7B.7 Influence of Cloud-Radiative Processes on Predecessor Rain Events

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ABSTRACT

A series of idealized numerical simulations is conducted to examine the effects of cloud-radiative processes on the formation of predecessor rain events (PREs). PREs are coherent mesoscale rainstorms that occur well in advance of recurving tropical cyclones (TCs) and have a high potential to cause flooding and adverse societal impacts. Simulations are performed using an aquaplanet version of the Weather Research and Forecasting v.3.6 model with a straight jet. This study finds that cloud-radiative forcing (CRF), the interaction of hydrometeors with longwave (LW) and shortwave (SW) radiation, produces a more robust PRE storm structure with stronger convective activity and, ultimately, more precipitation. It is hypothesized that LW cooling associated with low-level clouds outside of the PRE region induces a horizontal pressure gradient which enhances convergence near the surface and drives more vigorous ascent. In contrast, in-cloud warming in the middle troposphere generally serves to increase the static stability within the PRE structure. Therefore, the primary radiation driver of PRE formation occurs outside of the PRE itself and is based on how the model responds radiatively to low clouds. Because the recipe for PRE development requires many individual ingredients to come together in just the right way, accurately predicting heavy rainfall events associated with tropical cyclones remains a daunting forecast challenge.

1. Introduction

The term predecessor rain event (PRE) describes coherent mesoscale rainstorms that occur well in advance of recurving tropical cyclones (TCs) and have a high potential to cause flooding and adverse societal impacts (Cote 2007). This aspect has been underscored most recently by high-impact flood-producing PREs associated with TC Erin (2007; Galarneau et al. 2010; Schumacher et al. 2011; Schumacher and Galarneau 2012) and TCs Ike and Lowell (2008; Schumacher and Galarneau 2012; Bosart et al. 2012). PREs typically occur near a low-level baroclinic zone, beneath the equatorward entrance region of an upper-level jet streak, and in the presence of a low-level moisture advection from a TC (Galarneau et al. 2010).

This study uses "semi-idealized" numerical modeling to investigate the influence of cloud-radiative-forcing (CRF), the interaction of hydrometeors with longwave (LW) and shortwave (SW) radiation, on the development of PREs (Fovell et al. 2010a,b; Bu et al. 2014). While the characteristics, formation, and climatology of PREs have been documented extensively in recent literature (e.g. Moore et al. 2013), there have been limited studies with numerical models and no studies using an idealized modeling framework. The overall goal of this research is to improve the understanding of PRE development in weather prediction models, giving operational forecasters the ability to provide more accurate and advanced warning to potentially affected communities.

2. Model and Experiment Design

A series of experiments is conducted using an aquaplanet version of the Weather Research and Forecasting (WRF) model Advanced Research (ARW) core v.3.6 developed at the National Center for Atmospheric Research (NCAR). The single domain consists of a 6000 km square region with 30 km horizontal resolution, 31 irregularly spaced vertical levels, and a 50 mb model top. The background environment is based on the Dunion (2011) moist tropical sounding with no winds. The RRTMG (Rapid Radiative Transfer Model for General Circulation Models) radiation scheme is specified for both LW and SW radiation. CRF effects are activated via the namelist parameter *icloud*.

The major components of the PRE system consist of an upper-tropospheric jet, low-level baroclinic zone, and a TC. An upper-tropospheric straight jet is centered at 36°N and zonal winds increase with height to a maximum value of 50 m s^{-1} at 175 mb (Fig. 1). The corresponding mass

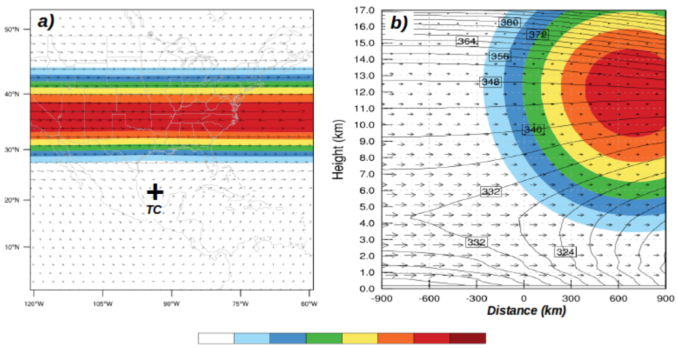

Figure 1: Initial zonal wind distribution (m s^{-1}, colored contours) for a) the full simulation domain and b) a meridional cross-section through the center of the domain centered at 30 deg N and 76 deg W. The black plus sign in panel (a) indicates the initial position of the TC. The black contours in panel (b) represent equivalent potential temperature (K).

