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WORKSHOP ON CLOUD PHYSICS AND CLIMATE

23 November - 20 December 1985

CLOUD AND PRECIPITATION PROCESSES
Part VI

MIDLATITUDE CYCLONES

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LECTURE 6 MIDLATITUDE CYCLONES.

Selected references:

Harrold & Austin 1974, J. Rech. Atm. pp 41-57

Carlson 1980 M. Wea. Rev. pp 1498-1504

Browning & Mason, 1980/81 PAGEOPH pp 577-593

Matejka et al 1980 QJRMS pp 29-56

Parsons and Hobbs, 1983 J. Atmos. Sci. 2377-2397
(This is part XI of a series, references to earlier ones found within)

Carbone, 1982 J. Atmos. Sci, 258-279 and 2639-2654

Hierarchy of scales of organization

Norwegian Polar Front model; modified by "conveyor belt" concept

Rainbands - Univ of Washington project

Precipitation processes

Severe cold-front - Carbone

Keywords: Mesoscale Meteorology, Rainbands, Cyclones, Precipitation, Clouds, Fronts

1. SCALES OF ORGANIZATION

Extratropical cyclones are organized on several spatial and temporal scales. Characteristic dimensions and durations of the cloud and precipitation features (and therefore, presumably, of the relevant dynamical features)

are usually strongly concentrated by frontogenetic processes into two primary frontal zones. Circulations associated with the intensification of the temperature gradients cause sloping, frontal scale ascent to occur above and sometimes within the frontal zones. The vertical velocities associated with these ascents are about 10 cm s^{-1} and they produce the widespread frontal cloud layers at and ahead of the surface warm front and at or behind the surface cold front. Frontal-scale clouds and precipitation can affect the weather at a locale for periods from several hours (for a rapidly moving cold front) to over a day (for a well-developed warm front).

Table 1

Characteristic dimensions and durations of cloud, precipitation, and dynamical features organized on various scales in extratropical cyclones, and magnitudes of horizontal divergence fields and vertical air motions associated with the features. O( ) indicates "on the order of". (Adapted from Ref. 1, based on original estimates and information contained in Refs. 2-7).

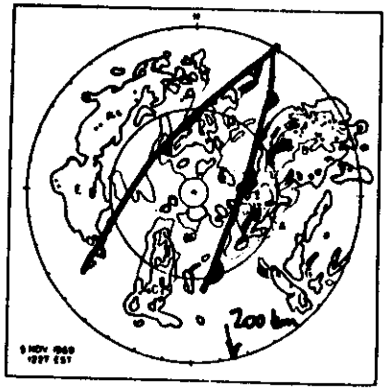
	Horizontal area (km^2)	Duration as a continuous, recognizable entity (min)	Duration at a fixed location (min)	Magnitude of horizontal divergence field (s^{-1})	Magnitude of vertical air motions (cm s^{-1})
Cyclonic scale	$O(10^6)-1\times10^7$	$O(10^4)$	few 10^3	$O(10^{-5})$	O(1)
Frontal scale	$O(10^5)$	$O(10^3)-1\times10^4$	several 10^2 -2×10^3	$O(10^{-4})$	O(10)
Large mesoscale	2×10^3 - few 10^4	$O(10^2)-1\times10^3$	$O(10)-1\times10^2$	$3\times10^{-4}-O(10^{-3})$	few $10-O(10^2)$
Small mesoscale	$O(10)-2\times10^3$	$O(1)-O(10^2)$	1-20	$3\times10^{-4}-O(10^{-3})$	few $10-O(10^2)$
Cumulus scale	O(1)-O(10)	3-50	few	$O(10^{-3})$	$O(10^2)$ (or less)

Proc IAMAP Symposium, Hamburg, 25-28 August 1981 (ESA SP-165, June 1981)

