

# 15B.1 INTERNAL DYNAMIC CONTROL OF HURRICANE INTENSITY CHANGE: THE DUAL NATURE OF POTENTIAL VORTICITY MIXING

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## 1. INTRODUCTION

Hurricane intensity change is known to be governed by a number of factors. The climatology of intensity change was most recently demonstrated by Emanuel (2000) and shows that an average storm intensifies at a rate of about  $12 \text{ m s}^{-1} \text{ day}^{-1}$  for about 5 days, and then begins to weaken at a slower rate of about  $8 \text{ m s}^{-1} \text{ day}^{-1}$ . We also know that environmental conditions play a key role — for example, if a storm moves over colder water or land, or if the ambient environmental vertical wind shear increases, weakening typically follows. Alternatively, an environment that is not conducive for intensification can become more favorable over time, and strengthening would typically occur. Ideally then, we would be able to explain the variance of hurricane intensity change in terms of the variance of the synoptic-scale storm environment. This is not the case however, and it is fairly typical for storms to strengthen or weaken, sometimes rapidly, without any commensurate changes in the external storm environment. Although the specific processes involved remain an open question, this behavior is widely believed to result from internal vortex-scale processes that can have a profound effect on how storm intensity evolves, and this means that our ability to model and ultimately predict hurricane intensity change is dependent on our ability to contemporaneously model a very broad range of spatial scales.

From a more pragmatic viewpoint, it's revealing to note that our operational ability to accurately forecast hurricane motion (track) has improved dramatically in the past 20 years, and that the reason for this lies in our improving ability to capture evolving synoptic-scale fields with our present numerical guidance. With the exception of occasional small-amplitude trochoidal oscillations, which are on the order of tens of km and are caused by transient potential vorticity asymmetries near the storm center, the track is controlled almost entirely by the environmental steering flow that the storm vortex is em-

bedded in. Contrary to track forecasting, our ability to forecast hurricane intensity change has shown almost no progress in the past 20 years and again it is widely believed that this is due to our present inability to model small-scale internal processes in hurricanes.

Here we seek to uncover and elucidate these small-scale processes in the hurricane-inner core. It is presently unknown what the exact internal processes are, but it is believed that the rearrangement of the inner-core potential vorticity (PV) structure plays an important role. To gain further understanding of these internal governing mechanisms, we are considering the role of two-dimensional barotropic processes in the hurricane inner-core when non-conservative forcing (diabatic heating and friction) is applied.

## 2. RESULTS

Using a 2D barotropic numerical model with spatially and temporally varying PV forcing, we've uncovered an internal mechanism that interrupts the intensification process resulting from diabatic forcing in the hurricane eyewall. This internal control mechanism is due to PV mixing in the region of the eye and eyewall, and can manifest itself in two antithetical forms — 1) as a transient “intensification brake” during symmetric diabatically-forced intensification, or 2) as an enhancer of intensification through efficient transport of PV from the eyewall, where it is generated, to the eye.

We find that when non-conservative forcing is included in the physics, PV mixing occurs episodically in the form of well-defined events and these events act as a suppressant to intensification until a critical point in the lifetime of the vortex. After this time, the PV mixing events allow the vortex to intensify well beyond the potential intensity that could be realized through diabatic heating in the eyewall in the absence of PV mixing. The amplitude of the disruption of intensification is found to depend on a number of factors, such as eyewall size and diabatic heating rates, and frictional dissipation

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in the eye.

Here we show an example from our numerical simulations (Fig. 1 on the following page). We initialize the model with an axisymmetric monotonic tower of PV. The initial maximum tangential wind is  $\sim 33 \text{ m s}^{-1}$ . We then impose an annulus of diabatic forcing to represent latent heating in the eyewall, and we impose a weak uniform Rayleigh friction everywhere. The diabatic eyewall forcing is “logistically limited” to simulate the tendency toward a steady-state balance between diabatic PV production and vertical PV advection.

The initially monotonic and barotropically stable vortex is forced toward unstable flow by the eyewall heating and eventually becomes unstable at  $t \sim 18 \text{ h}$ . As the unstable modes grow, the PV in the eyewall is mixed into the eye. The PV transport away from the heating region reduces the efficiency of the PV production in the eyewall, but the PV eventually rebuilds and again the flow becomes unstable and another mixing episode follows after  $t \sim 68 \text{ h}$ . A third mixing event occurs after  $t \sim 110 \text{ h}$  — this repeating process of episodic mixing events continues indefinitely in the presence of both heating and frictional forcing.

