P102 A numerical sensitivity study on the energetics of Tropical Cyclone Megi (2010) during intensification

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1. INTRODUCTION

As discussed in the literature, tropical cyclones (TCs) are energized by the released latent heat due to condensation of moist convection within the eyewall and rainbands (Nolan 2007, Sawada and Iwasaki 2010). Fraction of this latent heat energy is transformed into available potential energy (APE) and kinetic energy. According to Emmanuel's MPI theory (Emanuel 1997, Wang 2010), the **production rate** of the kinetic energy during intensification increases linearly with wind speed, αV^1; however, the **dissipation rate** due to surface friction increases even faster, αV^3, until the kinetic energy balances and reaches steady state. To examine this energy adjustment mechanism, sensitivity experiments were performed to TC Megi (2010) using the JMA/MRI Non-hydrostatic Model (Saito et al., 2007). This work focuses on the intensification of Megi from the energetics point of view and its sensitivity to planetary boundary layer (PBL) schemes.

CASE STUDY: TC MEGI (2010)

❑ JMA BEST TRACK DATA (Oct. 13 to 24)

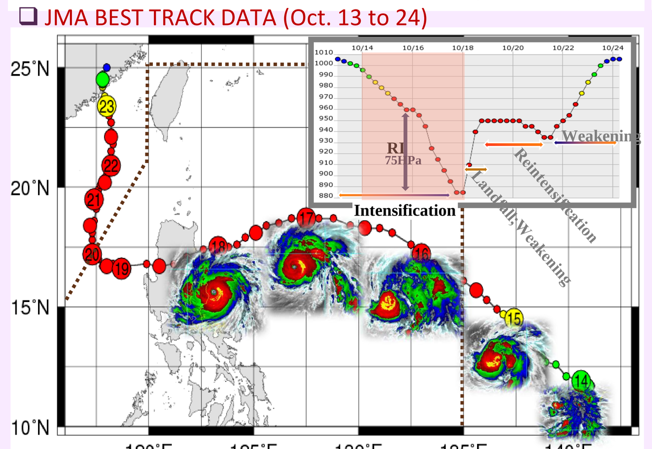


Image Source: Digital Typhoon; Japan National Institute of Informatics; and NOAA (MTSAT IR-NHC Enhanced Image)

PBL EXPERIMENTS:

- MRI/JMA NHM (Saito et.al. 2007)
- JRA25(1.25deg,6hrly) and MDGSST(0.25deg,daily)
- Res.= **2km**

DF: Deardorff PBL scheme (control case)

MYNN: Change of Scheme (Mellor-Yamada-Nakanishi-Niino Lev. 3 scheme)

Cd1.5: 50% Increased Surface Drag Coeff.

