HWRF Weekly Meeting Telecon
24 May 2018

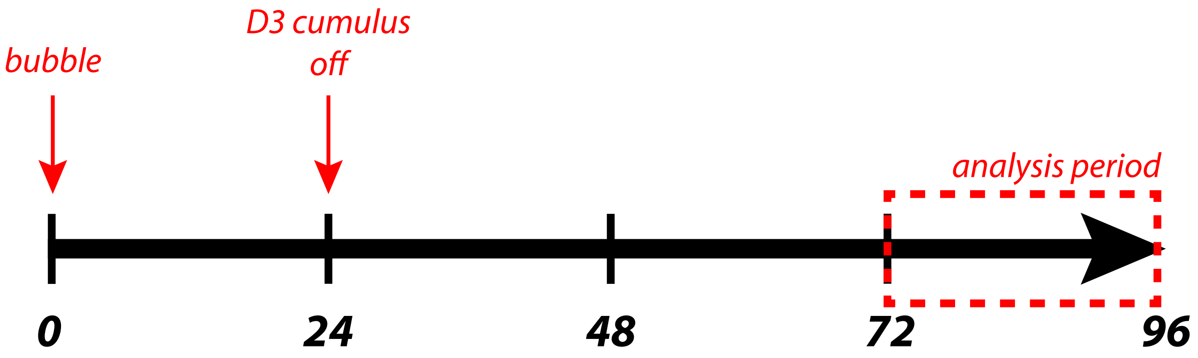
Boundary layer influences on hurricane structure

Robert Fovell
University at Albany, State University of New York
rfovell@albany.edu

Semi-idealized HWRF experiments

- Largely based on H218 with nearly operational configuration, but
  - Single hurricane season sounding
  - No ocean model
  - No initial wind
  - No land
  - Constant SST
  - TC initiated with a synoptic-scale buoyancy perturbation
  - Integrated for 4 days
  - Bu et al. (2014, 2017), Fovell et al. (2016)
- Standard settings:
  - icoef_sf = 6
  - coac = 1.5, 2.0, 2.5
  - codamp = 12., 12., 12.
  - icloud = 3
- Physics time step (nphs) varies among experiments shown

Timeline of experiments

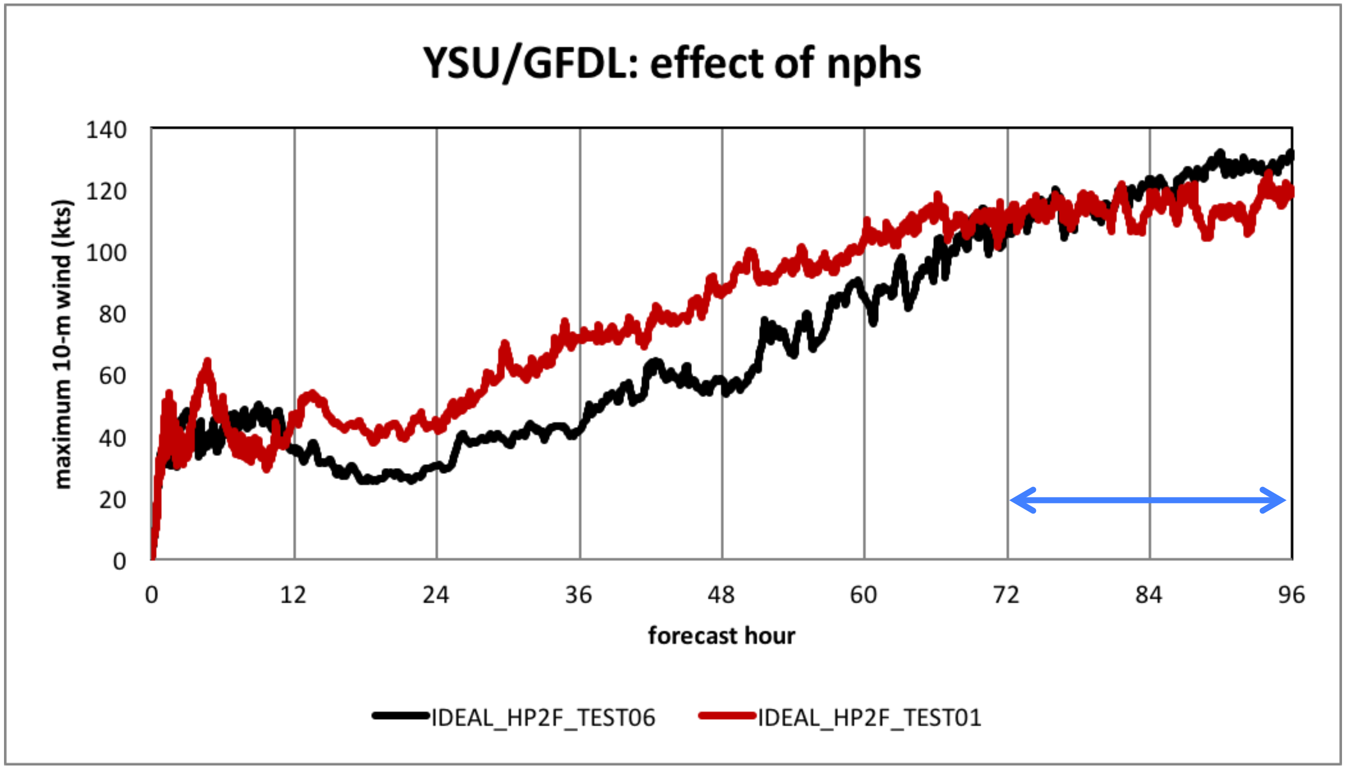


Fields averaged temporally over Day 4 and also azimuthally.

PBL/surface layer schemes

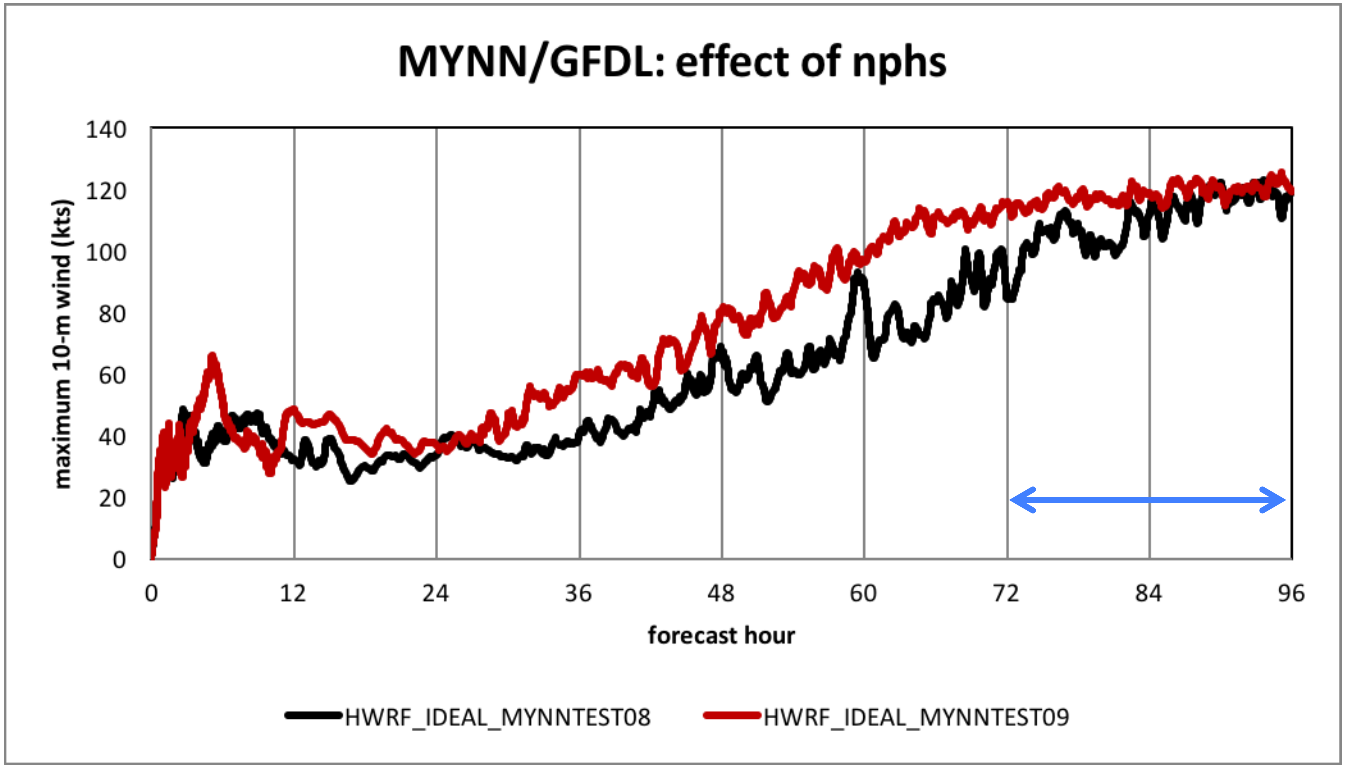
- GFSEDMF "capped" with GFDL surface layer (**operational**)
  - Has vertical alpha adjustment
- GFSEDMF/GFDL without cap (original version)
- YSU with GFDL surface layer (implemented by Fovell)
- MYJ with MYJ surface layer
- **MYNN with GFDL surface layer (NEW, implemented by Fovell)**
- **[In contrast with ARW experiments, HWRF storms made without GFDL surface scheme are NOT strong]**

Effect of nphs



- Operational nphs = 2, 6, 6
- Experimental nphs = 1, 1, 1
- Long physics time step causes slower spin-up
- **GFSEDMF & YSU: operational nphs adopted**; MYNN: nphs = 1

Effect of nphs



- Operational nphs = 2, 6, 6
- Experimental nphs = 1, 1, 1
- Long physics time step causes slower spin-up
- GFSEDMF & YSU: operational nphs adopted; **MYNN: nphs = 1**

Background

K-Profile parameterization

Troen and Mahrt (1986)

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

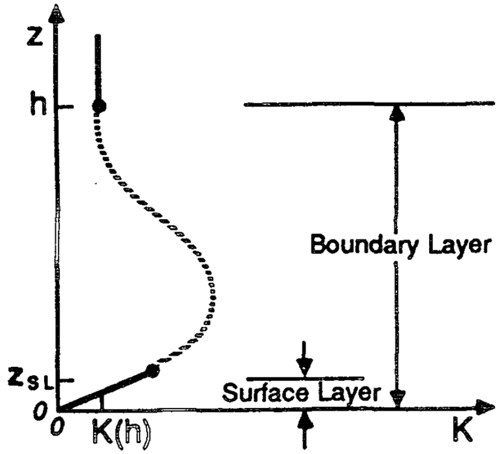
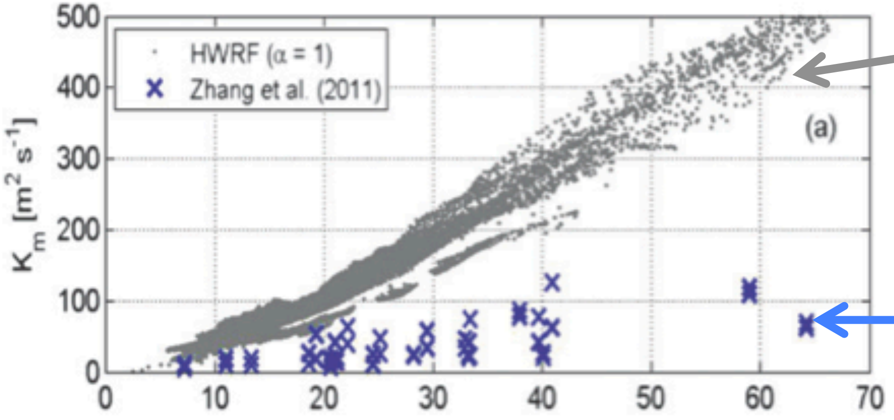


FIG. 1. Typical variation of eddy viscosity *K* with height in the boundary layer proposed by O'Brien (1970). Adopted from Stull (1988).

With PBL depth *h* based on critical *Ri*,
scheme yields mixing magnitude and depth;
Everything scales with *h*.

Eddy mixing K_m



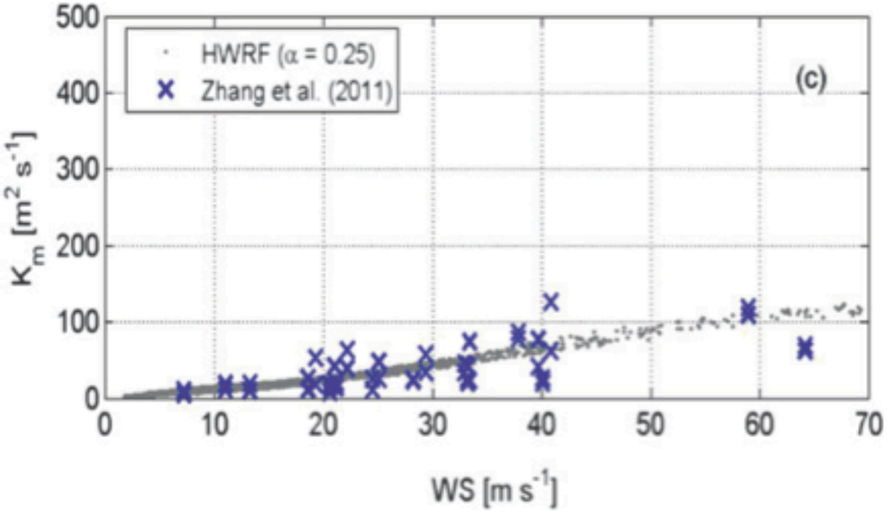
HWRF GFS PBL scheme

Observations @ 500 m MSL
From Zhang et al. (2011)

Wind speed

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

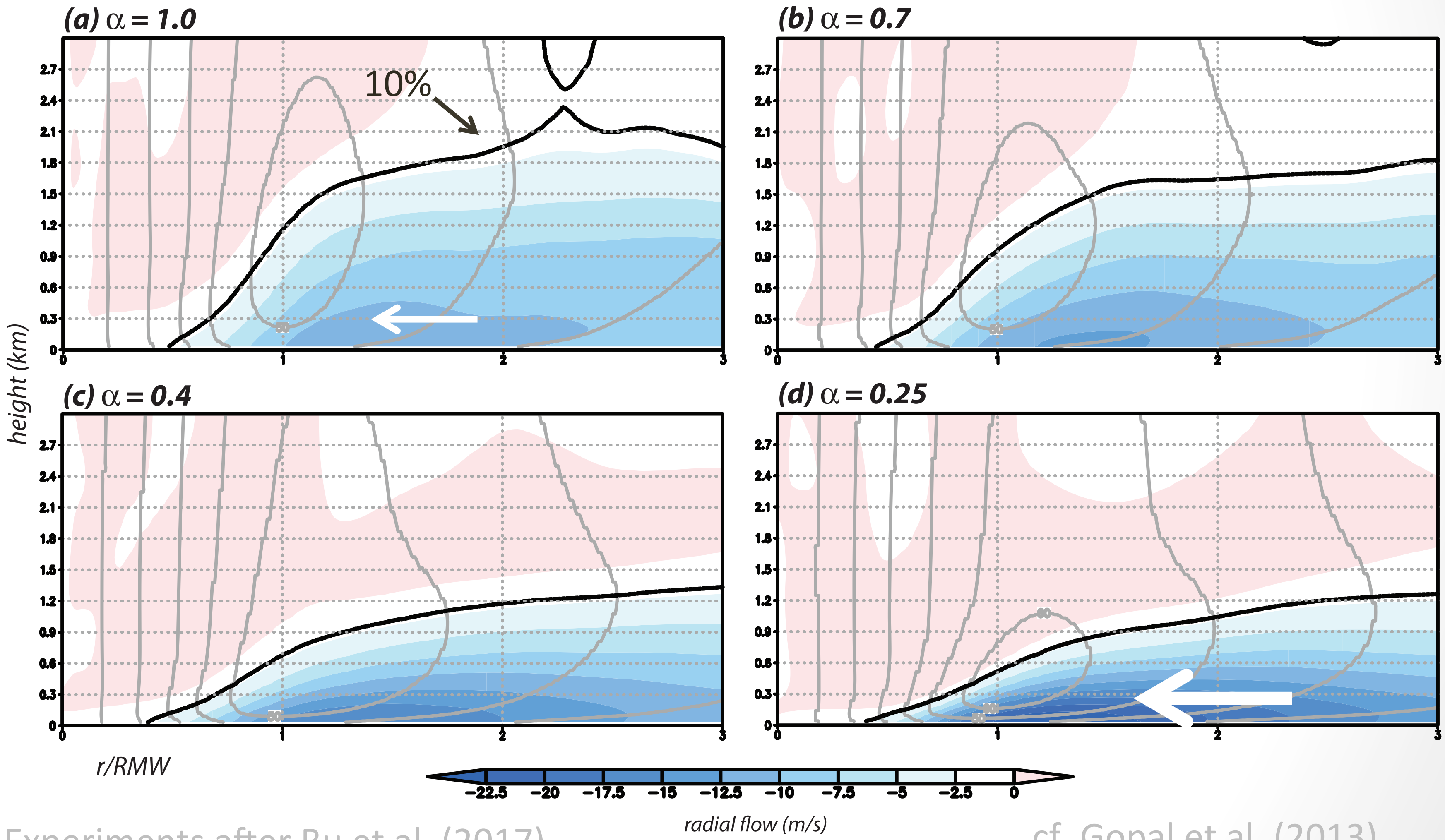
α parameter (“gfs_alpha”)



$\alpha = 0.25$

Gopalakrishnan et al. (2013)

α strongly impacts inflow strength & depth (& width)



