Detectability of subsurface oceans and their flows by JUICE

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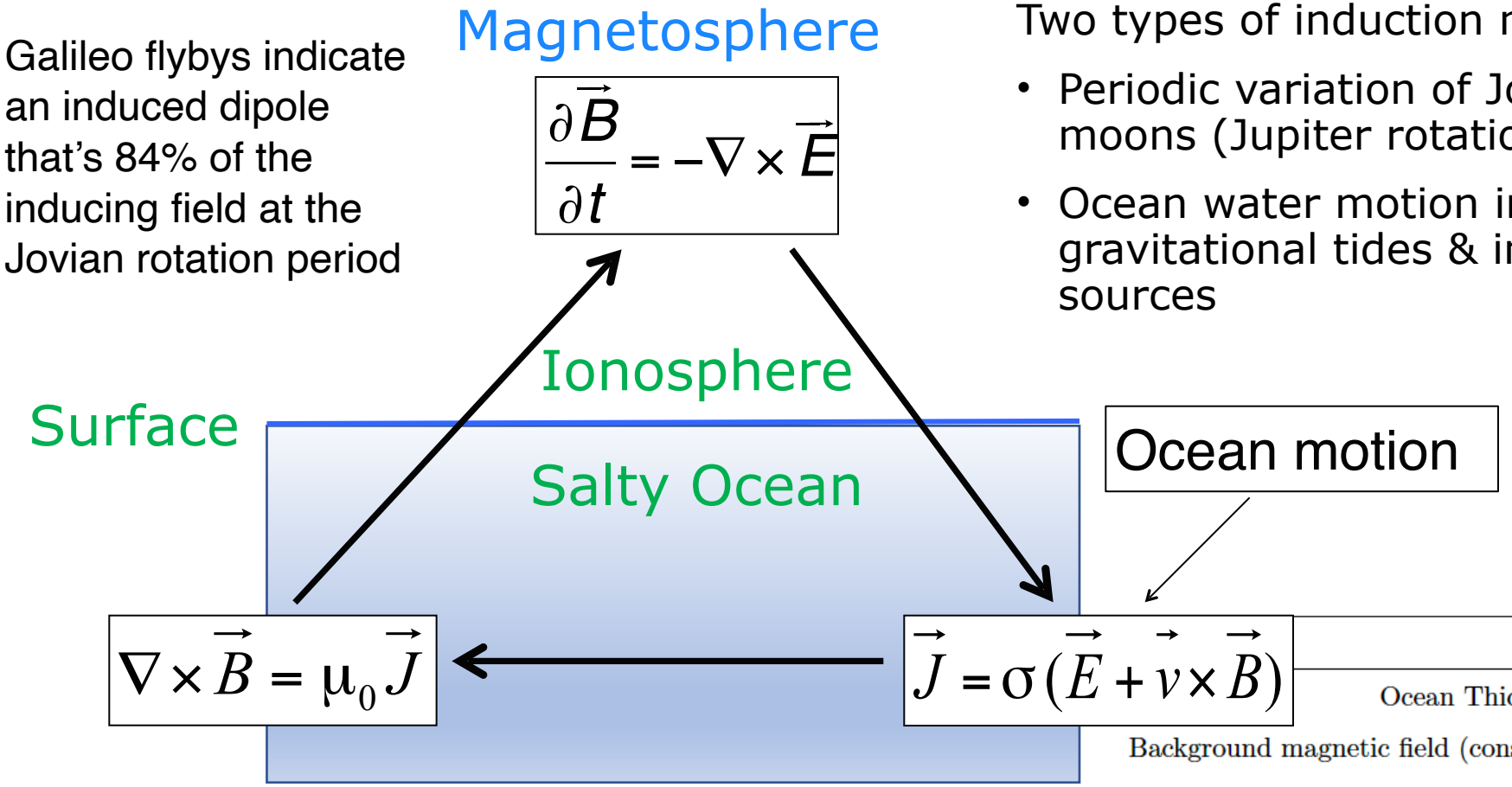
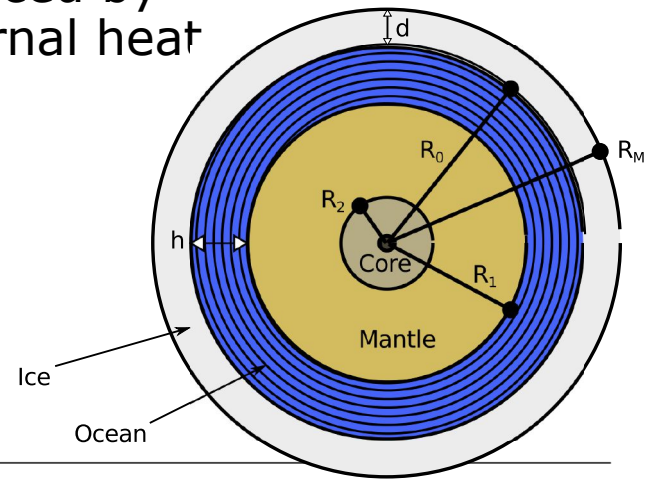
Overview of magnetic induction at Galilean moons

Galileo flybys indicate an induced dipole that's 84% of the inducing field at the Jovian rotation period



Two types of induction mechanism:

- Periodic variation of Jovian B-field at moons (Jupiter rotation, orbital motion)
- Ocean water motion induced by gravitational tides & internal heat sources

