HFIP Annual Review telecon
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Influence of cloud-radiative processes on tropical cyclone storm structure

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Greg Thompson, NCAR/DTC; Ligia Bernardet and Mrinal Biswas, DTC;
Brad Ferrier, NCEP; Hui Su and Longtao Wu, JPL; Kristen Corbosiero, U at Albany

Motivation

- Model physics can have a sizable impact on track, intensity, and structure (including radius of 34-kt wind, for example)
- Past: HWRF lacked physics diversity
- Augment real-data cases with "semi-idealized" simulations to deduce common strengths and weaknesses of available physics packages
    - Objective is mimic operational configuration as much as possible

HWRF experiments

- HWRF rev. 6557 (28 March 2013)
  - Greg Thompson's microphysics scheme
  - RRTMG radiation package
- Semi-idealized "bubble" initialization
  - Curved Earth & *f*-plane
- 2012 domain configuration (3 telescoping domains)
- Sensitivity to microphysics (Thompson vs. Ferrier)
- Sensitivity to radiation (RRTMG vs. HWRF-GFDL)
- Sensitivity to time-stepping (model and physics Δt)
- Sensitivity to cumulus schemes (DTC runs)
- Sensitivity to model diffusion
- Real-data cases
- Comparison with ARW

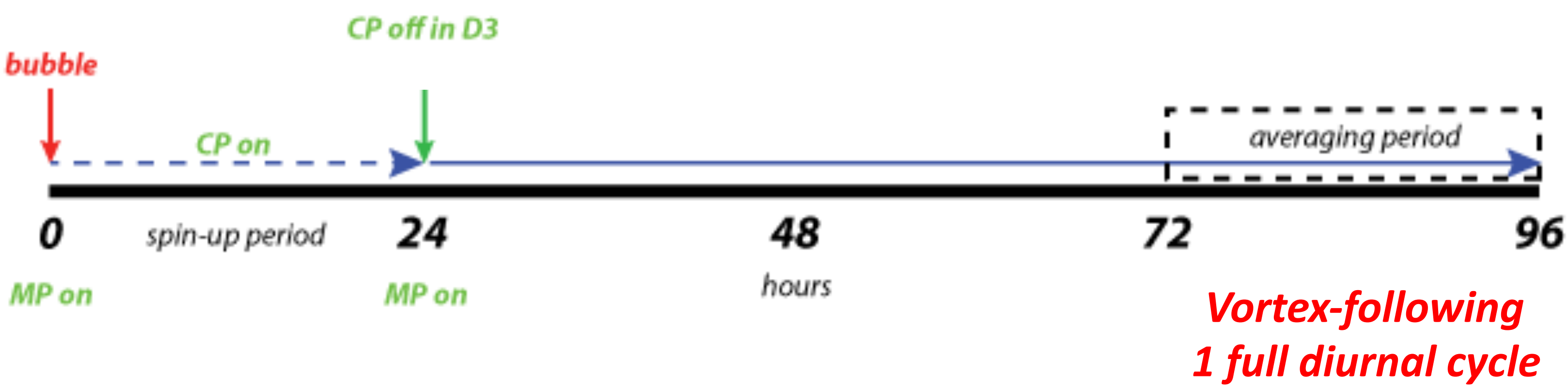
connected

Grey = not covered in presentation

Synopsis of findings

- Recent HWRF releases develop *significantly improved* storm structures
- Cloud-radiative forcing (CRF) is (still) largely missing from HWRF/GFDL radiation scheme
  - Emphasis here is on *hydrometeor modulation of background radiative forcing*
- CRF consists of:
  - Pronounced net diabatic cooling along cloud top (with substantial diurnal variation owing to competition between longwave and shortwave)
  - Weak, but extensive and deep tropospheric longwave (LW) warming
- CRF direct impacts:
  - Enhances upper tropospheric radial outflow
  - Encourages broad tropospheric ascent
- CRF indirect impacts:
  - Enhances convective activity beyond inner core
  - Broadens tangential wind field (including R34, etc.)
  - Widens eye
- No systematic influence on maximum wind speed noted
- Ferrier's microphysics is unique among available schemes
- Sensitivity to time stepping and cumulus is significant

HWRF simulation strategy
for semi-idealized experiments

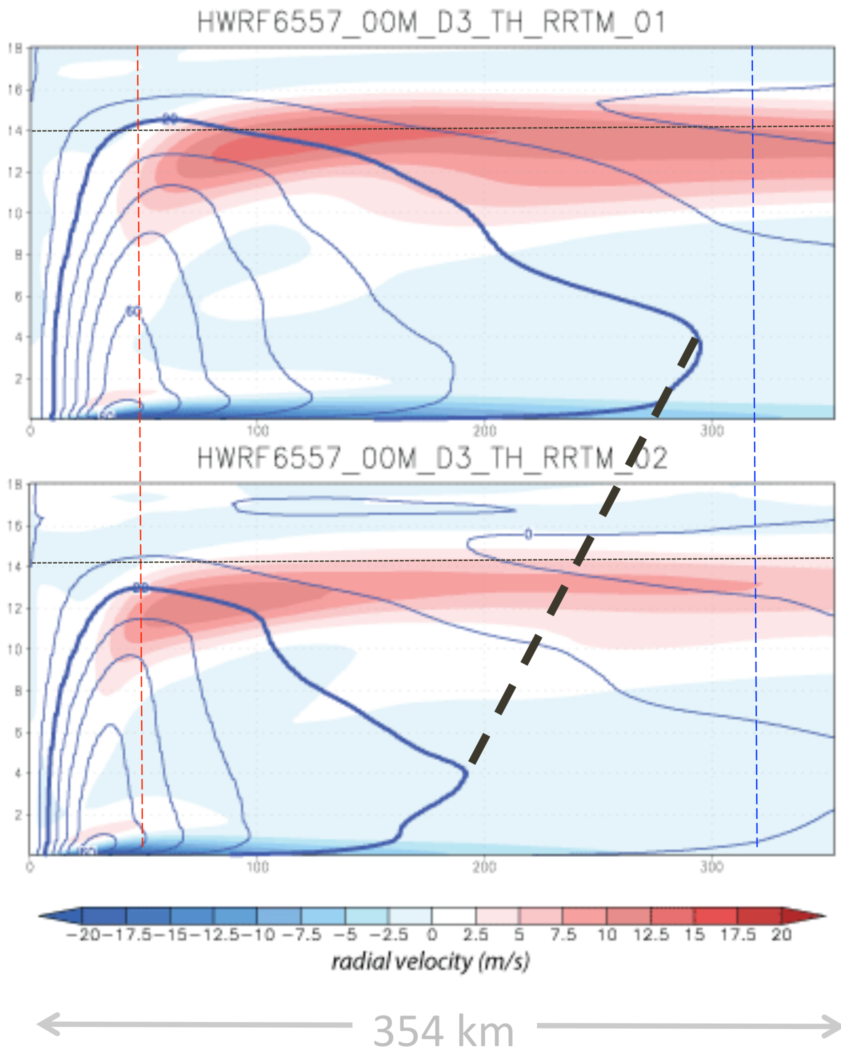


Owing to needs of Thompson scheme, model physics called *every time step*

Cumulus scheme (SAS)
remains ON in domains 1 and 2 after spin-up period;
This does influence results.

Results with Thompson/RRTMG & comparisons with Ferrier

Microphysics called every time step



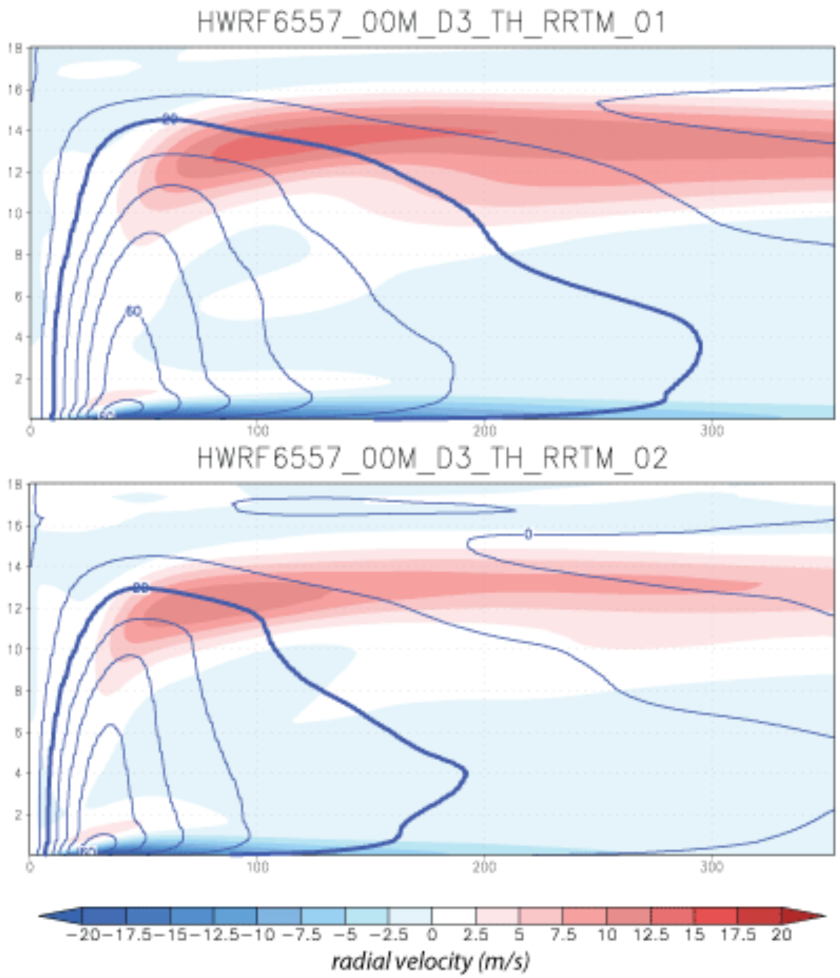
Radial velocity (colored) &
Tangential velocity (contoured, m/s)

Thompson/RRTMG
CRF-on

Thompson/RRTMG
CRF-off

CRF-on storm: wider eye, stronger outflow, broader wind field

20 m/s tangential wind contour highlighted

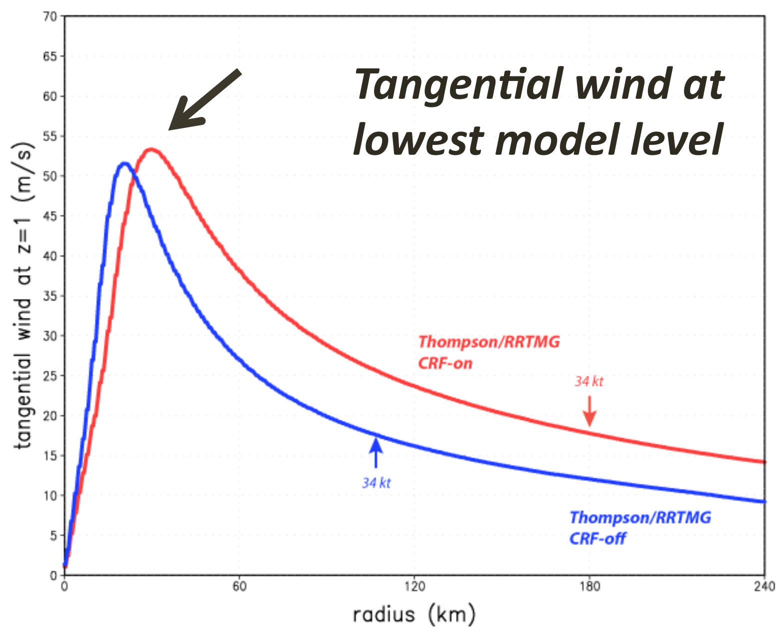


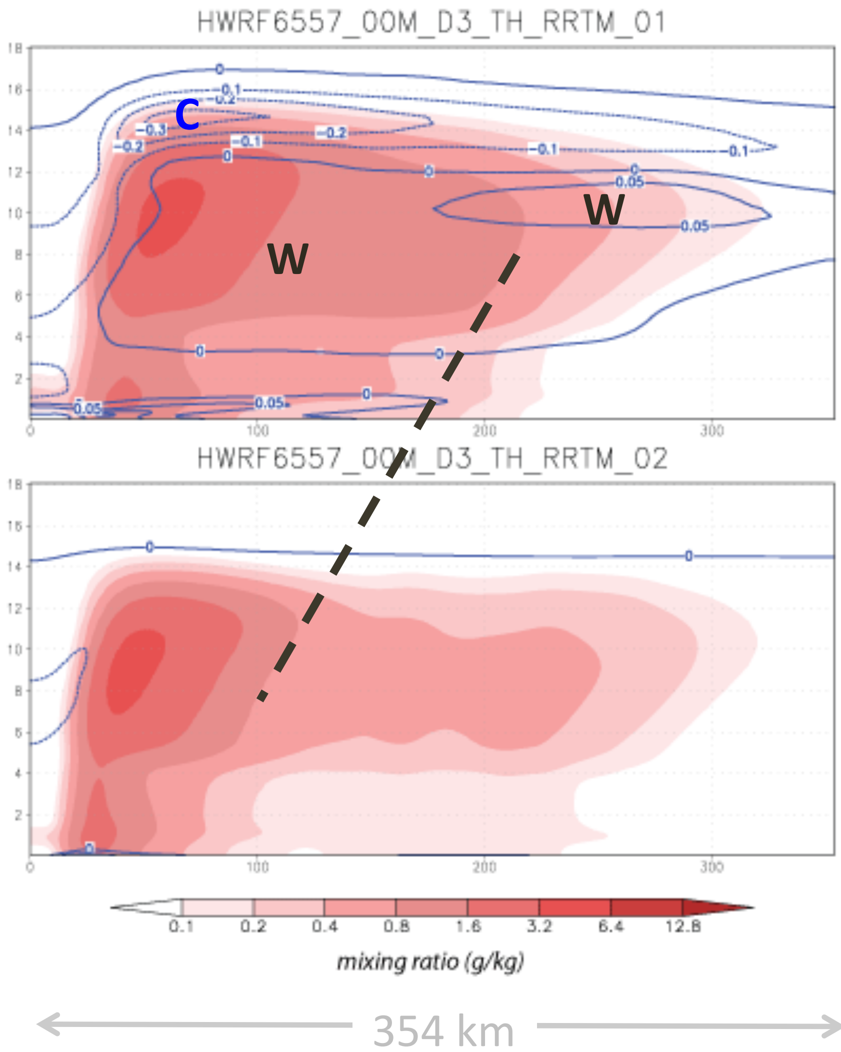
Radial velocity (colored) &
Tangential velocity (contoured, m/s)