2. INITIAL RESULTS: PBL EXPERIMENTS

INTENSITY

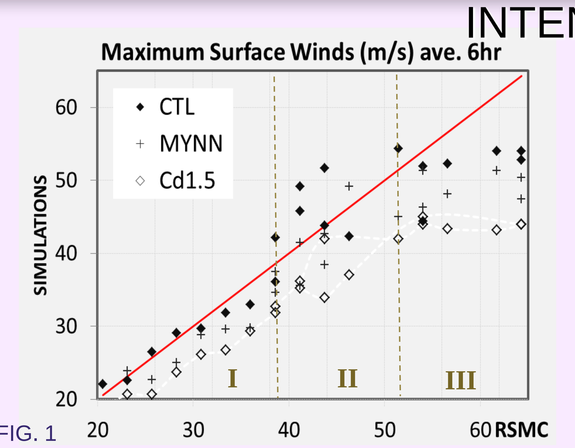


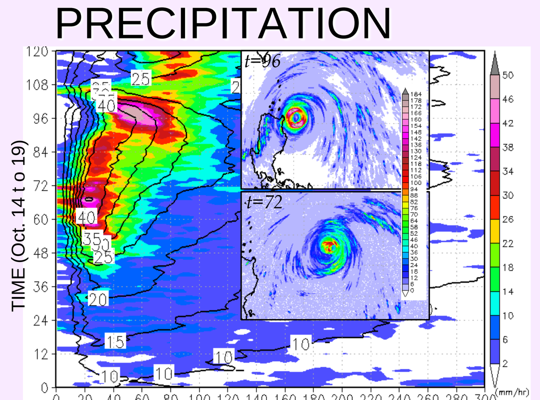
FIG. 1

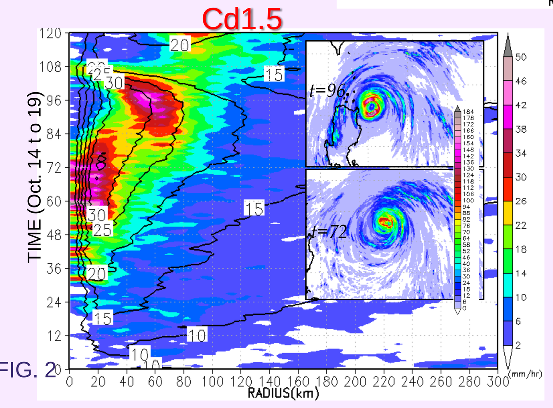
- ❑ DF: overestimation at mid-strong winds (Region II) and underestimation at high-wind region(vmax>50m/s)
- ❑ Increasing Cd and changing the PBL scheme to MYNN weakens the maximum surface wind.

PRECIPITATION

Time-radius cross section of the Calculated Precipitation rate (mm/hr; shaded) with its corresponding Tangential wind (black contour).

The insets represent the horizontal distribution of 3hr accumulated rainfall (mm) at t-72 (RI) and t-96 (max Intensity)





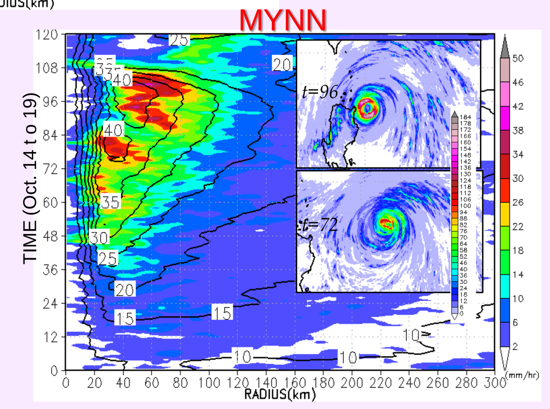


FIG. 2

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3. KINETIC ENERGY TENDENCY: Impacts of increasing Cd and changing the DF PBL scheme to MYNN

The Energetics Formulation

Mean KE

$$KE = \frac{1}{2}\rho\left(v_r^2 + v_\phi^2\right) \quad (1)$$

$\frac{dKE}{dt}$

Momentum equations

$$\frac{dv_r}{dt} = \frac{v_\phi^2}{r} + fv_\phi - \frac{1}{\rho}\frac{\partial p}{\partial r} - F_r \quad (2)$$

$$\frac{dv_\phi}{dt} = -\frac{v_\phi v_r}{r} - fv_r - \frac{1}{\rho r}\frac{\partial p}{\partial \phi} - F_\phi \quad (3)$$

Continuity eqn

$$\frac{\partial KE}{\partial t} + \frac{1}{r}\frac{\partial}{\partial \phi}v_\phi KE + \frac{1}{r}\frac{\partial}{\partial r}rv_r KE = -v_r\frac{\partial p}{\partial r} - \frac{v_\phi}{r}\frac{\partial p}{\partial \phi} - \rho\mathbf{v}\cdot\mathbf{F} \quad (4)$$