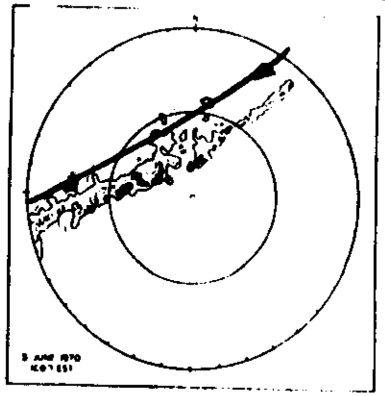
TABLE 1

Definition and characteristics of precipitation areas of different scales

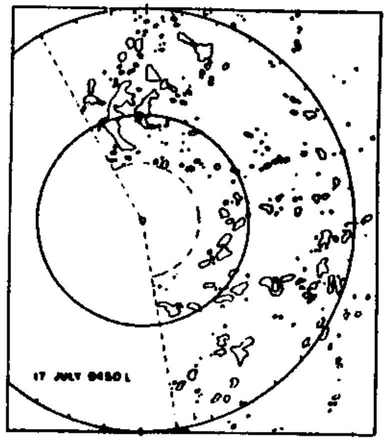
Feature	Austin and Houze [7]				Harrold [2]	
	Area range definition km^2	Area range characteristic km^2	Duration hr	Movement	Typical area km^2	Movement
Synoptic	> 10^4		> 12	with synoptic feature	5.10^4	with synoptic feature
Large mesoscale area (LMSA)	10^3 to 10^4	2×10^3 to 5×10^3	1.5 to 4	tend to be same as SMSAs and cells within it	4.10^3	close to the synoptic feature
Small mesoscale area (SMSA)	50 to 10^3	100 to 500	0.5 to 1	same as cells except for some thunderstorms	600	with the conveyor-belt wind (3 to 6 km height
Cell	50	3-10	0.7	with wind at mid-cell level	16	



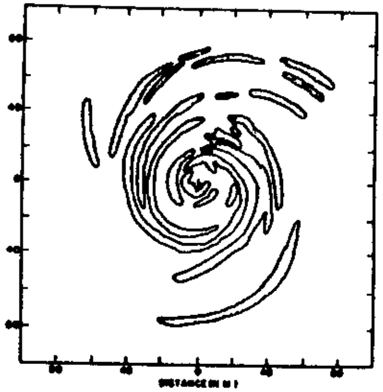
a. Extratropical cyclone observed with 10-cm radar at Cambridge, Mass.
Range : 200 km.
Contours : 2, 4, 8, 16 (solid black) and 32 (black spots) mm hr^{-1}.



b. Cold-frontal band observed with 10-cm radar at Cambridge, Mass.
Range : 200 km.
Contours : 1, 3, 10, 35 (black) and > 70 (white spots) mm hr^{-1}.



c. Miki tropical disturbance observed with 3-cm radar at Barbados Islands.
Range : 150 miles (from Iwanchuk [10]).



d. Distribution of radar echoes around Hurricane Dora, 4 September 1964 (from Atkinson [11]).

FIG. 3. — Examples of mesoscale precipitation areas and banded structures as depicted by radar.

model which accounts for the principal synoptic-scale features of cloud precipitation and provides a useful framework for understanding the smaller phenomena we shall be considering later, has been developed by HARROLD (19 BROWNING (1971) and CARLSON (1980). According to this model, depicted in Fig.