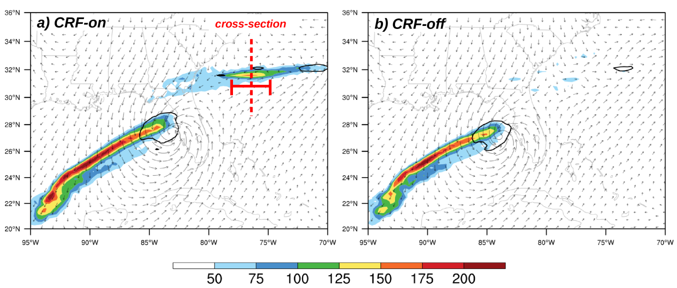

Figure 2: Total precipitation accumulation (mm) at the end of the 72-hr simulation for (a) CRF-on and (b) CRF-off. Wind vectors represent surface winds. Black contours indicate rainfall rates exceeding 100 mm in a 24-hr period for a duration of 6 hrs. The cross-section location is averaged across a 300 km longitudinal direction over a 24-hr period.

and temperature fields are constrained to be in geostrophic and hydrostatic balance. To initiate PRE development, a balanced TC with a maximum wind speed of 20 m s^{-1} at a radius of 60 km is placed south of the jet at 21°N using WRF's TC bogus algorithm. The simulation is integrated over a period of 72 hours.

3. Results and Analysis

In our control simulation retaining cloud-radiative forcing (CRF-on), a realistic-appearing PRE forms just south of the jet axis, well in advance of the TC (Fig. 2a). Comparison with a CRF-off run (Fig. 2b) reveals that CRF effects support a more robust PRE storm structure with stronger convective activity and, ultimately, more precipitation. CRF produces LW cooling along the cloud tops of the PRE structure, in-cloud (primarily LW) warming in the mid-levels, and cooling above the low level clouds to the north and south of the PRE (Fig. 3a). In contrast, the CRF-off case possesses only the rather smaller net clear sky cooling (Fig. 3b). The CRF-on storm's greater convective activity is revealed via difference fields

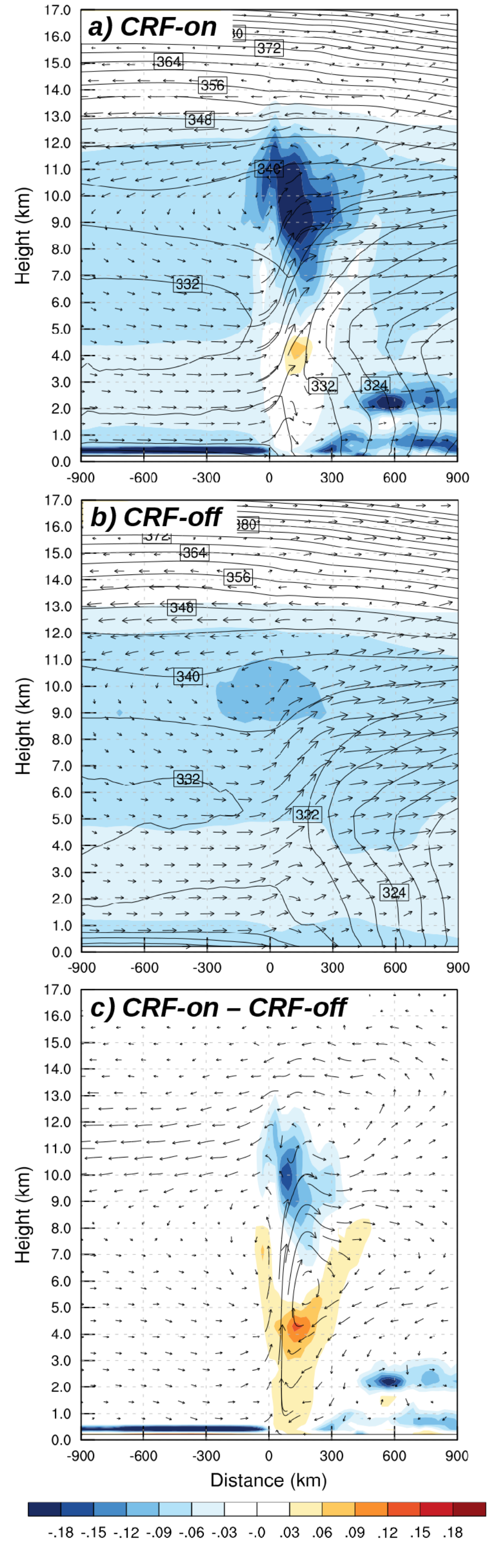

Figure 3: 24-hr averaged cross-sections of radiational heating tendency (K hr^{-1}) for (a) CRF-on, (b) CRF-off, and (c) difference between CRF-on and CRF-off. The black contours represent equivalent potential temperature (K). The cross-section location is depicted in Fig. 2a.

