Potential Vorticity Perspectives on the Development of Inertial Instability in Tropical Cyclones

Ian C. Beckley[1] and Ángel F. Adames Corraliza[1]
[1]Dept. of Atm. & Ocn. Sci., Uni. of Wisconsin-Madison

Motivation:

Modern reanalysis reveals that inertial instability is relatively common on the equatorward side of the subtropical jet in regions of negative potential vorticity (NPV).

It is thought that the distribution of events is highly influenced by tropical and sub-tropical convection.

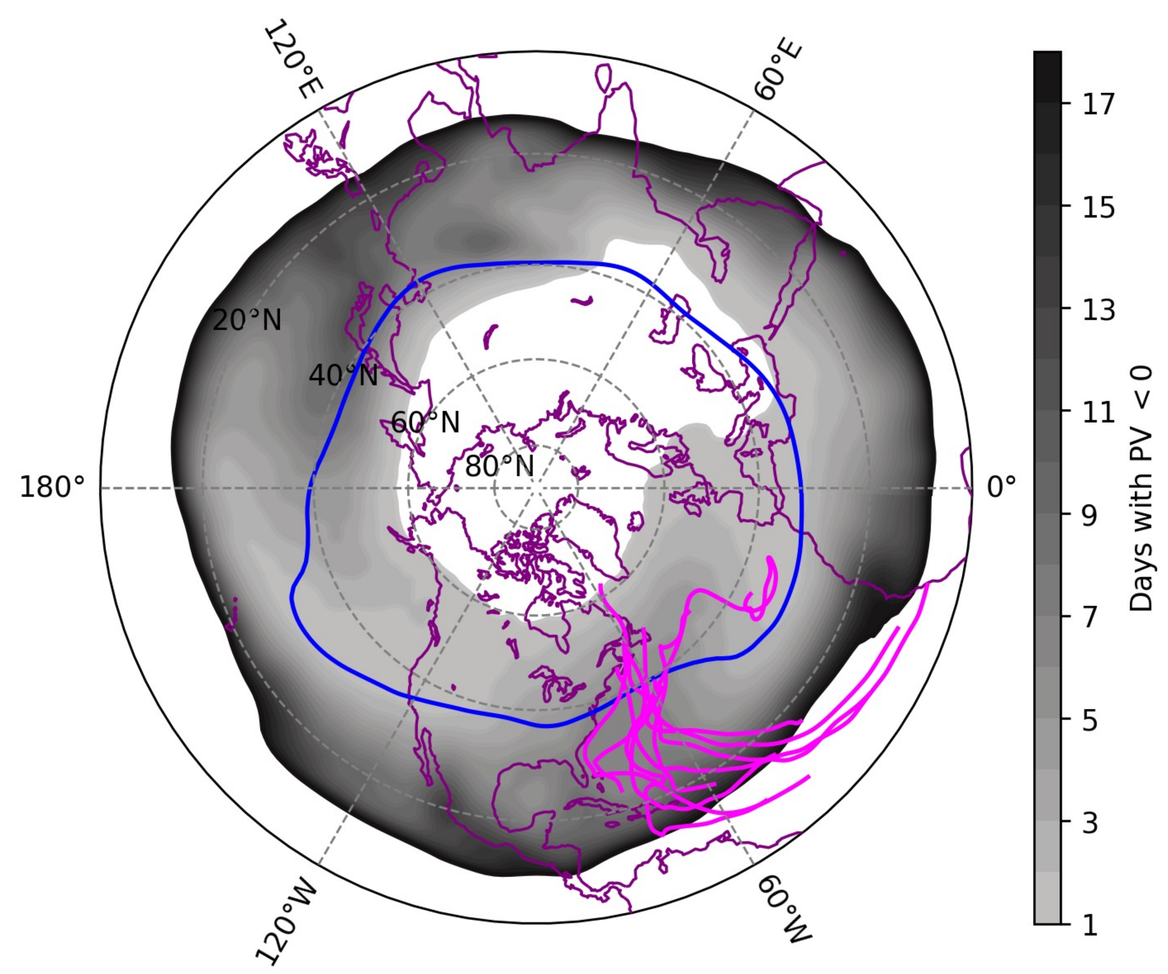

Fig. 1 The climatological location of the subtropical jet (i.e. the 2 PVU isertel on the 350 K isentropic surface) during September (solid blue), the average number of September days wherein inertial instability was analyzed in the 330-360 K isentropic layer over the same period (filled greys) and paths of recurving tropical cyclones 2018-2023 (pink).

Moist PV perspective:

In a convective plume, the tropical boundary layer is linked to the upper-troposphere along a characteristic moist isentrope.

