Some model physics influences on tropical cyclone size

Robert Fovell and Yizhe Peggy Bu
University of California, Los Angeles
rfovell@ucla.edu

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Background

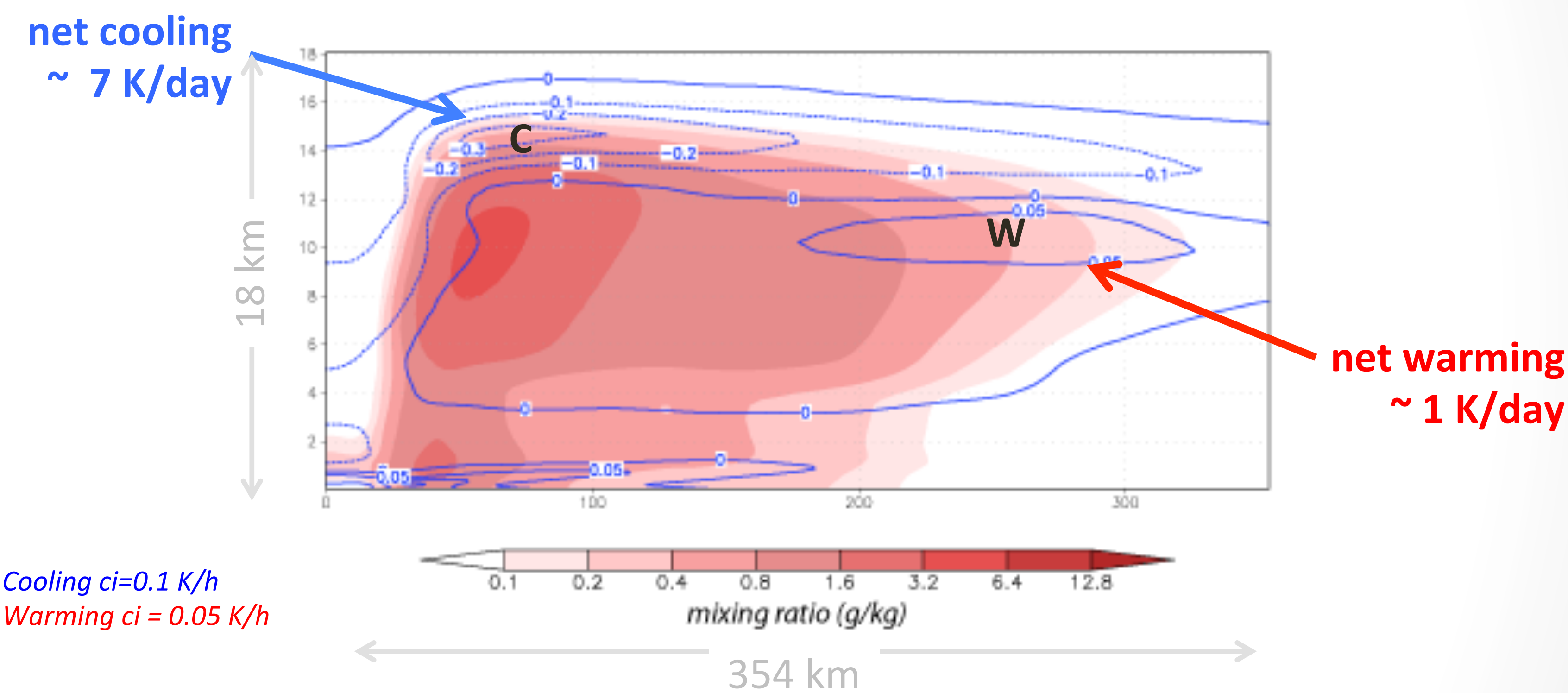
Bu et al. (2014)

Fovell et al. (2015)

Terminology

- “Semi-idealized” = experiments with simplified initial conditions utilizing operational model configurations as starting points
- “Cloud-radiative forcing” (CRF) = influence of hydrometeors on longwave and shortwave radiation
- CRF-on = total radiative forcing includes clear- and cloudy-sky components
- CRF-off = clouds transparent to radiation but clear-sky radiative forcing still ongoing

"Semi-idealized" HWRF experiment
Thompson/RRTMG



Cooling ci=0.1 K/h
Warming ci = 0.05 K/h

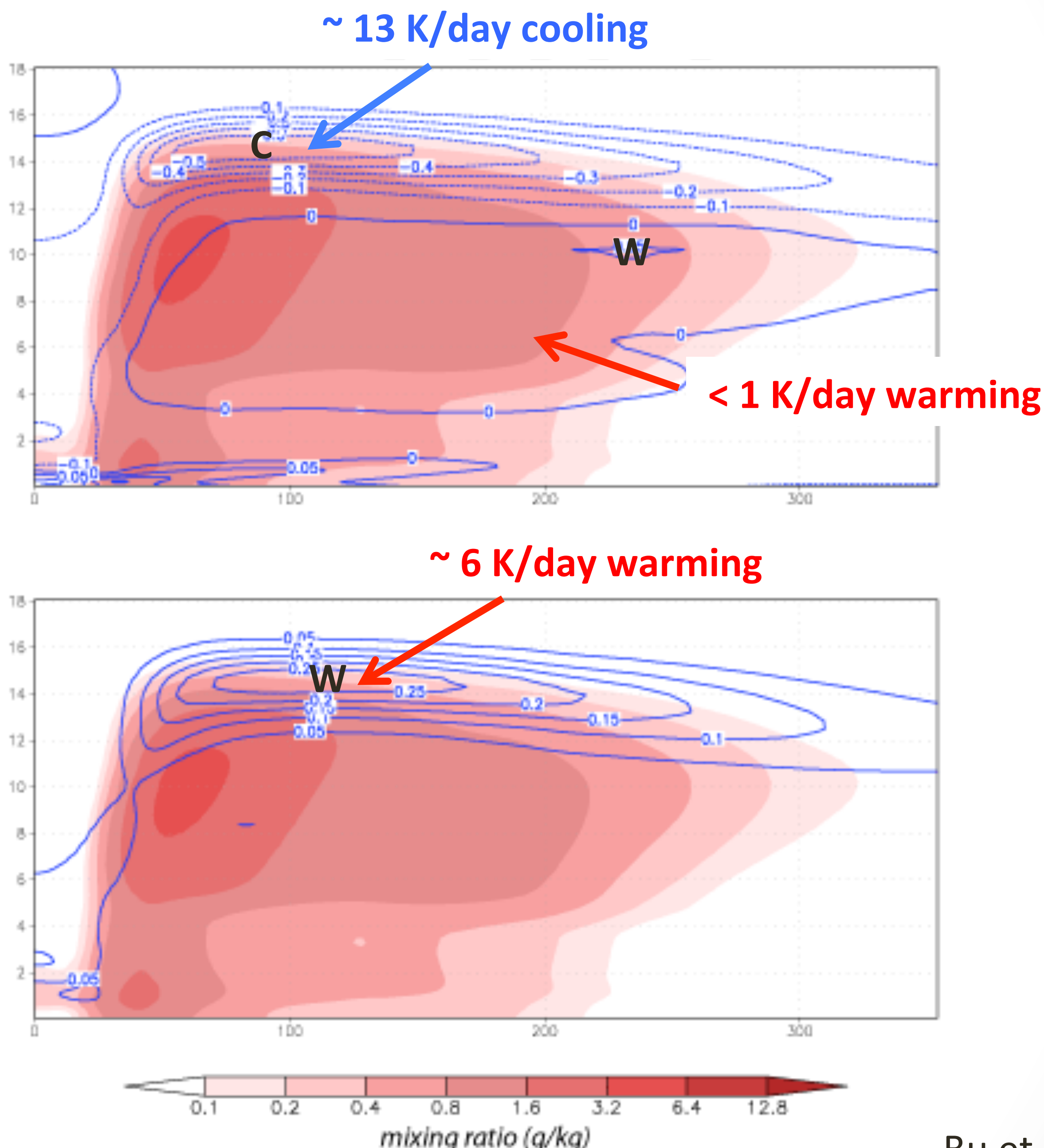
Condensate (shaded) and net radiative forcing (K/h)
(symmetric fields, temporally averaged through day 4)

Net radiation = LW + SW and includes background (clear-sky) forcing
Radiation contour interval differs for positive and negative values

Bu et al. (2014)

LW only

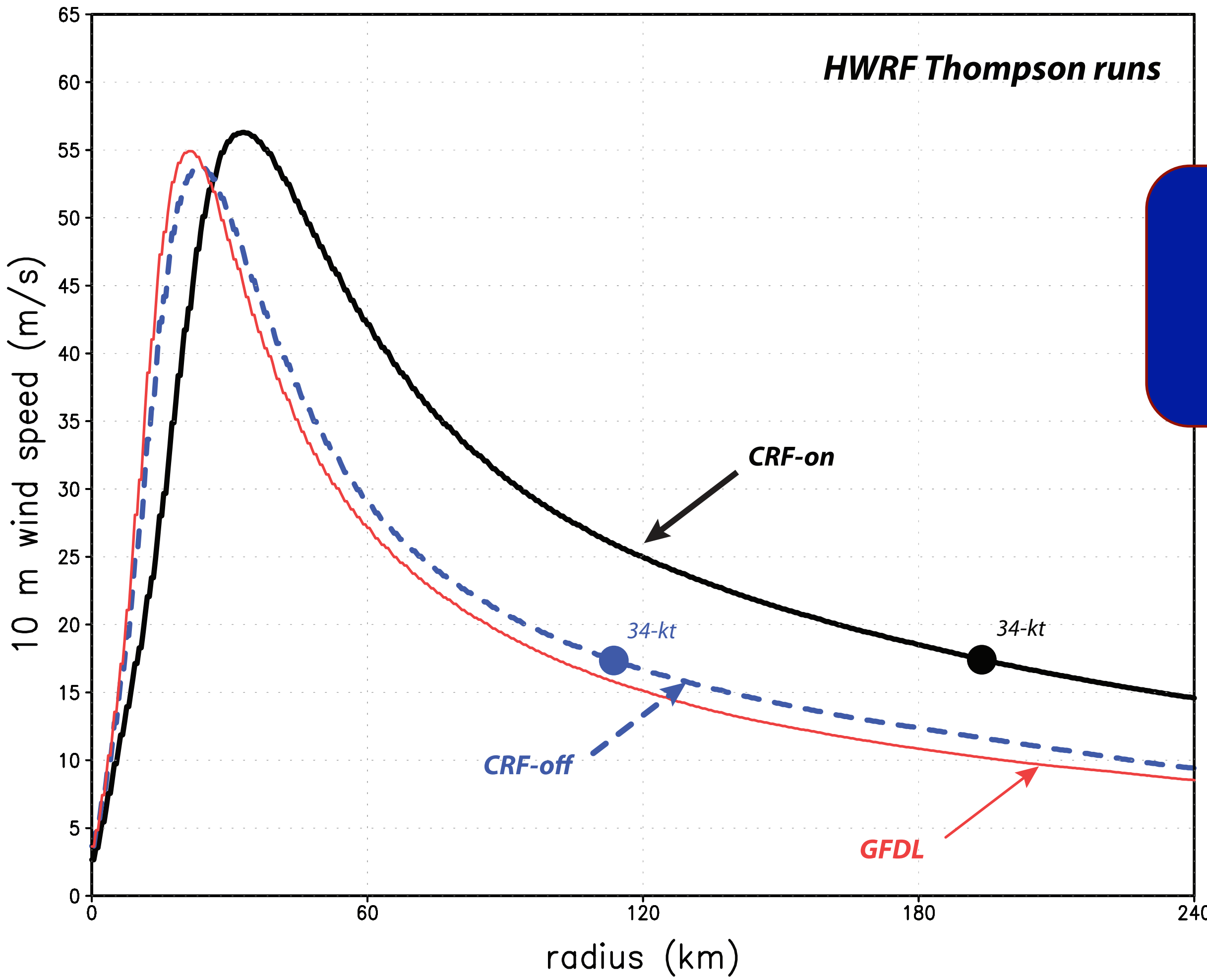
SW only



Bu et al. (2014)

"Semi-idealized" HWRF experiment

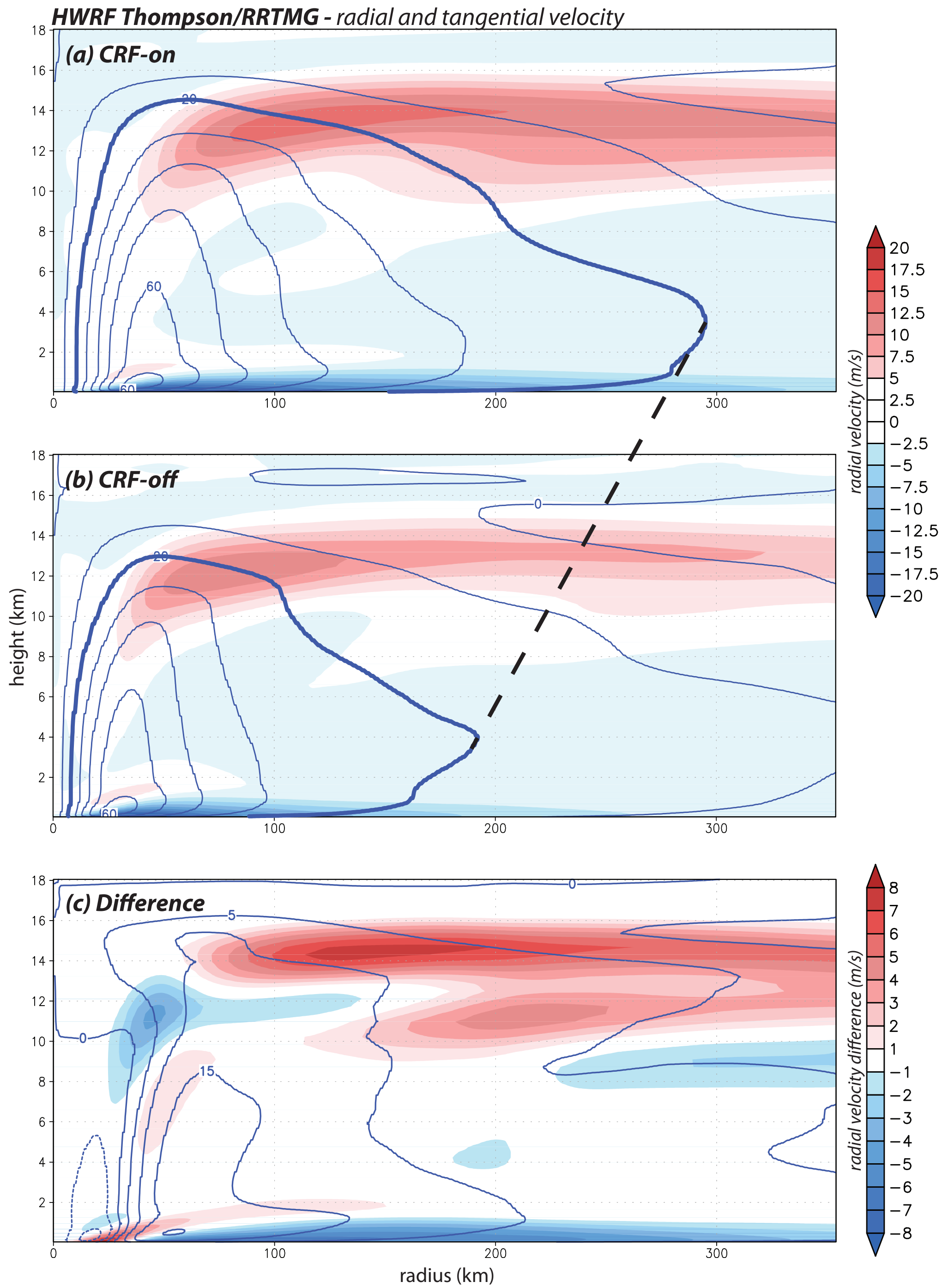
Thompson/RRTMG CRF-on and CRF-off
Thompson/GFDL



34-kt wind radius > 70% larger with CRF-on

Symmetric fields, temporally averaged through day 4

Bu et al. (2014)



Radial velocity (colored) &
Tangential velocity (contoured, m/s)