The time evolution of the palinstrophy in the model is shown in Fig. 2. The palinstrophy is a measure of the PV gradients in the evolving model flow and serves as a good indicator of PV mixing events, during which the gradients increase. As noted above, these events occur at around 18, 68, and 110 hours. The time evolution of the maximum tangential wind of the model fields is shown by the solid curve in Fig. 3. The heating and PV production in the eyewall increases the maximum wind until the PV mixing event near  $t = 18 \text{ h}$ . During the mixing, the maximum wind decreases even though PV production is still occurring in the eyewall. After about 10 h (at  $t \sim 30 \text{ h}$ ), the heating begins to dominate again and the maximum wind begins to increase again. The intensification rate remains fairly steady until the next mixing event near  $t = 68 \text{ h}$ . This mixing event is not as vigorous as the previous (as can also be seen in Fig. 2), but the intensification rate is still affected as shown by the flattening of the solid line in Fig. 3. The third mixing event is more vigorous and the maximum wind again decreases. At  $t$  approaches 168 h, the maximum wind is asymptoting to around  $55 \text{ m s}^{-1}$ .

The dashed curve in Fig. 3 shows the hypothetical maximum wind in the presence of our prescribed heating and friction when the asymmetric mixing processes are turned off. We refer to this as the axisymmetric potential intensity. The comparison

of the solid and dashed curves demonstrates the dual nature of PV mixing in the hurricane inner-core. Near the beginning of the vortex lifetime, the model maximum wind and the axisymmetric potential intensity are congruent. But the initial mixing event acts as a braking mechanism to the intensification process and for  $t < \sim 65 \text{ h}$ , the vortex is weaker than it would be from non-conservative forcing alone. However, the mixing events also serve as an efficient transporter of high PV from the eyewall to the eye, and eventually this allows the maximum wind to exceed the axisymmetric potential intensity.

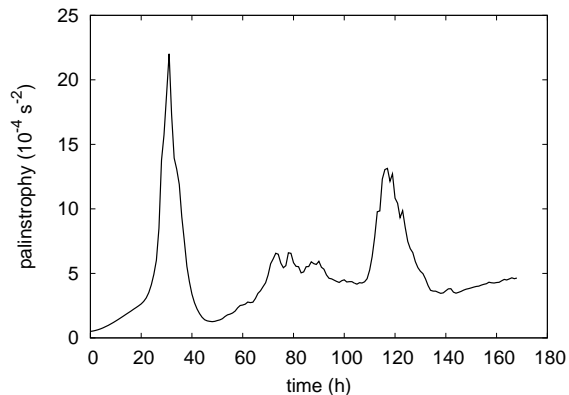


Figure 2: Evolution of the palinstrophy in the model fields. The PV mixing events are identified by the spikes at  $t \sim 18, 68,$  and  $110 \text{ h}$ .

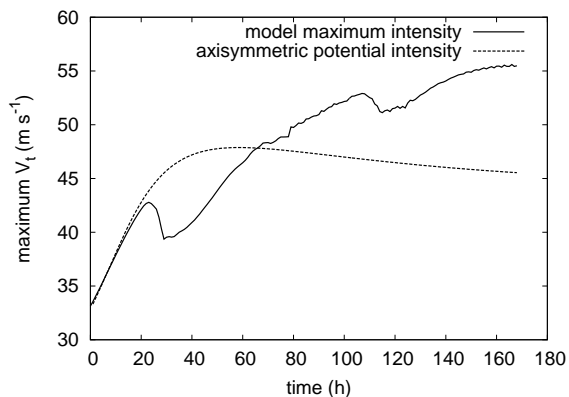


Figure 3: Evolution of the maximum tangential wind in the model (solid curve) and the axisymmetric potential intensity (dashed curve) that would result from the forcing alone.

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Emanuel, K. A., 2000: A statistical analysis of tropical cyclone intensity. *Mon. Wea. Rev.*, **128**, 1139–1152.

