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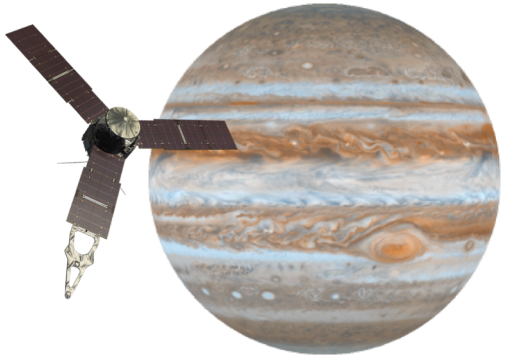

# The range of Jupiter's flow structures fitting the Juno asymmetric gravity measurements

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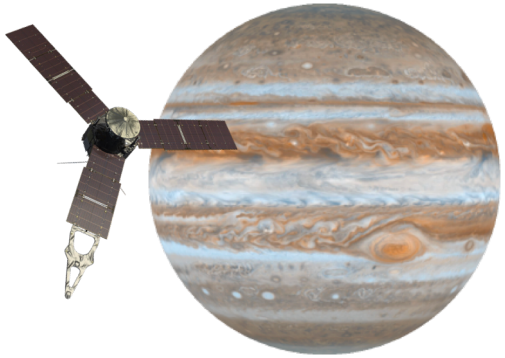
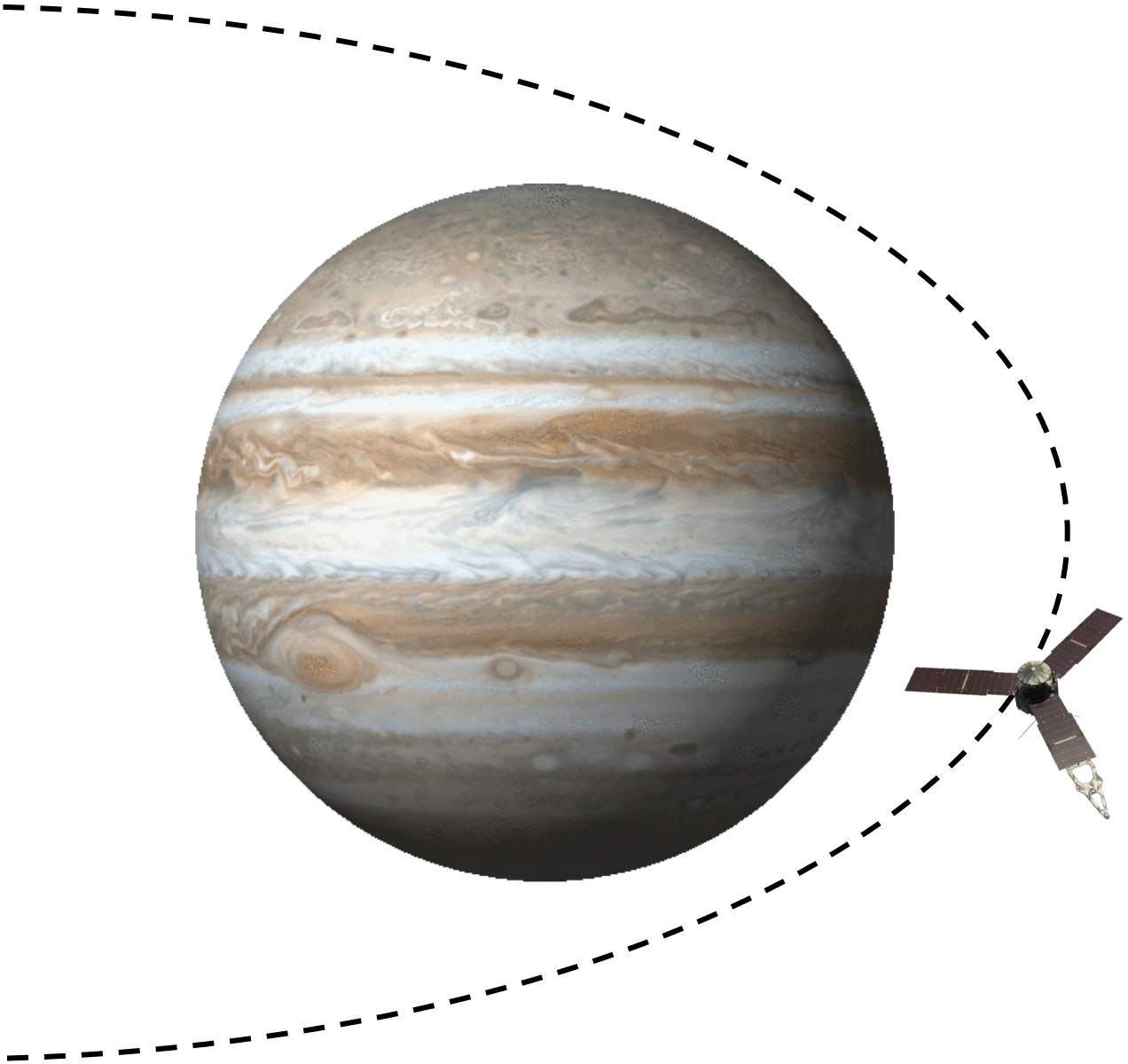
# Outline



- The Juno measurements
- Connecting the flow and gravity fields
- Motivation: Explore the probability of possible solutions.
- A hierarchy of zonal wind structures:
  - Analysis Ⅰ: the vertical profile
  - Analysis Ⅱ: add the meridional profile
- Conclusions

