中尺度氣象學
(Mesoscale Meteorology)

授課老師: 游政谷

Cheng-Ku Yu

Mesoscale(1)

1-1 課程介紹
(Course Introduction)

隨著近年來觀測儀器(技術)的進步以及數值模式的廣泛應用，使得我們慢慢了解到，較劇烈且具傷害力的天氣現象(如強烈降水與風暴)常侷限於中小尺度的範疇. 可是，由於發生這些劇烈天氣現象的原因相當多樣化且複雜，傳統的綜觀氣象理論基礎已無法滿足我們對於這些中尺度天氣現象的了解. 本課程的內容除了說明中尺度基本概念與原理外,也會詳細介紹實際大氣各種不同的中尺度天氣系統，並廣泛說明它們內部的結構與隱含的物理與動力過程；這其中，現階段的了解為授課重心，然而目前最新的研究成果也會在課堂上適時予以補充說明.

As revealed by advances in observing technology such as Doppler radar remote sensing and in numerical modeling, it has been recognized that most of hazardous weather occurring in the real atmosphere are typically organized on an intermediate (viz. meso) scale. Particularly, because of the inherent complex of mesoscale phenomena, theoretical principal of the synoptic meteorology usually cannot be applied to explain dynamical processes associated with these severe weather events. The main objective of this course is to introduce various mesoscale phenomena occurring in the atmosphere, with special emphasis on their internal structure and associated dynamics. In this course, current understanding of mesoscale processes will be the major theme but it will be also complemented by including some new findings from the latest results of mesoscale research.

課程內容將針對下列主題作有系統的闡釋:

1. **中尺度的基本概念**
2. **氣象都卜勒雷達觀測原理**
3. **大氣對流觀念與擾動氣壓診斷**
4. **中緯度及熱帶中尺度對流系統**
5. **劇烈風暴**
6. **地形降水**

The course outline will primarily include :

(1) Fundamental Concepts of Mesoscale, (2) Fundamental Principle of Radar Observations (3) Concept of Atmospheric Convection and Perturbation Pressure Diagnosis, (4) Midlatitude and Tropical Mesoscale Convective Systems, (5) Severe Storms, (6) Orographic Precipitation.

參考書名 (reference book):

(1) Mesoscale Meteorology and Forecasting. P. S. Ray, 1986.

(2) Radar in Meteorology. D. Atlas and L. J. Battan, 1990.

(3) A Short Course in Cloud Physics, Third Edition. R. R. Rogers and M. K. Yau, 1989.

(4) Severe Convective Storm. Carles A. Doswell, 2001.

(5) Storm and Cloud Dynamics. W. R. Cotton and R. A. Anthes, 1989.

(6) Cloud Dynamics. R. A. Houze, Jr, 2014.

(7) Radar Observations of the Atmosphere. Louis J. Battan, 1981.

(8) Mesoscale Meteorology in Midlatitudes. Paul Markowski and Y. Richardson, 2010

書面與口頭報告(written report and oral presentation):

書面報告繳交時間 (deadline of written report): 12/28 2020

圖文約3~10頁 (length of text plus figure: 3~10 pages)

口頭報告 (oral presentation): 針對書面報告內容進行3分鐘簡短說明 1/4 2021 (3 min for each student)

主題 (Topics):

1. 組織性雨帶 (氣旋雨帶, 鋒面雨帶, 熱帶氣旋雨帶, 台灣雨帶, 地形雨帶等等)

   Organized rainbands (Cyclone rainbands, Frontal rainbands, tropical cyclone rainbands, Taiwan rainbands, Orographic rainband etc.)

2. 其它中尺度天氣現象

   Other mesoscale phenomena

書面報告須包含下列項目 (Report must contain following components):

(1) 現象之定義與背景介紹 (Definition and background)

(2) 現象之觀測或模擬特徵 (Observational or modeling characteristics)

(3) 物理或動力過程 (Physical or dynamical processes)

(4) 尚未解決的問題或未來研究方向 (Unresolved problems or future research directions)

(5) 參考文獻 (References)

成績計算方式 (Grading):

期中考試 (Mid-term exam 30%)
期末考試 (Final exam 30%)
作業與報告 (Homework and presentation/report 30%)
出席率 (Attendance 10%)

1-2 中尺度的定義與概念 (Mesoscale Definition and Concept)

“Mesoscale” defined in Glossary of Meteorology

—Pertaining to atmospheric phenomena having horizontal scales ranging from ***a few to several hundred kilometers***, including thunderstorms, squall lines, fronts, precipitation bands in tropical and extratropical cyclones, and topographically generated weather systems such as mountain waves and sea and land breezes.

Orlanski (1975):

Macro > 2000 km (大尺度)

Meso α 200-2000 km (中尺度)

Meso β 20-200 km (中尺度)

Meso γ 2-20 km (中尺度)

Micro < 2 km (小尺度)

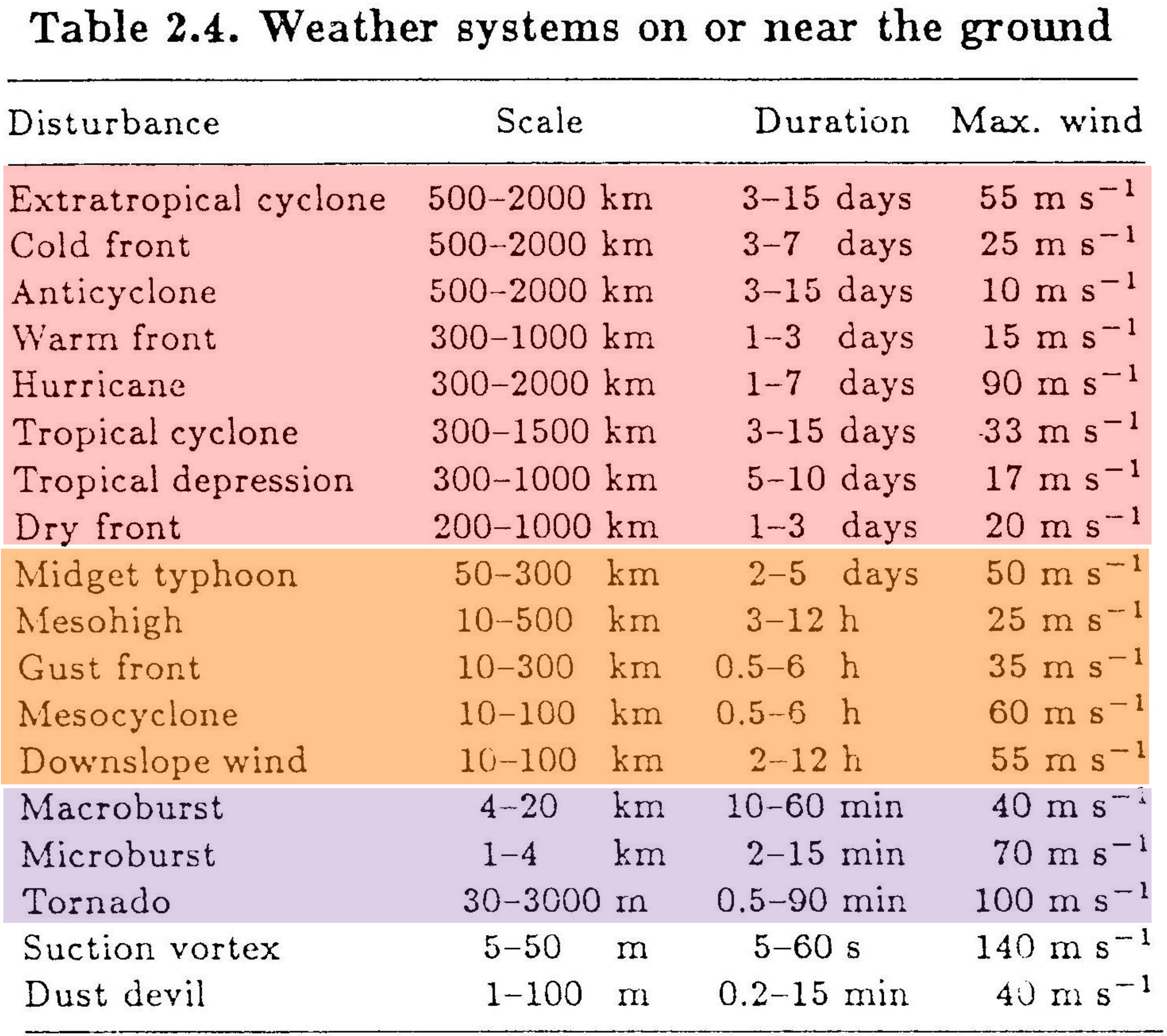


Table 2.4. Weather systems on or near the ground

	Disturbance	Scale	Duration	Max. wind
	Extratropical cyclone	500–2000 km	3–15 days	55 m s^{-1}
	Cold front	500–2000 km	3–7 days	25 m s^{-1}
Meso α	Anticyclone	500–2000 km	3–15 days	10 m s^{-1}
	Warm front	300–1000 km	1–3 days	15 m s^{-1}
	Hurricane	300–2000 km	1–7 days	90 m s^{-1}
	Tropical cyclone	300–1500 km	3–15 days	33 m s^{-1}
	Tropical depression	300–1000 km	5–10 days	17 m s^{-1}
	Dry front	200–1000 km	1–3 days	20 m s^{-1}
	Midget typhoon	50–300 km	2–5 days	50 m s^{-1}
	Mesohigh	10–500 km	3–12 h	25 m s^{-1}
Meso β	Gust front	10–300 km	0.5–6 h	35 m s^{-1}
	Mesocyclone	10–100 km	0.5–6 h	60 m s^{-1}
	Downslope wind	10–100 km	2–12 h	55 m s^{-1}
	Macroburst	4–20 km	10–60 min	40 m s^{-1}
Meso γ	Microburst	1–4 km	2–15 min	70 m s^{-1}
	Tornado	30–3000 m	0.5–90 min	100 m s^{-1}
	Suction vortex	5–50 m	5–60 s	140 m s^{-1}
	Dust devil	1–100 m	0.2–15 min	40 m s^{-1}