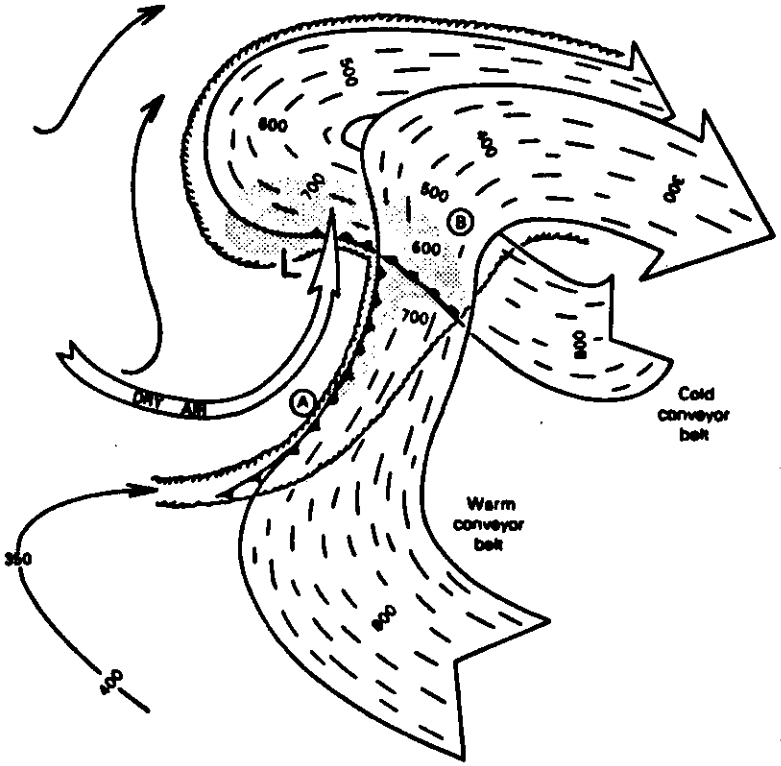


Figure 1

Model depicting the main features of the large-scale flow that determine the distribution of cloud precipitation in a mature mid-latitude depression in the northern hemisphere. (Redrawn from CARLS 1980.) The two shaded arrows represent flow (relative to the motion of the synoptic system) at the top the warm and cold conveyor belts, the height of which is labelled in mb. The scalloped line represents the outline of the comma-cloud pattern produced by these flows and the dotted shading represents the extent of precipitation reaching the ground.

the overall distribution of cloud and precipitation in a baroclinic disturbance can

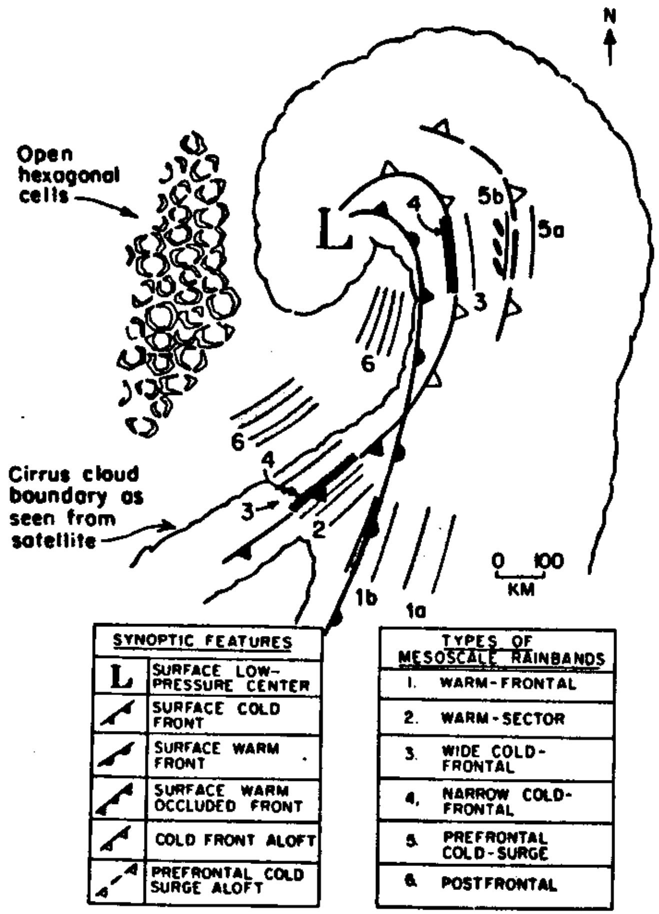


Fig. 3.2.1 Schematic depiction of the types of mesoscale rainbands (darkly stippled areas) observed in extratropical cyclones just off the coast of Washington. The upper-level cloud shield of the cyclone is shown in white; lower cloud decks are shaded light gray. (Hobbs, 1981.)

liquid water contents were approximately $0{\cdot}10\,g\,m^{-3}$.

The process by which precipitation in a mesoscale warm frontal rainband grows is summarized in the model shown in Fig. 5. Ice particles nucleated in generating cells aloft