Duer, K., Galanti, E., & Kaspi, Y. (2020). The range of Jupiter's flow structures fitting the Juno asymmetric gravity measurements. *Journal of Geophysical Research: Planets*, e2019JE006292

# The measurements



| Harmonic | Value |
|---|---|
| $J_3(\times 10^{-8})$ | −4.24 ± 0.91 |
| $J_5(\times 10^{-8})$ | −6.89 ± 0.81 |
| $J_7(\times 10^{-8})$ | 12.39 ± 1.68 |
| $J_9(\times 10^{-8})$ | −10.58 ± 4.35 |

Iess et al. (2018)

$$\Delta J_n = -\frac{2\pi}{M{R_J}^n}\int_0^{R_J}\int_{-1}^{1} r^{n+2}\rho'(r,\mu)P_n(\mu)d\mu dr$$

The gravity field is an integrative measure of the density field.

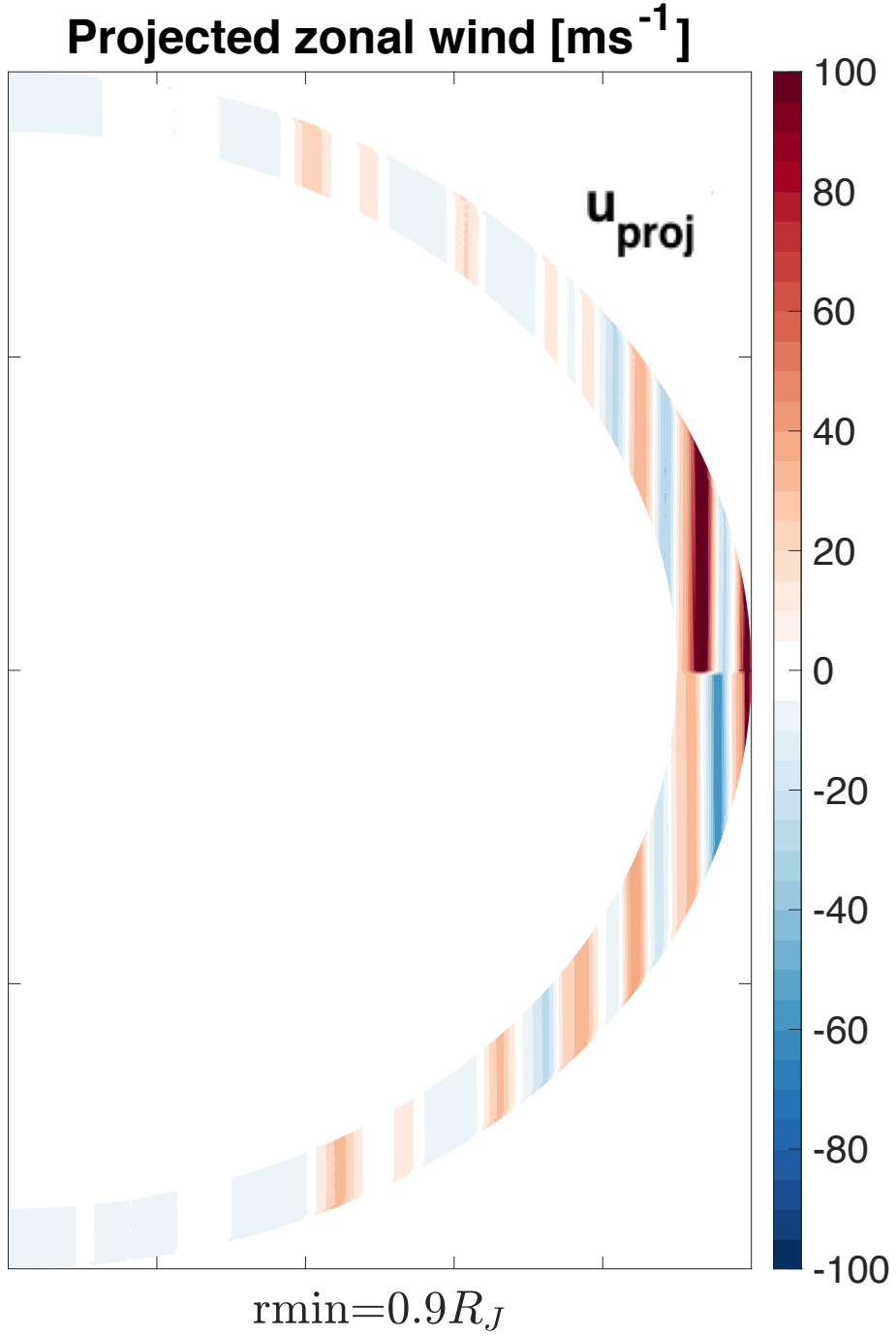
# The flow-density relation

The relation between the density field and the flow field is manifested in the thermal wind balance:

$$2\Omega r \frac{\partial(u\tilde{\rho})}{\partial z} = g_0 \frac{\partial \rho'}{\partial \theta}.$$

Therefore, we can relate the odd gravity harmonics to the deep flow profile.

