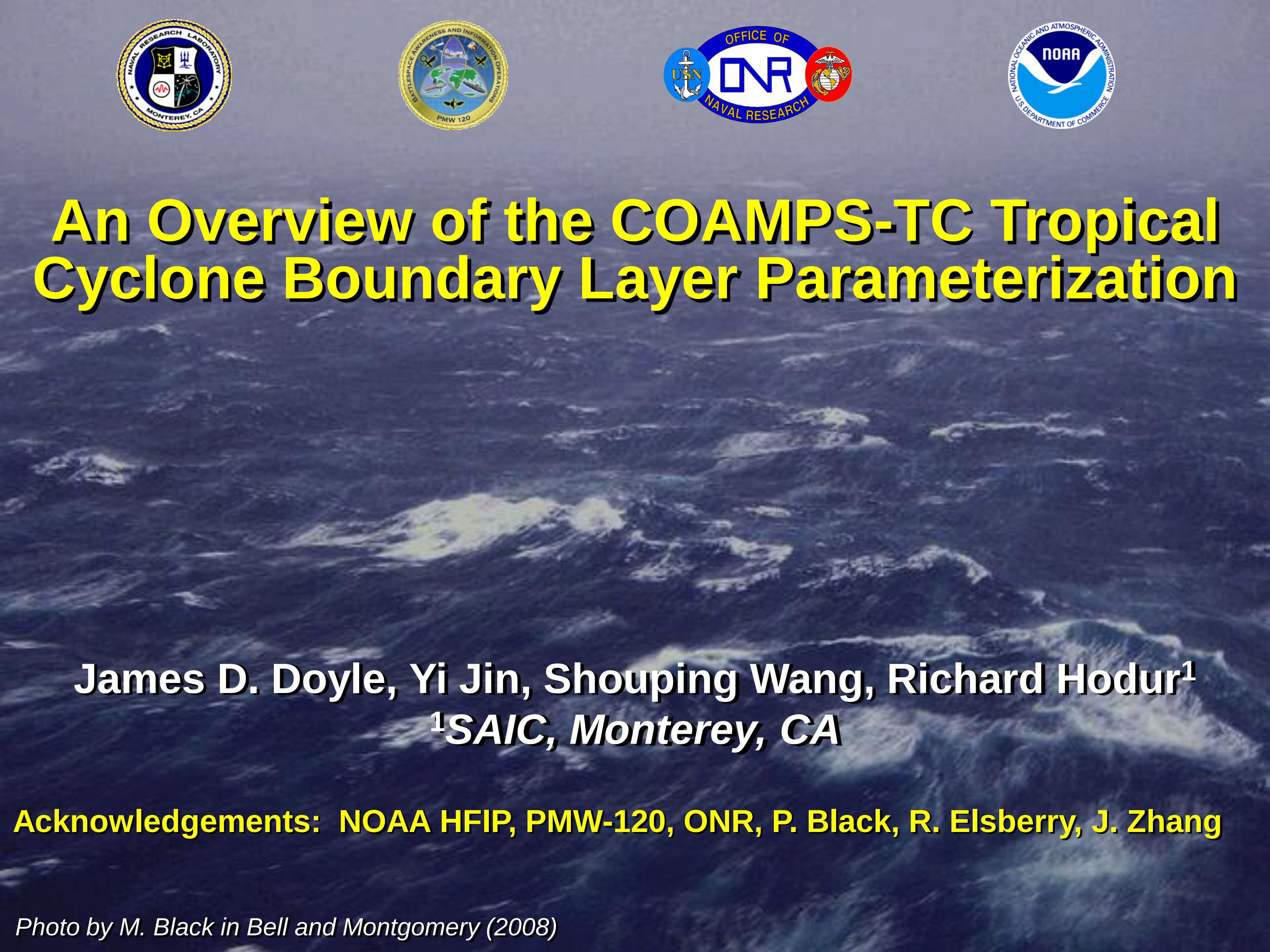

An Overview of the COAMPS-TC Tropical Cyclone Boundary Layer Parameterization

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Acknowledgements: NOAA HFIP, PMW-120, ONR, P. Black, R. Elsberry, J. Zhang

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)

