Jupiter's unearthly jets

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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-convection 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: $1\frac{1}{2}$-layer, doubly-periodic, 2L × L, 512 × 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 $U_{1\max(t=0)} = 35\text{ms}^{-1}$, $L_D = 1,200$km, and $L = 10,000$km.
- Deep jet strength is fixed at $U_{2\max} = 14.9\text{ms}^{-1}$ 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

$$\frac{D_1}{Dt}\left(\nabla^2\psi_1 + \beta y - \frac{\psi_1}{L_D^2} + \frac{\psi_2}{L_D^2}\right) = S(x,y,t) + D, \qquad (1)$$

where $S(x,y,t)$ is a forcing that will be discussed, dissipation term D is a very small quasi-hyperdiffusion, ψ_1 is the streamfunction for the upper layer, and ψ_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 β. (D-I = Dowling-Ingersoll)
- **'Modified D-I scenario'**: Excludes the systematic deep flow that cancels β.

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.

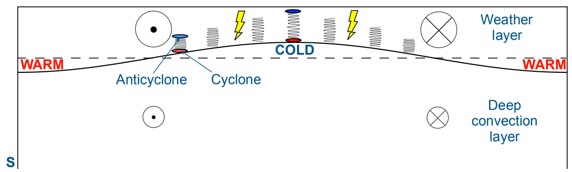


Figure 1: Formation of vortices through MC events.

- PV anomaly-pairs can be biased, having unequal strengths.
- Assume colder base temperature gives stronger MC with more anticyclonic bias. An extreme case is the pure-anticyclonic forcing used in recent studies by Li et al (2006) and by Showman (2007).
- Biased forcing should be more realistic than the unbiased forcing used in standard 'β-turbulence' models.

Results so far

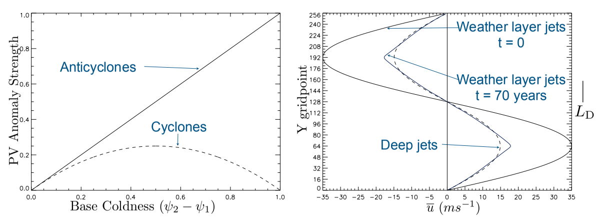


Figure 2: 'Fully biased' forcing (left hand plot) and corresponding jet profiles (right hand plot) for a pure D-I scenario (β effectively zero) at a late, quasi-steady stage.

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

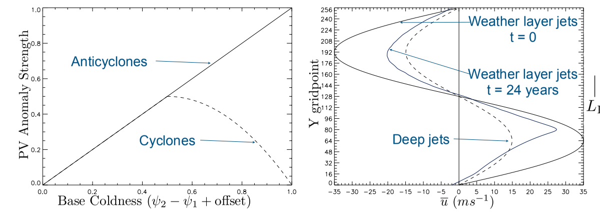
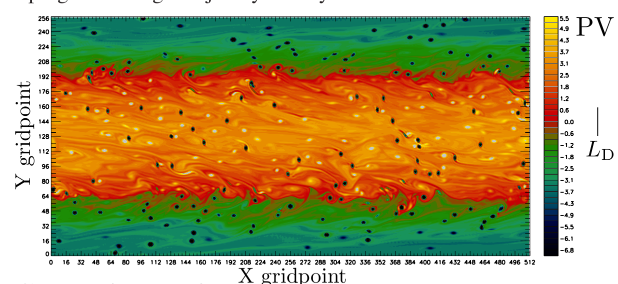


Figure 3: 'Half biased' forcing with temperature offset (LH plot) and corresponding jet profiles (RH plot) for a modified D-I scenario (β restored) at a late, quasi-steady stage.

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



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 $\overline{S}$) usually dominates all other mechanisms: upscale cascade, PV mixing, vortex migration, and Kelvin passive shearing.

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