$$J_n \leftrightarrow \rho' \leftrightarrow u$$

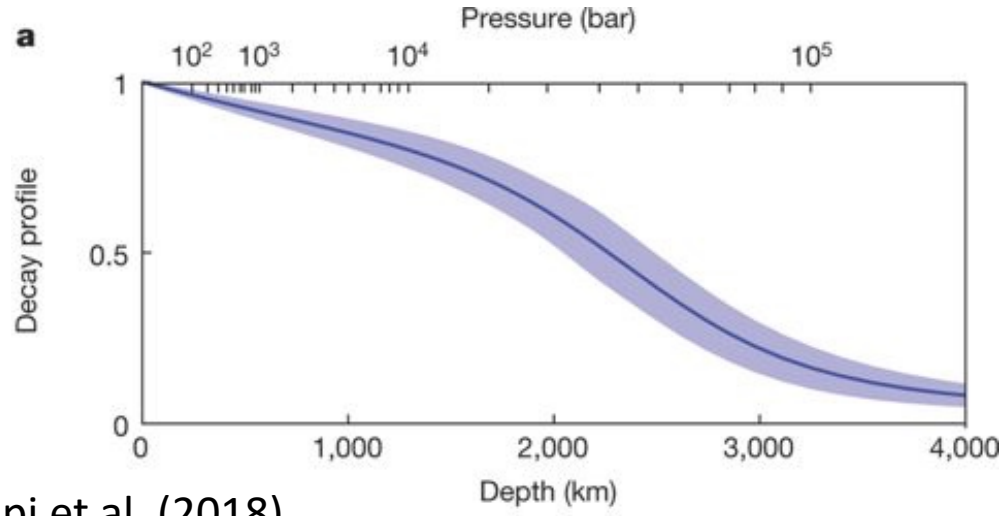


# The motivation – nonuniqueness of the solution

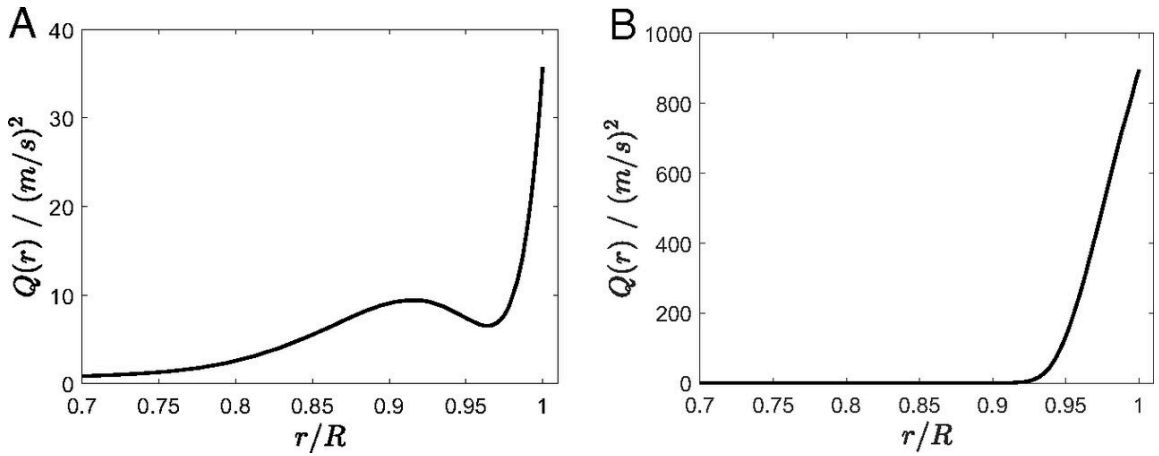
Using just 4 numbers (the odd gravity harmonics) to constrain the 2D density field (flow field) dictates that the problem is ill-posed.

Therefore, any solution for the deep flow is non-unique.

→ Explore the probability of possible solutions.




Kaspi et al. (2018)




Kong et al. (2018)

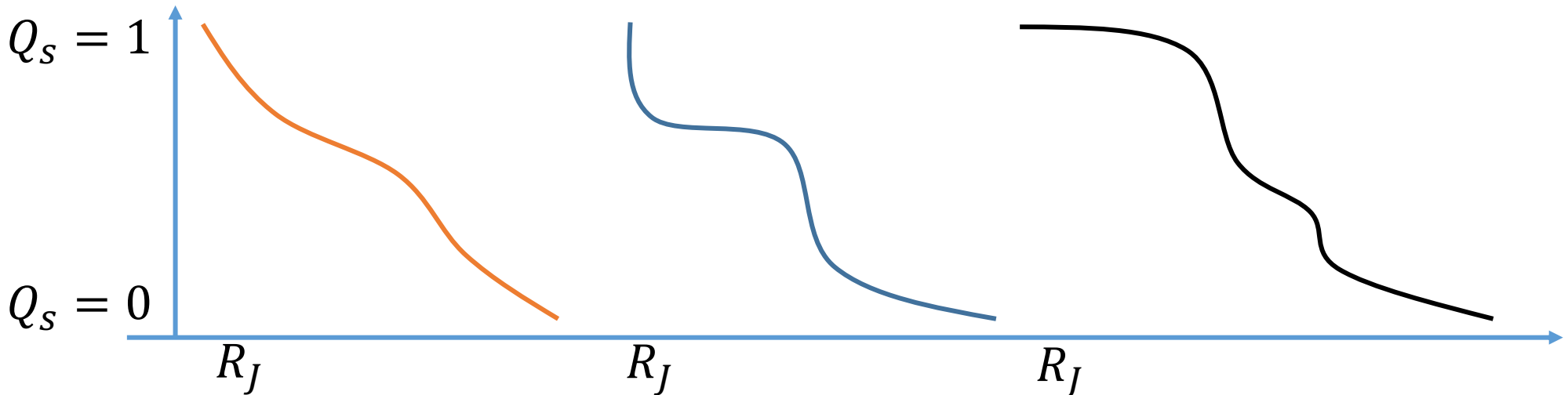
# Analysis I - varying the vertical structure ($Q_S$)