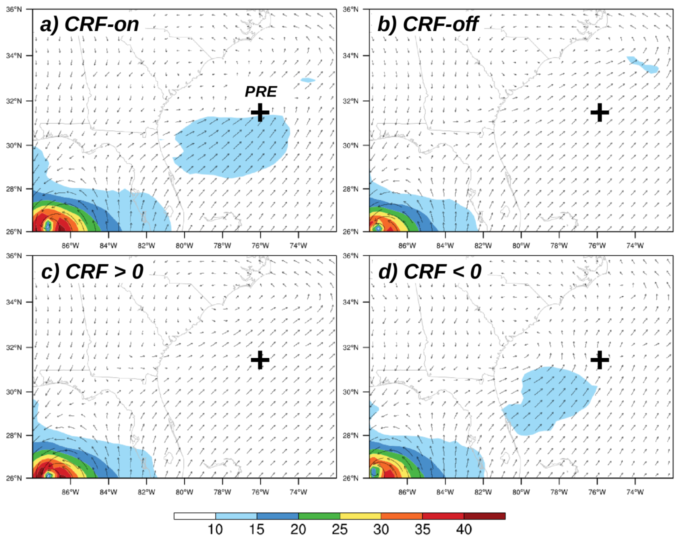

Figure 4: Average boundary layer winds (m s^{-1}) at T+60 hrs for (a) CRF-on, (b) CRF-off, (c) CRF > 0, and (d) CRF < 0. Wind vectors represent average boundary layer winds. The black cross represents the location of the maximum PRE rainfall in the CRF-on experiment.

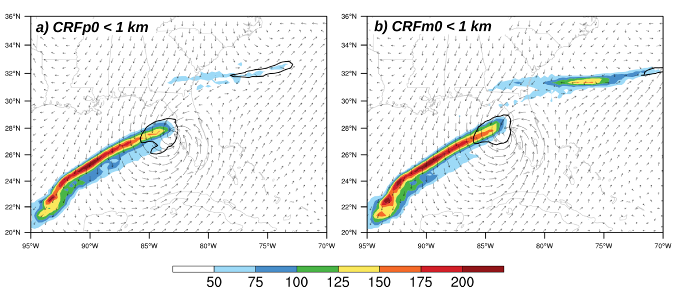

Figure 5: As in Fig. 2, but for (a) no CRF cooling below 1 km and (b) no CRF warming below 1 km experiments.

(Fig. 3c) and is also manifested as the stronger boundary layer winds (leading to greater low-level convergence) seen immediately south of the PRE location (compare Figs. 4a, 4b).

Experiments separating the warming and cooling CRF components (labeled CRF > 0 and CRF < 0; Figs. 4c, d) reveal that the *LW cooling* is largely responsible for the enhanced convergence and convection. This contrasts with Bu et al.'s (2014) study, which showed that only LW warming directly impacted TC structure. In our case, however, only LW cooling associated with the *low clouds* north and south of the PRE region is relevant. Note that a version of the CRF-on experiment that neglects radiative cooling associated with hydrometeors in the lowest 1 km MSL (labeled CRFp0 < 1 km) generates much less precipitation (Fig. 5a).

This surprising result transpires because the LW cooling associated with shallow clouds raises the surface