A saturated parcel conserves its value of moist potential vorticity, defined,

$$P_e = -g\zeta_a \frac{\partial \theta_e}{\partial p},$$

such that...

$$\zeta_{a_1} \frac{\partial \theta_e}{\partial p}_1 = \zeta_{a_2} \frac{\partial \theta_e}{\partial p}_2 .$$

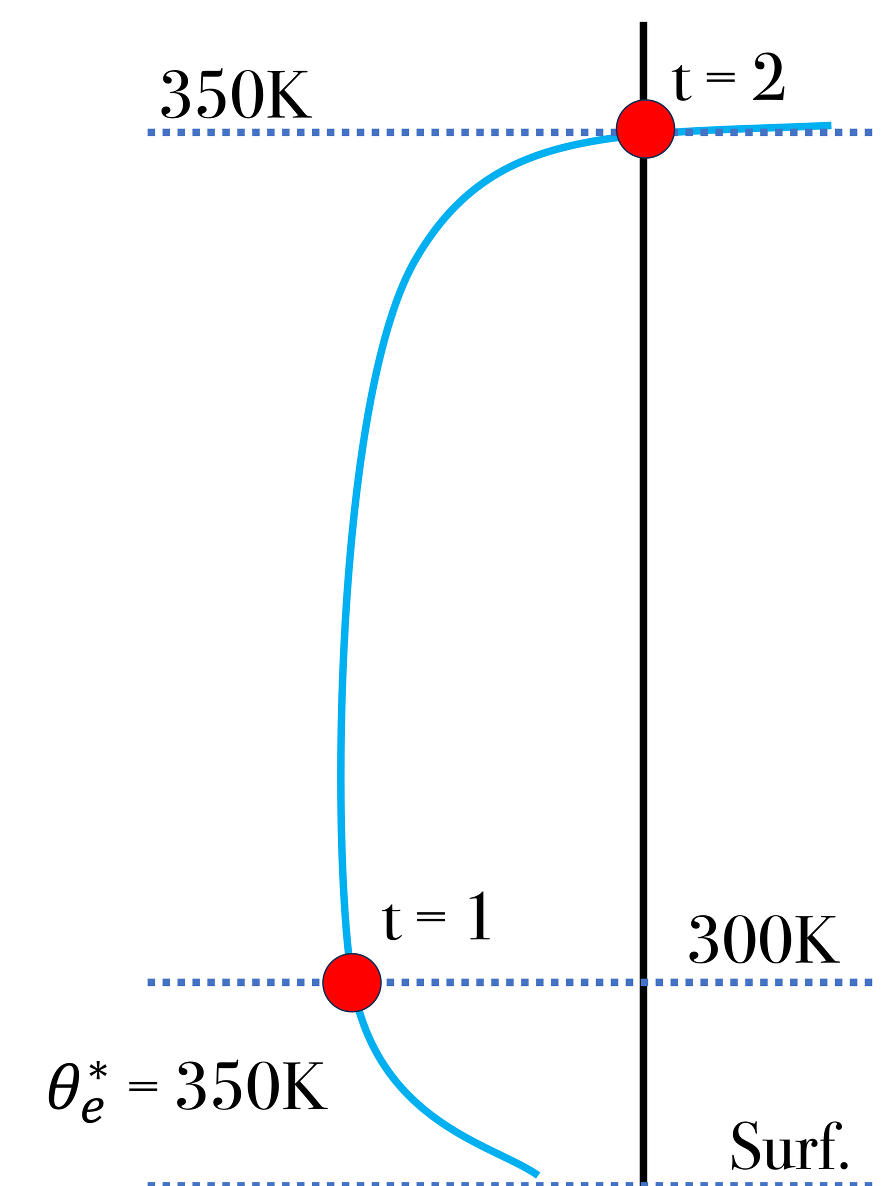

Fig. 2 A conceptual model of an idealized convective plume. The solid blue line indicates the characterisc moist isentrope or "moist enropy current"

At t=1, the parcel is inertially stable and convectively unstable with a negative value of moist PV. At t=2, the parcel is convectively stable and inertially unstable. Since the upper-troposphere is dry, this manifests as both negative moist and dry (Ertel's) PV.

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Contact: Ian C. Beckley, ibeckley@wisc.edu

Ertel's PV perspective:

In a strong tropical cyclone (TC), updraft parcels experience a strong PV tendency while transitioning between the inner, high-PV tower and the low-PV outflow region.

Some of these parcels have been shown to have negative PV values, a departure from prevailing TC theory and an indication of the breakdown of the axisymmetric assumption.