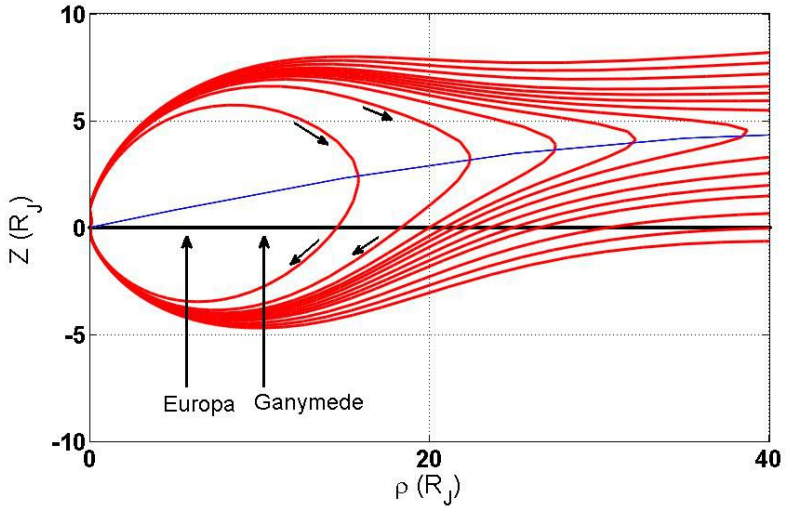


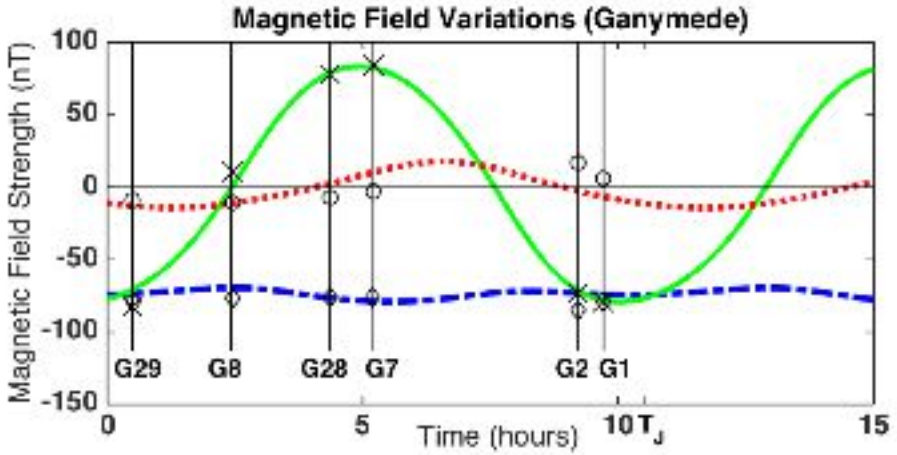
		Ganymede	Europa
Ocean Thickness	h	10 km-300 km	10 km-100 km
Background magnetic field (constant)	$\|B\|$	750 nT (equator)	500 nT
Background magnetic field (time-varying)	$\|B'\|$	100 nT	250 nT
Jovian rotation period (moon frame)	P_J	10.45 h	11.2 h
Orbital period	P_O	85.2 h	171.7 h

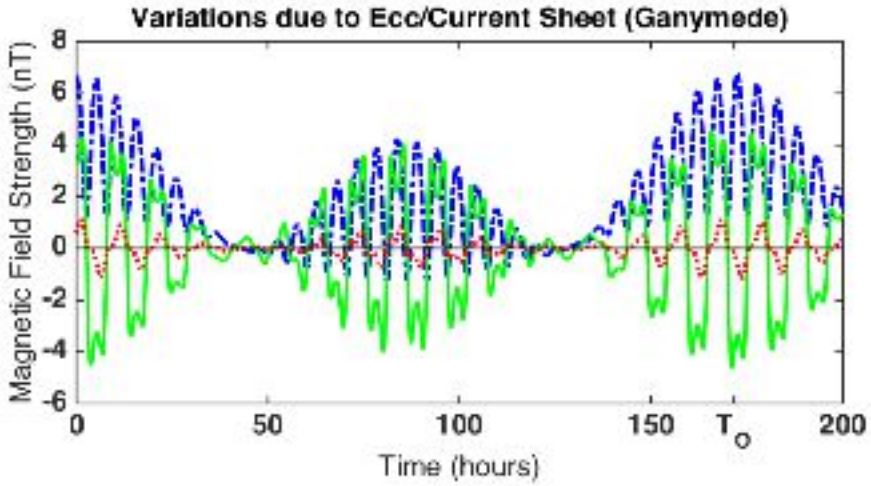
We have developed a model to simulate this coupled system at Ganymede & Europa, including electrodynamics and ocean motion

Jovian B-field at Ganymede

- Main oscillation at the ~10h Jupiter rotation period
- Additional finer oscillations are expected:
  - 171h orbital period of Ganymede
  - 8h/15h period due to envelope behaviour of current sheet hinging
- Several additional harmonics at multiples of these frequencies

