Evaluation of the HWRF Model via Comparing with the ARW Model

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Purpose of this study:

Investigate the HWRF model's asymptotic behavior in idealized tropical cyclone intensification simulations and its sensitivity to model physics.

Motivation

The asymptotic characteristics of idealized tropical cyclone intensification, as simulated beyond 3+ days by a numerical weather prediction model, can provide useful information about the model's behavior and performance.

Assumption of Asymptotic Behavior

The simulated topical cyclone will reach a quasi-steady state in a quiescent environment:

No significant and progressive variation in the intensity and the radius of maximum wind

Model Experiment Setup

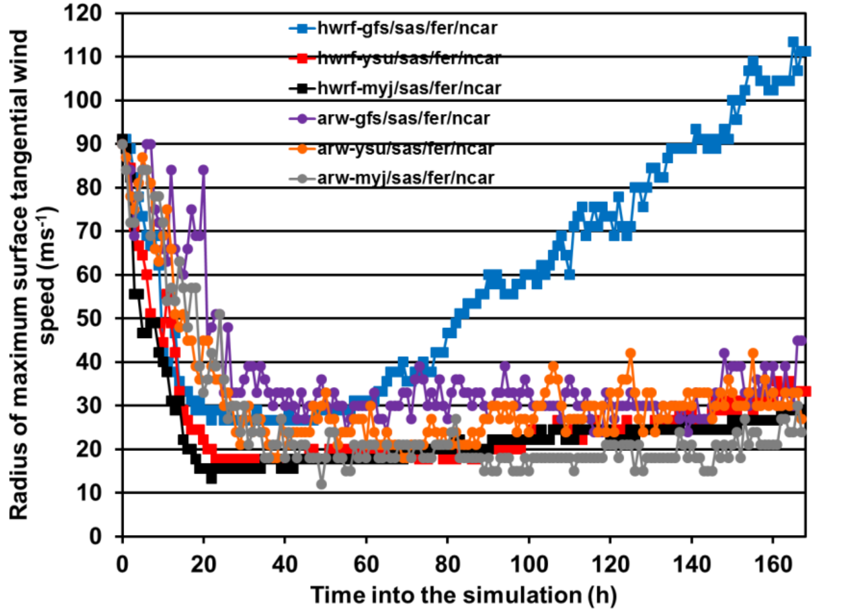
Both the HWRF and ARW models are initialized with a weak axisymmetric vortex disturbance in an idealized tropical environment that is favorable for the vortex disturbance to develop into a hurricane. The initial mass and wind fields associated with the weak vortex disturbance are obtained by solving the nonlinear balance equation for the given wind distributions of the initial vortex (Wang 1995, MWR), and the prescribed background thermal sounding and winds.

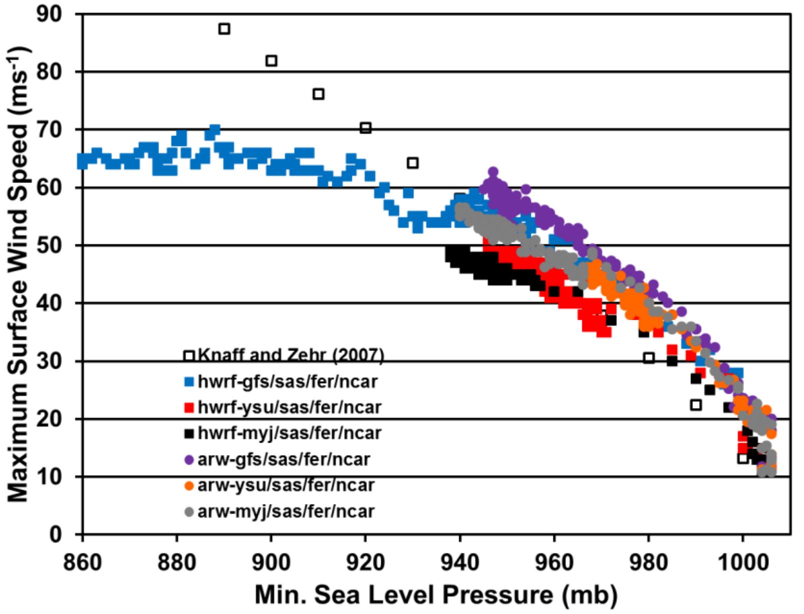
- *f*-plane located at 12.5^{o}N
- The prescribed axisymmetric vortex:
  — maximum surface tangential wind: 15 ms^{-1}
  — radius of surface maximum wind: 90 km
- Quiescent environment thermally corresponding to the Jordan sounding with a constant sea surface temperature of 29 ^{o}C
- Both models are run with 2 domains, a 9 km outer domain with a moving 3-km nest and 43 vertical levels