$$e = \overline{(u'^2 + v'^2 + w'^2)} / 2$$

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

Diffusion Shear Buoyancy Dissipation Advection

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

- **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

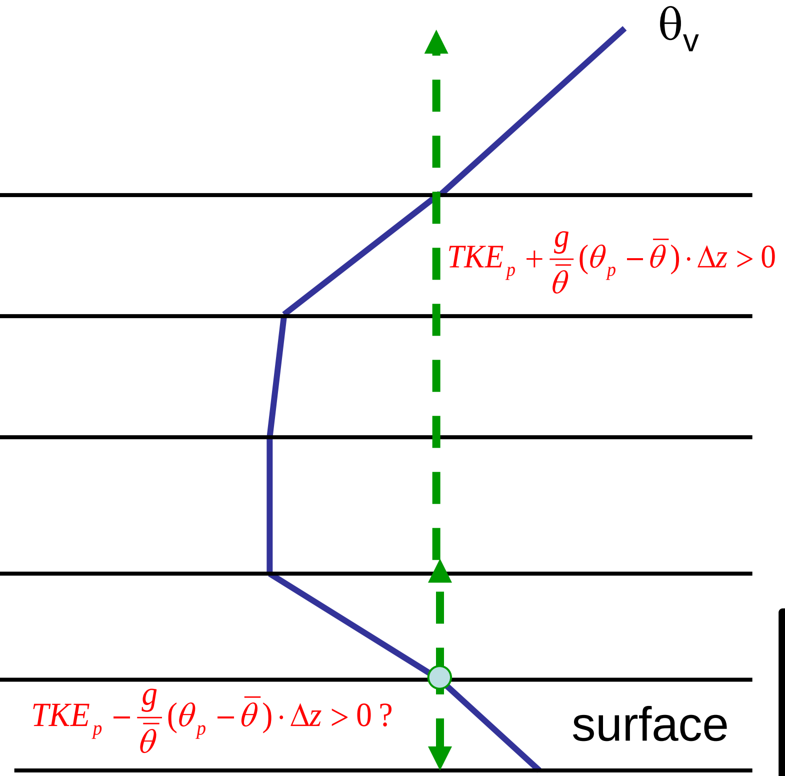
$$l = \left(\phi_M / (\kappa z + b(z/L)^2) + (1/\lambda)\right)^{-1}$$

  2. New mixing length for TCBL (Bougeault & Andre 1986; Bougeault & Lacarrère 1989) Option for θ_e for buoyancy

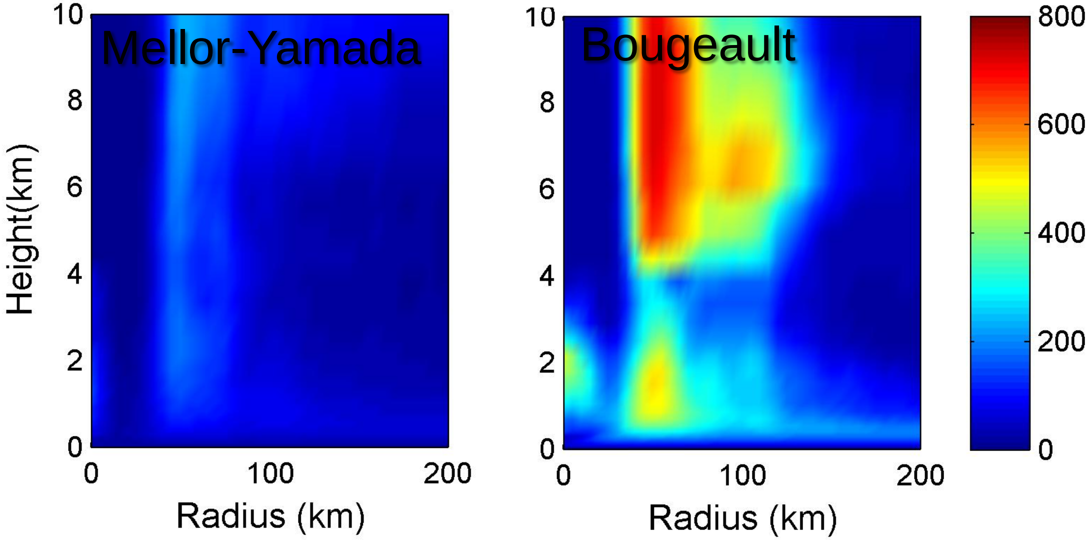
Comparison of Mixing Length Formulations

Bougeault and Mellor-Yamada

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



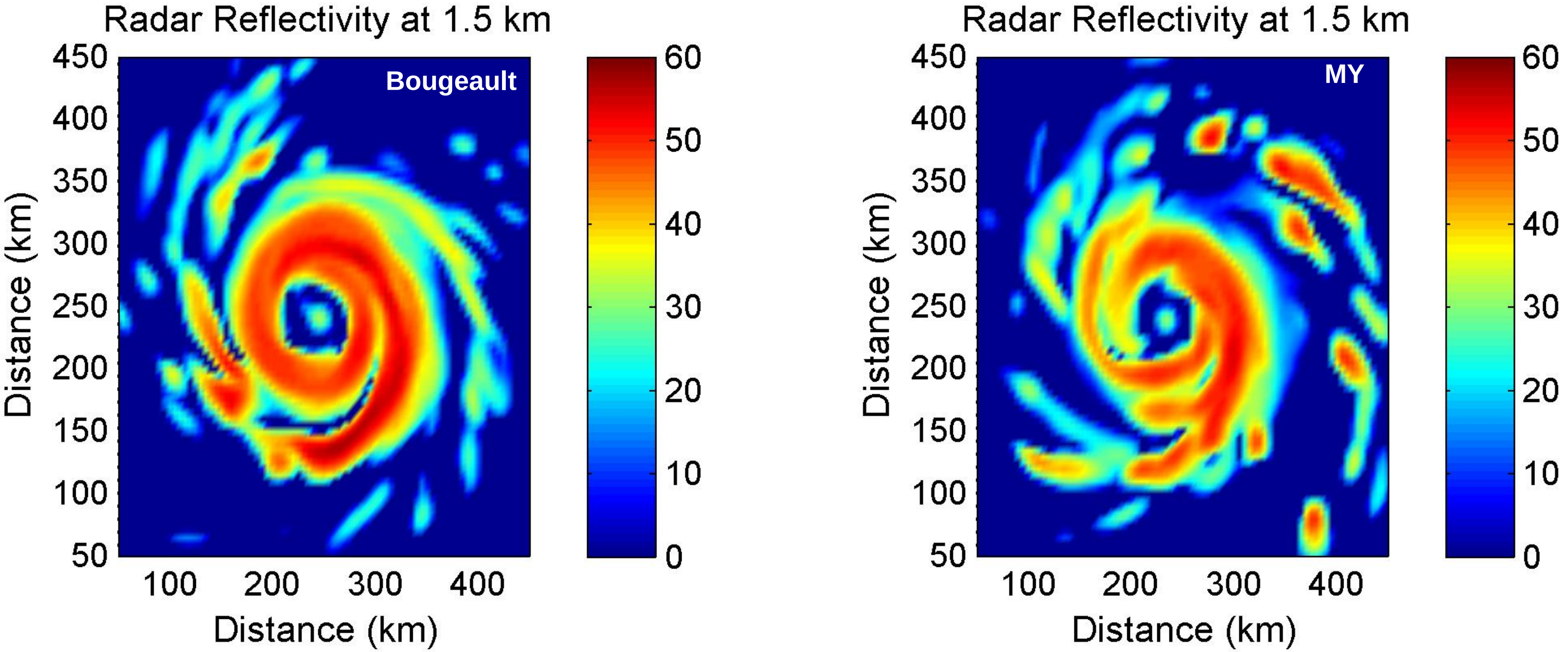
Azimuthal Average of Mixing Length (Isabel 2003)