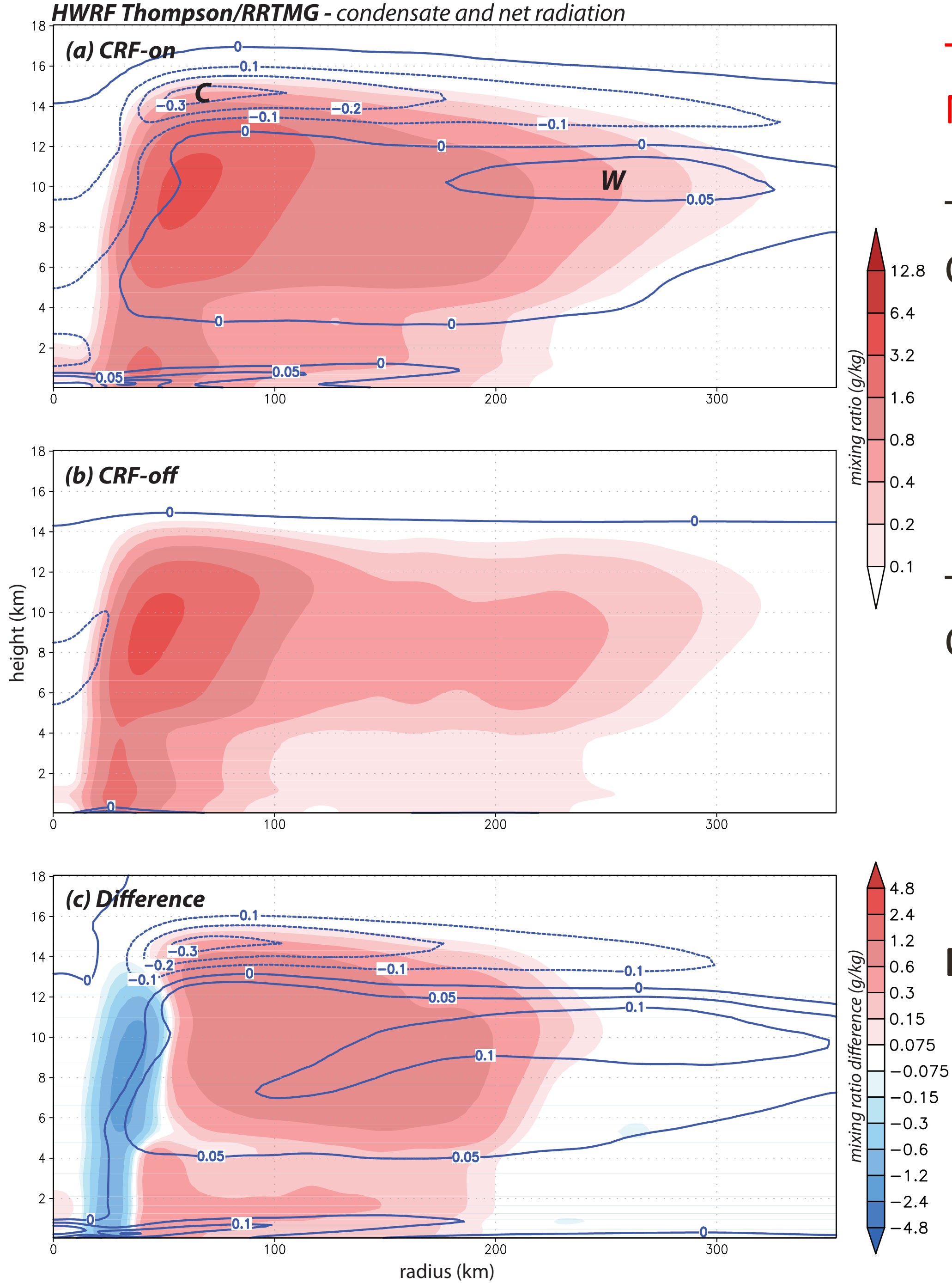
Thompson/RRTMG
CRF-on

Thompson/RRTMG
CRF-off

Symmetric fields, temporally averaged through day 4

Difference field

Bu et al. (2014)



Total condensate (colored) &
Net radiative forcing (contoured, K/h)

Thompson/RRTMG
CRF-on

Thompson/RRTMG
CRF-off

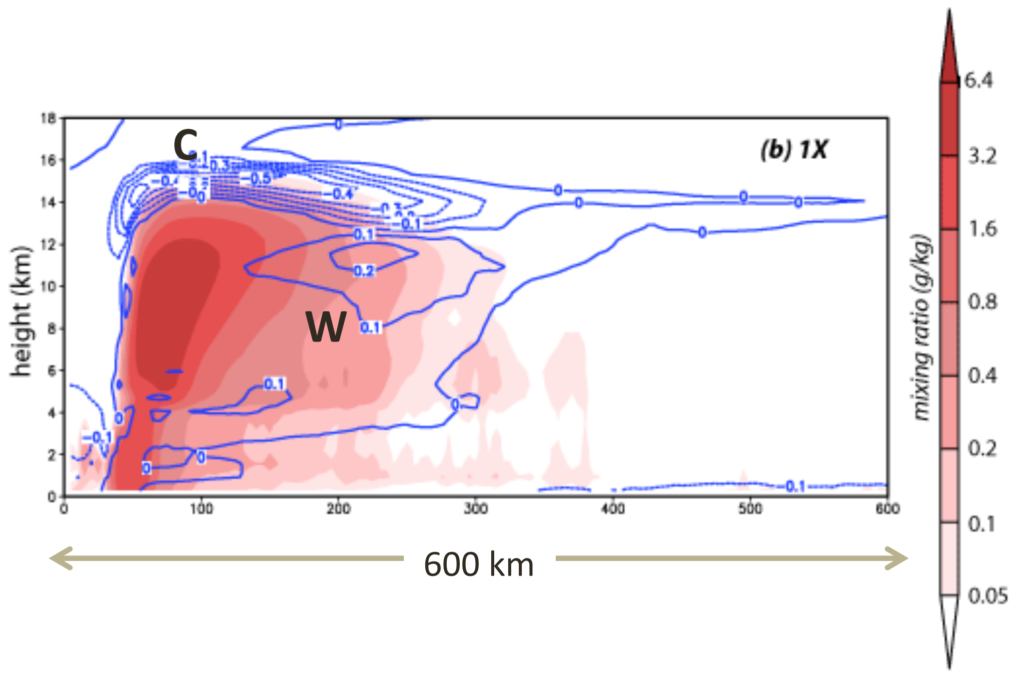
Symmetric fields, temporally averaged through day 4

Difference field

Bu et al. (2014)

CRF influences storm size

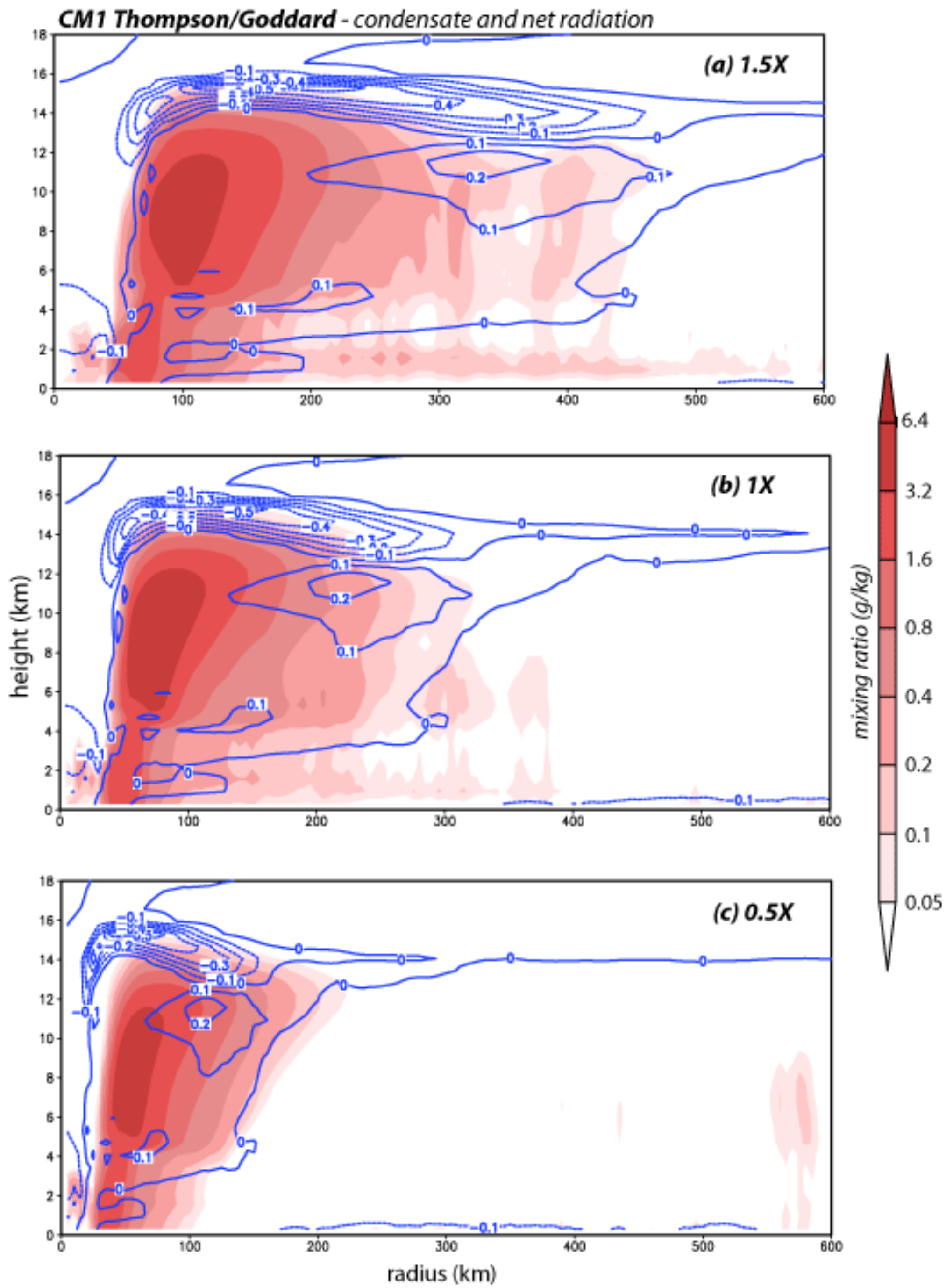
CM1 axisymmetric Thompson/Goddard



- Condensate and radiation fields in axisymmetric model
- Radiation field imposed as **external forcing**
- Showed that cloud-top forcing almost irrelevant. *Within-cloud LW warming is the key*.

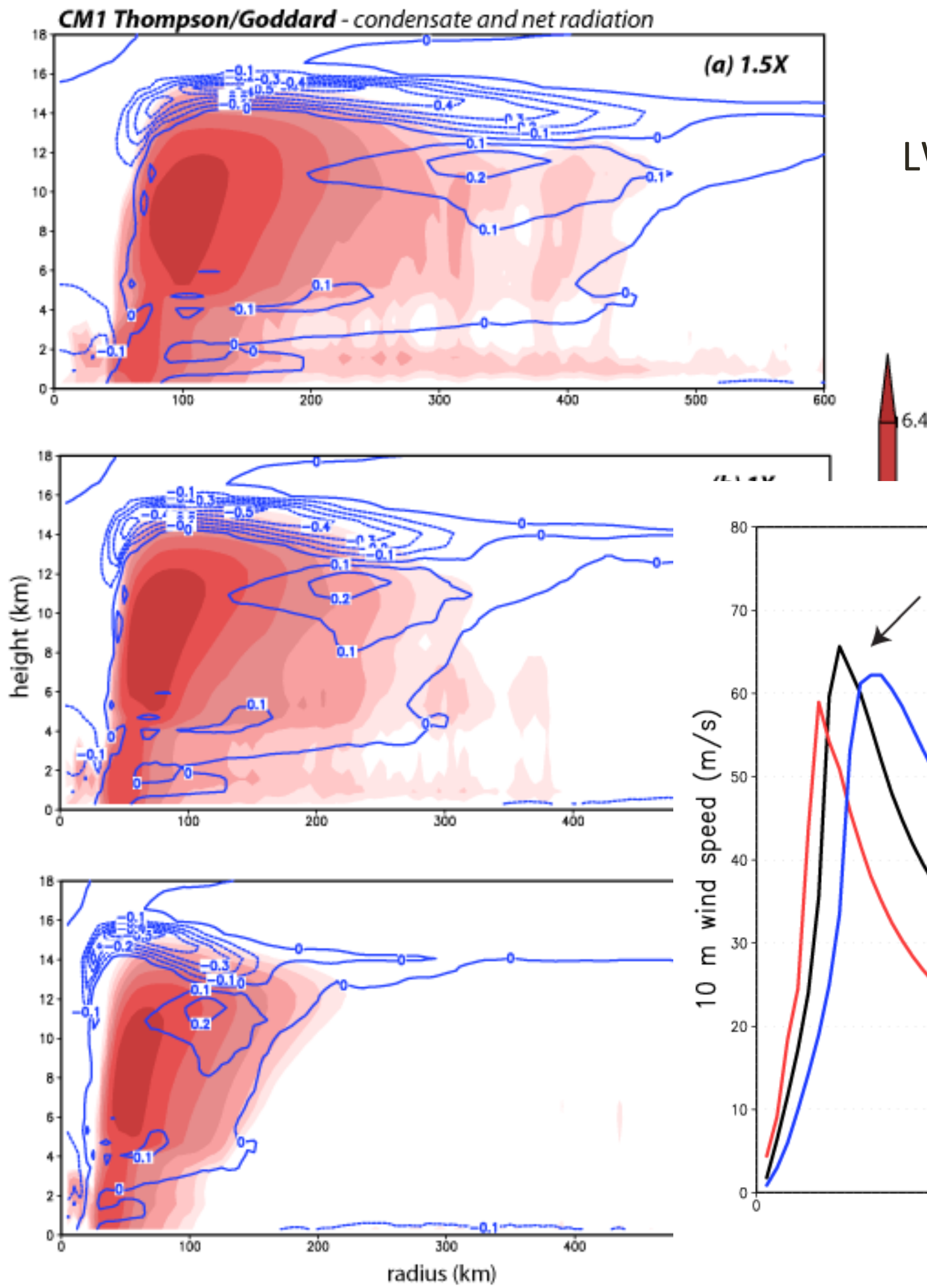
Symmetric fields, temporally averaged over several diurnal cycles

Bu et al. (2014)
Fovell et al. (2015)

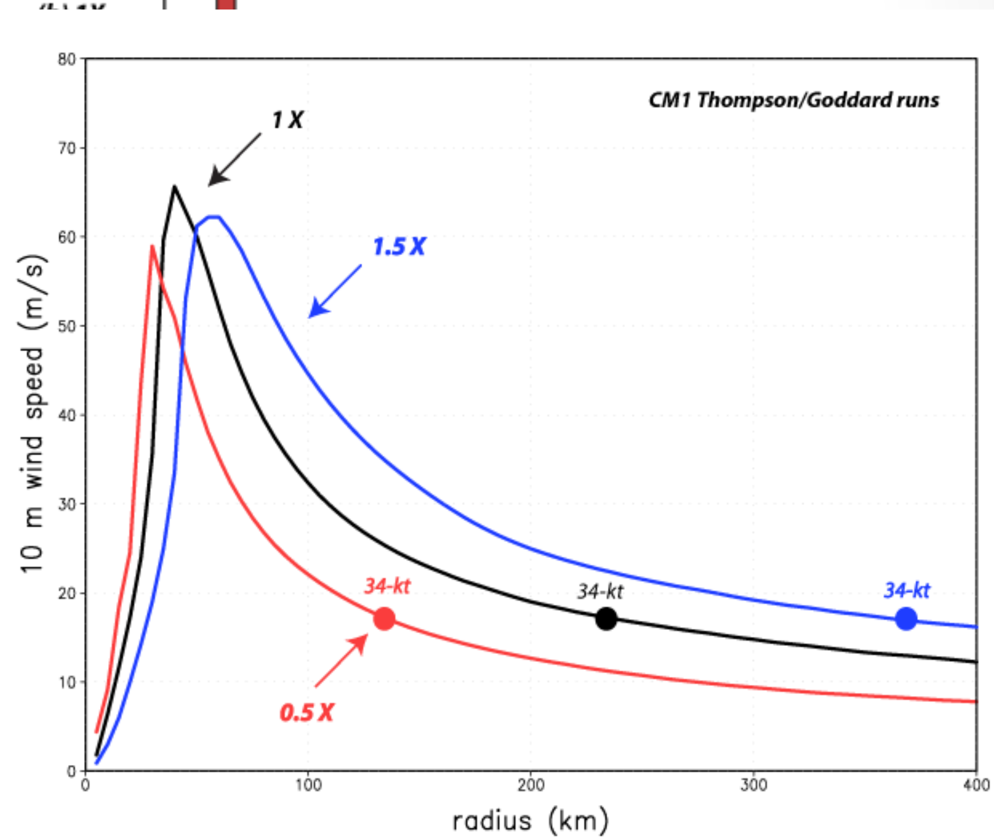


- **Expanded** radiation field
- Standard radiation field
- **Contracted** radiation field

Fovell et al. (2015)