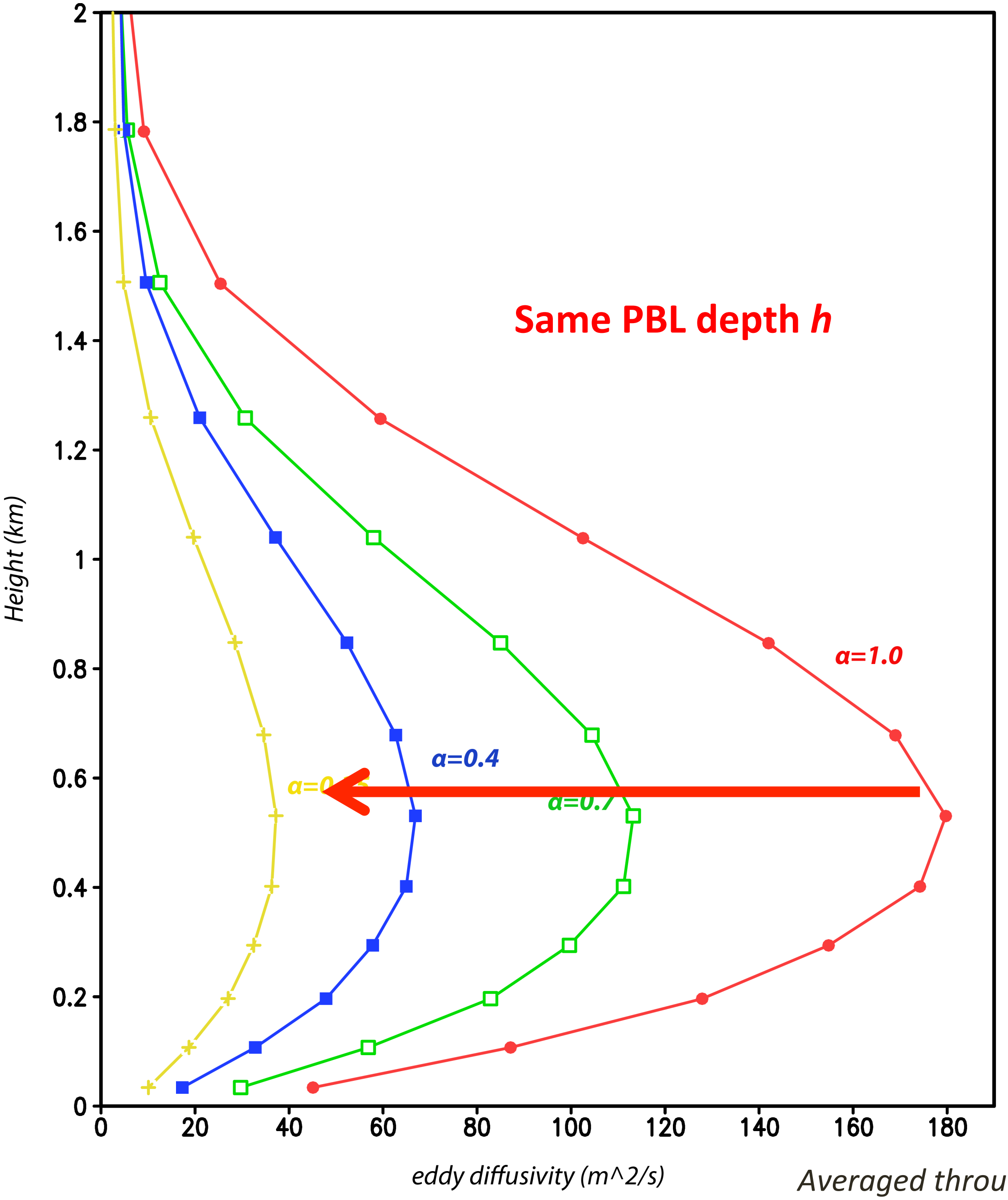
Experiments after Bu et al. (2017)

cf. Gopal et al. (2013)

Bu et al. 2017

Temporally, azimuthally, and radially averaged Km

HWRF with GFS PBL scheme



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

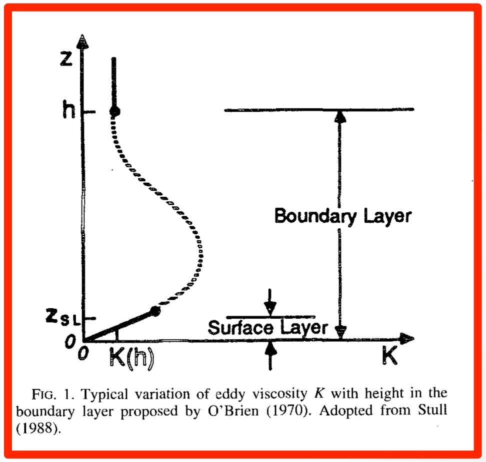


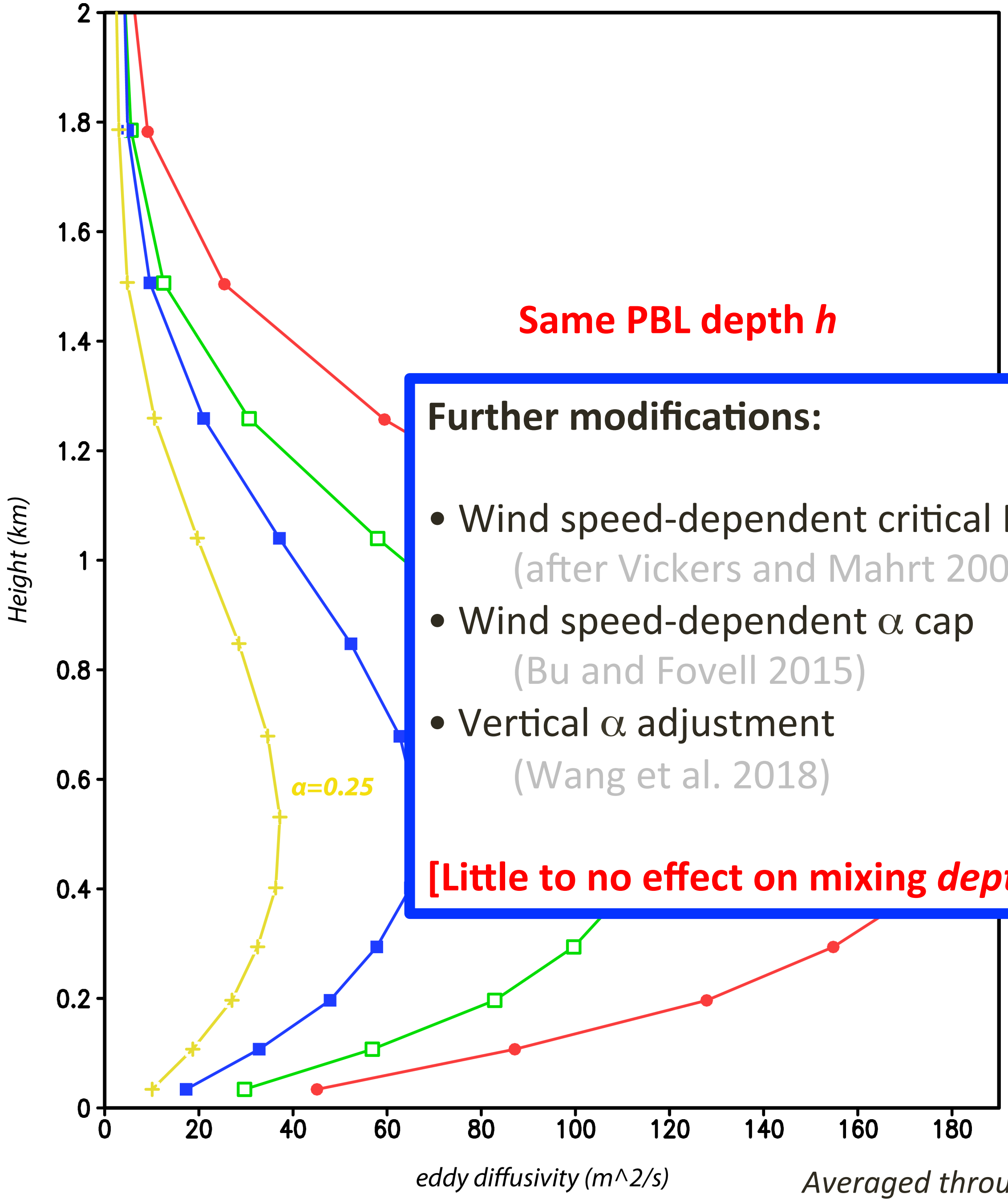
FIG. 1. Typical variation of eddy viscosity *K* with height in the boundary layer proposed by O'Brien (1970). Adopted from Stull (1988).

Averaged through 30-200 km annulus

Bu et al. 2017

Temporally, azimuthally, and radially averaged Km

HWRF with GFS PBL scheme



Same PBL depth *h*

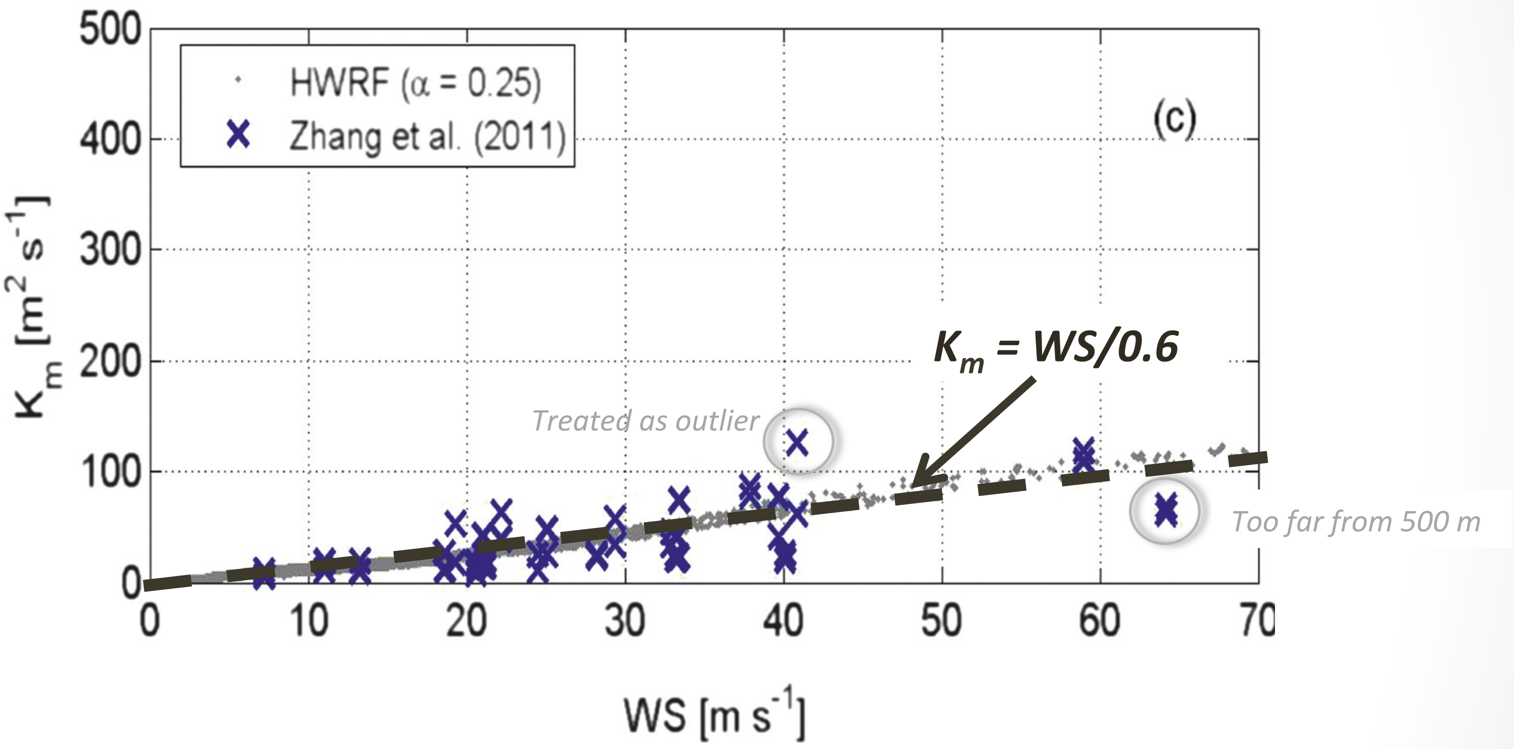
Further modifications:

- Wind speed-dependent critical Ri
  (after Vickers and Mahrt 2004)
- Wind speed-dependent α cap
  (Bu and Fovell 2015)
- Vertical α adjustment
  (Wang et al. 2018)

[Little to no effect on mixing *depth*]

Averaged through 30-200 km annulus

Capping K_m

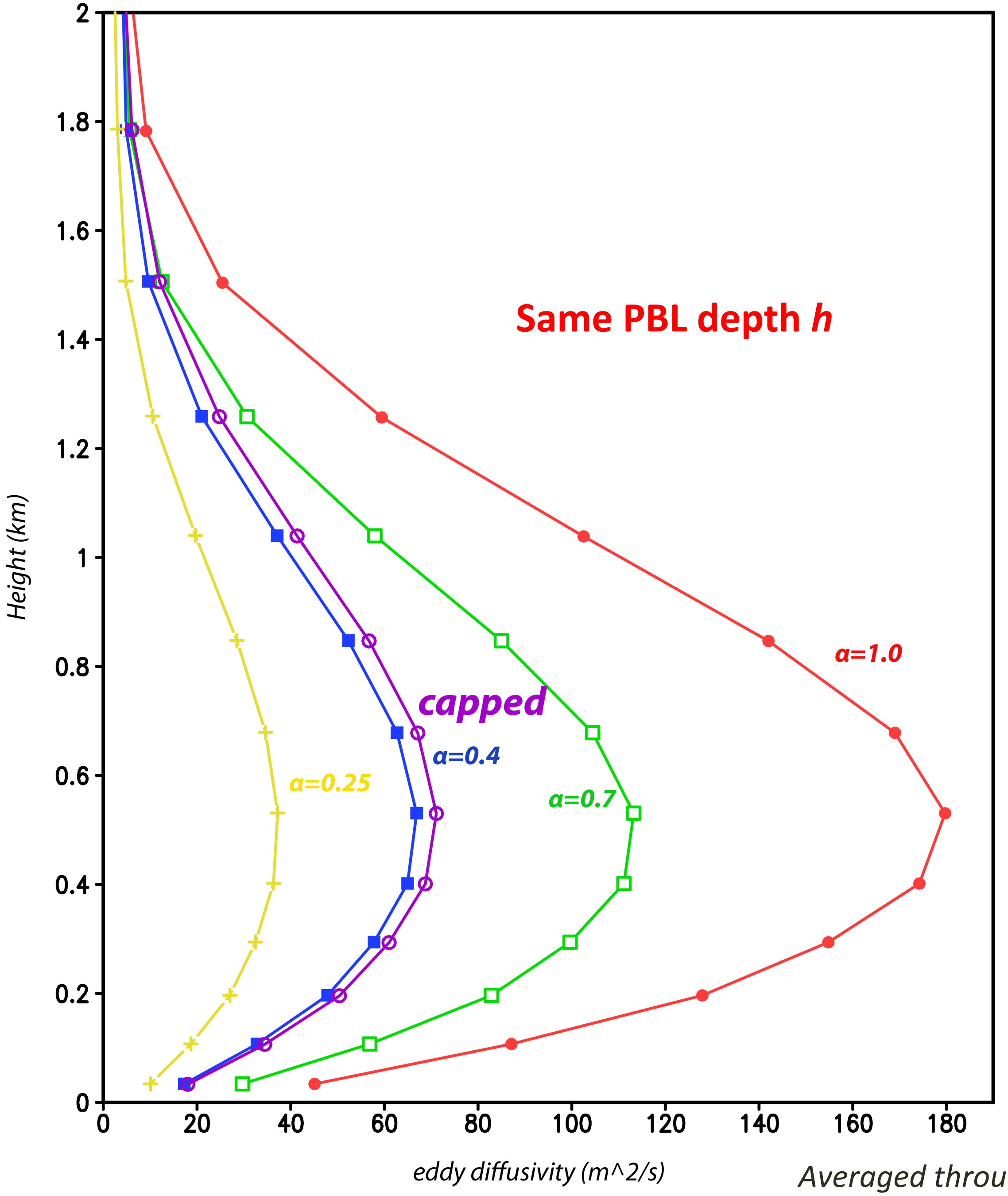


K_m = WS/0.6

Treated as outlier

Too far from 500 m

- Strategy was to restrain mixing, but only over water and where wind speeds were large at 500 m MSL, effectively removing α as a free parameter.
- Adopted into GFS (and later GFSEDMF) PBL, and currently still in use.



Temporally, azimuthally, and radially averaged Km

HWRF with GFS PBL scheme

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

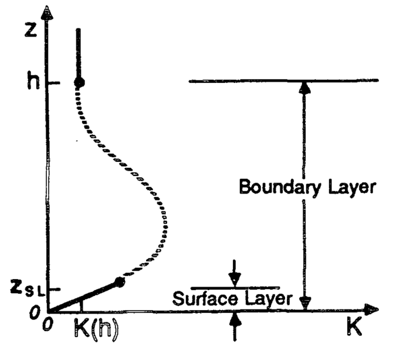


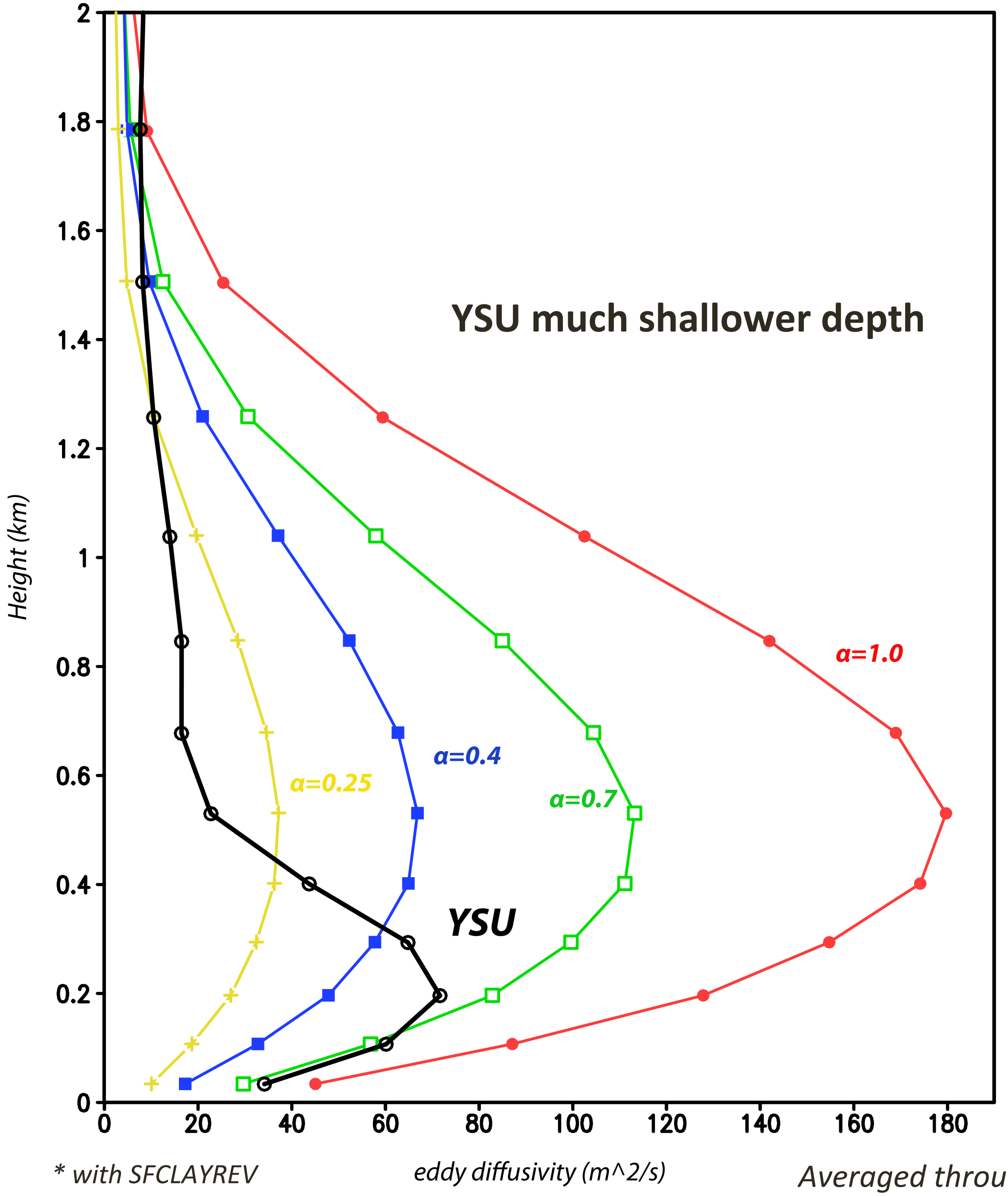
FIG. 1. Typical variation of eddy viscosity K with height in the boundary layer proposed by O'Brien (1970). Adopted from Stull (1988).