- **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.**

COAMPS-TC Simulation of Isabel

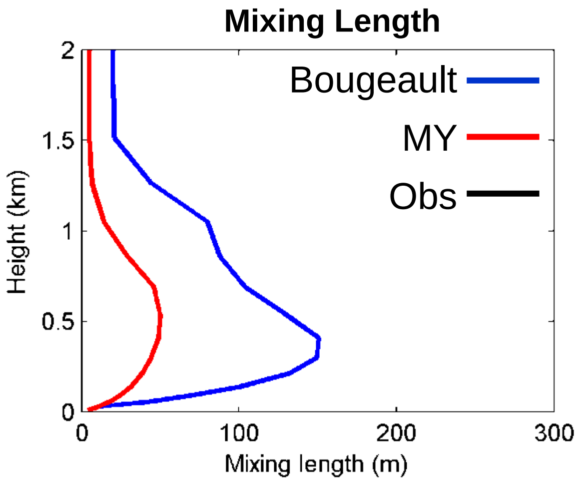
Bougeault and Mellor-Yamada Comparisons

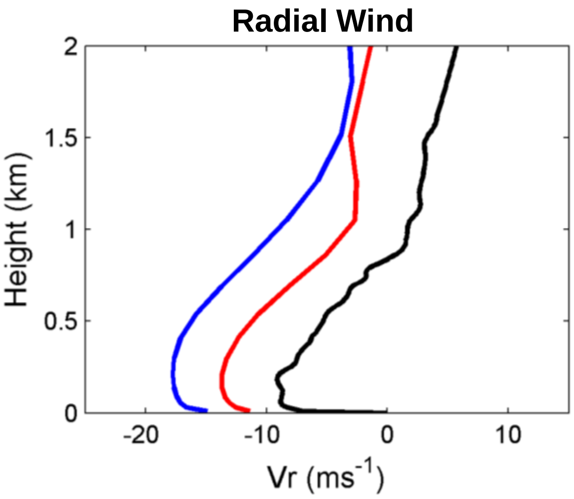


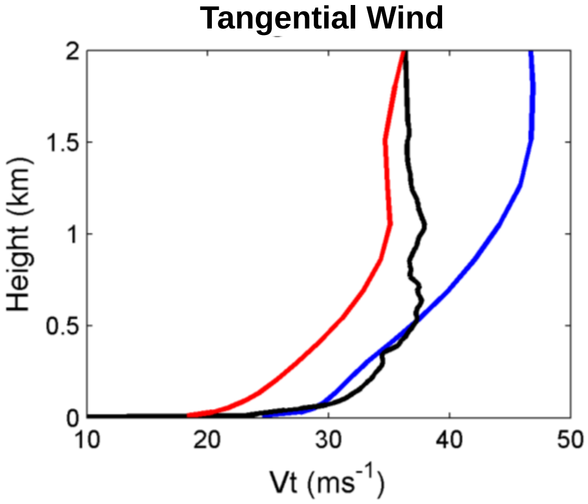
- Stronger convection in Bougeault run.
- Slightly larger size in Bougeault run.
- Dropsondes were launched in the rear-right quadrant.

Evaluation of TC Boundary Layer Param.

