HWRF/GFDL PBL Model and Sensitivity Experiments

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HWRF/GFDL PBL model

- Old operational NCEP GFS PBL scheme (MRF PBL scheme [Hong & Pan 1996; Troen & Mahrt 1986])
- A non-local scheme where a counter-gradient mixing due to large convective eddies is taken into account.
- A surface driven cubical diffusivity profile up to the PBL height is specified.
- Entrainment flux at the PBL top is given implicitly
- A local scheme (Louis et al. 1982) is used for free atmosphere above the PBL.

Heat flux

$$\overline{w'\theta'} = -K_h\left(\frac{\partial\theta}{\partial z} - \gamma_h\right)$$

$$K_m = \kappa w_s z\left(1 - \frac{z}{h}\right)^2$$

$$K_h = \mathrm{Pr}^{-1} K_m$$

$$\gamma_h = 7.8\frac{\overline{(w'\theta')_0}}{w_s h}$$

Non-local counter-gradient mixing term by large eddies

PBL height

$$h = Rb_{cr}\,\frac{\theta_{va}\left|U(h)\right|^2}{g(\theta_v(h)-\theta_s)}$$

$$\theta_s = \theta_{va} + 7.8\frac{\overline{(w'\theta')_0}}{w_s} \qquad\qquad w_s = \frac{u_*}{\phi_m}$$

Rb_{cr} : critical bulk Richardson number

h: height of zero heat flux, not height of minimum heat flux.

Vertical diffusivity for free atmosphere

$$K_{m,t} = l^2 f_{m,t}(Rig)\left|\frac{\partial U}{\partial Z}\right|$$

$$\frac{1}{l} = \frac{1}{kz} + \frac{1}{l_0}$$

l_0 : asymptotic length scale

Current HWRF/GFDL model – 150 m
Current GFS model - 150 m (unstable)
30 m (stable)

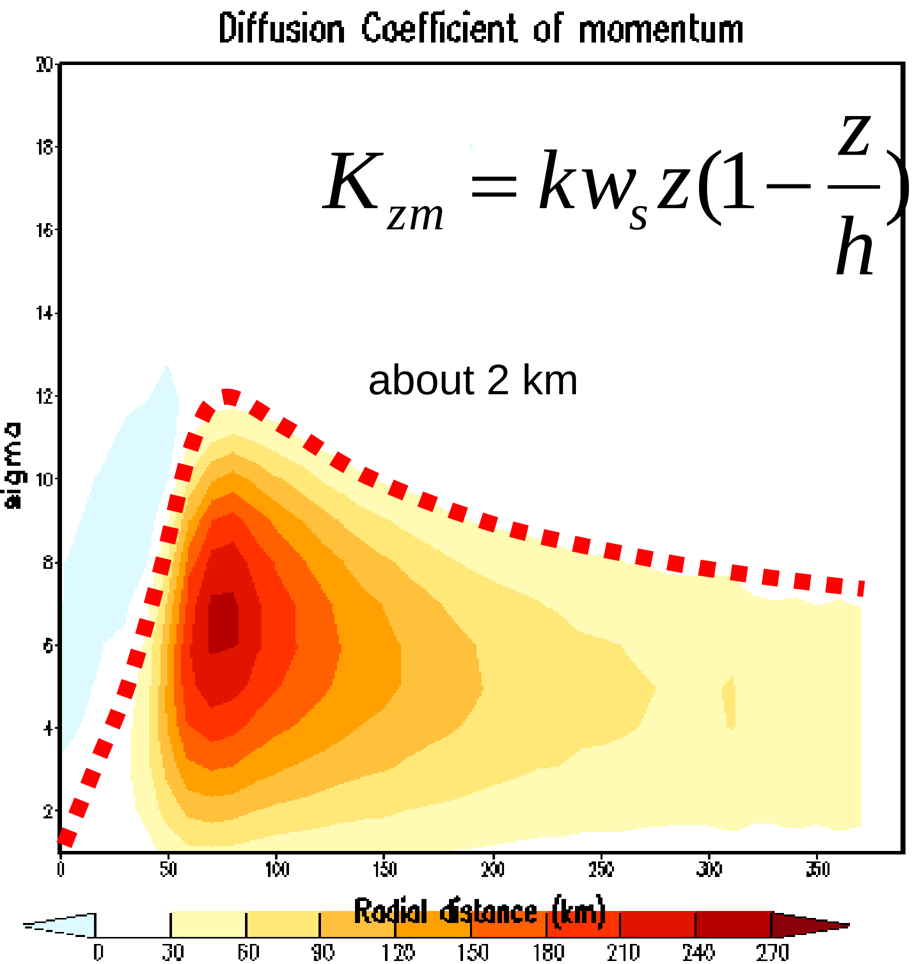
Sensitivity experiments for tunable parameters

