Linking surface enthalpy fluxes to the forces driving the secondary circulation: towards a causal theory of tropical cyclone intensification

Remi Tailleux, Bethan Harris, Christopher Holloway, and Pier-Luigi Vidale
University of Reading, Meteorology, Reading, United Kingdom of Great Britain and Northern Ireland
(r.g.j.tailleux@reading.ac.uk)

While it is well accepted that tropical cyclones (TCs) derive their energy from surface enthalpy fluxes over the ocean, there is still little understanding of the precise causes and effects by which the latter ends up as TC vortex kinetic energy. For example, Potential Intensity (PI) theory, which has been so far the main framework for predicting TC intensities, assumes a balance between the Carnot power input and the kinetic energy dissipated by surface friction, but says nothing of the detailed physical processes linking the two. A similar criticism pertains to the WISHE (Wind Induced Surface Heat Exchange) theory. To achieve a causal theory of TC intensification, the main difficulty is in linking the power input to kinetic energy production, rather than kinetic energy dissipation. Because kinetic energy is produced at the expense of available potential energy (APE), APE theory is arguably the most promising candidate framework for achieving a causal theory of TC intensification. However, in its current form, the usefulness of APE theory appears to be limited in a number of ways because of its reliance on a notional reference state of rest. First, APE production associated with standard reference states (i.e., horizontally averaged density field, density field of initial sounding, adiabatically sorted states, ...) is usually found to systematically overestimate the kinetic energy actually produced in ideal TC simulations, similarly as the Carnot theory of heat engines; moreover, the standard APE is only connected to vertical buoyancy forces, but says nothing of the radial forces required to drive the secondary circulation. To address these shortcomings, this work presents a new theory of available energy (AE) that is based on the use of an axisymmetric vortex reference state in gradient wind balance. This theory possesses the following advantages over previous frameworks:

- The available energy (AE) thus constructed possesses both a mechanical and thermodynamic component. The thermodynamic component is analogous to the well-known Slantwise Convective Available Potential Energy (SCAPE), whereas the mechanical component is proportional to the anomalous azimuthal kinetic energy;
- The rate of AE production by surface enthalpy fluxes is found to be a very accurate predictor of the amount of potential energy actually converted into kinetic energy in idealised TC simulations based on the Rotunno and Emanuel (1986) axisymmetric model, although a few
exceptions are found for cold SSTs;

- In addition to the expected thermodynamic efficiencies, the production term for AE also involves mechanical efficiencies predicting the fraction of the sinks/sources of angular momentum creating/destroying AE;
- The AE is related to a generalised buoyancy/inertial force that has both vertical and horizontal components; at low levels, such a generalised force has radially inward and vertically upward components, as required to drive the expected secondary circulation.

The new theory, therefore, appears to possess all the ingredients to form the basis for a causal theory of TC intensification.