"Nontraditional" Coriolis force and equatorial super-rotation in the destabilization of short Yanai waves

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OUTLINE

1. The “traditional” approximation

2. Equatorial super-rotation

3. Destabilization of short Yanai wave

1. The "traditional" approximation

$$\begin{aligned} Du/Dt &= -p_x + \beta y v - \gamma w \\ Dw/Dt &= -p_z - (\rho'/\rho_m)g + \gamma u \end{aligned}$$

- due to northward component of $\mathbf{\Omega}$, $\gamma \equiv 2\Omega$
- Neglect referred to as "traditional approximation" (*Eckart*)
- Effect small when $2\Omega H \cos\phi \ll U$ (*White & Bromley*) and when $\Omega \ll N$ (*Gill*, e.g.)

  $\Rightarrow$ Effect strongest near equator, for large vertical scale processes, and for weaker stratification
- Break vertical symmetry of equatorial wave modes
- Important in near vicinity of the equator (*Colin de Verdiére & Schopp 1994*); in equatorial inertial instability (*Hua et al. 1997*, *Fruman 2005*, *Fruman & Shepherd 2006*)

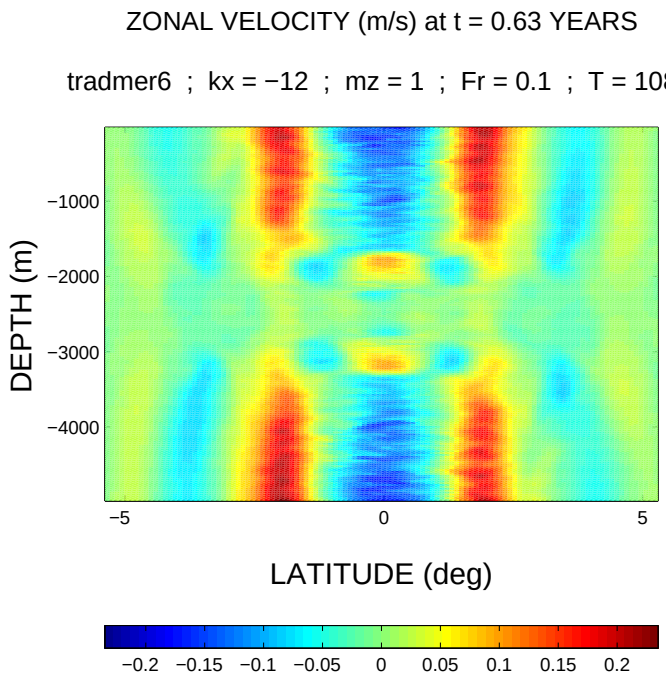
2. Equatorial super-rotation

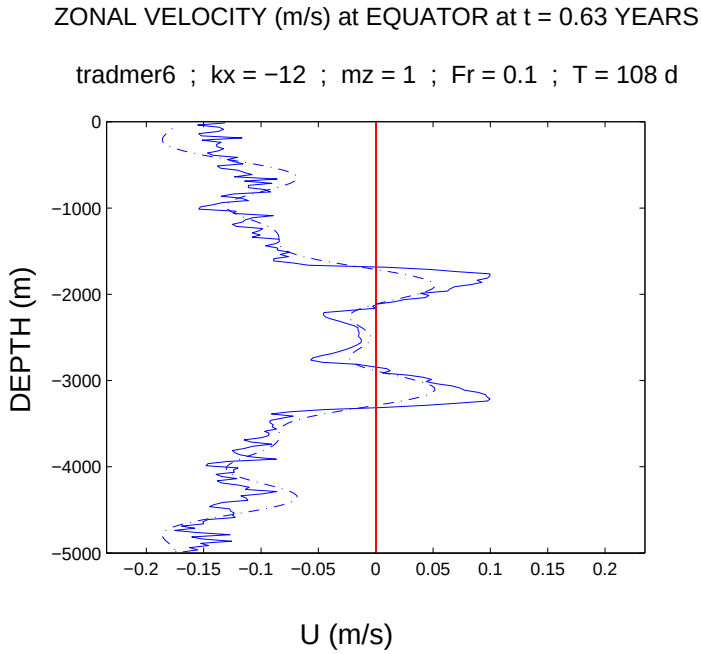
- Assuming eddy (read: departure from zonal mean) dissipation can be modeled as a viscous process, there cannot be a local maximum of absolute angular momentum in the interior of a steady flow (*Hide*)
- Hence no steady eastward flow possible at the equator (starting from zero mean case)
- numerical experiments showing possibility of sustained super-rotation in atmosphere (*Suarez & Duffy*, *Saravanan*, *Williams*, *Lee*, ...)
- other planets (*Gierasch*, ...)