The sample population ($5\times10^5$ decay options) is bounded by physical considerations:

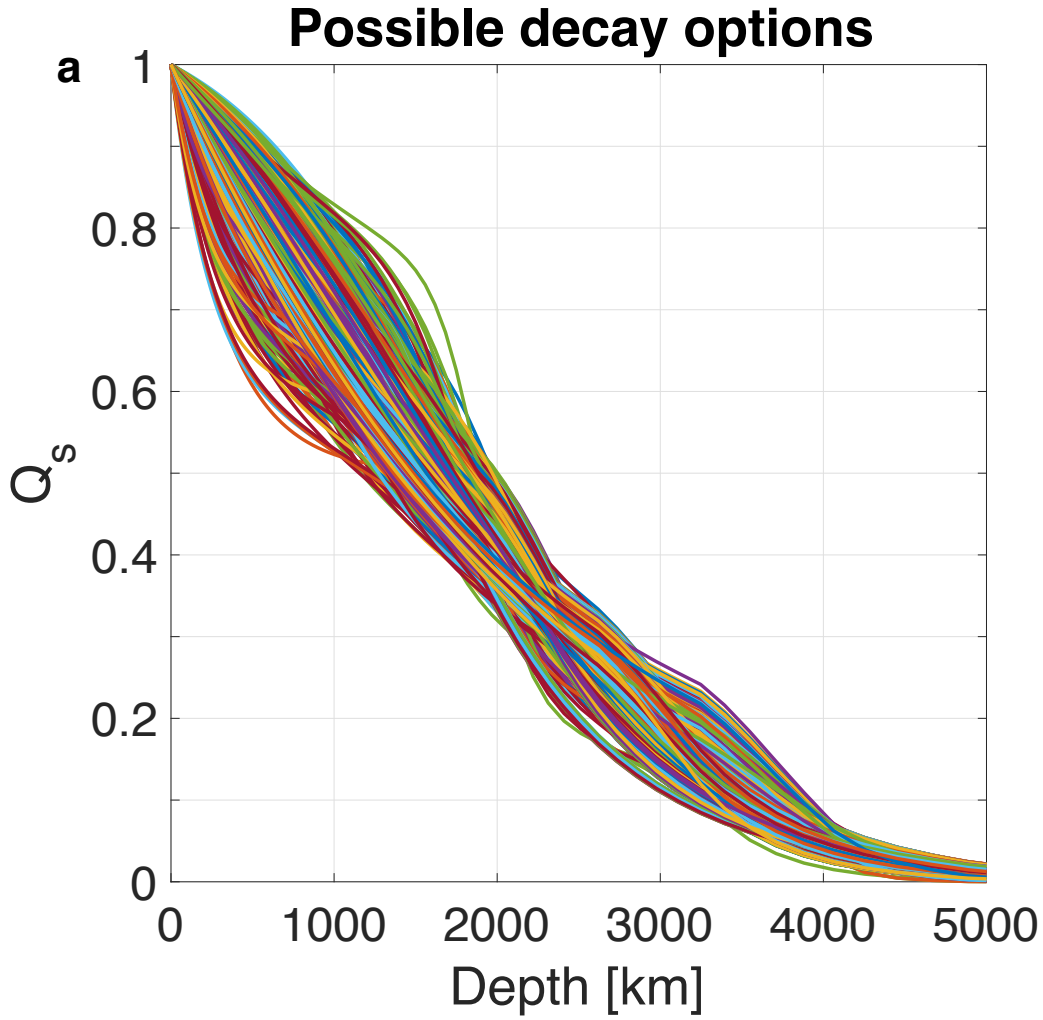
- The decay is continuous
- Exponential decay at the bottom (according to the nature of the electrical conductivity) [Duer et al. (2019), Moore et al. (2019)]

The population covers an extensive range of vertical structures.