Isabel Comparison Outer Core


Mixing Length


Radial Wind

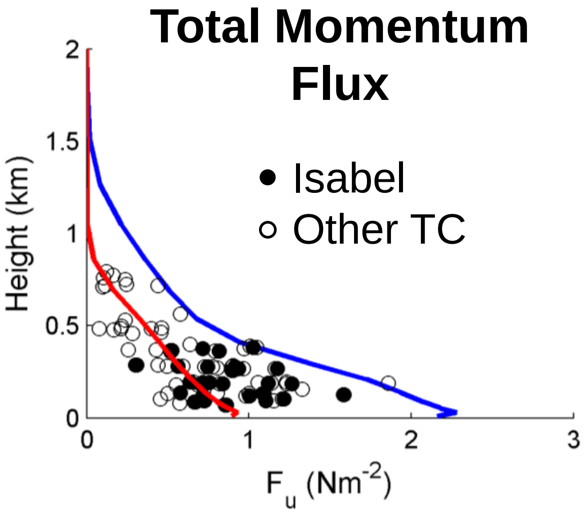

Tangential Wind

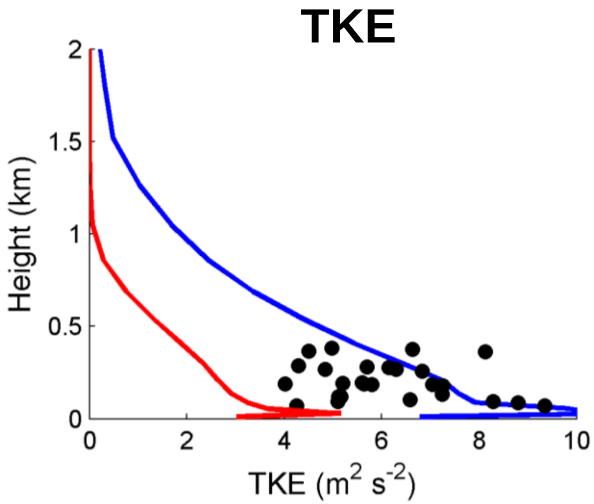
Winds (model vs. obs)

- 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.

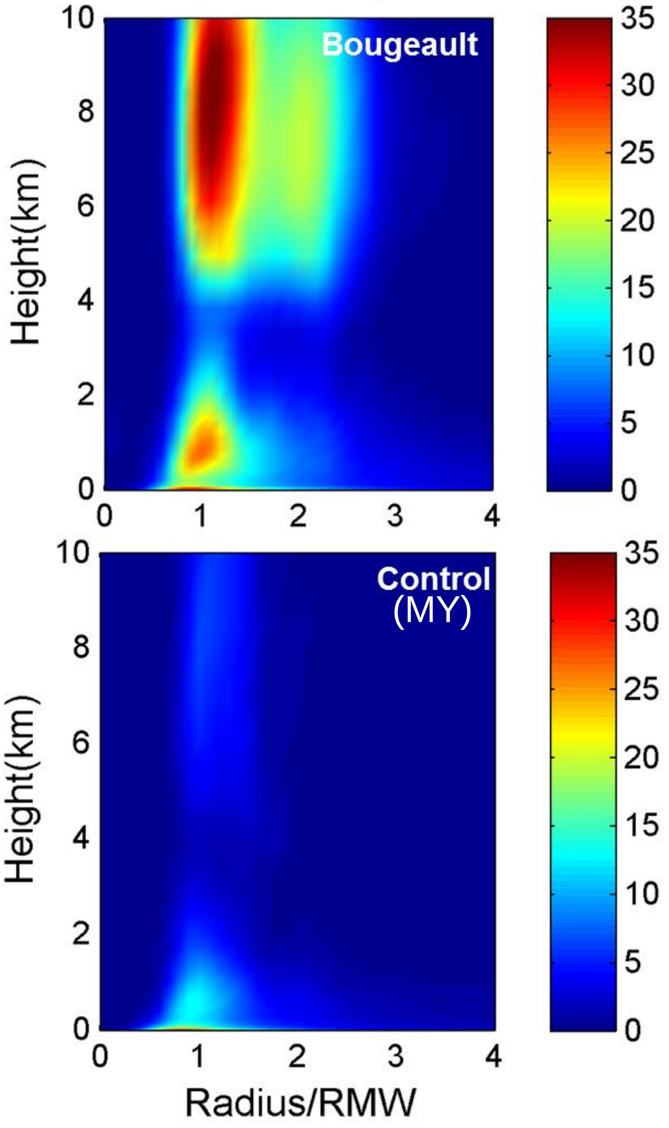

Total Momentum Flux


TKE

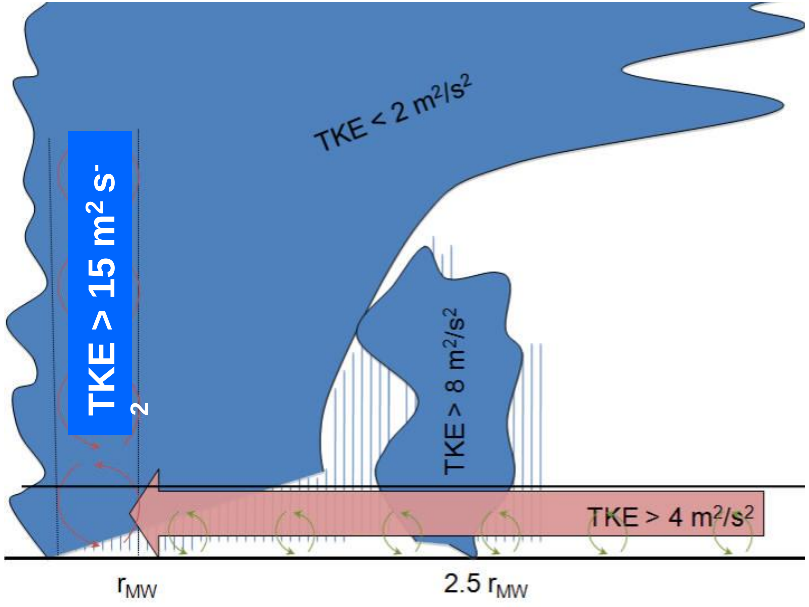
Dropsonde Observations (Zhang et al. 2009, JAS)