Averaged through 30-200 km annulus

Bu et al. 2017

Temporally, azimuthally, and radially averaged Km

HWRF with GFS PBL scheme **and YSU***



YSU much shallower depth

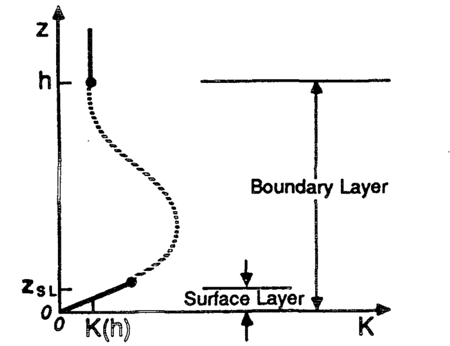


FIG. 1. Typical variation of eddy viscosity K with height in the boundary layer proposed by O'Brien (1970). Adopted from Stull (1988).

* with SFCLAYREV

Averaged through 30-200 km annulus

GFS and YSU schemes

Troen and Mahrt (1986)

GFSEDMF PBL scheme
(operational HWRF)

YSU PBL scheme
(cf. Noh et al. 2003, etc.)

Differ MOST in how they
determine PBL depth *h*
[critical Richardson number]

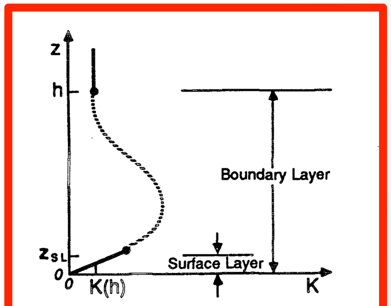
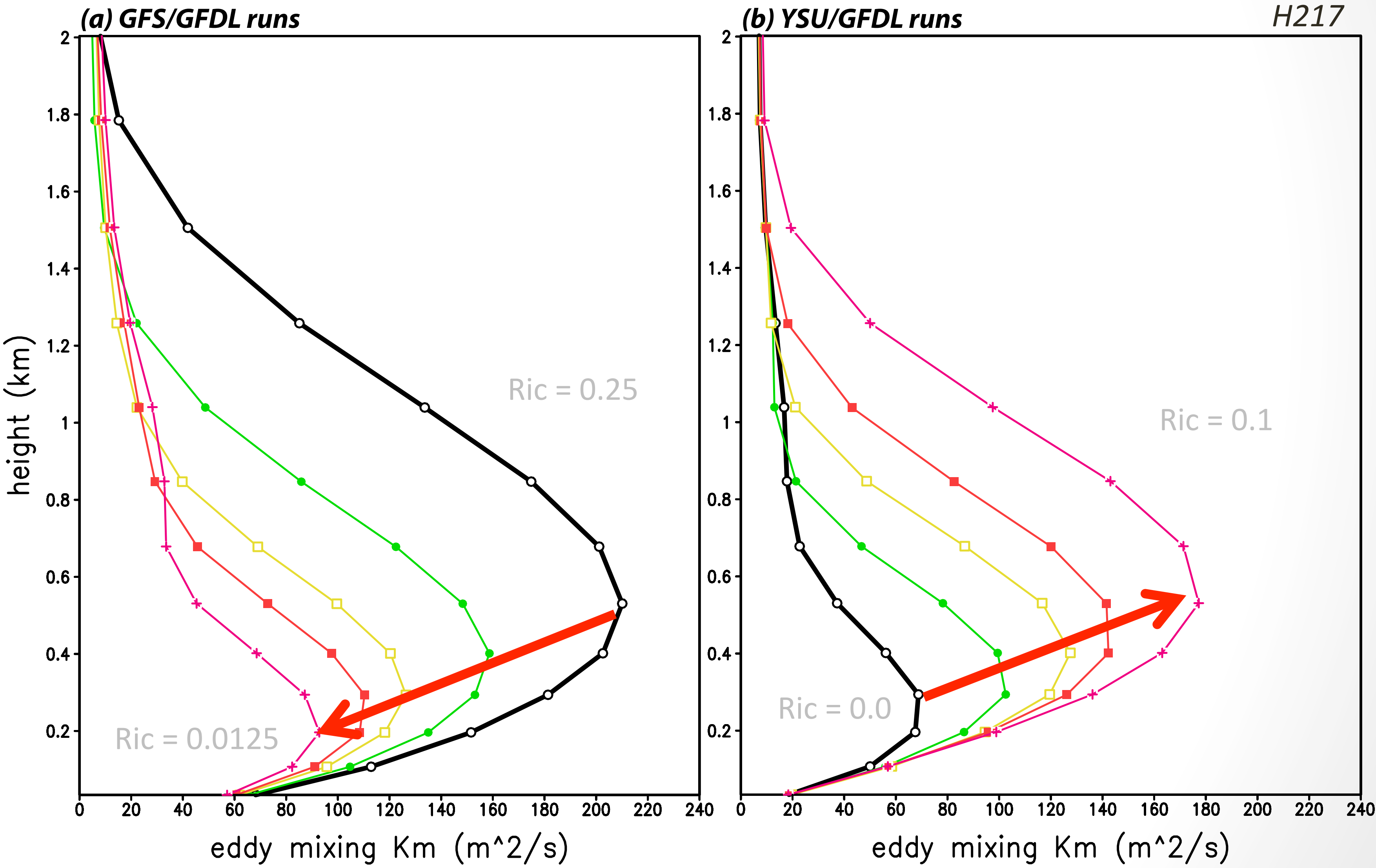


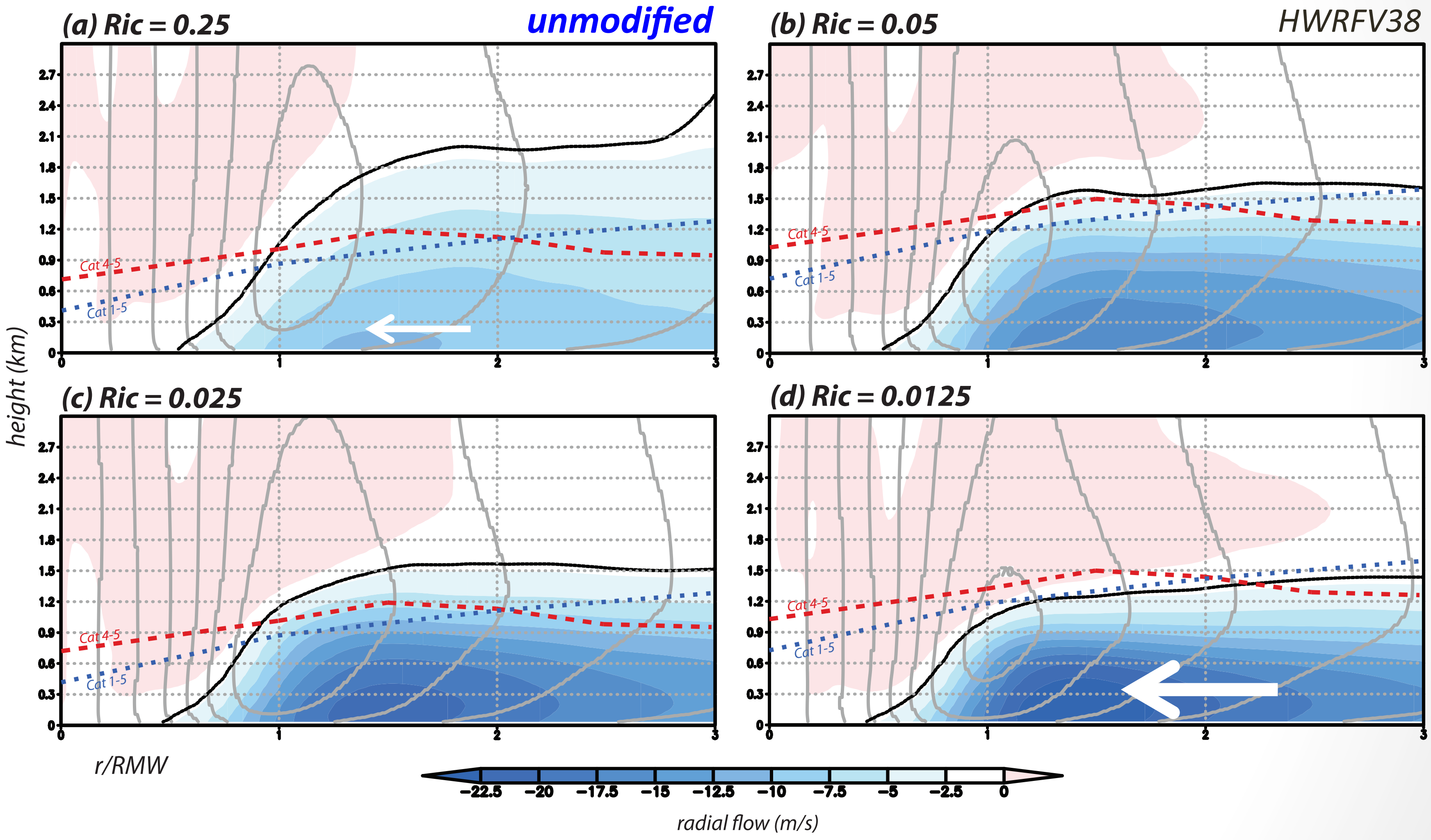
FIG. 1. Typical variation of eddy viscosity *K* with height in the boundary layer proposed by O'Brien (1970). Adopted from Stull (1988).

Effect of the critical Richardson number

(non-stable conditions)



GFS: changing Ri_c instead of α

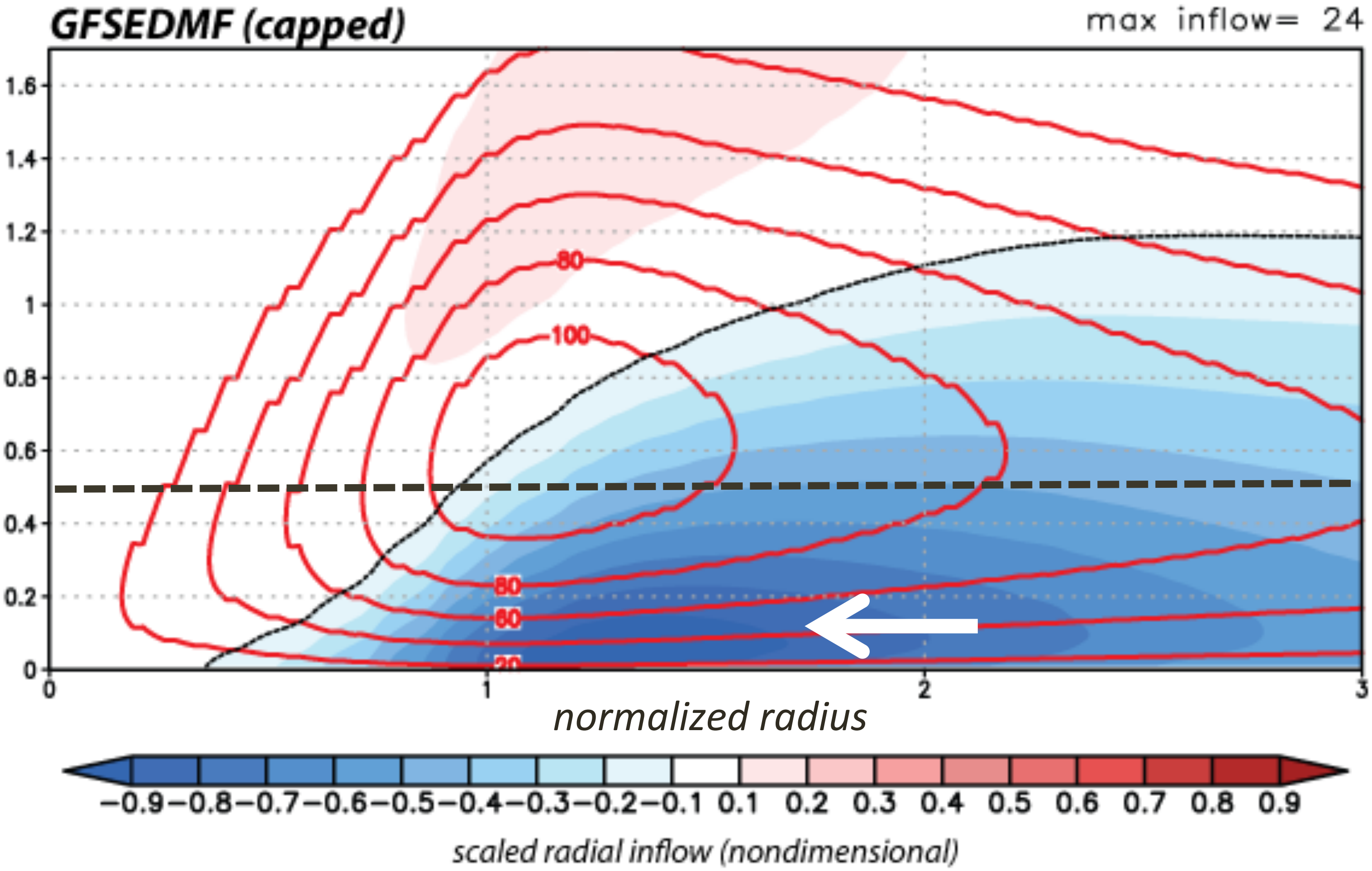


Zhang et al. (2011) composite inflow layer depths also shown

Mixing and inflow fields

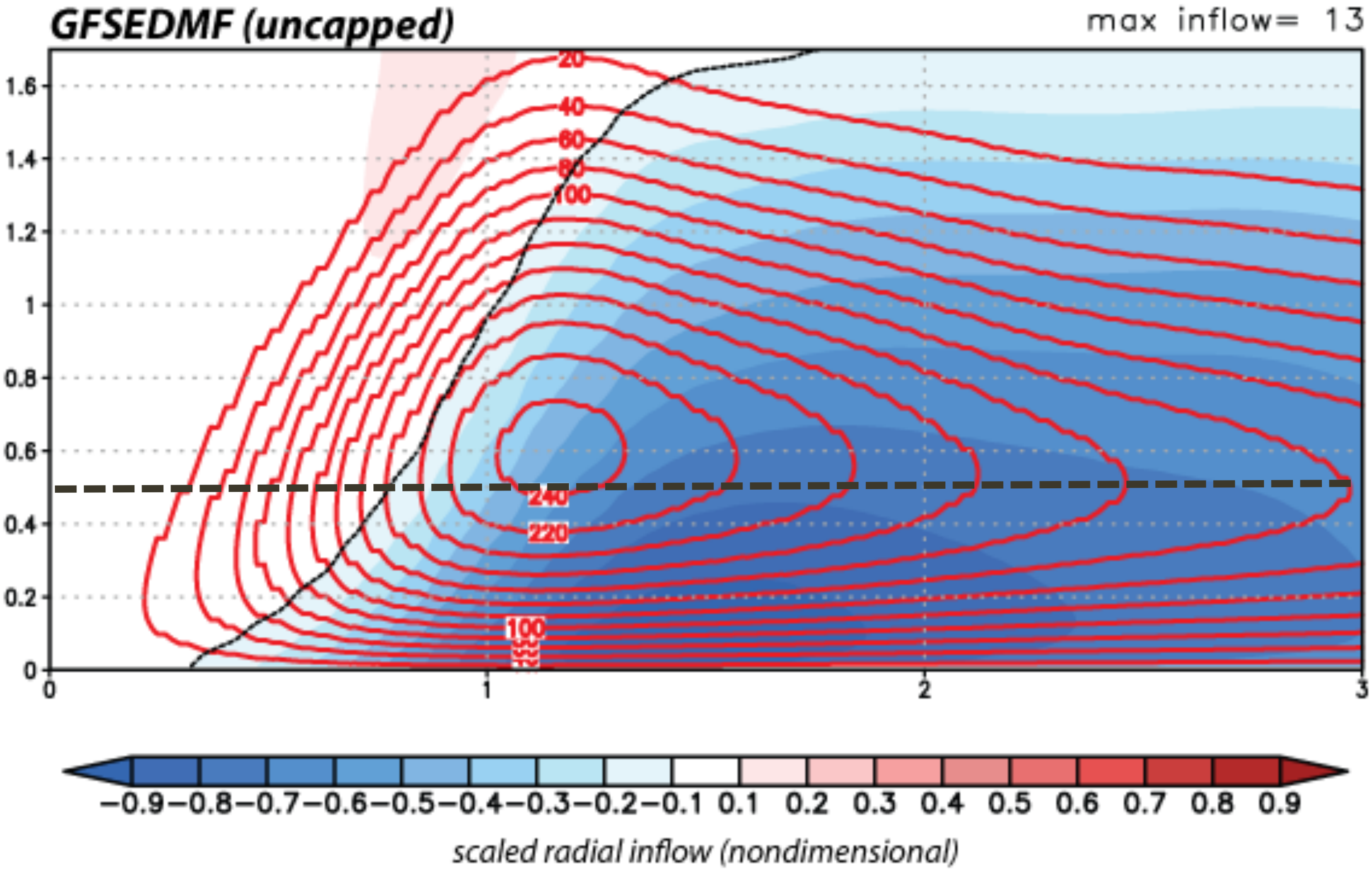
Semi-idealized experiments with near-H218 setup