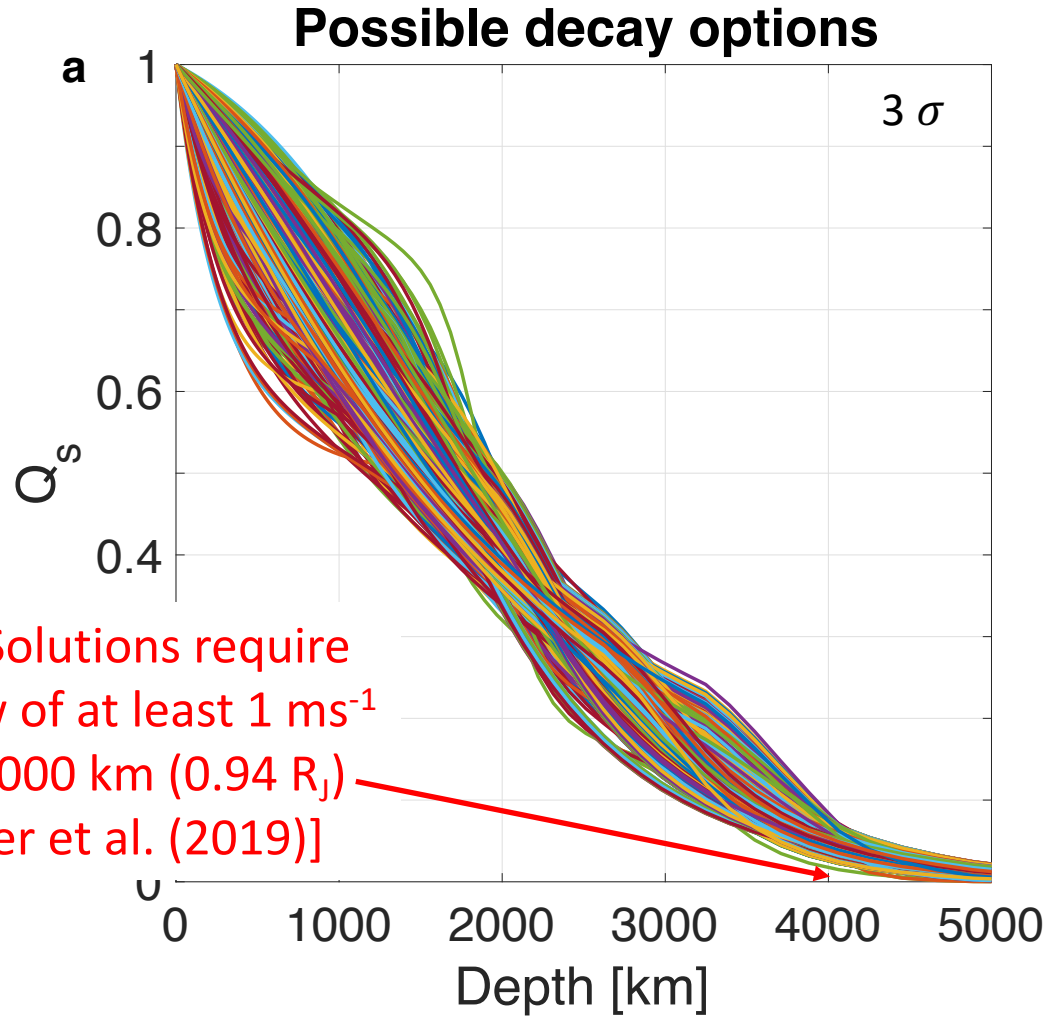
$$U(r,\theta) = U_{\text{proj}}(r,\theta) \cdot Q_s(r)$$



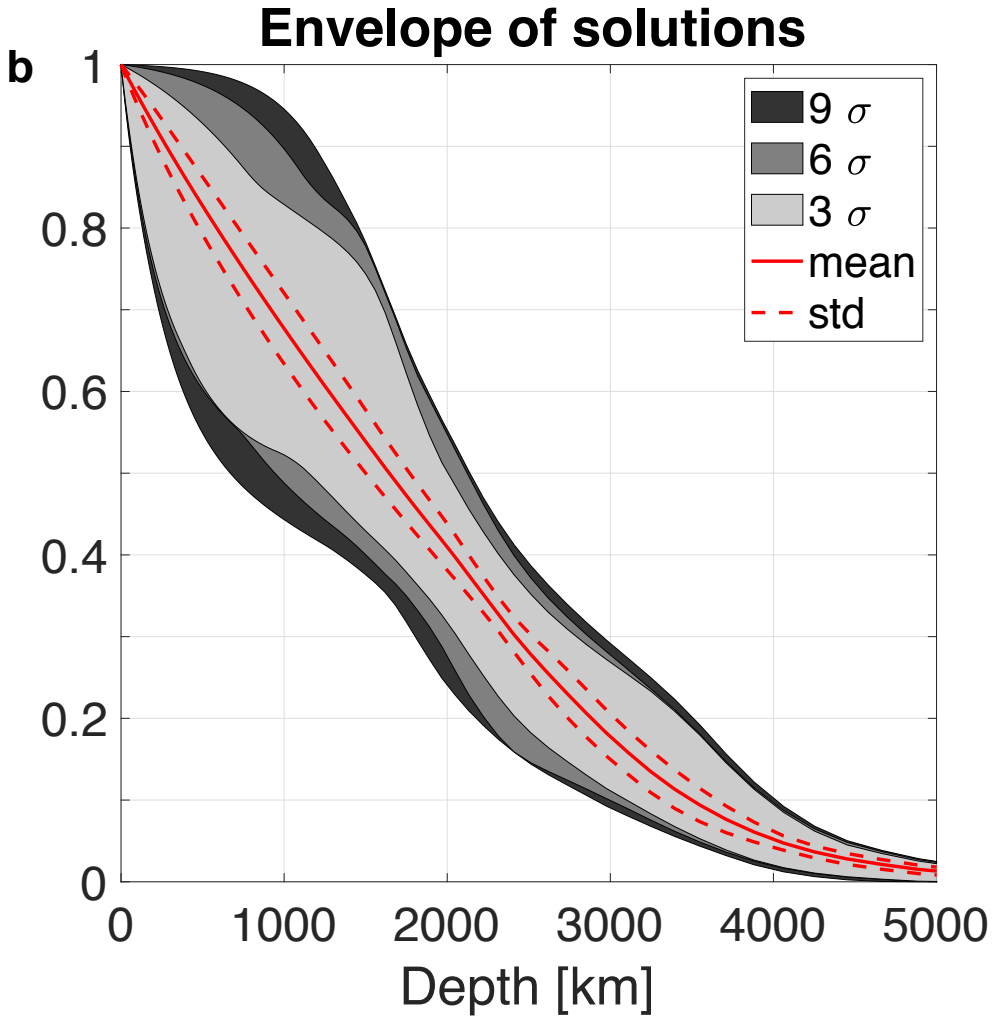
# Analysis I - solutions of the vertical decay profile