	Localization	Critical Bulk Richardson Number	Mixing length (l_0)
CTL (current HWRF PBL scheme)	NON-local diffusion	0.5	150
EXP1	NON-local diffusion	0.25	150
EXP2	NON-local diffusion	0.5	30
EXP3 (current GFS PBL scheme)	NON-local diffusion	0.25	30
EXP4	Local diffusion	-	30

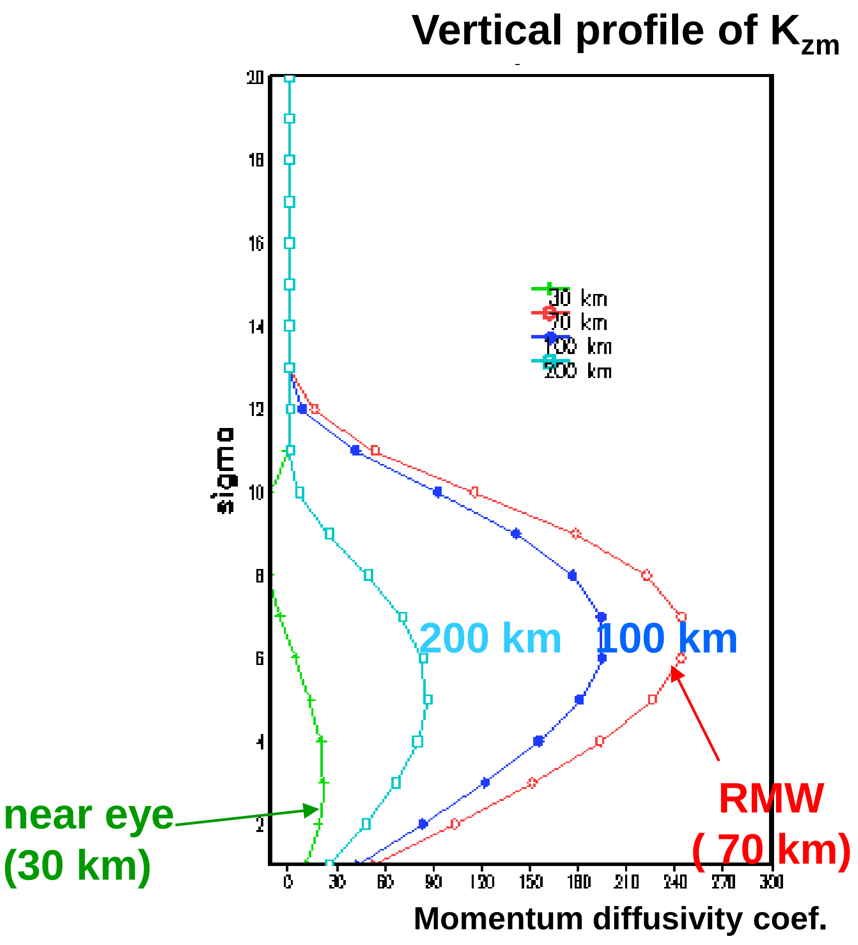
Local diffusion scheme for free atmosphere is applied through all levels