Comparison of Mixing Length Formulations

How Well does COAMPS TKE Distribution Compare with Obs?



Simulated TKE profile



Observation-based schematic of TKE

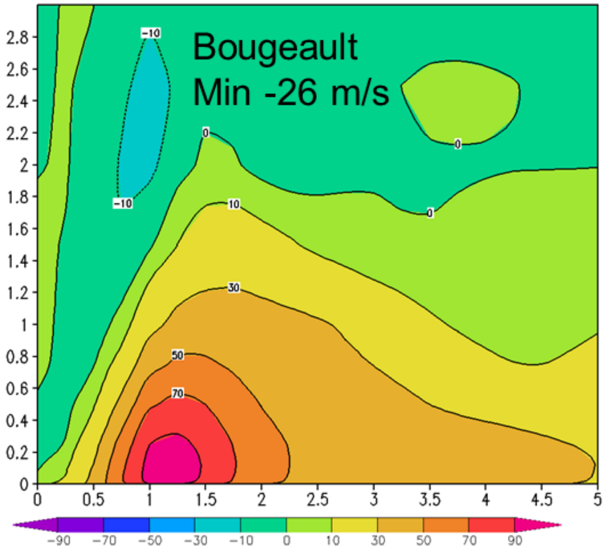
(Lorsolo *et al*. 2010)

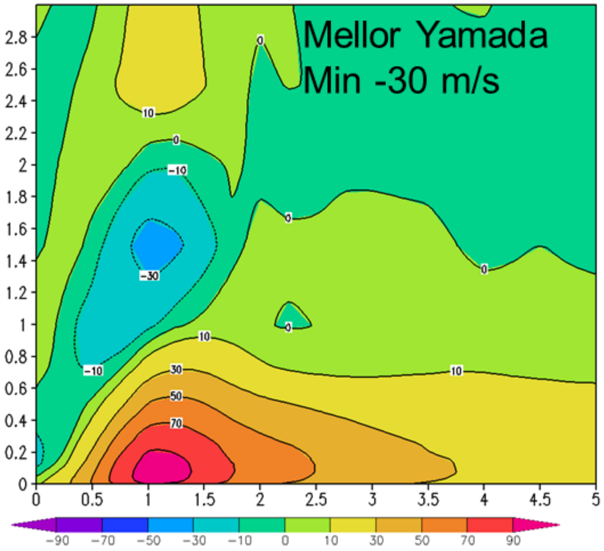
- **Bougeault mixing leads to much stronger turbulence intensity.**
- **Turbulence in deep convection is much stronger than in the BL.**

Comparison of TCBL in Idealized Test Case

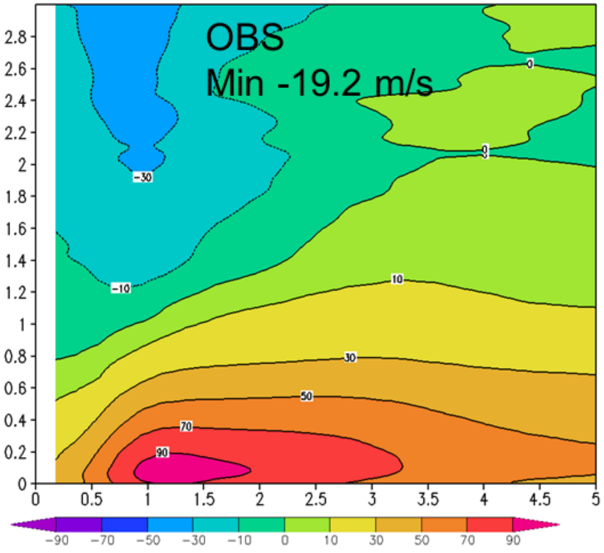
Radial Winds (normalized)

Idealized Tropical Cyclone Test Case (w/ HRD)





Dropsonde radial wind (normalized)