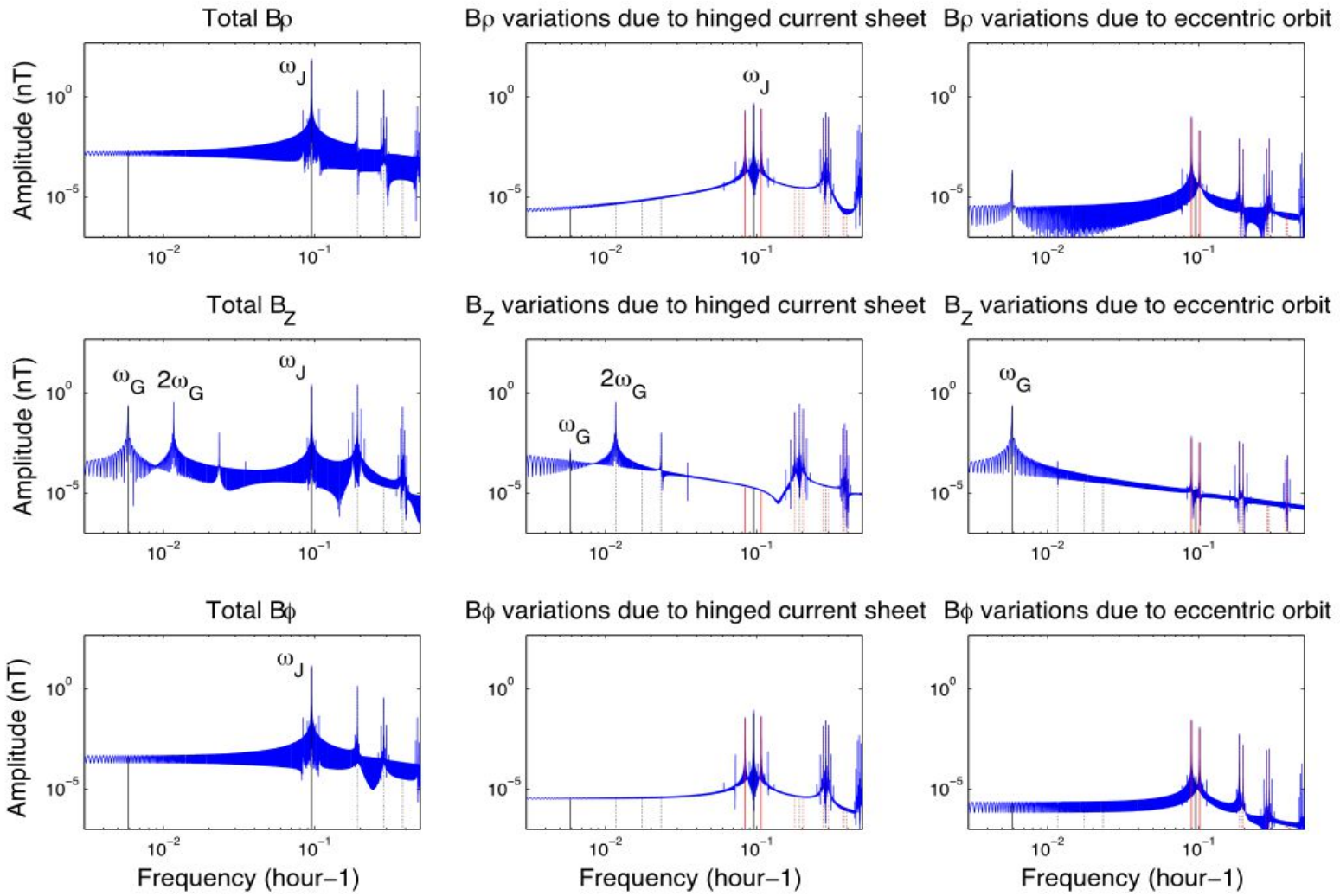






Variation of Jovian B field at Ganymede

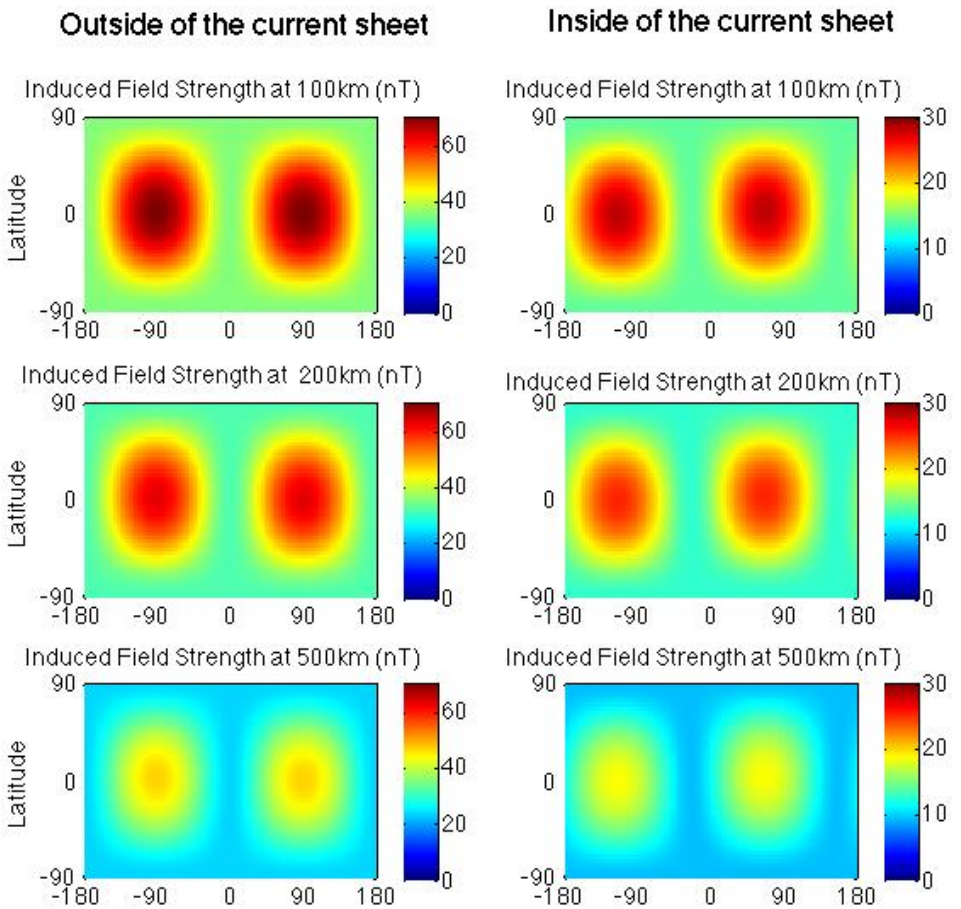
- B field model from Connerney (1993) + Khurana (2005)
- 10h period oscillation (dipole tilt)
- small perturbations at orbital period due to orbit eccentricity and day/night differences
- B_Z – along Jovian rotation axis
- B_ρ – along Jupiter-Ganymede axis
- B_ϕ – along Axis tangent to orbit
- Notice several frequencies of interest:
  - ω_J - Jovian rotation frequency
  - ω_G - Ganymede's orbital frequency
- red: linear combinations of these frequencies and their harmonics