# Analysis I - solutions of the vertical decay profile



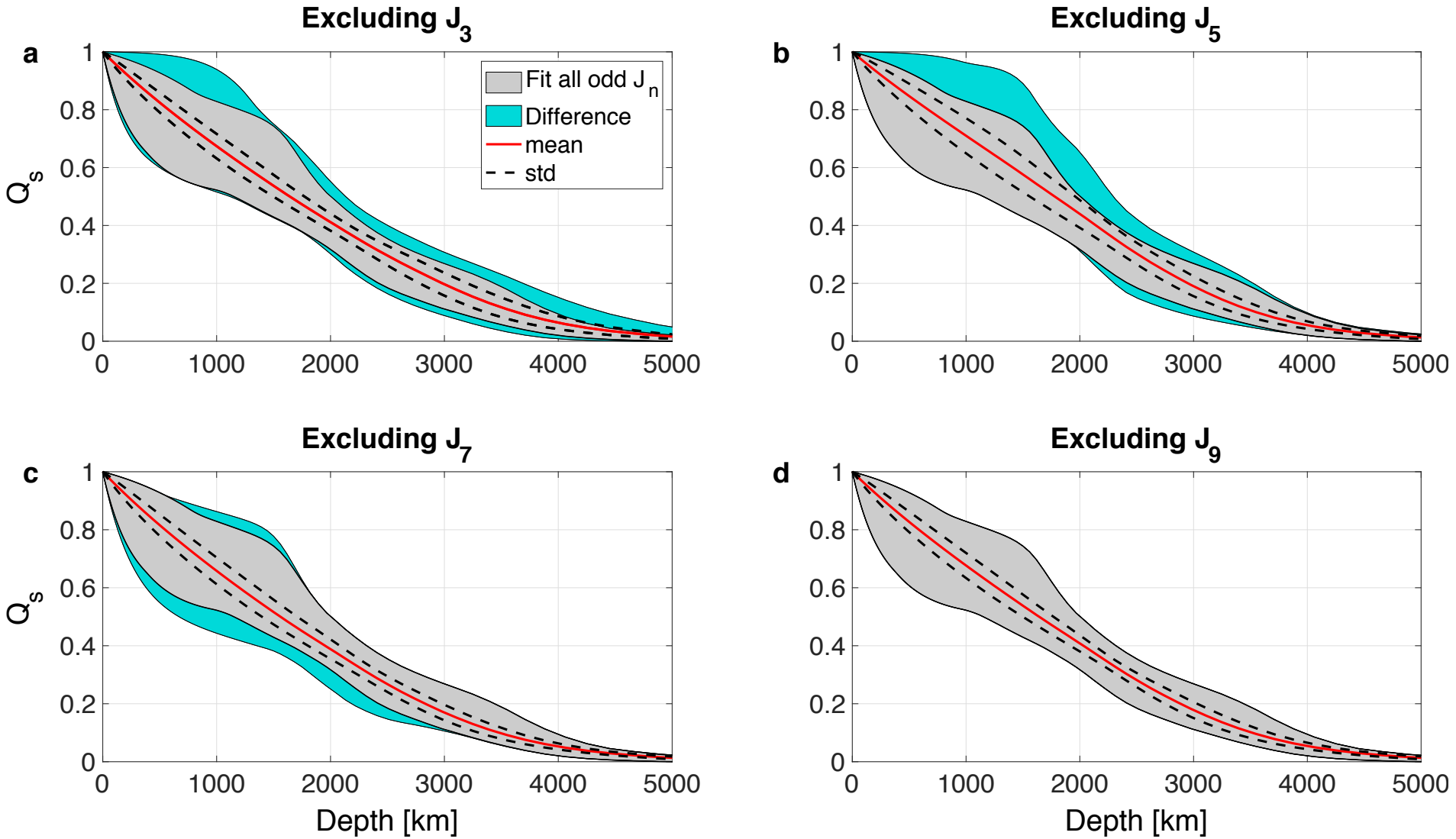

All Solutions require flow of at least 1 $ms^{-1}$ at 4000 km (0.94 $R_J$) [Duer et al. (2019)]




Duer et al. (2020)

~1% of the sample population generated odd gravity harmonics within the uncertainty range

# Analysis I - Excluding one harmonic




Each harmonic is sensitive in different regions.

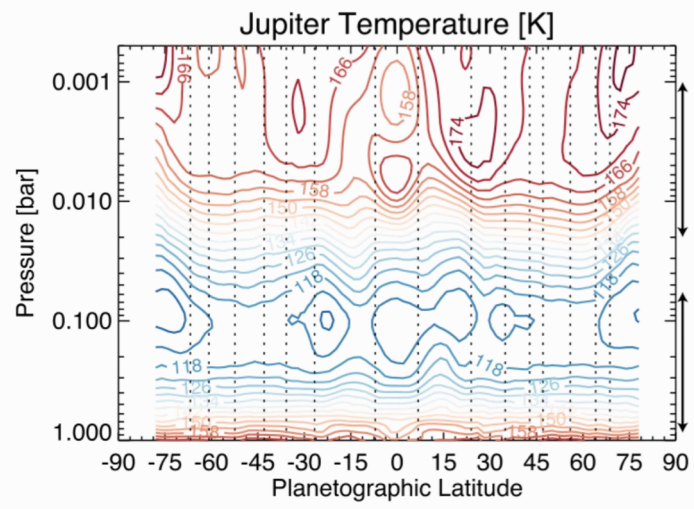
$J_9$ does not constrain the vertical flow profile.