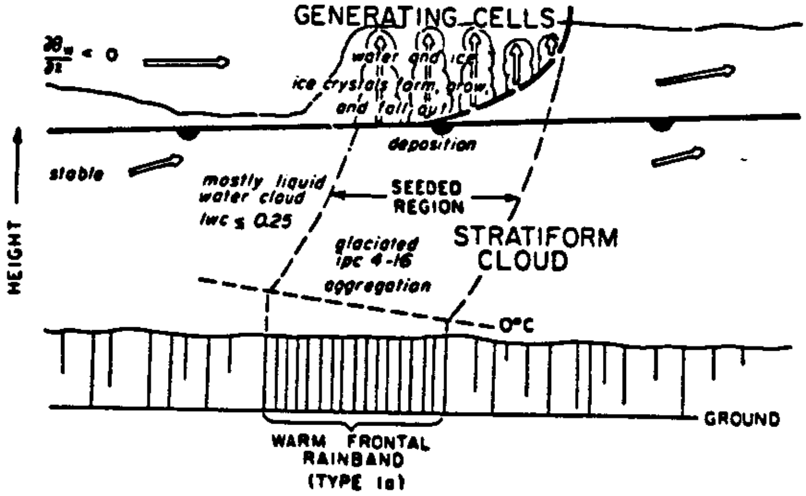


Figure 5. Model of a mesoscale warm frontal rainband (type 1a) shown in vertical cross-section. The structure of the clouds and the predominant mechanisms for precipitation growth are indicated. Vertical hatching below cloud bases represents precipitation: the density of the hatching corresponds qualitatively to the precipitation rate. The heavy, broken line branching out from the front is a warm frontal leaf (see text for explanation). Open arrows depict airflow relative to the warm front and contrast the stable lifting within and above the warm frontal zone with convective ascent in the generating cells. Ice particle concentrations (ipc) are given in numbers per litre; cloud liquid water contents (lwc) are in $g\,m^{-3}$. The motion of the rainband in the figure is from left to right.

grow to precipitable size and fall into the stratiform cloud below, growing first by deposition (as shown in Fig. 11 of Houze *et al.* 1976b) and, as they approach the 0°C level, by aggrega-

taken through the older rainband was nearly moist-adiabatic and saturated.

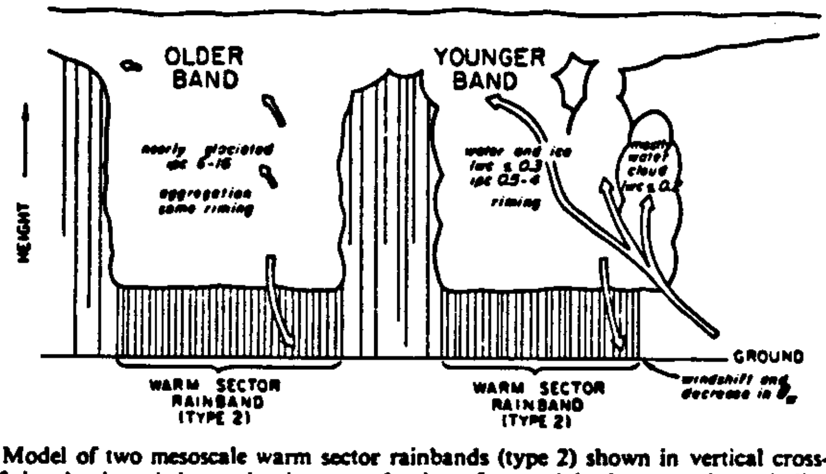


Figure 7. Model of two mesoscale warm sector rainbands (type 2) shown in vertical cross-section. The structure of the clouds and the predominant mechanisms for precipitation growth are indicated. Vertical hatching below cloud bases represents precipitation; the density of the hatching corresponds qualitatively to the precipitation rate. Open arrows depict airflow relative to the rainbands. θ_w is wet-bulb potential temperature. Ice particle concentrations (ipc) are given in numbers per litre; cloud liquid water contents (lwc) are in $g\,m^{-3}$. The motion of the rainbands in the figure is from left to right.

6. Cold frontal rainbands

(*a*) *Model*

The cold front in an extratropical cyclone may extend to the ground, or it may, in a warm-type occlusion, exist only aloft, above the warm frontal surface. In either case, two