Momentum diffusivity coefficient

(CTL, 48 hour forecast, azimuthally averaged)



$$K_{zm} = kw_s z(1 - \frac{z}{h})^2$$

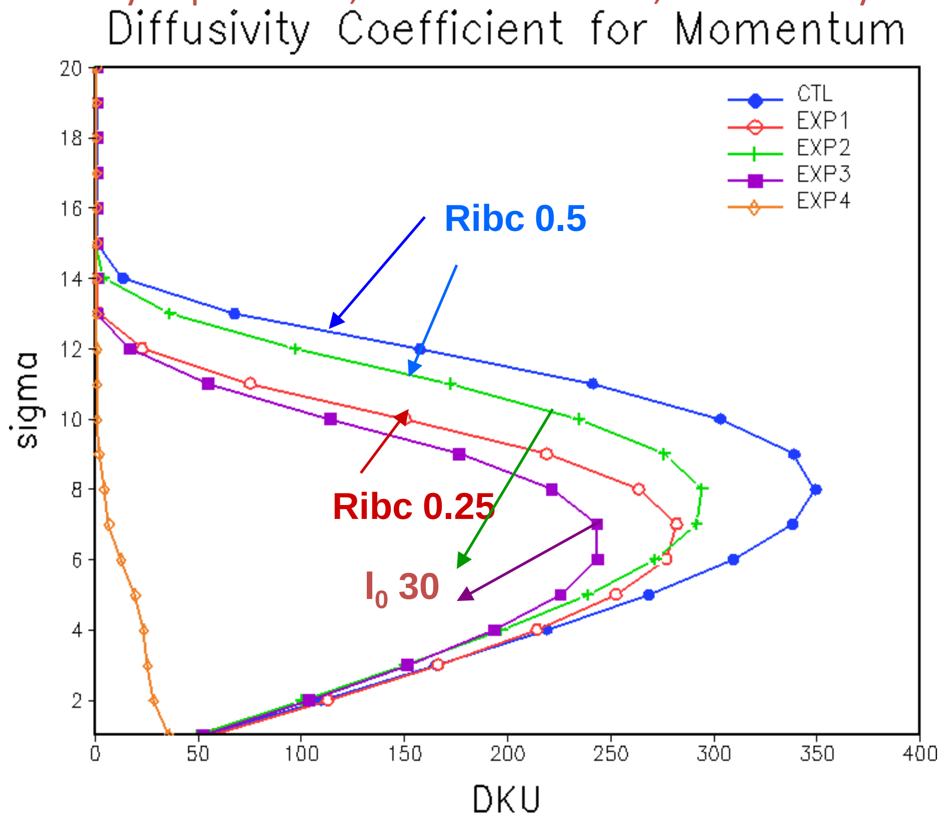


- In the hurricane environment (near neutral), **diffusivity and PBL height are proportional to wind speed**