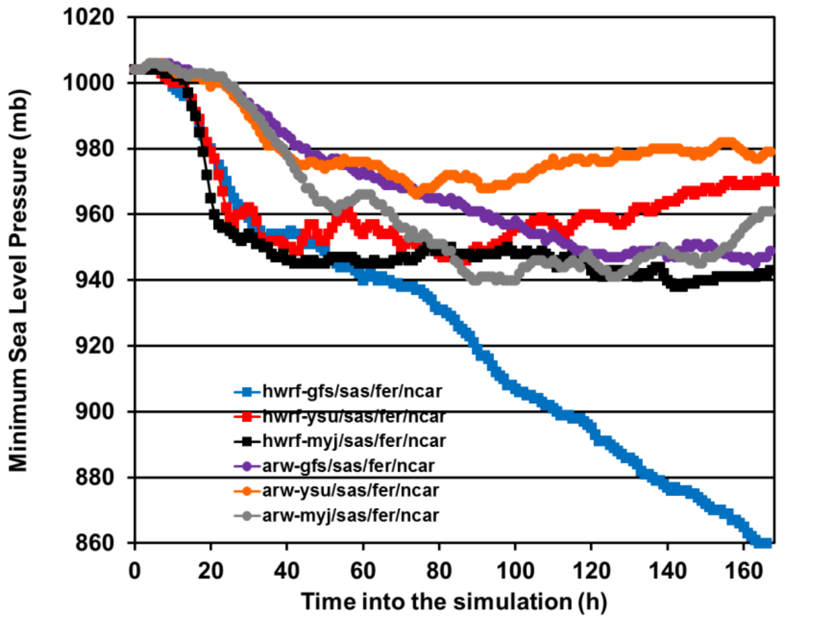
Physics Configurations

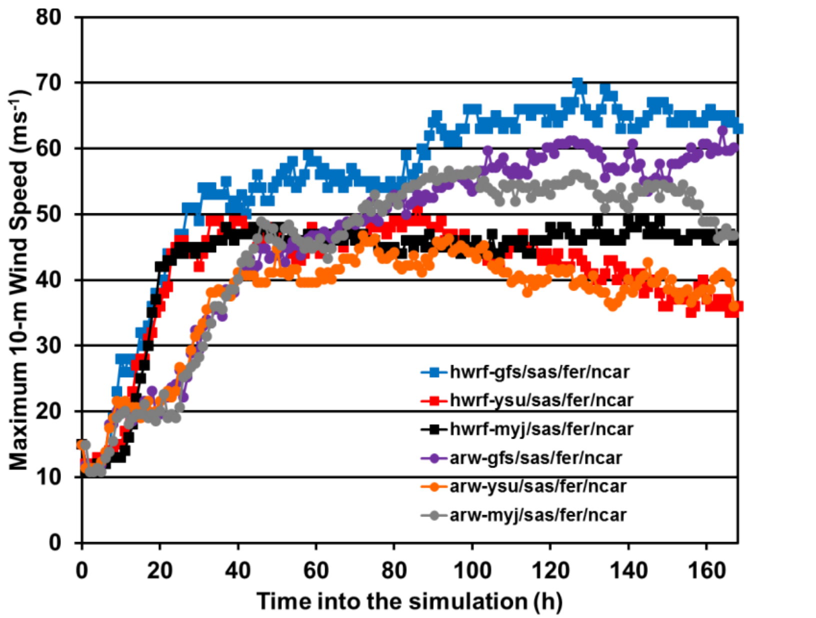
Experiment Name	Marker in PWR Plots	Dynamical core	Boundary Layer Scheme	Convective parameterization scheme (D1/D2)	Radiation Scheme	Microphysics scheme
HWRF GFS/SAS/FER/NCAR	Blue squares	HWRF	GFS	SAS/SAS	NCAR	Ferrier
HWRF YSU/SAS/FER/NCAR	Red squares	HWRF	YSU	SAS/SAS	NCAR	Ferrier
HWRF MYJ/SAS/FER/NCAR	Black squares	HWRF	MYJ	SAS/SAS	NCAR	Ferrier
HWRF GFS/SAS/WSM6/NCAR	Green squares	HWRF	GFS	SAS/SAS	NCAR	WSM6
HWRF YSU/SAS/WSM6/NCAR	Light blue squares	HWRF	YSU	SAS/SAS	NCAR	WSM6
ARW GFS/SAS/FER/NCAR	Purple circles	ARW	GFS	SAS/SAS	NCAR	Ferrier
ARW YSU/SAS/FER/NCAR	Orange circles	ARW	YSU	SAS/SAS	NCAR	Ferrier
ARW MYJ/SAS/FER/NCAR	Gray circles	ARW	MYJ	SAS/SAS	NCAR	Ferrier
ARW GFS/SAS/WSM6/NCAR	Magenta circles	ARW	GFS	SAS/SAS	NCAR	WSM 6
ARW YSU/SAS/WSM6/NCAR	Brown circles	ARW	YSU	SAS/SAS	NCAR	WSM6