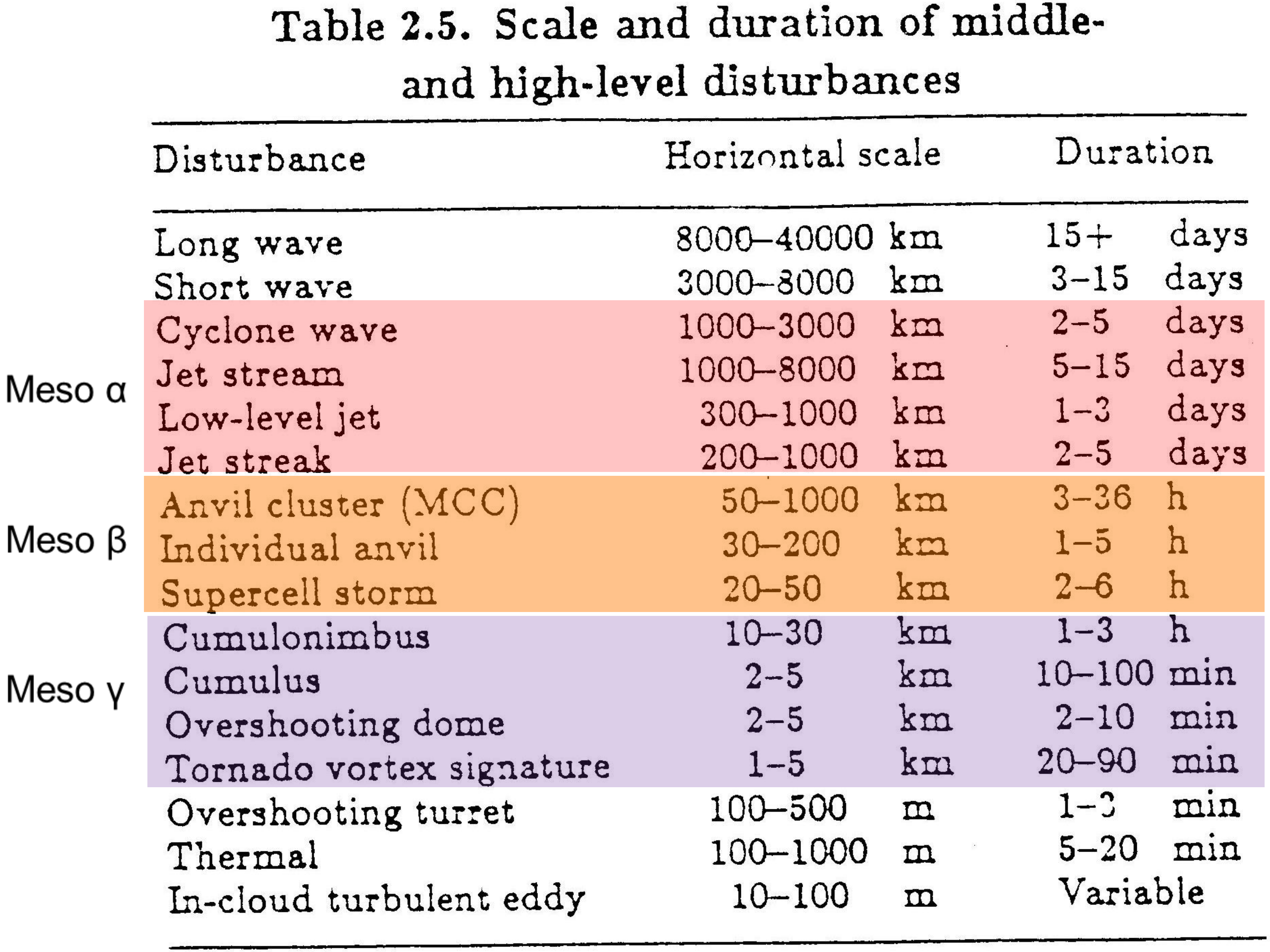
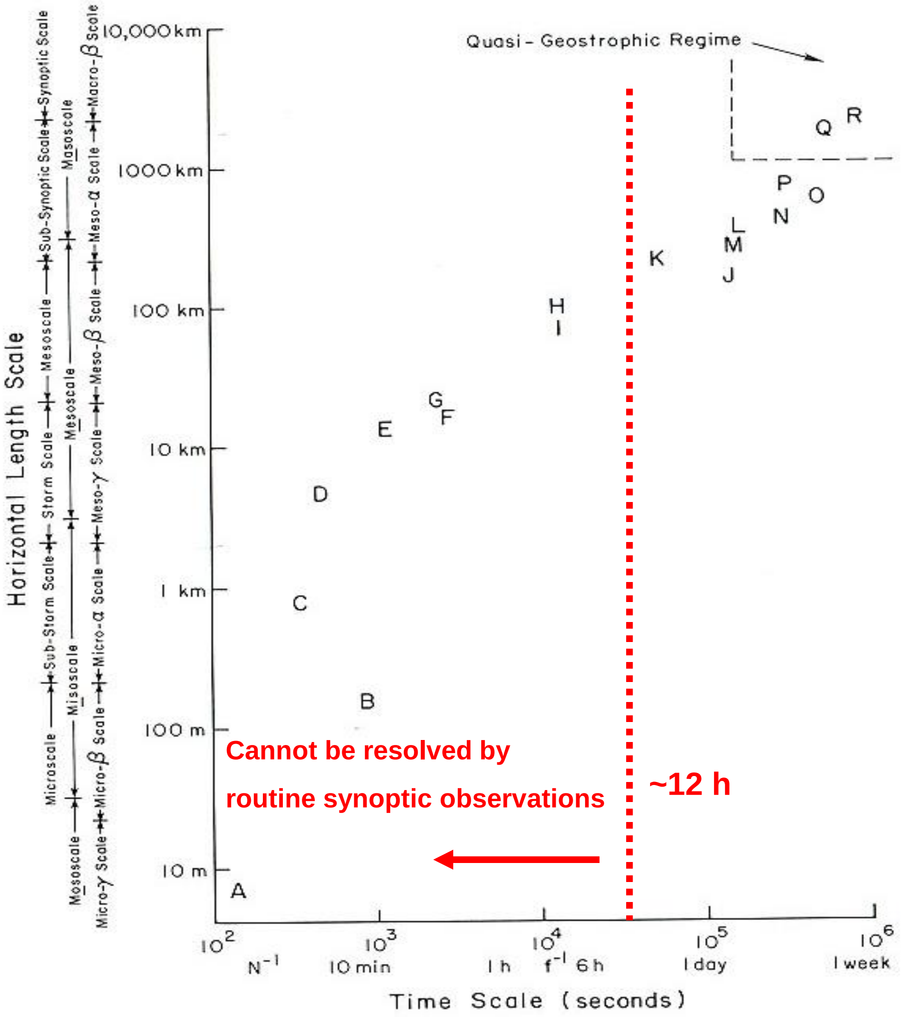


Table 2.5. Scale and duration of middle- and high-level disturbances

	Disturbance	Horizontal scale	Duration
	Long wave	8000–40000 km	15+ days
	Short wave	3000–8000 km	3–15 days
Meso α	Cyclone wave	1000–3000 km	2–5 days
	Jet stream	1000–8000 km	5–15 days
	Low-level jet	300–1000 km	1–3 days
	Jet streak	200–1000 km	2–5 days
Meso β	Anvil cluster (MCC)	50–1000 km	3–36 h
	Individual anvil	30–200 km	1–5 h
	Supercell storm	20–50 km	2–6 h
Meso γ	Cumulonimbus	10–30 km	1–3 h
	Cumulus	2–5 km	10–100 min
	Overshooting dome	2–5 km	2–10 min
	Tornado vortex signature	1–5 km	20–90 min
	Overshooting turret	100–500 m	1–3 min
	Thermal	100–1000 m	5–20 min
	In-cloud turbulent eddy	10–100 m	Variable