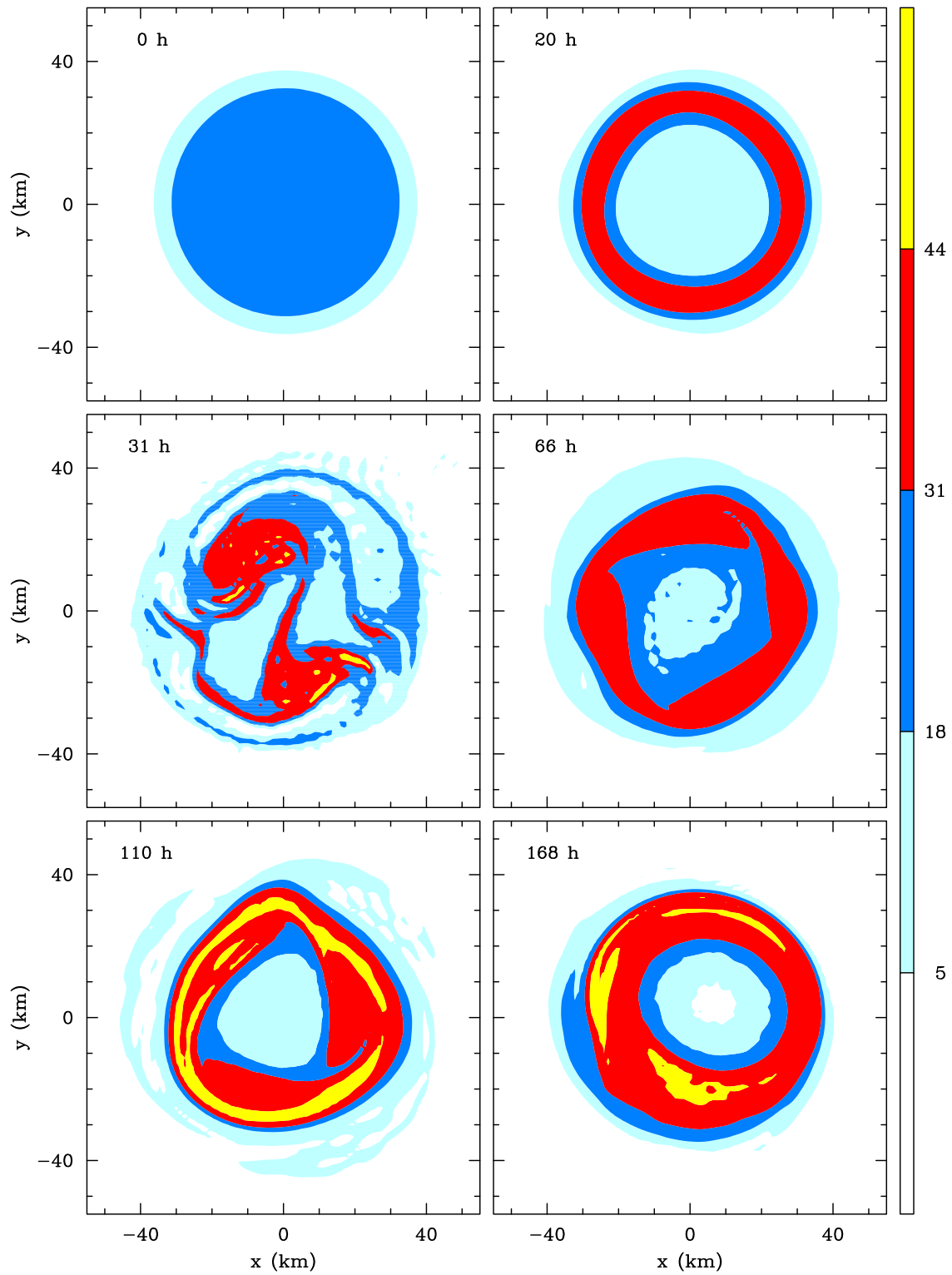


Figure 1: Potential vorticity (PV) evolution in the forced barotropic model. Eyewall heating forces an annulus that becomes barotically unstable and PV mixing ensues. The mixing events occur periodically, and allow efficient transport of high PV from the eyewall, where it's being generated, to the eye.