Sensitivity to Boundary Layer Parameterization Schemes



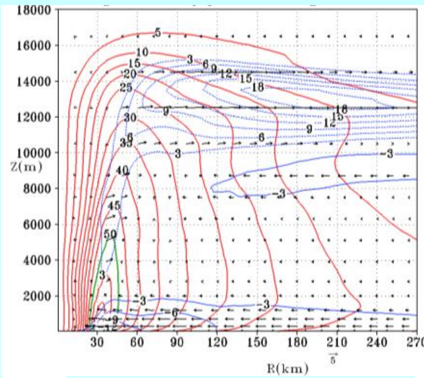




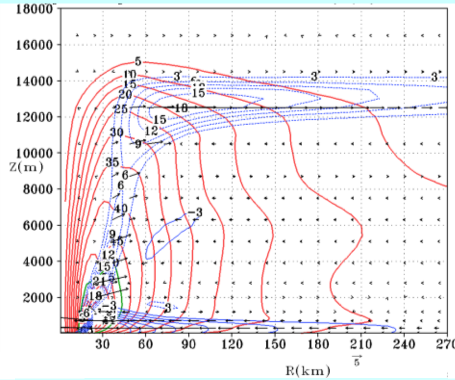


Azimuthally averaged tangential (red contours) and radial (blue contours, solid= incoming radial flow, dashed=outgoing radial flow) wind speed (ms^{-1}) along with circulation vectors averaged over the mature stage of the storm (96-108 hours). The green contour is the 50 ms^{-1} tangential wind speed contour.

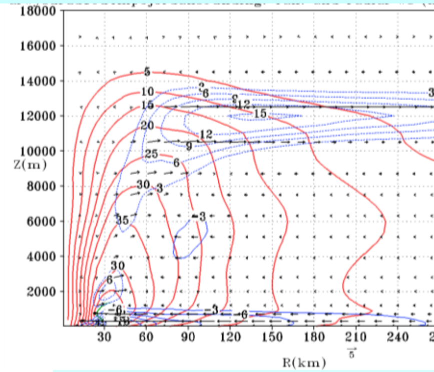
ARW-GFS/SAS/FER/NCAR



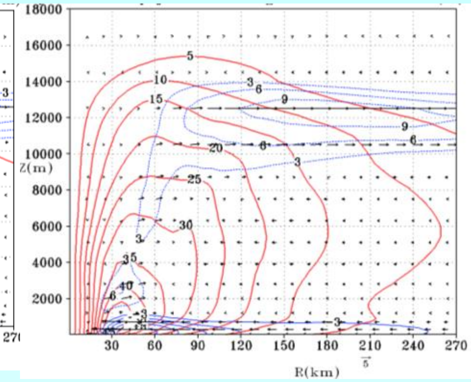
ARW-MYJ/SAS/FER/NCAR



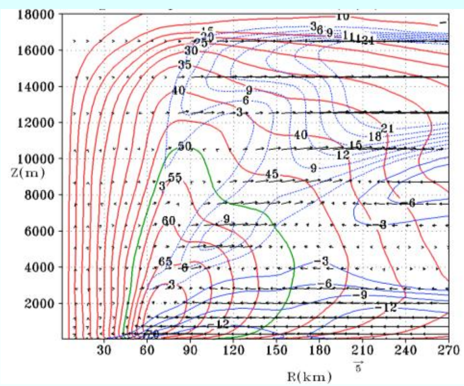
ARW-YSU/SAS/FER/NCAR



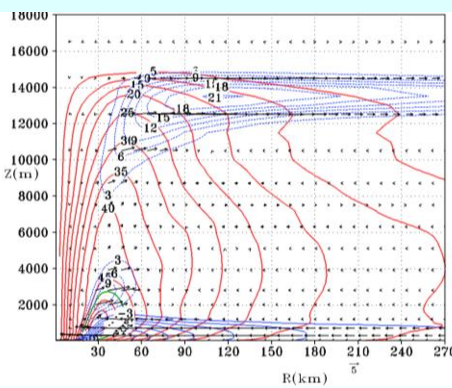
ARW-YSU/SAS/WSM6/NCAR



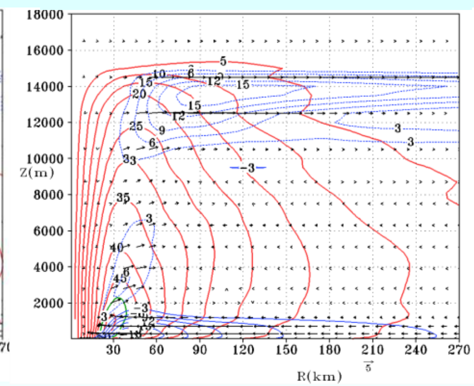
HWRF-GFS/SAS/FER/NCAR



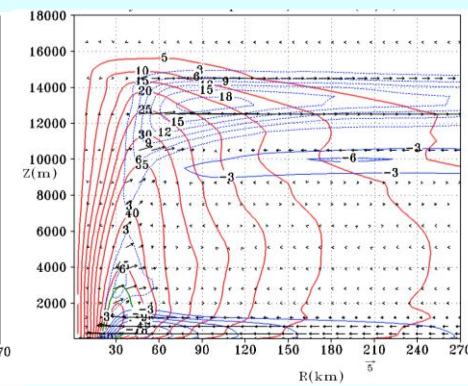
HWRF-MYJ/SAS/FER/NCAR



HWRF-YSU/SAS/FER/NCAR



HWRF-YSU/SAS/WSM6/NCAR



It is not just all about parameterized physics modules…

The model's components of "dynamics", such as horizontal and divergence Damping, are part of the physics governing the intensification!