Thompson/RRTMG
CRF-on

Thompson/RRTMG
CRF-off

Note 34-kt wind radius > 60% larger with CRF-on





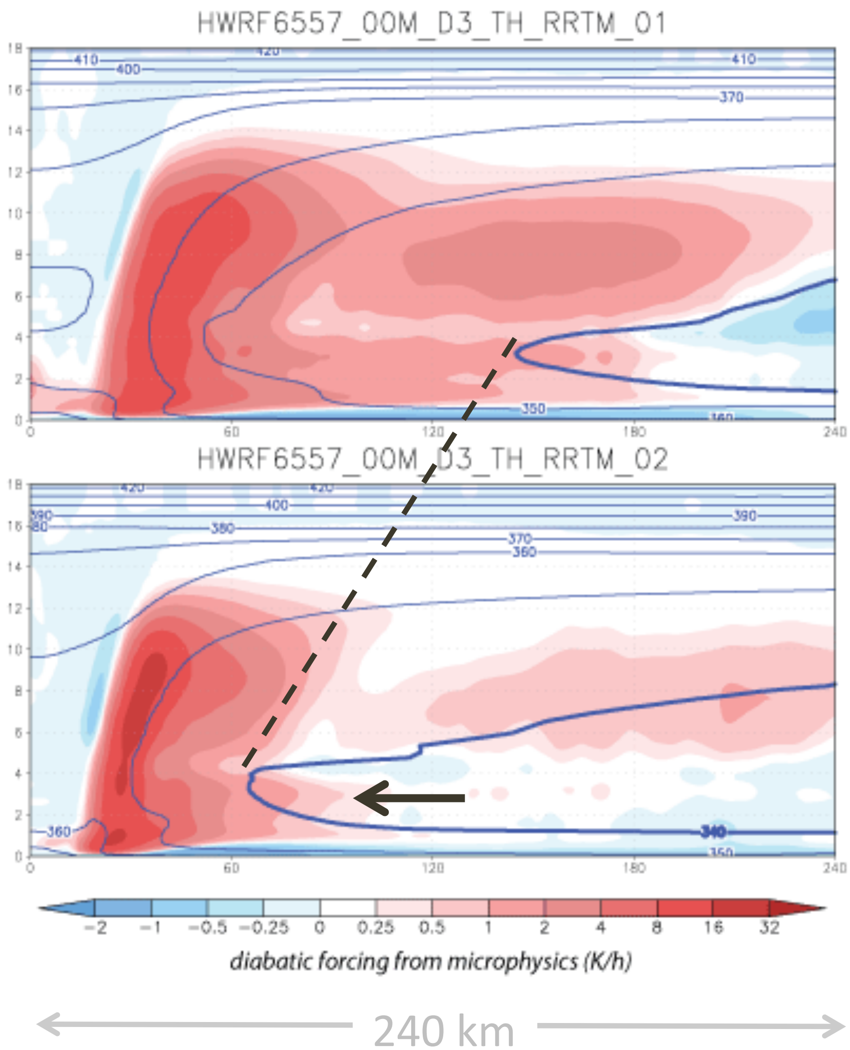
Total condensate (colored) &
Net radiative forcing (contoured, K/h)

Thompson/RRTMG
CRF-on

Thompson/RRTMG
CRF-off

CRF-on storm:
wider, thicker anvil

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



Microphysics diabatic forcing (colored) & θ_e (contoured, m/s)

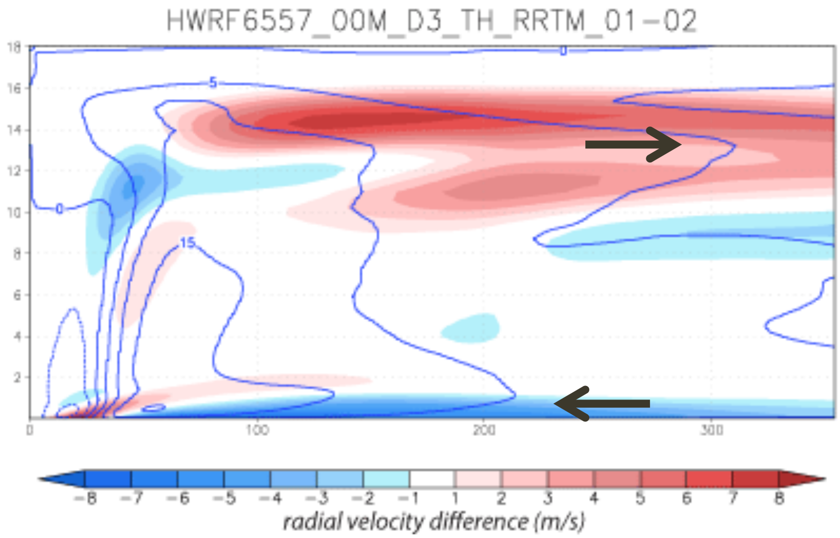
Thompson/RRTMG
CRF-on

Thompson/RRTMG
CRF-off

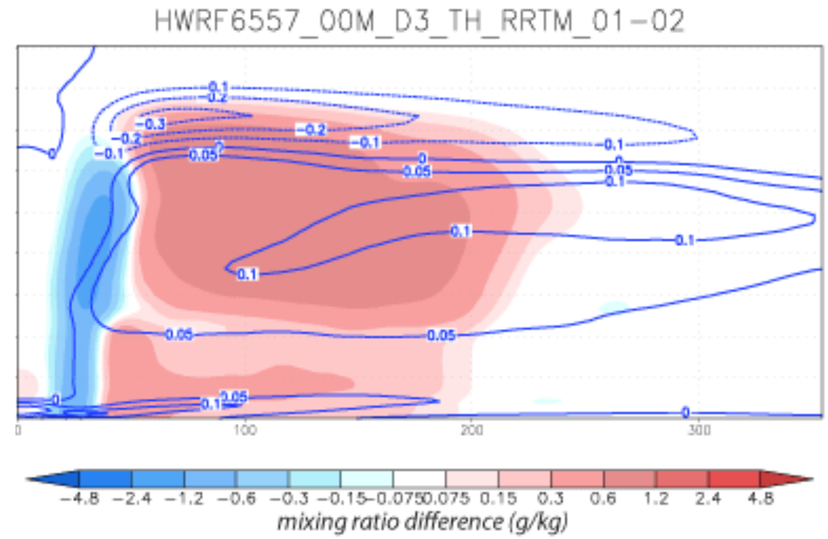
CRF-on storm: evidence of greater convective activity beyond eyewall

Microphysics forcing in Domain 3, where cumulus scheme is inactive
340K θ_e contour highlighted

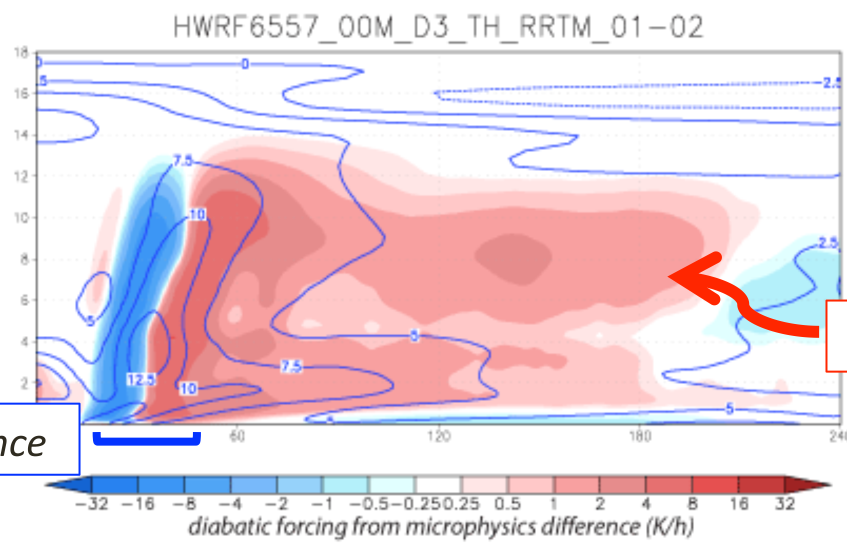
Thompson/RRTMG **difference fields**
CRF-on minus CRF-off



354 km



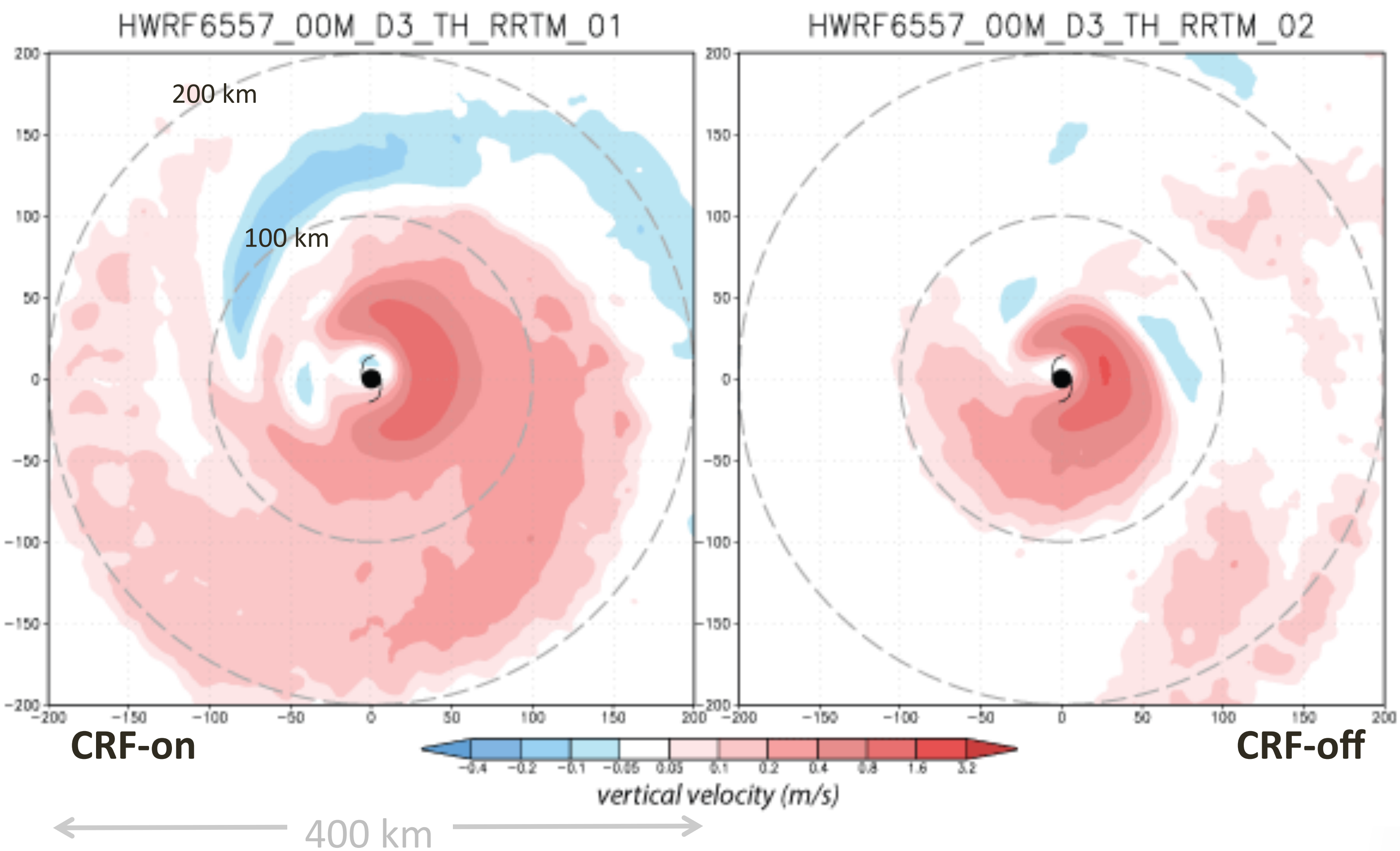
354 km



Extra heating

Eye size difference

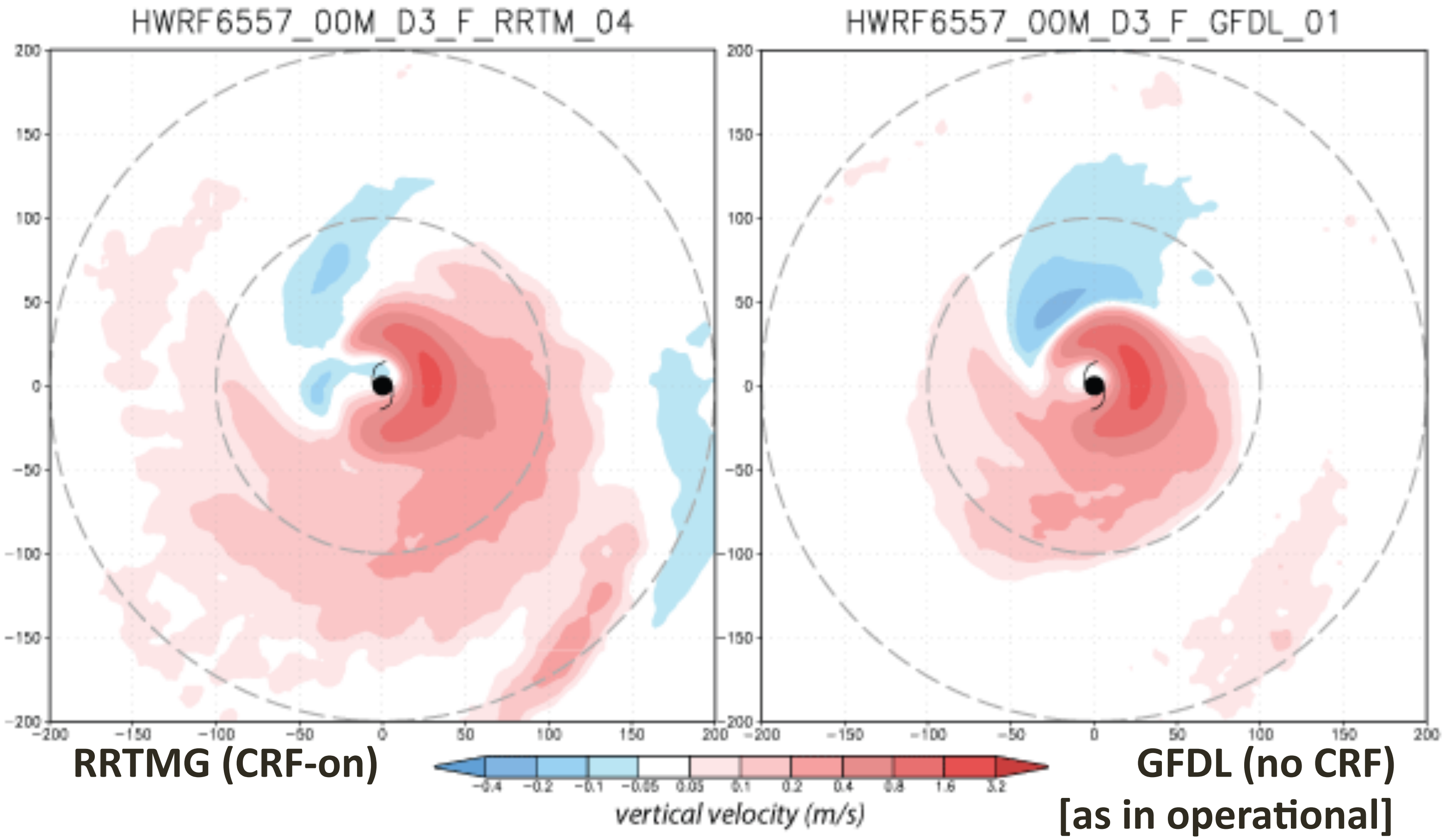
240 km



Lower troposphere vertical velocity
(sfc-500 mb)