Fourier analysis of the background jovian magnetic field at Ganymede

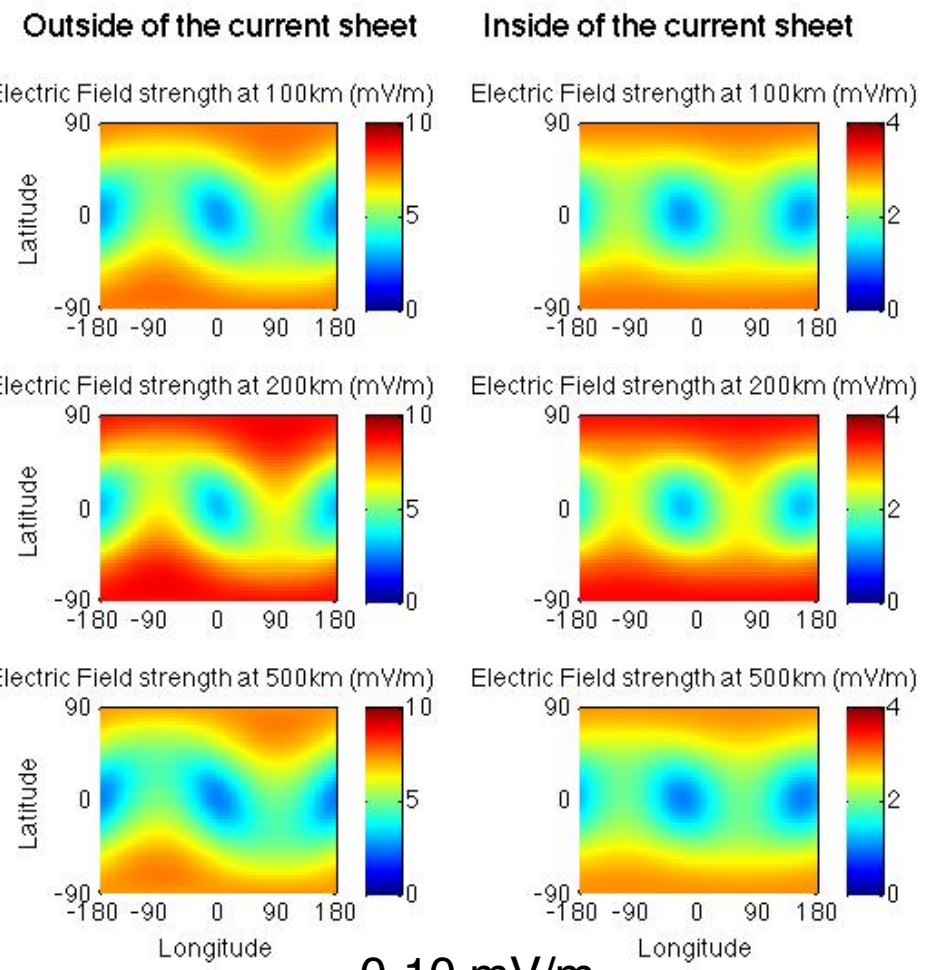
Induction response at Ganymede

B-field



~ 30-70 nT

E-field

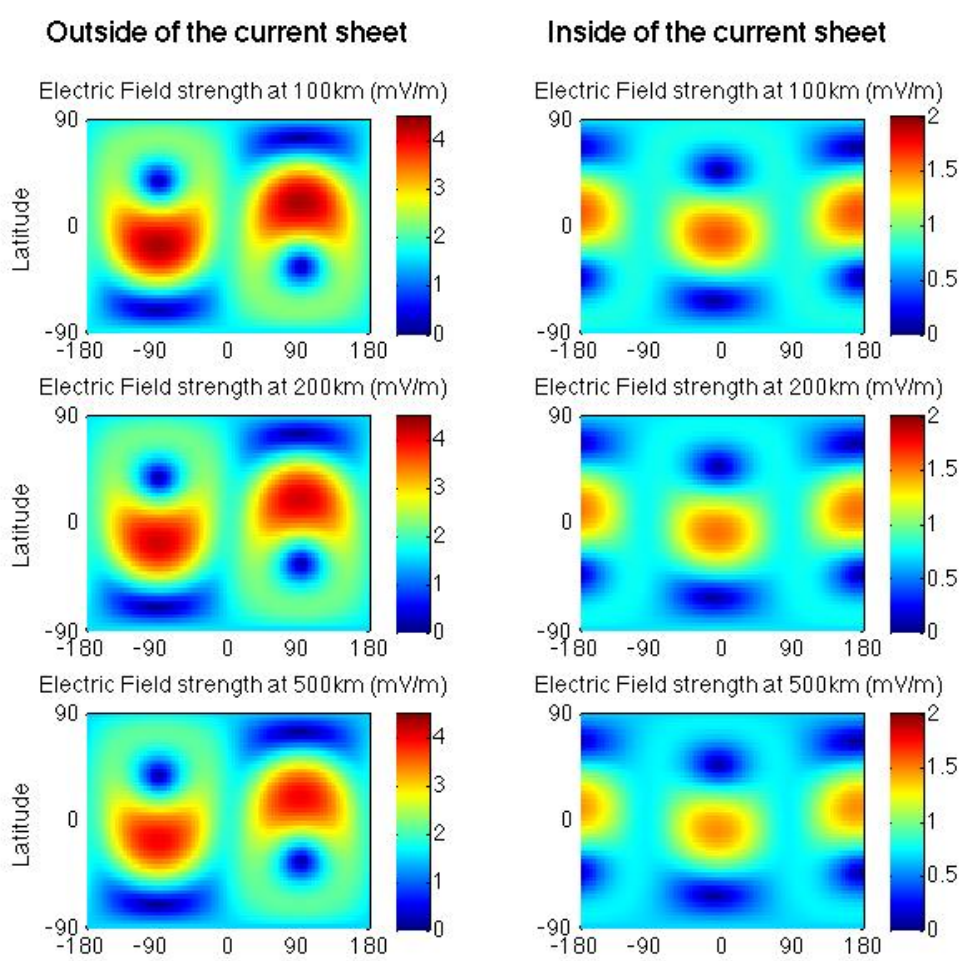


~ 0-10 mV/m

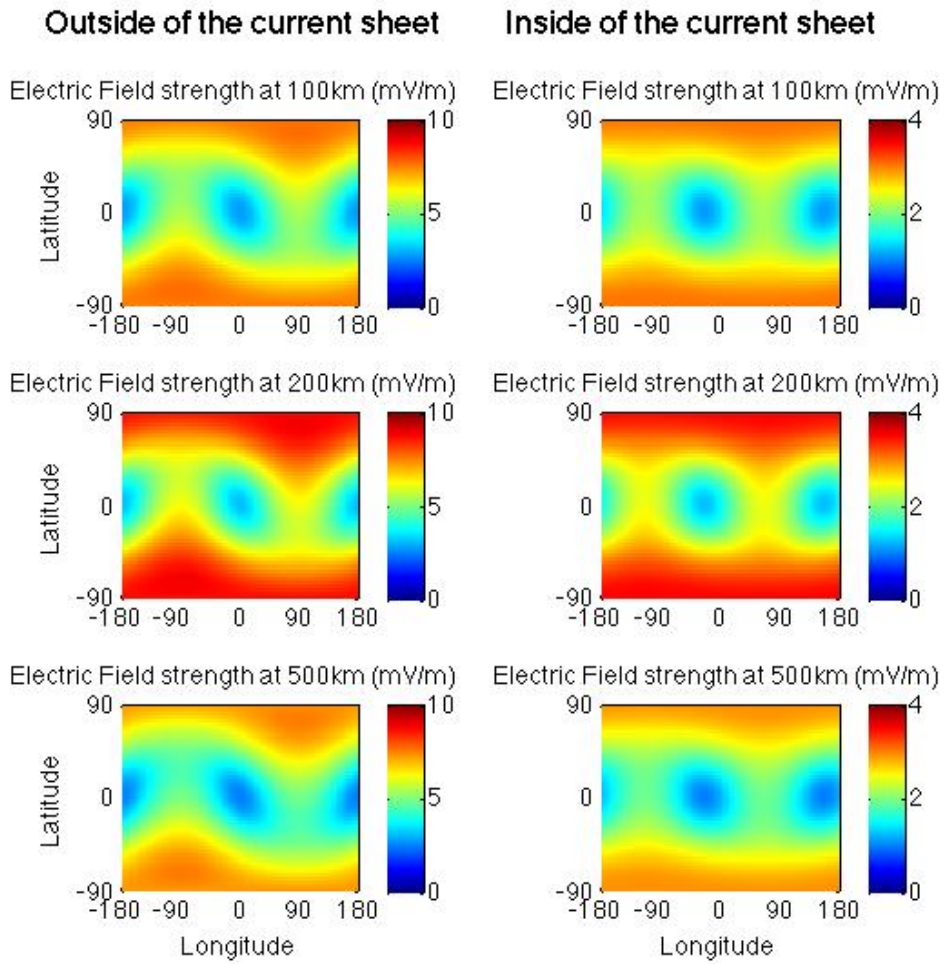
Induction E-field at Europa and Ganymede