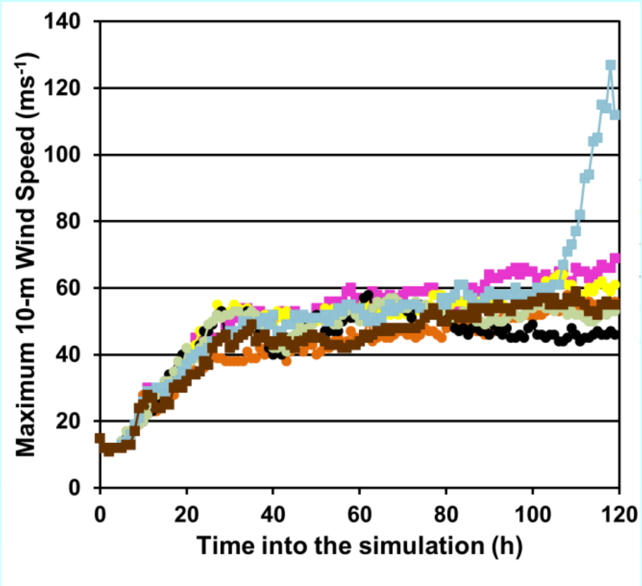
There is a need to investigate the sensitivity of the HWRF-simulated TC intensification to the changes in the horizontal and vertical diffusion and the divergence damping in the HWRF model.

Sensitivity to Horizontal Diffusion and Divergence Damping

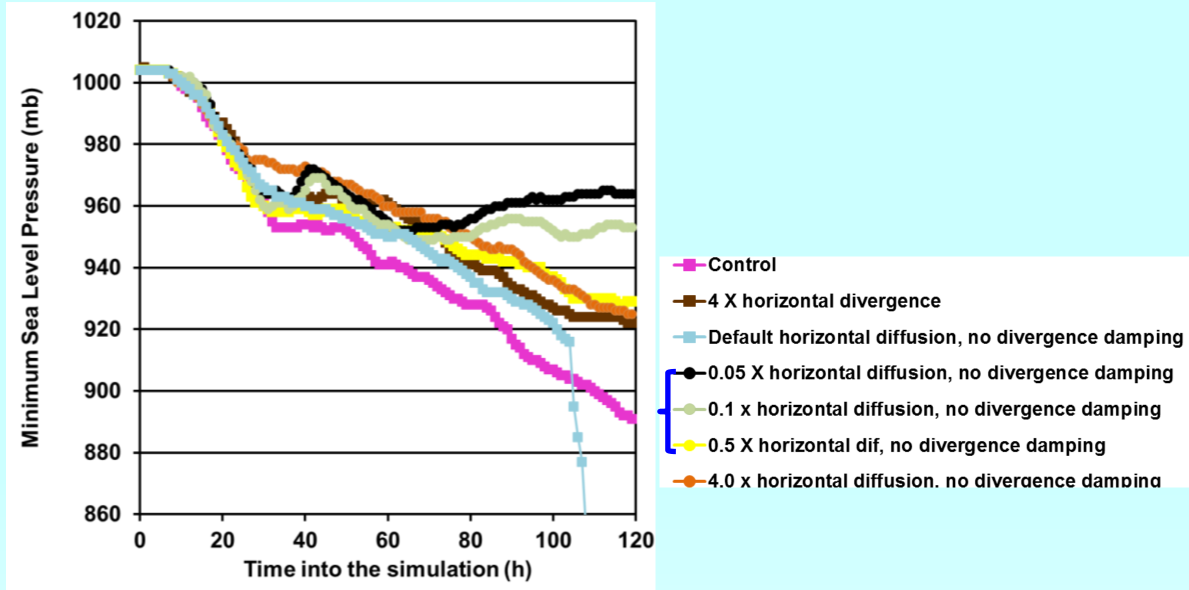
All experiments used GFS BL scheme, SAS convection scheme, Ferrier microphysics scheme and NCAR radiation schemes (RRTM long wave, Dudhia shortwave)

Exp. Name	Horizontal Diffusion	Divergence Damping
Control (magenta squares)	Default	Yes
4X horizontal diffusion (brown squares)	4.0*Default	Yes
Default horizontal diffusion, no divergence damping (aqua circles)	Default	No
0.1 X horizontal diffusion, no divergence damping (black circles)	0.05*Default	No
0.1 X horizontal diffusion, no divergence damping (light green circles)	0.01*Default	No
0.5 X horizontal diffusion, no divergence damping (yellow circles)	0.5*Default	No
4 X horizontal diffusion, no divergence damping (orange circles)	4*Default	No