Expected structural asymmetry owing to beta shear

Thompson/RRTMG

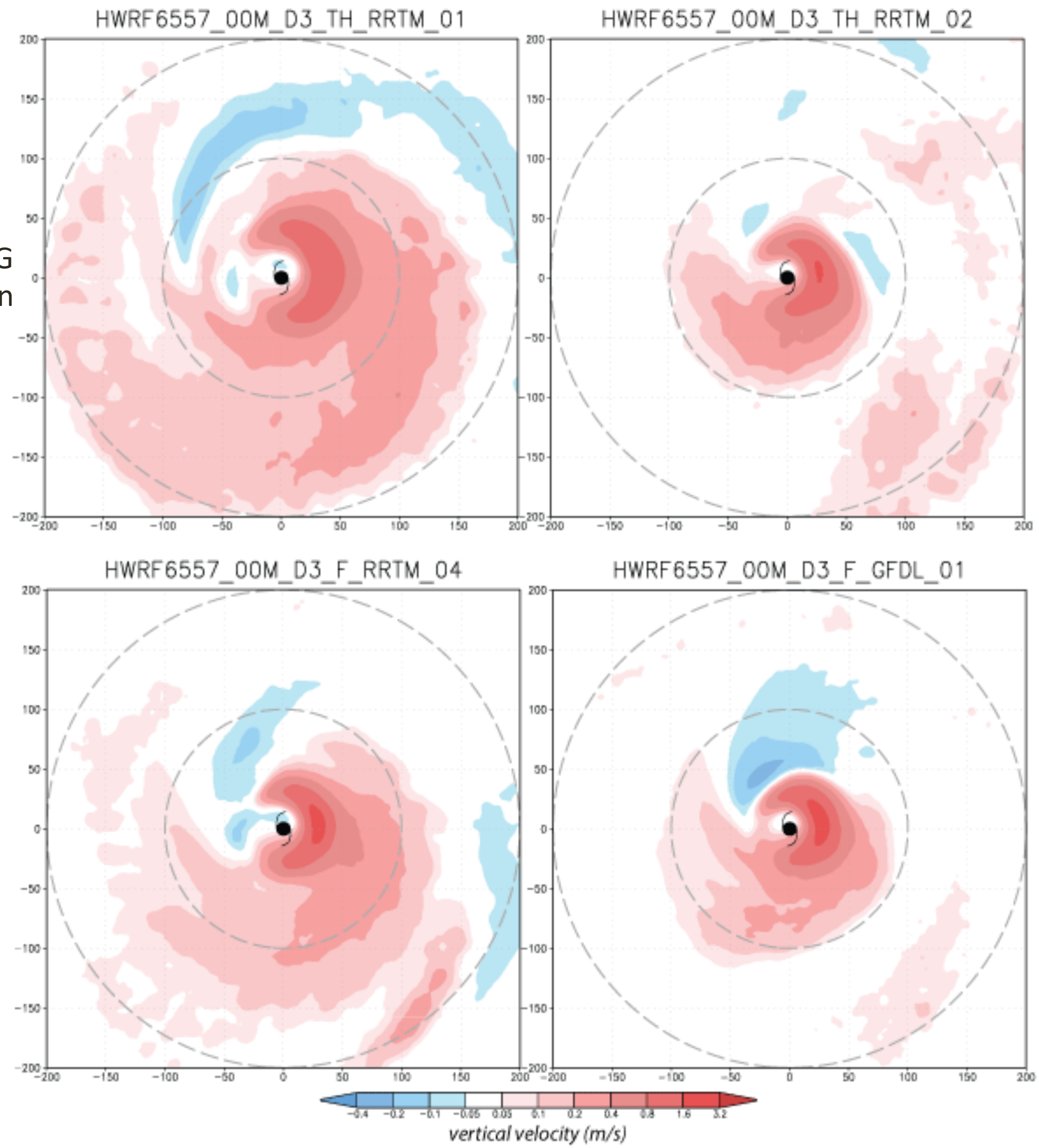


Lower troposphere vertical velocity
(sfc-500 mb)

Ferrier-based

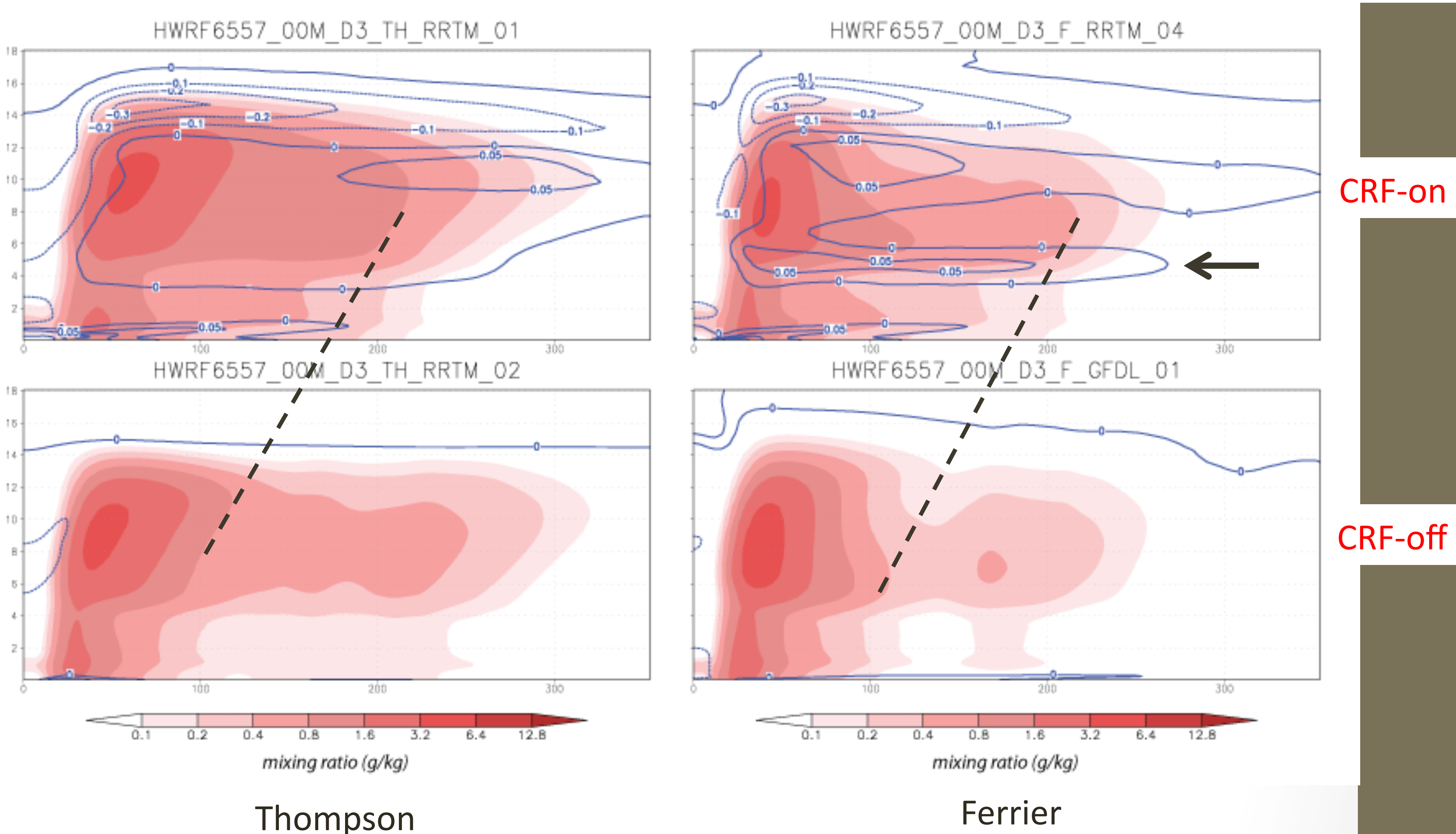
Thompson/RRTMG
CRF-on

Thompson/RRTMG
CRF-off

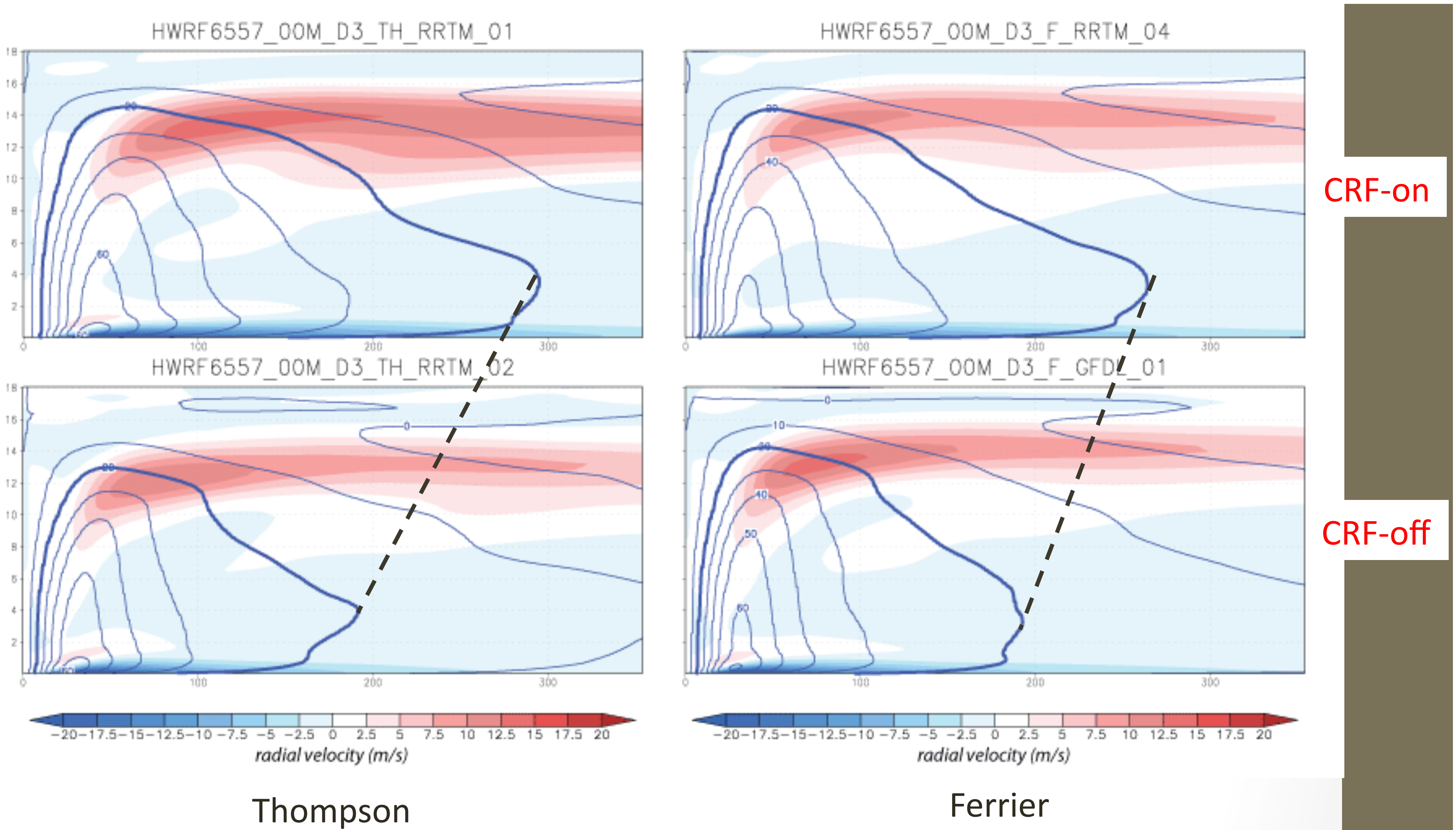


Ferrier/RRTMG
CRF-on

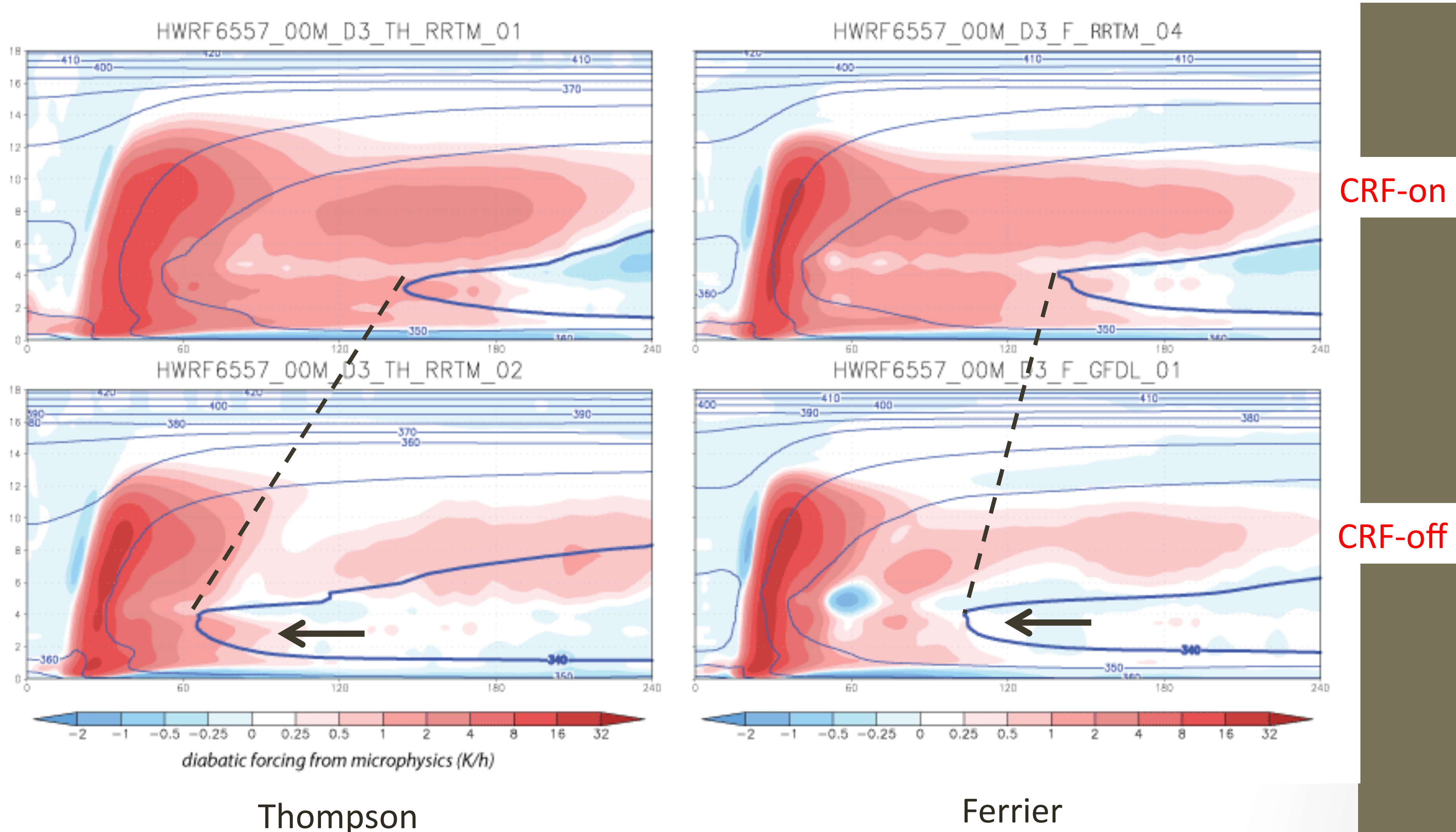
Ferrier/GFDL
No CRF



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

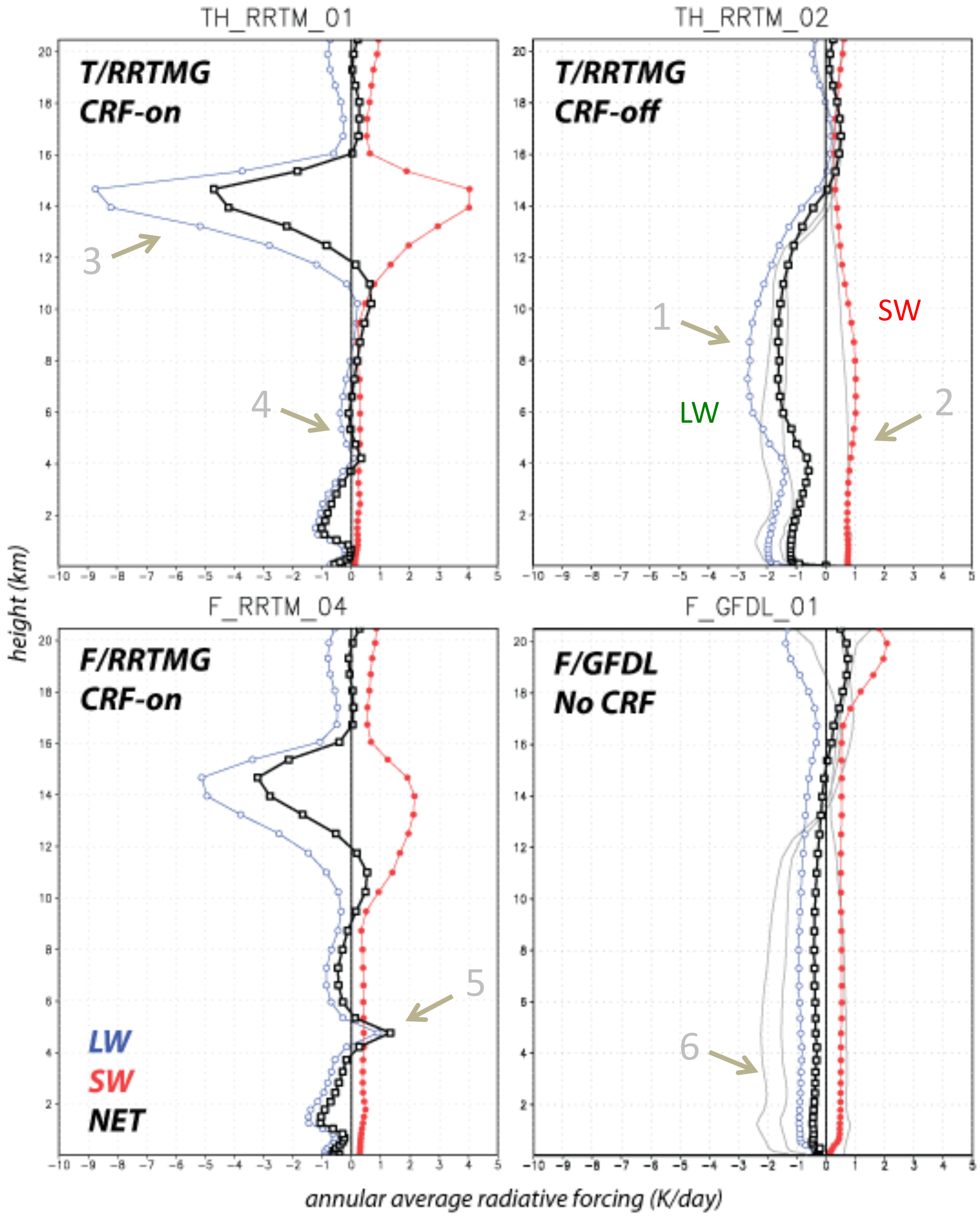


Radial velocity (colored) &
Tangential velocity (contoured, m/s)



