Organization of precipitation along cold fronts

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Browning and Roberts (1996) mention several possible mechanisms for the orientation of precipitation cores along a narrow cold-frontal rainband (NCFR). These include those suggested by Matejka (1980) and Hobbs and Persson (1982), as well as a mechanism described by Miller (1978) for the orientation of precipitation in an isolated cumulonimbus cloud. Matejka (1980) and Hobbs and Persson (1982) proposed a barotropic (shear) instability mechanism for regulating the distribution and orientation of precipitation along NCFRs. Miller (1978) proposed that precipitation from a cumulonimbus cloud was oriented along the vertical shear vector in the rain region. Browning and Roberts concluded that none of these mechanisms could explain the organization of precipitation cores in an NCFR that crossed the British Isles on 8 December 1994. They go on to state: ‘We are thus left without a well-defined theoretical explanation for the orientation of line-convection elements. Small-scale numerical modelling studies based on realistic observational data, with a model resolution capable of resolving the convection, are needed to address this issue.’

We have recently conducted a numerical simulation of an NCFR that occurred just off the eastern seaboard of the United States, with the intent of investigating mechanisms that may be responsible for the orientation and development of precipitation cores in NCFRs. This event was observed using an NWS WSR-57 radar and the National Center for Atmospheric Research (NCAR) dual-Doppler radars (Locatelli et al. 1995). Our modelling study was performed using a 2 km horizontal-resolution, non-hydrostatic mesoscale model (the NCAR-Penn State Mesoscale Model version 5), initialized with surface and upper-air observations. A mixed-phase precipitation scheme, including graupel, was employed and convection was explicitly resolved.

Our numerical simulations provide the first high-resolution numerical simulation of an NCFR that captures the organization and movement of the precipitation cores and the gaps between them, as first observed by James and Browning (1979) and Hobbs and Biswas (1979).

A comparison of the numerically modelled and the observed precipitation cores is provided in Figs. 1(a) and (b). Figure 1(a) depicts the observed radar reflectivity at 15 min intervals starting at 0007 UTC (T = 0) on 27 January 1986. Figure 1(b) depicts the corresponding model-generated precipitation mixing ratios. Note that units of radar reflectivity do not vary linearly with precipitation mixing ratio, therefore the areal extent and the contour intervals in Figs. 1(a) and (b) cannot be directly compared.

The observed precipitation cores were ~25–75 km long and ~10–25 km wide, while the modelled precipitation cores are somewhat smaller (~15–50 km long and ~5–15 km wide). The observations showed that the orientations of the precipitation cores were variable, but that most of the stronger cores were oriented ~30–40° from north (i.e. roughly south-east to north-west). The precipitation cores in the model simulations exhibit more regularity, with nearly all cores angled at ~30–50° from north. The movements of the precipitation cores in the numerical simulation are similar to the observed movements. Overall the model reproduces the observed organization of the precipitation in the NCFR to a remarkable degree.

Model results for a typical precipitation core at T = 105 min are shown in Fig. 2. Depicted are the core-relative winds, vertical air velocity, and precipitation mixing ratios at heights of 1 to 4 km. At heights ≥2 km (Figs. 2(a), (b) and (c)), there is significant precipitation production, the plume of precipitation is seen to be clearly aligned with the core-relative winds. At heights ≥3 km (Figs. 2(a) and (b)), where graupel is the dominant form of precipitation, there is significant downdraft transport of precipitation that is enhanced by the relatively slow fall speed of graupel compared to rain. At heights <3 km (Figs. 2(c) and (d)), where rain is the main form of precipitation, the precipitation cores are located close to the updrafts. This suggests that the low fall speed of graupel relative to the horizontal wind speed contributes to the elongation of the precipitation core.

From these modelling results, and detailed analyses of other precipitation cores generated in this numerical simulation, we conclude that the advection of precipitation by the core-relative winds is primarily responsible for the distribution of precipitation into elliptically shaped cores oriented at an angle to the NCFR. Since precipitation cores generally move towards the north-east along a front at speeds of ~10–40 m s⁻¹, the core-relative wind field can depart significantly from the actual wind field; it is the core-relative wind field that determines the distribution

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Figure 1. Time series showing the movement of precipitation cores (shaded regions) along (a) the observed narrow cold-frontal rainband (NCFR) and (b) the model-simulated NCFR on 27 January 1986. In (a) precipitation intensity is indicated by the radar reflectivity. In (b) precipitation is depicted in terms of a mixing ratio. The eastward movement of the cores has been expanded by 40 km per time-step to avoid overlap in the figure. The dashed lines indicate the motions of the precipitation cores. Both (a) and (b) have the same horizontal scale.

of precipitation. Consequently, it is not surprising that a variety of orientations of precipitation cores have been observed, including south-east to north-west (Locatelli et al. 1995, and the present paper), north-east to south-west (James and Browning 1979; Hobbs and Biswas 1979; Locatelli et al. 1995), as well as circular precipitation cores (Locatelli et al. 1995).

In a future paper, we will use the results of our numerical simulations to diagnose the mechanisms responsible for the organization of precipitation on cold fronts into core and gap regions.
Figure 2. Model results at heights of (a) 4 km, (b) 3 km, (c) 2 km, and (d) 1 km, for the airflow relative to a precipitation core (vectors—see scaling arrow), vertical air velocity (contours are labelled in m s$^{-1}$, dashed lines and negative values indicate downsraughts), and precipitation mixing ratio (shading—see key).

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REFERENCES


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