3. Destabilization of short Yanai wave

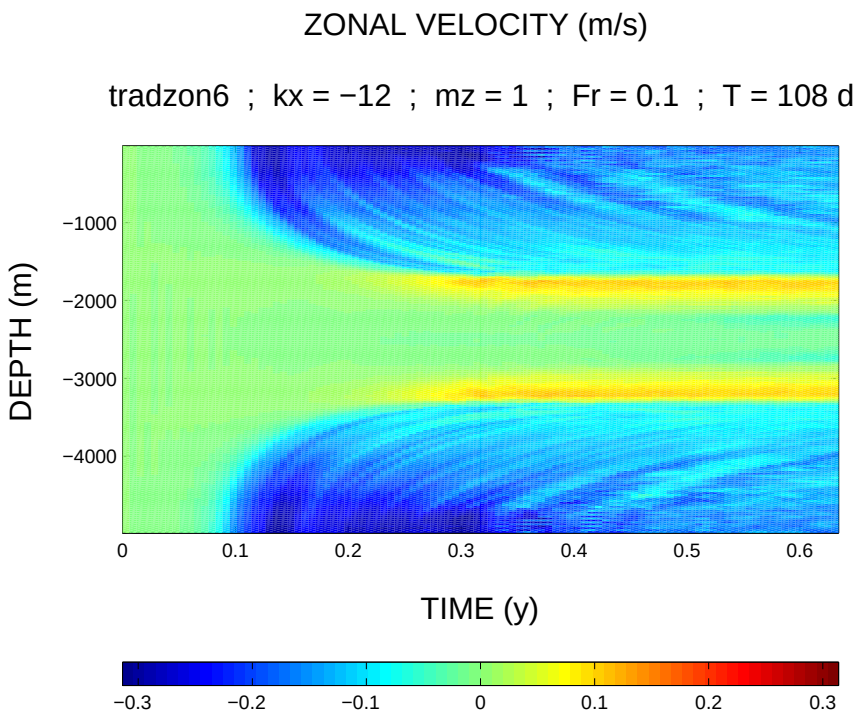
- short (low frequency) Yanai waves are unstable – barotropic shear type instability (*Gill 1974*) leading to exponentially growing modes in the form of short vertical scale zonal jets local to the equator and wider barotropic and low vertical mode jets (*Hua et al. 2006*)
- for $\hat{k} \gtrsim 6$, sufficiently large amplitude, and lowest vertical mode, observe (in numerical solution) formation of eastward (super-rotating) jet at the equator at mid-depth
- vertical structure of middepth jet depends on inclusion of γ terms.

- Yanai wave initialized in 10 deg equatorial channel, periodic bc's:
  - vertical wavelength 10 km
  - horizontal wavelength -1.7 deg ($\hat{k} \approx -12$, period 108 d)
  - meridional velocity amplitude 32 cm/s
- meridional cross-section at $t = 0.63$ years:

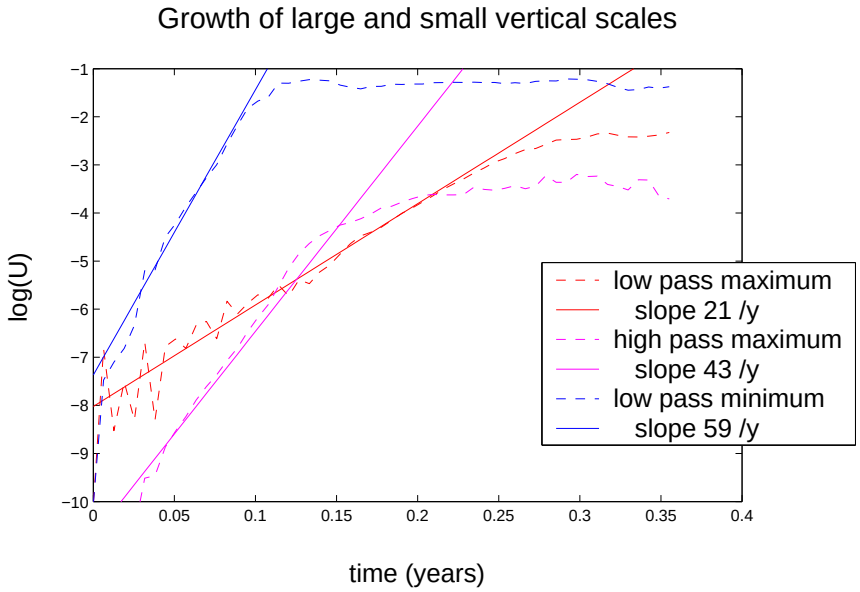




- Middepth, barotropic, and small vertical scale equatorial deep jets grow with distinct rates:



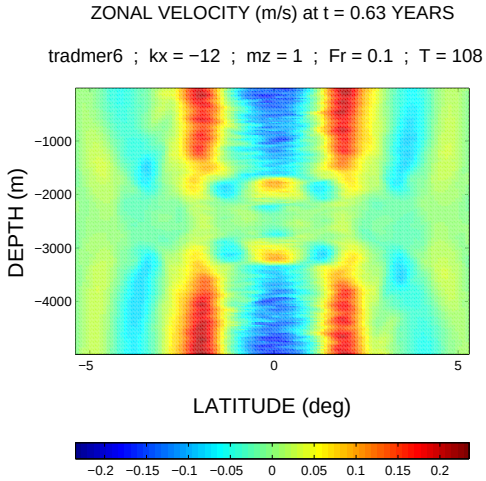
zonal velocity at equator as function of depth and time

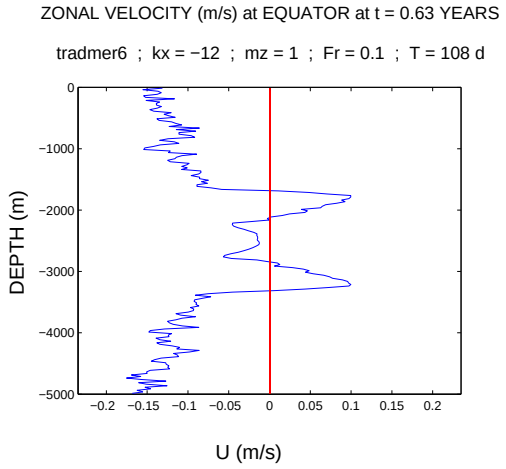


maximum eastward velocity (blue), westward velocity (red), and high pass filtered maximum (magenta)

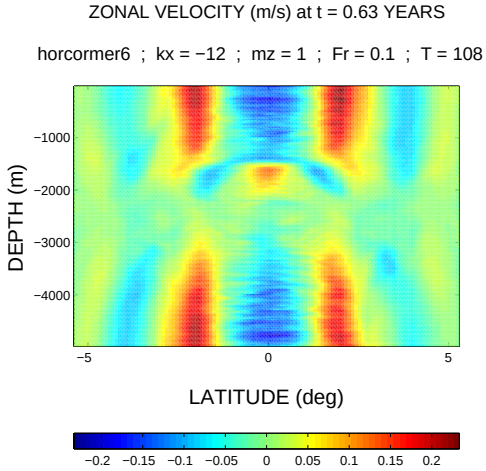
- Structure and amplitude of, and threshold Froude number for middepth eastward jet change with inclusion of γ:

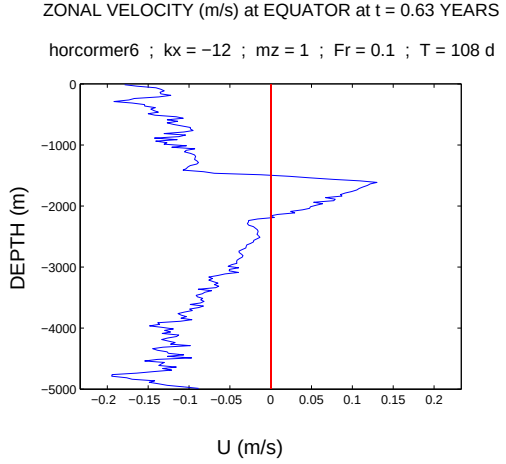
Without γ:



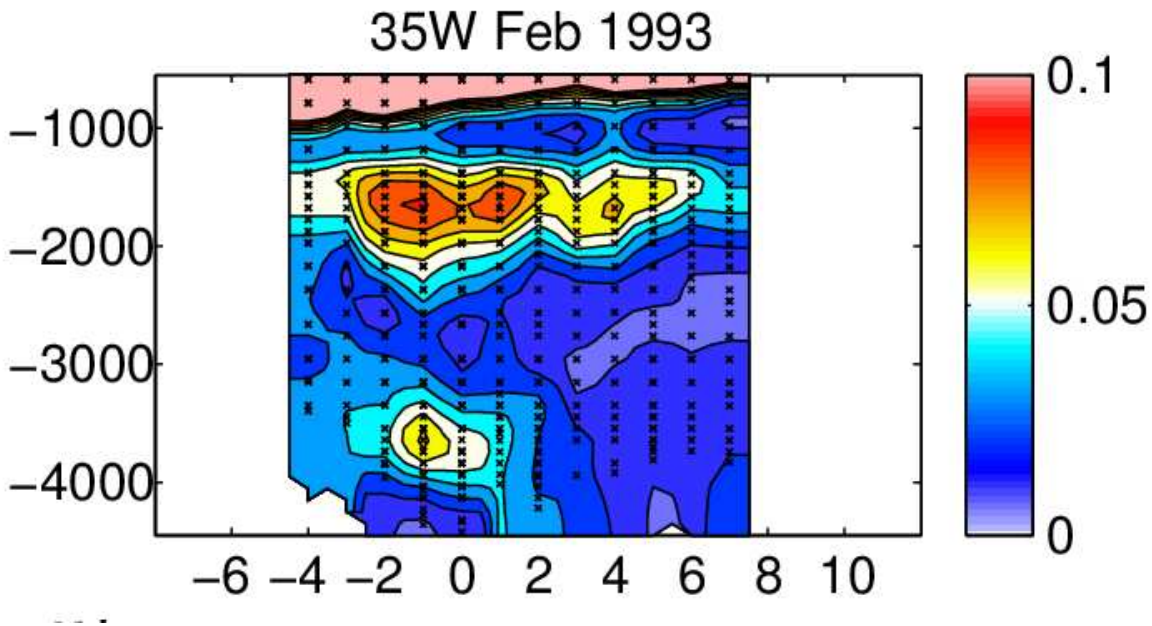


With γ:





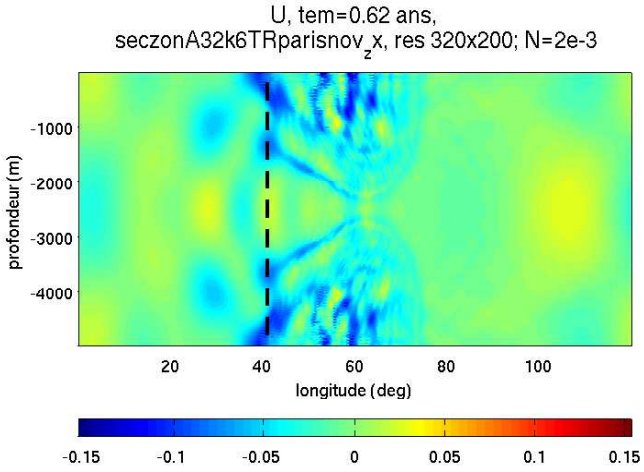
- Might be explanation for observed 1600 m jet in Atlantic:

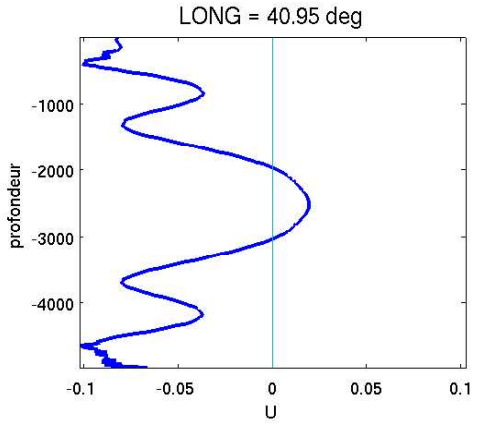


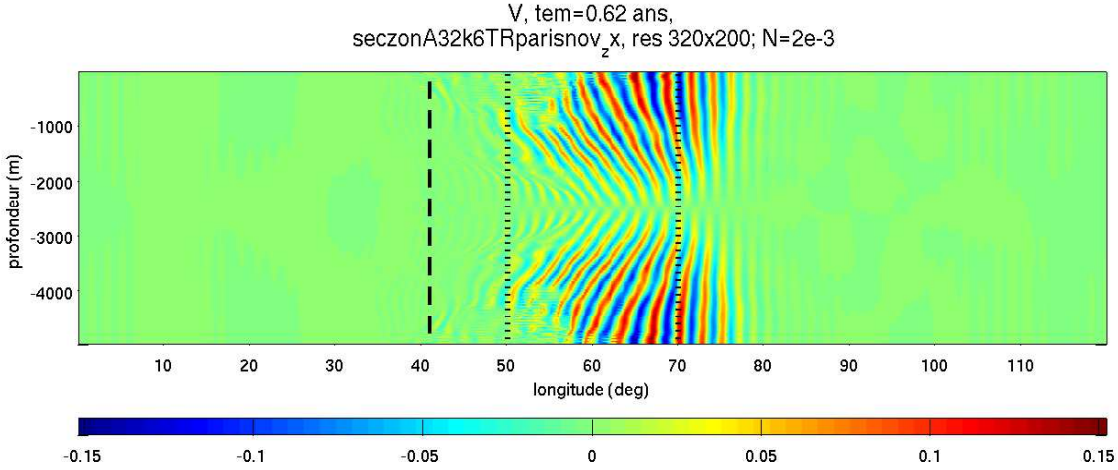
CFC concentration in western Atlantic; from *Eden 2006*

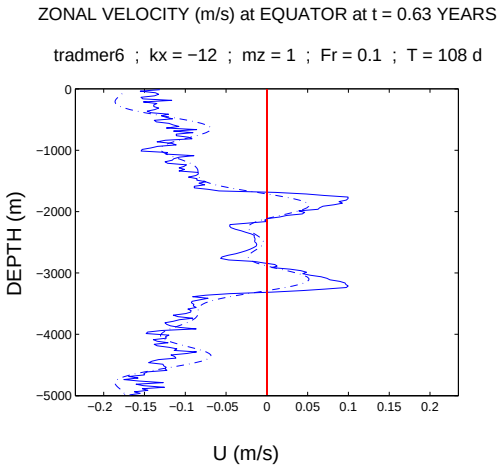
- However, forcing short Yanai wave from western boundary of basin (*D'Orgeville et al*) does not produce the middepth jet

- Yanai wave packet in center of long channel:









Suggests mid-depth jet is fast, long westward propagating Rossby wave signal

Summary

- Destabilization of zonally short, low vertical mode Yanai wave can lead to formation of super-rotating jet at the equator
- Structure and amplitude of and threshold Froude number for formation of super-rotating jet depend on inclusion of non-traditional Coriolis force terms
- instability leading to middepth eastward jet seems to take form of growing long equatorial Rossby wave; does not appear in simulation of basin forced from western boundary

Future Work

- Explain structure and propagation properties of super-rotating jet, with and without γ.
- How can middepth jet be forced in a basin; what effect does γ have in dynamics of forced waves in basin?