Europa

Ganymede



~ 0-4 mV/m



~ 0-10 mV/m

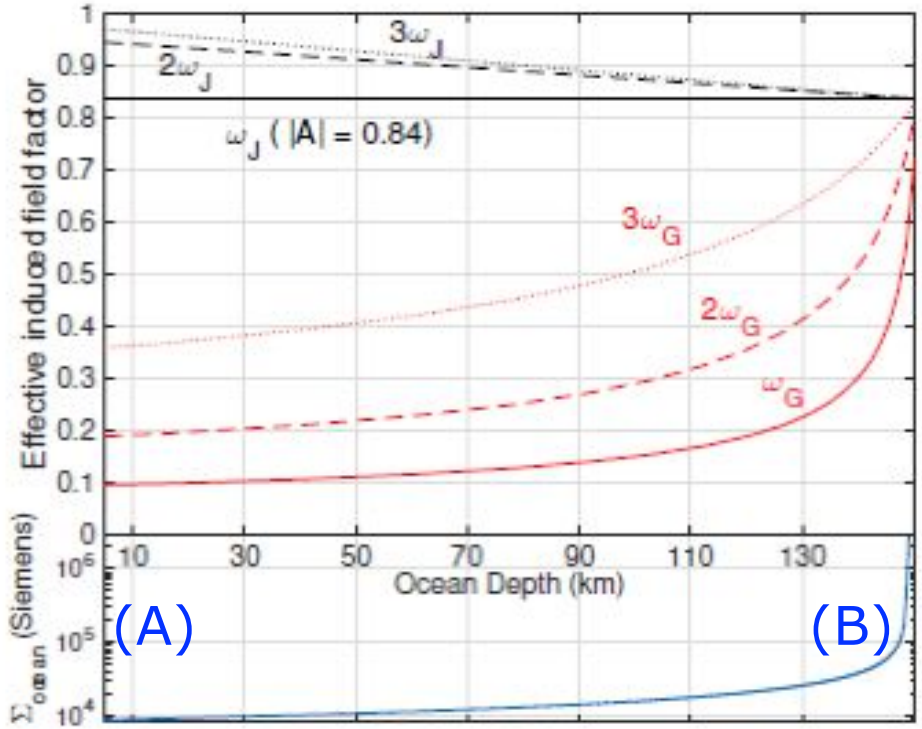
Bounds on long period oscillations

Ocean characteristics are chosen so as to obtain an 84% response at the Jovian rotation frequency (as measured by Kivelson)

Two extreme cases:

- Surface ocean with low conductivity (A)
- Deep and infinitely conductive ocean (B)

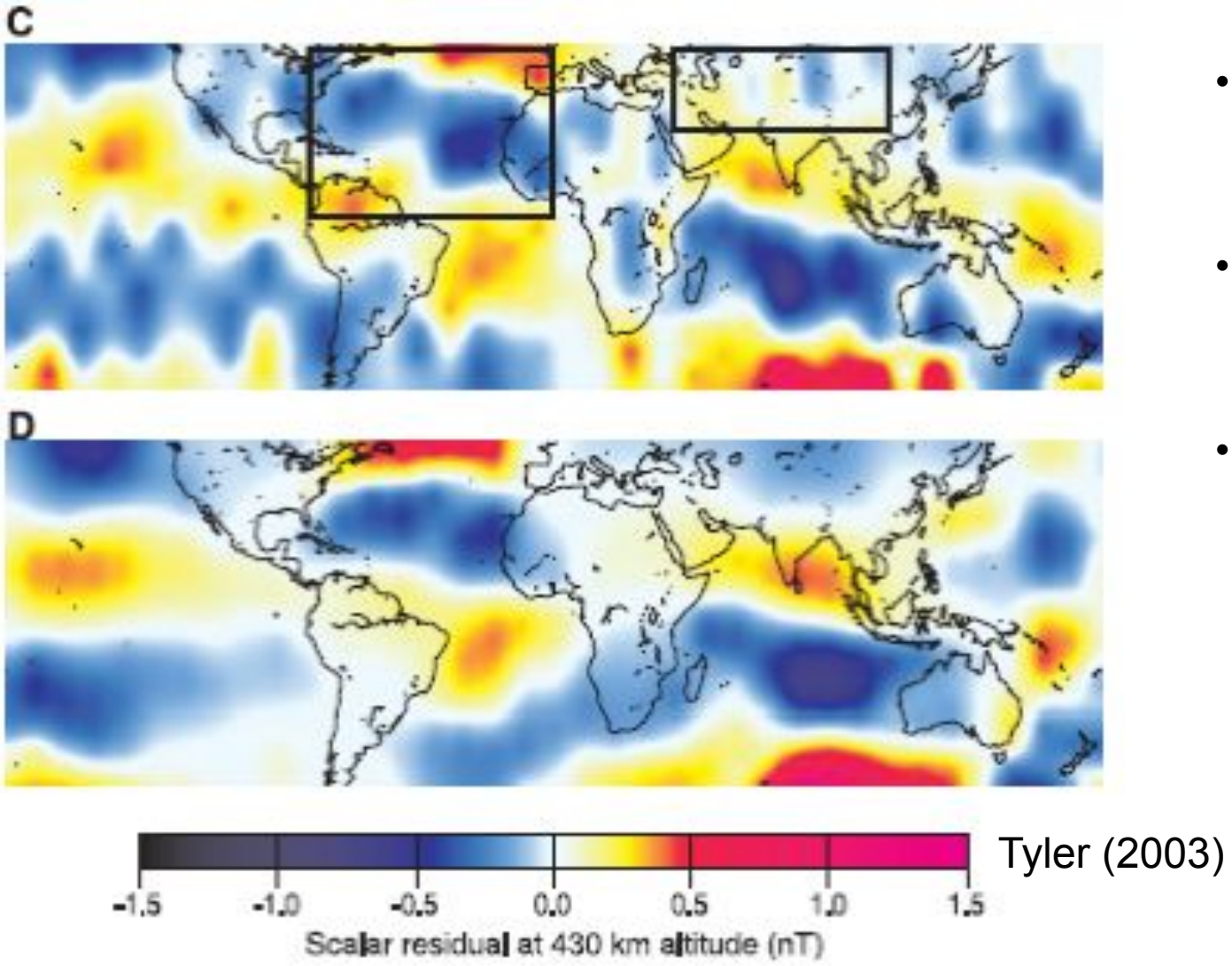
Finer frequencies will allow determining ocean depth and conductance