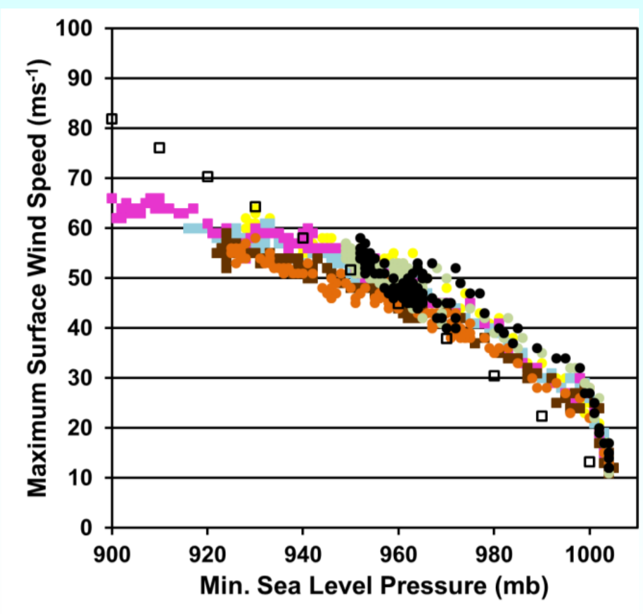
Maximum 10-m wind speed



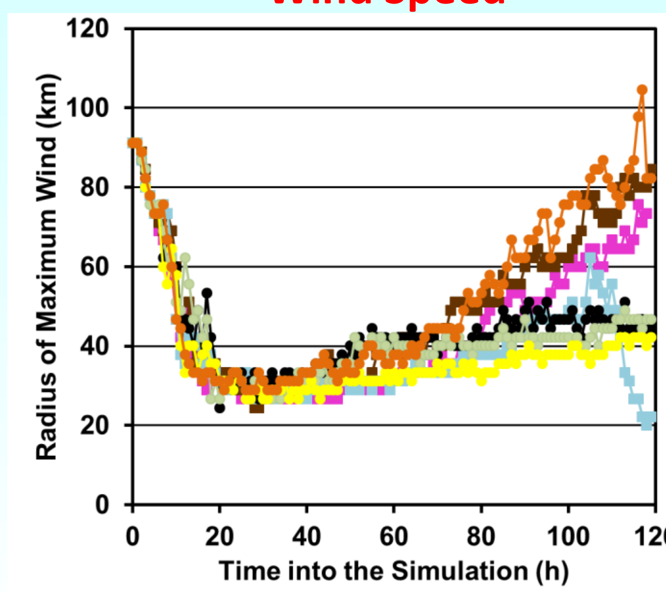
Minimum Sea Level Pressure



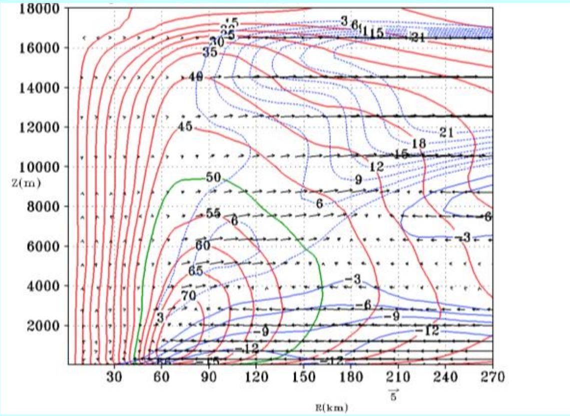
Pressure-Wind Relationship



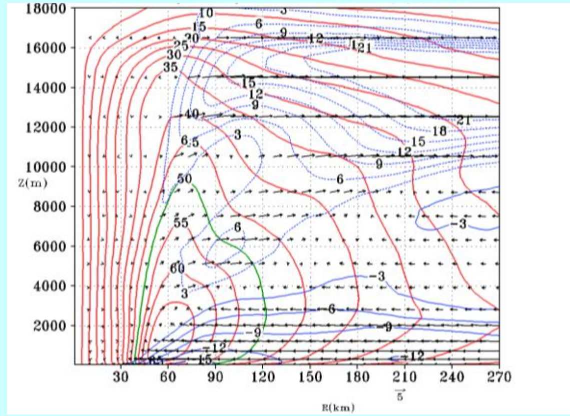
Radius of Maximum Tangential Surface Wind Speed



