A Simplified Approach to Understanding Boundary Layer Structure Impacts on Tropical Cyclone Intensity

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Part 1: Derive the Framework

Start with the tangential wind component of the momentum equation:

\[ \frac{\partial v_t}{\partial t} + u \frac{\partial v_t}{\partial r} + v \frac{\partial v_t}{\partial z} = \frac{1}{\rho} \left( \frac{\partial p}{\partial r} - f v_t \right) \]

End with:

Logistic Growth Equation (LGE)

\[ \frac{\partial C_t}{\partial t} + \frac{\partial}{\partial r} \left( \frac{C_t}{r} \right) = a \left( b - C_t \right) C_t \]

Instantaneous Logistic Potential Intensity

\[ ILPI = \frac{(b-1)C_t}{a} \]

Differential Form of \( C_t \)

\[ C_t \approx \frac{(b-1)C_t}{a} - \frac{1}{r} \frac{\partial}{\partial r} \left( \frac{C_t}{r} \right) \]

Part 2: Test the Framework with a Simplified Model

Experiment 2

The CM1 TCBL changes structure as both LGE and the Differential Form of \( C_t \) predict (Fig. 6). Still can be increased if the radial flow at the location of \( v_{max} \) can be assumed to be \(-3 \text{ m/s}\) (Fig. 7).

\( C_t \approx \frac{(b-1)C_t}{a} - \frac{1}{r} \frac{\partial}{\partial r} \left( \frac{C_t}{r} \right) \)

Experiment 3

Both the shape and size of turbulence do not reflect TCBL structure (Fig. 8). \( C_t \) retrievals are dependent on turbulence size and shape (Fig. 9).

Part 3: Test the Framework with Observations

Test with the published analyses of Hurricanes Fabian and Isabel (2003) from Bell et al. (2012), as well as new analyses of Hurricane Joaquin (2015) that are developed from the Tropical Cyclone Intensity Experiment (2015) dropsondes (Fig. 4). Results of \( C_t \) from hurricanes Fabian and Isabel are then compared with previously published \( C_t \) estimates.

Conclusions

The new conceptual relationships between surface friction, TCBL structure, and TC intensity proposed in this study are shown to exist in the simplified, axisymmetric version of CMI. The direct, individual relationships are summarized below (Fig. 13).

Applying this conceptual framework towards \( C_t \) retrievals from observations promises more, but future work quantifying error is needed. Preliminary tests with CMI show that individual errors can be optimized to within 100% if an appropriate constant \( u_c \) can be assumed. Testing with observations show a low bias for Hurricanes Fabian and Isabel (2003) compared to the method proposed by Bell et al. (2012), but retrievals are within the range of overall \( C_t \) uncertainty.

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