Axially symmetric system $\langle A\rangle \equiv \int\int\int_{z_1}^{z_2} A r dz d\phi dr$

$$\frac{\partial}{\partial t}\langle KE\rangle = -2\pi r\int_{z_1}^{z_2} v_r KE dz - \left\langle v_r\frac{\partial \Phi}{\partial r}\right\rangle - \langle \rho\mathbf{v}\cdot\mathbf{F}\rangle, \quad (5)$$

Kinetic Energy Tendency (**KET**) — Energy Flux (**EF**) — Energy Converted from APE (**EC**) — Energy Loss (**EL**)

Balancing KET: Control case

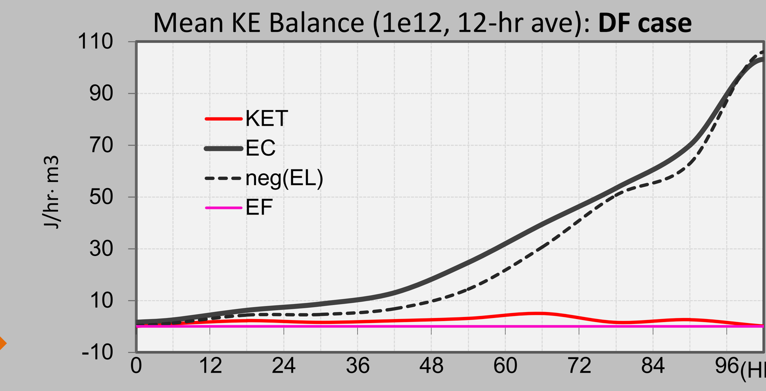


FIG. 3

→ Here, the tendency of the kinetic energy to increase or decrease largely depends on the generation of KE from APE and dissipation due to surface friction, that is

KET α EC + EL

$$\frac{\partial}{\partial t}\langle KE\rangle \approx -\left\langle v_r\frac{\partial \Phi}{\partial r}\right\rangle - \langle \rho\mathbf{v}\cdot\mathbf{F}\rangle \quad (6)$$

In an axisymmetric TC, dynamical EC from APE and EL due to frictional force can be described as a function of the secondary (MSF) and primary (AAM) circulation:

EC (MSF)

$$EC \approx \left\langle v_r\frac{\partial \Phi}{\partial r}\right\rangle = 2\pi\int\frac{1}{\rho}\frac{\partial \Phi}{\partial r}MSF(r,z)dr, \quad (7)$$

(Mass stream fcn) $MSF(r,z) = -r\int_0^z \bar{\rho}\bar{v}_r dz \quad (8)$ (inflow)

EL (AAM)

(F=Frictional Force) (Surface drag coeff.)

$$EL = \iint \mathbf{v}\bullet\mathbf{F}_s\, 2\pi r dr dz \approx \int C_d v_\phi^3 \Delta z\bullet 2\pi r dr, \quad (9)$$

$$\approx \int\left(\frac{\rho\Delta z}{r}v_r\frac{\partial(AAM)}{\partial r} - \tau\right)v_\phi \Delta z\bullet 2\pi r dr$$

(radial and downward momentum flux)