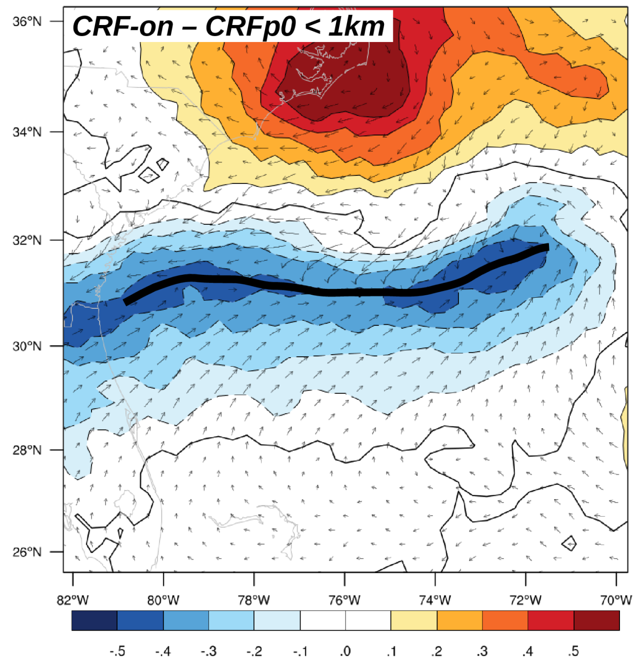

Figure 6: 24-hr averaged centered SLP difference (mb) between CRF-on and no CRF cooling below 1 km experiments. The black line represents the surface trough associated with lower pressures and enhanced convergence across the PRE region.

pressure (Fig. 6), thereby increasing the sea level pressure (SLP) gradient across the PRE region. This establishes stronger low level convergence, leading to more vigorous convection in the PRE (which lowers the SLP directly beneath). The within-cloud LW warming, even in shallow clouds, opposes this SLP increase, and neglecting that enhances PRE precipitation even more (Fig. 5b). Interestingly, the influence of radiative processes on convergence (Albrecht and Cox 1975) suggests that PRE development may also be sensitive to the diurnal cycle (Gray and Jacobson 1977).

As a consequence, we see PRE precipitation sensitively depends on the balance between subtle, competing processes involving radiation and microphysics schemes. These differences lead to changes in the SLP gradient, low-level convergence across the PRE region, and the resulting rainfall distribution (Fig. 7), rendering the forecasts sensitive to the microphysics and radiation parameterizations and, especially, how they interact. Therefore, when predicting the development of PREs, *radiation scheme differences are important!*

4. Summary

Cloud-radiative forcing can have a significant influence on TC structure and motion (cf. Bu et al. 2014). We have demonstrated that CRF also has a major influence on

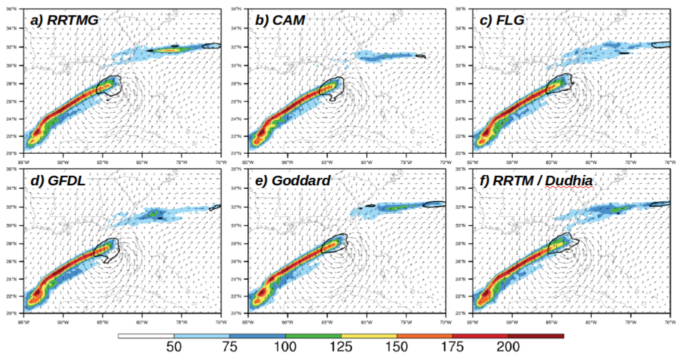

Figure 7: As in Fig. 2, but for different radiation schemes available in the WRF-ARW v.3.6 model.

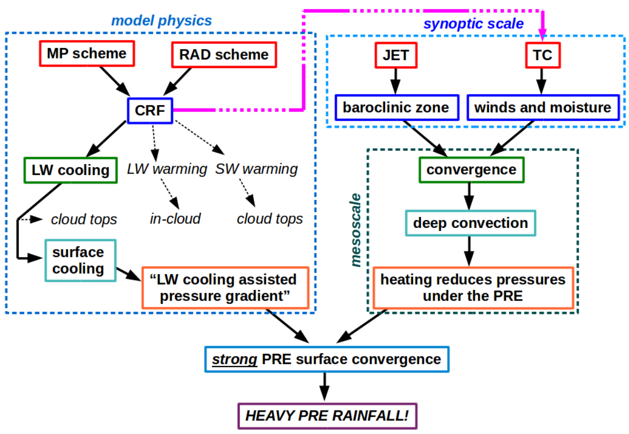

Figure 8: Schematic summarizing the influence of cloud-radiative processes on PRE development. Note that CRF also strongly influences TC characteristics and motion as well.

PRE development, but the primary driver actually resides outside of the PRE region itself and is based on how the model responds radiatively to low clouds. The schematic in Fig. 8 summarizes the influences of cloud-radiative processes on the generation of heavy PRE rainfall and how they interact between scales and parameterizations. Because the recipe for PRE development requires many individual ingredients to come together in just the right way, accurately predicting heavy rainfall events associated with tropical cyclones will remain a daunting forecast challenge.

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