Scaled inflow and eddy mixing



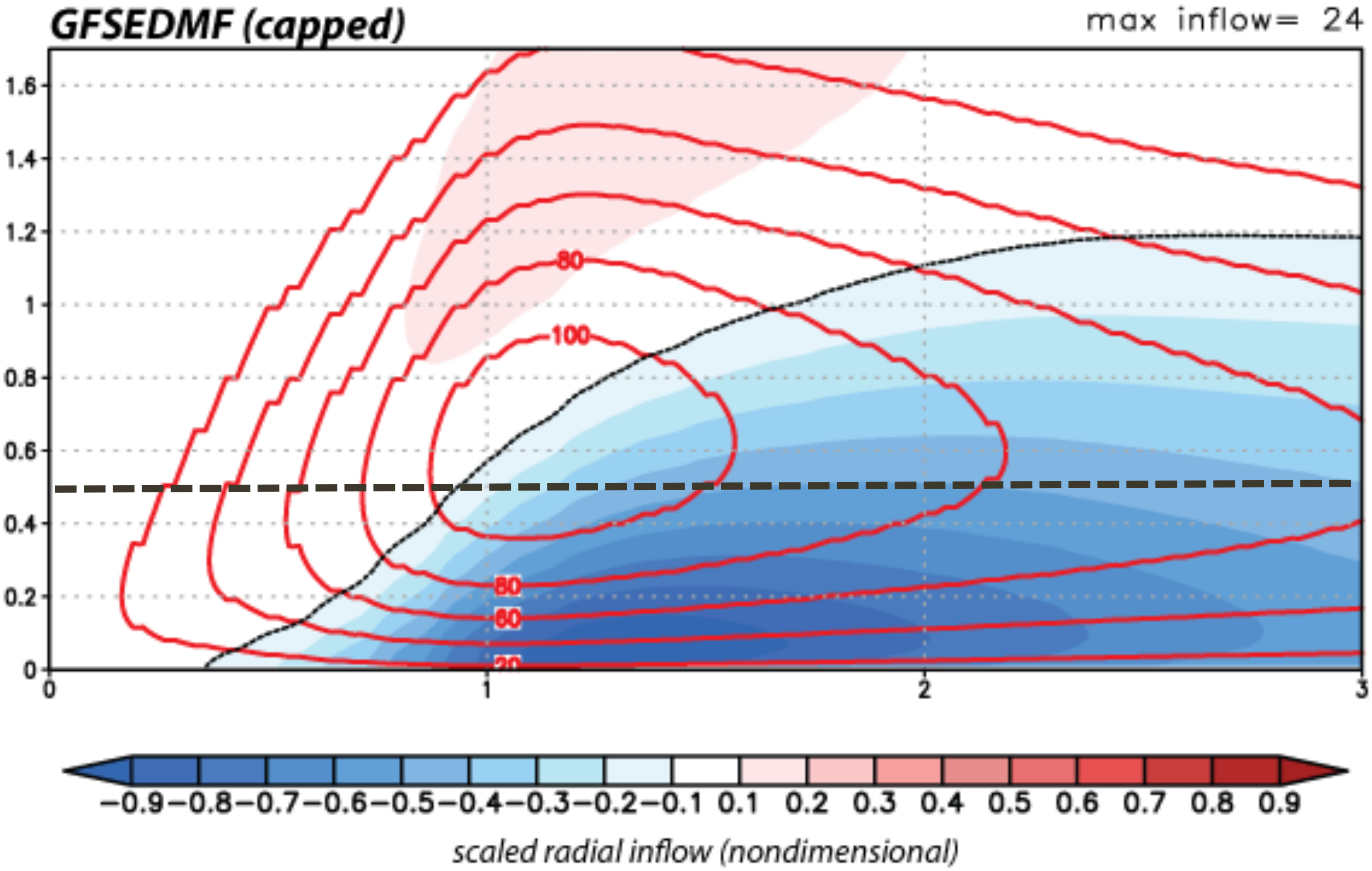
500 m

Scaled inflow and eddy mixing



500 m

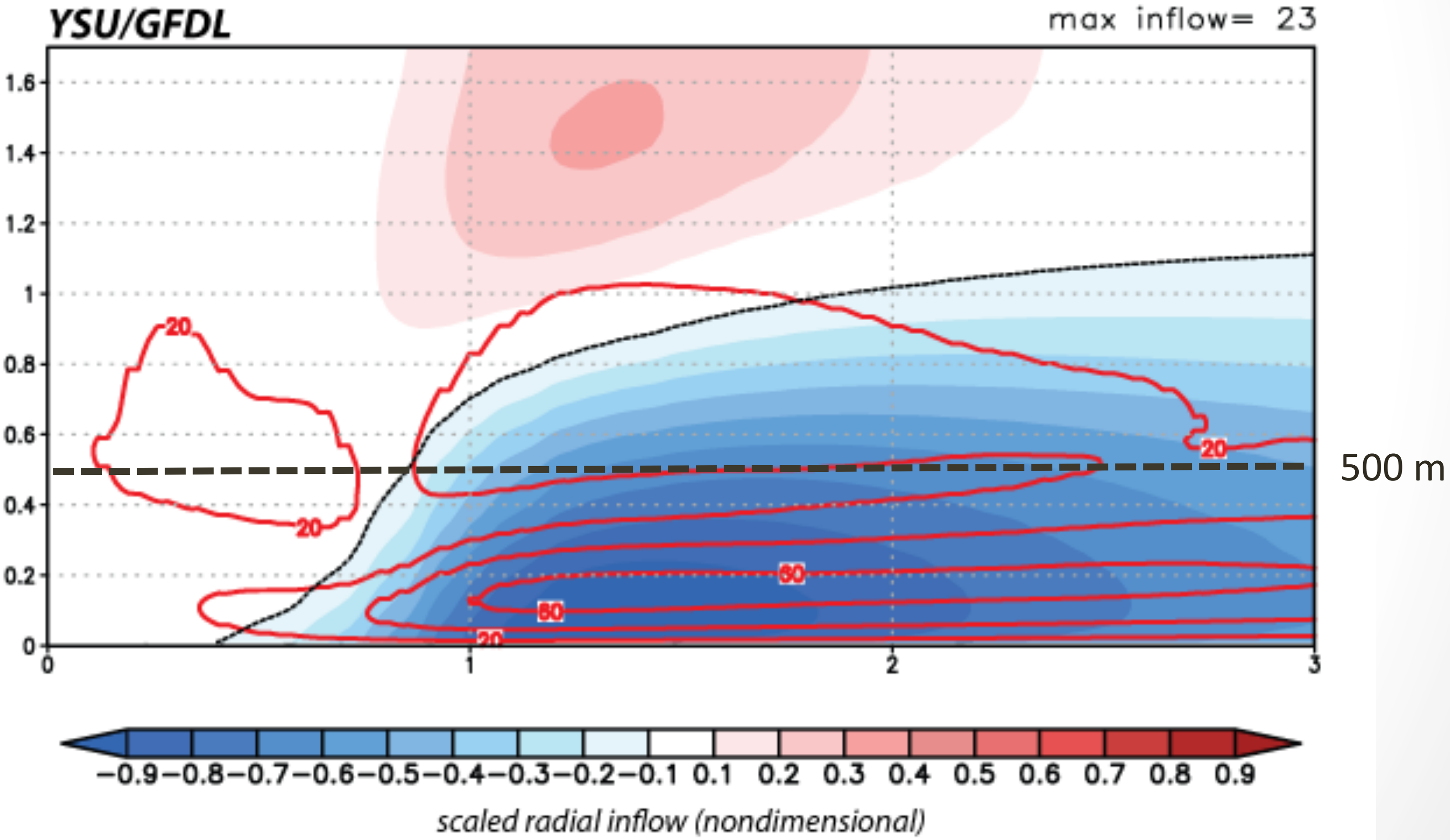
Scaled inflow and eddy mixing



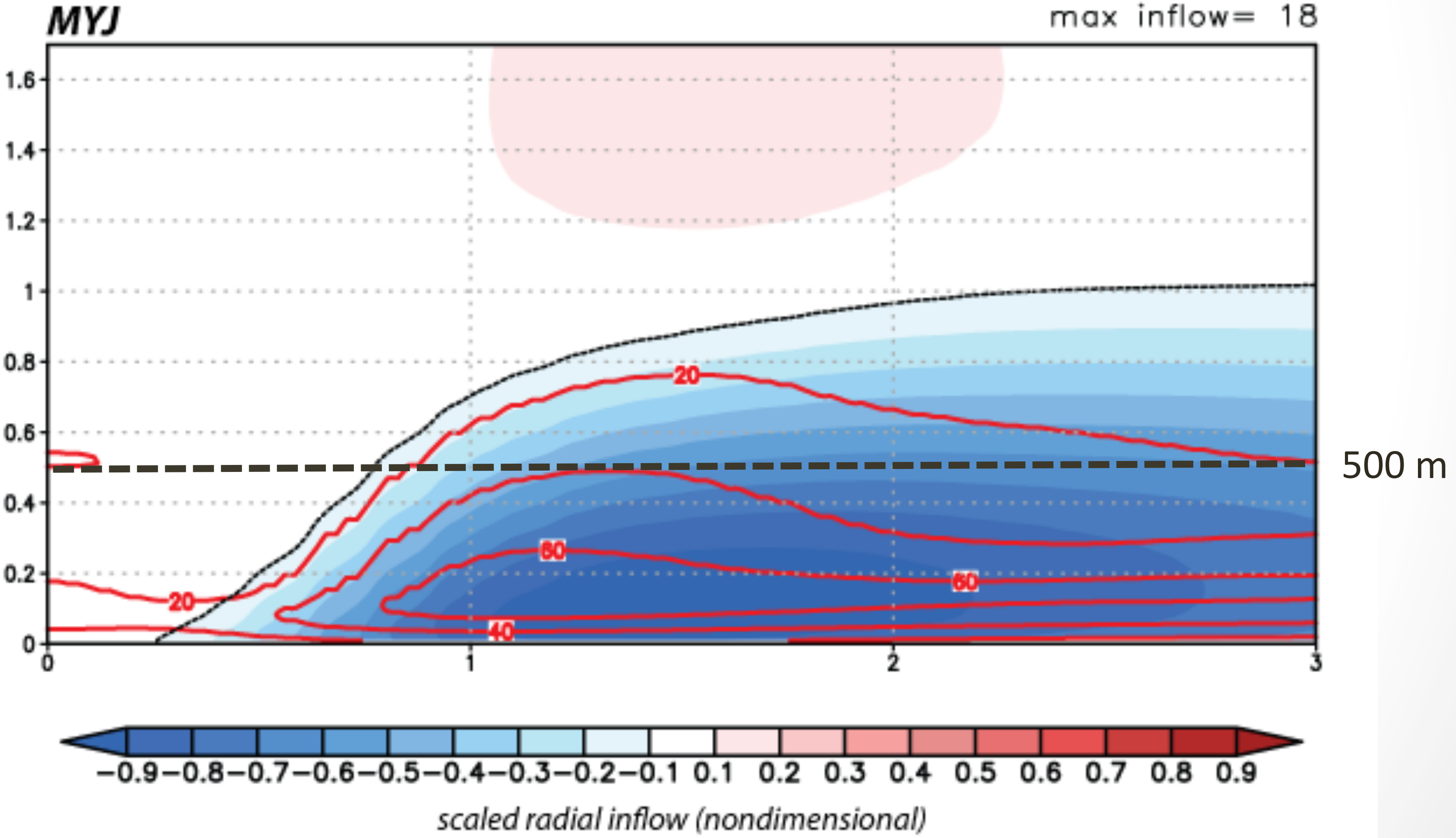
GFSEDMF (capped)

