An Overview of the COAMPS-TC Tropical Cyclone Boundary Layer Parameterization

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Photo by M. Black in Bell and Montgomery (2008)
COAMPS-TC Boundary Layer Parameterization

Background

- **COAMPS-TC 1.5 order closure hurricane boundary layer param.**
  - Prediction of TKE following Mellor and Yamada (1982) (substantially modified)
    
    \[ e = \frac{(u'^2 + v'^2 + w'^2)}{2} \]

    \[
    \frac{D}{Dt}(e) - \frac{\partial}{\partial z}(K_e \frac{\partial}{\partial z}(e)) = K_M \left( \frac{\partial U}{\partial z} \right)^2 + K_M \left( \frac{\partial V}{\partial z} \right)^2 - \beta g K_H \frac{\partial \theta}{\partial z} - \frac{(2e)^{3/2}}{\Lambda_1} + U \frac{\partial}{\partial x}(e)^* + V \frac{\partial}{\partial y}(e)^*
    \]

    \[ K_{h,m} = S_{h,m} l e^{-1/2} \]

- **Mixing Length (and \( S_h \), \( S_m \)) Often a PBL “Secret Ingredient”**
  1. Conventional method (operational COAMPS) follows Blackadar (1962), Mellor and Yamada (1982), Burk and Thompson
    \[
    l = \left( \phi_M / (\kappa z + b(z/L)^2) + (1/\lambda) \right)^{-1}
    \]
  2. New mixing length for TCBL (Bougeault & Andre 1986; Bougeault & Lacarrère 1989)
    Option for \( \theta_e \) for buoyancy
Comparison of Mixing Length Formulations

Bougeault and Mellor-Yamada

Bougeault Mixing Length: A nonlocal formulation depending on turbulence kinetic energy (TKE) and thermal stability.

\[ TKE_p + \frac{g}{\theta_p} (\theta_p - \bar{\theta}) \cdot \Delta z > 0 \]

Azimuthal Average of Mixing Length (Isabel 2003)

- Large mixing length is concentrated around RMW.
- Mixing length is larger above 4 km than in BL.
- Bougeault mixing length is larger than that of MY.
• Stronger convection in Bougeault run.
• Slightly larger size in Bougeault run.
• Dropsondes were launched in the rear-right quadrant.
Winds (model vs. obs)
- stronger inflow
- thicker inflow depth
- no outflow

Bougeault vs. MY mixing
- Larger mixing length gives stronger & thicker inflow.
- Momentum flux & TKE are reasonable in both.

Dropsonde Observations (Zhang et al. 2009, JAS)
Comparison of Mixing Length Formulations
How Well does COAMPS TKE Distribution Compare with Obs?

- Bougeault mixing leads to much stronger turbulence intensity.
- Turbulence in deep convection is much stronger than in the BL.
Comparison of TCBL in Idealized Test Case
Radial Winds (normalized)

Idealized Tropical Cyclone Test Case (w/ HRD)

• Bougeault shows faster intensification.
  ➢ 15 m s\(^{-1}\) and 25 hPa in 24 h
• Inflow depth is deeper in Bougeault.
• Radial inflow from MY compares better with dropsondes (from J. Zhang).
COAMPS-TC Tropical Cyclone Boundary Layer Summary and Challenges

➢ COAMPS-TC TC Boundary Layer Parameterization

• **Good:** Options for Mellor-Yamada (NRL) and Bougeault mixing lengths, gives robust results in agreement with observations, tested for 1000’s TC cases

• **Bad:** Large sensitivity to mixing length, but $l$ is still unknown for TCs

• **Ugly:** Lack of key observations to evaluate fully & constrain, interactions with other processes such as microphysics & convection, additional nonlinearities make adjoints difficult

➢ Challenges

• **TCBL:** (until recently) least well observed part of storms: Under utilized GPS dropsonde evaluations, issues with near sfc. structure, steadiness.

• **We’re not in Kansas:** Departures from log-law, homogeneity, mixing length

• **Air-sea exchange:** Parameterization of drag, heat, moisture, waves, spray

• **Balance:** Super-gradient jet, implications for initialization & intensification

• **Landfall:** Winds tend to be too weak, asymmetric stress forcing

• **TCBL rolls:** Emerging evidence of rolls in TCBL, importance?

• **3D Coherent eddies:** Gustiness, sub-roll structures may be critical
COAMPS-TC Idealized TC tests (6-km res)

- PBL2: 1.5-order turbulence closure scheme (Mellor and Yamada 1982)

- PBL3: Similar to PBL2, except using the Bougeault mixing length calculation.
Evaluation of TC Boundary Layer Param.
Comparison of MY and Bougeault

Radial (color, knots?), Total Wind (white contours)

Isabel Inner-Core BL Structure Comparison

- BL is defined by inflow depth.
- Larger mixing length leads to:
  - deeper BL;
  - larger RMW;
  - weaker inflow
- Overall structure is good.
- The MY is, in general, more consistent with the analyzed BL based on observations.
- The gradient in wind speed in the observational analysis is significantly stronger than the COAMPS-TC.
Evaluation of TC Boundary Layer Param.

**TKE Budget**

- Modeled wind shear dominates, being consistent with the obs.
- Buoyancy is very small.
- COAMPS shear is excessive at the surface, above mixed layer.
- Shear production parameterization needs to be investigated further.
Evaluation of TC Boundary Layer Param.
Isabel Comparison Outer Core

Model vs. Obs. (Sept 12)
- Similar $\theta$ and $q_v$
- MY cooler and moister
- Larger mixing length leads to stronger fluxes