Microphysics diabatic forcing (colored) &
θ_e (contoured, m/s)

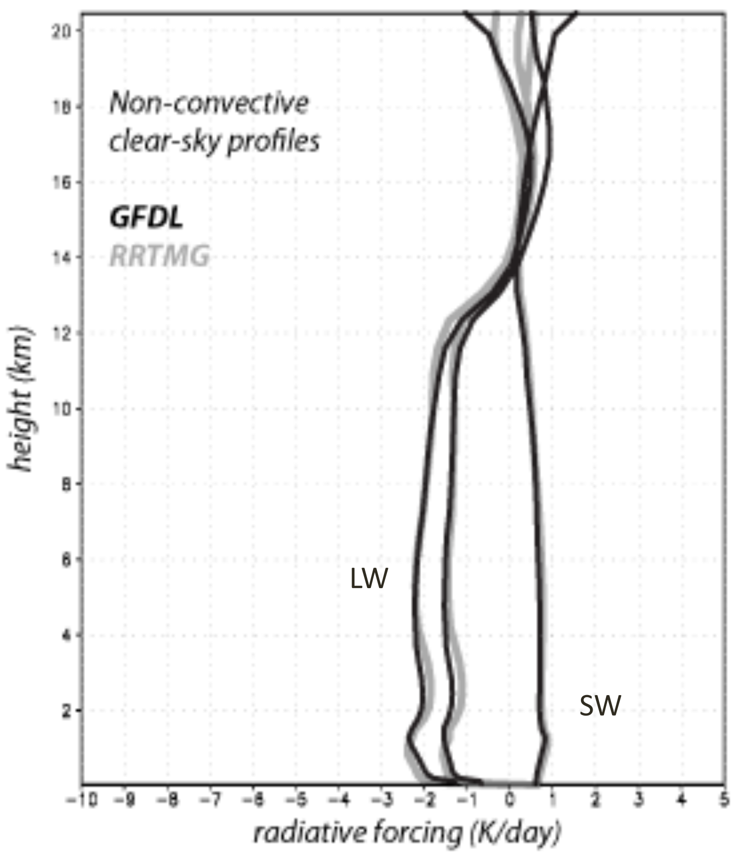
240 km



Radiative forcing (K/day) averaged 0 ≤ R ≤ 354 km in domain 2

One full diurnal cycle

T = Thompson
F = Ferrier



Non-convective, clear-sky profiles
for GFDL and RRTM are strongly similar

Obtained by running HWRF without a TC, microphysics or cumulus convection for 4 days, averaged over final diurnal cycle

Analysis

- TCs with CRF active have:
  - Wider eyes
  - Broader tangential wind fields
  - More radially extensive diabatic heating
  - Stronger, deeper upper-level outflow
- Differences between RRTMG and GFDL response to convective activity (changes in vapor, presence of hydrometeors) need to be understood
- Realism of radiative response needs to be assessed
- RRTMG operation with Ferrier needs to be evaluated

The physics of CRF: how and why

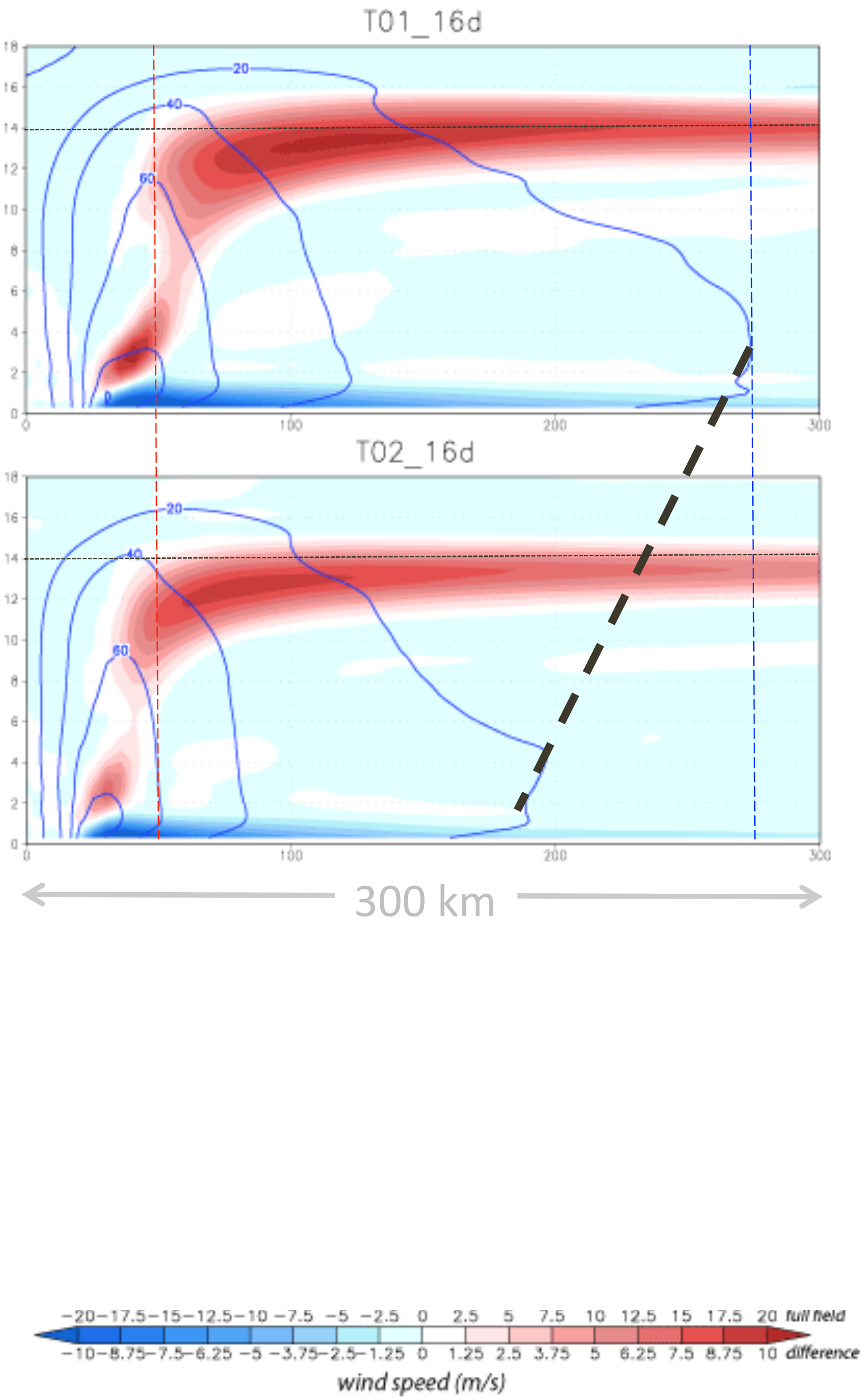
Axisymmetric simulations with George Bryan's CM1

Moist and dry versions

CM1 experimental design

- Axisymmetric framework (*f*-plane 20˚N)
- 5 km resolution
- Thompson microphysics*
- Rotunno-Emanuel moist-neutral sounding
- Goddard radiation
- Averaging period: 3-4 diurnal cycles
- Moist and dry models

**Not identical to HWRF version*



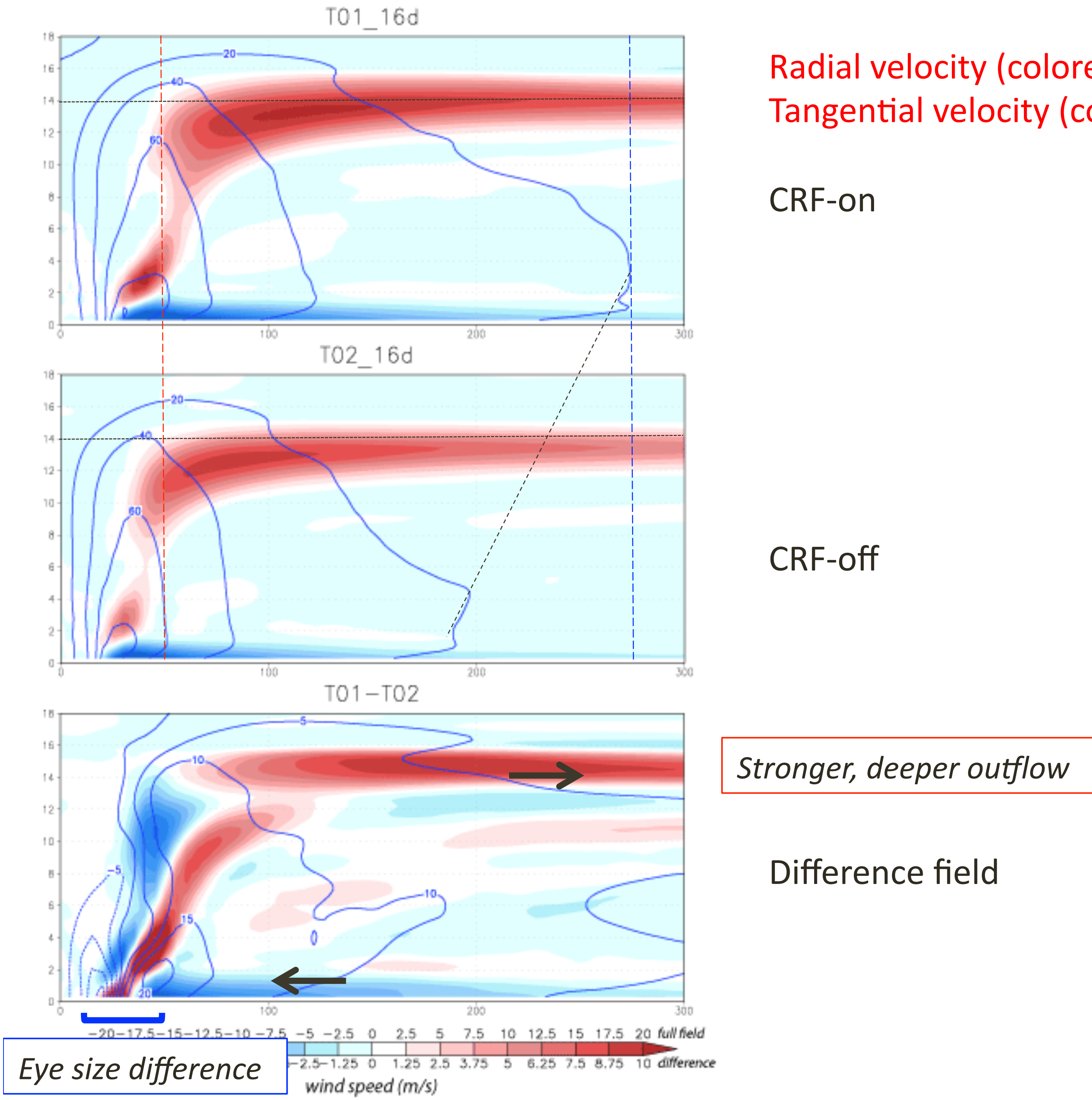
Radial velocity (colored) &
Tangential velocity (contoured, m/s)

CRF-on

CRF-off

CRF-on storm: wider eye, stronger outflow, broader wind field

Avg. period: days 10-12

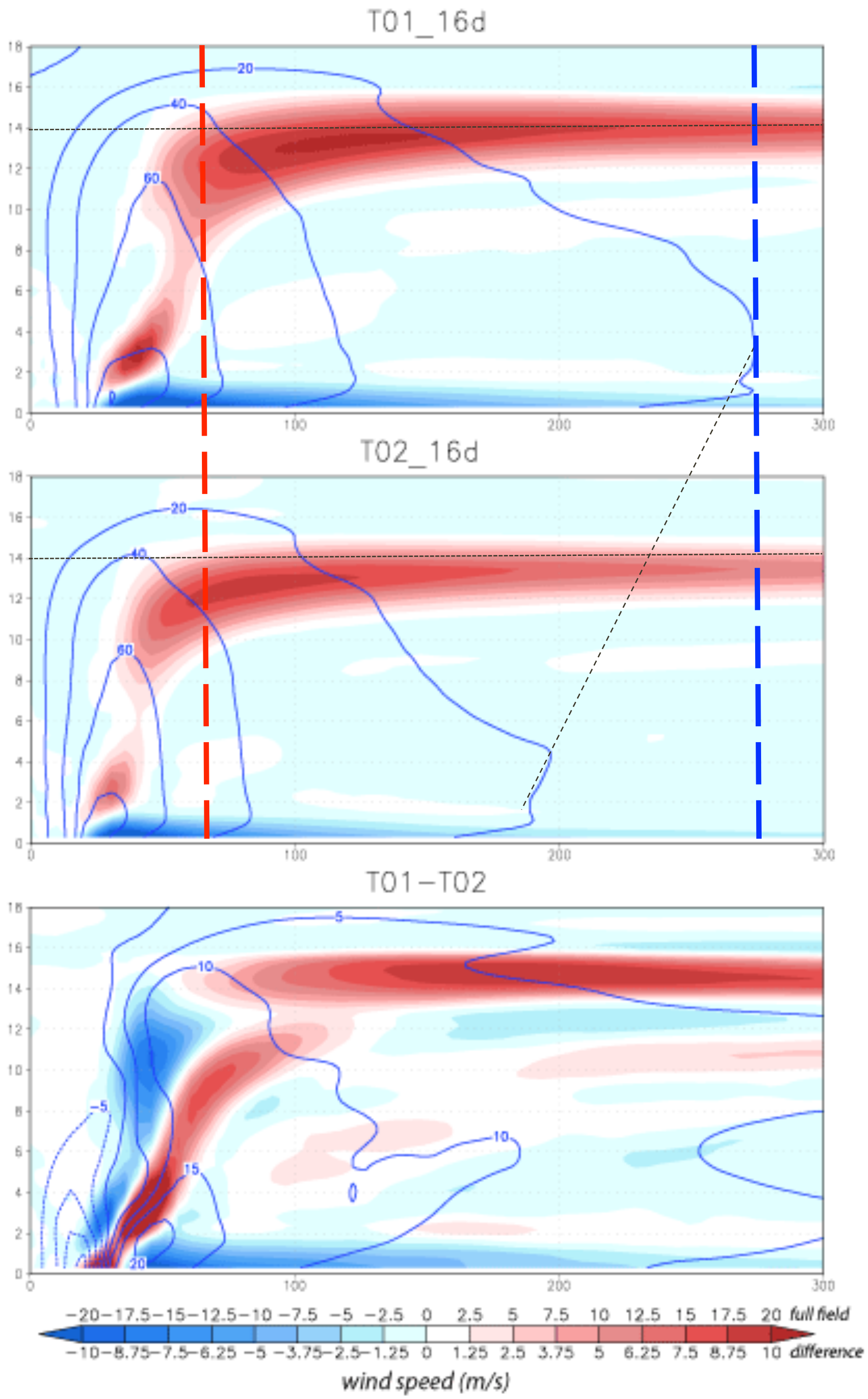


Radial velocity (colored) &
Tangential velocity (contoured, m/s)