500 m

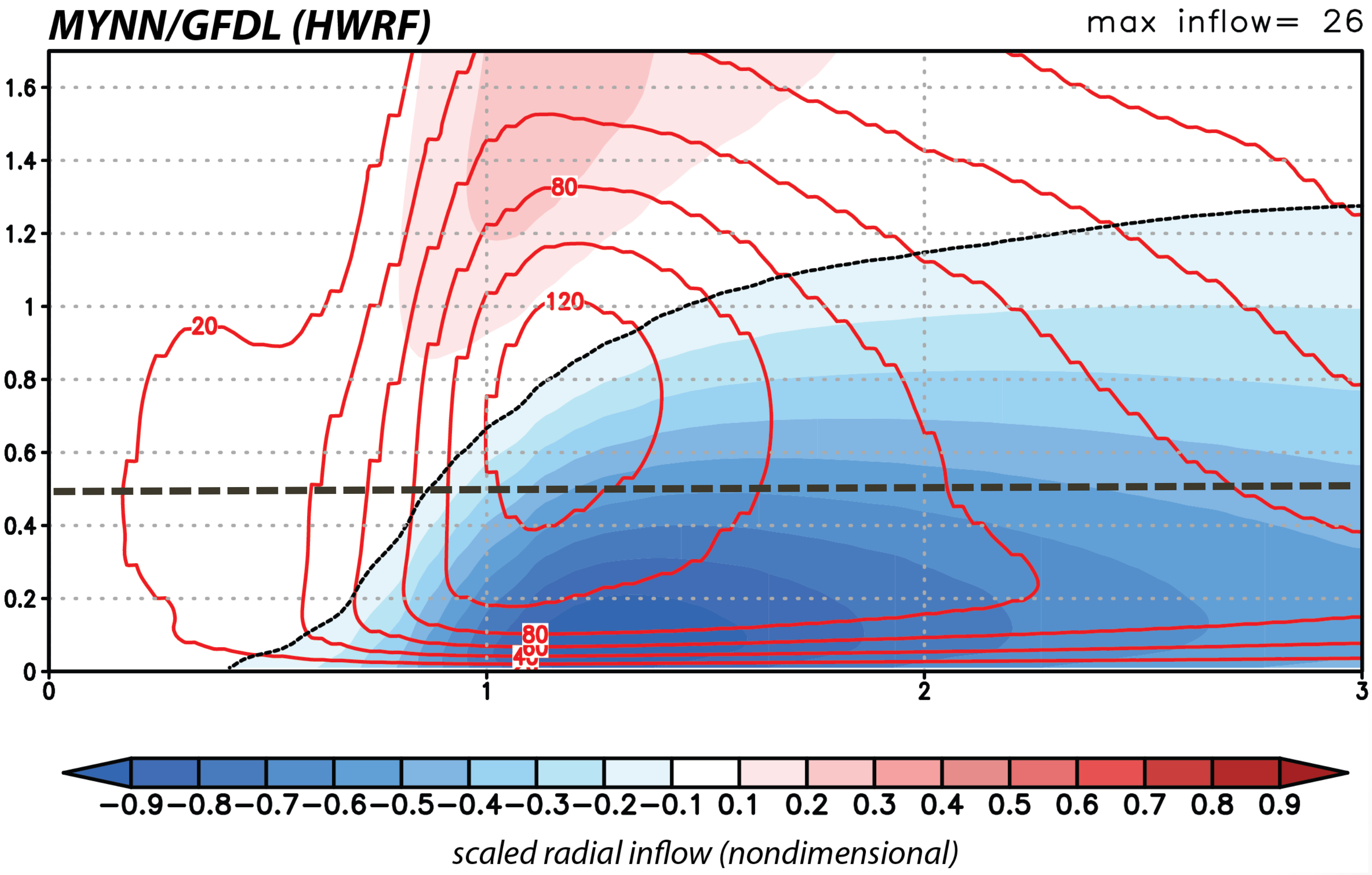
Scaled inflow and eddy mixing



Scaled inflow and eddy mixing

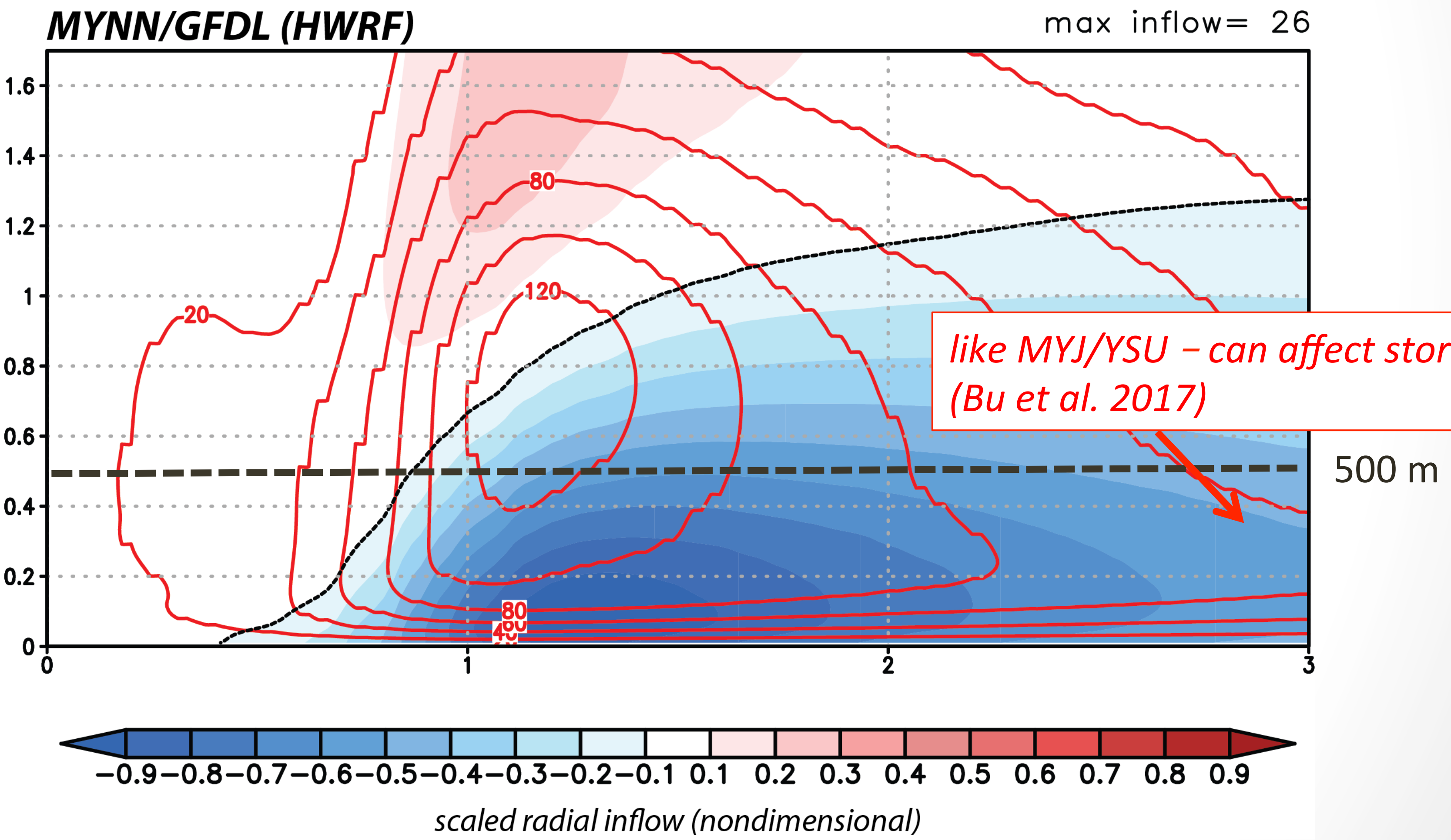


Scaled inflow and eddy mixing



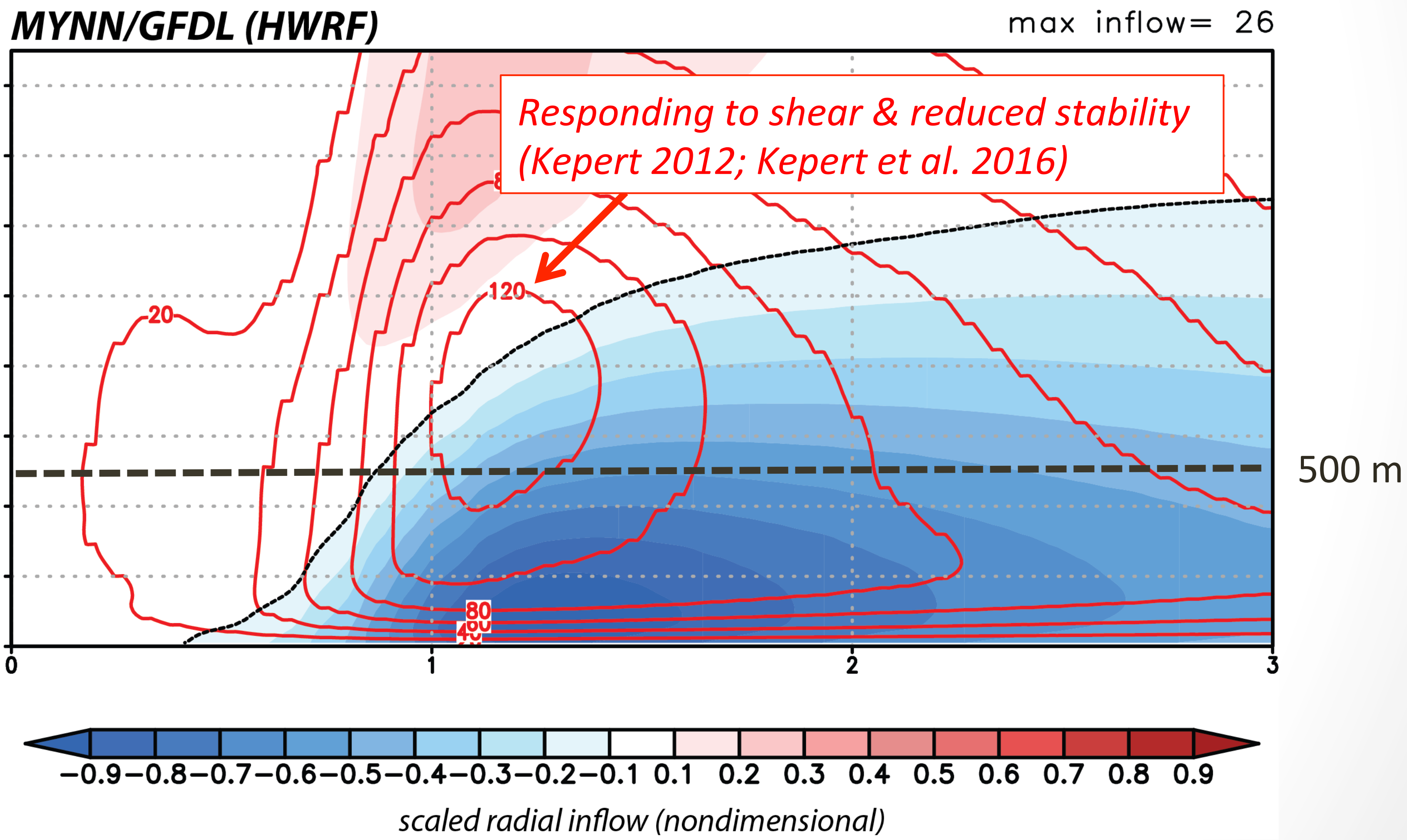
500 m

Scaled inflow and eddy mixing



like MYJ/YSU – can affect storm size (Bu et al. 2017)

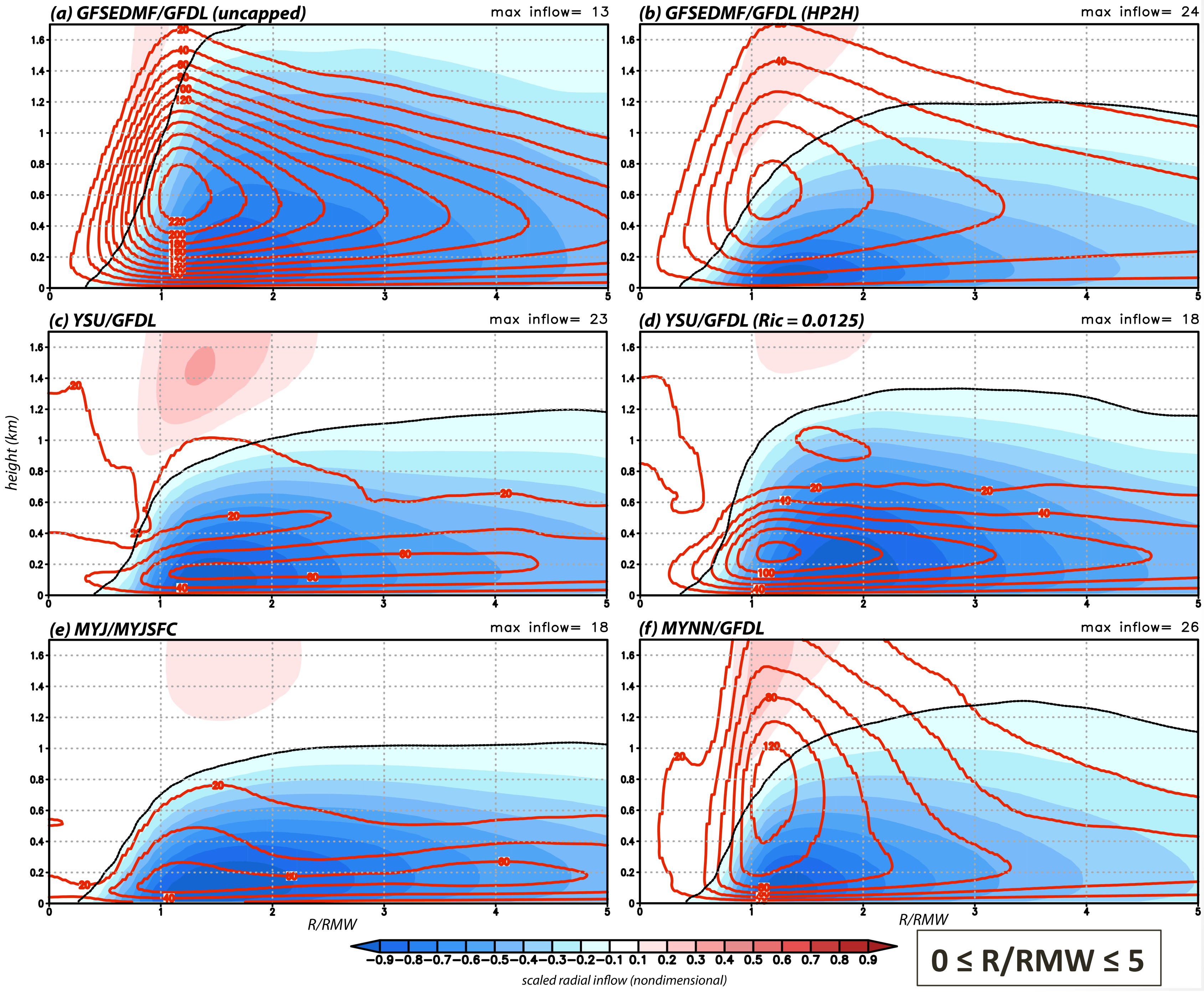
Scaled inflow and eddy mixing



MYNN/GFDL (HWRF)

Responding to shear & reduced stability (Kepert 2012; Kepert et al. 2016)

HWRF simulations (scaled inflow - shaded; eddy mixing - contoured)

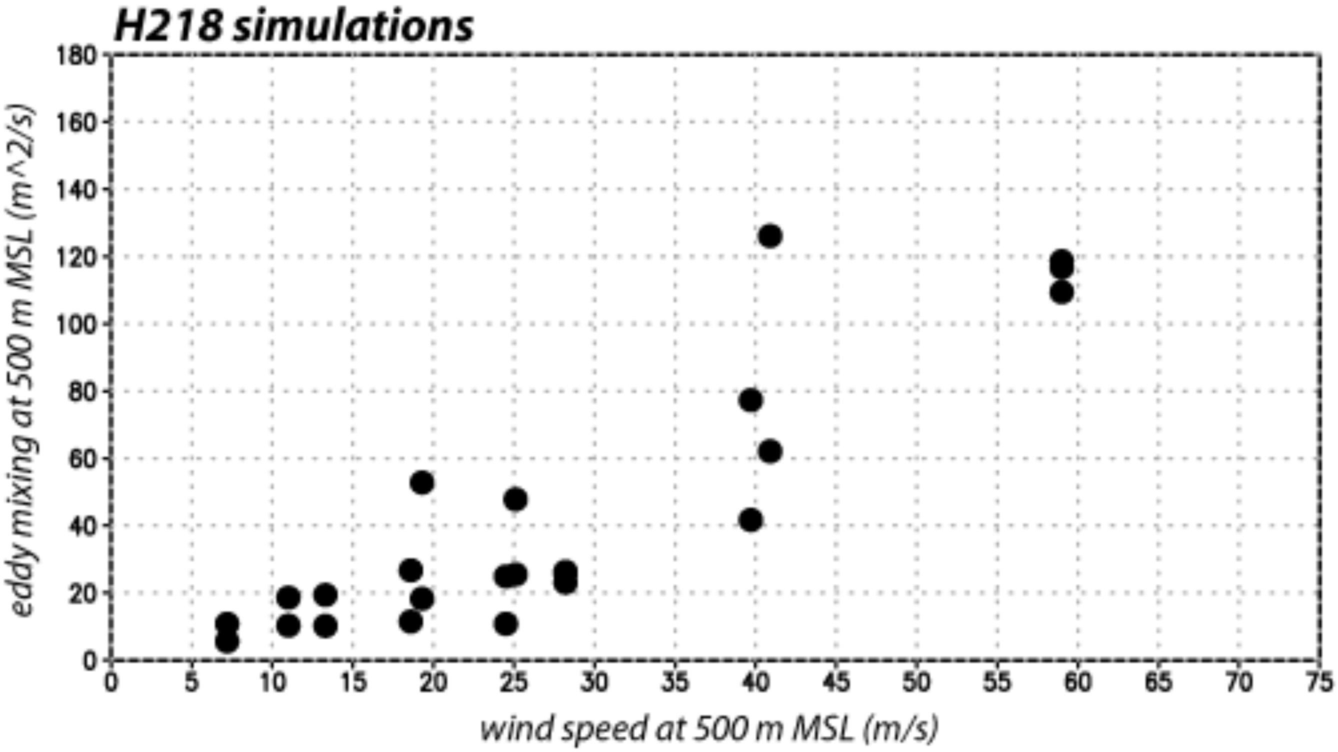


0 ≤ R/RMW ≤ 5

Observational comparisons

Zhang et al. (2011a, 2011b)

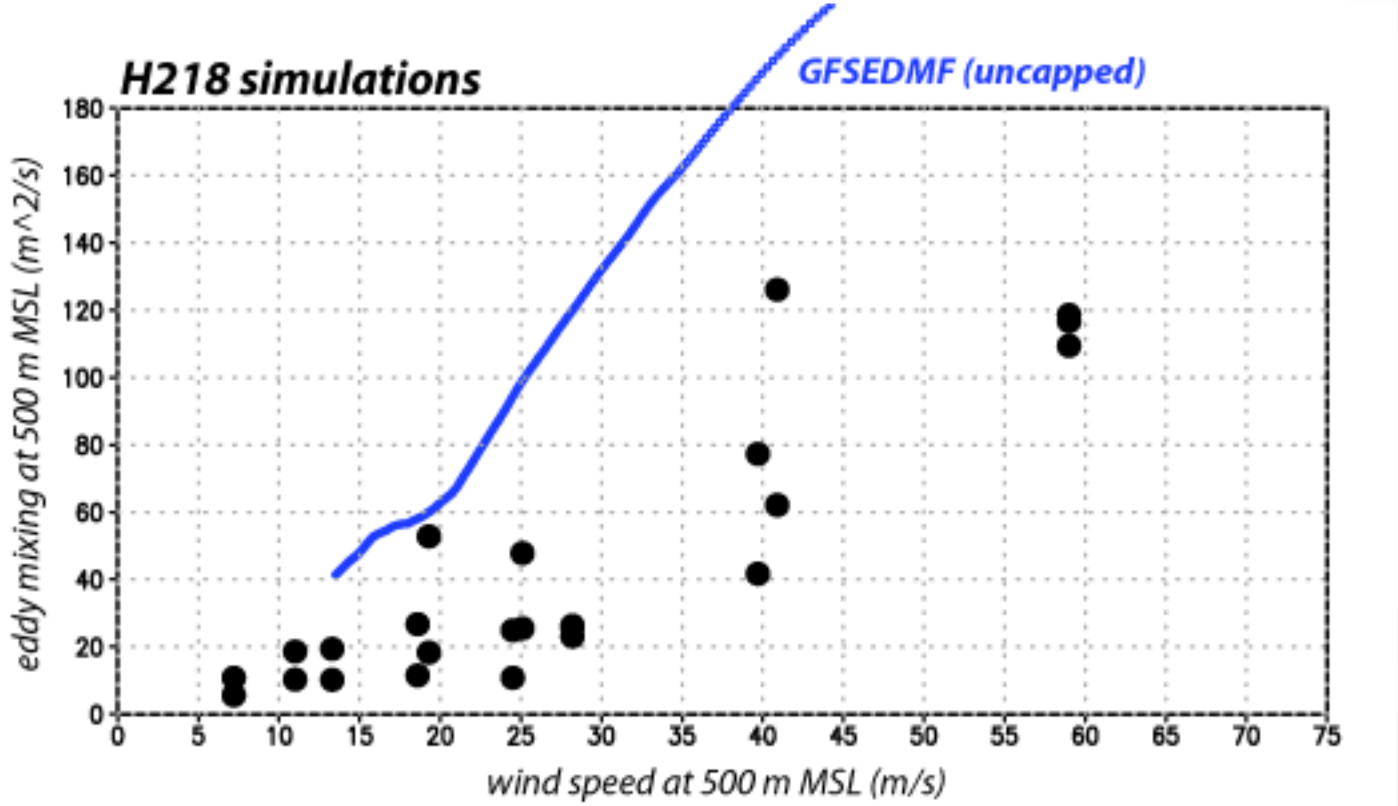
K_m estimated at 500 m MSL



Retained observations
very close to 500 m MSL

Data from Zhang et al. (2011a)

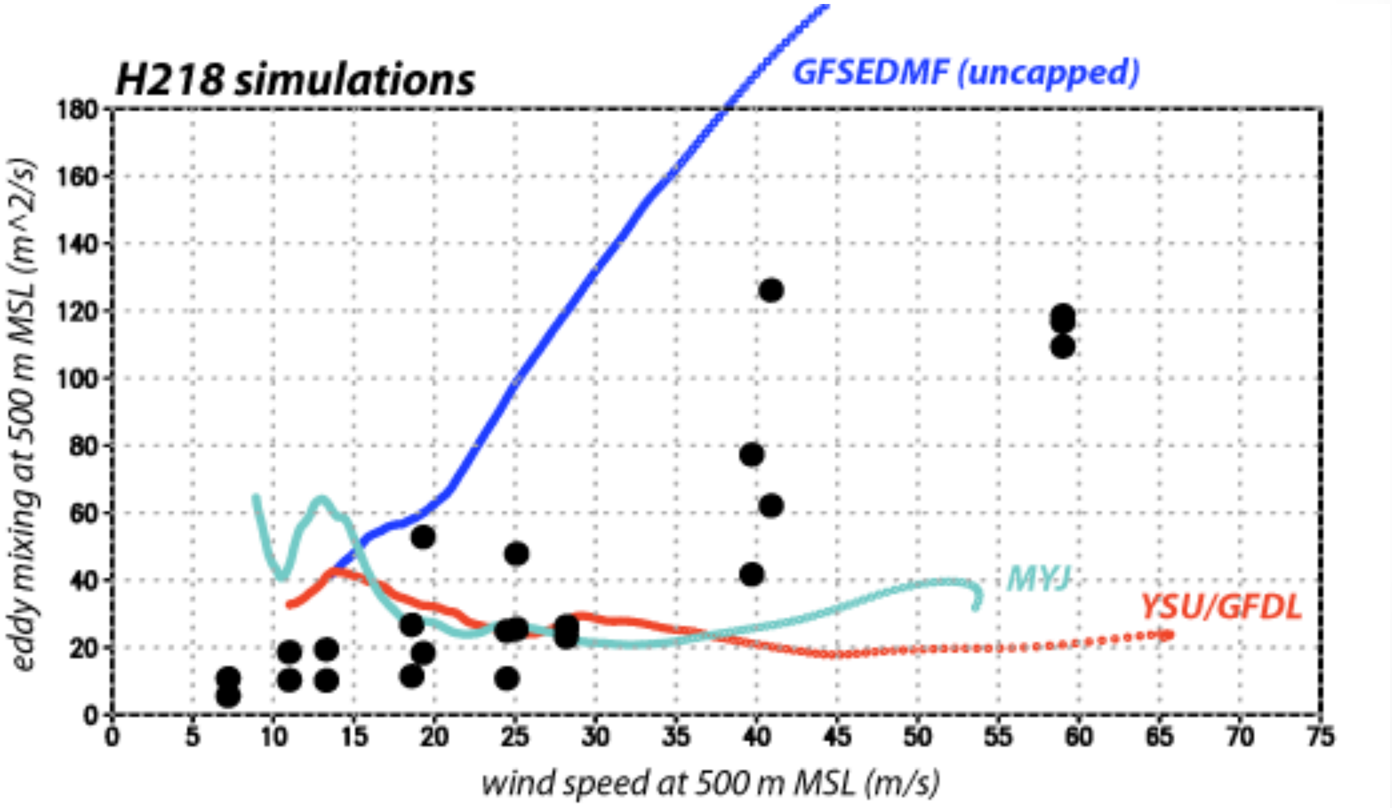
K_m estimated at 500 m MSL



Winds and mixing represent temporally and azimuthally averaged fields at 500 m within $1 \le R/RMW \le 5$