Strength of induced response as fraction of inducing signal at various frequencies

Inducing field strength	
ω_J	90 nT
$2\omega_J$	5 nT
$3\omega_J$	6 nT
ω_G	0.8 nT
$2\omega_G$	0.5 nT
$3\omega_G$	0.1 nT

Ocean magnetic induction on Earth



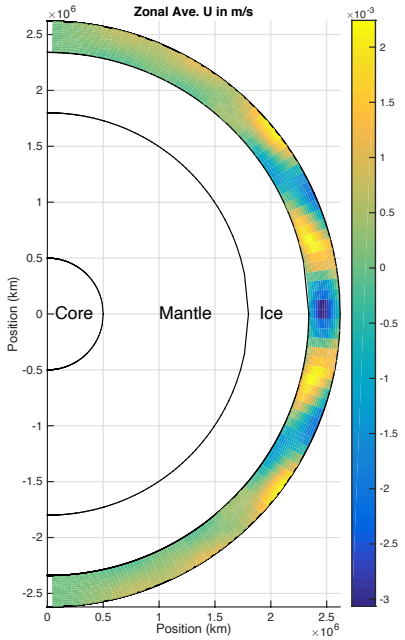
Tyler (2003)

- Ocean water flows have been shown to induce a detectable B-field
- Is the same happening on Ganymede and Europa?
- This would allow us to remotely constrain ocean flows

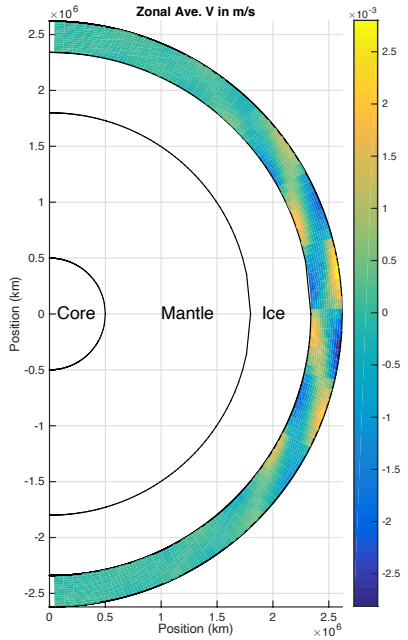
MITgcm ocean model

- We have adopted MITgcm to simulate the oceans of Ganymede and Europa
- Ocean motion driven by gravitational tides and internal heat sources (equatorial heat flux on sea-floor with maximum of ~10 mW/m^2)