Vertical profile of momentum diffusivity coefficient at RMW

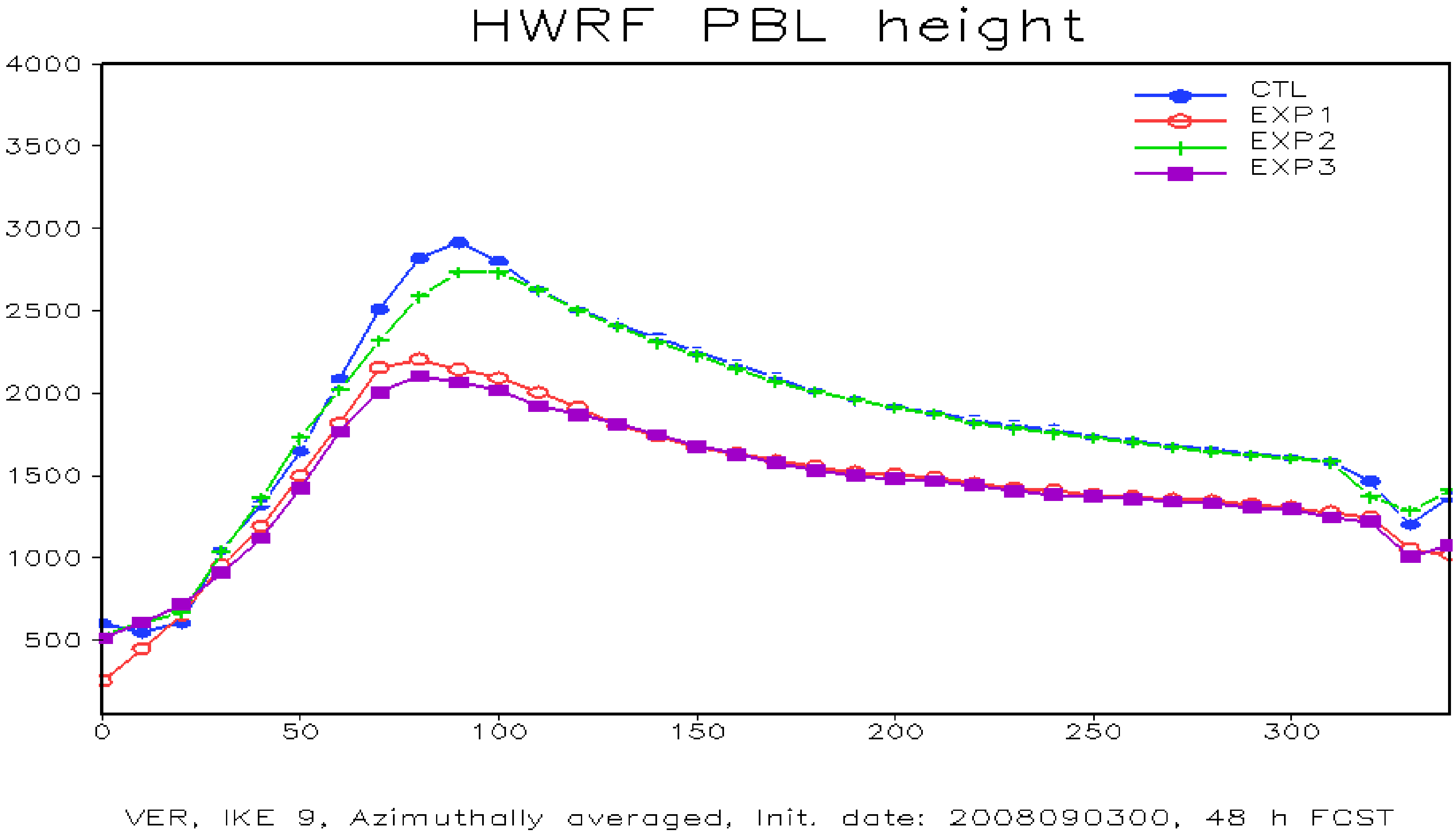
(Radius of Maximum wind)

(sensitivity experiment, 48 hour forecast, azimuthally averaged)