Control

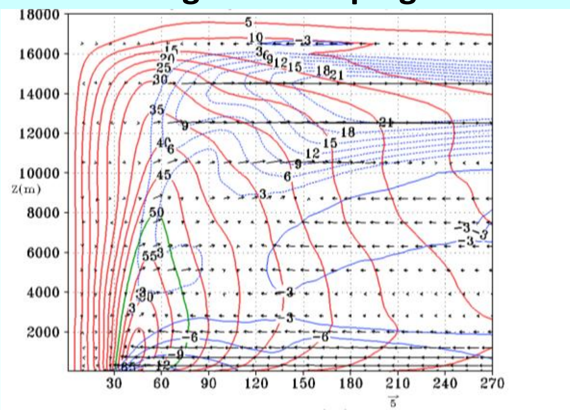


Default horizontal diffusion, no divergence damping

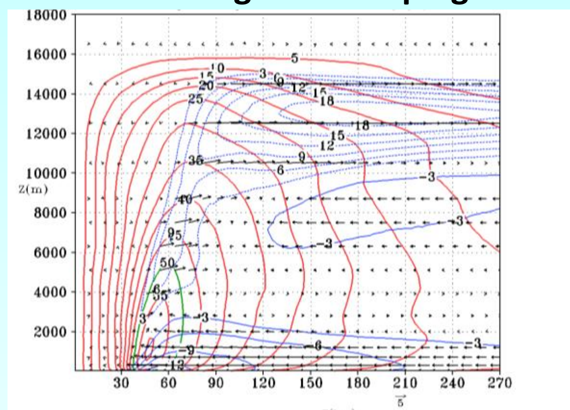


12-hour (96-108 hrs) azimuthally averaged tangential wind speed (red contours), radial wind speed (blue contours) and circulation vectors

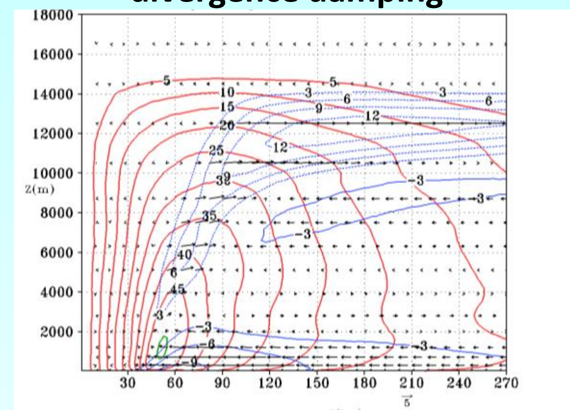
0.5 X horizontal diffusion, no divergence damping



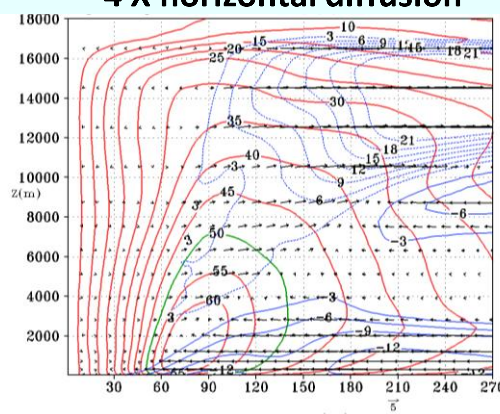
0.1 X horizontal diffusion, no divergence damping



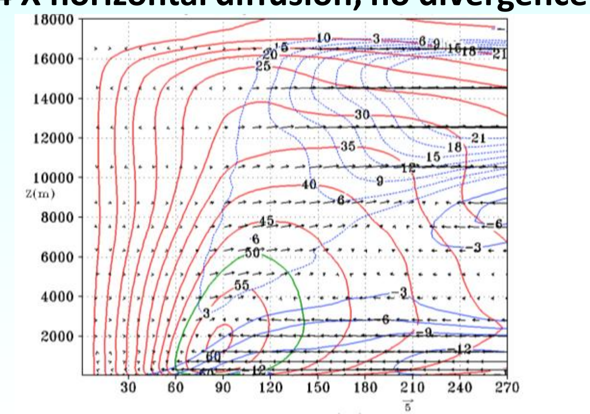
0.05 X horizontal diffusion, divergence damping



4 X horizontal diffusion



4 X horizontal diffusion, no divergence damping



Main Conclusions

1. Judging from the asymptotic behavior of the two models, the MYJ BL scheme is the best choice for both models, while the GFS BL scheme is the worst.

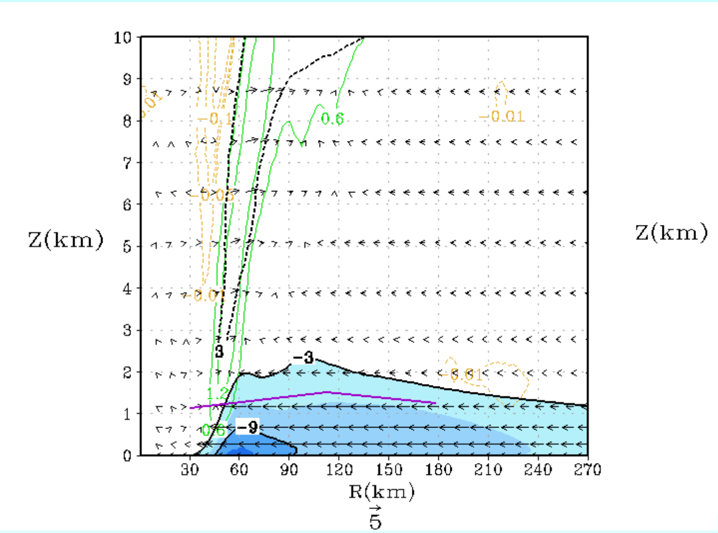
2. The GFS BL scheme produces a BL inflow that is significantly deeper than both the MYJ and the YSU BL schemes.