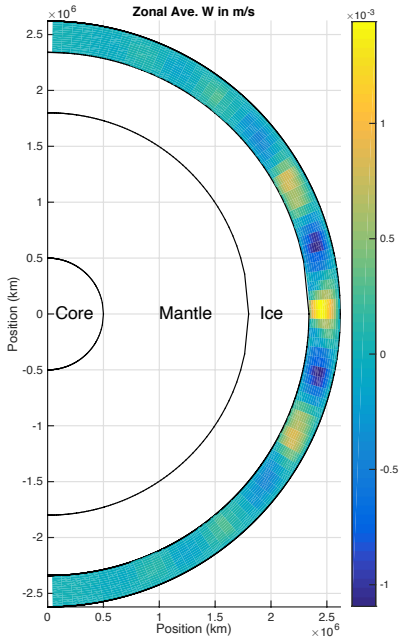
Zonal



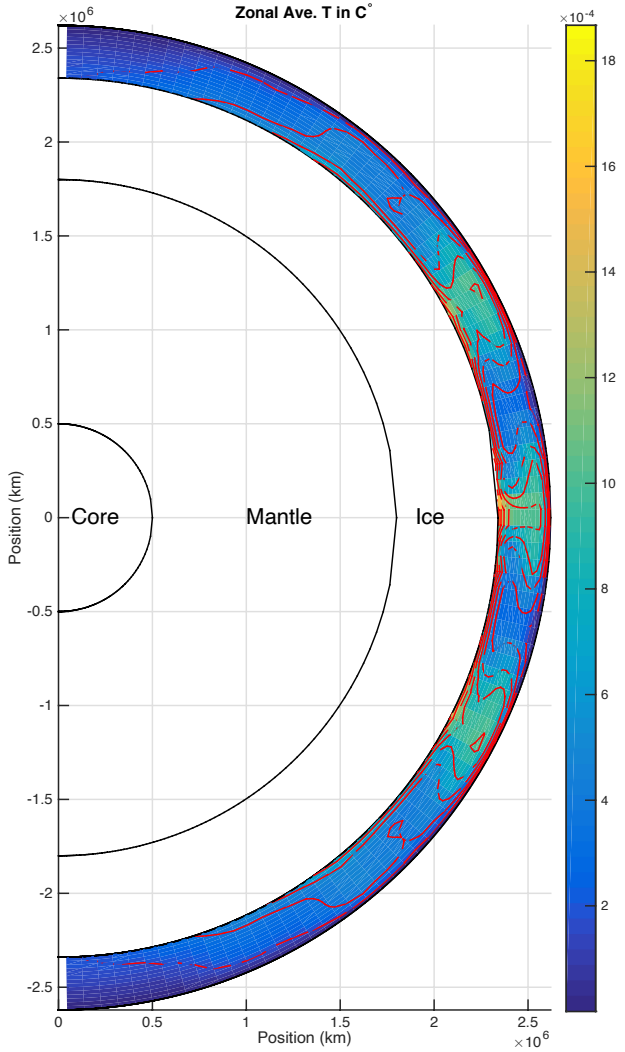
Meridional



Radial



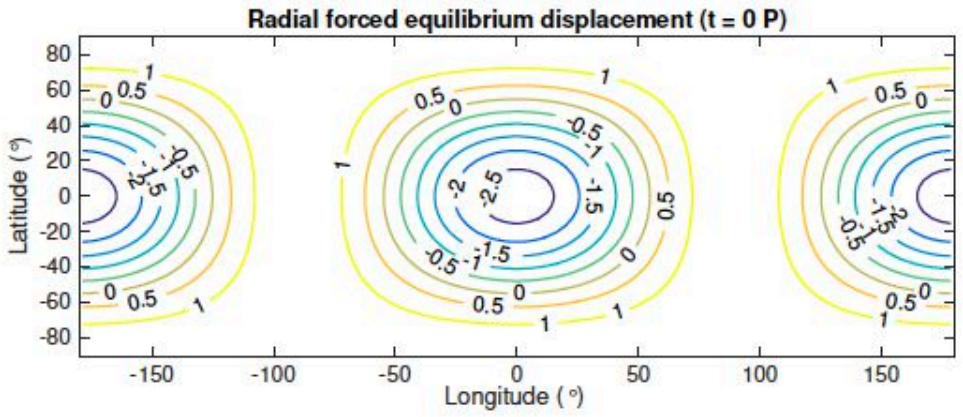
Temperature

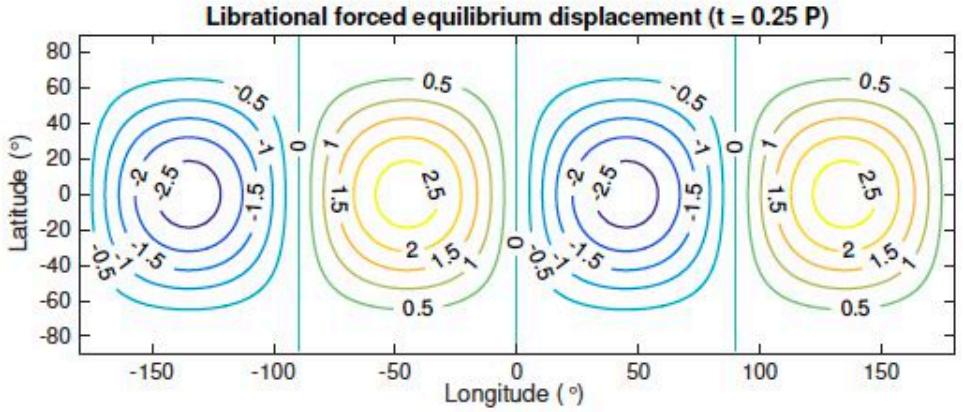


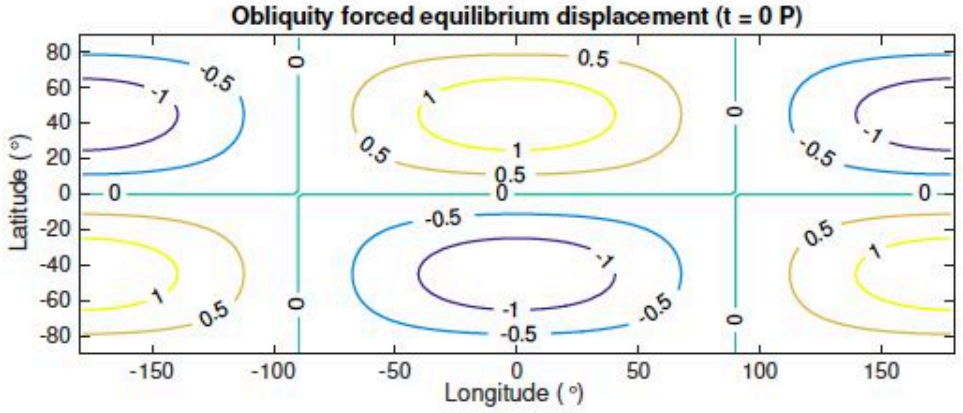
Ocean tides (gravitational)

- Ocean tides are induced gravitationally
- These lead to radial and horizontal flow of the water
- This, in turn, will induce a B-field
- Ocean flow can also be generated by internal heat sources (not shown)
- We have adopted the MIT-GCM to Ganymede to calculate these flows and associated induced fields