CRF-on

CRF-off

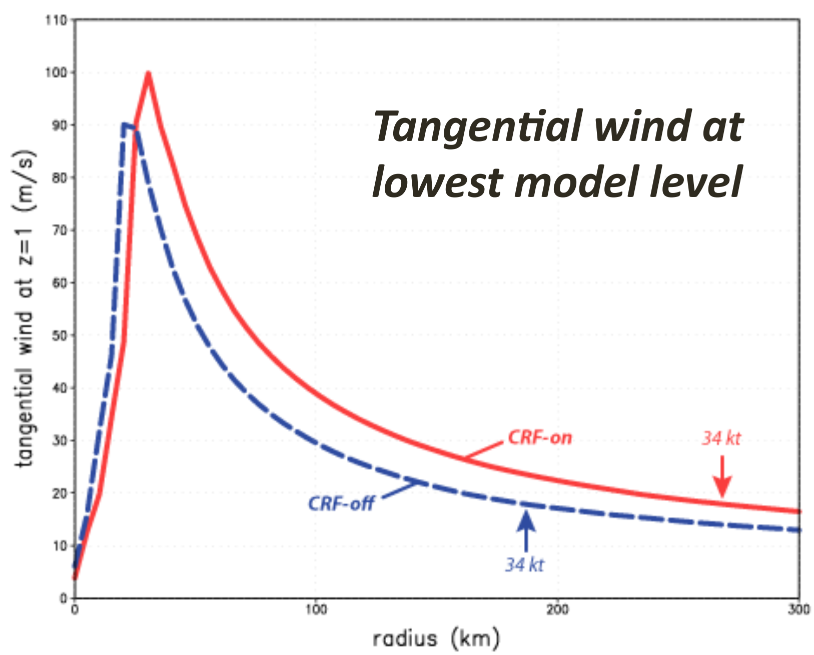
Difference field

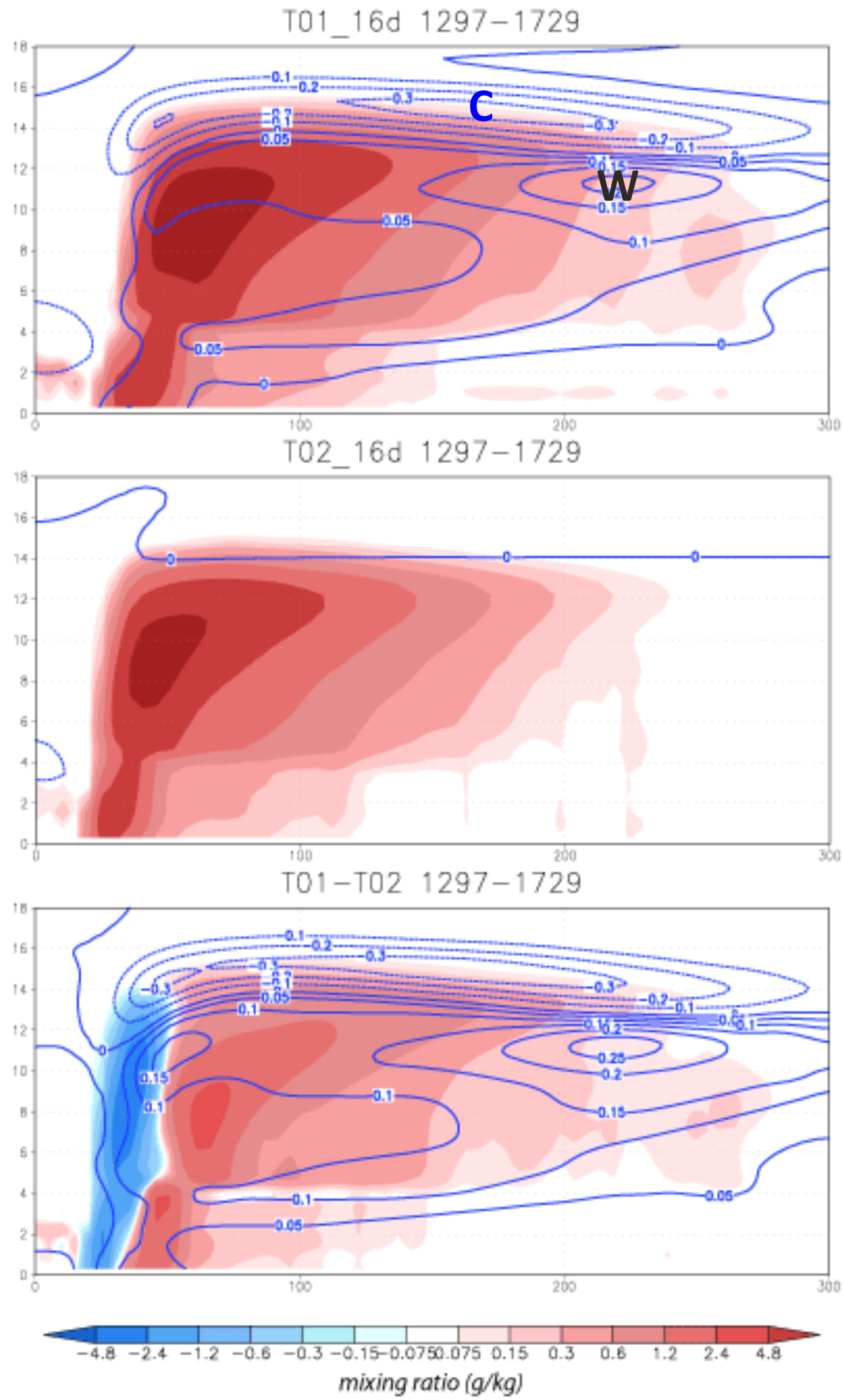


Radial velocity (colored) &
Tangential velocity (contoured, m/s)

CRF-on

34-kt wind radius considerably larger with CRF-on





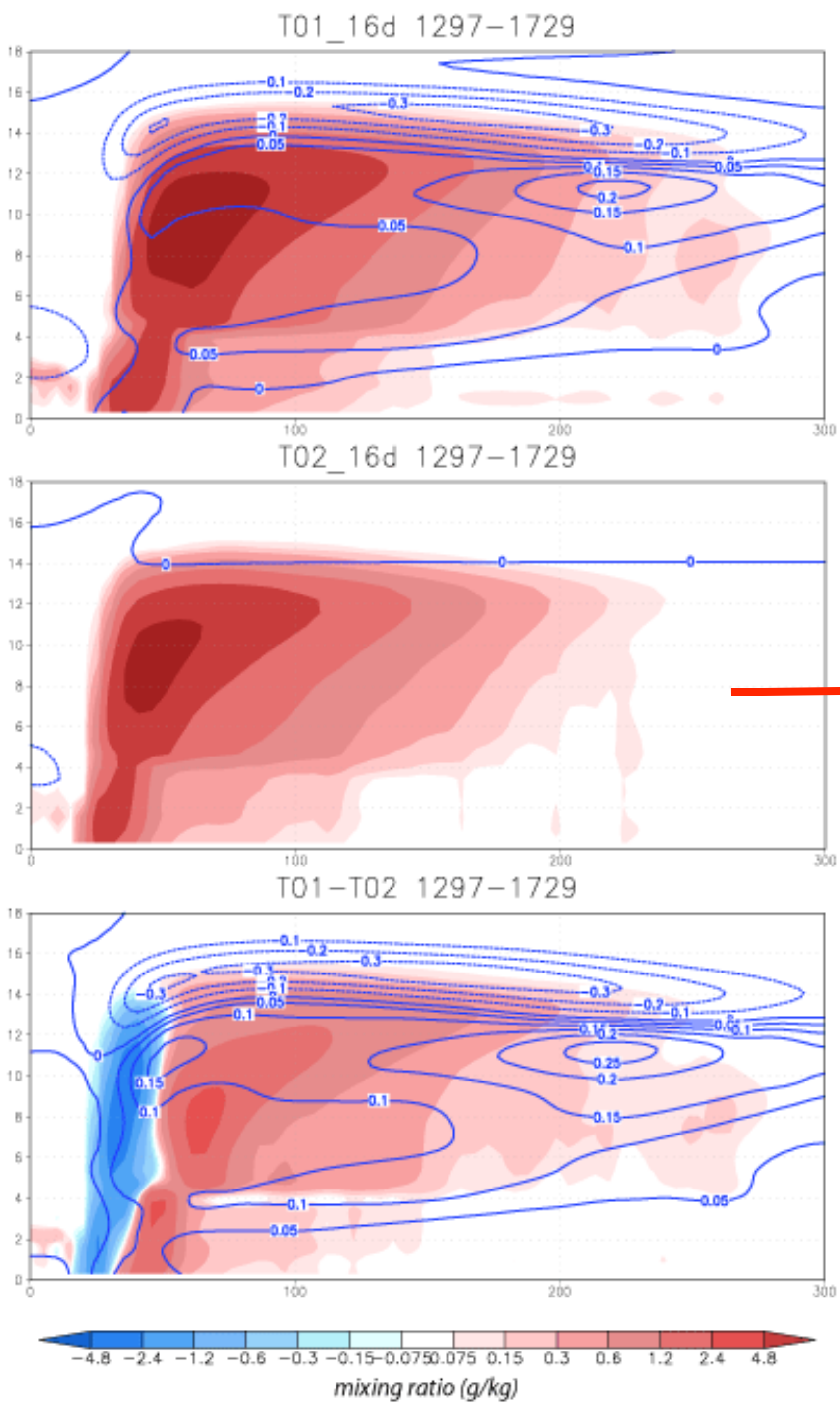
Total condensate (colored) &
Net radiative forcing (contoured, K/h)