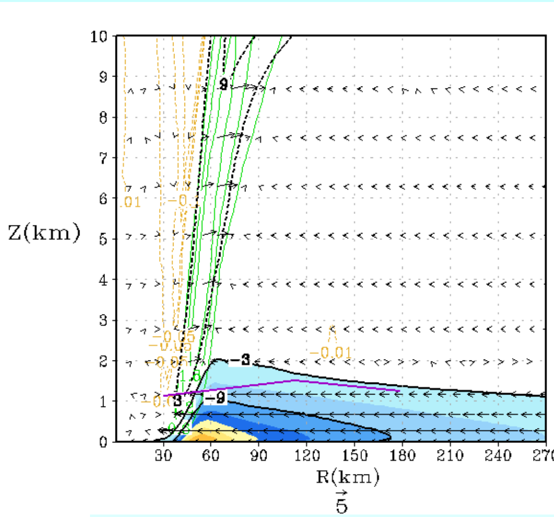
3. Both models are more sensitive to changes in the BL schemes than to the microphysics schemes.

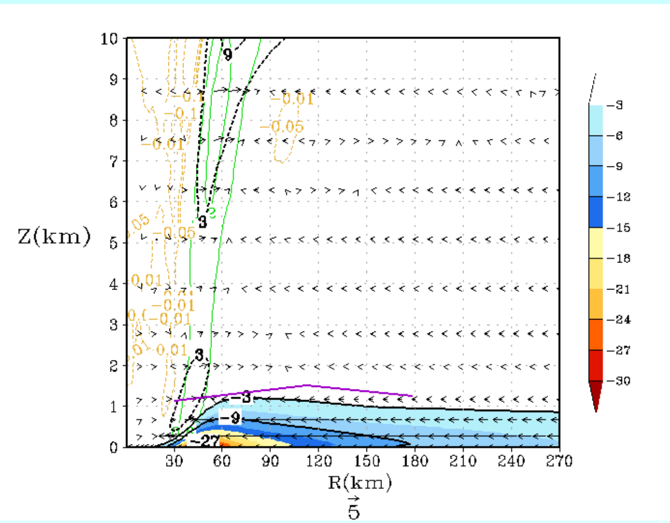
4. The conventional intensity metrics (i.e., the minimum sea-level pressure and maximum surface winds) do not reveal the sensitivity as well as the azimuthally averaged structural metrics, in particular with respect to the sensitivity to microphysics.

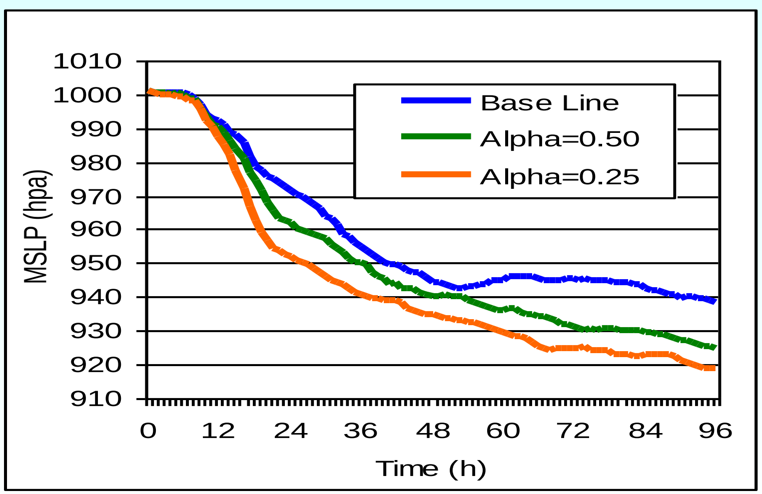
Influence of Vertical Diffusion on Structure and Intensity Evolution