(Absolute Angular Momentum) $AAM \equiv rv_\phi + \frac{1}{2}fr^2$

KE Budget (KE, KET, EC, EL): Sensitivity Experiments

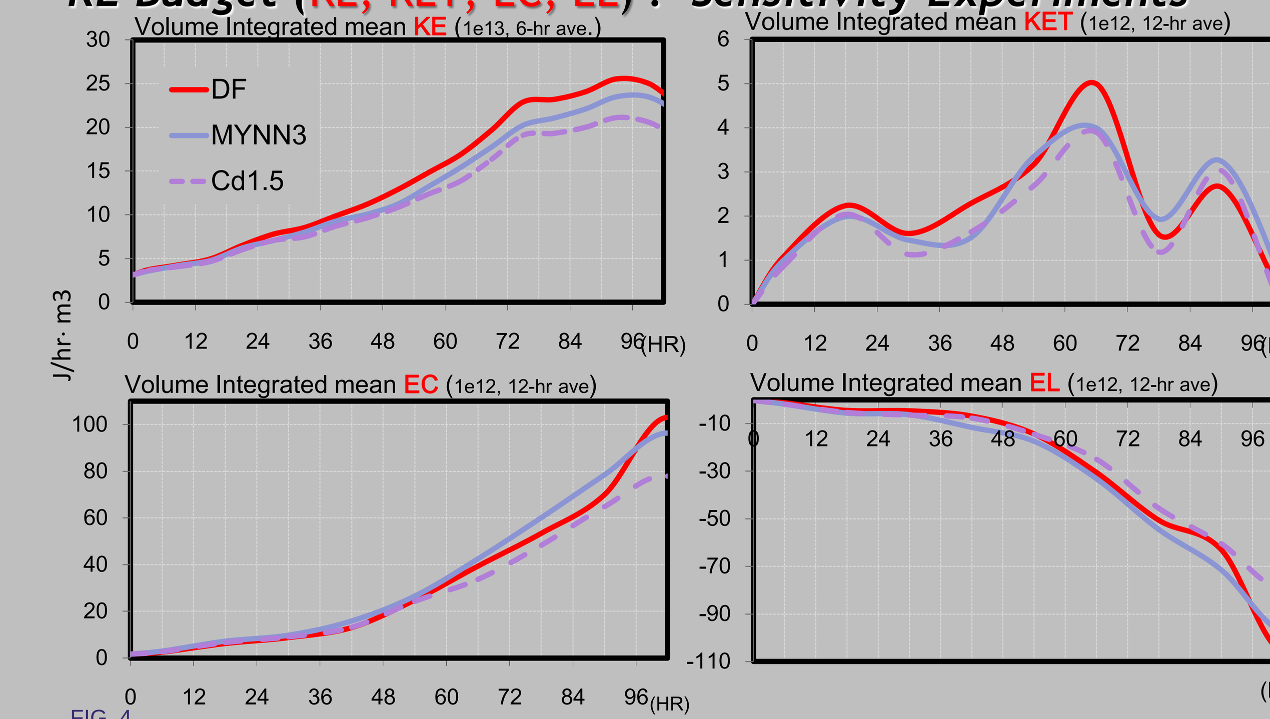


FIG. 4

❑ On the average, the increased in energy gain (EC) for both experiments (CD1.5 and MYYN) is overweight by the increased in energy loss (EL), hence the mean KE and KET is lower compare to the control run (DF case).

4. DISCUSSIONS: *How did EC and EL increased with Cd1.5 and MYYN scheme? Why did the TC weakened despite the increased in energy gain?*

Impacts of Cd1.5 and MYNN to MSF and AAM:

MSF: Secondary Circulation during Early Intensification

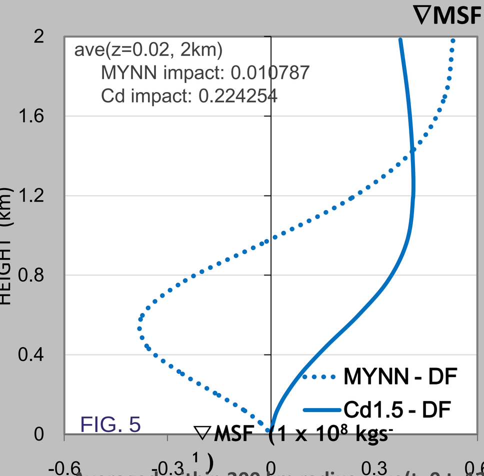


FIG. 5 Averaged within 300 km radius, ave(t=0,t=12)