Cannot be resolved by

routine synoptic observations

~12 h

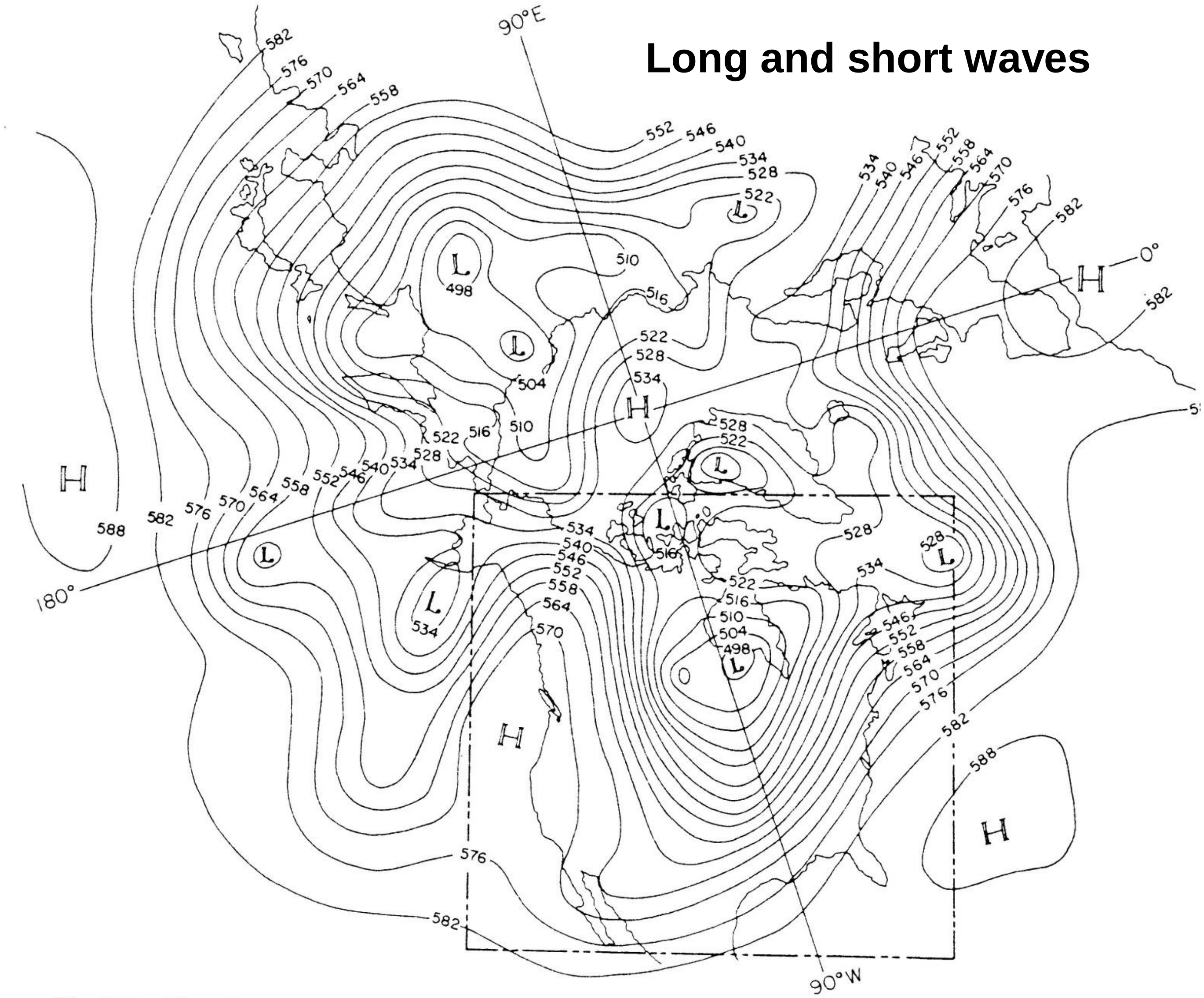
Figure 1.1 Horizontal-length scales and time scales for the following atmospheric phenomena: A, dust devils; B, tornadoes and waterspouts; C, cumulus clouds; D, downbursts; E, gust fronts; F, mesocyclones; G, thunderstorms; H, sea/land/lake breezes, mountain–valley circulations, and meso-highs and meso-lows; I, precipitation bands; J, coastal fronts; K, mesoscale convective systems; L, the low-level jet; M, the dryline; N, "bombs" and tropical cyclones; O, upper-level jets; P, surface fronts; Q, extratropical cyclones and anticyclones; and R, troughs and ridges in the baroclinic westerlies.

Q: Extratropical cyclones and anticyclones

R: Troughs and ridges in the baroclinic westerlies

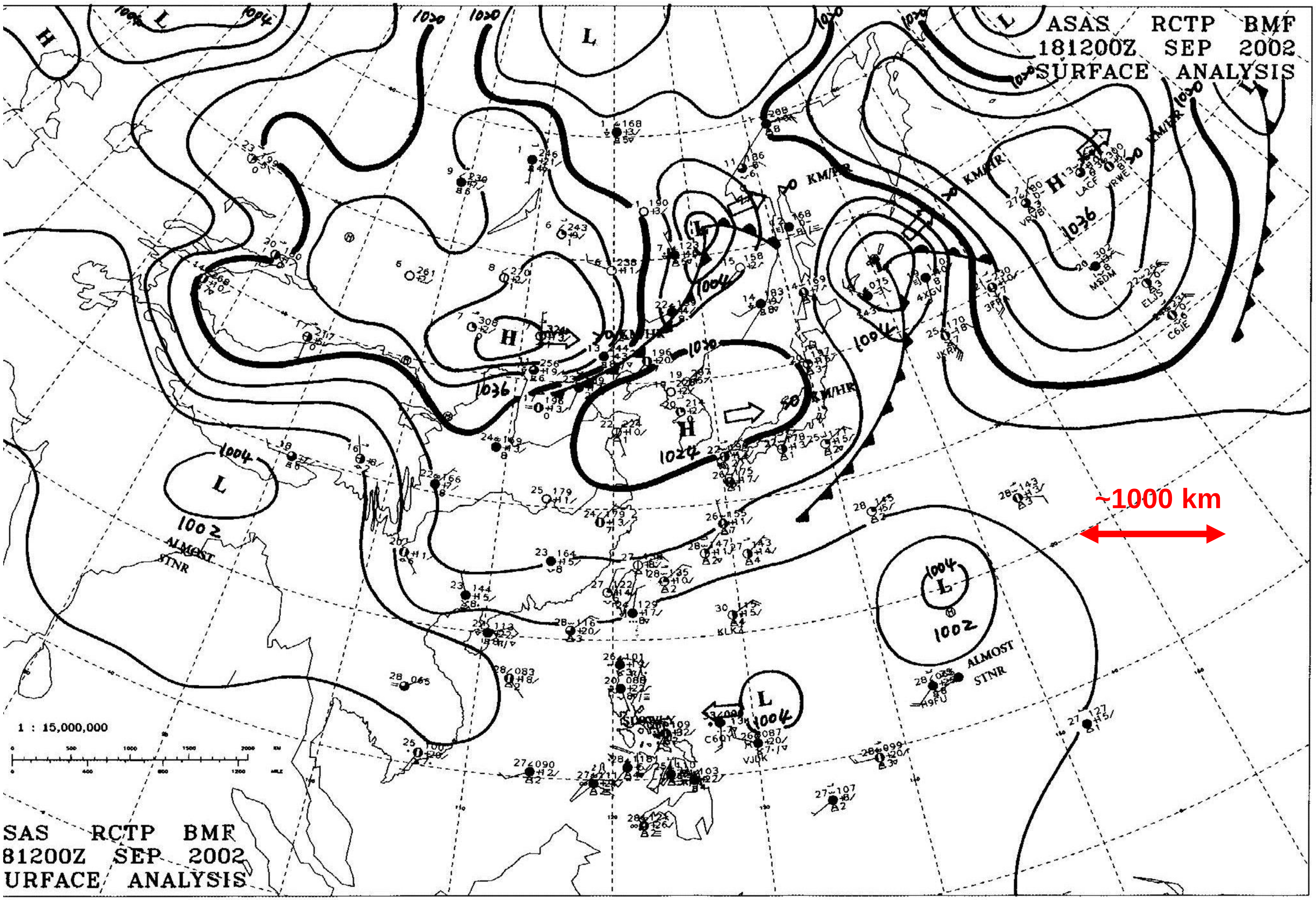
Only Q and R fit well in the quasi-geostrophic regime