Data from Zhang et al. (2011a)

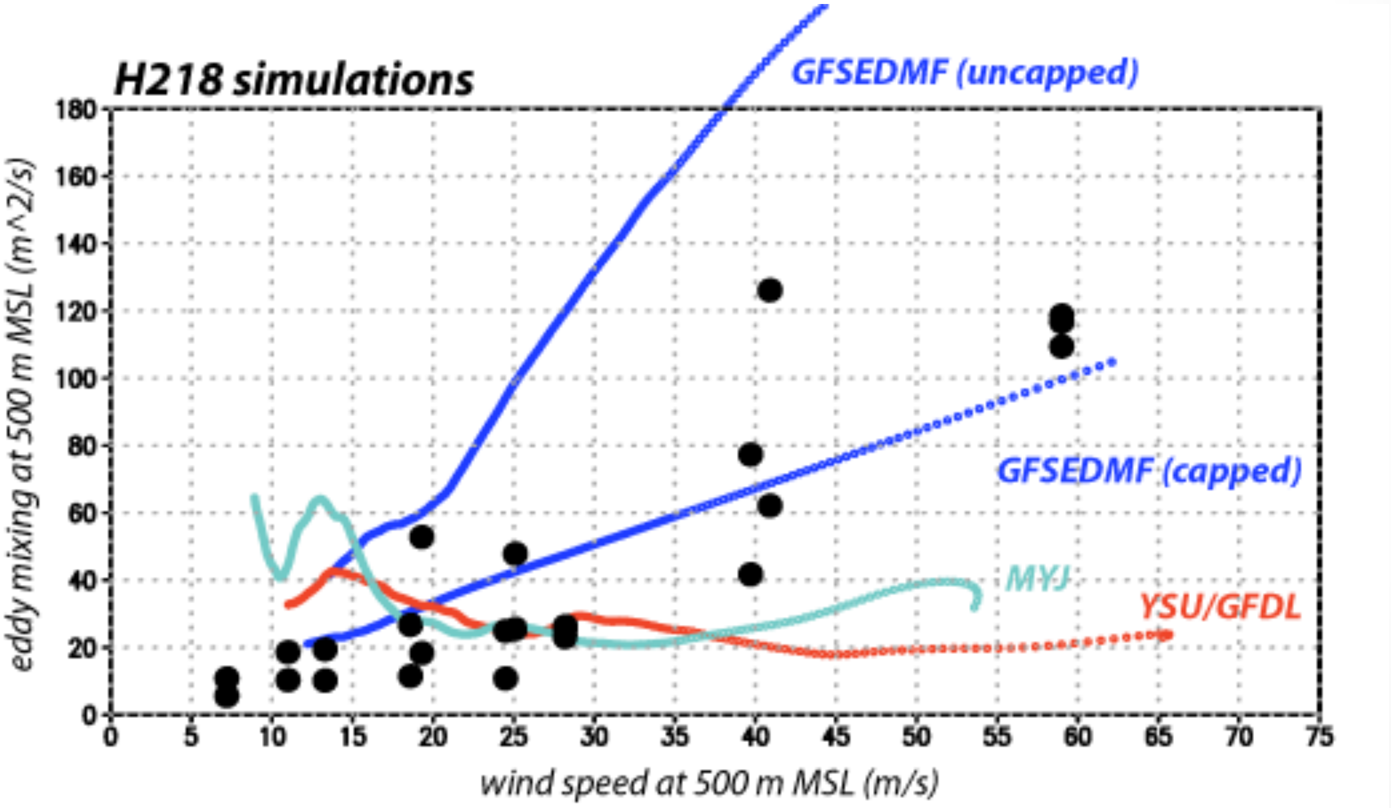
K_m estimated at 500 m MSL



Suggests YSU & MYJ mixing is **too shallow**

Data from Zhang et al. (2011a)

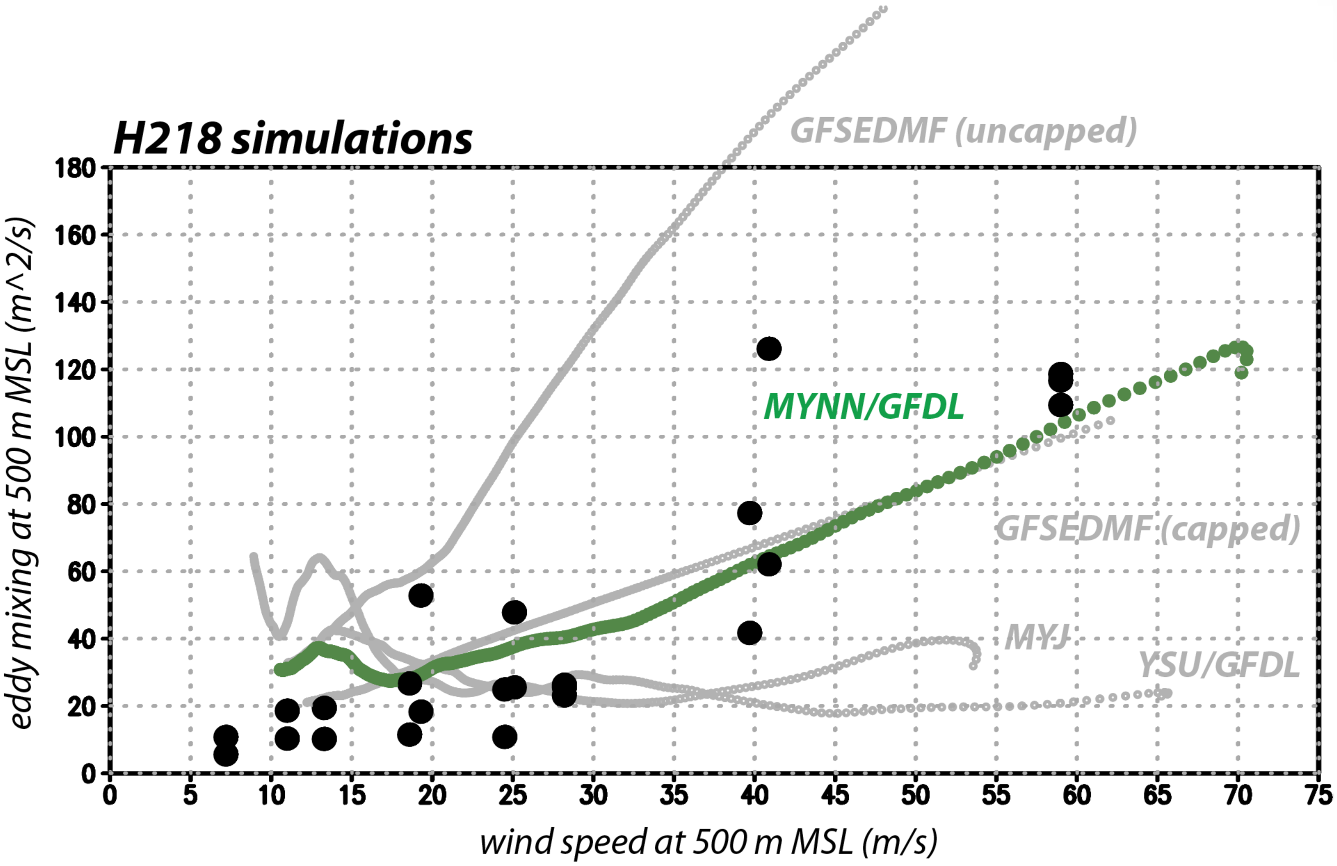
K_m estimated at 500 m MSL



Operational version **engineered** to produce this result

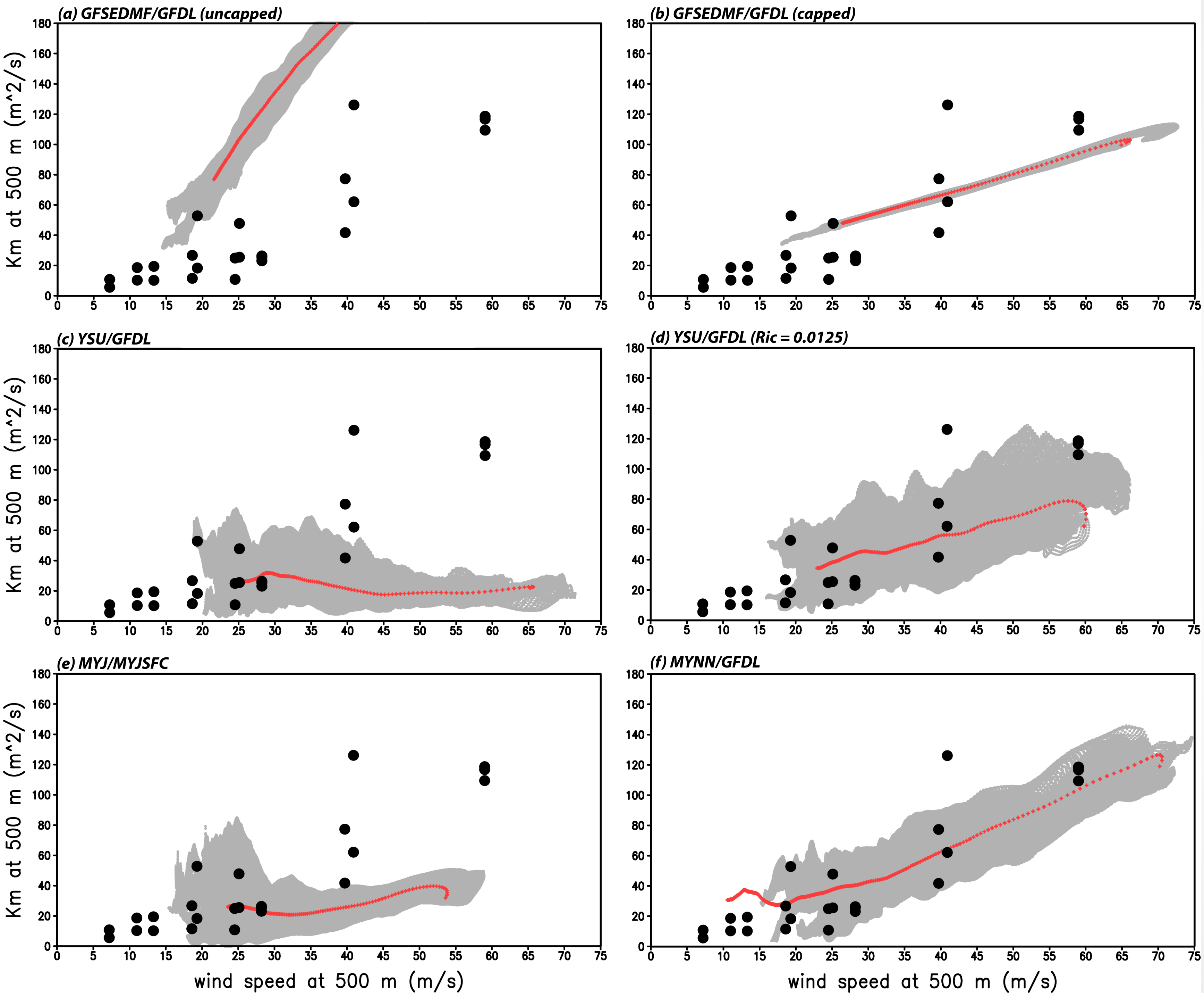
Data from Zhang et al. (2011a)

K_m estimated at 500 m MSL

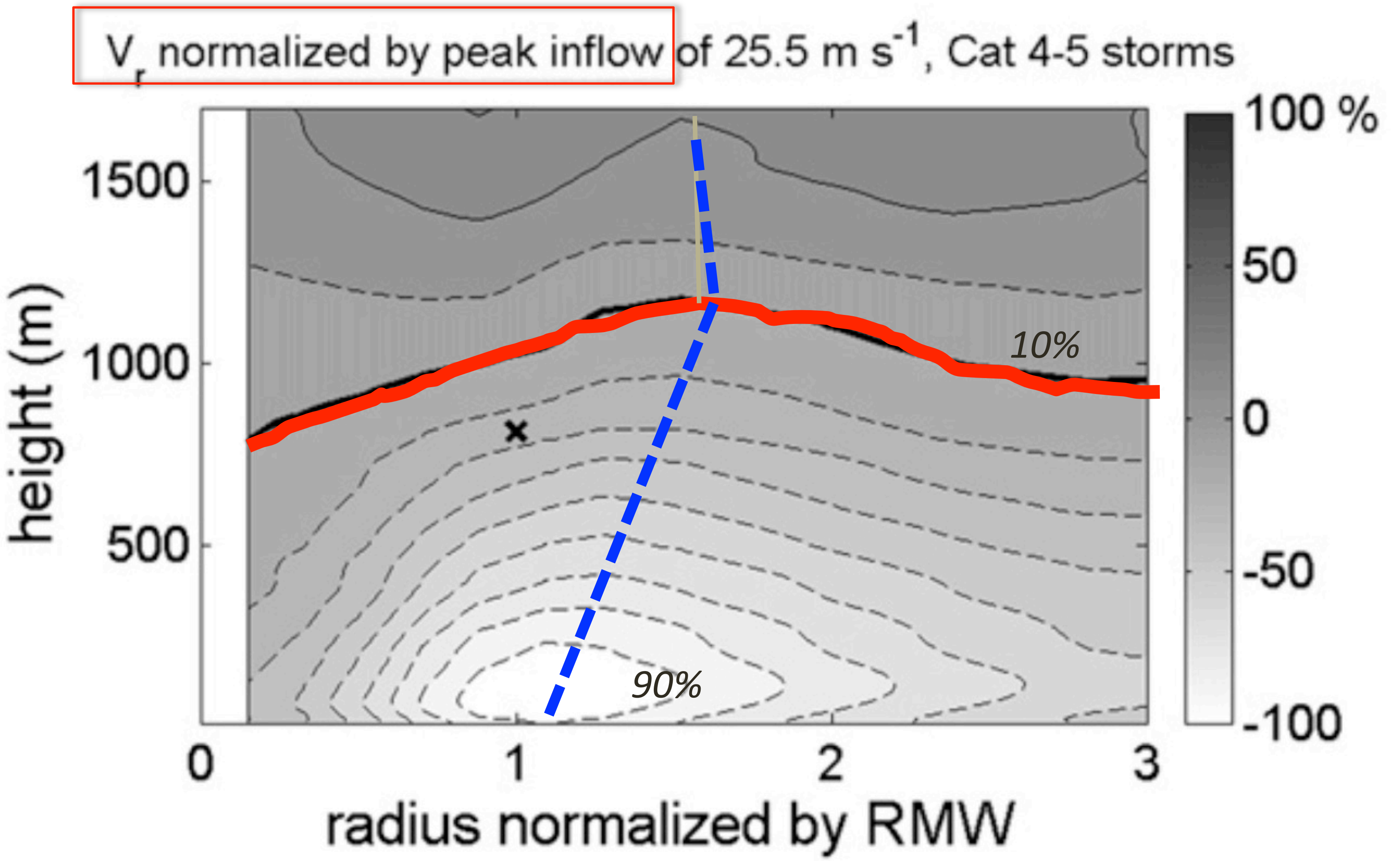


Difference is MYNN's mixing
into the eyewall updraft

Data from Zhang et al. (2011a)

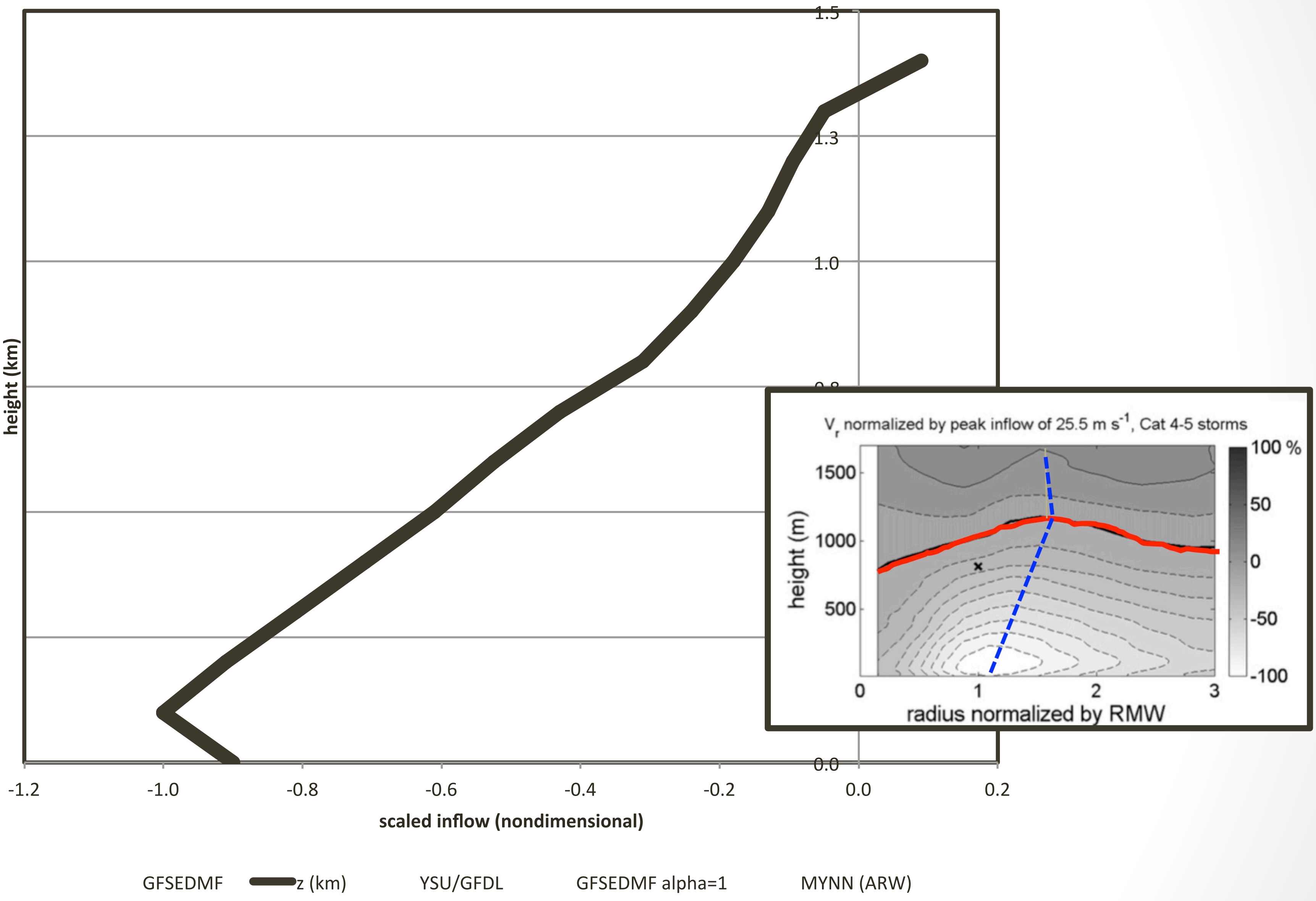

(a) GFSEDMF/GFDL (uncapped)
(b) GFSEDMF/GFDL (capped)
(c) YSU/GFDL
(d) YSU/GFDL (Ric = 0.0125)
(e) MYJ/MYJSFC
(f) MYNN/GFDL
Km at 500 m (m^2/s)
wind speed at 500 m (m/s)
0
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75