LW warming → ascent
→ condensation heating
→ broadened wind field

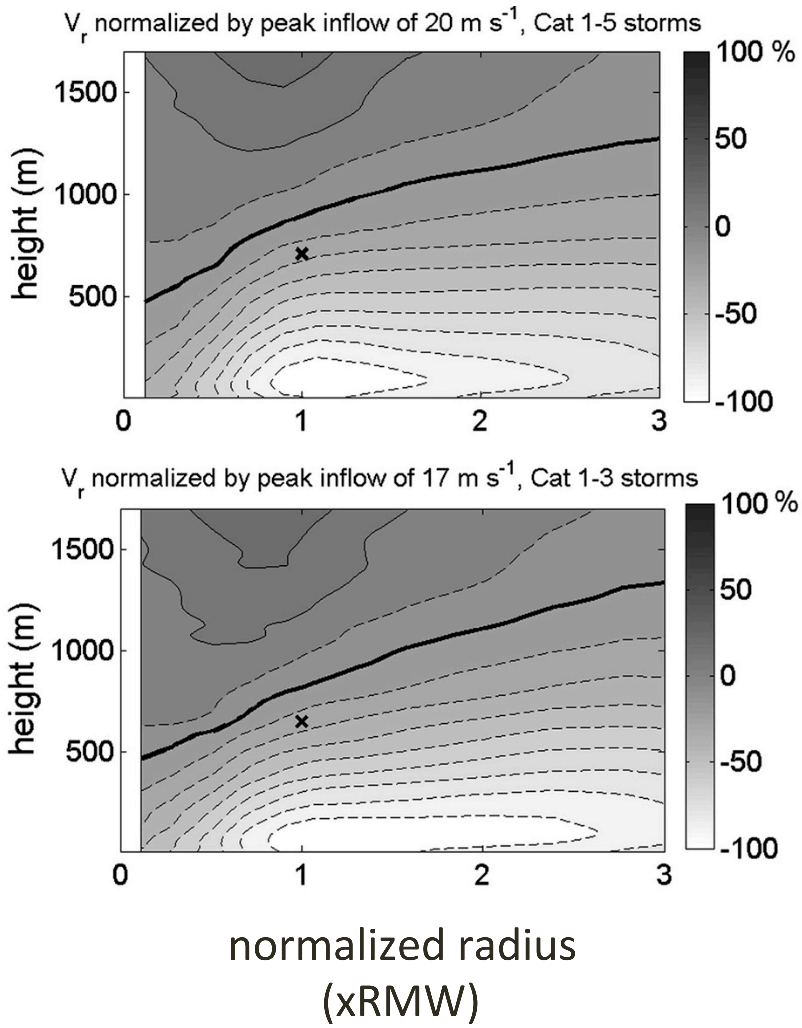


PBL influences on storm size

Zhang et al. (2011)

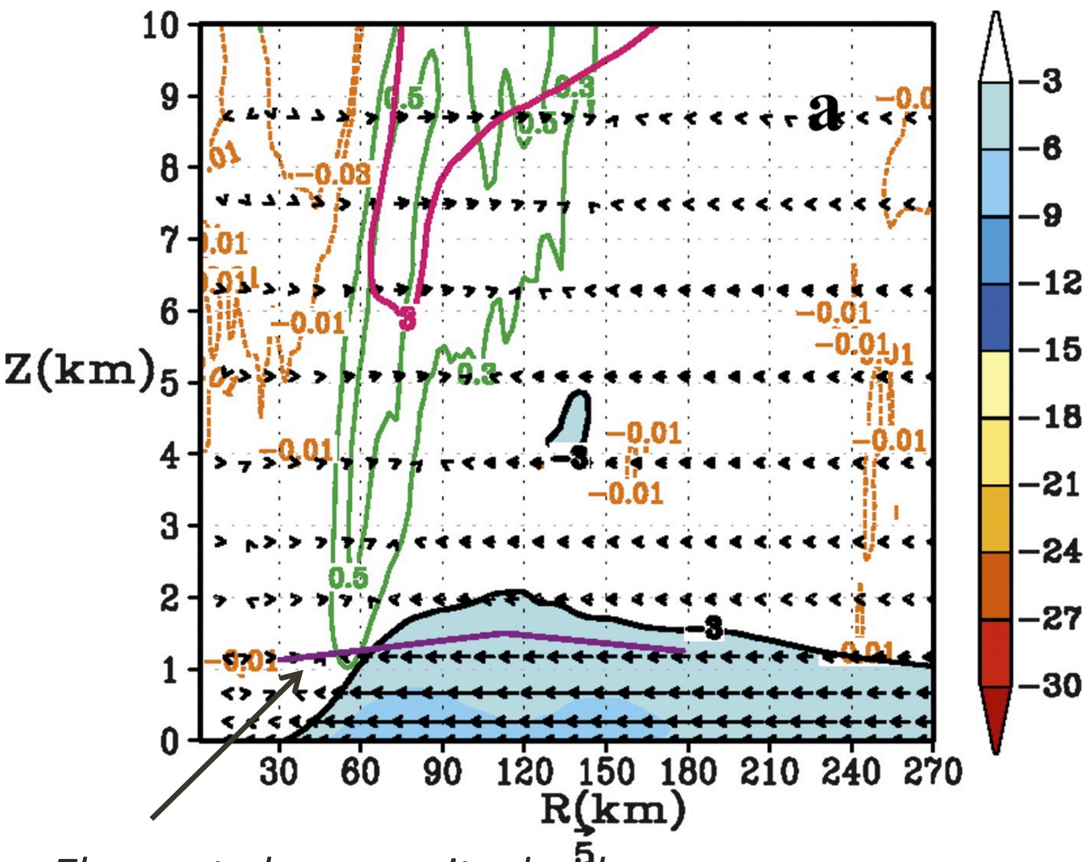
Gopalakrishnan et al. (2013)

Zhang et al. (2011)



- Composite radial inflow vs. normalized radius for Cat 1-5 (top) and Cat 1-3 storms
- BL top defined as **10% of max inflow** (one of several PBL depths examined)
- BL depth increases to ~ 1300 m by 3RMW

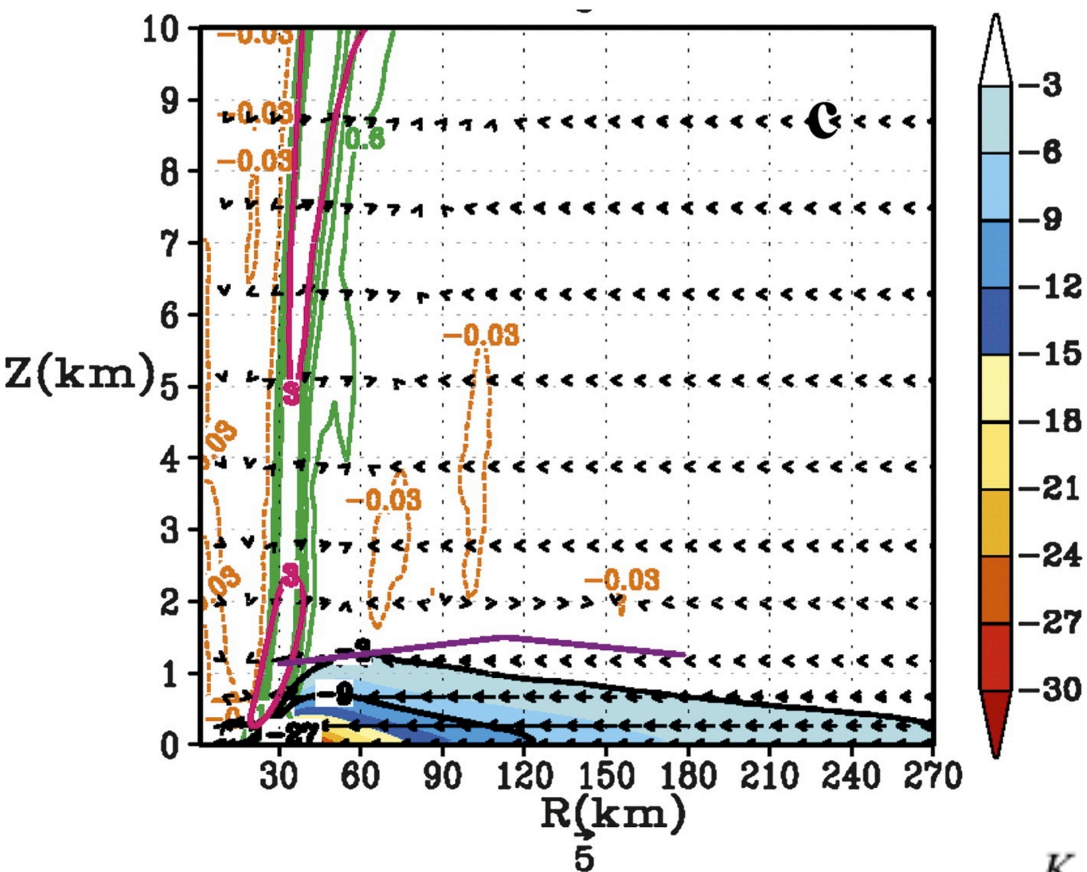
HWRF inner core inflow depth



Zhang et al. composite depth (purple line; for Cat 4-5?)

- Gopal et al. (2013) **idealized HWRF**
- inner-core inflow too deep relative to observations with standard GFS PBL scheme

HWRF inner core inflow depth

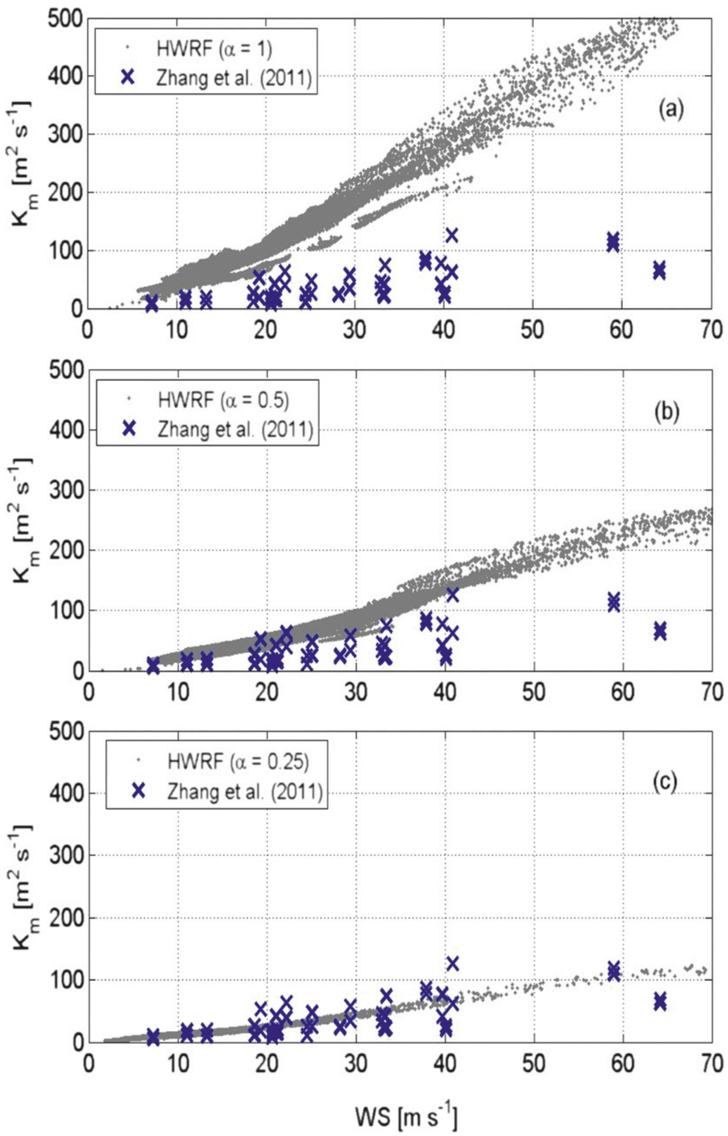


- Gopal et al. (2013) **idealized HWRF**
- depth more realistic, and RMW smaller when PBL diffusion *artificially suppressed*
- **α = 0.25 (“`gfs_alpha`”)**

$$K_m = k(U_*/\Phi_m)Z[\alpha(1 - Z/h)^2],$$

Tuning the PBL scheme

`gfs_alpha` parameter



$$K_m = k(U_*/\Phi_m)Z[\alpha(1 - Z/h)^2],$$

- **α = 0.25** fits Zhang et al.'s estimates of eddy diffusivity best
- 2012 operational HWRF used **α = 0.25** (in nests)
- 2013 operational HWRF used **α = 0.7**, and added variable Ric factor

Gopal et al. (2013)

Note in passing:
Two separate approaches to controlling the hurricane PBL now exist in HWRF

`(1) gfs_alpha`

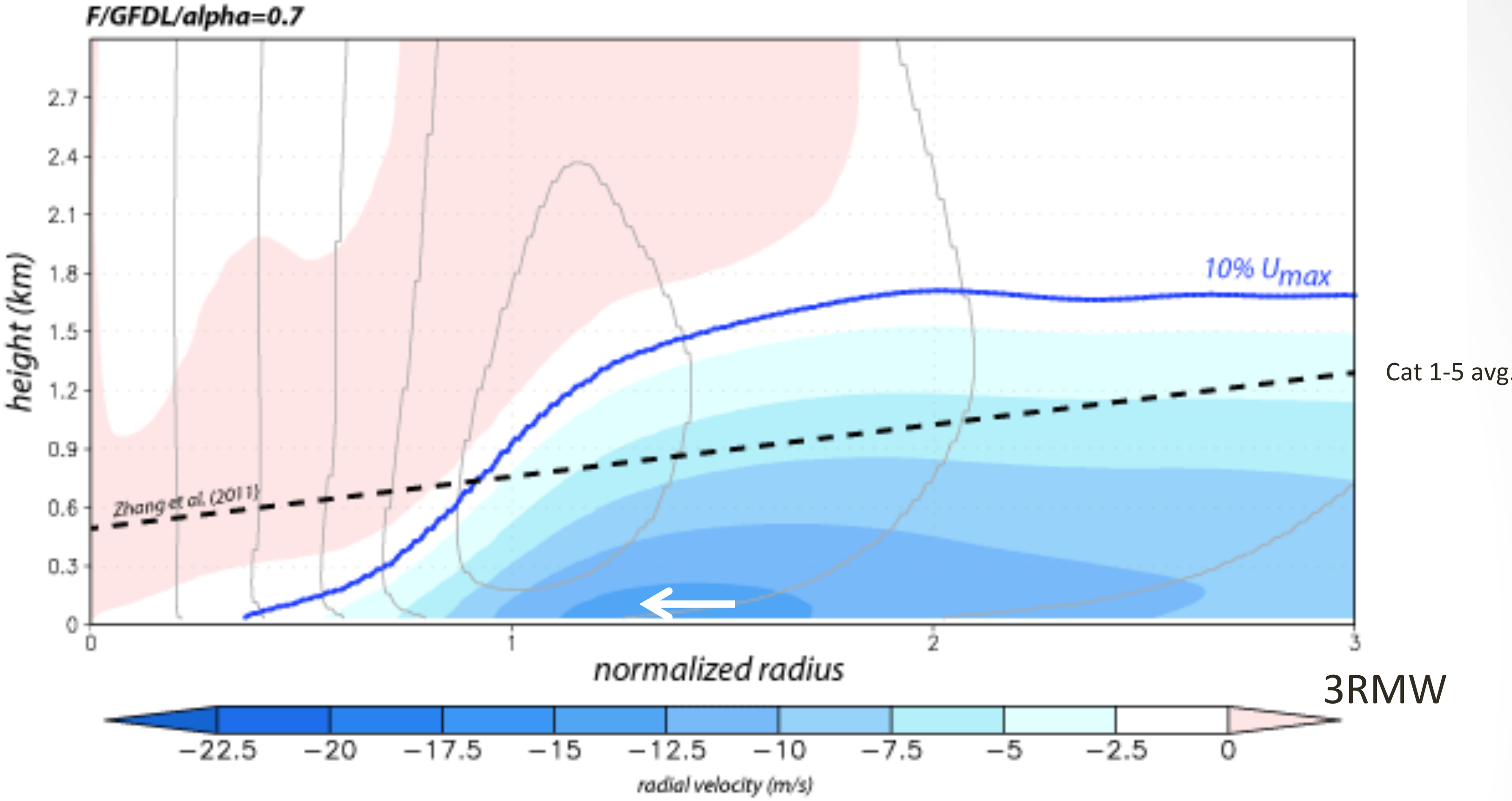
`(2)` Variable critical Richardson number (`var_ric`), added in 2013

- So far, semi-idealized aquaplanet experiments suggest `var_ric` in isolation has little impact on storm width, a small influence on intensity, and a **cosmetic** effect on reported PBL height (see **Appendix**)