- 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

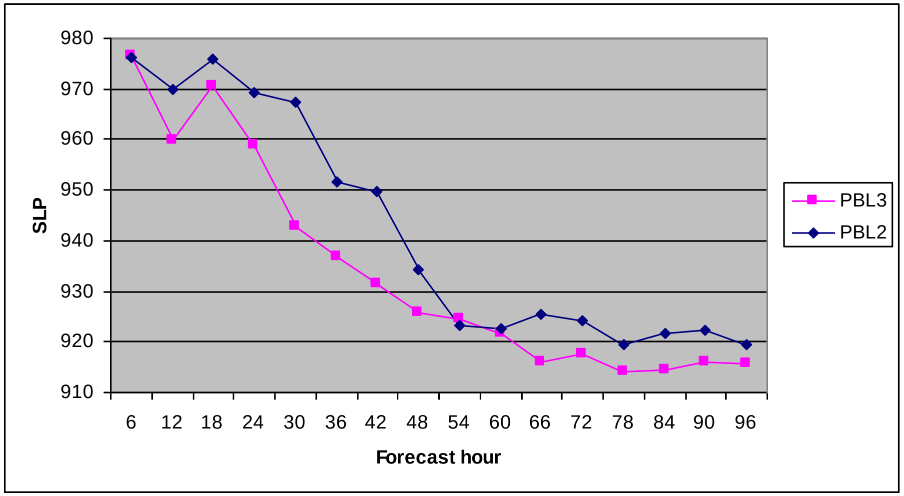
➢Challenges

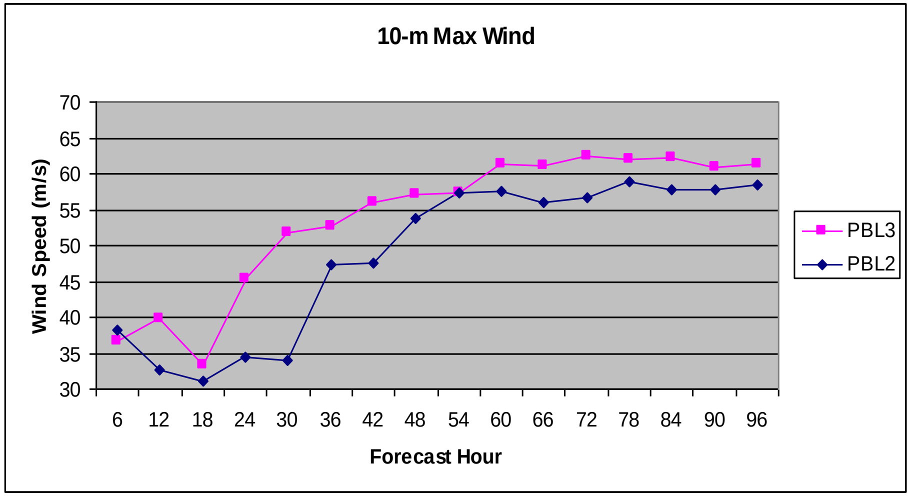
- **TCBL: (until recently) least well observed part of storms:** **Under utilized GPS dropsonde evaluations, issues with near sfc. structure, steadiness.**
- **We’re not in Kansas:** **Departures from log-law, homogeneity, mixing length**
- **Air-sea exchange:** **Parameterization of drag, heat, moisture, 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.

