How radiative processes can influence tropical cyclones

Robert Fovell and Yizhe Peggy Bu

University of California, Los Angeles

rfovell@ucla.edu

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

- Focus is on cloud-radiative forcing (CRF)
- CRF...
  - Is not clear-sky or “background” radiative forcing
  - Is modulation of clear-sky forcing by hydrometeors
- CRF consists of...
  - Longwave (LW) cooling at cloud tops, at all times
  - Shortwave (SW) warming at cloud tops, during day
  - LW warming within clouds
- CRF depends on microphysics parameterizations (MP)
  - Interaction with radiation is particle size-dependent, thus species-dependent
  - MPs should share size information to the radiation scheme... and one of them finally does (thanks to Greg Thompson)
Background & motivation
Semi-idealized experiment

- Real-data WRF-ARW @ 3 or 4 km for 72 h
- Uniform SST
- Single sounding
- No initial flow
- NO LAND
- 7 MPs
- One initial condition

Fovell et al. (2009)
Fovell et al. (2010)
Semi-idealized experiment

very small part of domain shown

- MPs yielded different…
  - …amounts of various hydrometeors
  - …diabatic heating patterns
  - …symmetric wind structures
  - …asymmetry patterns
  - …motions
  - …intensities

Fovell et al. (2009)
Fovell et al. (2010)
Influence of CRF

Fovell et al. (2010)
Troposphere-averaged vertical velocity

CRF caused storms to be wider, less asymmetric, weaker
Semi-idealized HWRF experiments

Single sounding, uniform SST, no initial flow, no land
HWRF experimental design

- HWRF rev. 6557 (28 March 2013)
  - Greg Thompson’s microphysics scheme
  - RRTMG radiation package
- 2012 operational configuration (3 telescoping domains)
- Thompson/RRTMG CRF-on vs. CRF-off
- Operational HWRF* is Ferrier + GFDL
- Focus on structure

* For 2013 and earlier seasons
HWRF simulation strategy for semi-idealized experiments

- Vortex-following 1 full diurnal cycle
- HWRF model physics called *every time step*
HWRF results when “clouds are cloudy”

Control run: Thompson/RRTMG with CRF-on
Averaged over 1 diurnal cycle
Lower troposphere vertical velocity (sfc-500 mb)

Expected structural asymmetry owing to beta shear

Thompson/RRTMG
Thompson/RRTMG structure

Radial (shaded) and tangential velocity (m/s)
Temporally and azimuthally averaged
Thompson/RRTMG structure

Condensation (shaded) and net radiative forcing (K/h)
Thompson/RRTMG structure

Condensation (shaded) and net radiative forcing (K/h)

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

Averaged over annulus of 350 km radius and one diurnal cycle
Clear-sky radiative forcing
(after TC development; clouds still transparent)

Averaged over annulus of 350 km radius and one diurnal cycle

From a CRF-off simulation
Total radiative forcing
(after including CRF)

Averaged over annulus of 350 km radius and one diurnal cycle
CRF-on vs. CRF-off

Averaged over 350 km radius
“A difference is a difference only if it makes a difference.”

– Darrell Huff, *How to Lie With Statistics*
Lower troposphere vertical velocity
(sfc-500 mb)

Thompson/RRTMG

$icloud = 0$ in namelist.input
Note 34-kt wind radius
> 70% larger with CRF-on
Radial velocity (colored) & Tangential velocity (contoured, m/s)

Thompson/RRTMG CRF-on

Thompson/RRTMG CRF-off

20 m/s tangential wind contour highlighted
Radial velocity (colored) & Tangential velocity (contoured, m/s)

Thompson/RRTMG
CRF-on

Thompson/RRTMG
CRF-off

Difference field

**CRF-on storm:** wider eye, stronger outflow, broader wind field
Total condensate (colored) & Net radiative forcing (contoured, K/h)

Thompson/RRTMG CRF-on

Thompson/RRTMG CRF-off
has clear-sky forcing only

Net radiation = LW + SW and includes background (clear-sky) forcing
Radiation contour interval differs for positive and negative values
Total condensate (colored) & Net radiative forcing (contoured, K/h)

Thompson/RRTMG
CRF-on

Thompson/RRTMG
CRF-off

Difference field

Eye size difference

CRF-on storm: wider, thicker anvil
Microphysics diabatic forcing (colored) & $q_e$ (contoured, m/s)

Thompson/RRTMG CRF-on

Thompson/RRTMG CRF-off

Microphysics forcing in Domain 3
340K $q_e$ contour highlighted
Microphysics diabatic forcing (colored) & $q_e$ (contoured, m/s)

Thompson/RRTMG
CRF-on

Thompson/RRTMG
CRF-off

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

**Difference field**

Extra heating

**Eye size difference**

Microphysics forcing in Domain 3
340K $q_e$ contour highlighted
Analysis

- TCs with CRF active have:
  - Wider eyes
  - Broader tangential wind fields
  - More radially extensive diabatic heating
  - Stronger, deeper upper-level outflow (stronger inflow, too)

- Comparable results from WRF-ARW versions of this experiment (not shown)
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 experiments

*Not identical to HWRF version
Radial velocity (colored) & Tangential velocity (contoured, m/s)

CRF-on

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

CRF-off

Stronger, deeper outflow

Difference field

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

CRF-on

34-kt wind radius considerably larger with CRF-on

Tangential wind at lowest model level
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
Warming appears to be more significant factor

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

Radial velocity difference (colored) & CRF-clear sky radiative forcing difference (contoured, K/h)

CRF-enhanced outflow carries hydrometeors outward, positive feedback
Warming appears to be more significant factor (again)
Dry model vertical velocity response (colored) to applied radiative forcing difference (contoured, K/h)

0.0075 m/s
~ 650 m per day
**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 (in-cloud) 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 \((\text{CRF-on} - \text{CRF-off})\)

![Diagram showing extra heating owing to CRF and eye width difference within a 400 km range.](image-url)
Diabatic forcing from moist model
CRF-on

Dry model response
Diabatic forcing from moist model CRF-on

Dry model response

widens, broadens
Diabatic forcing from moist model
CRF-on

Dry model response
CRF-related cooling and warming in HWRF
Thompson/RRTMG runs

Tangential wind at z=1 (m/s)

CRF-on

CRF-off

Radius (km)
Warming appears to be more significant factor (again)
Operational HWRF deep clouds are not cloudy

Operational physics called every time step
“[A]ll models are wrong; the practical question is how wrong do they have to be to not be useful.”

– George E. P. Box
Schematic model - I
Schematic model - II
Schematic model - III
Schematic model - IV
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
  • **Quickly** -- much faster than one might guess

• Operational HWRF physics produces little to no CRF response
• Is direct validation of in-cloud LW forcing even possible?
• Thanks Jimy and Wei for the invitation
• Supported by the NOAA Hurricane Forecast Improvement Program (HFIP)
[end]
Total condensate (colored) & Net radiative forcing (contoured, K/h)

Thompson/RRTMG
Lower troposphere vertical velocity (sfc-500 mb)

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

354 km

CRF-on

CRF-off
Radial velocity (colored) &
Tangential velocity (contoured, m/s)
Microphysics diabatic forcing (colored) & $q_e$ (contoured, m/s)
Radiative forcing (K/day) averaged $0 \leq R \leq 354$ km in domain 2

One full diurnal cycle

$T = \text{Thompson}$

$F = \text{Ferrier}$