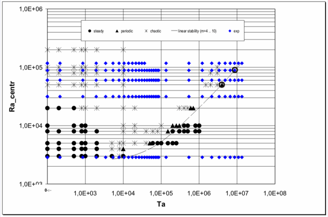


WSI II (turned by 90°)
interferogram scaled to $\Delta T = 10\ K$ with blue circle marking observation window, i.e. the top of a single image captures polar region

Alignment for single image: Identification of fringe pattern as 'columnar cells'





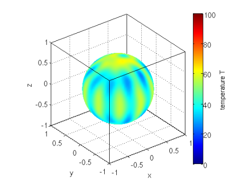


	experimental	numerical
Ra_{centr}	$9 \cdot 10^4$	$5 \cdot 10^4$
Ta	$9 \cdot 10^6$	$4 \cdot 10^6$

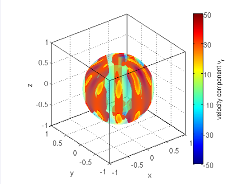
$\longrightarrow$ shift between experimental and numerical stability regimes

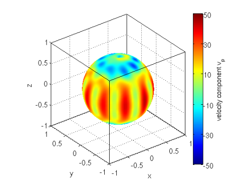
Character of columnar cells: qualitative at $Ra_{centr} = 5 \cdot 10^4$, $Ta = 4 \cdot 10^6$

temperature field
on spherical surface

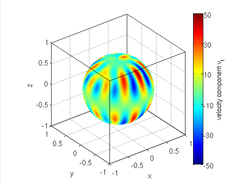


radial velocity component
on spherical surface





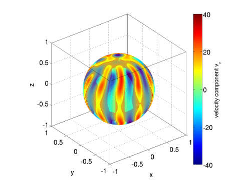
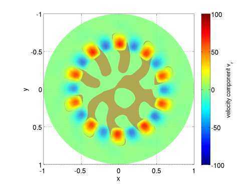
azimuthal velocity comp.
on spherical surface



meridional velocity comp.
on spherical surface

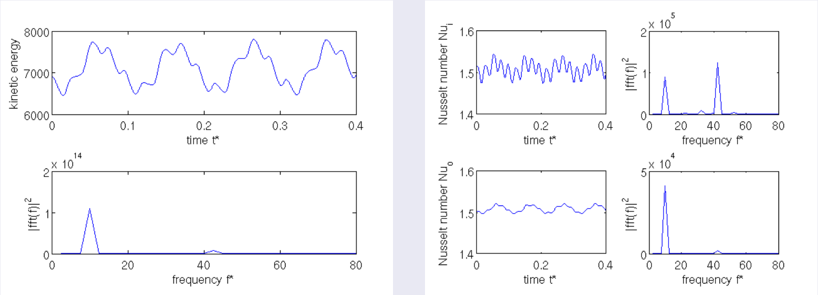
- alignment of convective cells along a tangent cylinder, touching the inner sphere

Character of columnar cells: qualitative at $Ra_{centr} = 5 \cdot 10^4$, $Ta = 4 \cdot 10^6$

radial velocity comp. on spherical surface view 3D with an isosurface	radial vel. comp. on spherical surface view from equatorial plane to pole
	

- drift prograde
- exchange of columns in the polar region

Character of columnar cells: kinetic energy and Nusselt number at $Ra_{centr} = 5 \cdot 10^4$, $Ta = 4 \cdot 10^6$)



- amplitude with quasi-periodic behaviour:
  $f^* = 10 \rightarrow f = 0.001\ Hz\ (t \approx 15.7\ min)$
  $\rightarrow$ drift prograde at a slow rate compared to rotation rate of the sphere ($n = 1.09\ Hz$)
- amplitude of E_{kin} high and of Nu low
  $\rightarrow$ mass transfer dominates heat transfer due to rotational drive

Character of columnar cells: experimental identification of quantitative values

- thermal
  $\longrightarrow$ Nusselt number
- kinetic
  $\longrightarrow$ tracking of patterns

Formulas for calculation of a Nusselt number

- common sense

$$Nu = \frac{\alpha \cdot L}{\lambda}$$

α - convective heat transfer coefficient of a boundary
L - characteristic length of the system
λ - thermal conductivity of the thermal working fluid (M5)

- estimation of coeff. α via heat flux (measured by control of circuits)

$$q = \alpha \cdot A \cdot \Delta T$$

A - boundary are $(4\Pi \cdot r_o^2)$
ΔT - temperature difference between T_{fluid} and T_{bound}

- energetic averaged temperature

$$T_{fluid} = \frac{\int \rho \cdot u \cdot c_P \cdot T dA}{\int \rho \cdot u \cdot c_P \cdot dA}$$

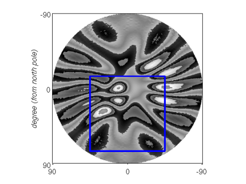
- logarithmic temperature difference

$$T_{bound} = \frac{\Delta T_{in} - \Delta T_{out}}{ln \frac{\Delta T_{in}}{\Delta T_{out}}}$$

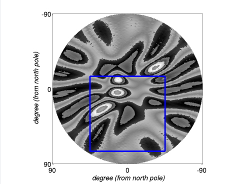
Tracking of patterns at $Ra_{centr} = 5 \cdot 10^4$, $Ta = 4 \cdot 10^6$

interferogram
temporal behaviour

numerical time slot



experimental time slot



- overall time of the movie in the rotating reference frame:
  $t^* = 0.2 \rightarrow t \approx 30\ min$
- time of the movie in the rotating reference frame with experimental time slot:
  $t^* = 0.0002 \rightarrow t \approx 2\ s$
  (position of every 60° is captured every $0.2\ s$)

Tracking of patterns at $Ra_{centr} = 1.17 \cdot 10^5$, $Ta = 1.34 \cdot 10^7$

time | pos. 0° | 60° | 120° | 180° | 240° | 300°

penultimate turn

last turn

- marginal change between every single position
- marginal change between repeated position

→ character of columnar cells are captured
→ columnar cells are the clear pattern of rapid rotation, even in the presence of a central symmetry buoyancy field
→ can be taken as a reference case for the GeoFlow experiment

Patterns of convection in the non-rotating case

to be continued . . .
with Part III: Preliminary Results of the Non-Rotating Case