Impact of `gfs_alpha` on storm size in semi-idealized simulations

`gfs_alpha` acts similarly to CRF, but for different reason…

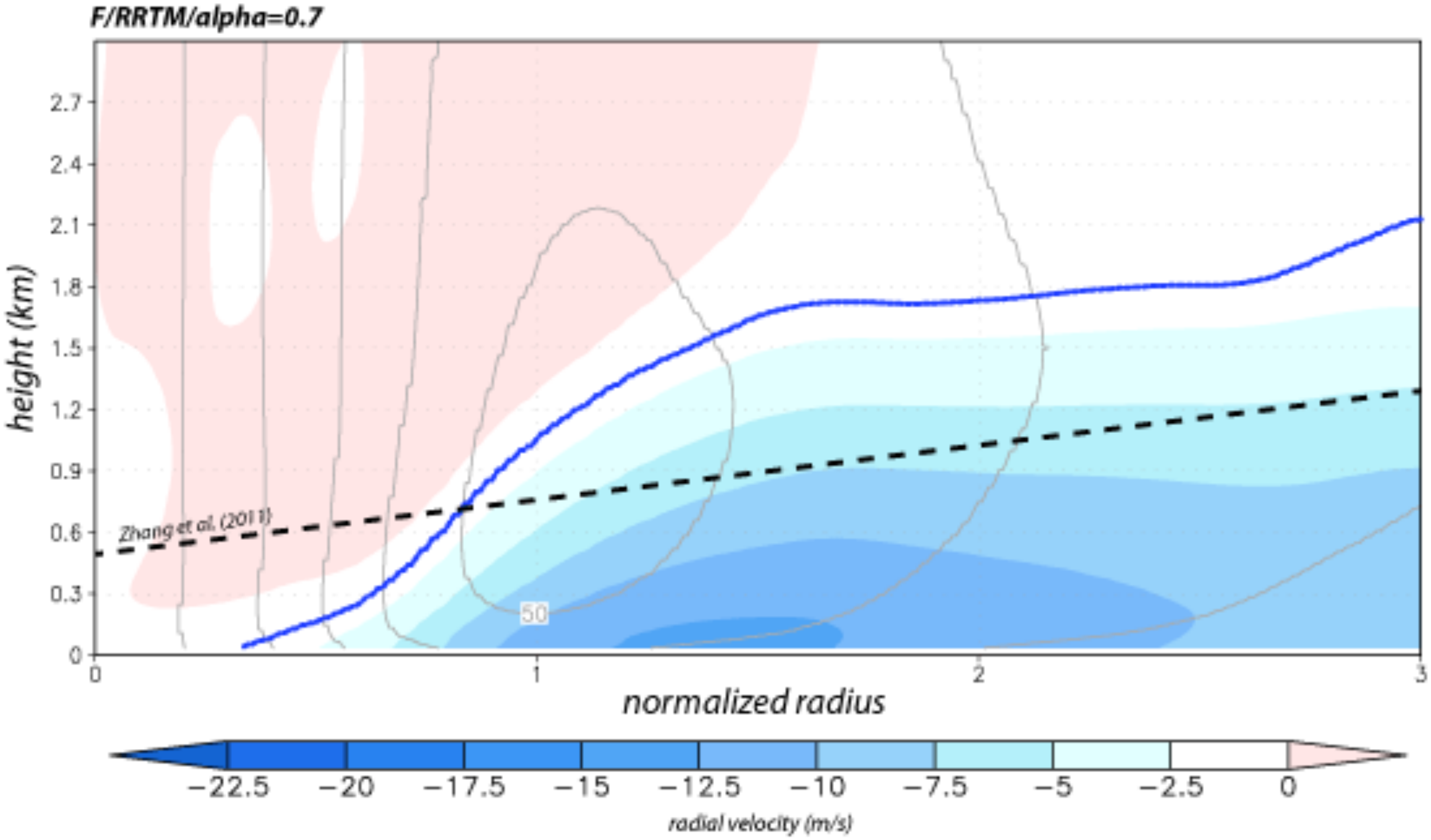
Simulations use HWRF 2013 official release via DTC



- Symmetric radial and tangential winds
  hours 72-96

- Operational configuration
  gfs_alpha = 0.7, 0.7, 0.7 (in 2013)
  coac = 0.75, 3.0, 4.0
  Ferrier MP
  GFDL radiation
  Variable Ri

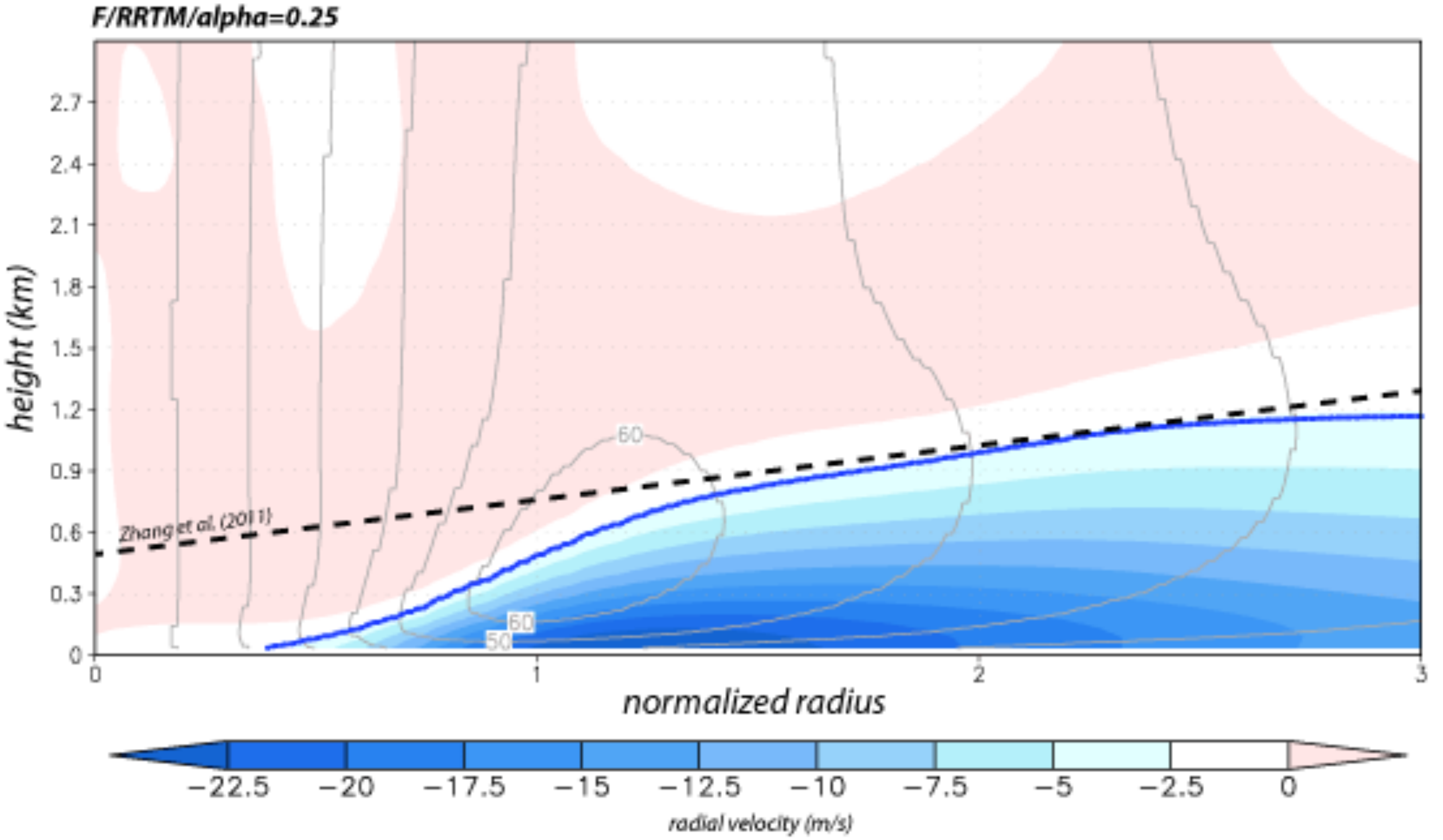
- **Differences** from operations
  2012 domain configuration
  simplified initial conditions, no land
  no ocean model coupling
  model physics called every time step



- Symmetric radial and tangential winds
  hours 72-96

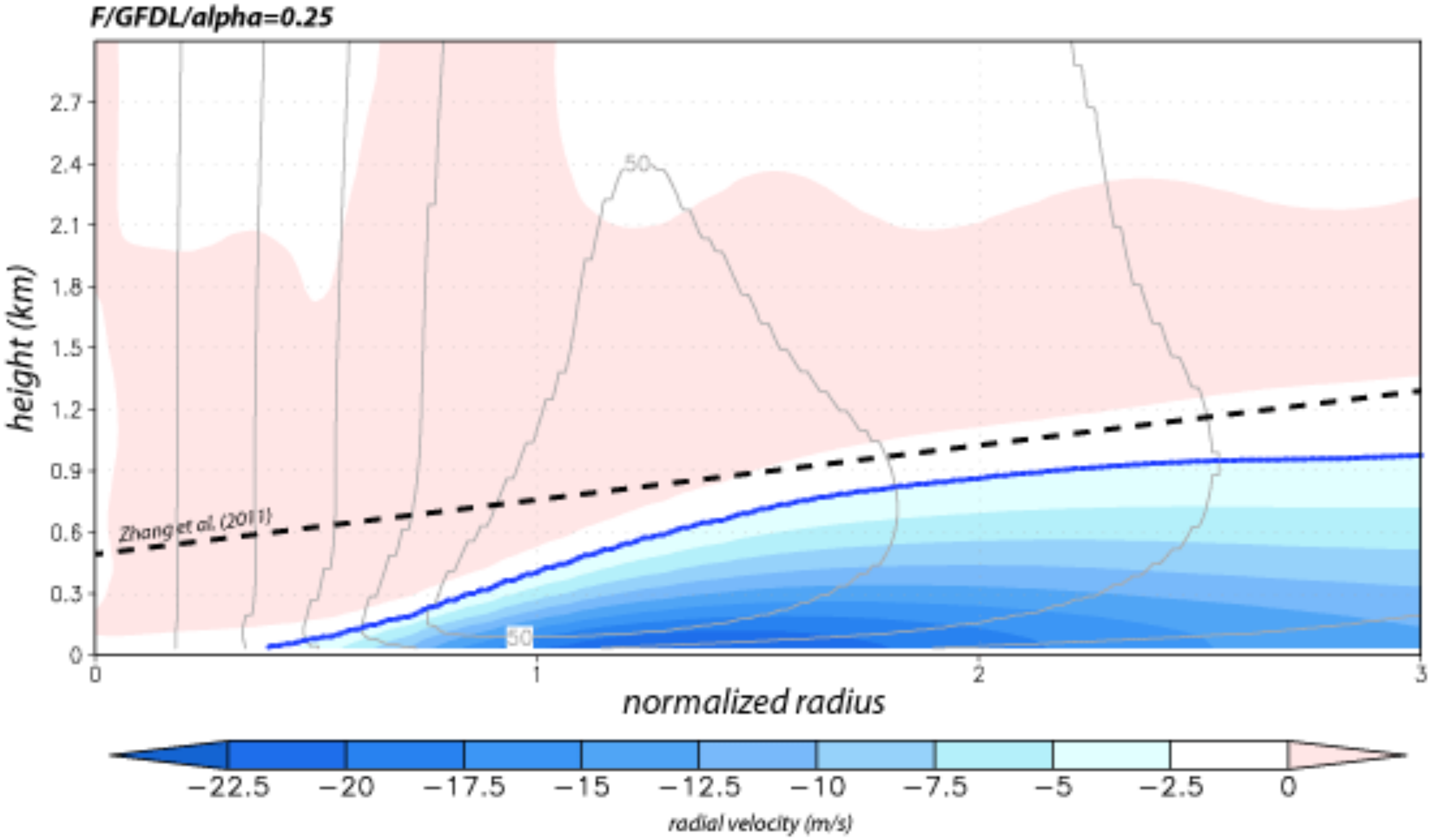
- **Modified** configuration
  gfs_alpha = 0.7, 0.7, 0.7
  coac = 0.75, 3.0, 4.0
  Ferrier MP
  RRTMG radiation
  Variable Ri

Horizontal size differences obscured by nondimensionalization



- Symmetric radial and tangential winds
  hours 72-96

- **Modified** configuration
  gfs_alpha = 1.0, 0.25, 0.25 (as used in 2012)
  coac = 0.75, 3.0, 4.0
  Ferrier MP
  RRTMG radiation
  Variable Ri



- Symmetric radial and tangential winds
    hours 72-96

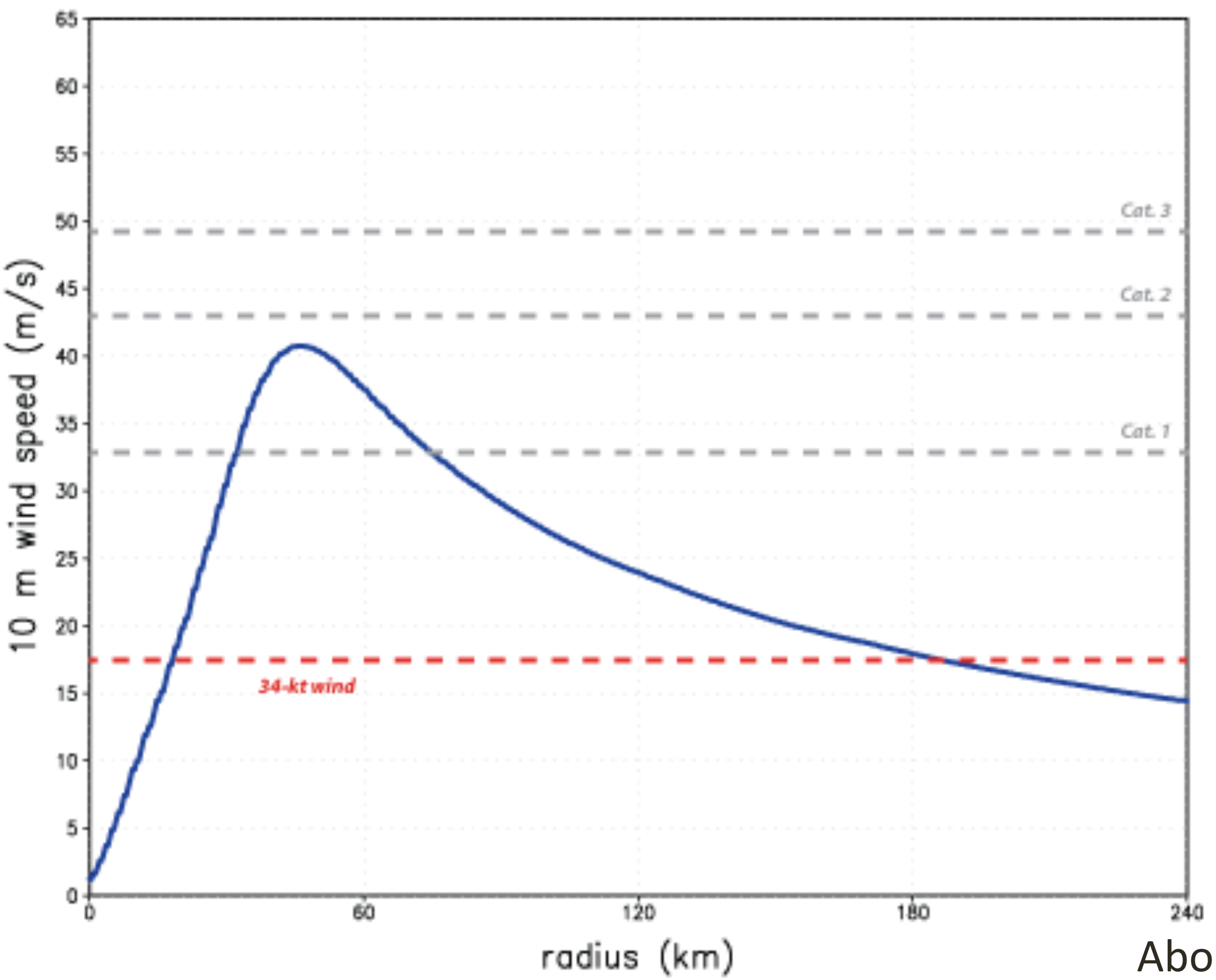
- **Modified** configuration
    gfs_alpha = 1.0, 0.25, 0.25
    coac = 0.75, 3.0, 4.0
    Ferrier MP
    GFDL radiation
    Variable Ri

- *Results congruent with Gopal et al. (2013)*
- *2013 operational `gfs_alpha` produces deeper, weaker inflow, even with variable critical Richardson number*

`gfs_alpha` *also* influences outer winds…

Width differences were disguised with nondimensionalized radius
Direct impact on storm structure and size
Indirect impact on motion (via beta drift)