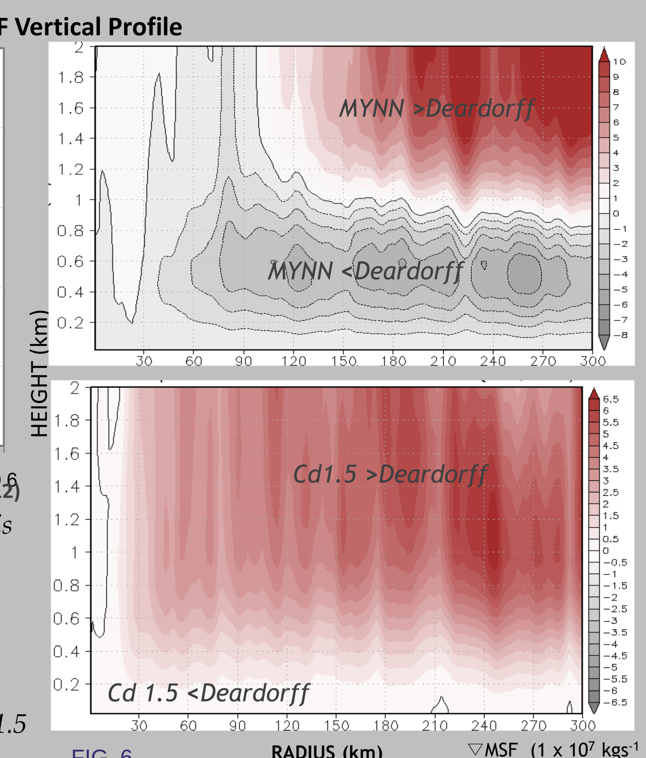


FIG. 6

- ❑ The resulting secondary circulation is stronger with the increased in the surface momentum exchange coefficient → agradient force (Cd1.5).
- ❑ Near the surface the MYNN scheme produces a negative tendency.
- ❑ On the average (z=0.02 to 2km), Cd1.5 and MYNN strengthened the MSF.

Perturbations to wind's vertical structure

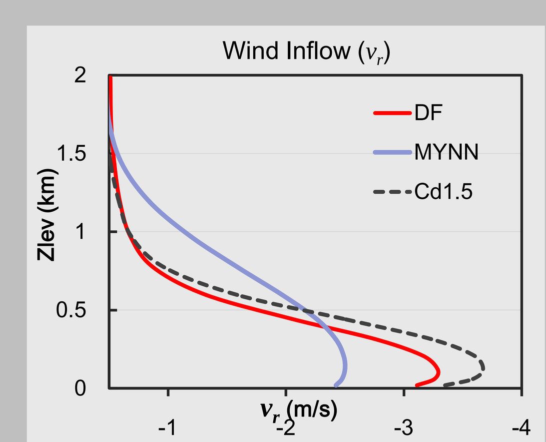
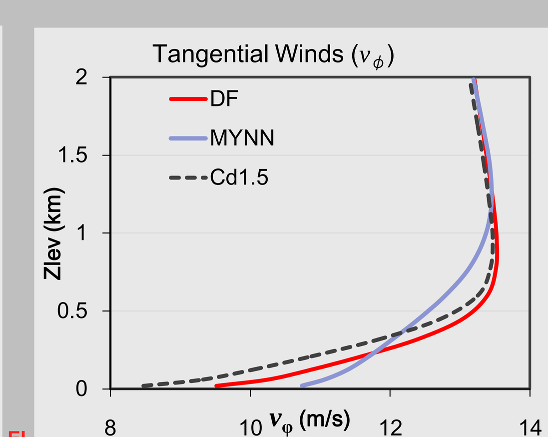