The distribution of 500-mb geopotential height at 00 UTC 20 Nov. 1964

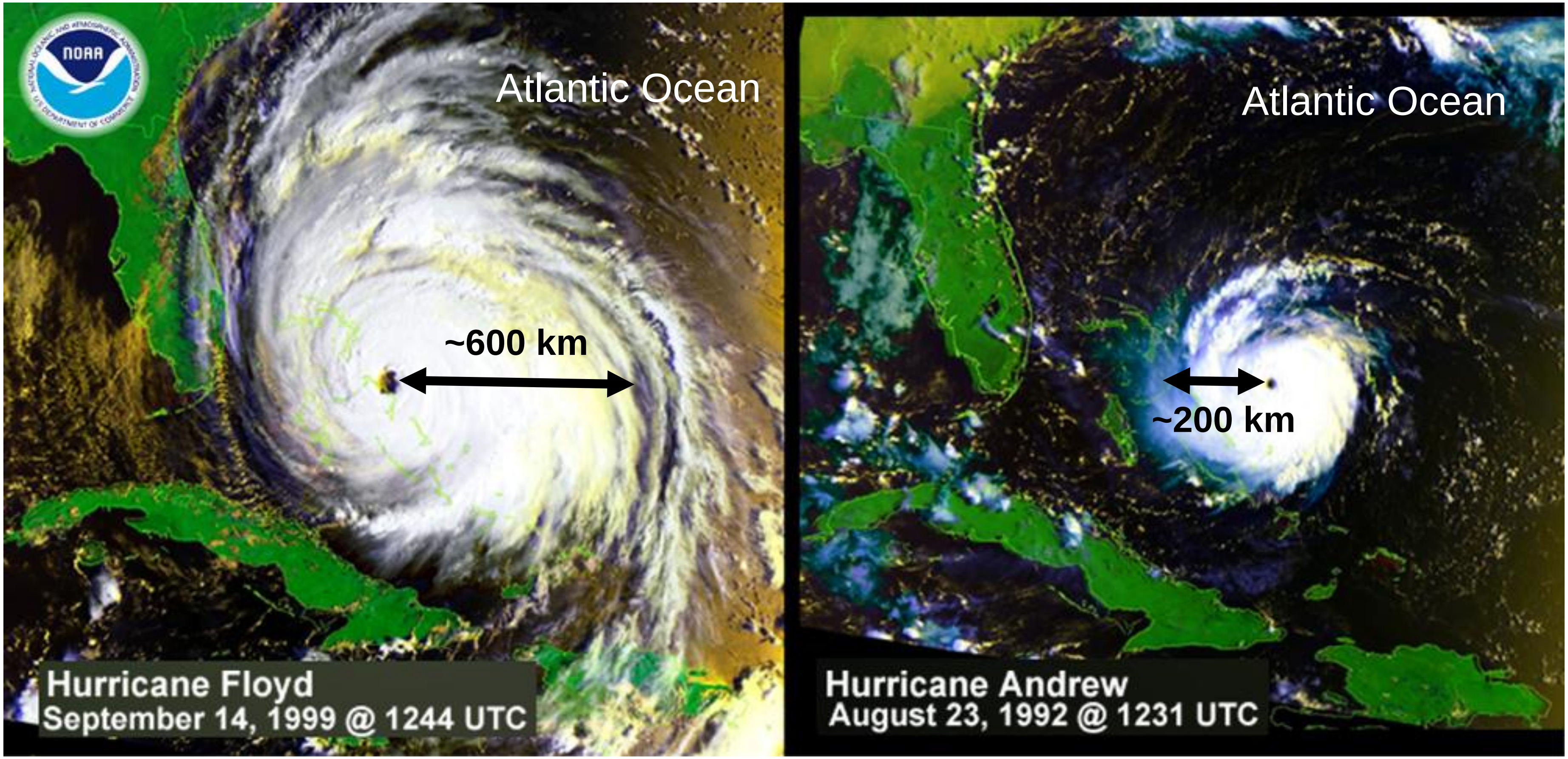


Long and short waves

Weather analysis map showing the horizontal scales of synoptic cold and warm fronts, anticyclone and tropical depression.



Satellite image showing different sizes for Hurricane Floyd and Andrew



Mesoscale Convective Complex (MCC) revealed by an enhanced infrared satellite

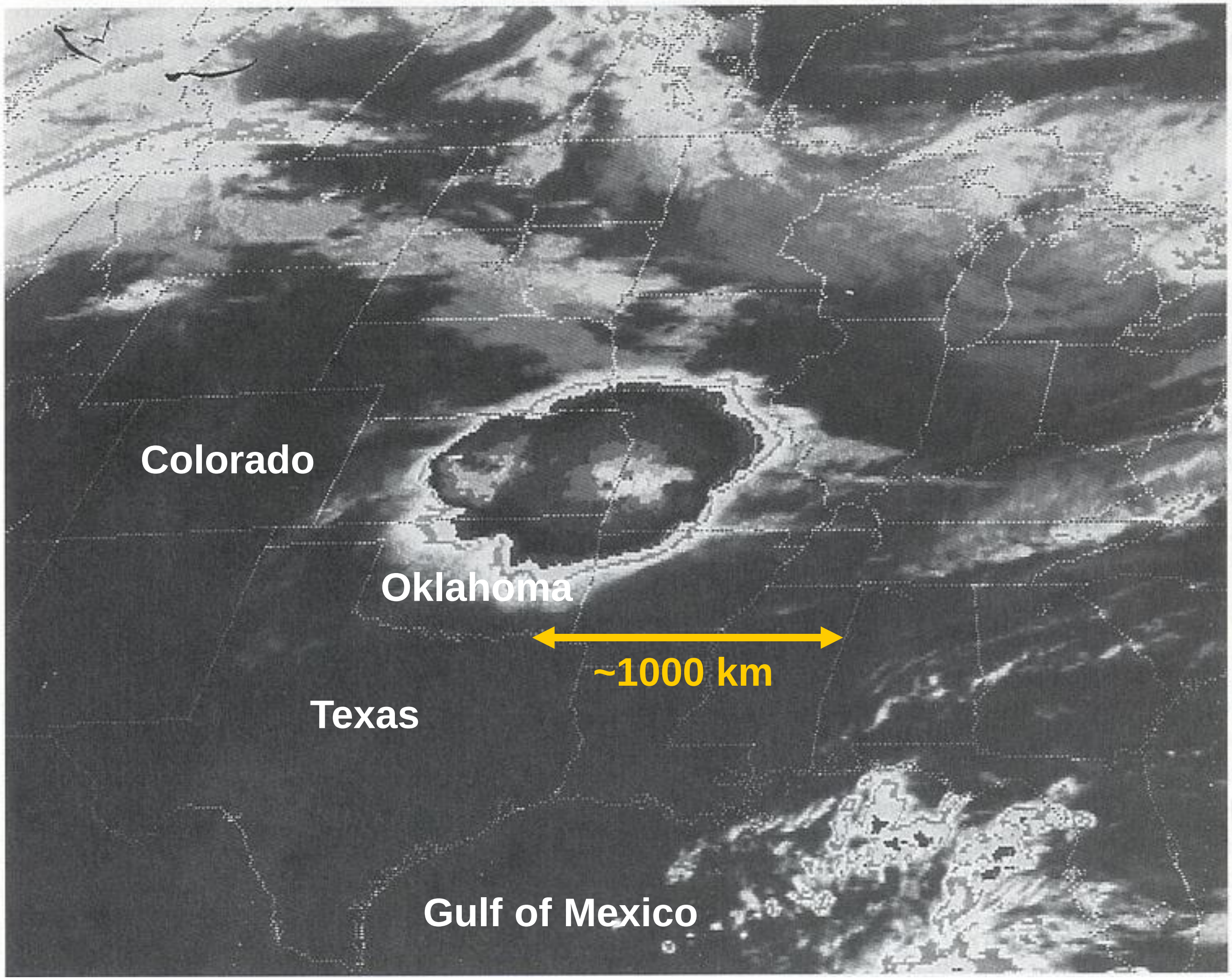


Figure 10.11
An enhanced infrared satellite picture for June 22, 1981, which shows a Mesoscale Convective Complex extending from central Kansas across western Missouri. This organized mass of thunderstorms brought hail, heavy rain, and flooding to this area.