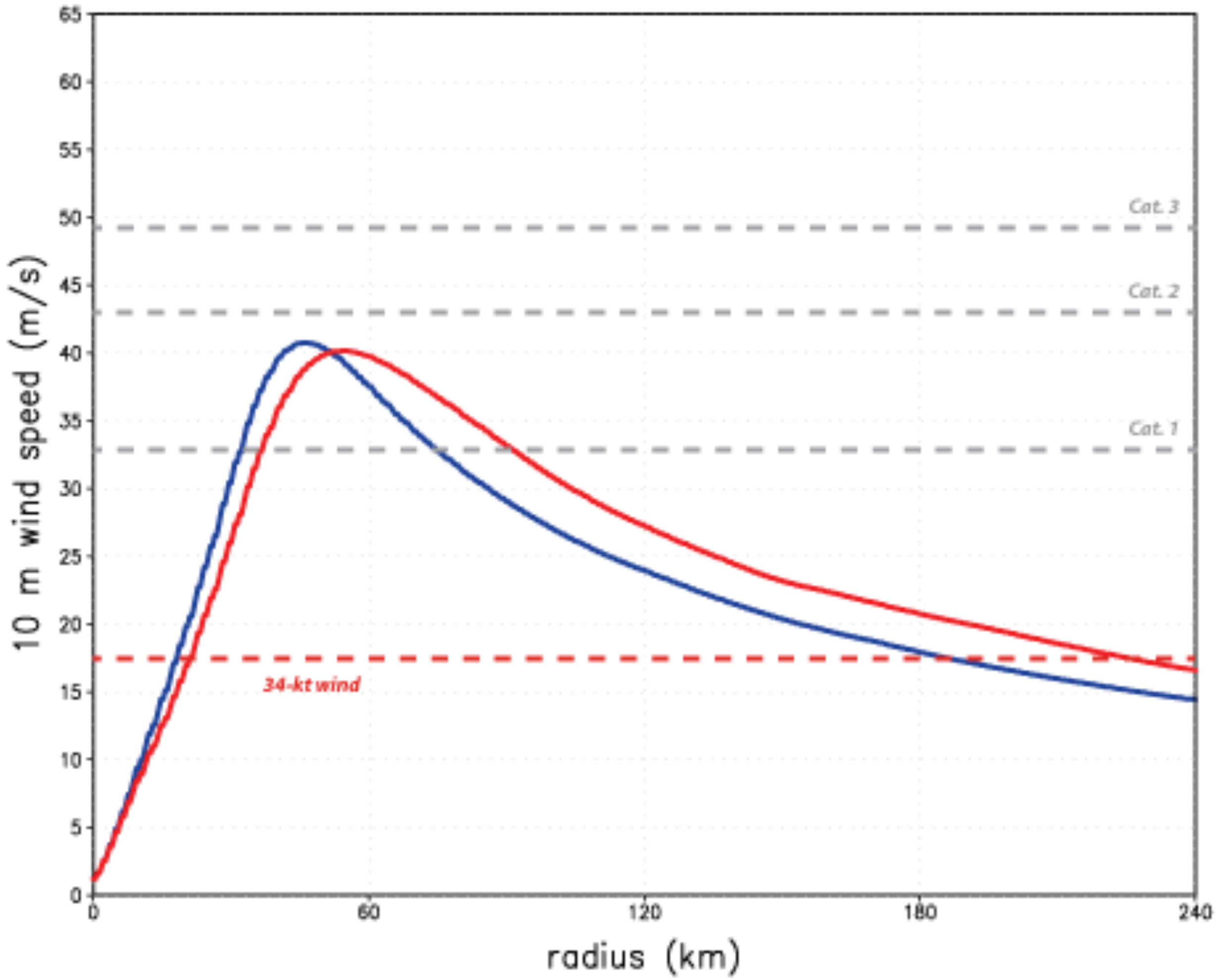
10-m symmetric wind speed



Ferrier/GFDL/α=0.70
(operational alpha)

About 6RMW

10-m symmetric wind speed

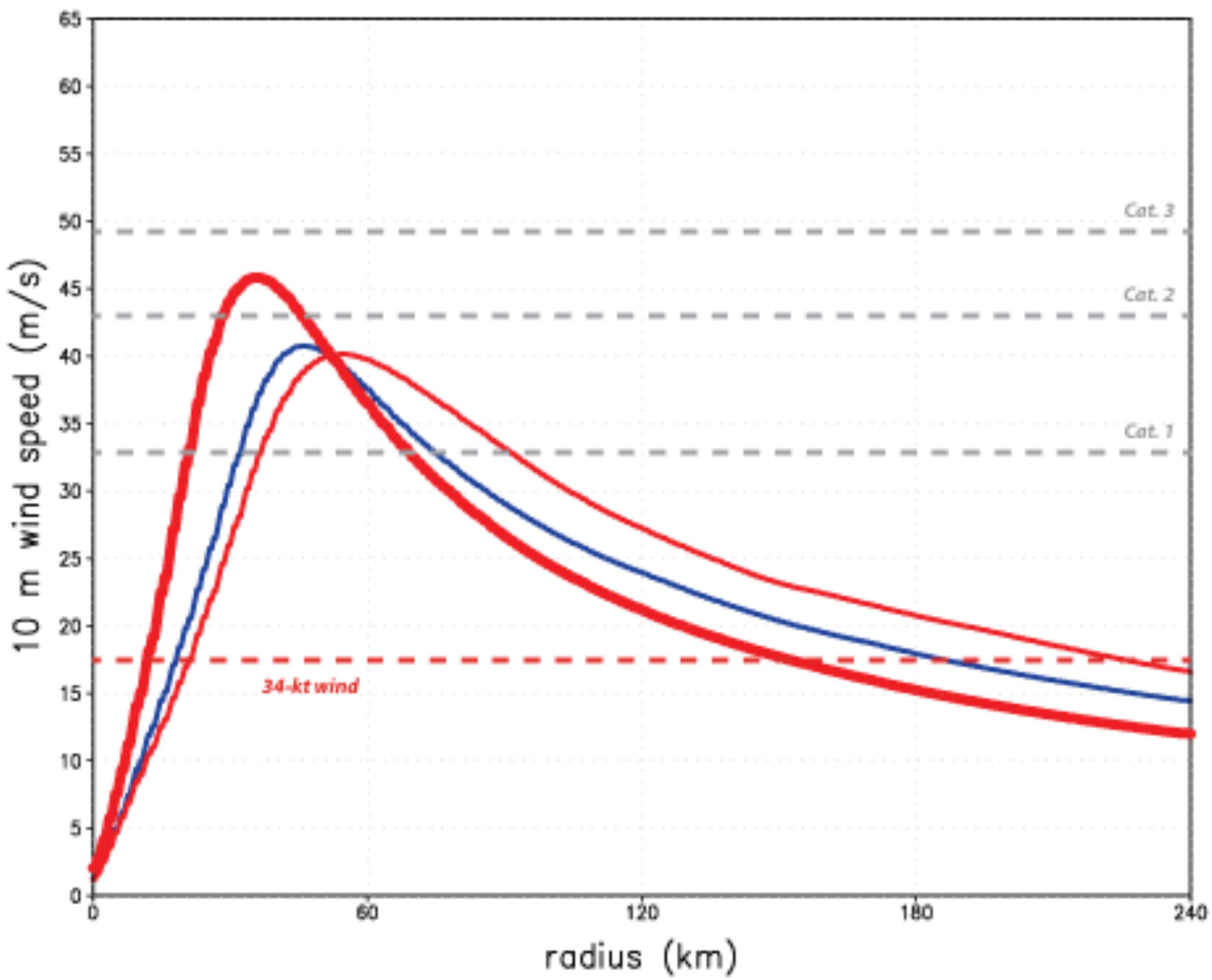


Ferrier/RRTMG/α=0.70
(operational alpha)

CRF-related expansion

*[Expansion is **larger** farther above surface … "tip of the iceberg"]*

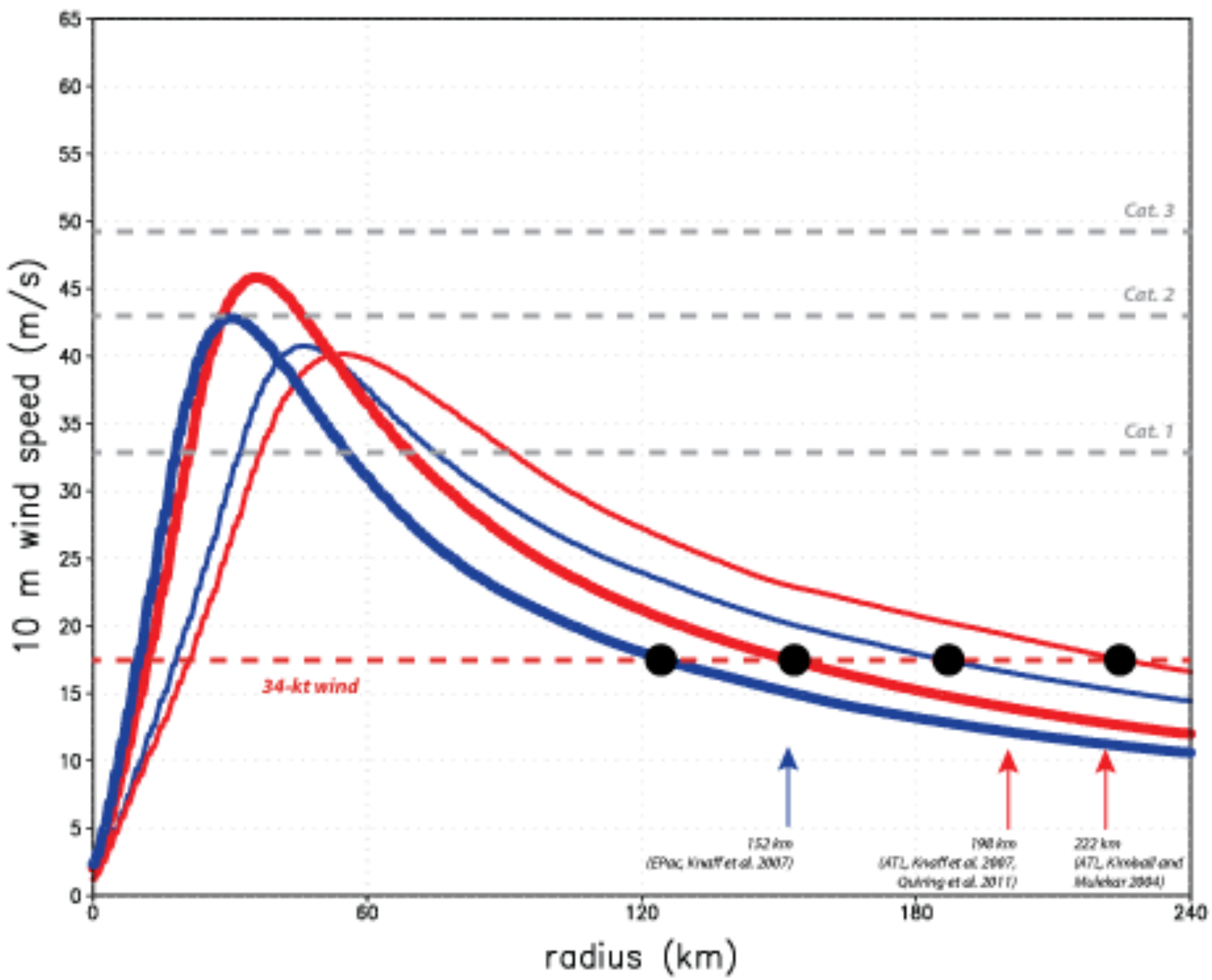
10-m symmetric wind speed



Ferrier/RRTMG/α=0.25 (reduced alpha)

Storm contraction when α reduced

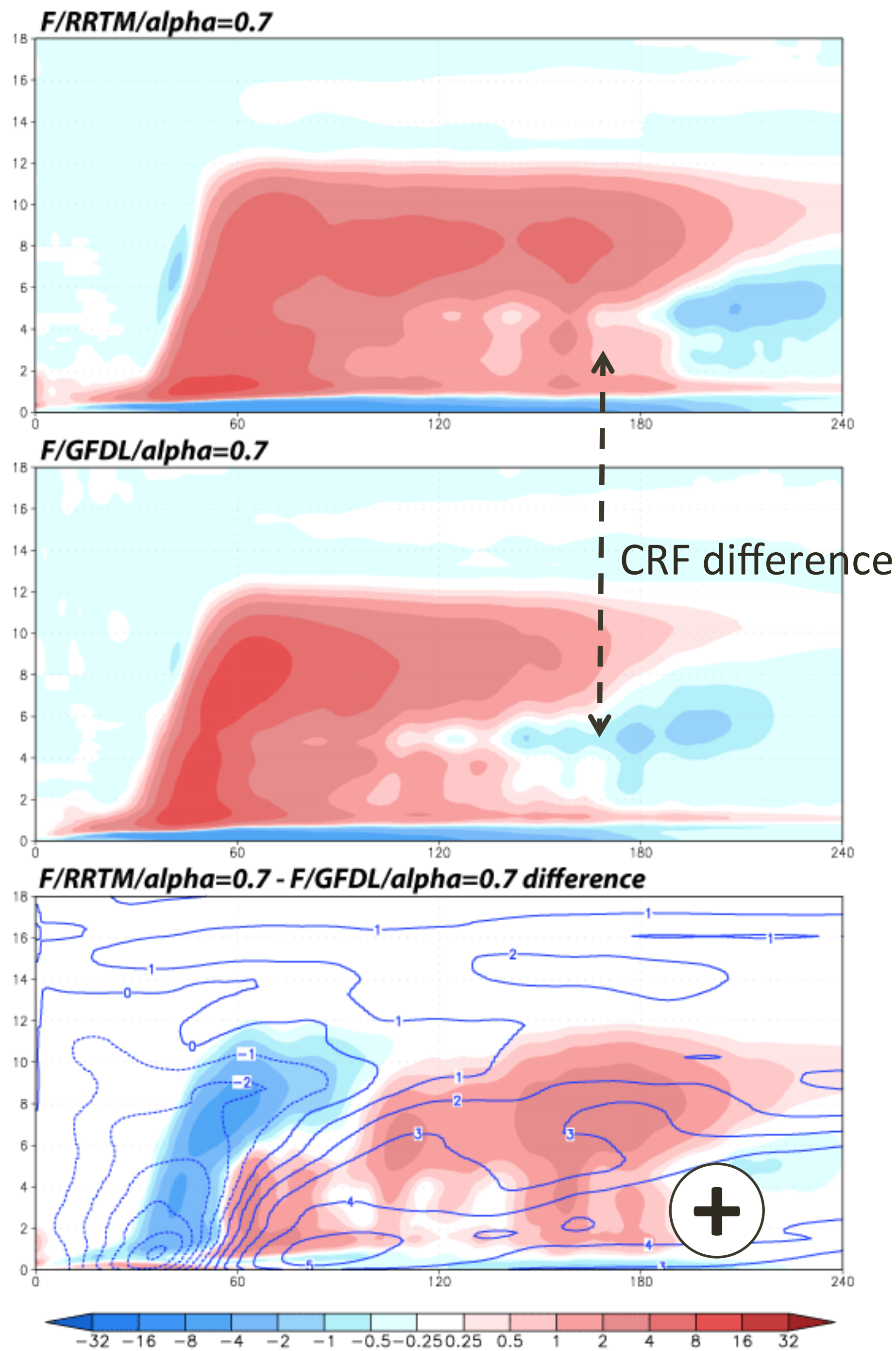
10-m symmetric wind speed



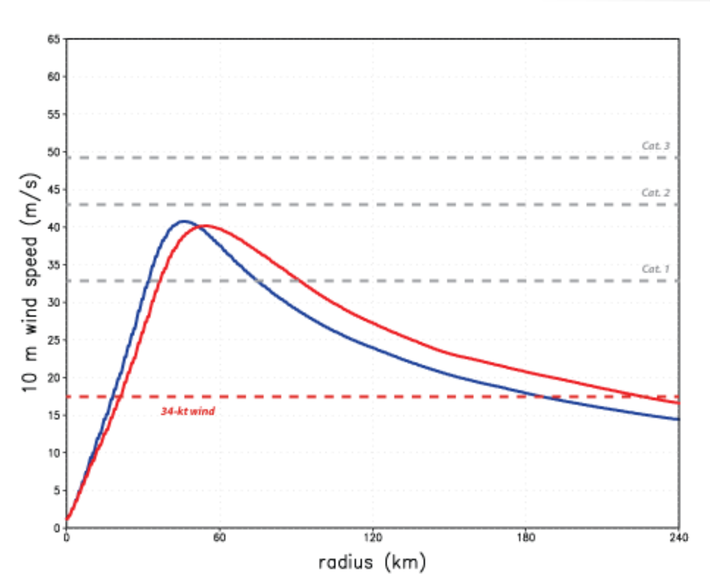
Ferrier/GFDL/α=0.25 (reduced alpha)

GFDL has virtually no CRF

R34 varies by factor of 2!