FIG. 7

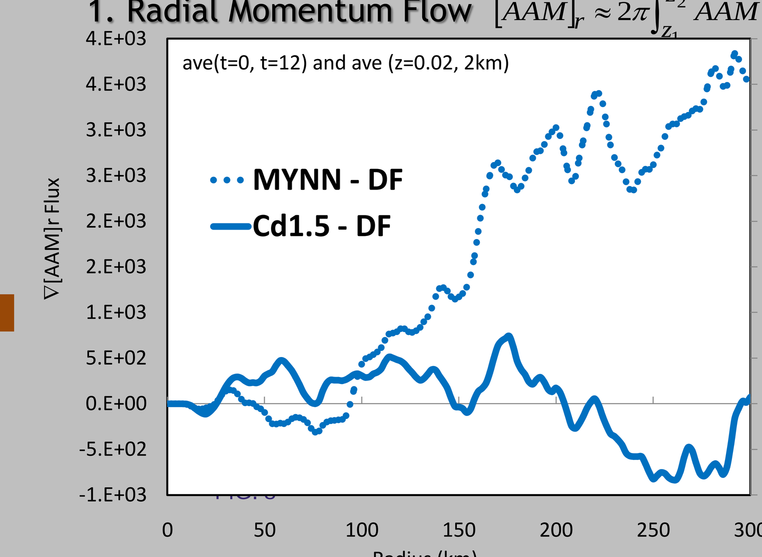


EI ave(t=0, 12) (Averaged within 300 km radius)

- ❑ Near the surface, the resulting v_ϕ increases with MYNN but weakens with Cd1.5 during EI.
- ❑ The resulting inflow v_r, on the other hand, decreases with MYNN but increases with Cd1.5.
- ❑ The reduction of surface cyclonic wind for Cd1.5 case disrupted the gradient wind balance resulting to a stronger inflow of agradient wind (Montgomery and Smith 2010).

AAM: Primary Circulation during Early Intensification

1. Radial Momentum Flow $[AAM]_r \approx 2\pi\int_{z_1}^{z_2} AAM\, v_r r dz$



- ❑ Cd1.5 shows a positive and increasing AAM radial flux towards the eyewall.

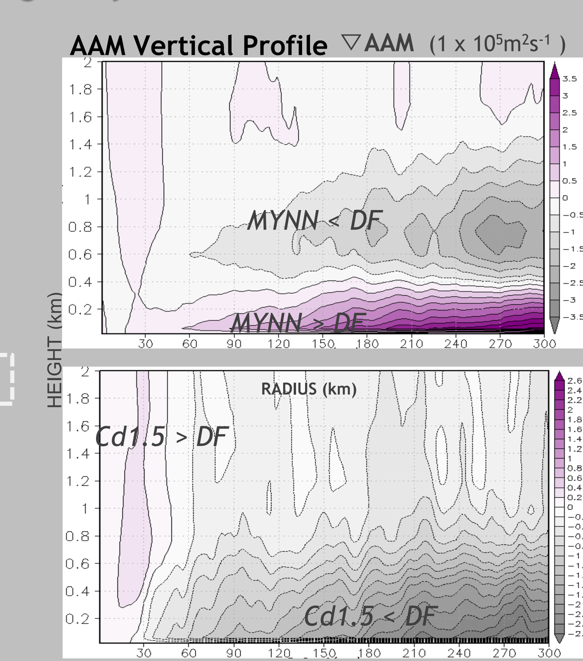


FIG. 9

- ❑ Cd1.5 shows a negative distribution of AAM from the surface but increasing towards the eyewall.