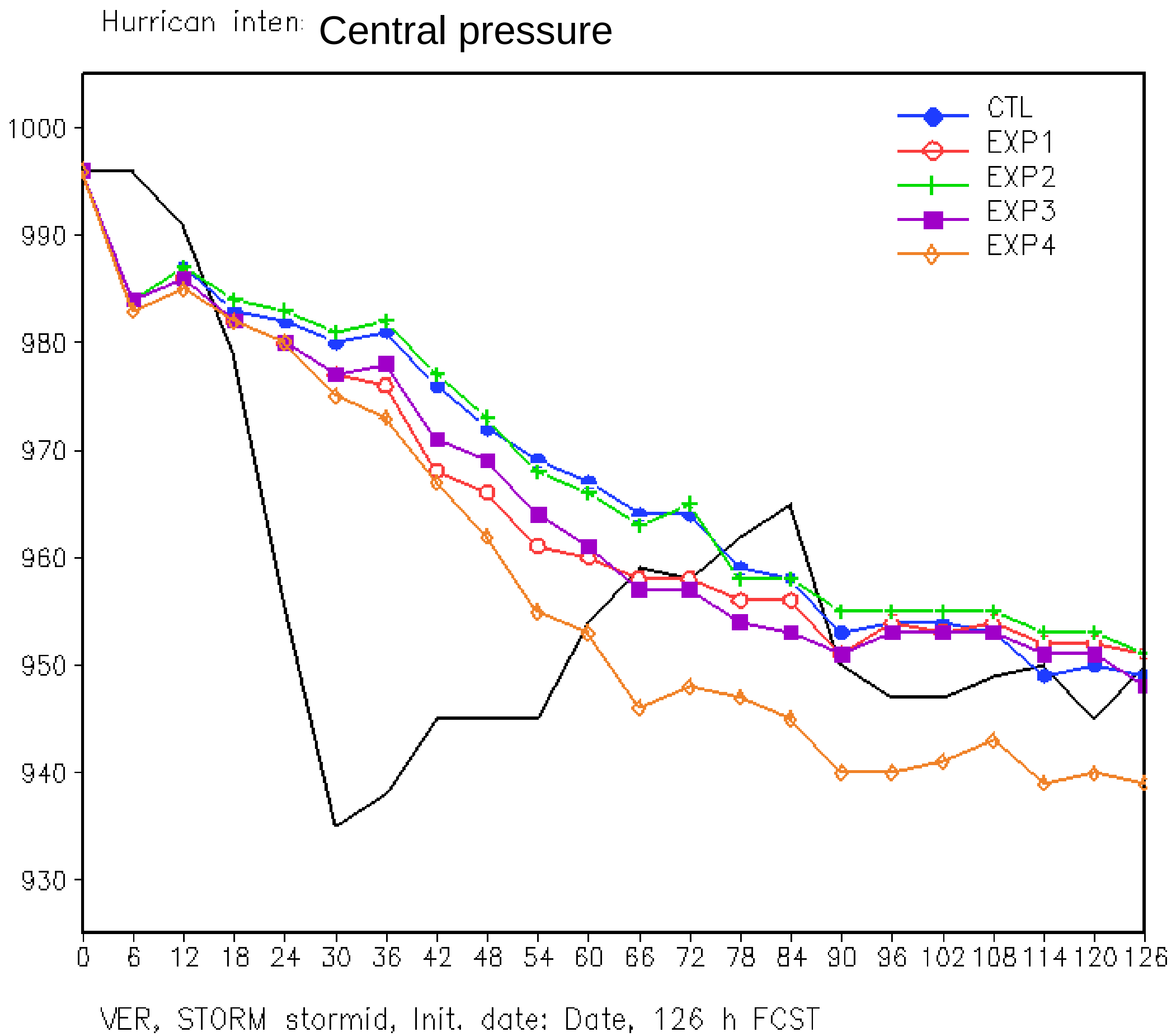
- Smaller RiBc(e.g. RiBc = 0.25) makes the PBL height lower and the diffusivity weaker (exp1& exp3) .

- Smaller mixing length (e.g. l_0=30 m) also makes the diffusivity weaker (exp2 & exp3) but not as much as smaller RiBc .