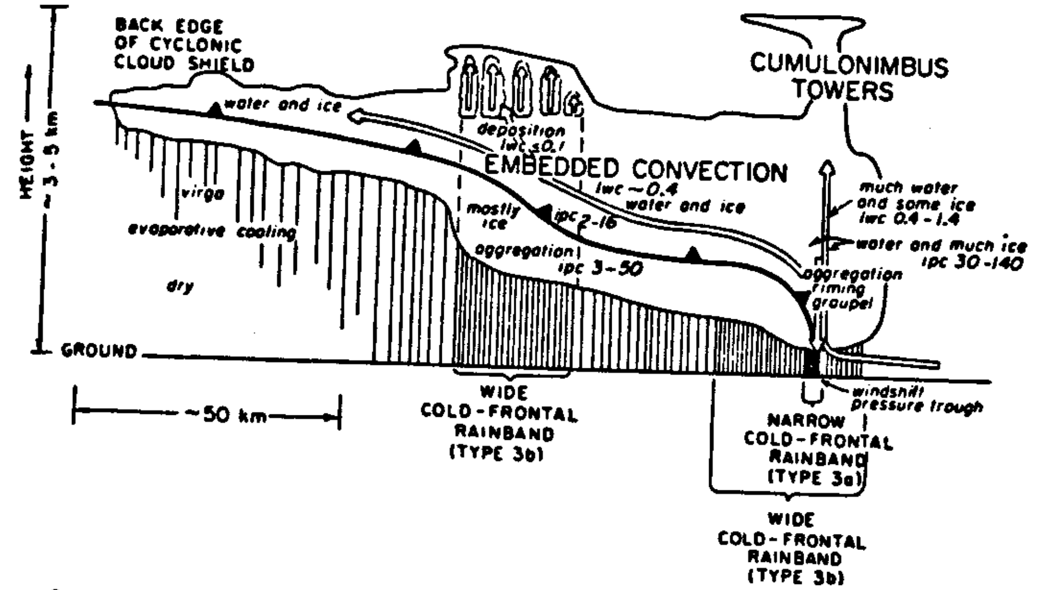


Figure 8. Model of the clouds associated with a cold front showing narrow and wide mesoscale cold frontal rainbands (types 3a and 3b) in vertical cross-section. The structure of the clouds and the predominant mechanisms for precipitation growth are indicated. Vertical hatching below cloud bases represents precipitation; the density of the hatching corresponds qualitatively to the precipitation rate. Open arrows depict airflow relative to the front: a strong convective updraught and downdraught above the surface front and pressure trough, and broader ascent over the cold front aloft. Ice particle concentrations (ipc) are given in numbers per litre; cloud liquid water contents (lwc) are in $g\,m^{-3}$. The motion of the rainband in the figure is from left to right. Horizontal and vertical scales are approximate, but typical of aircraft and radar observations in specific cases.

(b) Cold frontal air motions

tation ahead of the cold front in an occlusion.

Two types of mesoscale rainband may be associated with the passage aloft of a prefrontal cold surge; these are illustrated in the model cross-section in Fig. 13. The first type of rainband, shown on the right in Fig. 13, is a deep and wide mesoscale band of cloud and