2. Vertical Momentum Flow $[AAM]_z \approx 2\pi\int_{r_1}^{r_2} \rho\tau_{\phi,0} r^2 dr$

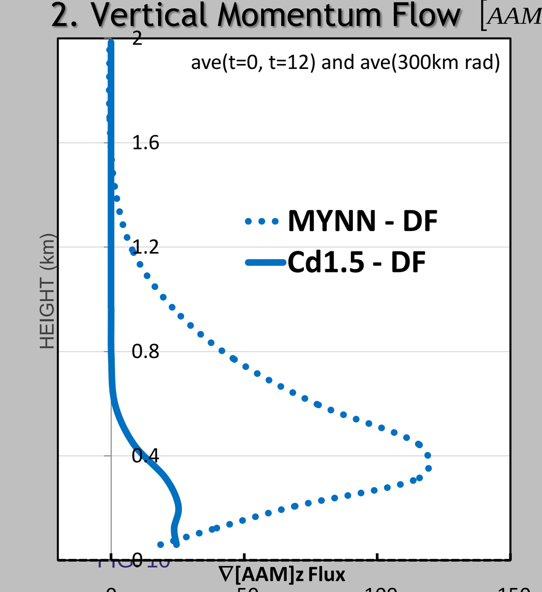
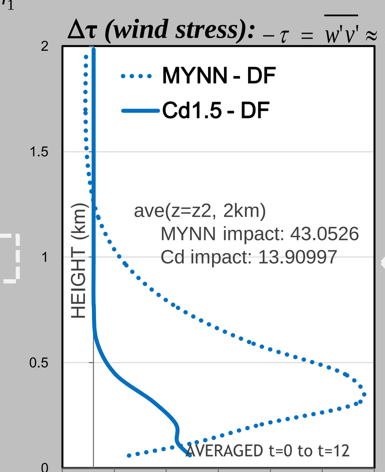


FIG. 10

- ❑ MYYN shows larger increased on the vertical flux of AAM.

Δτ (wind stress): $-\tau = \overline{w'v'} \approx K\frac{\partial v_\phi}{\partial z}$



- ❑ The MYNN produces a larger eddy κ_m resulting to a stronger downward flux than CTL and Cd1.5.
- ❑ The impact of surface drag is relatively negligible compare to MYNN.