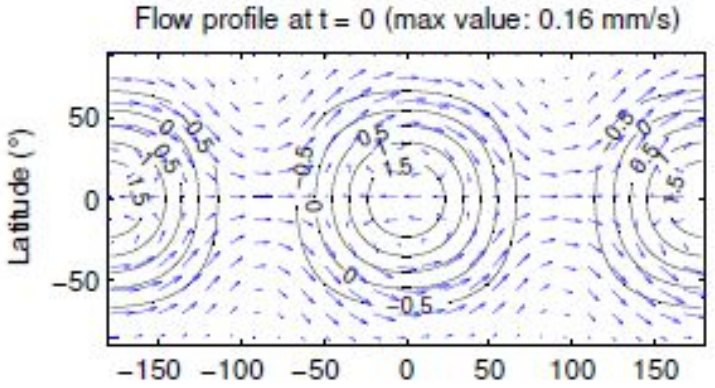
Radial displacement

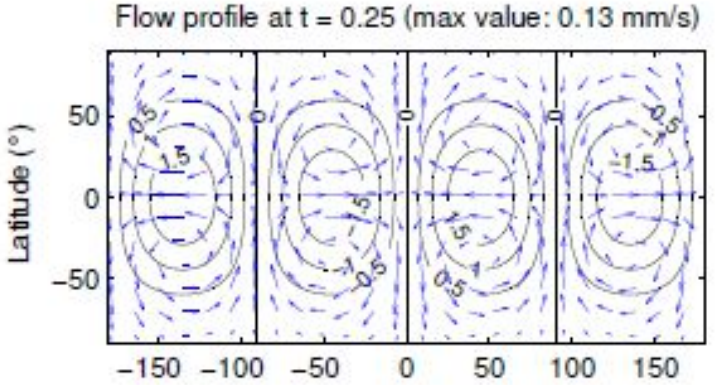


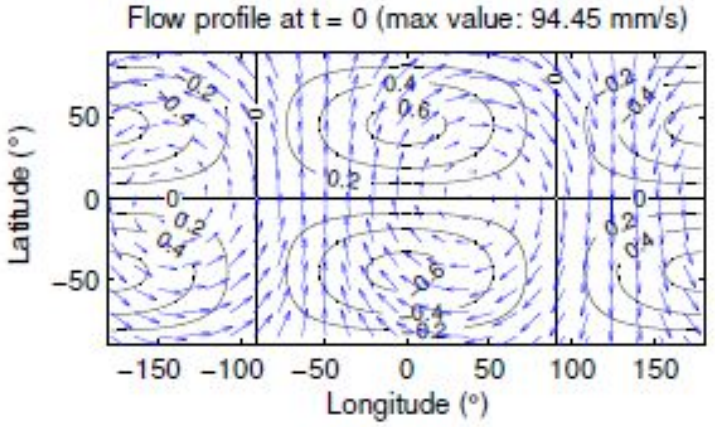




Horizontal flow





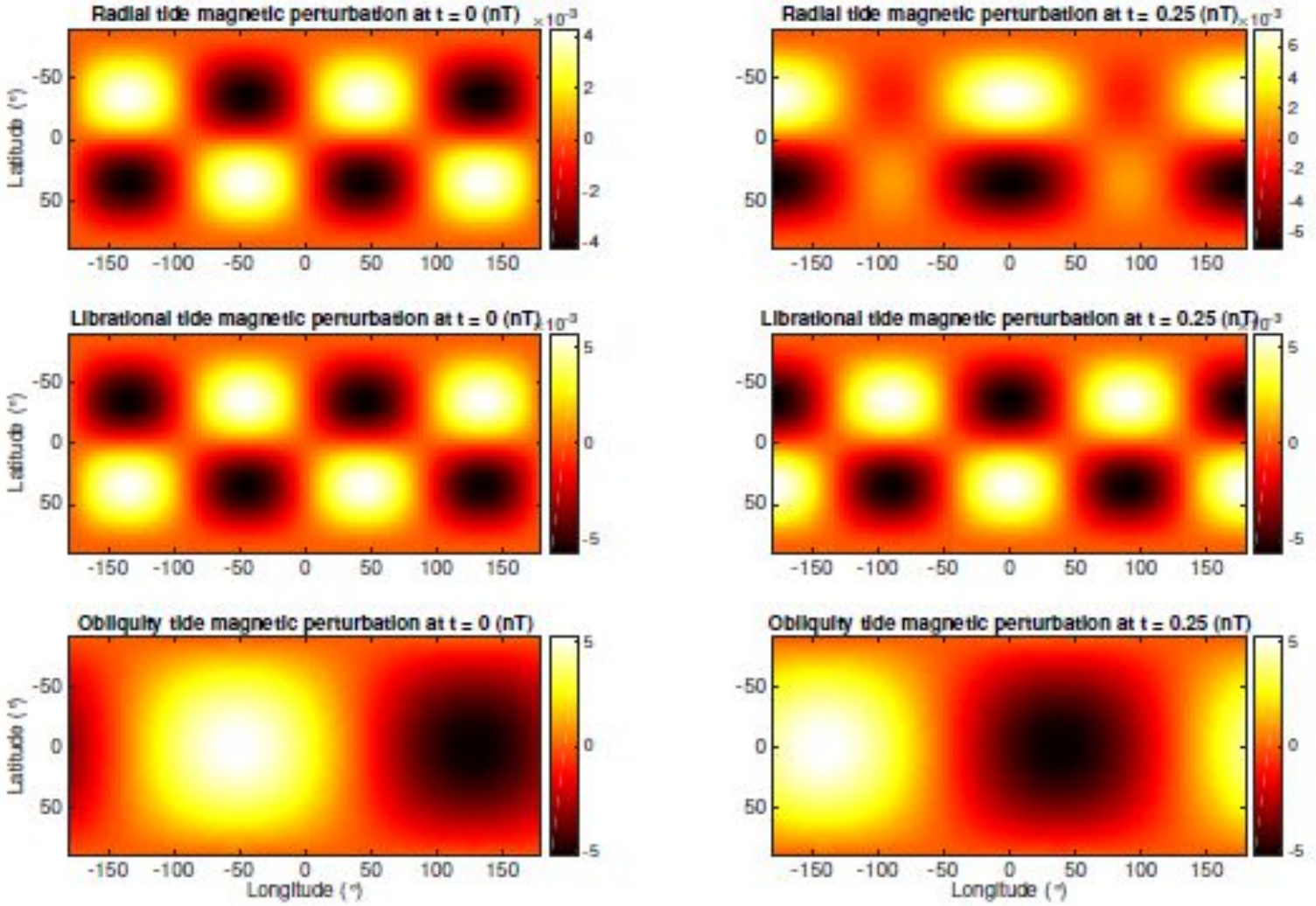


B-field induced by ocean tides (gravitational)

- Ocean flows through Ganymede's fixed dipole induces a small magnetic perturbation b_r:

$$\left(i\Omega - \frac{1}{\mu_0 \sigma}\nabla^2\right) \boldsymbol{b_r} = \boldsymbol{v} \cdot \nabla B_{0r} + B_{0r}\frac{\partial \zeta}{\partial t}$$

- Amplitudes:
  - Eccentricity : 5×10^{-3} nT
  - Obliquity: 4 nT
  - Librational: 5 nT



→ ~ 10% of response induced by Jovian B field induction

Outlook

- Predicted induced E- & B-field perturbations at Ganymede and Europa are detectable by JUICE instrumentation (RPWI & MAG)
- Our model allows us to detangle the contributions from Jovian B-field and ocean motion
- Will potentially allow us to constrain:
  - Ocean depth
  - Ocean conductance
  - Characteristics of internal heat sources
- Continuous measurements needed to constrain harmonics (order of ω_G & ω_E) - higher harmonics of particular interest