Duer et al. (2020)

# Analysis Ⅱ - vary the meridional profile

A somewhat different meridional profile might exist below the cloud level, due to:

- Measurement uncertainty
- Internal dynamics



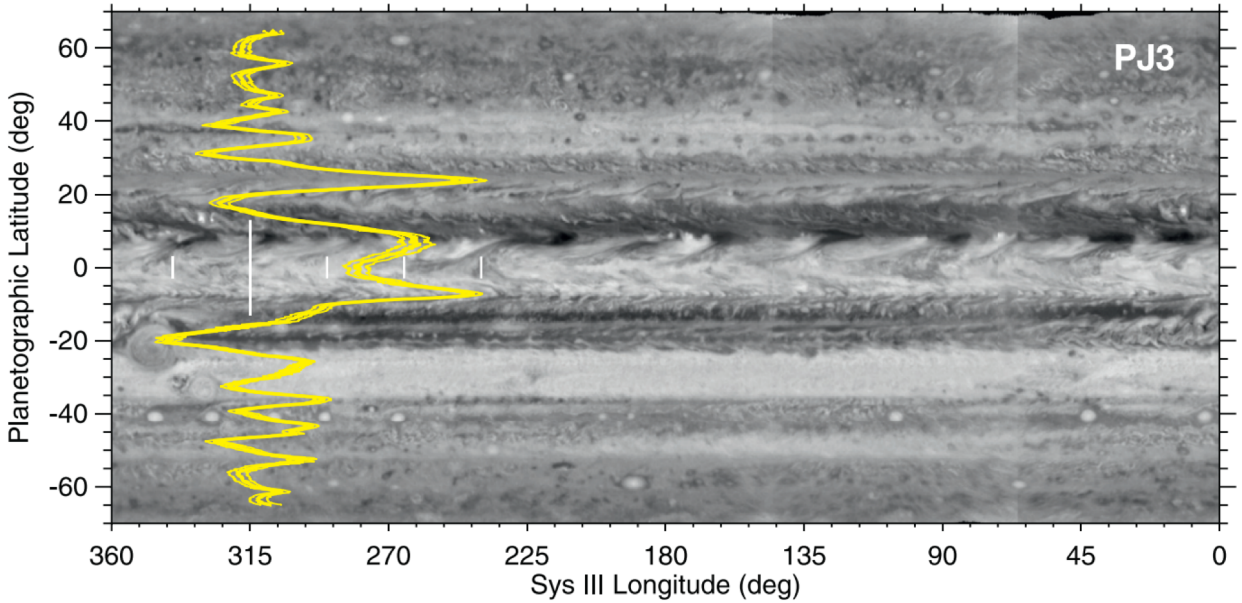

Fletcher et al. (2020)

Evidence comes from:

- Cloud tracking
- Thermal IR (Cassini)
- Juno's MWR measurement

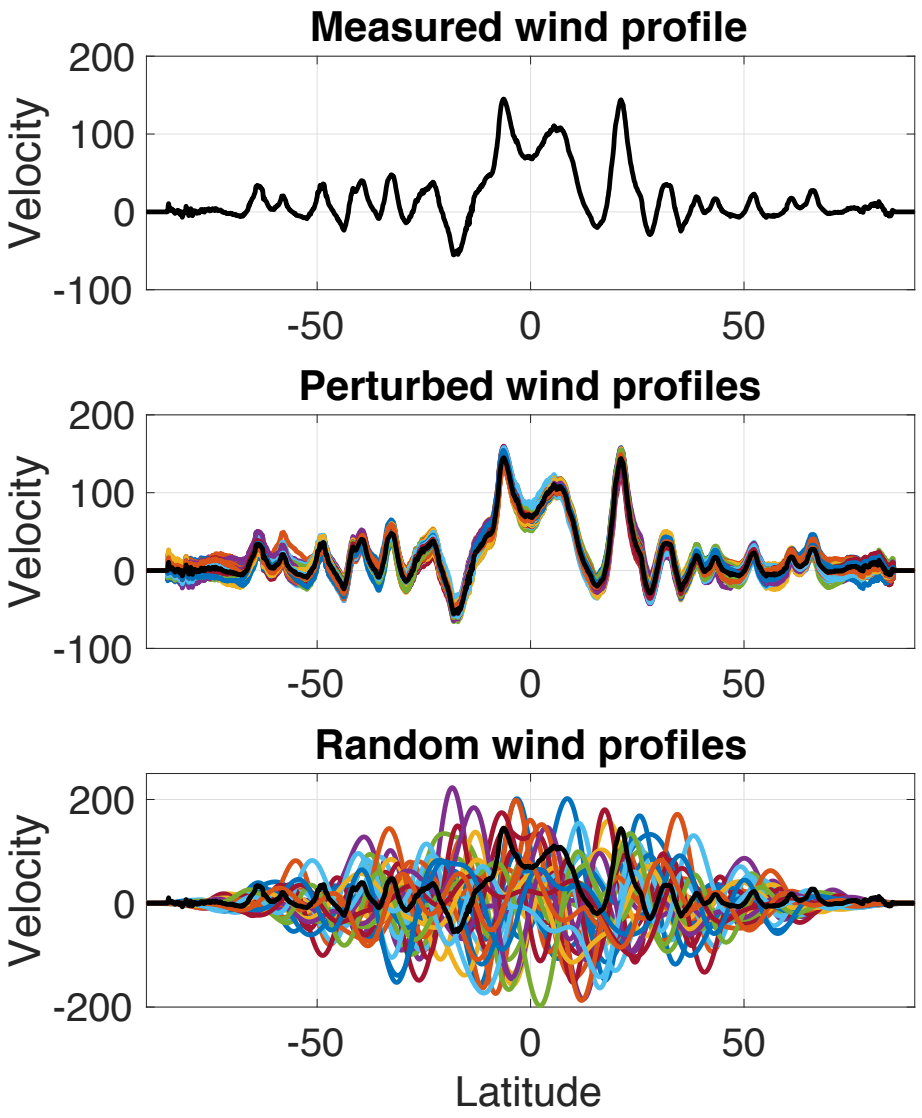
  (see analysis Ⅲ)