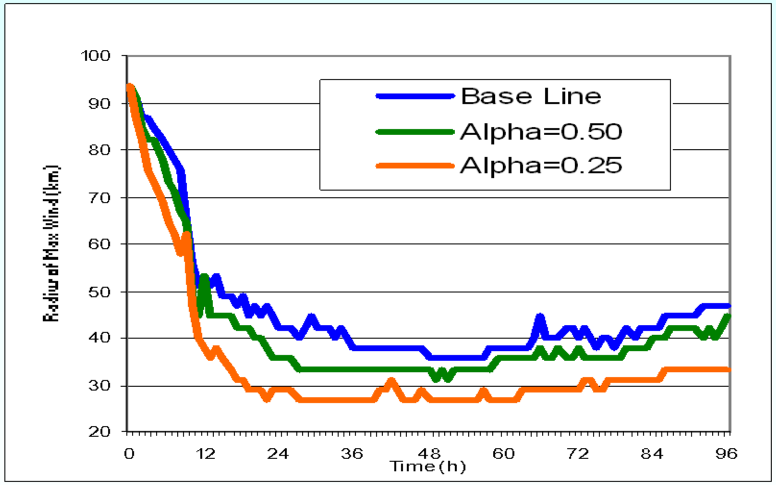
<u>Original Km in HWRF (baseline)</u> <u>Km reduced 50% (alpha=0.5)</u> <u>Km reduced 75% (alpha=0.25)</u>







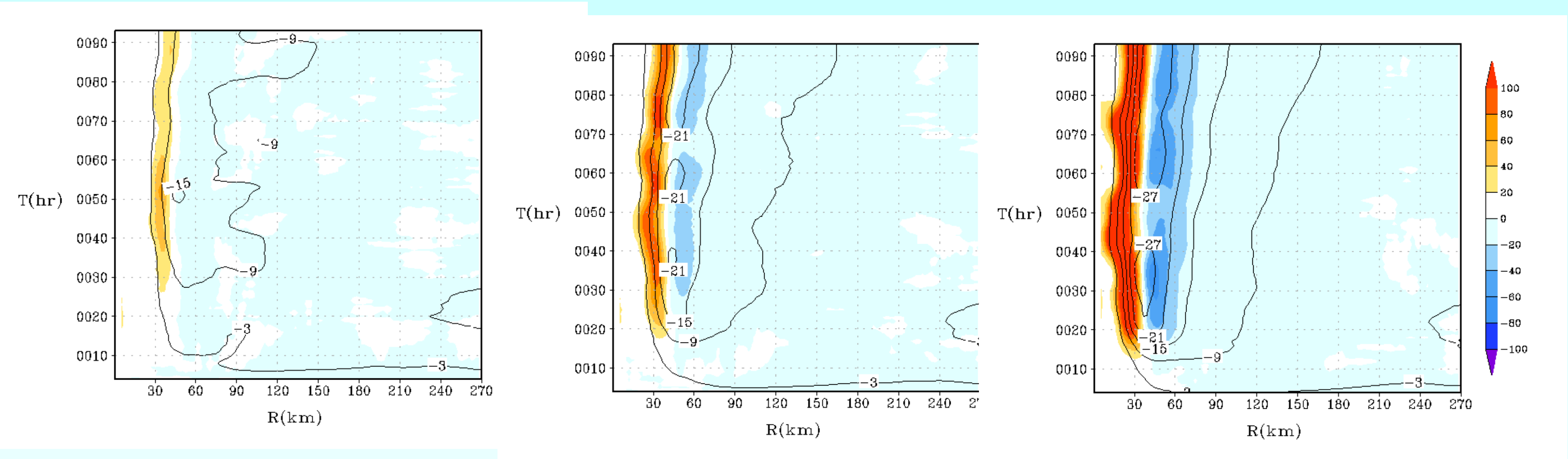




The Spin Up and Acceleration Mechanism

$$\frac{dv_\lambda}{dt} = -\frac{1}{\rho r}\frac{\partial p}{\partial \lambda} - \frac{u_r v_\lambda}{r} - f u_r + D_{v\lambda} \longrightarrow$$ Controls Spin up

$$\frac{du_r}{dt} = -\frac{1}{\rho}\frac{\partial p}{\partial r} + \frac{v_\lambda v_\lambda}{r} + f v_\lambda + D_{ur} \longrightarrow$$ Controls Size ?



Hovemoller diagram of the tangentially averaged, 6-hourly time averaged radial component of velocity (in ms^{-1}). Superposed on those contour lines is the shaded in color the net radial radial forcing term *including radial friction* in the governing equation for the secondary circulation (equation 2) for the HWRF runs with (i) alpha=1, (ii) alpha=0.5 and (iii) alpha=0.25 runs at the 30-m level. The blue end of the spectrum represents radial acceleration (convergence), and the red end of the spectrum represents deceleration within the inner eyewall region. Units of the net radial radial forcing term are in $ms^{-1}\ h^{-1}$.

Main Conclusions (cont'd):
It is not just all about the parameterized physics

- **Decreased horizontal diffusion with the divergence damping turned off makes the RMW behave quasi-steady after 80 h, instead of increasing towards the end of the run with the default horizontal diffusion.**

- **The RMW is larger with larger horizontal diffusivity when the divergence damping is turned off.**

- **Turning off the divergence damping decreases the intensity.**

- **The divergence damping term is a significant contributing factor for the deteriorated wind-pressure relationship when the GFS PBL scheme is used.**