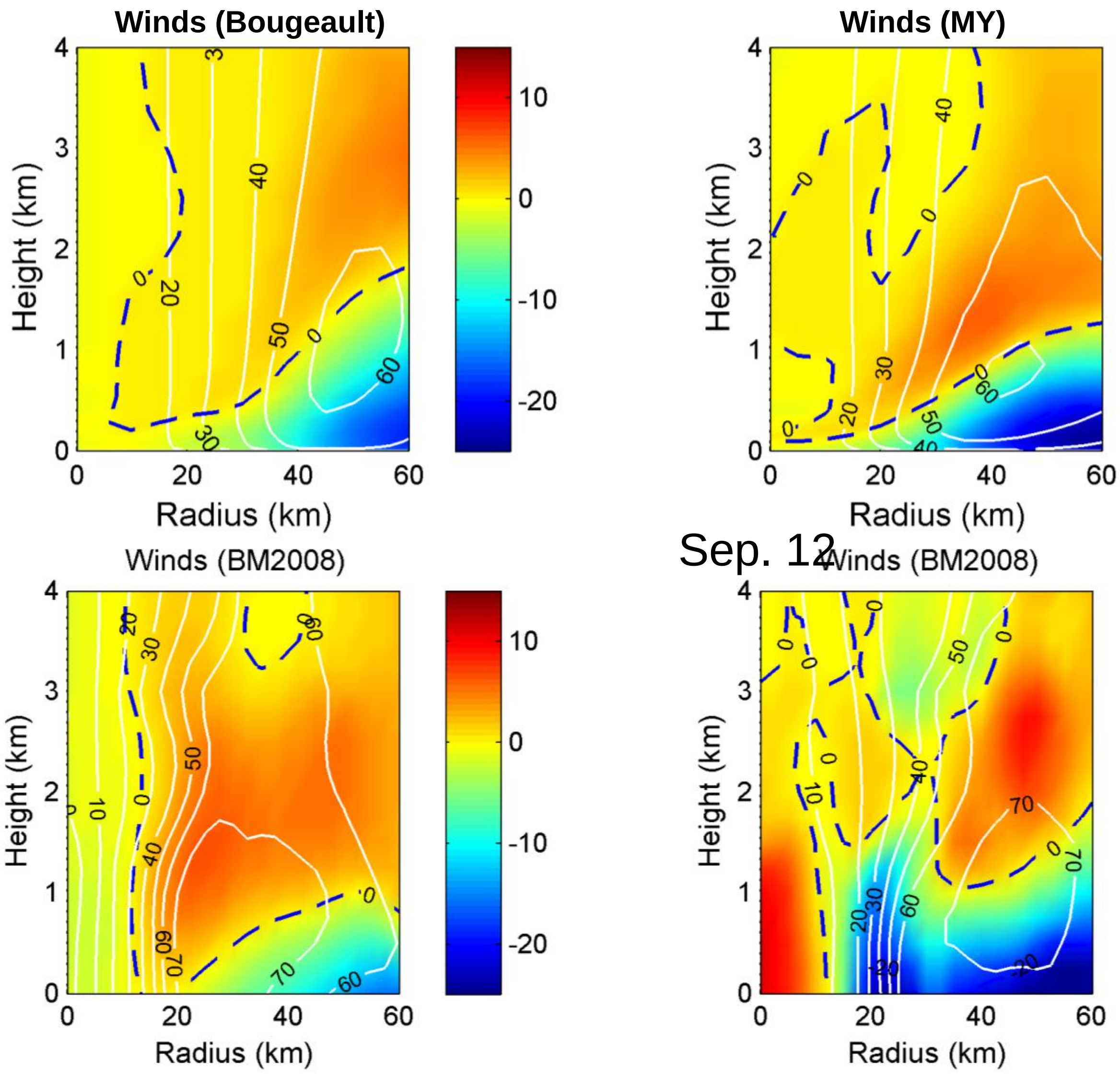




Evaluation of TC Boundary Layer Param.

Comparison of MY and Bougeault

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



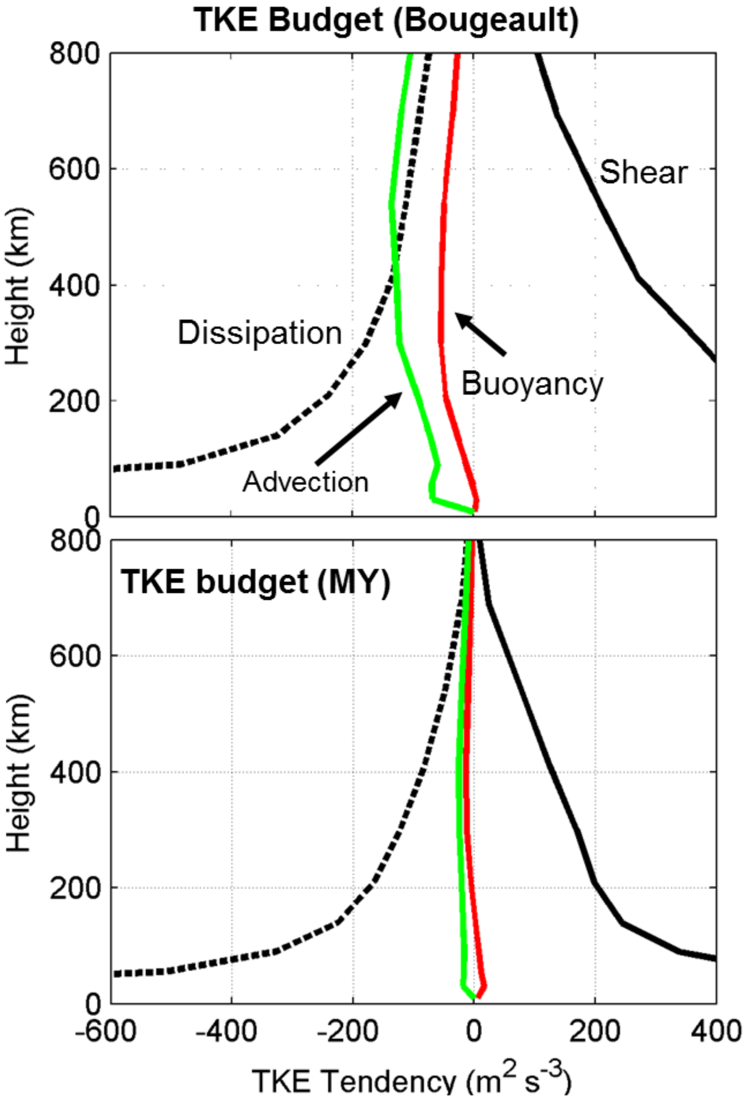
Sep. 12

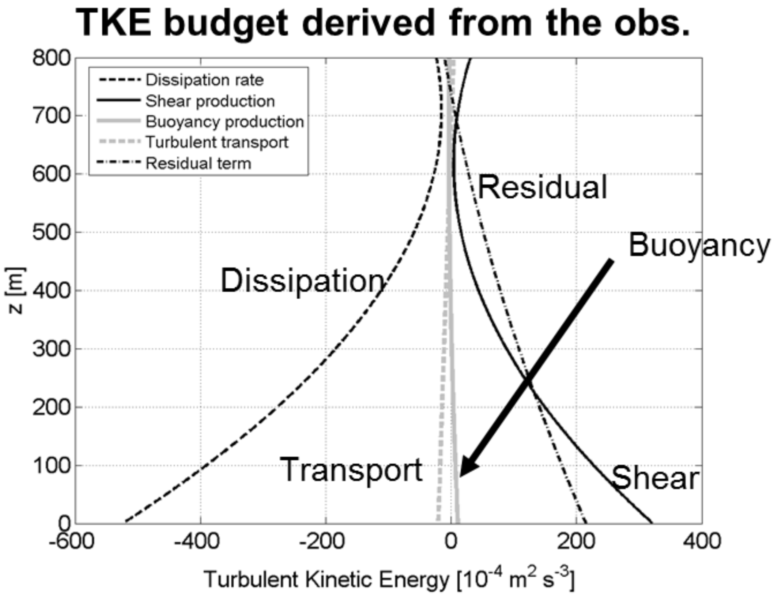
Isabel Inner-Core BL Structure Comparison