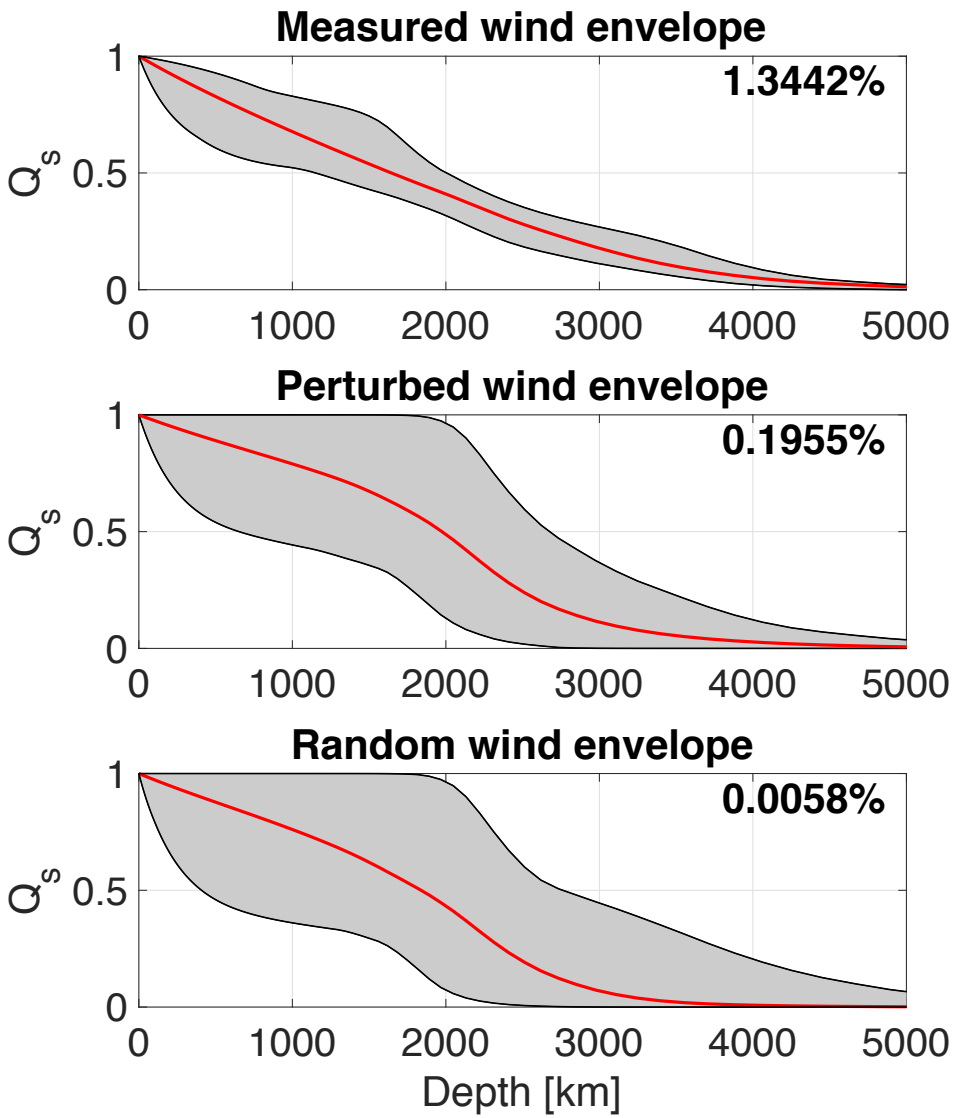
But are such cases likely to happen?




Tollefson et al. (2017)

# Analysis Ⅱ - Possible solutions of the wind profiles




Perturbation ↑

Envelope ↑

Probability ↓

# Conclusions

- Jupiter's asymmetric gravity field confines the vertical profile of the flow to a narrow deep envelope.
- $J_3$ (and the magnetic field) bound the flow between 3000 to 5000 km.
- $J_9$ does not constrain the flow *if* the other three harmonics are within the uncertainty range.
- Increasing the meridional perturbation leads to an increase in the width of the envelope of possible solutions while the possibility to find a solution decreases.
- Deep zonal flows with a meridional profile significantly different from that of the cloud-level are possible, but statistically unlikely.

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