We are interested in the distribution of PV tendencies in the TC environment and, especially, along-flow changes in the sign of the PV

The frictionless PV tendency equation is given in flux form,

$$\frac{dP}{dt} = \nabla \cdot \vec{\zeta}\dot{\theta}.$$

The absolute vorticity vector can be partitioned into components along and across local isentropes,

$$\frac{dP}{dt} = \nabla \cdot \left(\vec{\zeta}_{\parallel}\dot{\theta} + \vec{\zeta}_{\perp}\dot{\theta}\right)$$

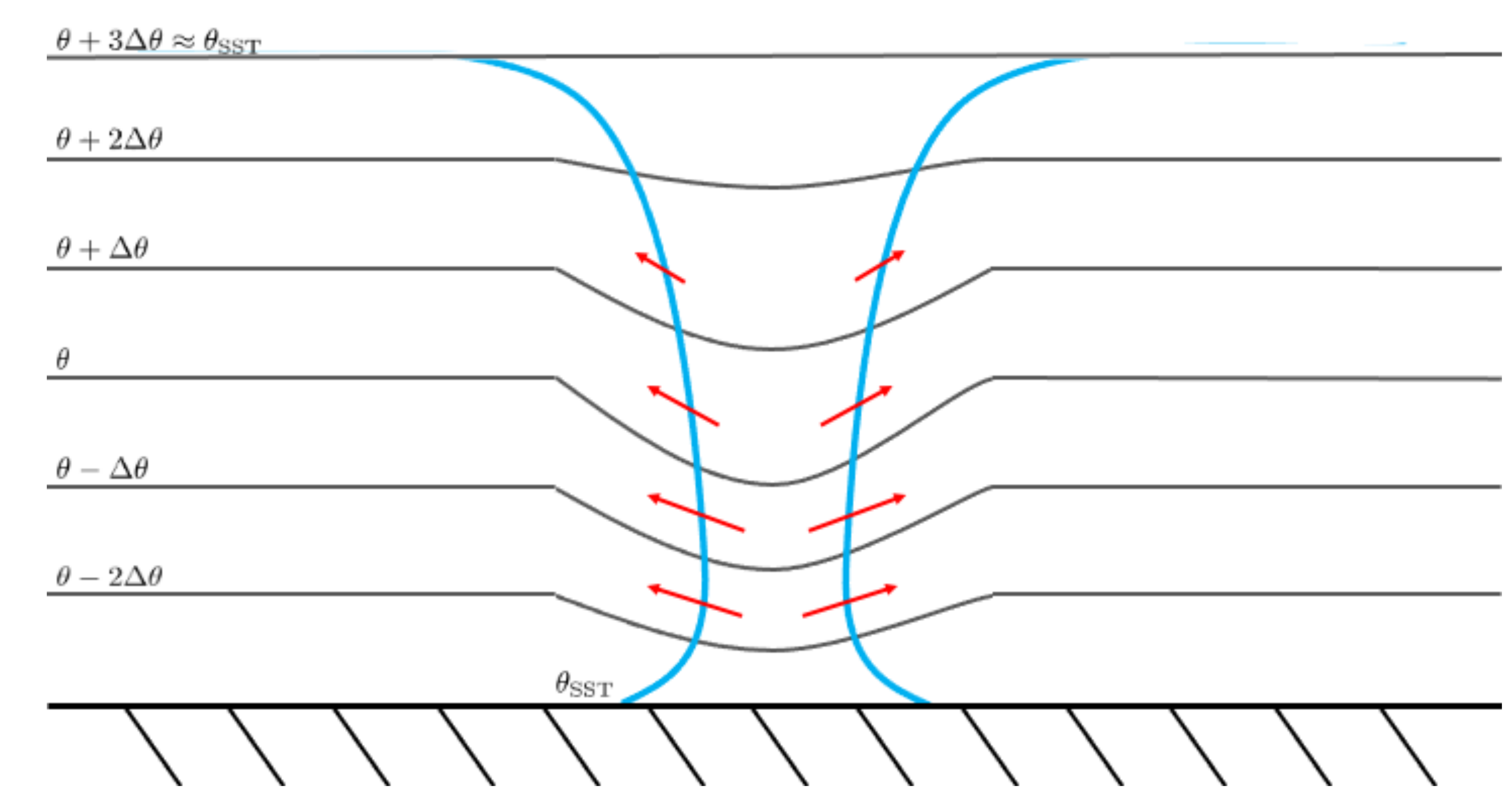

Fig. 3 A conceptual model of an idealized TC with isentropes (grey), the moist entropy current (blue), and the along-isentrope portion of the diabatic PV flux.

Since the second term on the RHS is dependent on the PV, only the first term on the RHS is associated with sign changes.

The portion of the PV tendency responsible for sign changes is given by the convergence of the along-isentrope diabatic PV flux. It is thought that this term contributes to the development of the TC's inner high-PV tower and allows some fringe-eyewall parcels to acquire NPV.

Take-home Points:

Inertial instability is relatively rare in the mid-latitude upper-troposphere, though it occurs more frequently in the west-central Pacific and western Atlantic and is frequently associated with the extra-tropical transition of tropical cyclones.

Sign changes in PV are associated with convergence of the along-isentrope diabatic PV flux.

More work is needed to ensure the compatibility of moist and dry PV perspectives.