A multicell storm

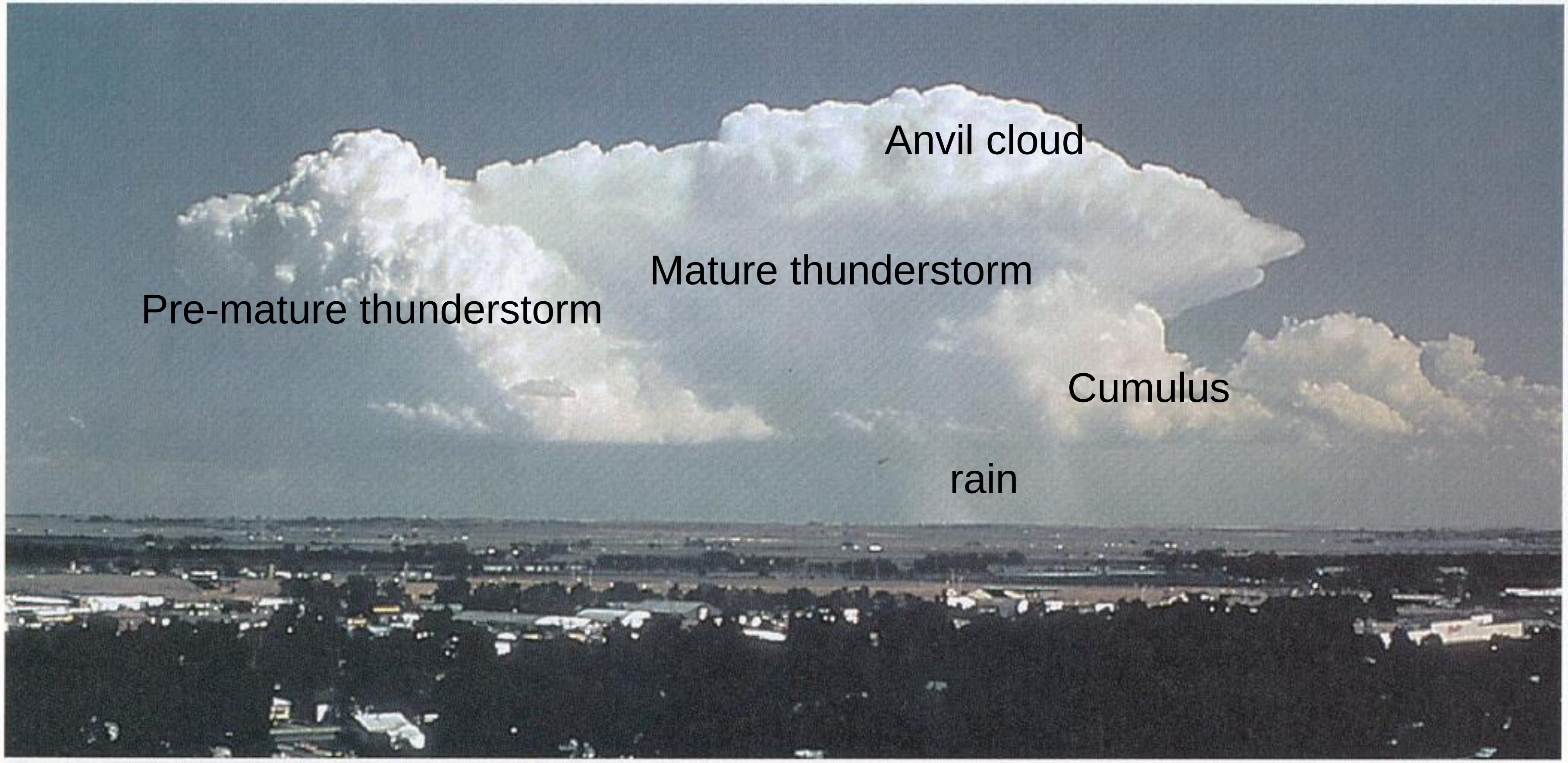
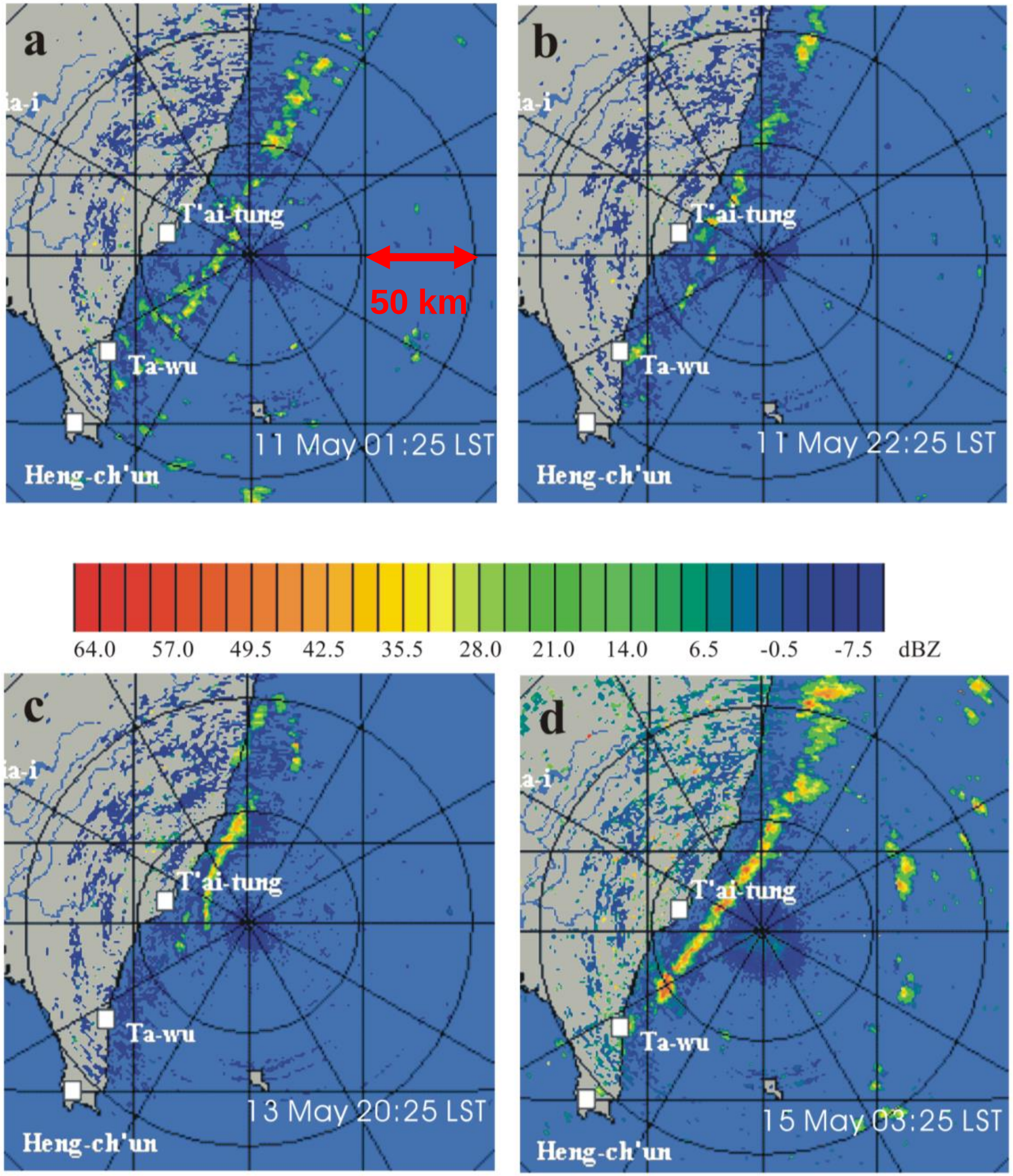


Figure 10.3
A multicell storm. This storm is composed of a series of cells in successive stages of growth. The thunderstorm in the middle is in its mature stage, with a well-defined anvil. Heavy rain is falling from its base. To the right of this cell, a thunderstorm is in its cumulus stage. To the left, a well-developed cumulus congestus cloud is about ready to become a mature thunderstorm.



Convective lines along the southeastern coast of Taiwan

新航失事80死51傷

飛安會完成黑盒子初步解讀 失事原因目前未排除任何可能

【記者劉添財／台北報導】新航[illegible]失事，新航[illegible]死亡八十人，五十一人受傷住院，其中四十八人已出院，家屬由新航安排住宿。[illegible]已完成[illegible]資料[illegible]，[illegible]，不過飛安會[illegible]，但表示目前尚未排除任何可能。

昨天[illegible]，新航[illegible]現場的罹難[illegible]，[illegible]

[illegible]

[illegible]飛安會[illegible]。

飛安會由於[illegible]失事調查，[illegible]飛安會[illegible]行政院[illegible]工作。

[illegible]

另外，[illegible]新航[illegible]失事[illegible]，[illegible]。

新航台北[illegible]

[illegible]。相關新聞見二、七、八、十版

聯合報　中華民國八十九年十一月二日　星期四

象神浩劫

全台55死10失蹤25人受傷 汐止積水達兩層樓高 北縣也有20人遇難

基隆一護理之家14老人淹死

一貫道天道學院15學員罹難

風雨劫

基隆市百福社區淹水嚴重，社區內的建基護理之家有十四名老人喪生。圖為救難人員用橡皮艇救出一批一批的老人。／記者[illegible]／攝影

【本報記者／連線報導】象神颱風過境帶來的豪雨，洪水氾濫成災，[illegible]五人死亡、十人失蹤、[illegible]五人受傷，[illegible]。

根據各縣市消防單位統計，基隆市[illegible]，台北縣廿人死亡、八人失蹤、十一人受傷；彰化縣二人死亡、一人受傷；[illegible]一人死亡、一人失蹤；宜蘭縣、台北市各一人死亡；屏東縣一人失蹤。

[illegible]

