Jupiter’s unearthly jets

A new idealized model

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Introduction

• Jupiter’s zonal jets, as visualized through cloud tracking, are straight – they don’t meander (unearthly!).
• These jets exist in Jupiter’s thin, moist-convecting weather layer.
• Deep jets may well exist in the dry-convecting layer beneath the weather layer, and could play an important role in the dynamics of the weather layer jets (Dowling-Ingersoll 1989).
• The magnitude and spatial structure of any deep jets are not well constrained observationally.

Question: How do deep jets affect the motion of the upper jets, and what is the role of moist convection?

One and a half layer model

• Simplest possible approach: \( \frac{1}{2} \)-layer, doubly-periodic, \( 2L \times L \), 512 \times 256, quasigeostrophic model with fixed deep zonally-symmetric jets and finite deformation length \( L_D \).
• Upper jet strength, \( L_D \), and jet spacing \( L \) are given values thought to be realistic around 35° latitude, with \( U_{\text{min}}(y=0) = 35 \text{ms}^{-1} \), \( L_D = 1, 200 \text{km} \), and \( L = 10,000 \text{km} \).
• Upper jet strength is fixed at \( U_{\text{max}} = 14.9 \text{ms}^{-1} \) to make upper jets initially marginal to Arnol’d’s second stability criterion (A2) with reversed upper potential vorticity (PV) gradients (Dowling 1993, Stamp-Dowling 1993).
• Upper jets are made stronger than the deep jets to make the cyclonic shear regions (‘belts’) convect.

The numerical code solves the equation

\[
\frac{D}{Dt} \left( \nabla^2 \psi_1 + \beta y - \frac{\psi_1}{L_D} + \frac{\psi_2}{L_B} \right) = S(x,y,t) + D, \tag{1}
\]

where \( S(x,y,t) \) is a forcing that will be discussed, dissipation term \( D \) is a very small quasi-hyperdiffusion, \( \psi_1 \) is the streamfunction for the upper layer, and \( \psi_2 \) is the streamfunction for the steady deep jets.

Deep jets, and Arnol’d’s second stability criterion

Distinguish two A2-stable jet configurations:

• ‘Pure D-I scenario’: Includes a systematic deep flow that cancels \( \beta \) (D-I = Dowling-Ingersoll)
• ‘Modiﬁed D-I scenario’: Excludes the systematic deep flow that cancels \( \beta \).

Forcing by moist convection

• Observations suggest that belts convect, implying that the upper jets are stronger than the deep jets (belt base isobarically cold, meaning \( \psi_2 - \psi_1 > 0 \)).
• Model a moist-convective (MC) event by injecting a pair of PV anomalies, with opposite signs.

One and a half layer model

• Opposite-extreme case: Modified D-I (\( \beta \) restored), ‘half-biased’ forcing, with a finite base-temperature offset 0.125 to make MC more active at small base coldness \( \Rightarrow \) less deceleration of the upper jets \( \Rightarrow \) stronger remaining vertical wind shear \( \Rightarrow \) MC events conﬁned to the belts. This scenario also allows some prograde/retrograde jet asymmetry. Looks more realistic!

Results so far

• PV anomaly-pairs can be biased, having unequal strengths.
• Assume colder base temperature gives stronger MC with more anticyclonic bias.
• Biased forcing should be more realistic than the unbiased forcing used in standard ‘\( \beta \)-turbulence’ models.

Figure 1: Formation of vortices through MC events.

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Figure 2: ‘Fully biased’ forcing (left hand plot) and corresponding jet proﬁles (right hand plot) for a pure D-I scenario (\( \beta \) effectively zero) at a late, quasi-steady stage.

• Extreme case: Pure D-I (\( \beta \) effectively zero), with ‘fully-biased’ forcing. This forcing decelerates the upper jets so that they nearly match the deep jets \( \Rightarrow \) weak vertical wind shear at the interface between the layers \( \Rightarrow \) weak base coldness \( \Rightarrow \) weak MC events spread throughout the domain (‘zones’ and belts). Looks unrealistic!

Figure 3: ‘Half biased’ forcing with temperature offset (LH plot) and corresponding jet proﬁles (RH plot) for a modiﬁed D-I scenario (\( \beta \) restored) at a late, quasi-steady stage.

Conclusions so far

• Weather layer jet dynamics is very sensitive to the forcing bias.
• Bias tends to make the upper jets decelerate toward the deep jets, making initial A2 marginality into A2 submarginality – consistent with straight jets!
• Bias (affecting \( S \)) usually dominates all other mechanisms: upscale cascade, PV mixing, vortex migration, and Kelvin passive shearing.

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