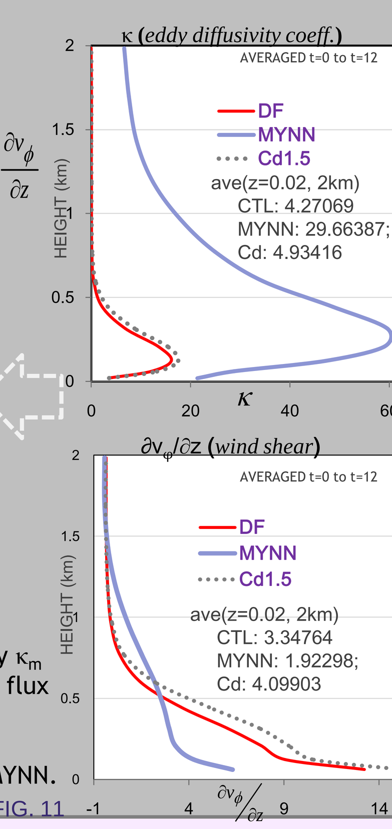


FIG. 11

5. CONCLUSION: KET α EC + EL α *Intensity*

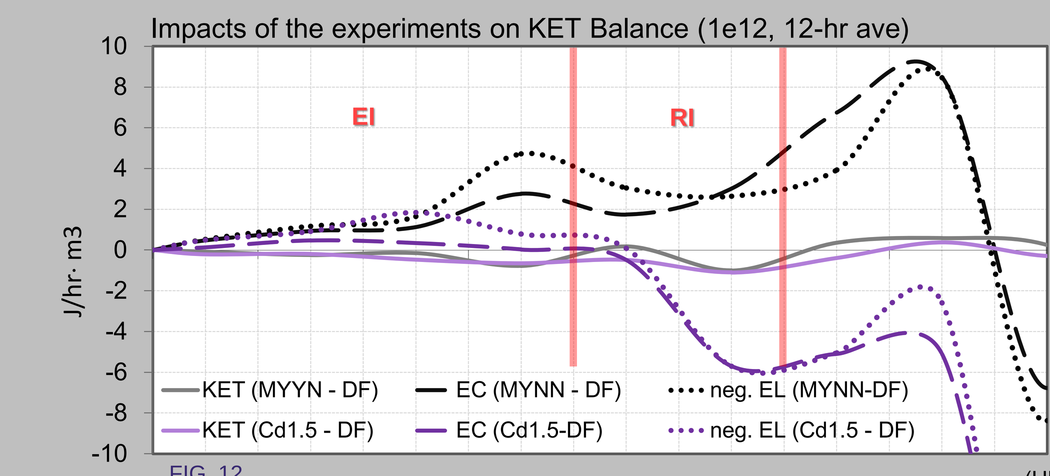


FIG. 12

EI	RI
MYNN: +EL > +EC → neg. impact (-KET) Cd1.5 : +EL > +EC → neg. impact (-KET)	MYNN: + EL > + EC → neg. impact (-KET) Cd1.5 : -EL > -EC → neg. impact (-KET)

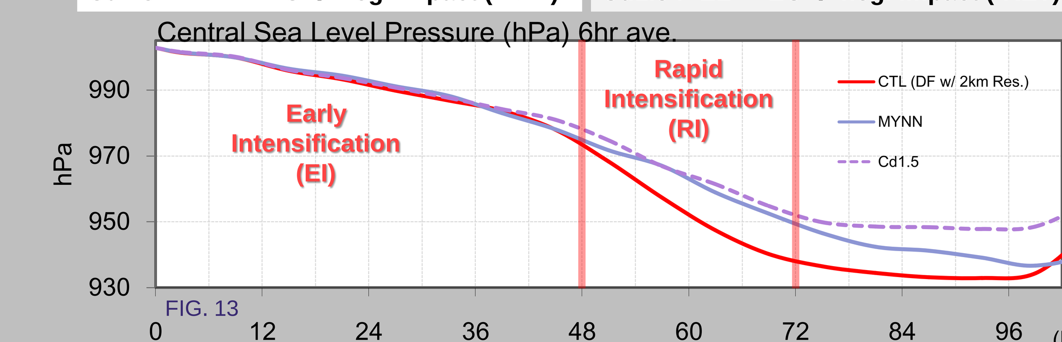


FIG. 13

The KET curves show the impacts of the test cases (MYNN and Cd1.5) with respect to the control run.

- ❑ The experiments show substantial impacts to KE balance by introducing perturbations on the inflow (v_r) and tangential winds (v_ϕ) during EI. Changes on v_r, and hence on MSF, affect EC; while variations on v_ϕ, subsequently on momentum flux, affect EL. In this work, both experiments intensified the volume-integrated MSF which in turn enhanced EC. However, lower energy tendency, and subsequently slower intensification, is observed due to a higher increased in EL. The results suggest that the MYNN scheme overestimate energy loss by simulating a stronger flux of AAM. For the case of Cd1.5, most of the energy loss is a result of an intensified inward momentum flux:

- ❑ MYNN: higher EL ← larger κ → enhanced τ → increased AAM vertical flux [AAM]z → TC Megi's weakening.
- ❑ Cd1.5: higher EL ← increased surface drag Cd and inward AAM flux [AAM]r → TC Megi's weakening.

SUMMARY

Energy Conversion from APE α MSF

$$EC \approx \left\langle v_r\frac{\partial \Phi}{\partial r}\right\rangle = 2\pi\int\frac{1}{\rho}\frac{\partial \Phi}{\partial r}MSF(r,z)dr$$

↑mean axisymmetric secondary circulation MSF → ↑EC → Intensification? (Gradient wind balance)

Energy Loss due to surface friction α AAM

$$EL \approx \int\left(\frac{\rho\Delta z}{r}v_r\frac{\partial(AAM)}{\partial r} - \tau\right)v_\phi \Delta z\bullet 2\pi r dr$$

↑mean axisymmetric primary circulation AAM → ↑EL → Weakening?

↑Mass Stream Function ⇨ ↑Energy Conversion + ↑Energy Loss } ↓KET → Weakening

MYNN: ↑vertical flux of AAM; Cd1.5: ↑ radial flux of AAM; ⇨ ↑Energy Loss