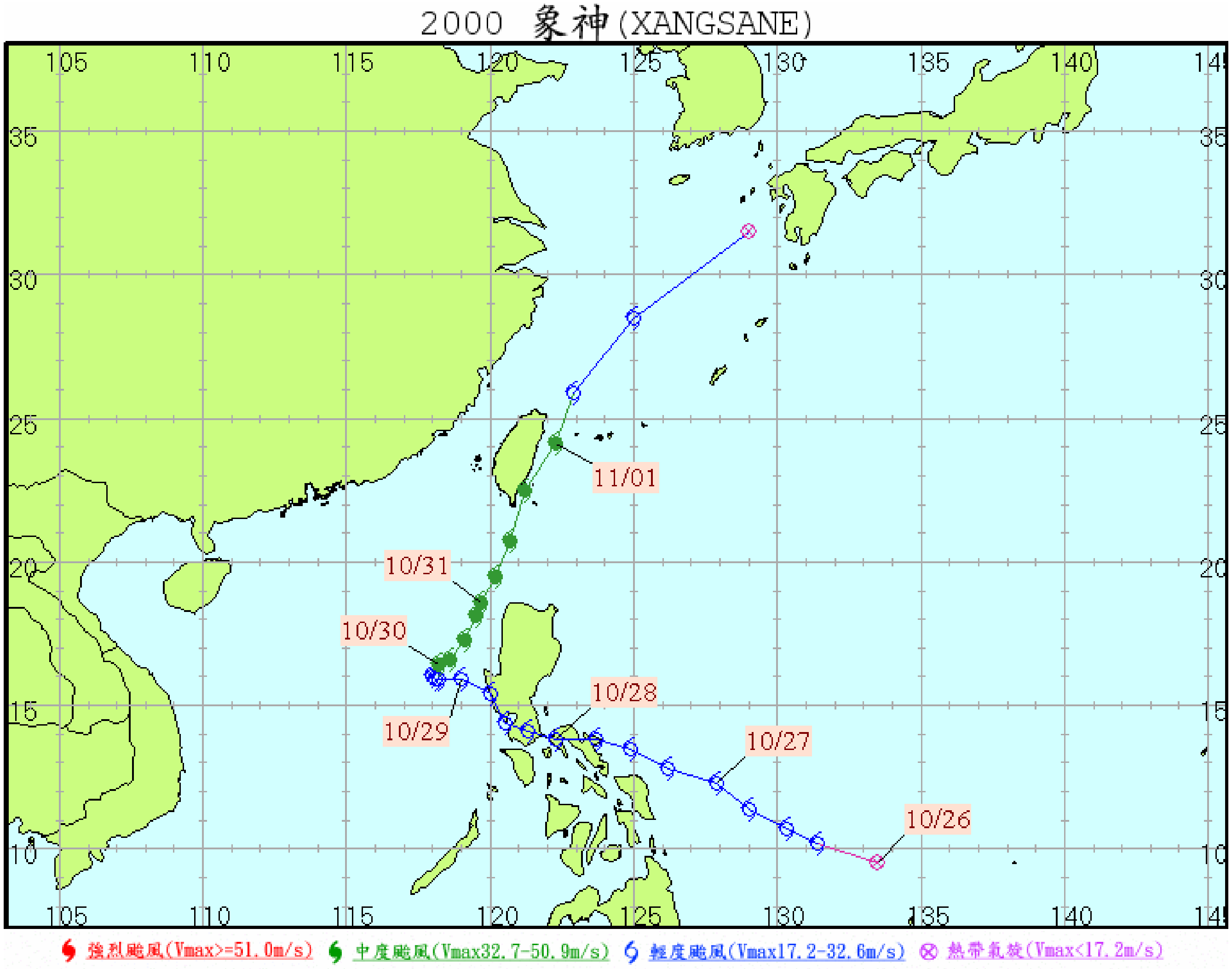
基隆市[illegible]一貫道的天道學院[illegible]

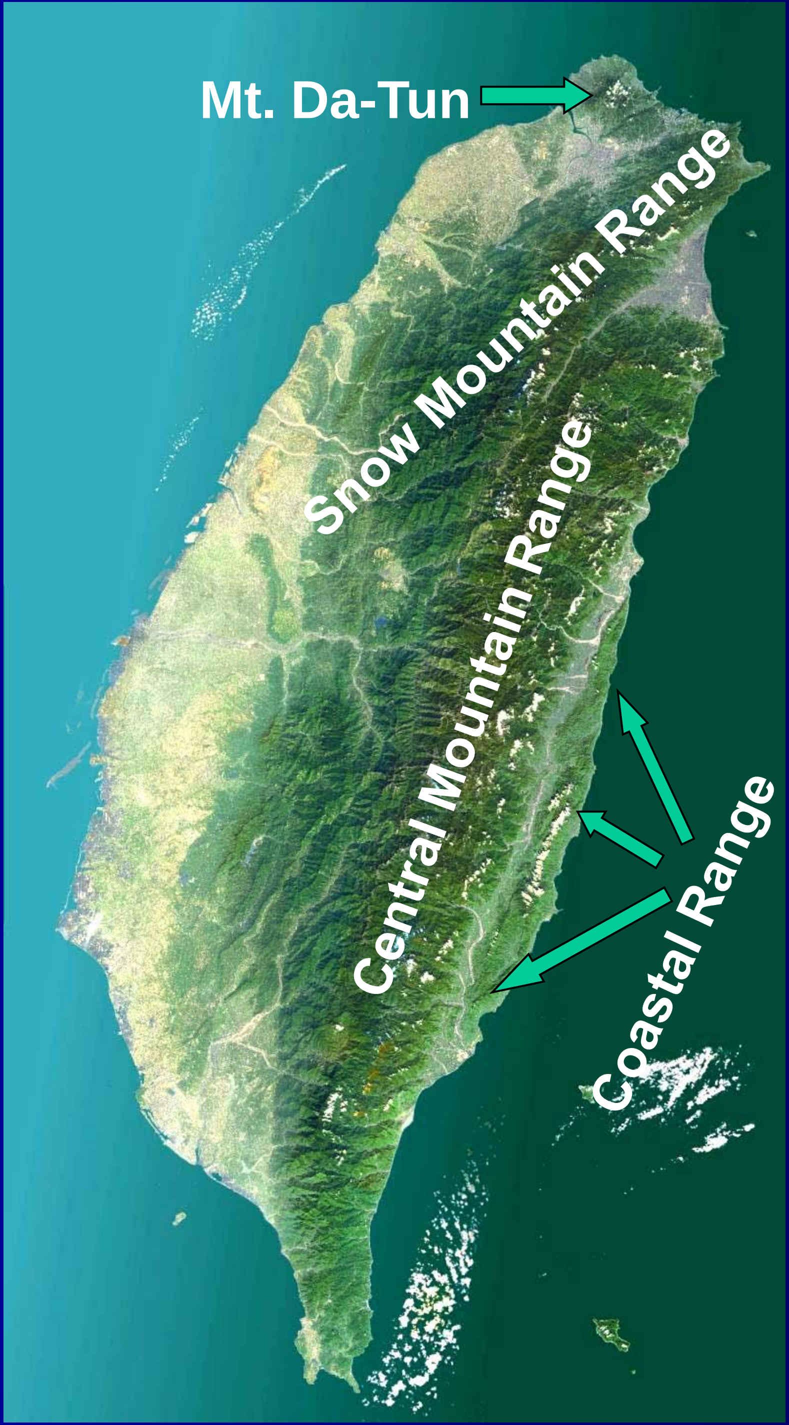
台北縣政府災害應變中心表示，[illegible]

[illegible]

[illegible]。相關新聞見三、四、五、六版

Track of Xangsane (2000)





Major Mountain Barrier over Taiwan (highest mountain ~4 km MSL)