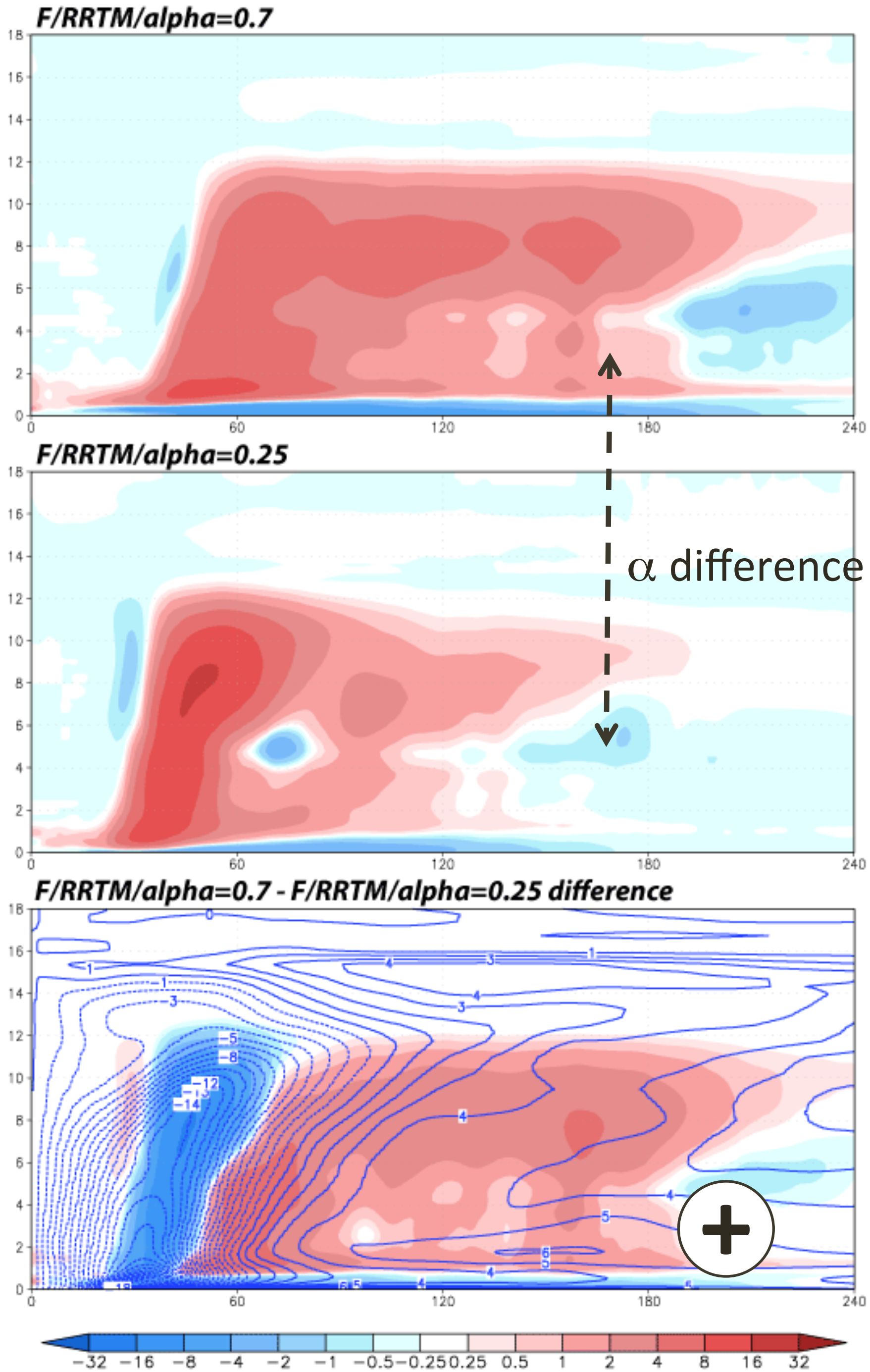


← Diabatic forcing from microphysics

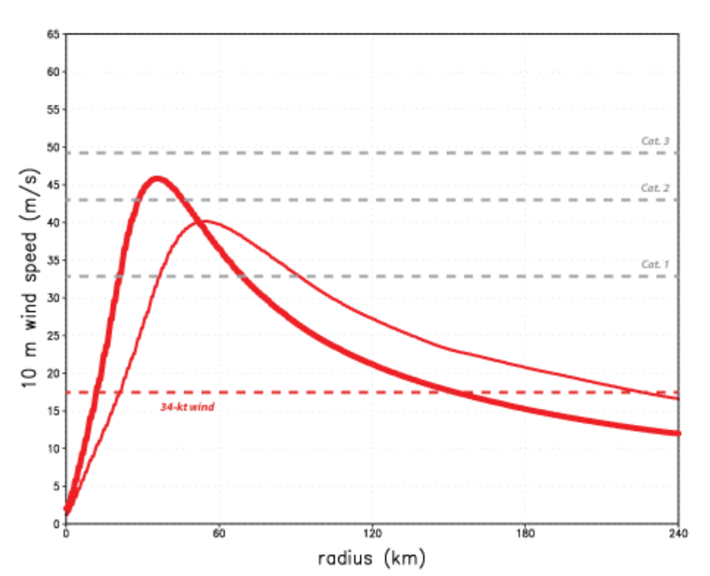


Diabatic forcing (colored) and tangential wind (contoured) ***difference*** *fields*

Enhanced cyclonic flow larger *above* the surface



← Diabatic forcing from microphysics



Diabatic forcing (colored) and tangential wind (contoured) ***difference*** *fields*

Enhanced cyclonic flow larger *above* the surface

Other factors being equal…

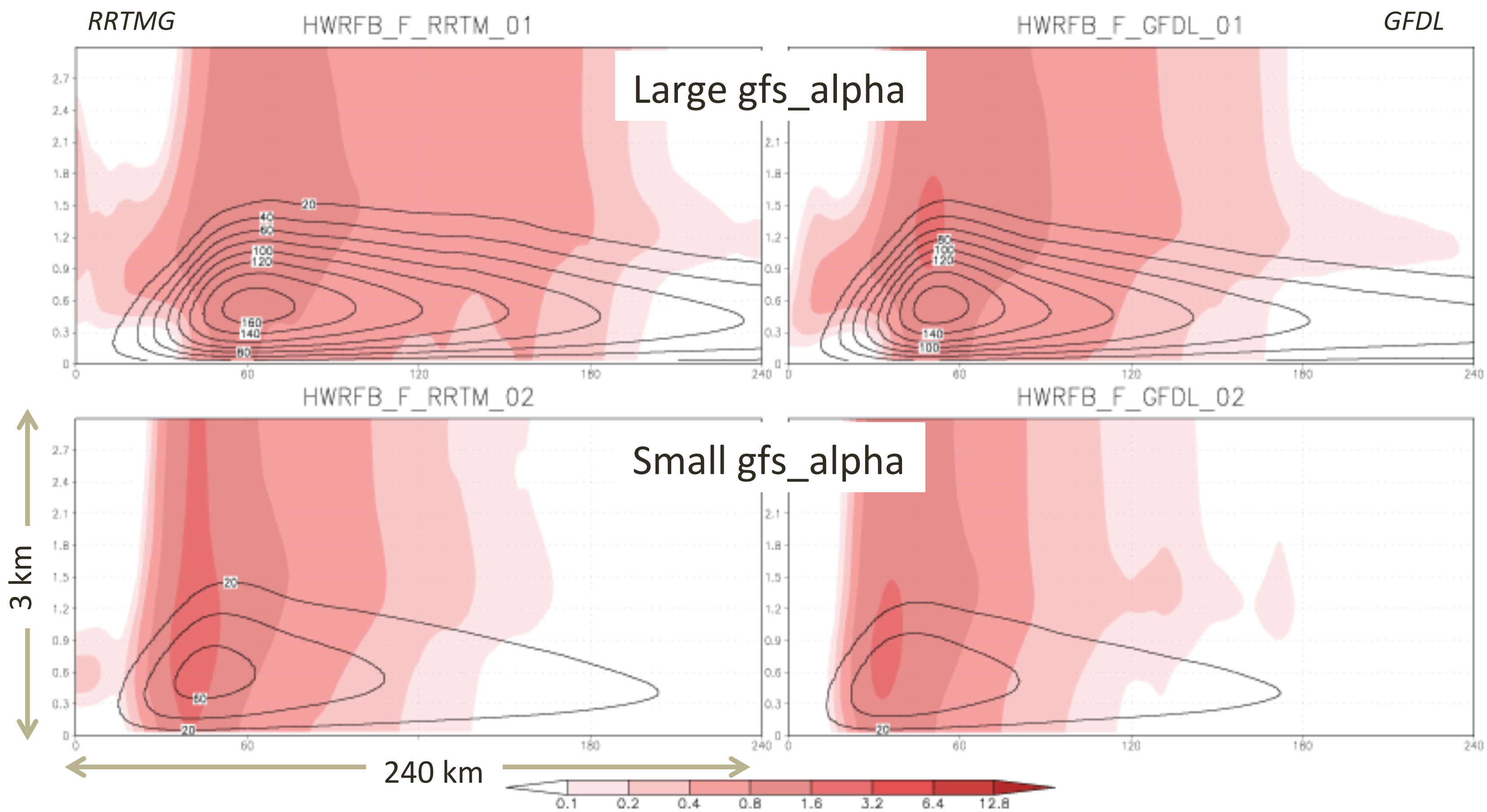
- CRF encourages wider storms
  - LW in-cloud warming → gentle ascent → enhanced heating → broader horizontal wind profile
  - Bu et al. (2014, JAS) explains how and why
- Increasing `gfs_alpha` **also** encourages wider storms
- Using radiation package lacking significant CRF (e.g., current operational HWRF) can partially compensate for a possibly too-large value of `gfs_alpha`
- Using a CRF-enabled radiation scheme (e.g., RRTMG) AND a large value of `gfs_alpha` may force storms to be too wide
  - Summer 2014 DTC visit - started examining DTC microphysics/radiation ensemble. Clear evidence of positive size bias for Thompson/RRTMG in Atlantic; East Pacific more complex (track errors → demise when SST gradients are large)

How is `gfs_alpha` modulating storm size?

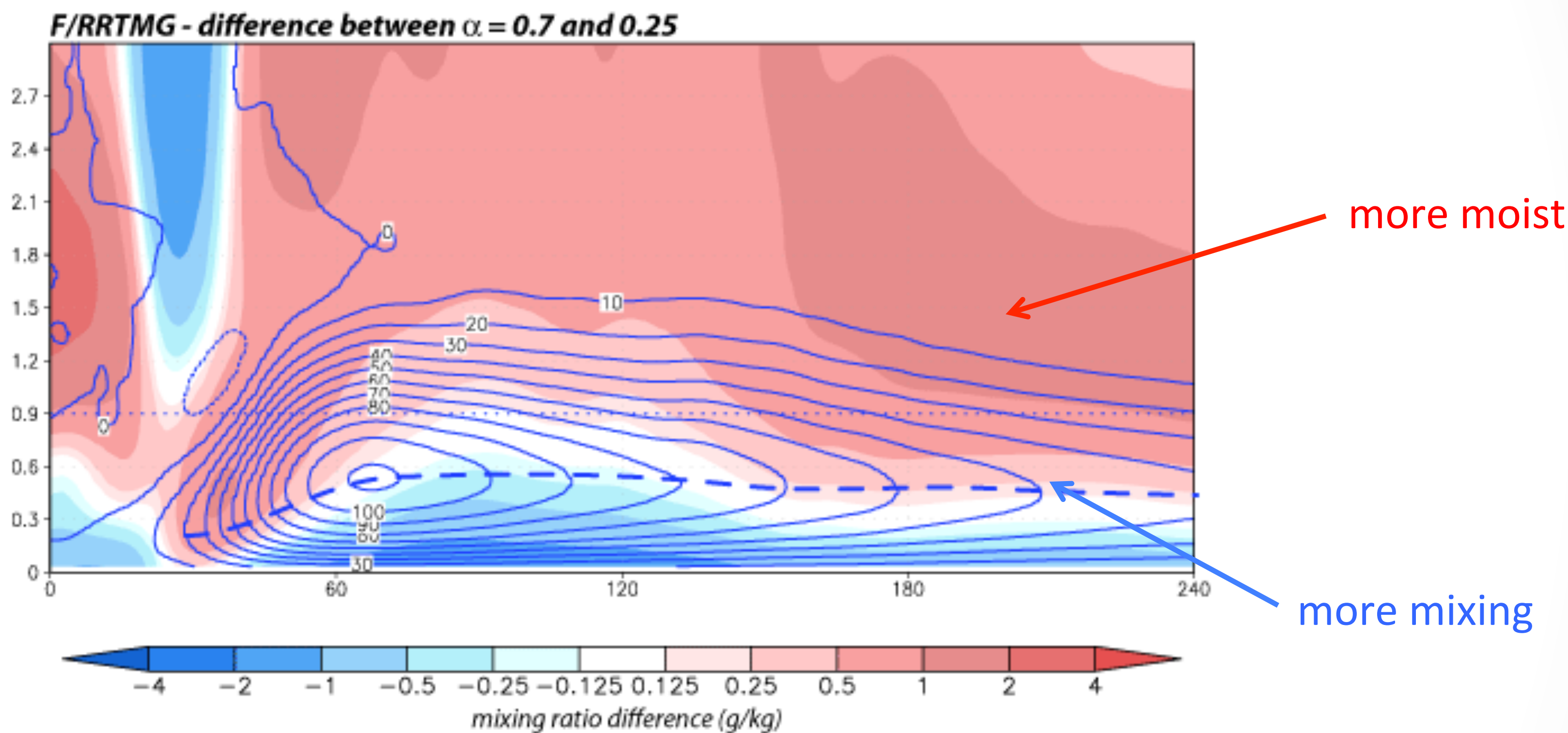
(And when might it fail to have much impact?)

Condensation and K_m

- As shown in Gopal et al. (2013), increasing `gfs_alpha` permits larger K_m
- Condensate (shaded) and K_m (contoured)



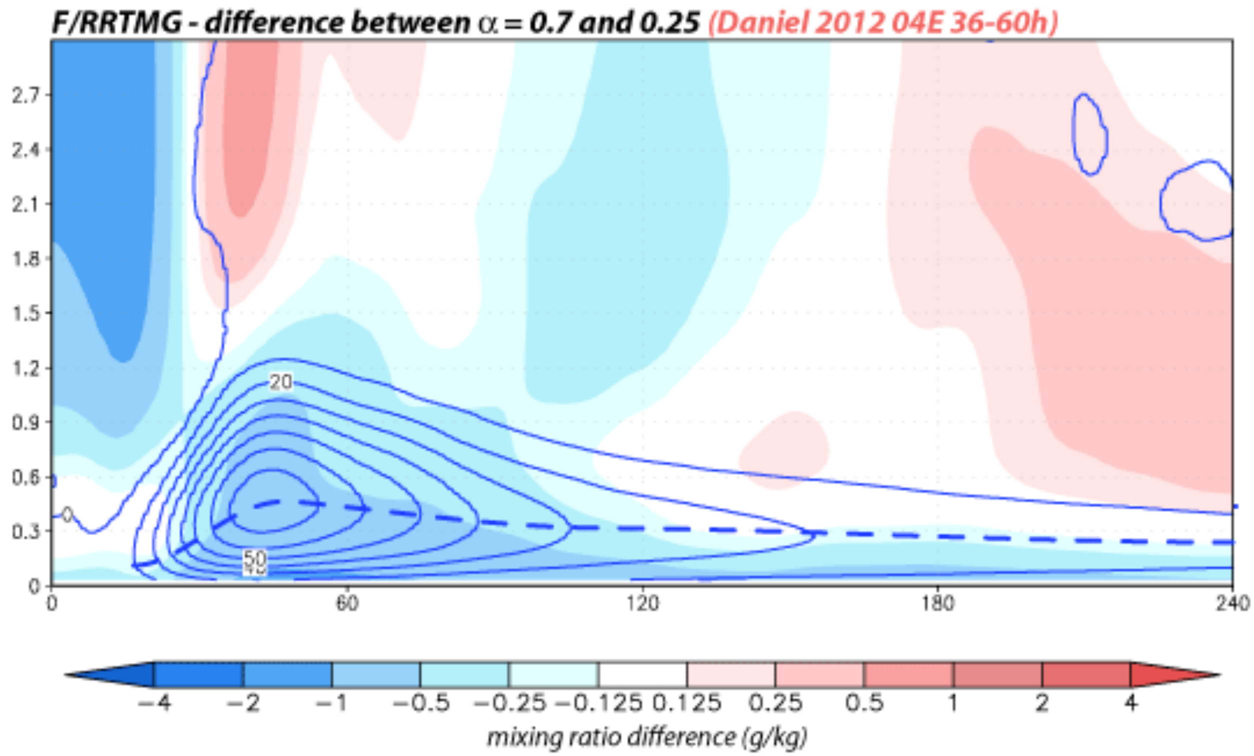
Water vapor and K_m differences due to α (semi-idealized)



- Larger `gfs_alpha` permits greater K_m
- … which increases vapor at PBL top
- … which enhances chance of saturation
- … which produces heating that broadens the wind profile
- Effect will be diminished if Km too small, environment too stable, or too dry

$$\frac{\partial}{\partial z} K_h \frac{\partial q}{\partial z}$$

Water vapor and K_m differences due to α (Daniel 04E 2012070406)

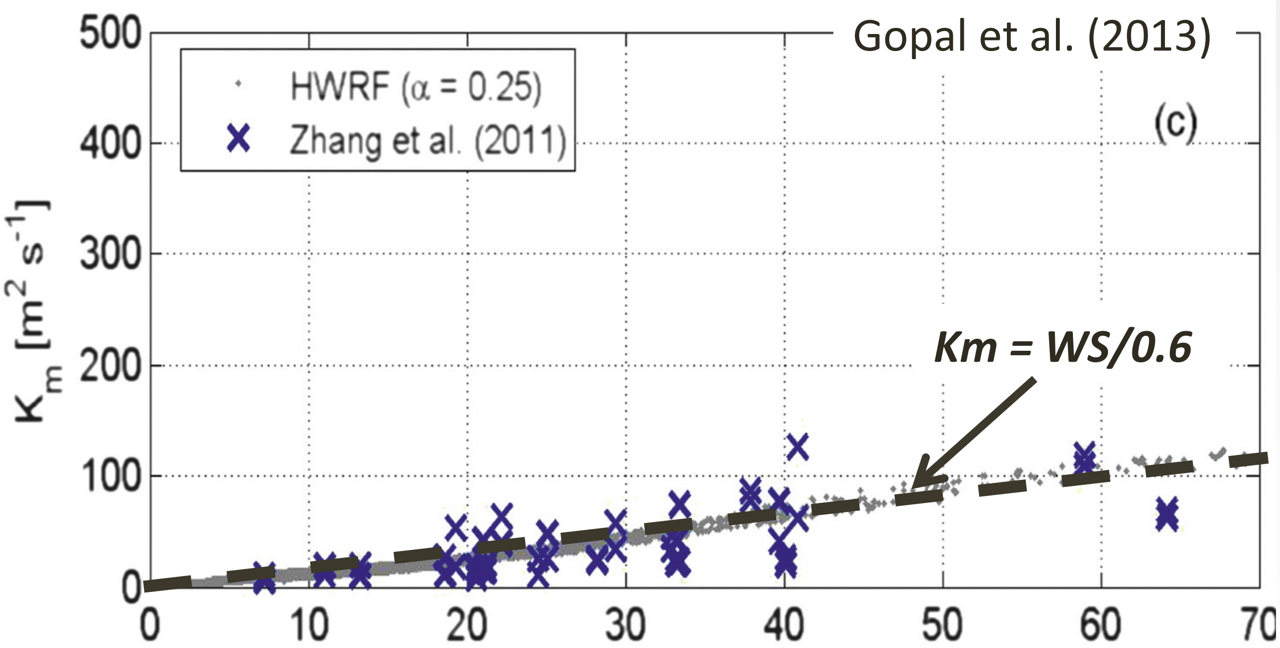


- Pattern somewhat similar but magnitudes reduced, shifted downward, impact smaller
- Environment more stable, SST lower, than in semi-idealized experiment
- Example of when `gfs_alpha` will have less influence

What's the optimal value of `gfs_alpha`?