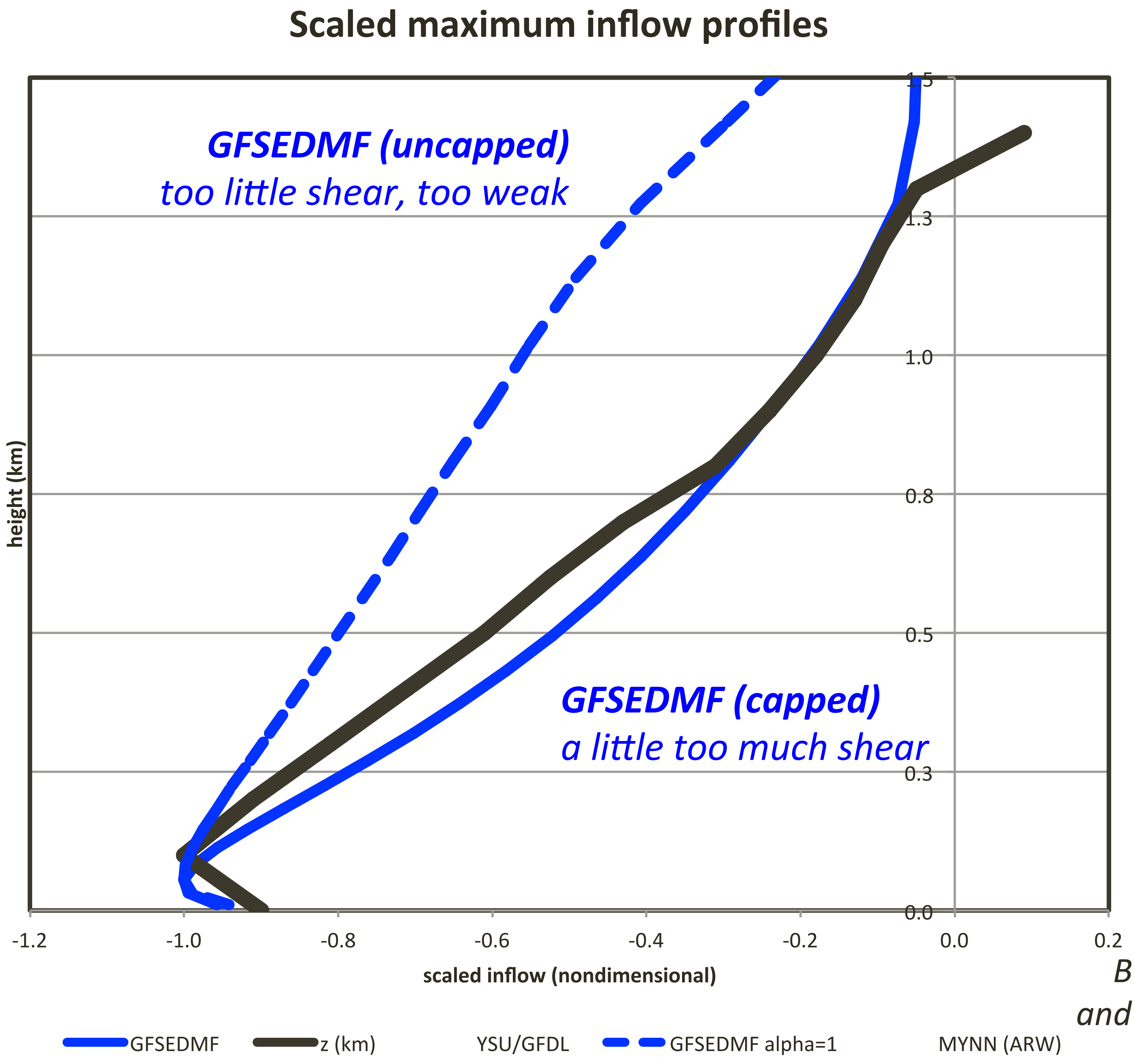
Normalized radial inflow composite



Zhang et al. (2011b)

Scaled maximum inflow profiles

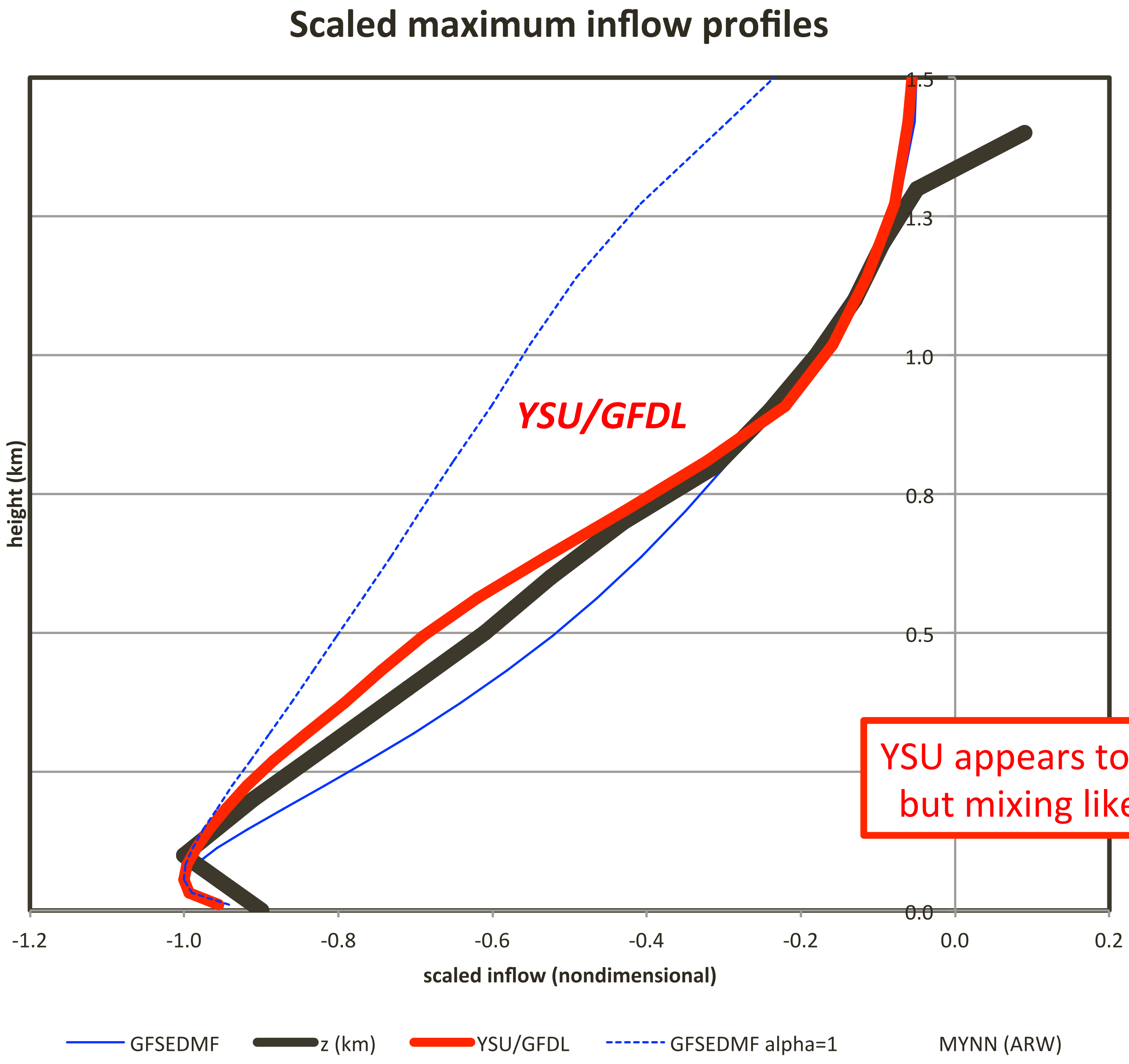




GFSEDMF (uncapped)
too little shear, too weak

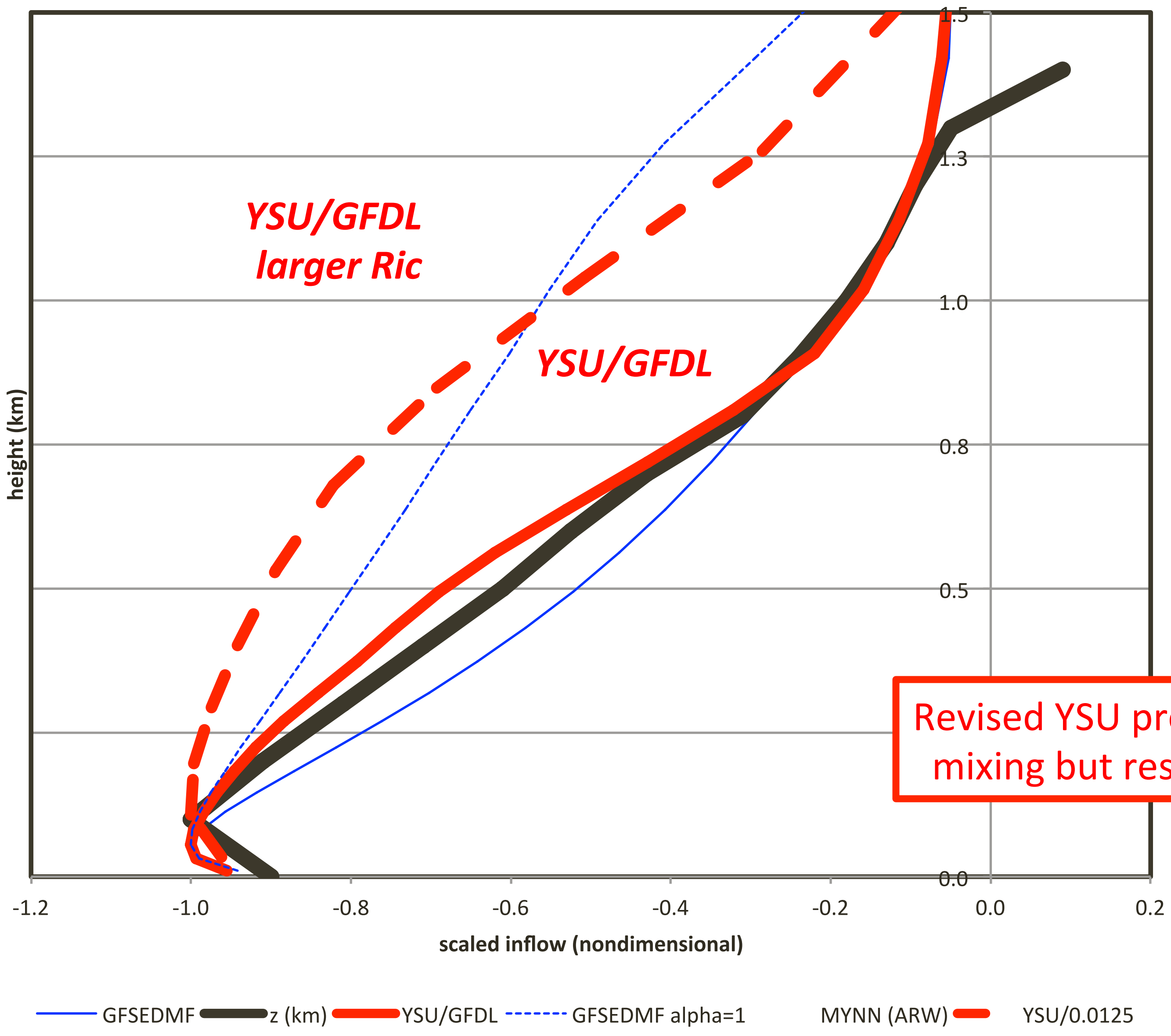
GFSEDMF (capped)
a little too much shear