- 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



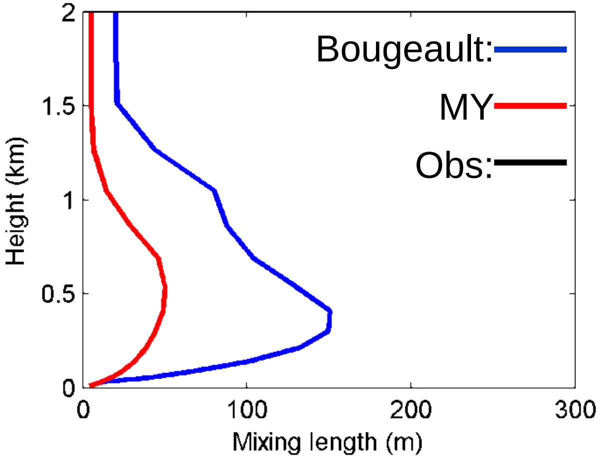


- Modeled wind shear dominates, being consistent with the obs.
- Buoyancy is very small.
- COAMPS shear is excessive at the surface , above mixed layer.
- Shear production parameterization needs to be investigated further.

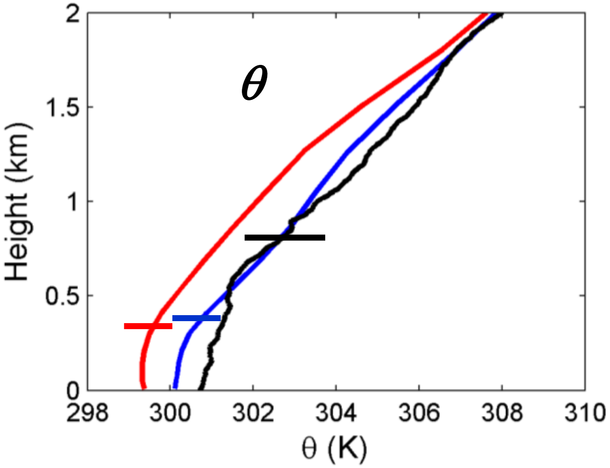
Evaluation of TC Boundary Layer Param.

Isabel Comparison Outer Core

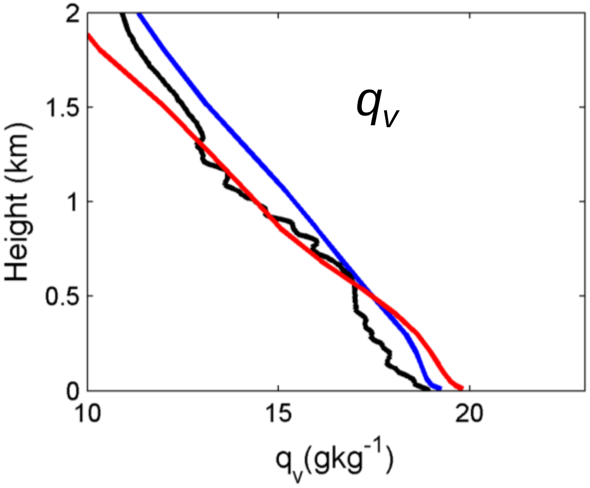
Mixing Length



Potential Temperature



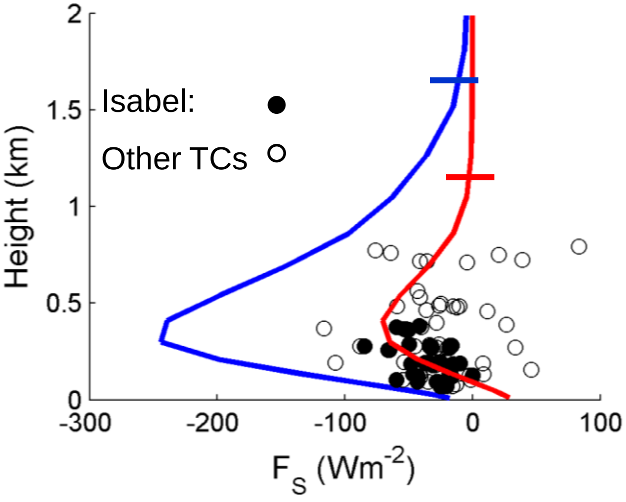
Water Vapor



Model vs. Obs. (Sept 12)

- Similar θ and q_v
- MY cooler and moister
- Larger mixing length leads to stronger fluxes

Sensible Heat Flux



Latent Heat Flux