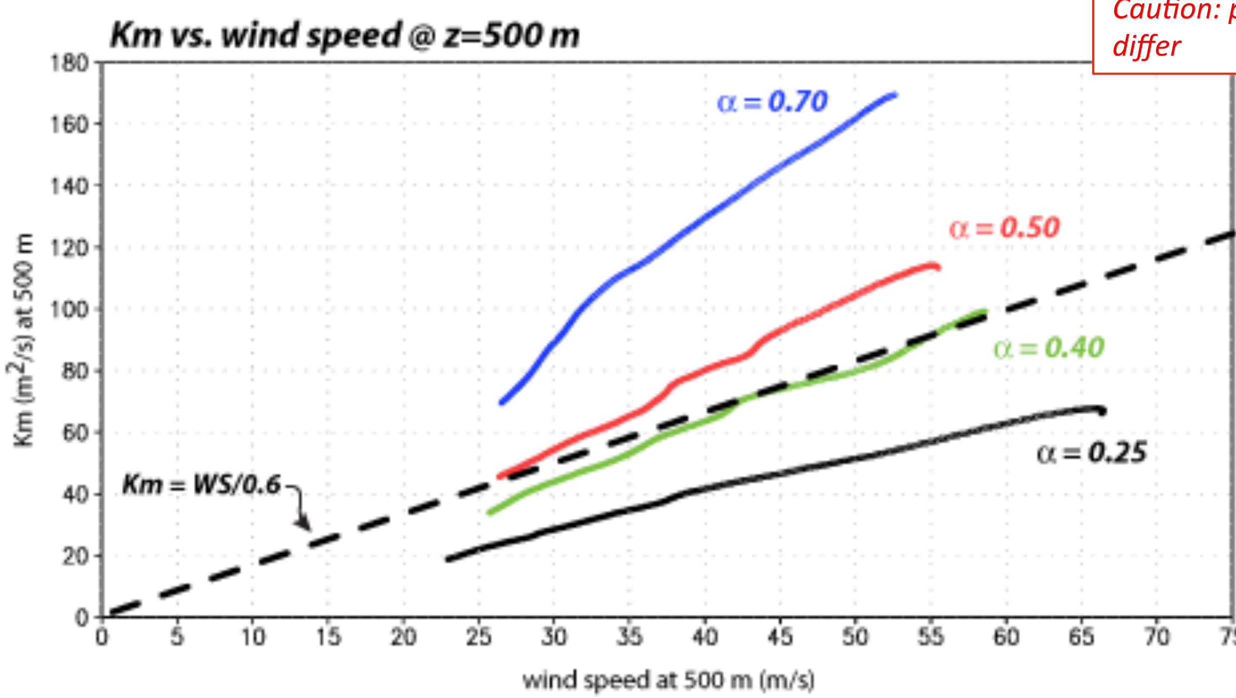
(if any)

Zhang et al. (2011) obs-based K_m estimates



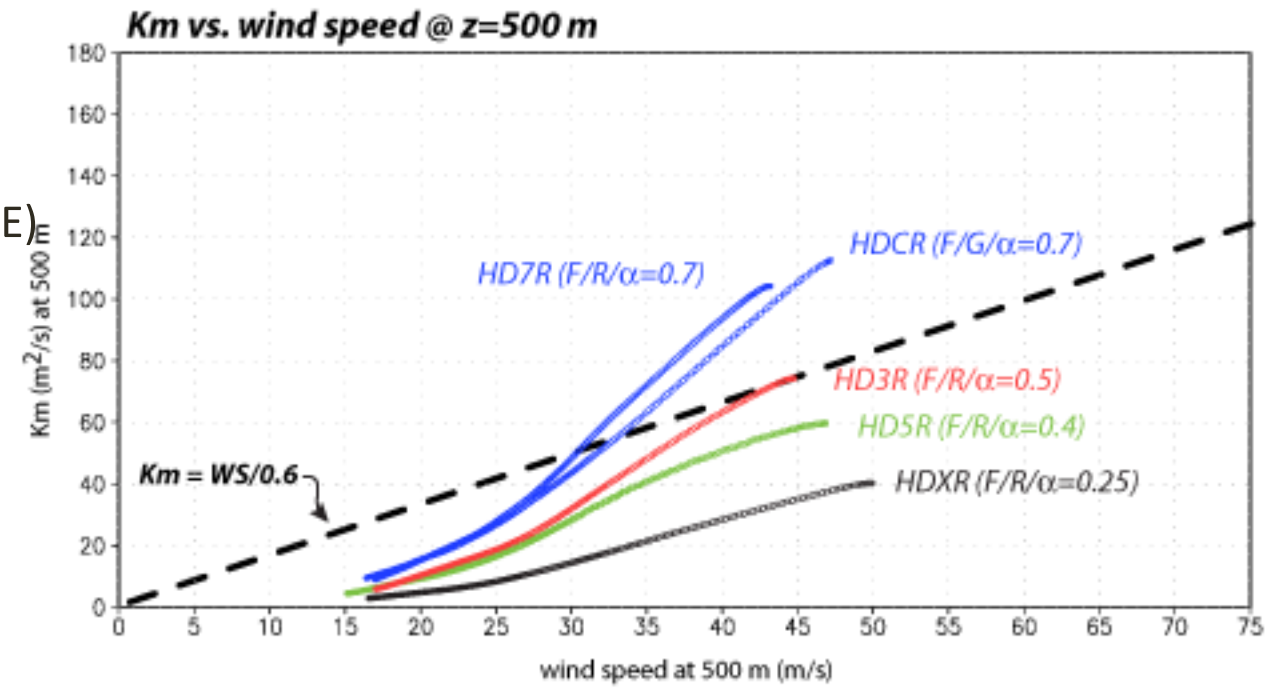
Semi-idealized runs
Symmetric K_m,
day 4

α = 0.4-0.5 may fit observations "best" for this scenario



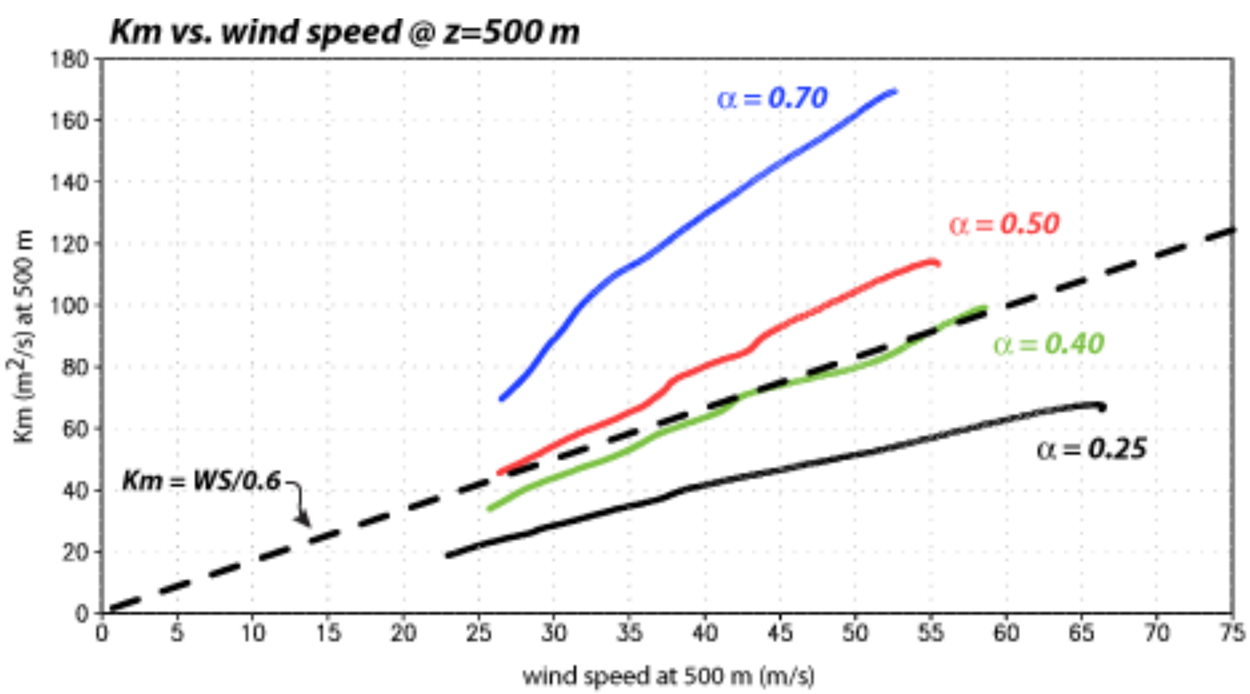
Caution: plot axes differ

Hcn. Daniel (2012 04E)
Symmetric K_m
2012070406
day 4
(DTC ensemble)



Semi-idealized runs
Symmetric K_m,
day 4

α = 0.4-0.5 may fit observations "best" for this scenario



Summary

- Enabling CRF and enhancing PBL mixing can ***both*** lead to wider storms, as measured by R34, etc..
- Connection appears to be indirect, largely via ***convective activity*** (moistening → heating → wind field broadening)
  - CRF gently lifts air through a large storm volume, mainly above PBL (Bu et al. 2014)
  - PBL mixing lofts moisture
- Both enabled CRF and larger `gfs_alpha` can fail to influence storm size, when interaction with convection is weak or absent
  - This may dilute aggregated ensemble statistics

Future work

- Explore more direct capping of K_m based on wind speed
  - Being tested at EMC now
  - May obviate need to hunt for optimal `gfs_alpha` value
- Examine and analyze a range of `gfs_alpha` values in retrospective simulations, mindful of physics interactions
  - Hypothesis: CRF-enabled radiation schemes may require smaller α values. This may be why RRTMG hasn't yet been adopted as default operational HWRF
- Understand the direct impact of variable Richardson number (`var_ric`) in real-data simulations

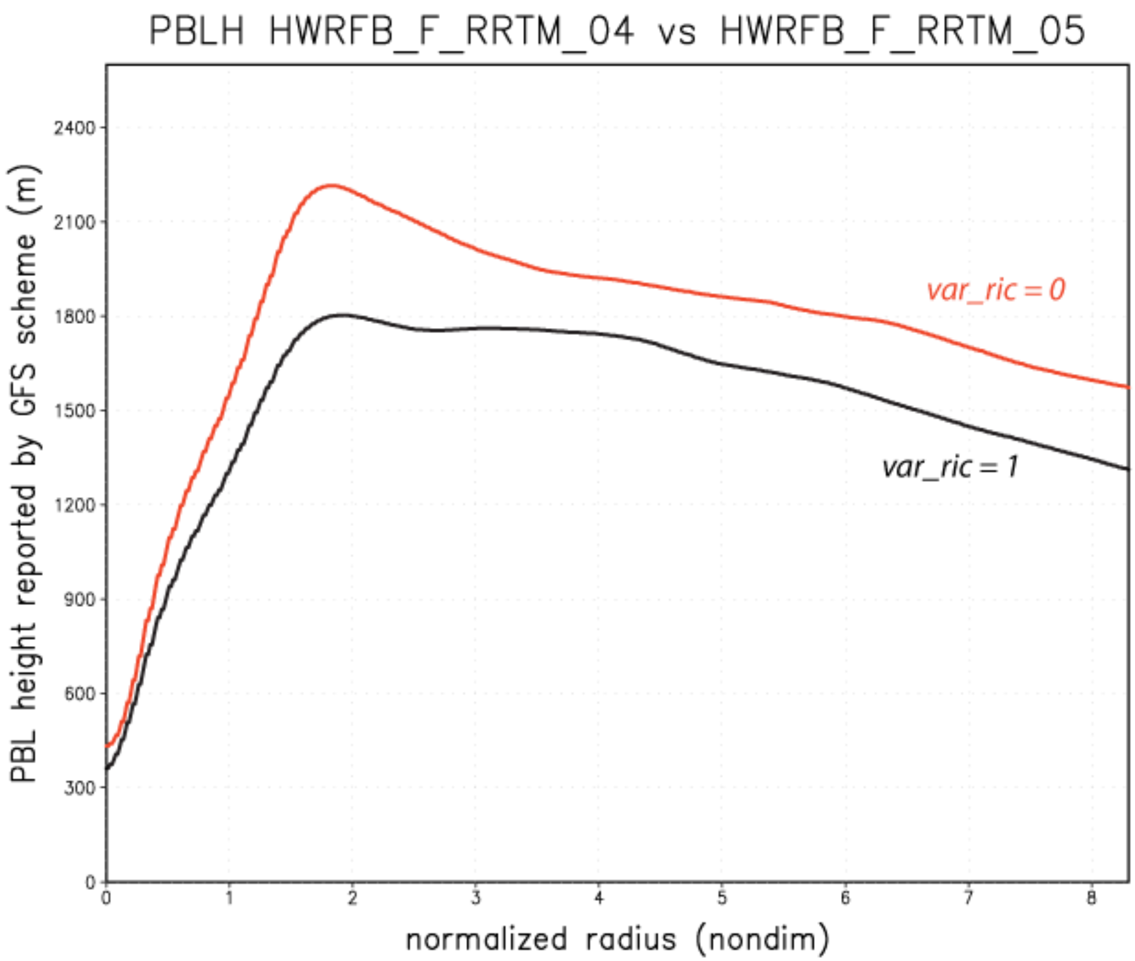
[end]

Extra slides

Effect of variable critical Ri (`var_ric`) on semi-idealized storm structure: Preliminary assessment

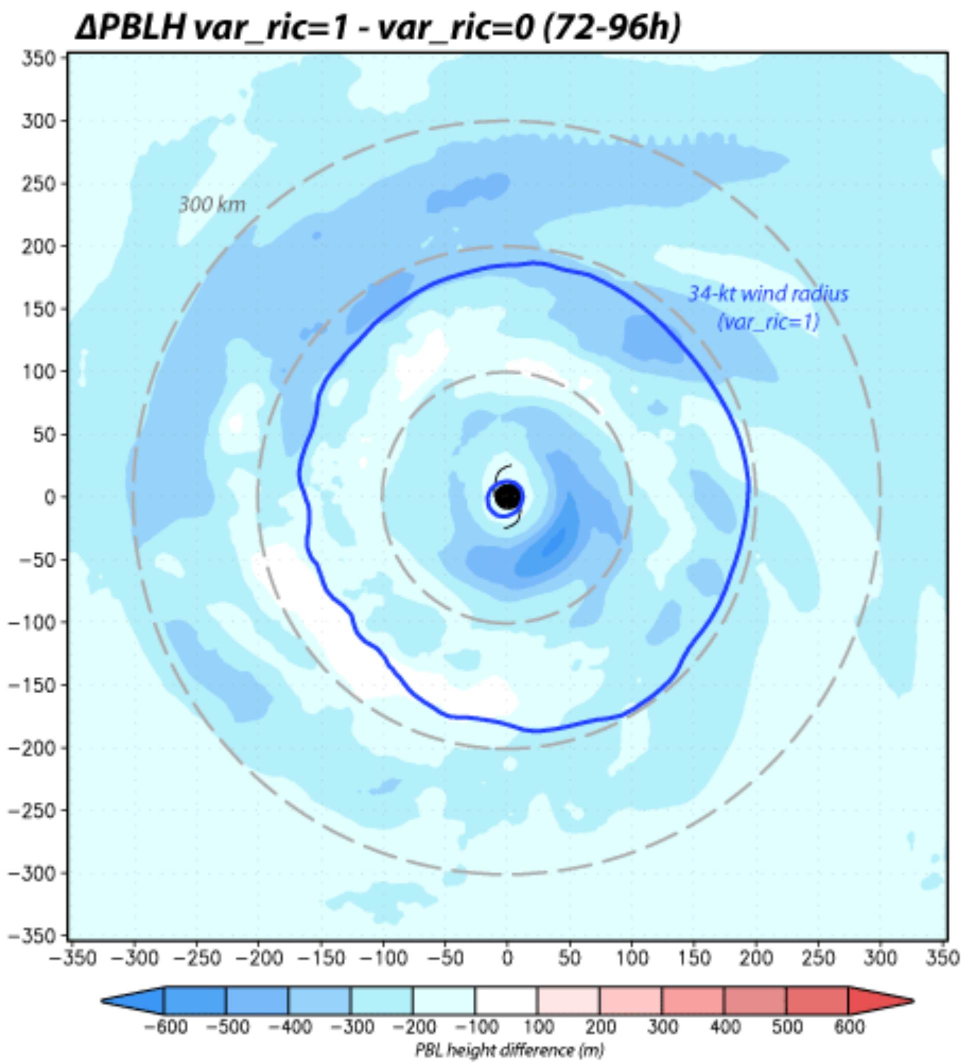
Executive summary: impact is minor on aquaplanet runs, dwarfed by `gfs_alpha` influence