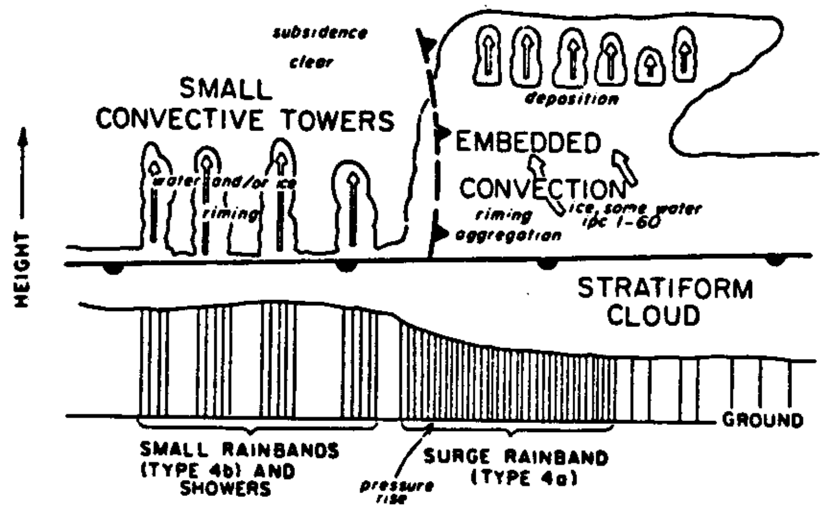
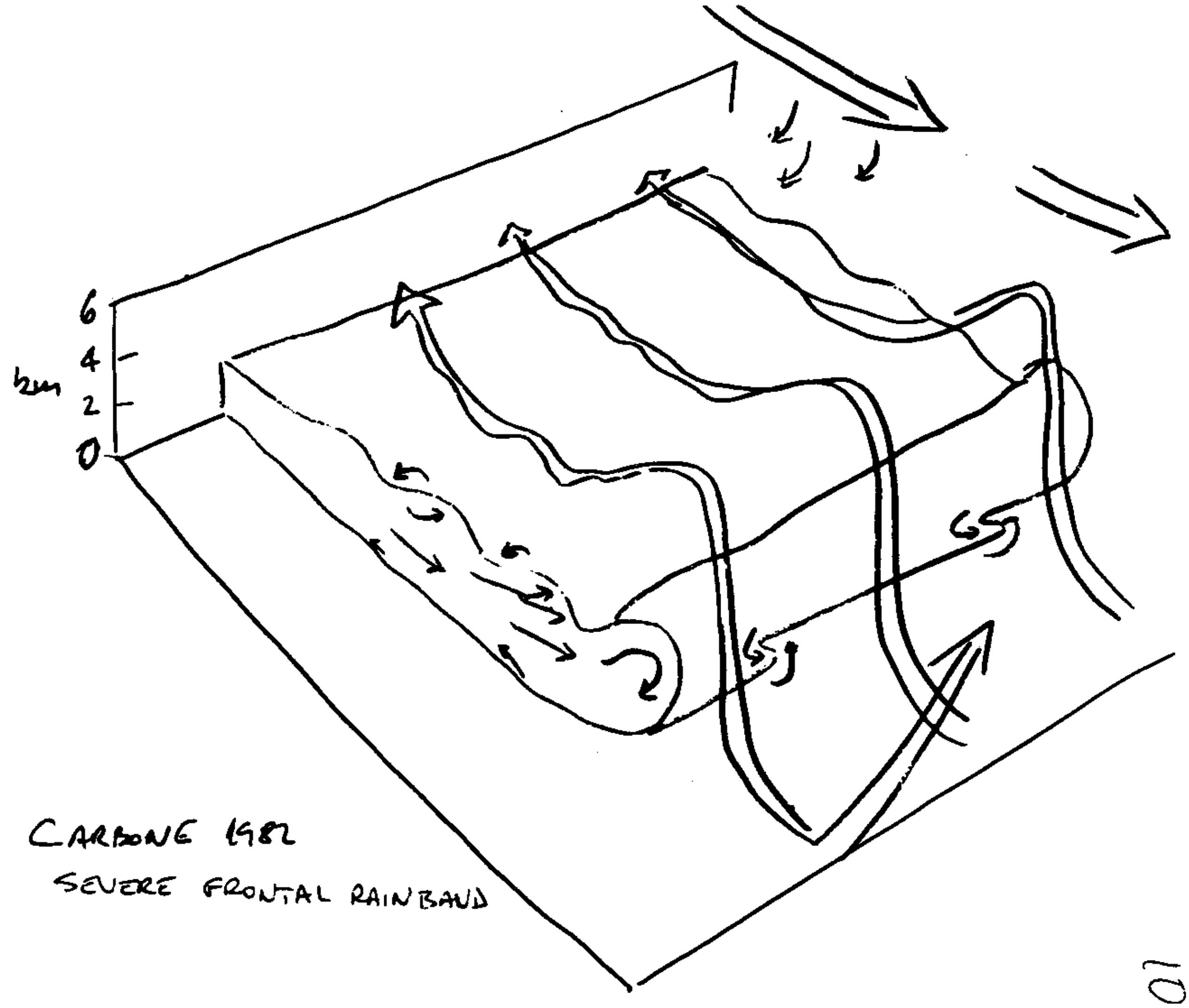


Figure 13. Model of mesoscale rainbands (types 4a and 4b) associated with a prefrontal surge of cold air aloft, ahead of an occluded front. The broken cold front symbol indicates the leading edge of the surge. (The primary cold front is off the figure to the left.) The structure of the clouds and the predominant mechanisms for precipitation growth are indicated. Vertical hatching below cloud bases represents precipitation; the density of the hatching corresponds qualitatively to the precipitation rate. Open arrows depict airflow relative to the cold surge and convective ascent. Ice particle concentrations (ipc) are given in numbers per litre. The motion of the cold surge and the rainbands in the figure is from left to right.

precipitation that precedes or straddles the leading edge of the prefrontal surge, whose passage overhead is marked at the surface by a temporary, slight rise in pressure (or a lessening in its general fall). This rainband, here called the 'surge rainband' (type 4a in Fig. 1), is similar to a wide cold frontal rainband, although it often appears less coherent on radar



CARBONE 1982

SEVERE FRONTAL RAINBAND