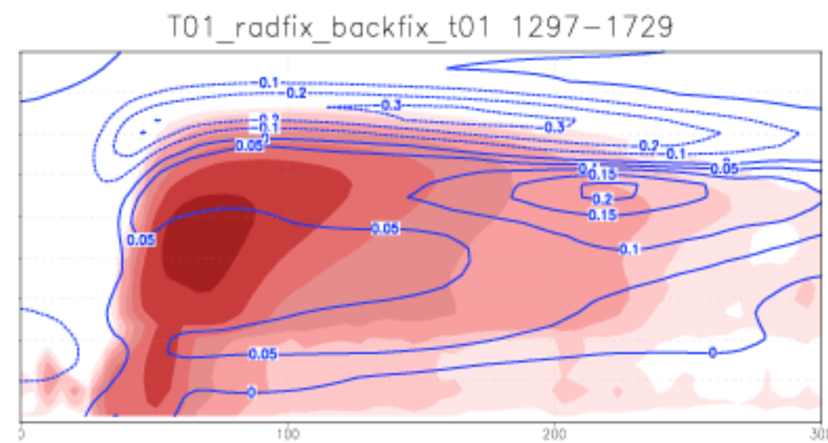
CRF-on

CRF-off

CRF-on storm: evidence of broader convective activity

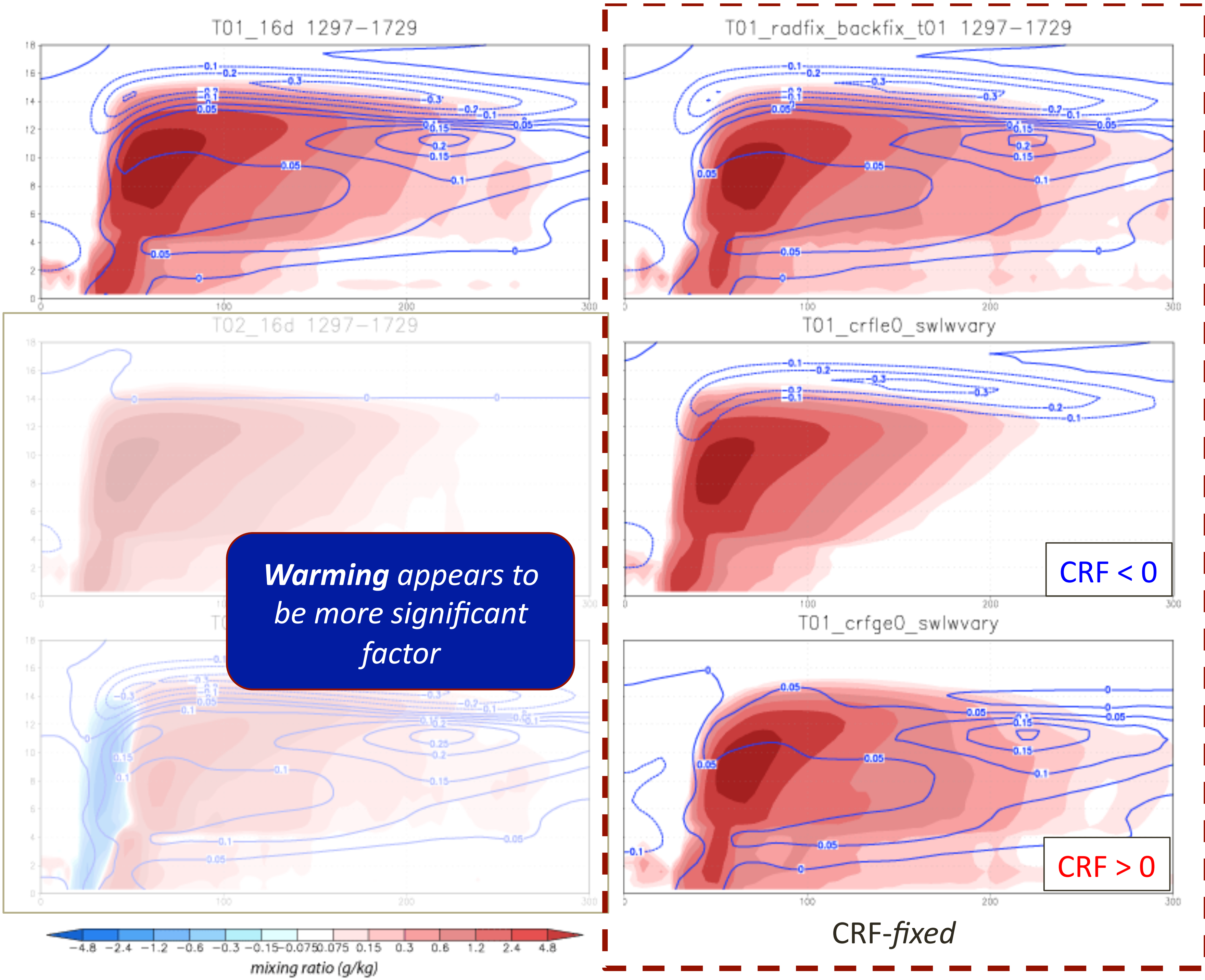
Difference field

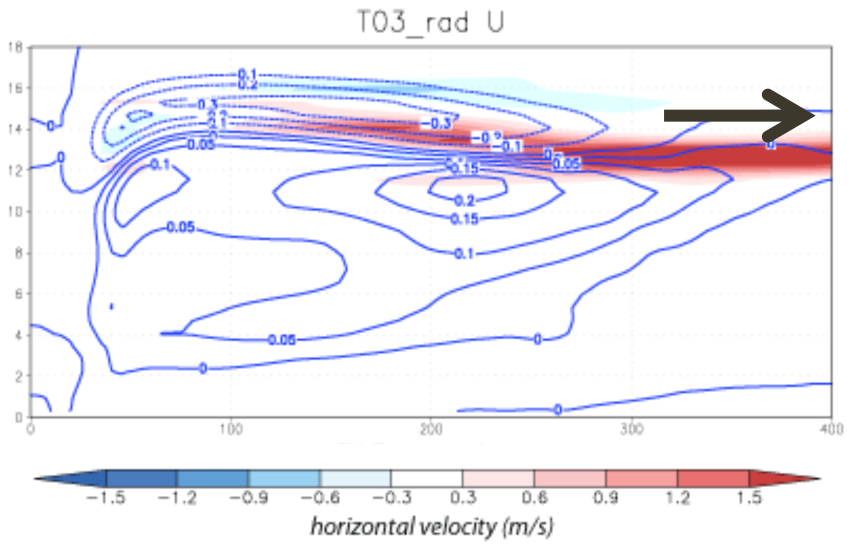


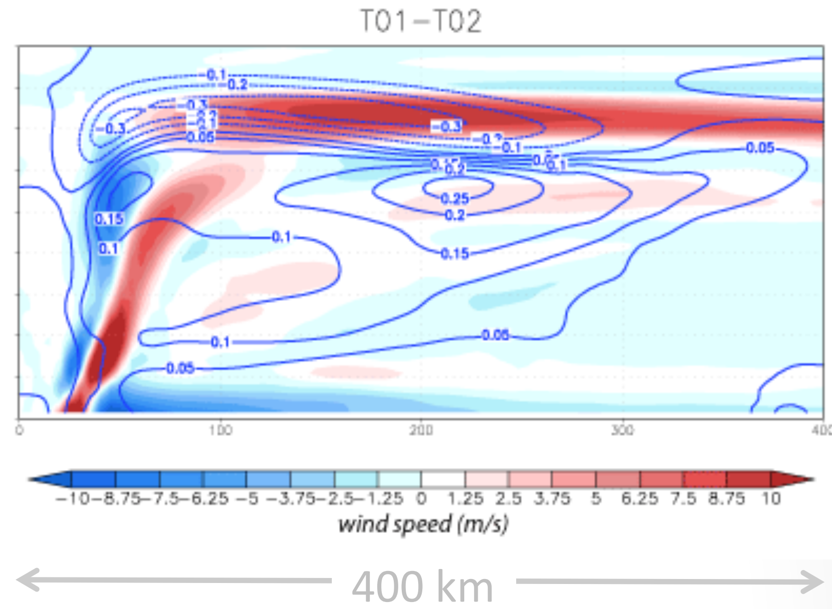


CRF-*fixed*

CRF forcing ***actively*** *encourages storm expansion*


T01_16d 1297–1729
T01_radfix_backfix_t01 1297–1729
T02_16d 1297–1729
T01_crfle0_swlwvary
T01_crfge0_swlwvary
CRF < 0
CRF > 0
CRF-*fixed*
***Warming** appears to be more significant factor*
−4.8 −2.4 −1.2 −0.6 −0.3 −0.15 −0.075 0.075 0.15 0.3 0.6 1.2 2.4 4.8
mixing ratio (g/kg)

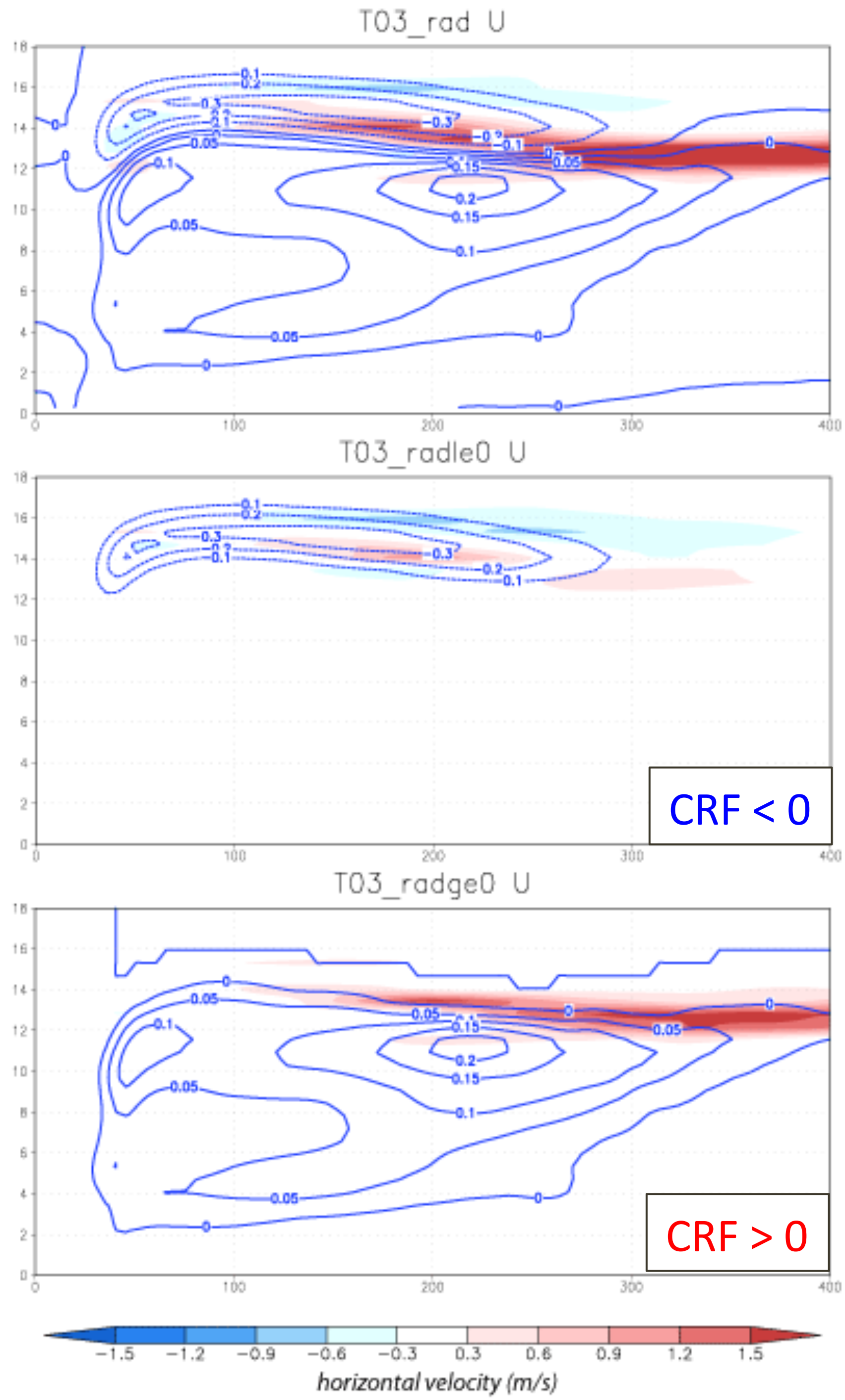


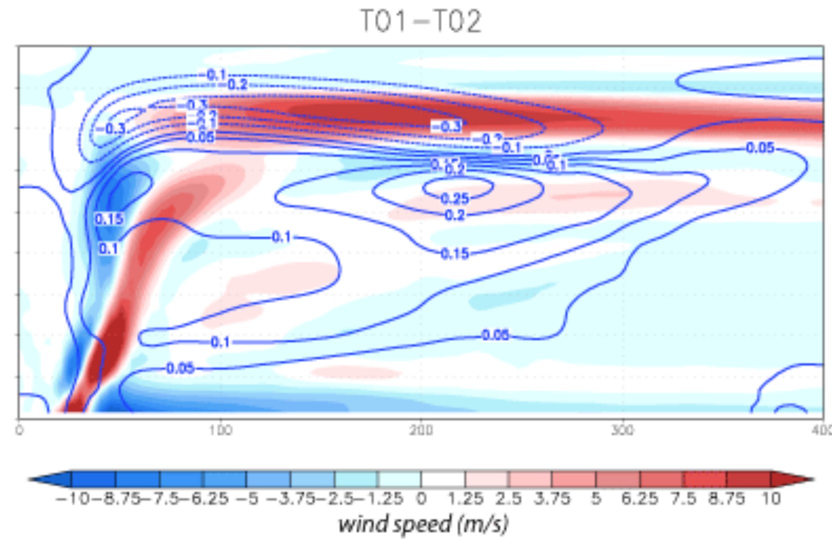


Dry model radial wind response (colored) to applied radiative forcing (contoured, K/h)

Radial velocity difference (colored) & Net radiative forcing difference (contoured, K/h)

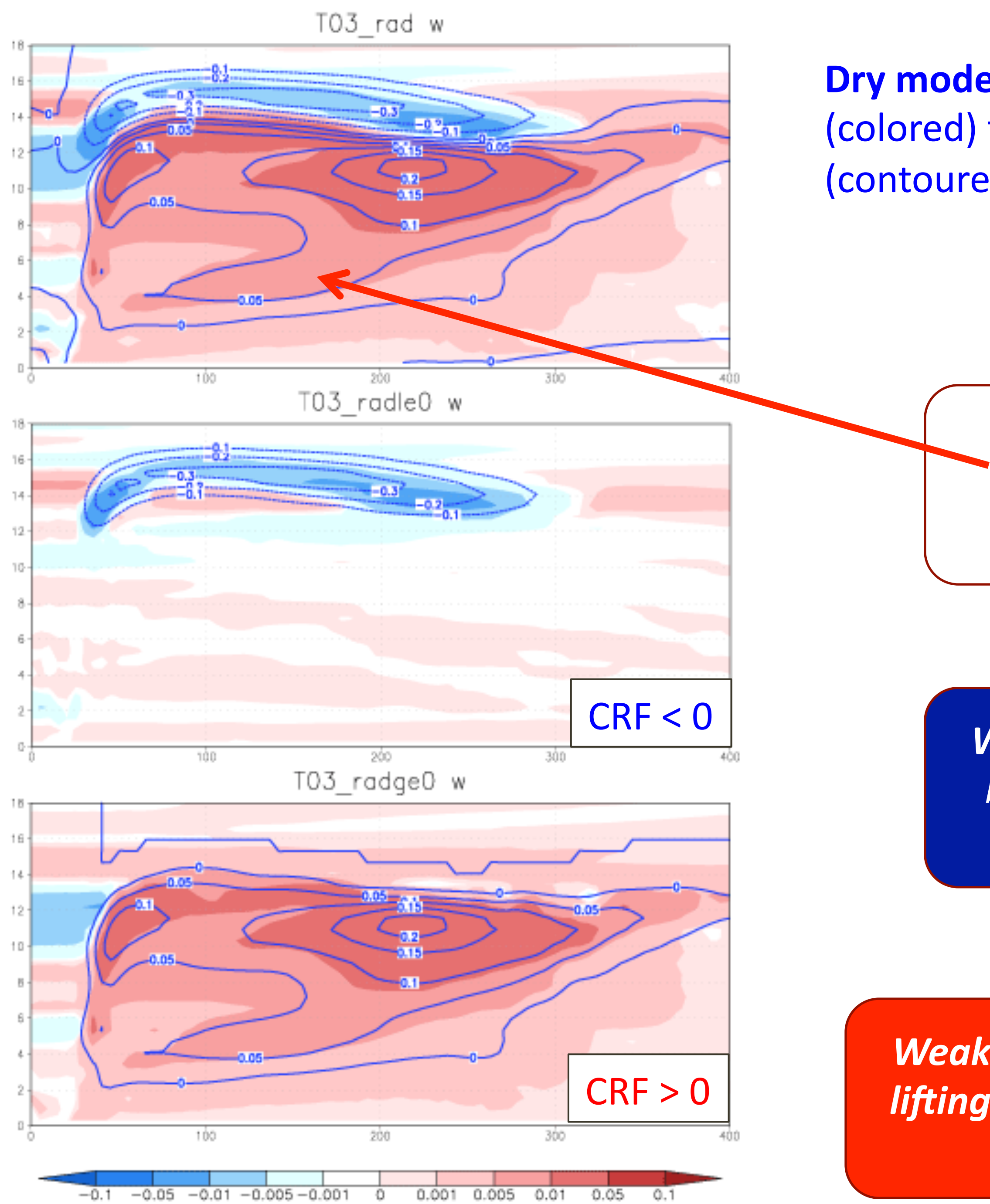
CRF forcing appears to enhance upper-level outflow





***Warming** appears to be more significant factor (again)*

Enhanced outflow carries hydrometeors outward, positive feedback



Dry model vertical velocity response (colored) to applied radiative forcing (contoured, K/h)