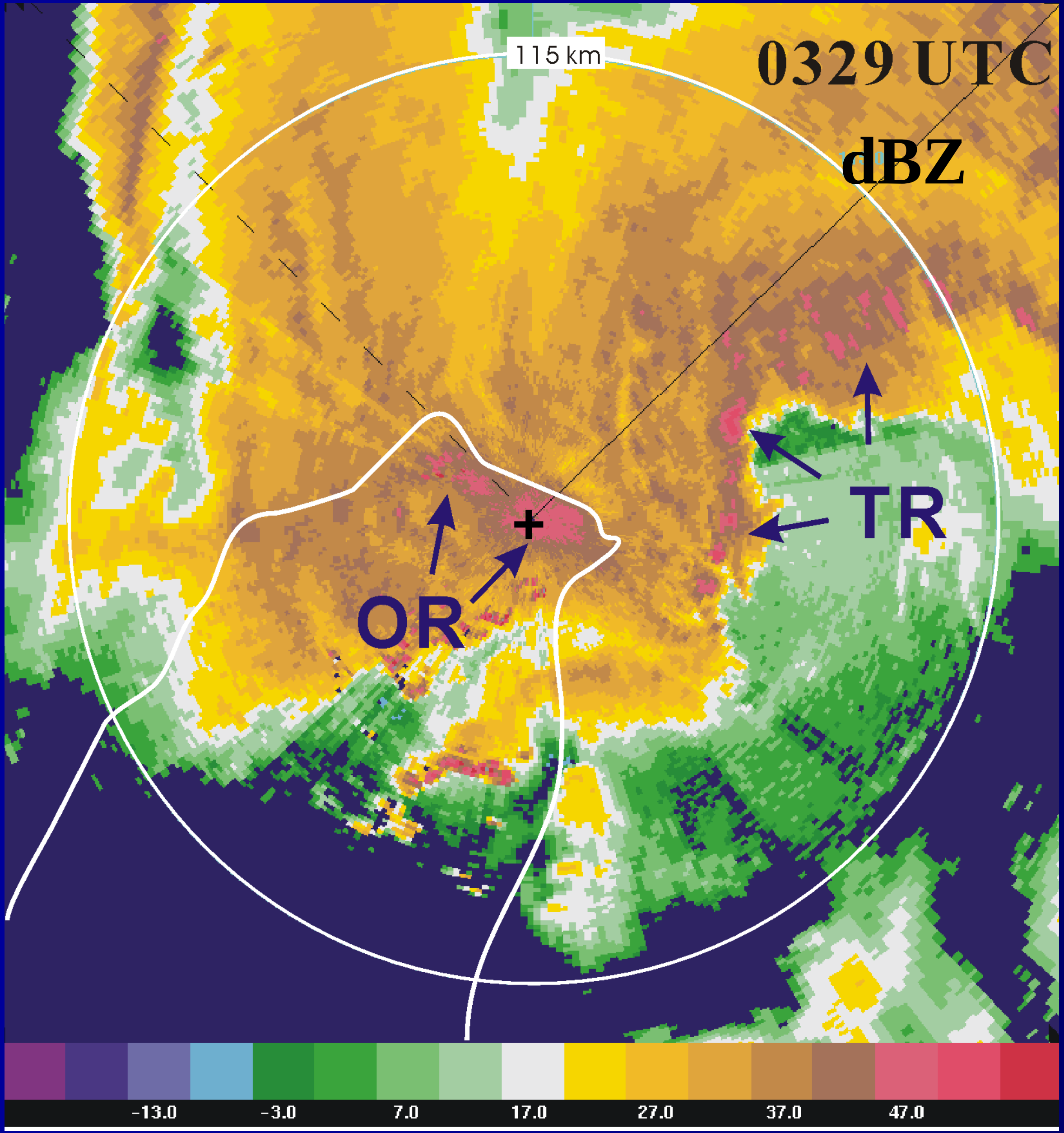
SMR: Snow Mountain Range

DTM: Da-Tun Mountain

CMR: Central Mountain Range

CR: Coastal Range

Low-level PPI of radar reflectivity



Orographic Rainband (OR)

--- Quasi-stationary

--- Orientation closely linked to the terrain feature

Typhoon Rainband (TR)

--- Fast movement

--- Curved feature

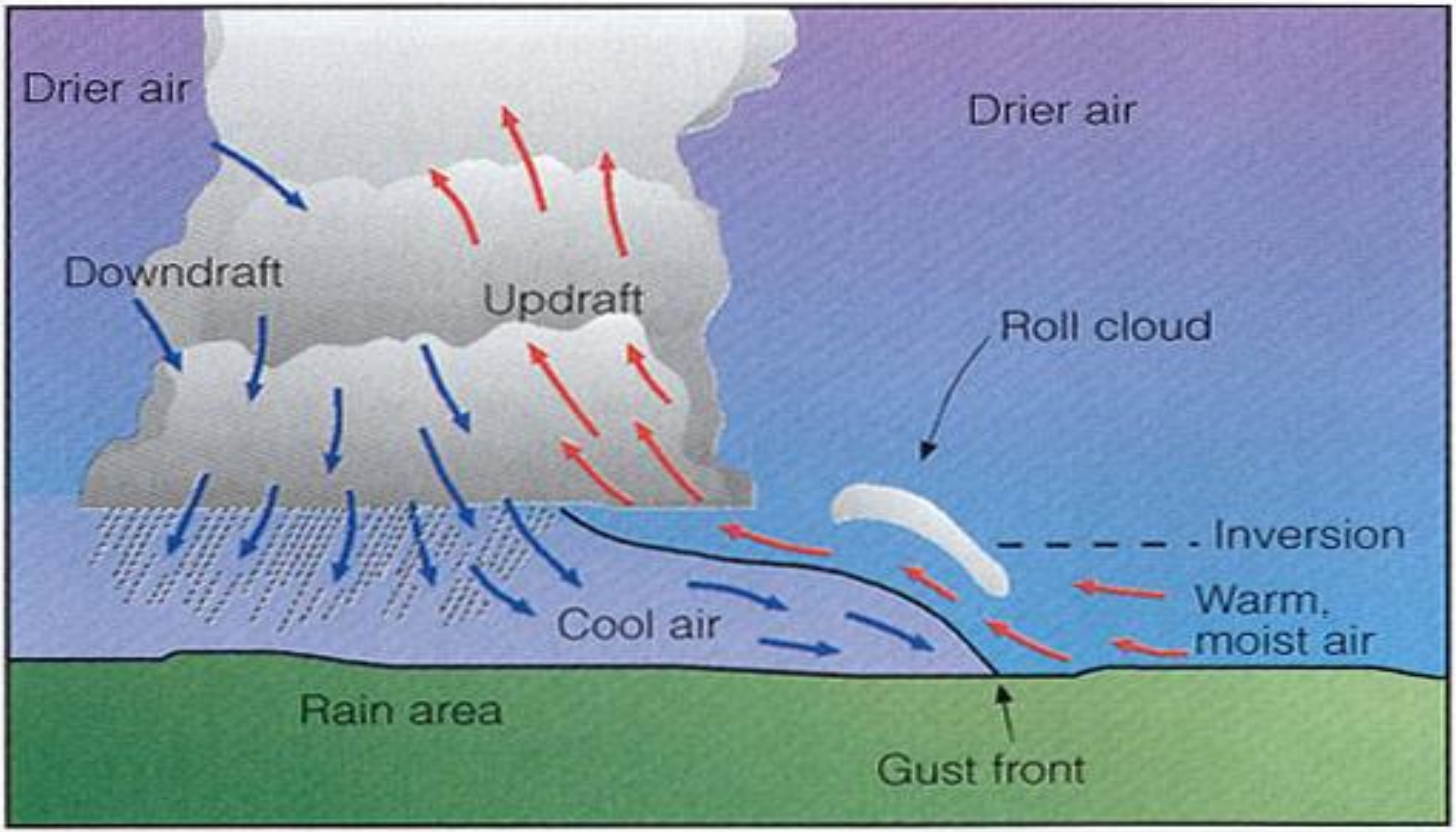
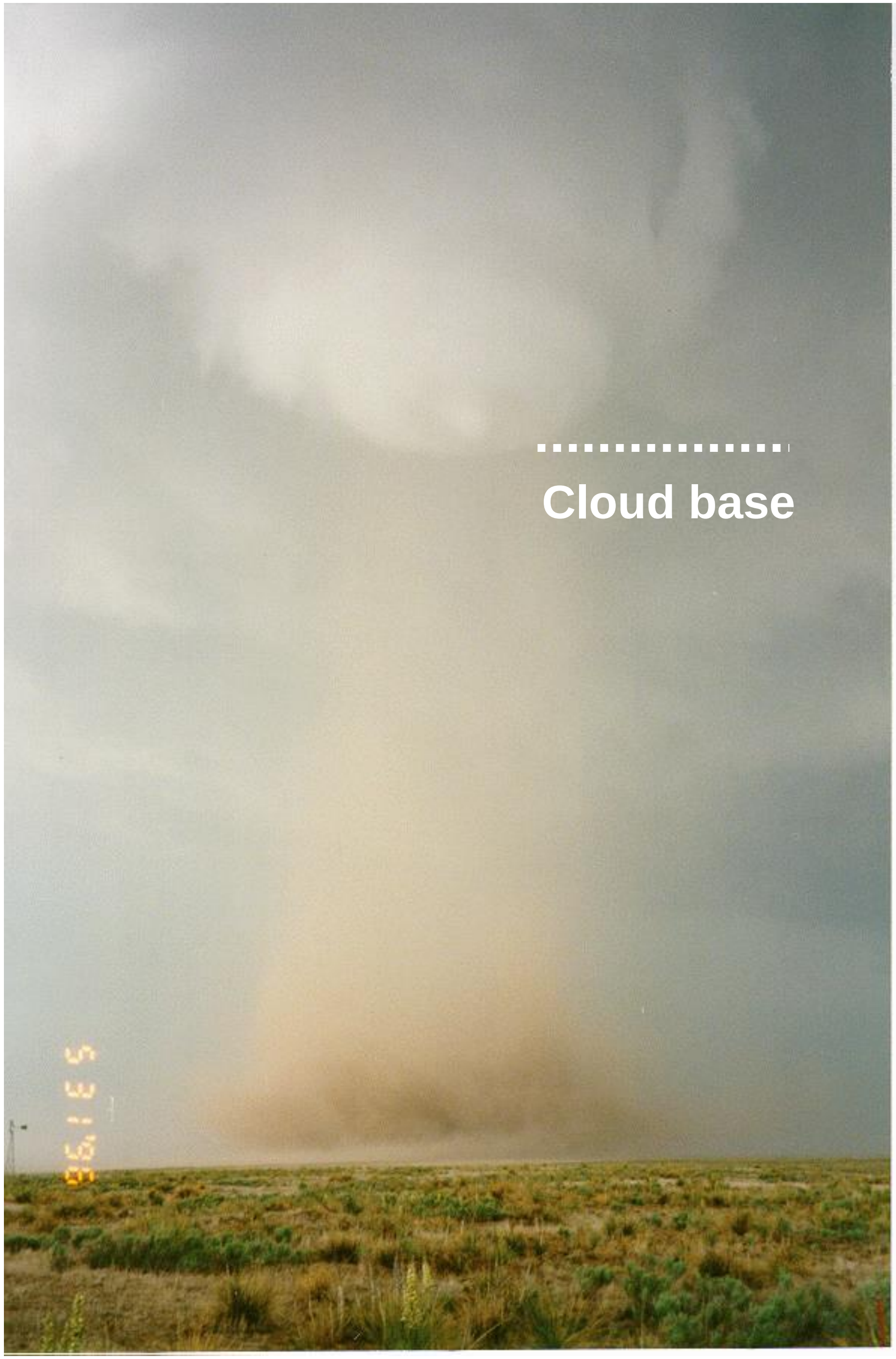


Figure 10.5
The lower half of a severe squall-line-type thunderstorm and some of the features associated with it.