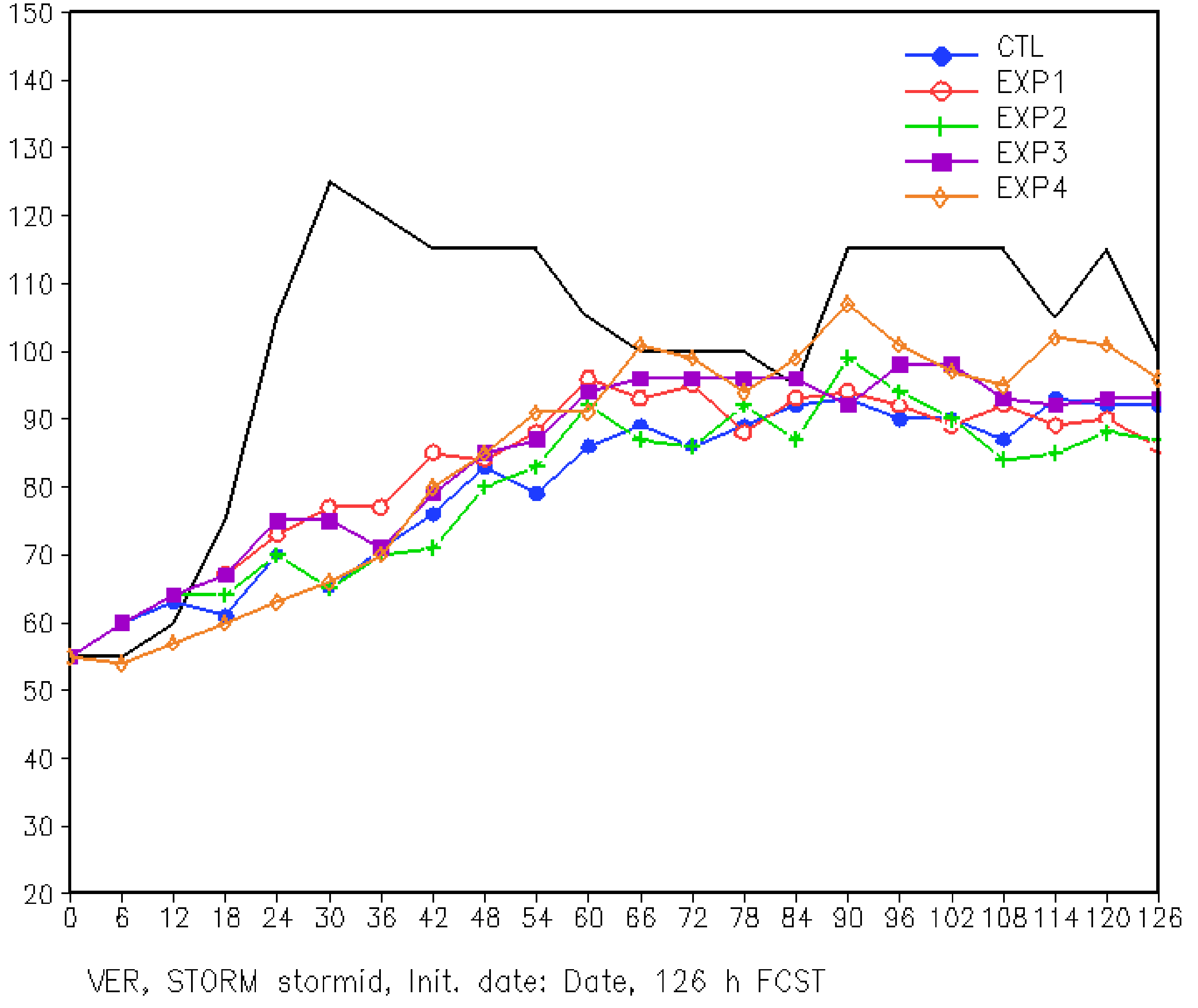


- Smaller RiBc(e.g. RiBc = 0.25) makes the PBL height lower (exp1& exp3) .
- Smaller mixing length (e.g. l_0=30 m) also makes the PBL height low but only slightly (exp2 & exp3) .