***Warming** appears to be more significant factor (again)*

Weak but broad and persistent lifting leads to more convective activity

Cloud-radiative forcing encourages stronger outflow and deep, broad ascent

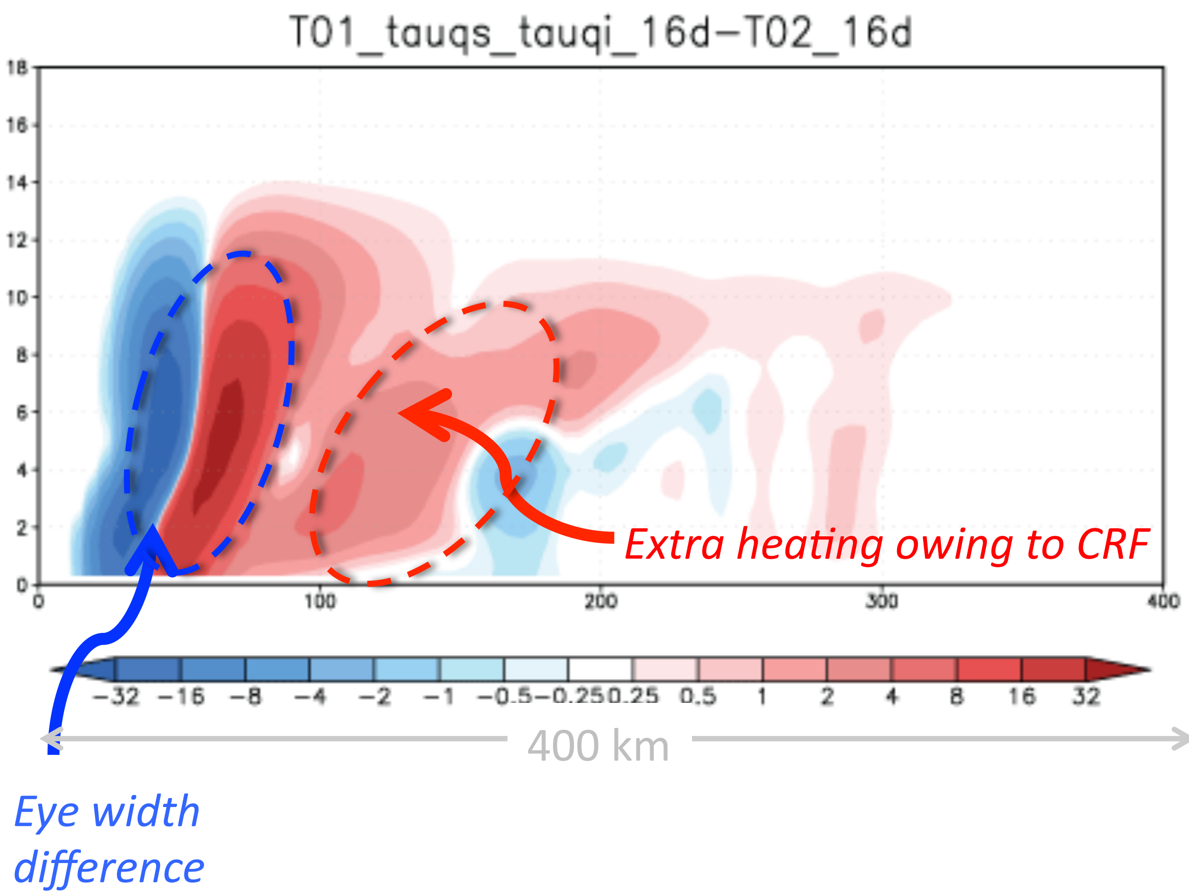
↓

…leading to more radially extensive convective activity…

↓

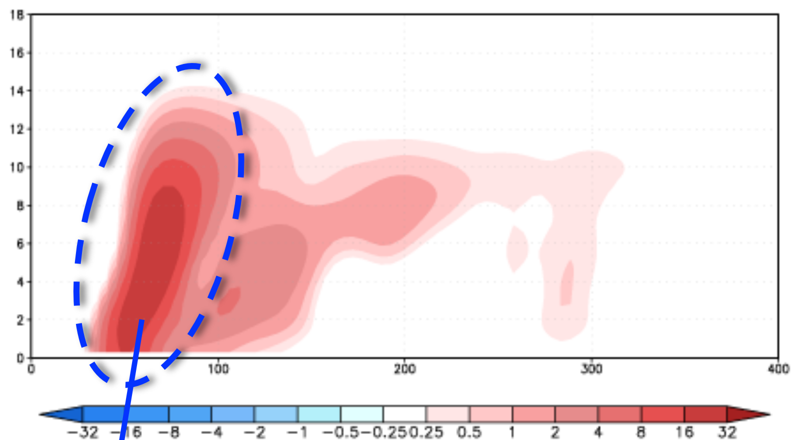
…resulting in a broader wind field

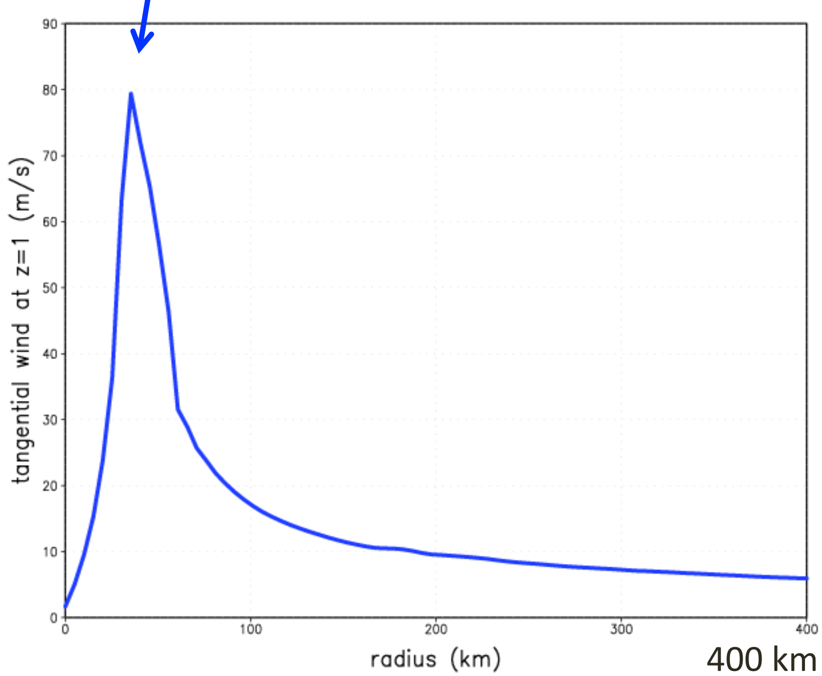
A CM1 microphysics diabatic heating difference field (CRF-on – CRF-off)