PBL height vs. normalized radius: `var_ric` = 1 vs. 0

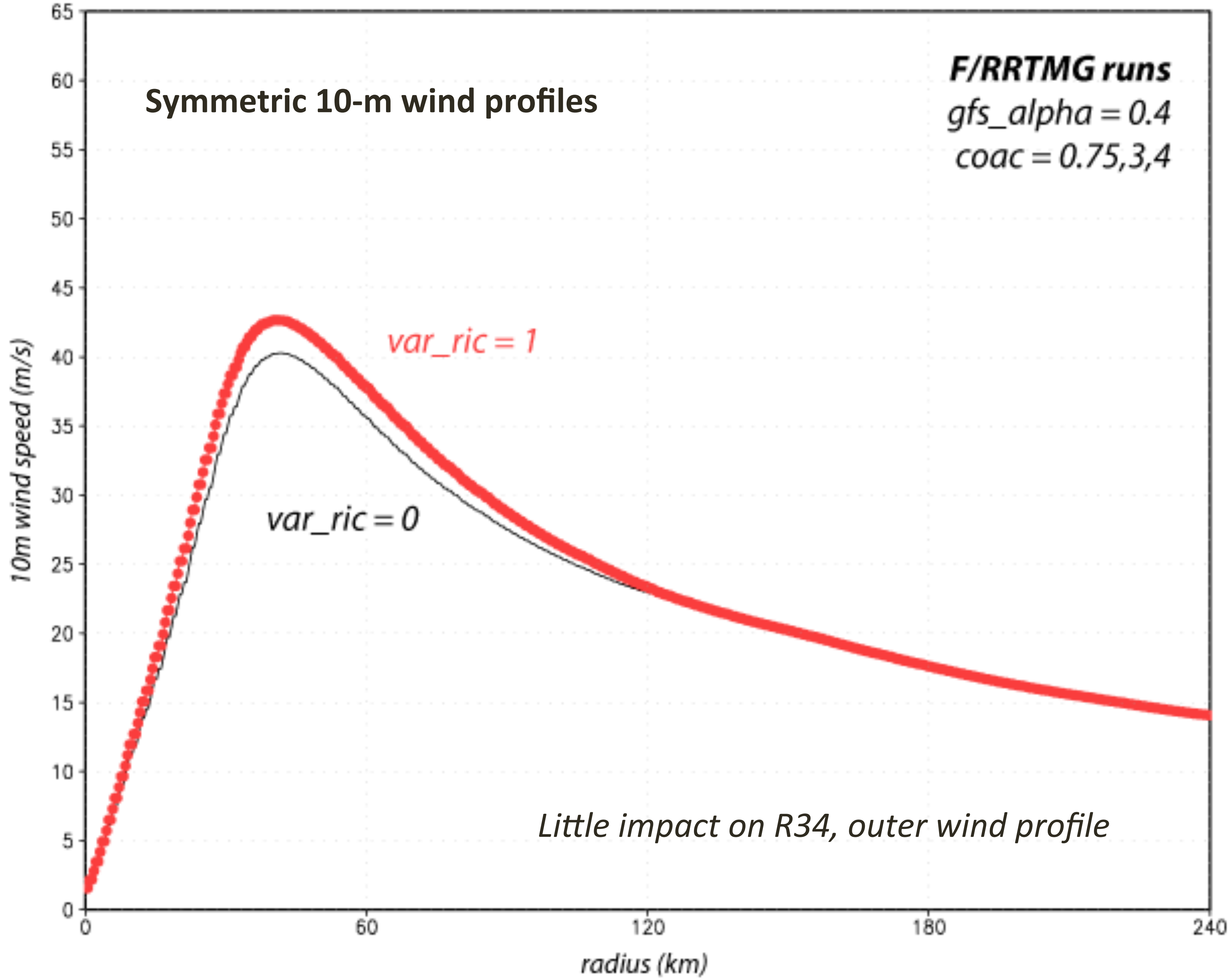


- PBL height reported by GFS PBL subroutine is *consistently lower* when variable Ri is permitted.

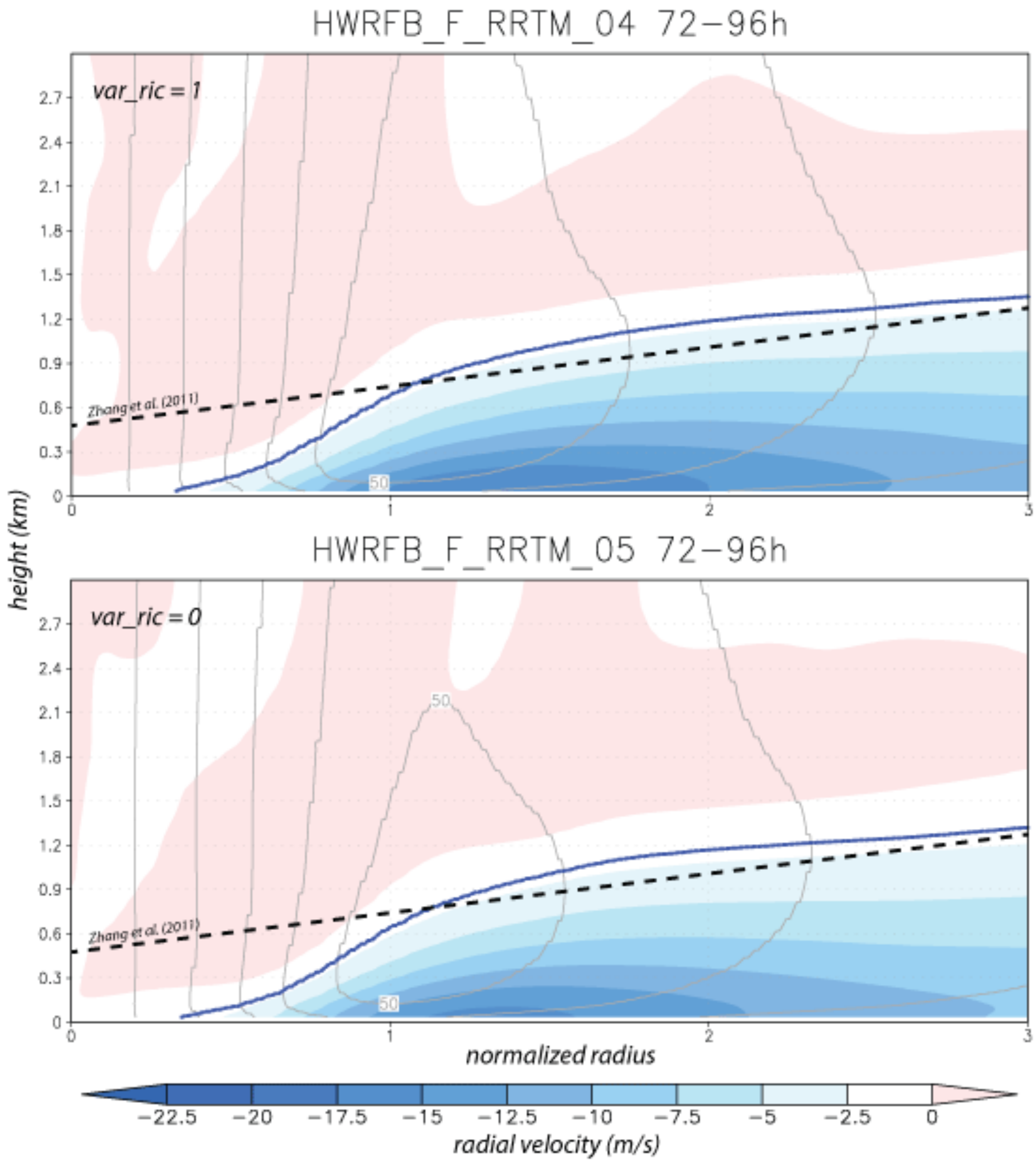
PBL height vs. normalized radius: var_ric = 1 vs. 0



- Difference in PBL height reported by HWRF, averaged over one diurnal cycle



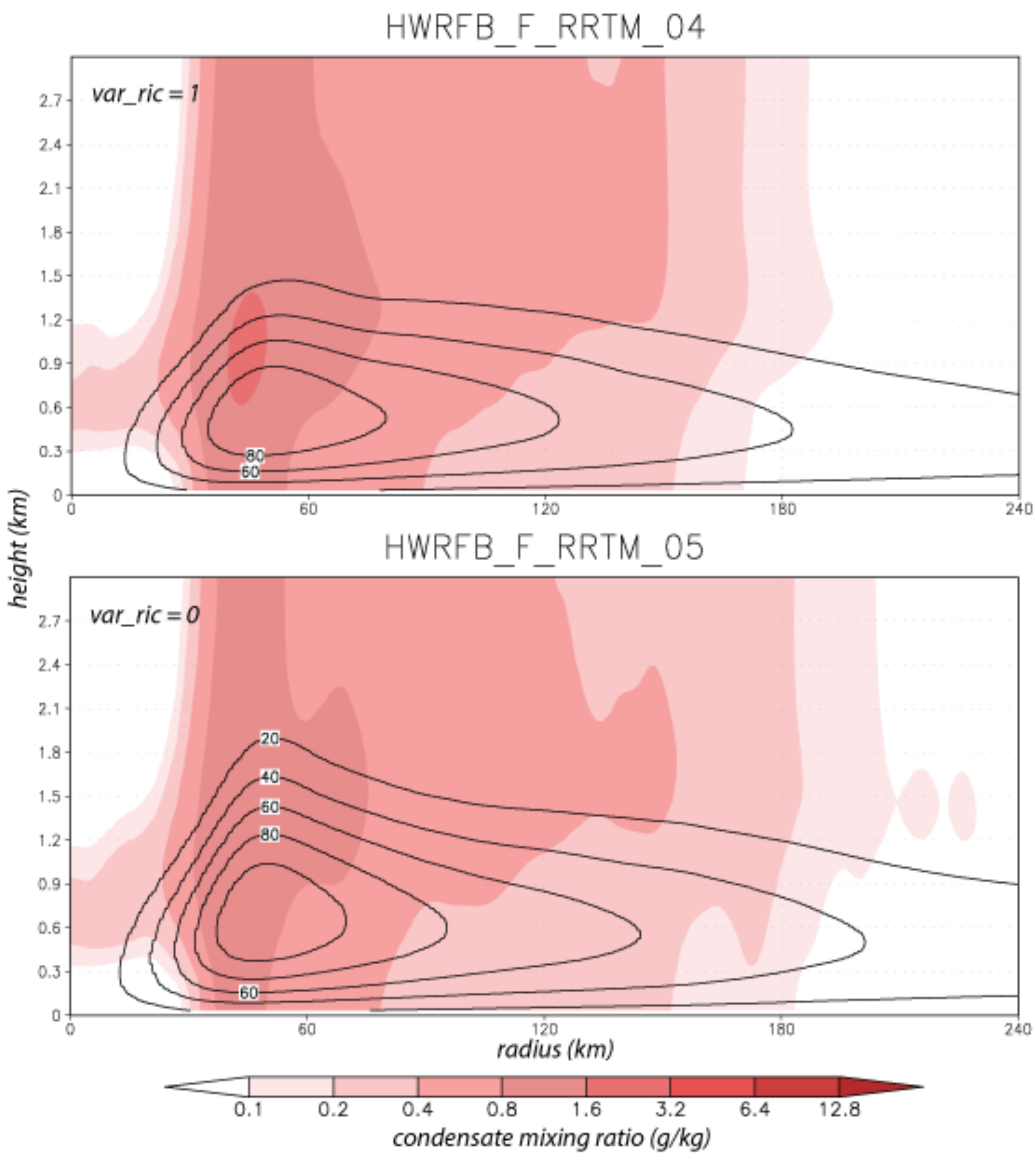
Symmetric 10-m wind profiles
F/RRTMG runs
gfs_alpha = 0.4
coac = 0.75,3,4
var_ric = 1
var_ric = 0
Little impact on R34, outer wind profile
10m wind speed (m/s)
radius (km)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
0
60
120
180
240



Radial inflow (colored) and tangential wind (contoured)

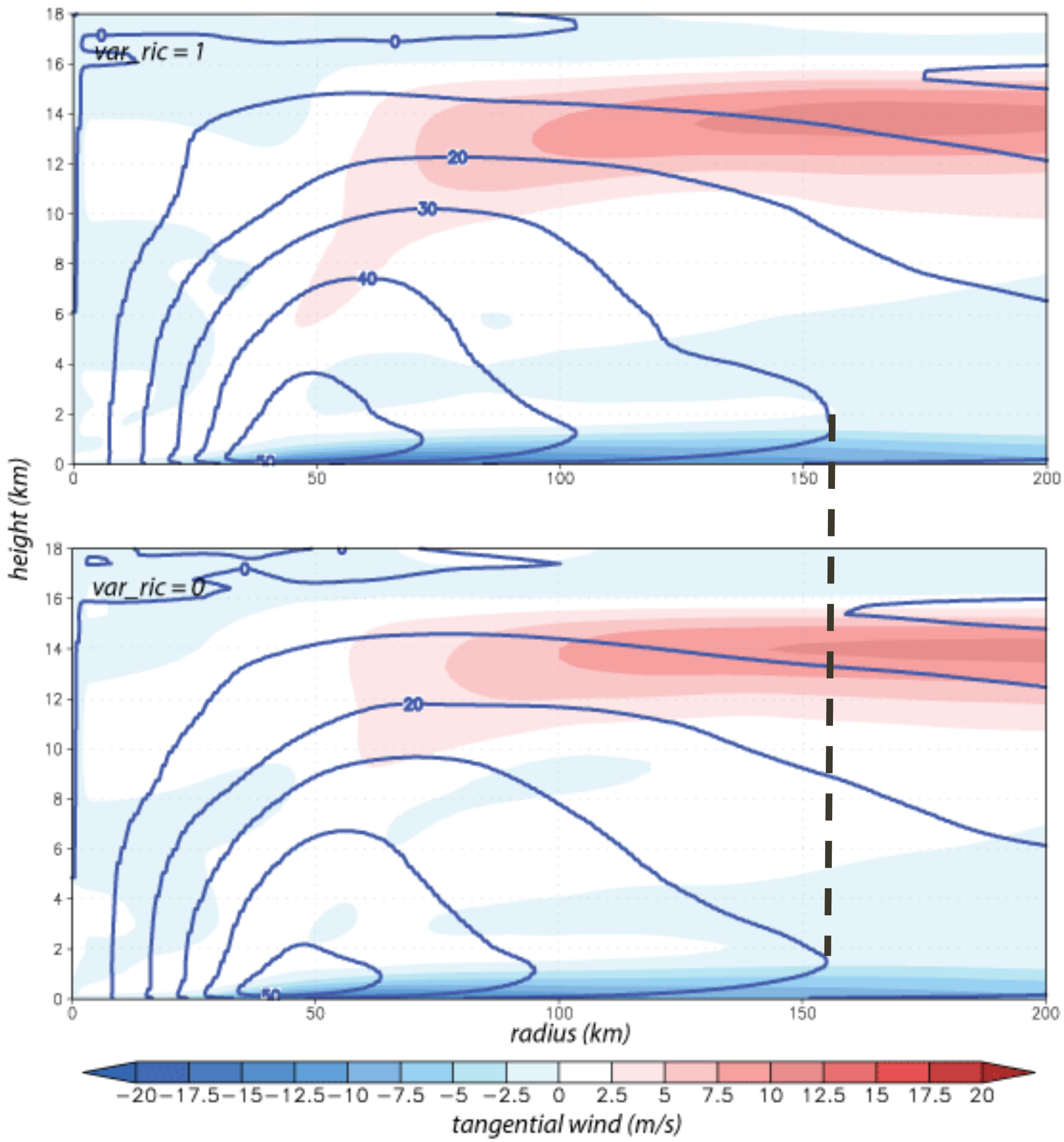
vs. height & normalized radius

- Note HWRF-reported PBL heights reside well above inflow layer



Condensate (shaded) & momentum diffusivity (contoured)

vs. height and radius



Radial (shaded) and tangential velocity (contoured)

vs. height and radius