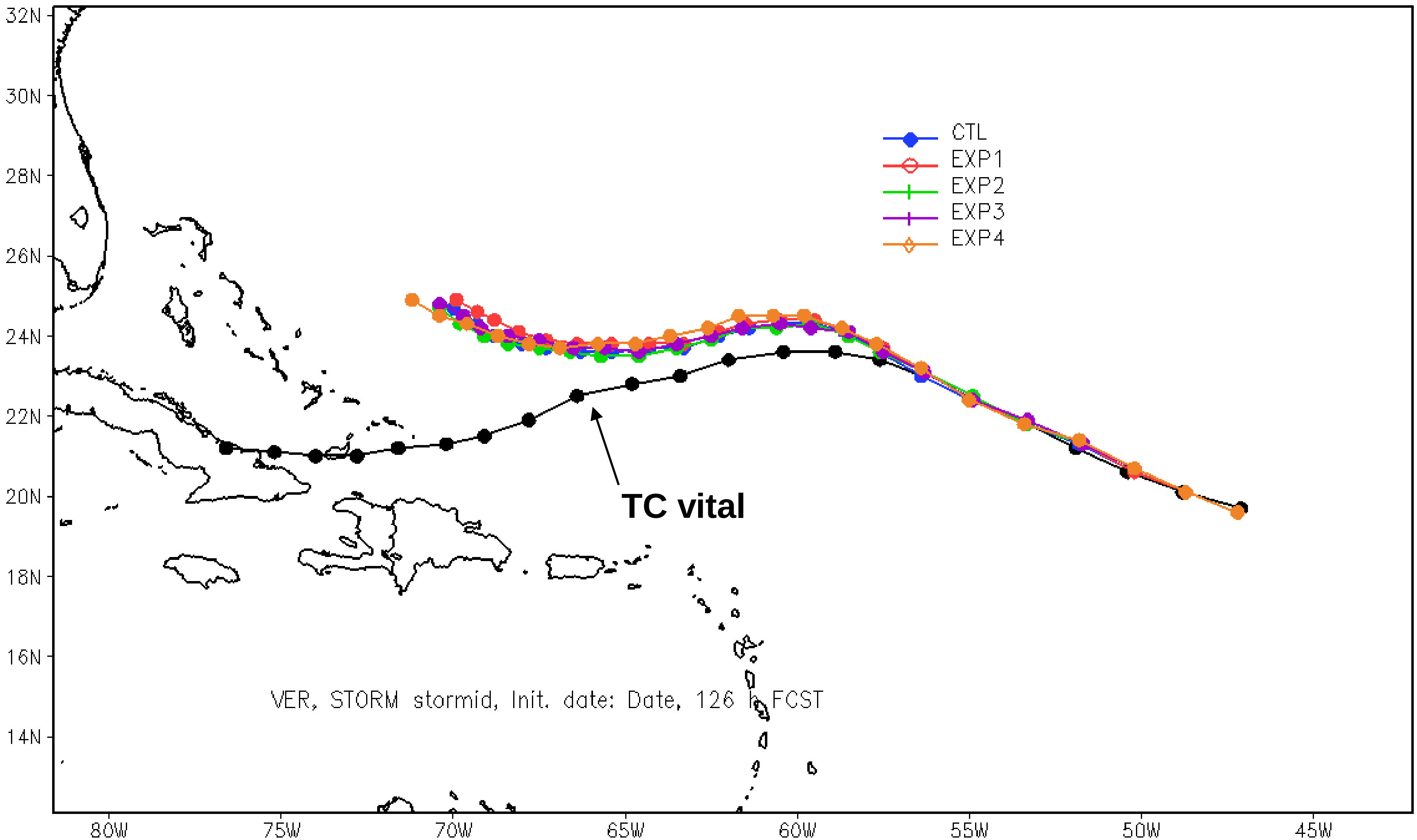
Central pressure



Maximum 10m wind



Hurricane WRF track



Experiment summary

- In the hurricane environment (near neutral), diffusivity and PBL height are proportional to wind speed.
- Smaller RiB_c (e.g. RiB_c=0.25) makes the PBL height lower and the diffusivity weaker, and as a result, hurricane stronger.
- The effect of mixing length in free atmosphere on hurricane intensity is very small.
- The local PBL scheme which has weakest diffusivity gives rise to the strongest hurricane intensity, especially in terms of central pressure.