Diabatic forcing from moist model

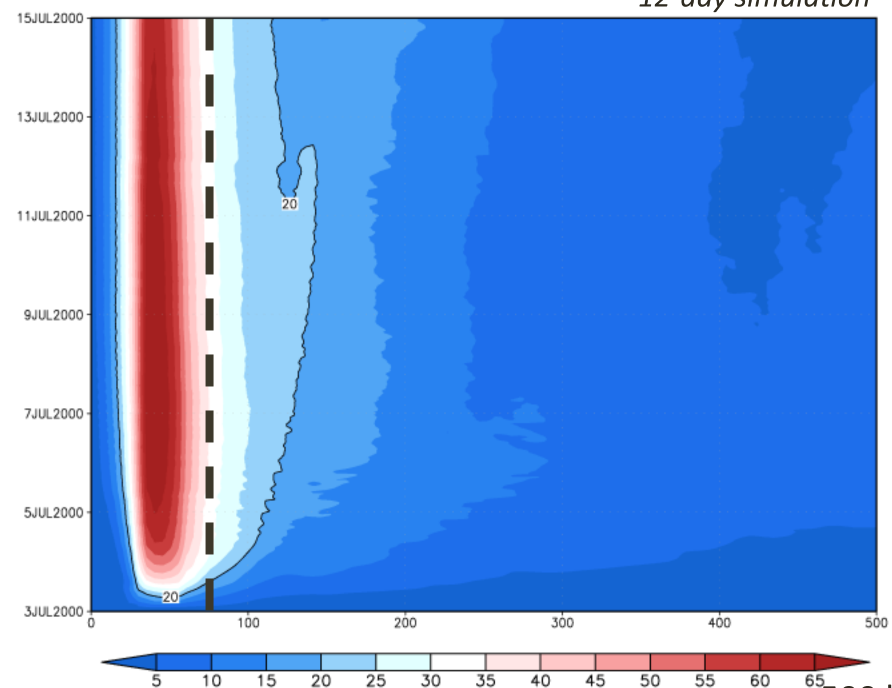
CRF-on





400 km

12-day simulation

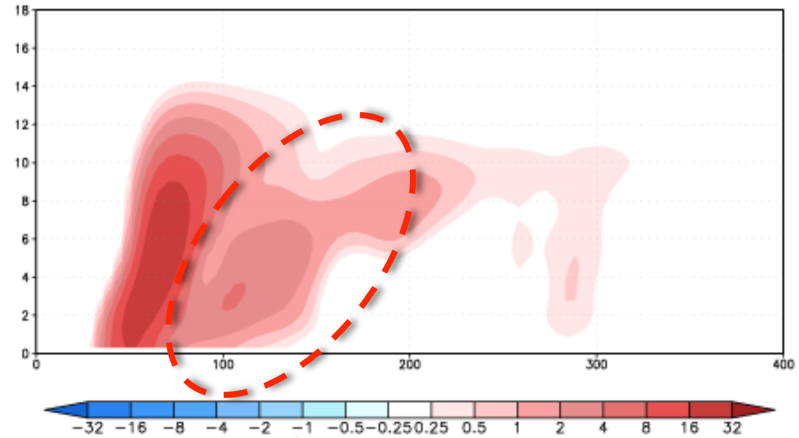


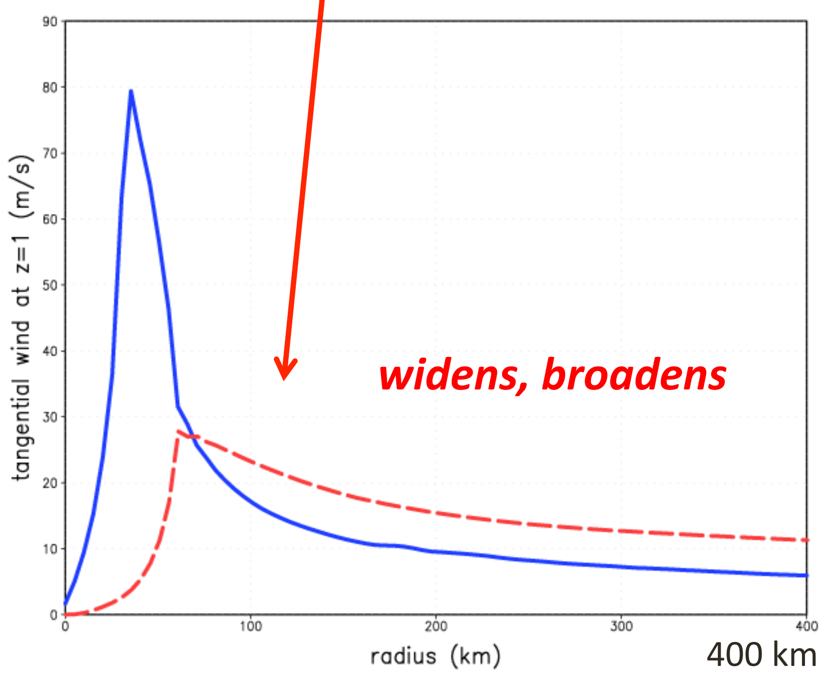
500 km

Dry model response

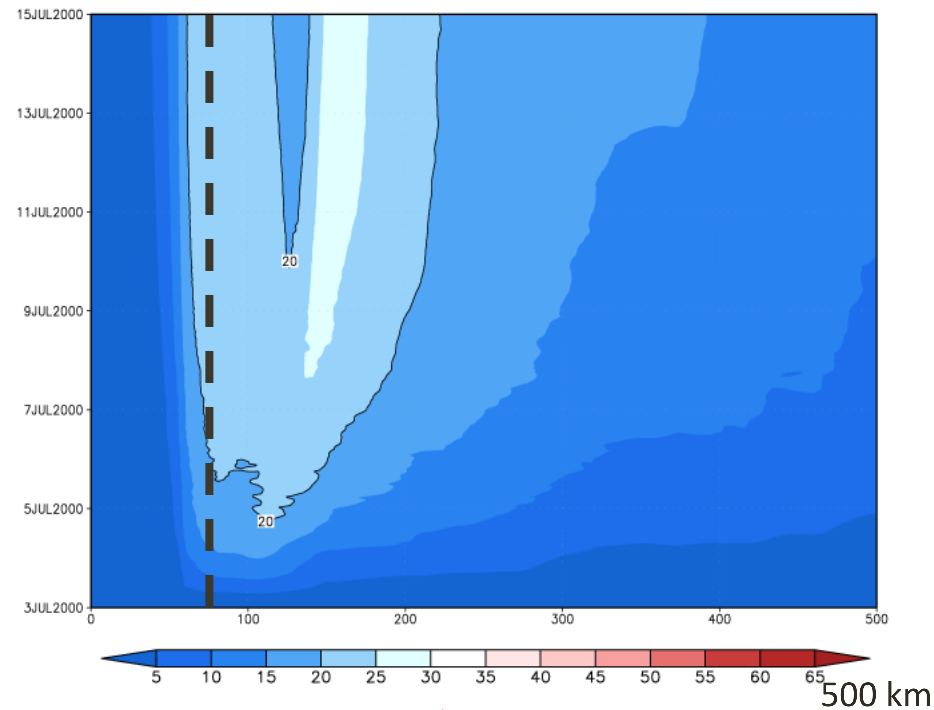
Diabatic forcing from moist model

CRF-on



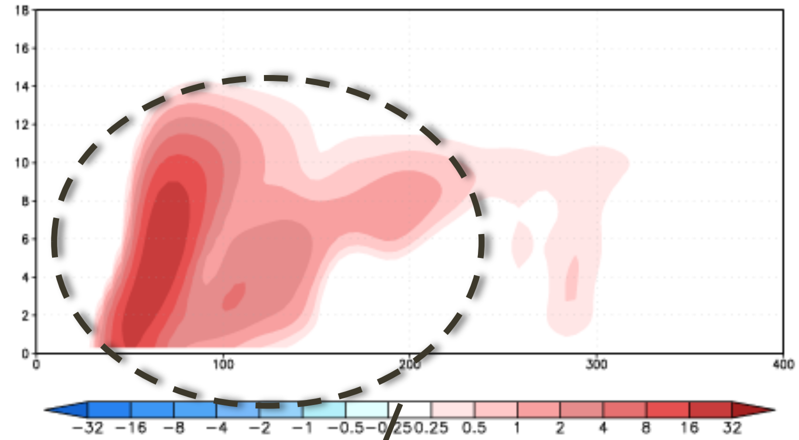


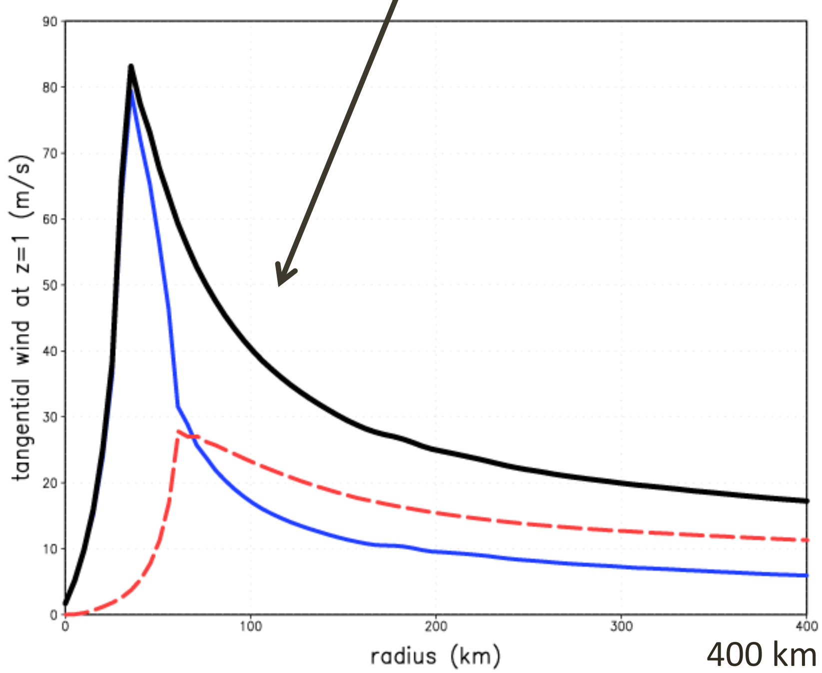
widens, broadens

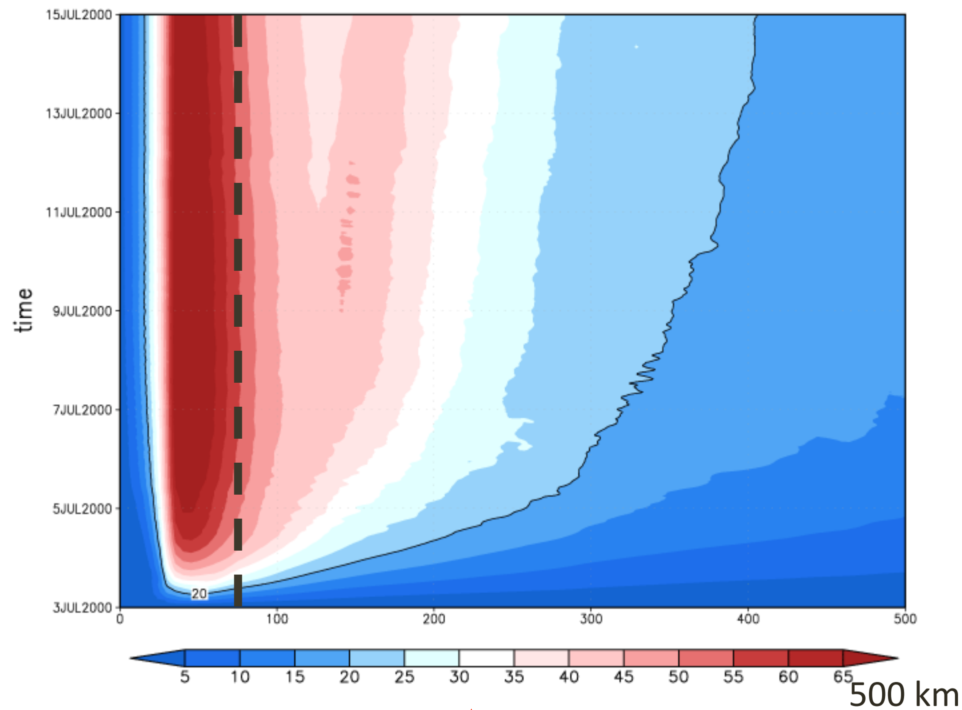


Dry model response

Diabatic forcing from moist model
CRF-on







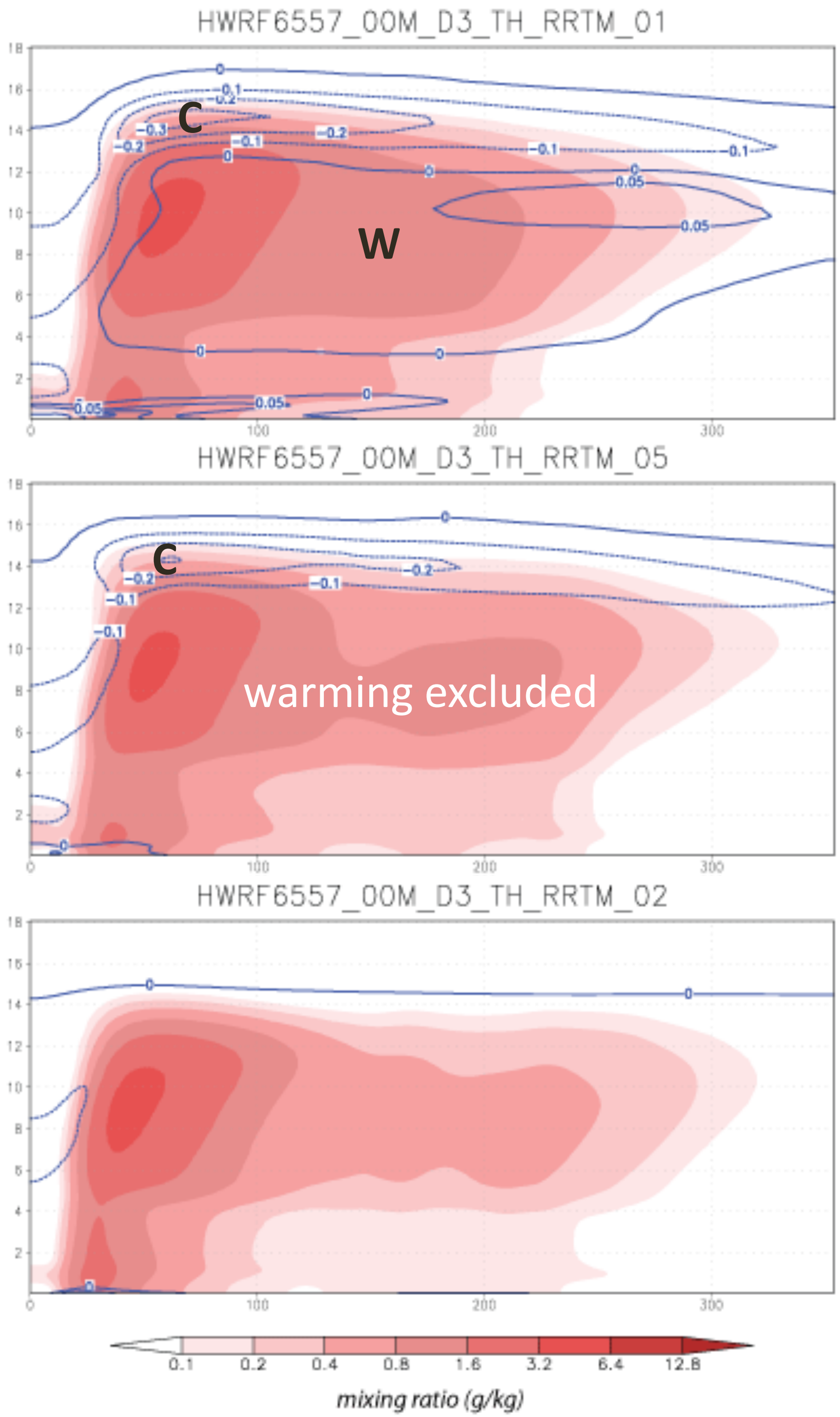
Dry model response

Caveat

- CM1 storms generate somewhat less LW anvil-top cooling and a fair bit more midtropospheric LW warming than HWRF/ RRTMG, which may exaggerate the importance of CRF > 0 relative to the cloud-top cooling (presuming HWRF and/or RRTMG is 'correct')

How much does the midtropospheric LW warming accomplish in HWRF?

An experiment in progress…



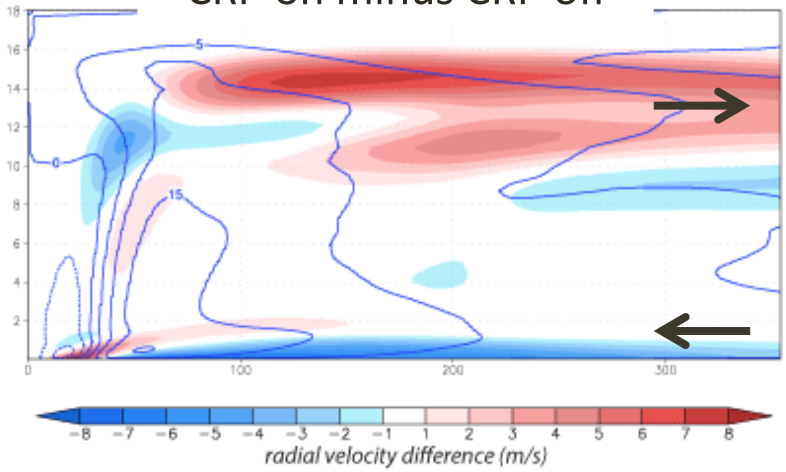
Total condensate (colored) &
Net radiative forcing (contoured, K/h)

Thompson/RRTMG
CRF-on

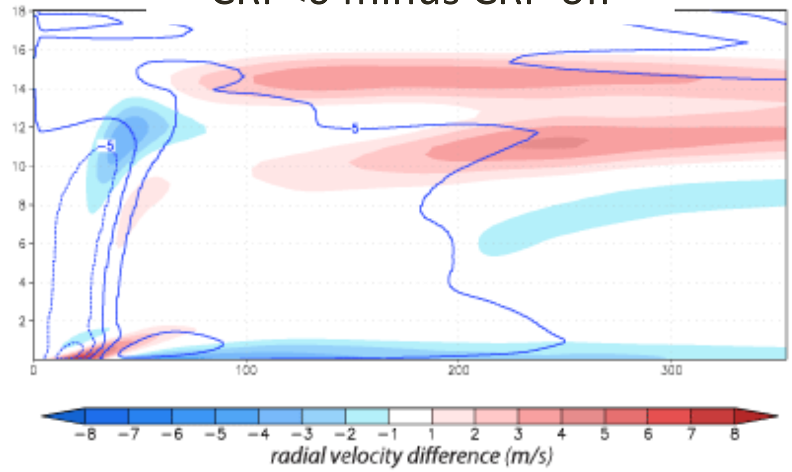
Thompson/RRTMG
CRF < 0 only

Thompson/RRTMG
CRF-off

CRF-on minus CRF-off



CRF<0 minus CRF-off

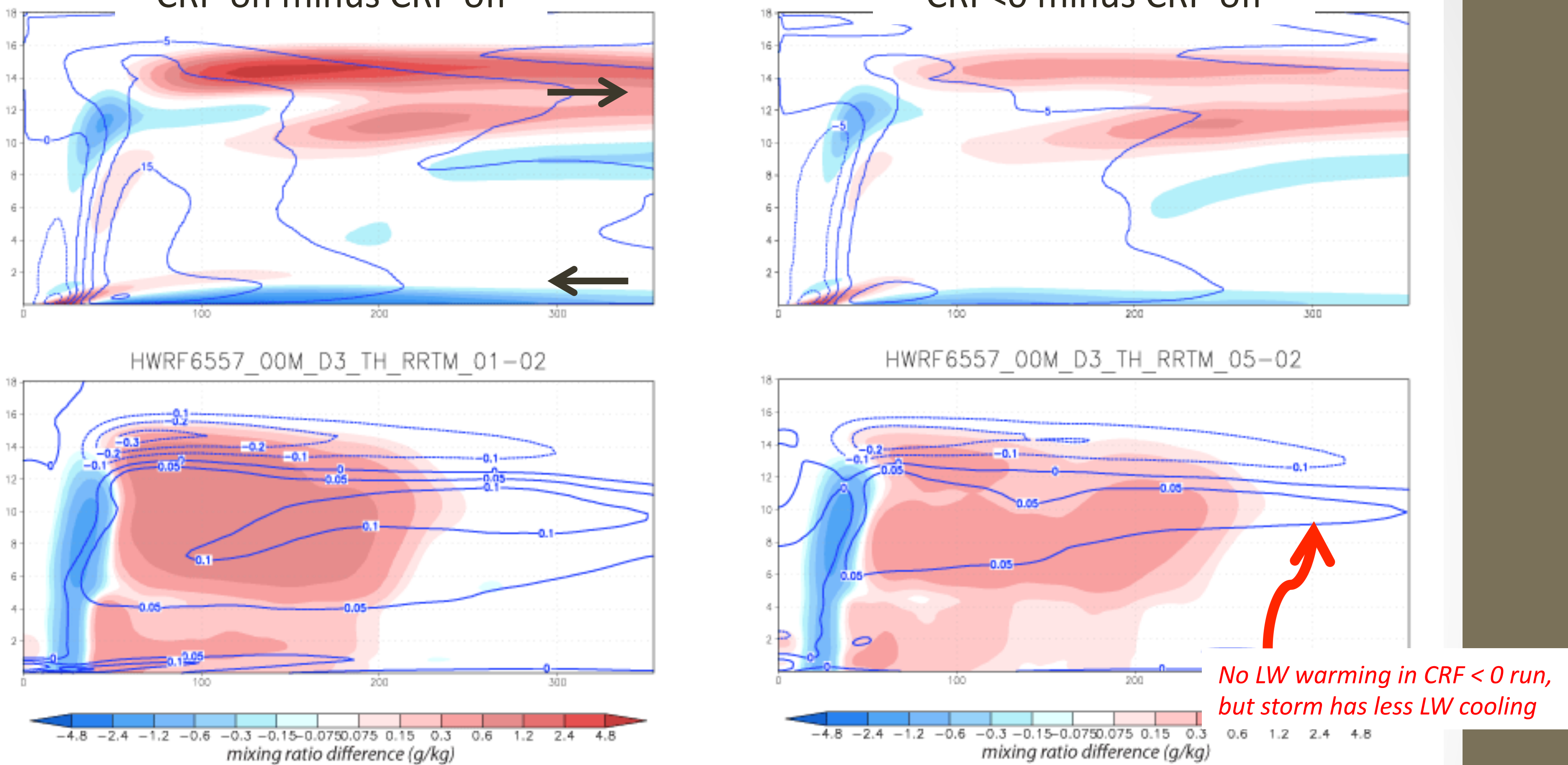


Radial velocity (shaded) &
Tangential velocity differences

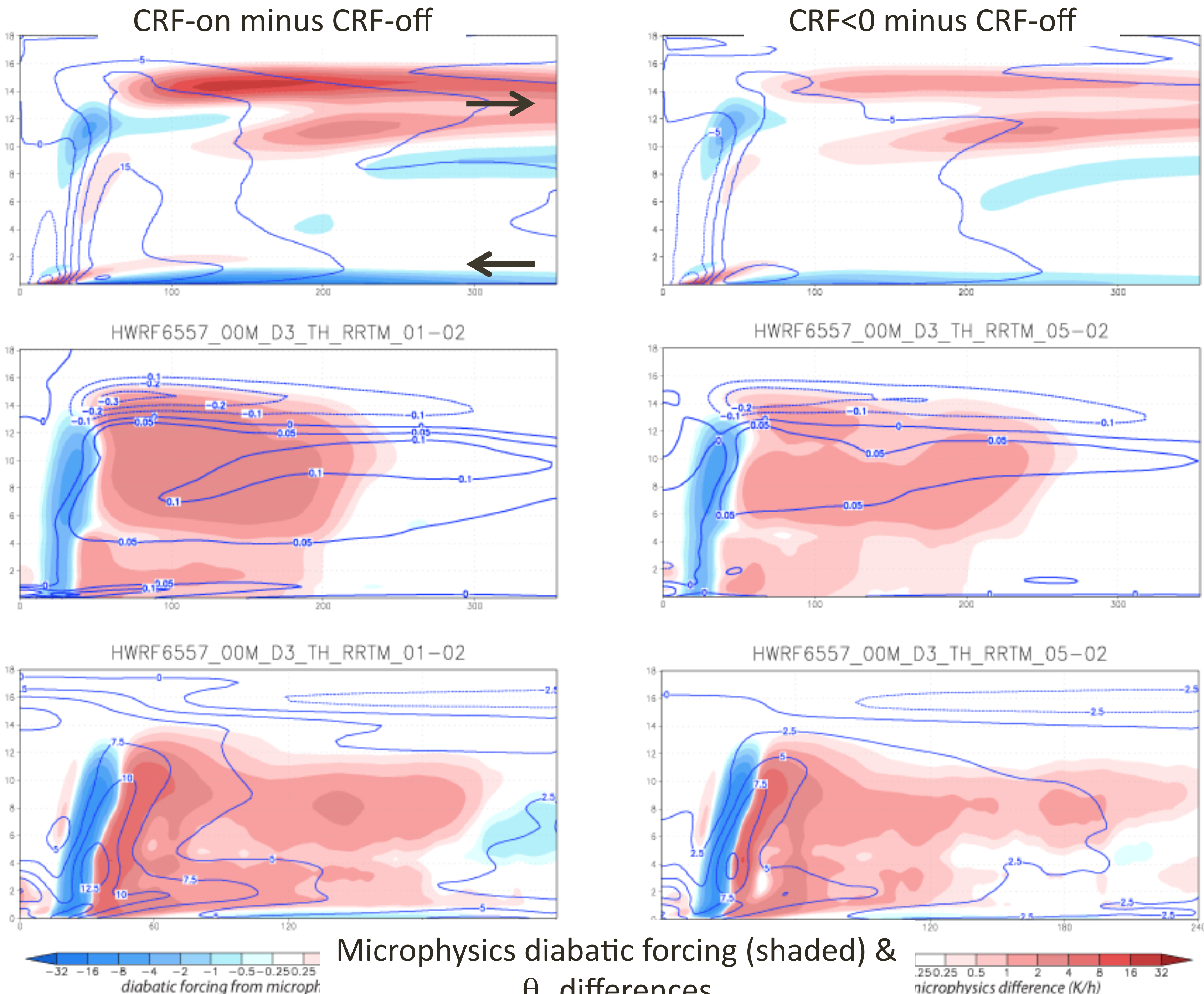
Thompson/RRTMG **difference fields**

CRF-on minus CRF-off

CRF<0 minus CRF-off



Total condensate (shaded) &
Radiative forcing differences



Microphysics diabatic forcing (shaded) & θ_e differences

Summary

- Cloud-radiative forcing can have a significant impact on storm structure
  - Directly by encouraging stronger outflow, broad ascent
  - Indirectly by fostering enhanced convective activity
- Radiation schemes differ substantially with respect to CRF magnitude (and pattern, to some degree)
  - HWRF roughly half the “work” is done by cloud-top cooling, half by midtropospheric warming
- No systematic influence on intensity noted, among simulations made using HWRF, ARW, CM1

Suggestions

- Evaluate Thompson and RRTMG in past cases, with and without CRF, to see if any improvement results
  - If improvement is found, revise/simplify Thompson microphysics for efficiency
    - Thompson runs require 2.4x more time relative to operational configuration
    - Suspect that numerous, time-consuming computations can be simplified or excised without material damage
    - Time step issues, in particular, need to be resolved
  - If improvement is *not* found:
    - Need to assess Thompson assumptions for tropical environment
    - Need to consider how Thompson/RRTMG interacts with other model physics
- Keep in mind: both Thompson and Ferrier microphysics were developed for other uses (different environments, scales, phenomena, etc.). Further optimization for TCs is possible, and beneficial.

[end]