Based on temporally and azimuthally-averaged inflow wind fields

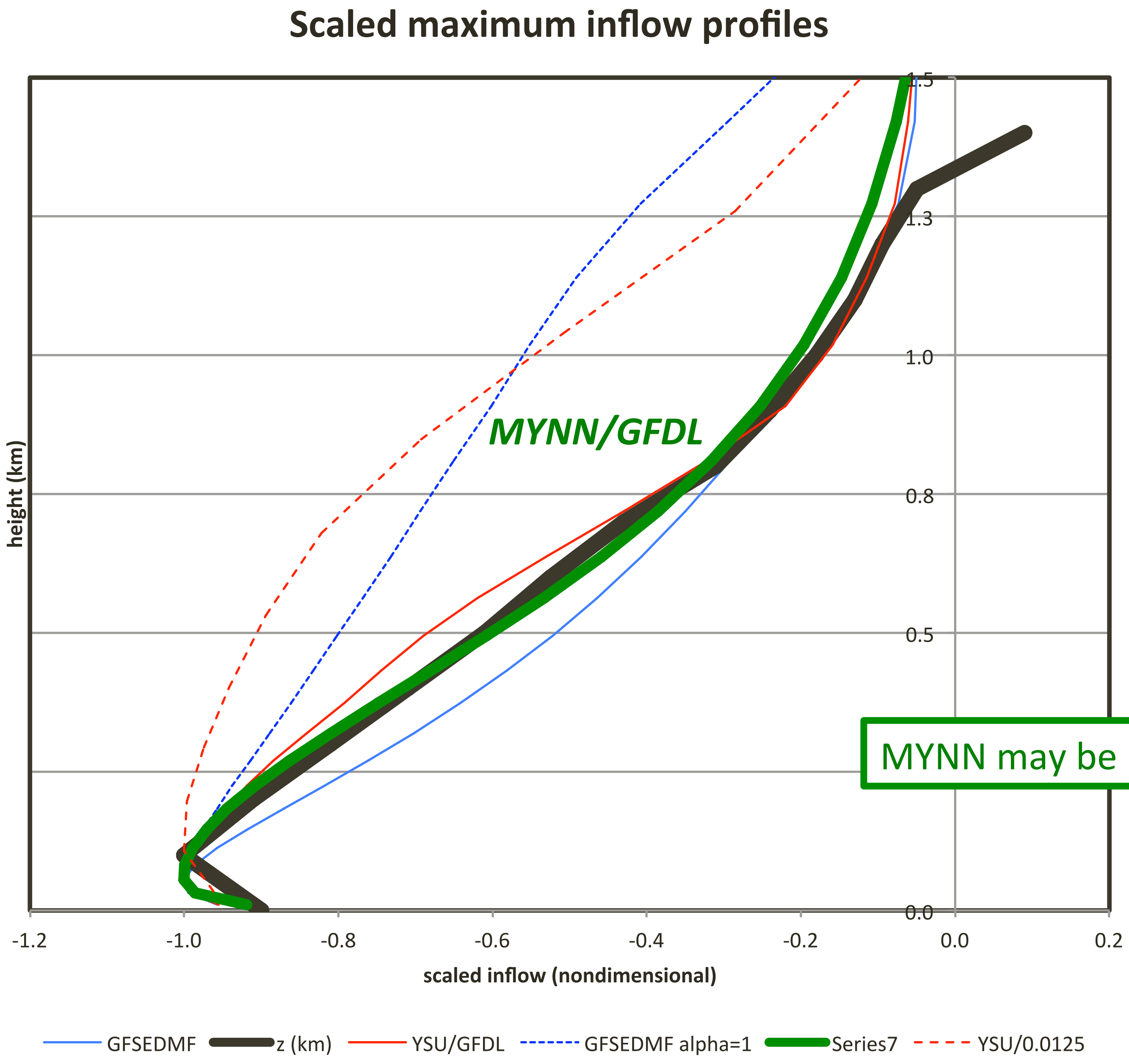


YSU appears to fit well
but mixing likely too shallow

Scaled maximum inflow profiles

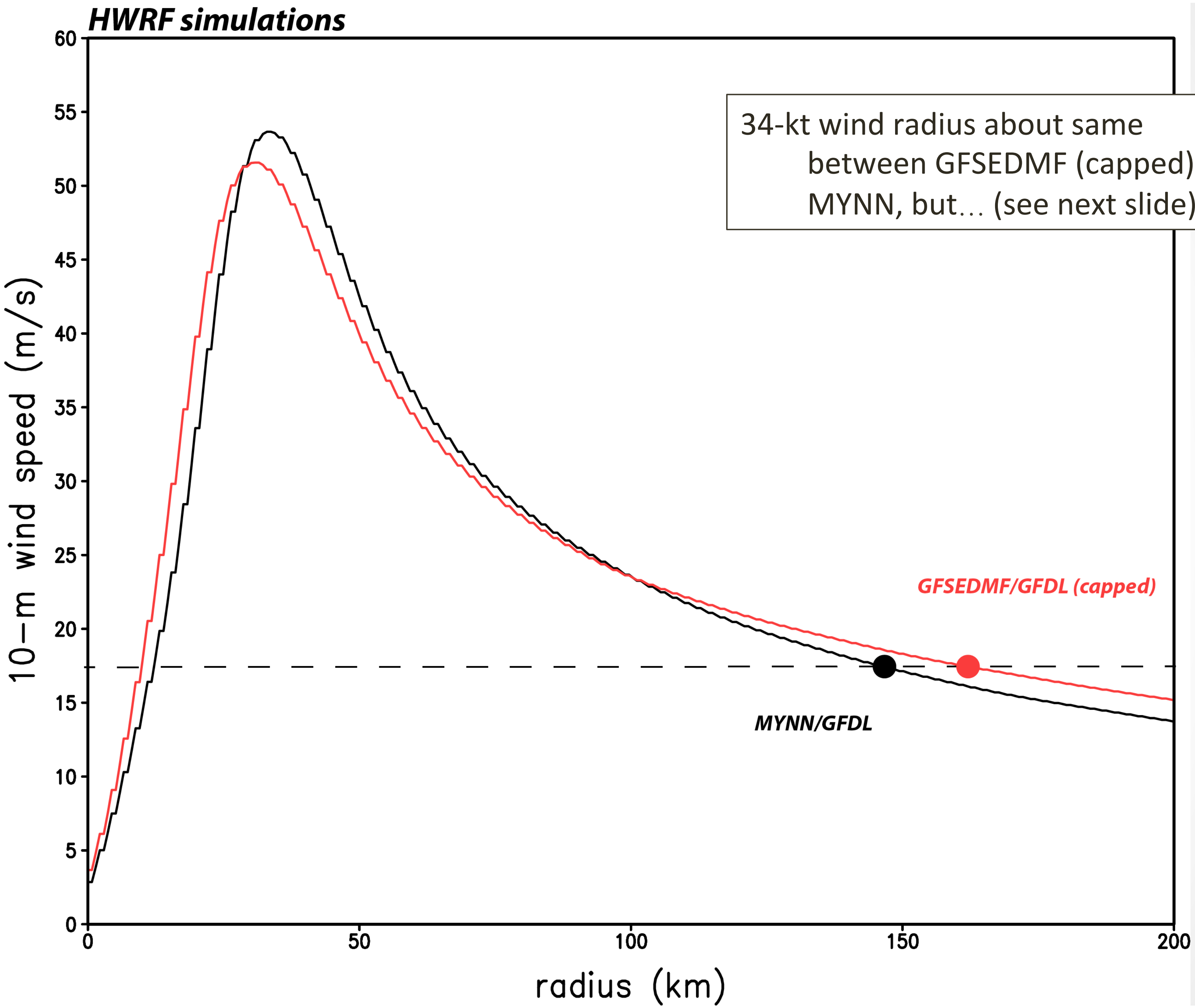


Revised YSU produces deeper mixing but results in less shear



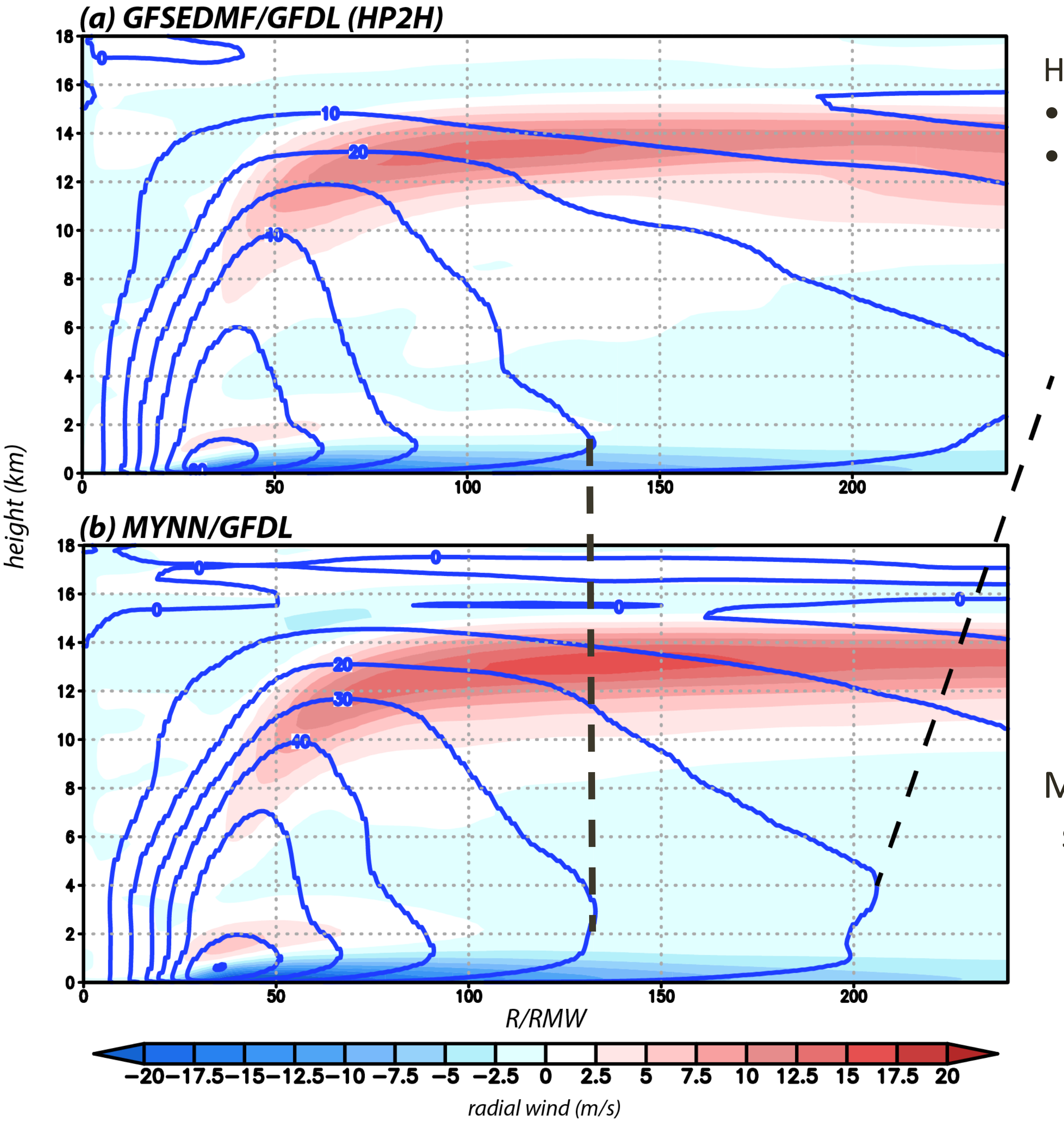
MYNN may be “less wrong”

Storm size comparison



34-kt wind radius about same between GFSEDMF (capped) and MYNN, but… (see next slide)

HWRF simulations (radial wind - shaded; tangential wind - contoured)



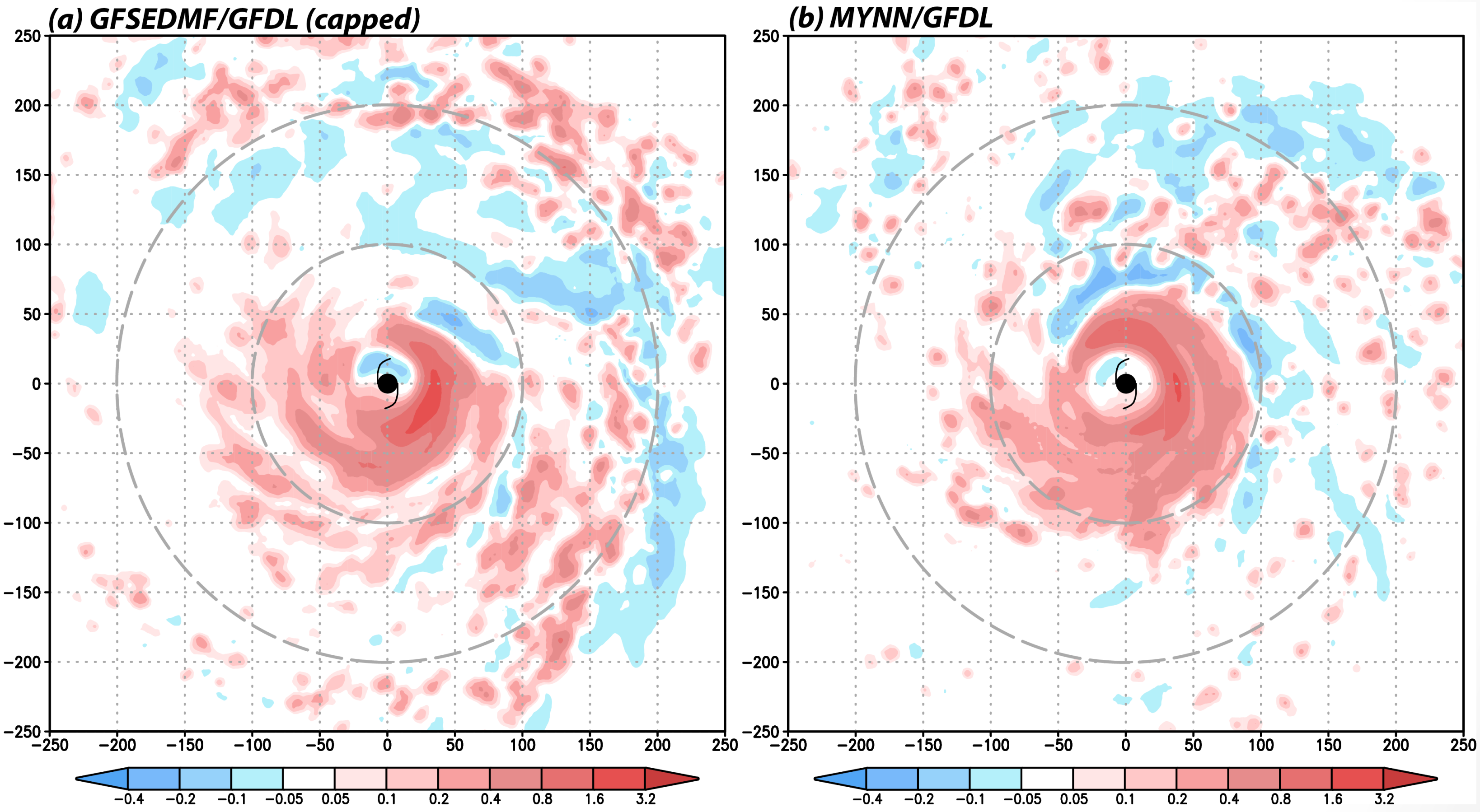
HWRF simulations:

- radial wind (shaded)
- tangential wind (contoured)

MYNN not as wide *above* surface at outer radii

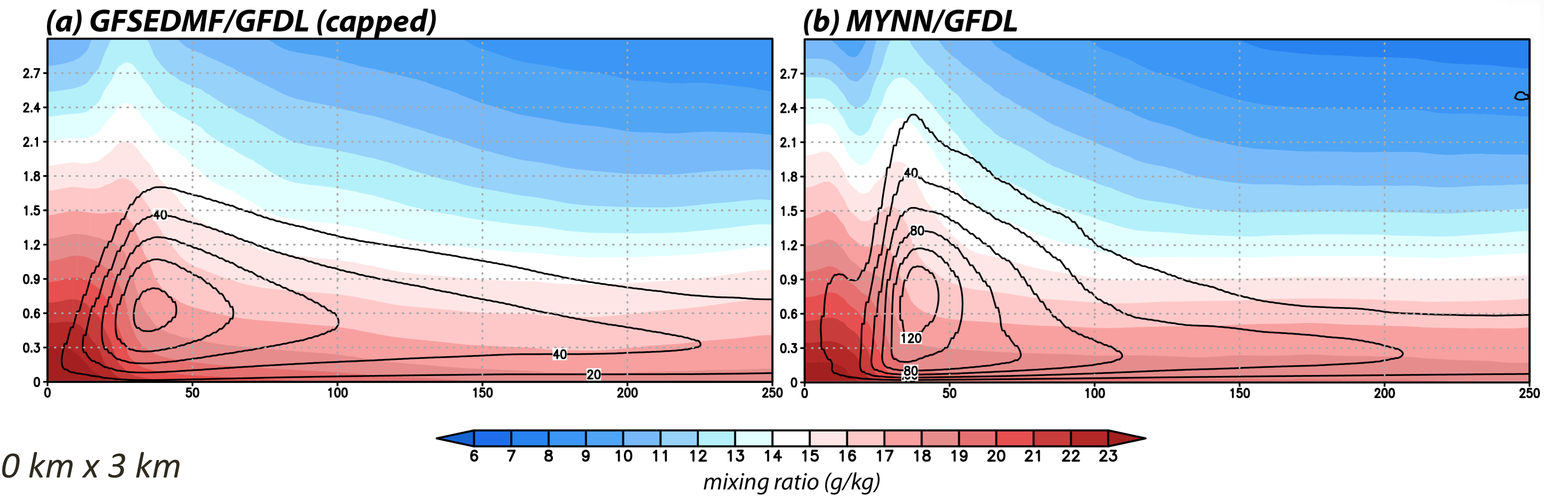
Surface-500 mb vertical velocity

500 km x 500 km



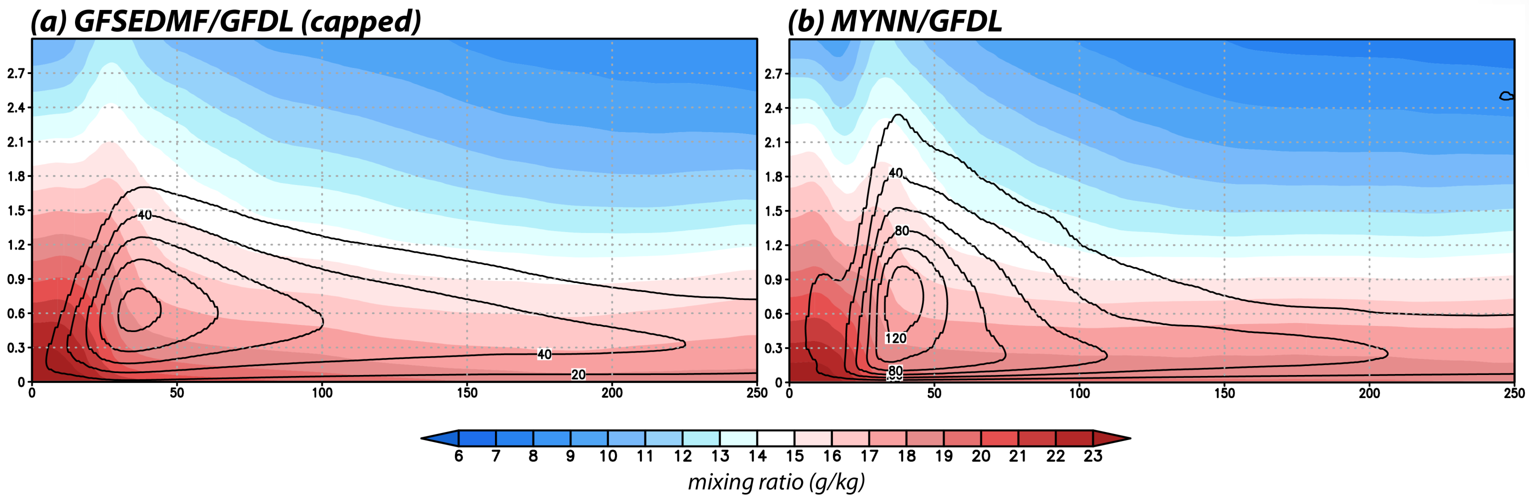
GFSEDMF: somewhat more peripheral convective activity

Vapor (shaded) and Km fields (contoured)



250 km x 3 km

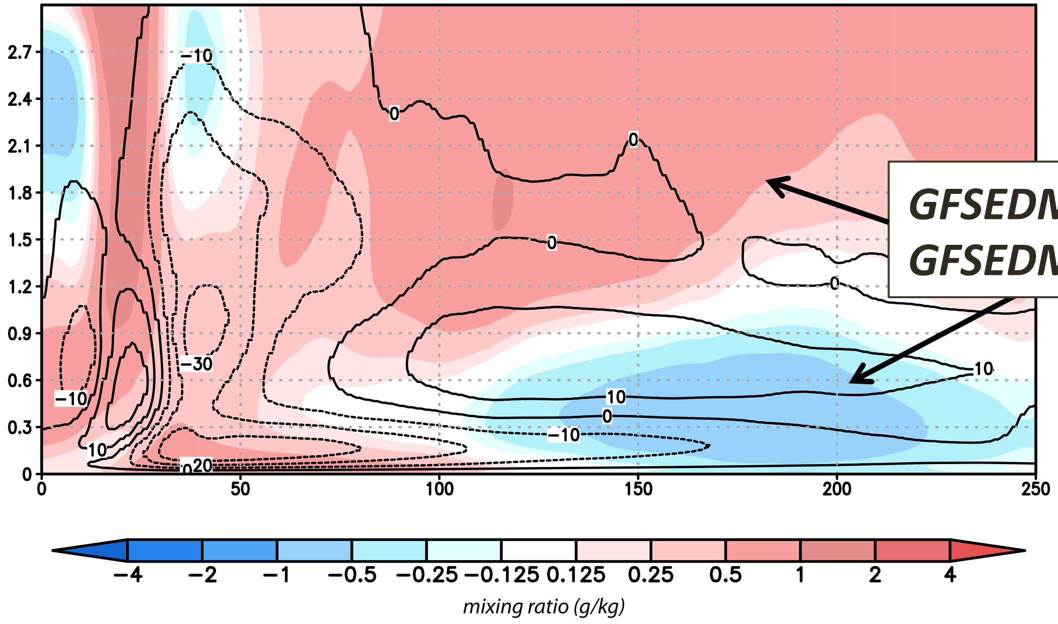
Vapor (shaded) and Km fields (contoured)



(a) GFSEDMF/GFDL (capped)

(b) MYNN/GFDL

Difference fields



GFSEDMF more vapor
GFSEDMF more mixing

Summary

- MYNN has been implemented in HWRF and adapted to GFDL surface layer scheme, for comparison with GFSEDMF (capped and uncapped), YSU/GFDL, and MYJ
  - Not all of MYNN scheme works yet: Level 3 version untested, mass flux stuff unimplemented, scale-aware code not perfectly correct
- In inner core, MYNN vertical inflow profile appears consistent with observations
- MYNN mixing is deeper, stronger up into eyewall than with YSU (more resemblance with GFSEDMF capped)
  - More congruent with estimates from available observations
- At larger radius, MYNN mixing is shallower and weaker than GFSEDMF capped (more resemblance with YSU)
  - This can affect storm size, via vertical vapor transport (cf. Bu et al. 2017)
- Other factors being equal, MYNN appears to provide reasonable results, without being “forced”. As a consequence, it might work in the hurricane core, in the hurricane periphery, over the open ocean, and over land
  - TKE schemes do have (known) deficiencies in non-TC environments