Critical reports for the MRF (HWRF/GFDL) PBL scheme from literature

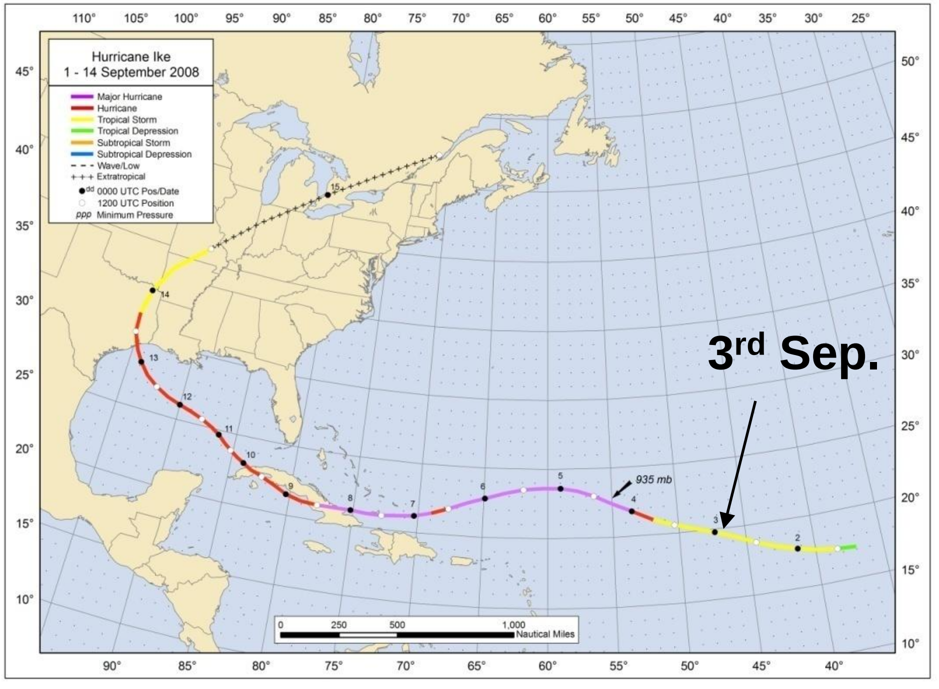
- Too high PBL height
- Too much mixing
- Too weak low level Jet
- Too early development of the PBL in the morning

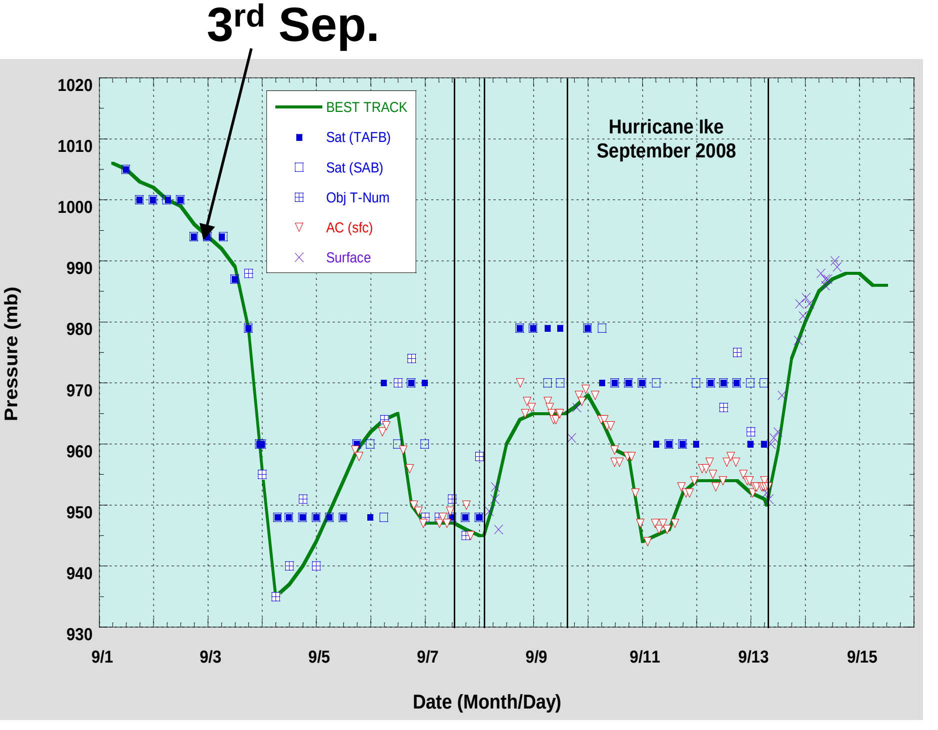
Potential improvements for the HWRF/GFDL PBL model

- Reduce RiBc and mixing length in free atmosphere
- Use local scheme for the stable boundary layer
- These modifications have been already implemented into the GFS (2010) and showed improvements in forecast skill
- Need a detailed observation (and LES experiment) for investigating the PBL turbulence structure in hurricane environment so that we can tune the model parameters

Case (single)

- IKE (2008)
- Initial time : 3rd Sep. 2008





Analysis of control experiment

(CTL, 48 hour forecast , azimuthally averaged)