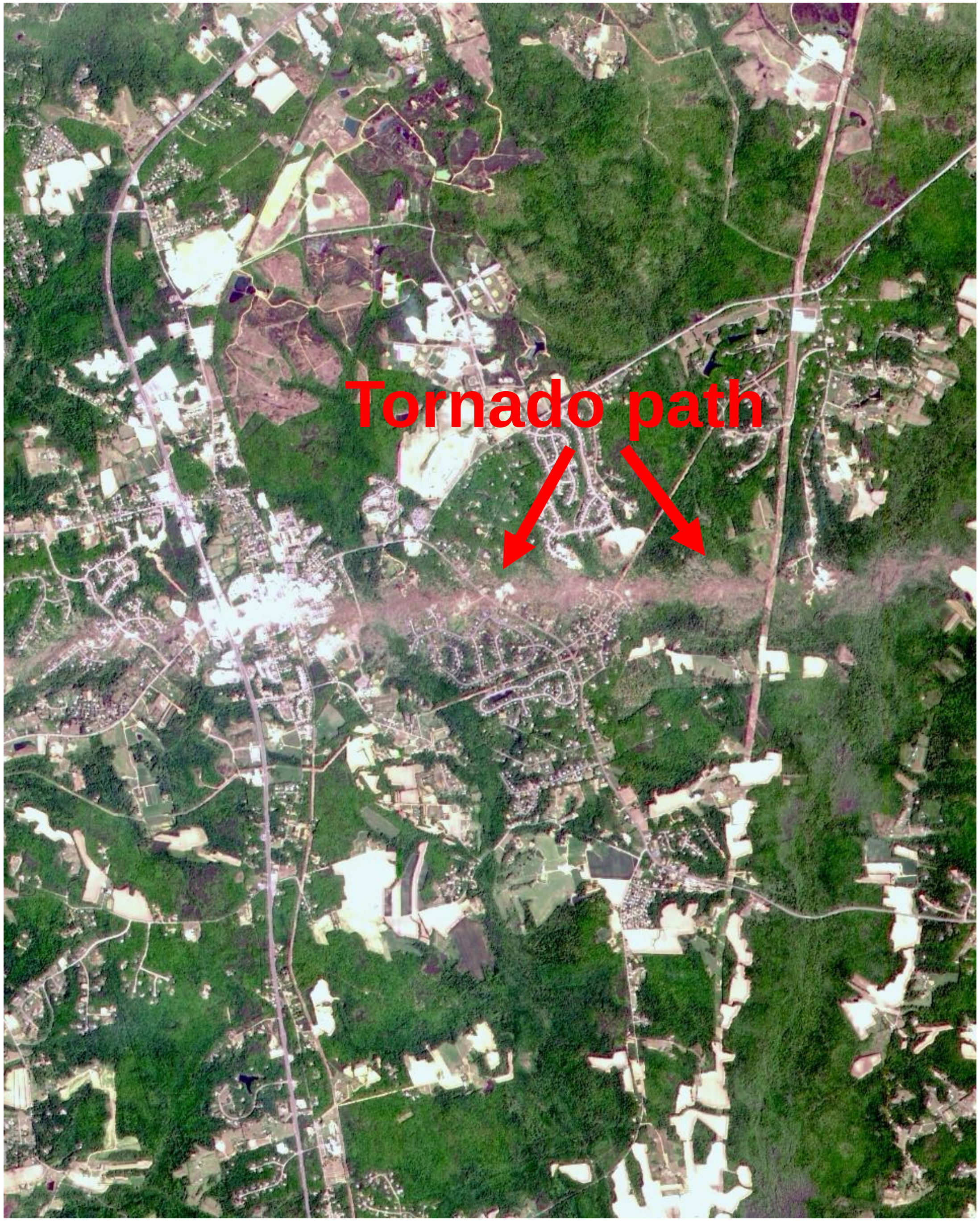


Microburst associated with a small-scale vortex touching the ground

Tornado photographed near Tracy, Minnesota

Figure 10.22
A devastating F5 tornado about 200 meters wide plows through Hesston, Kansas, on March 13, 1990, leaving almost 300 people homeless and 13 injured.

Figure 10.28
Graduate students of the University of Oklahoma use a portable Doppler radar to probe a tornado near Hodges, Oklahoma.

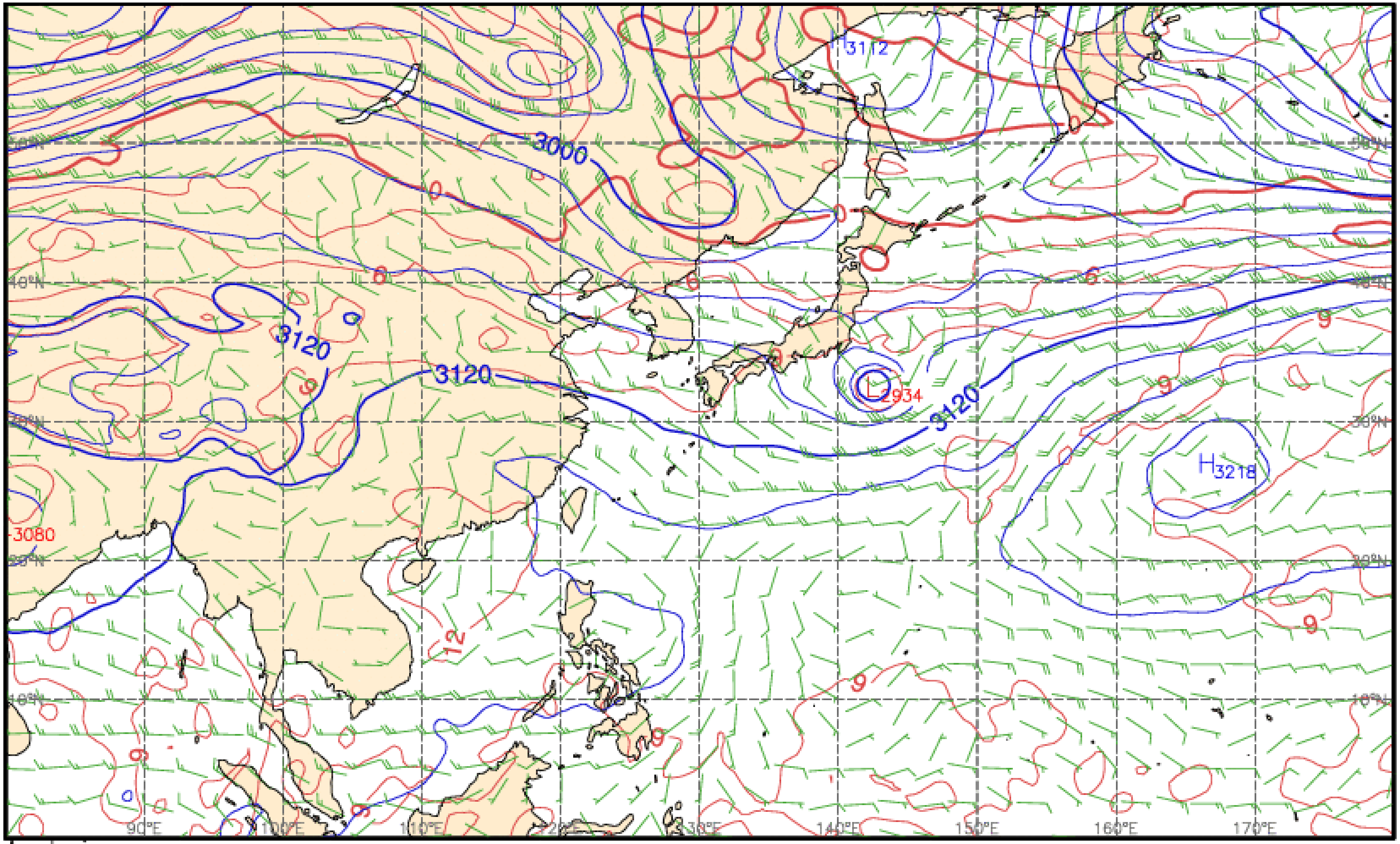


The powerful tornado touched down in southern Maryland and ripped through the town of La Plata, destroying most of the historic downtown. The twister--the strongest ever recorded to hit the state and perhaps the strongest ever recorded in the eastern U.S.--flattened everything in its path along a 24-mile (39 km) swath running west to east through the state.

The tornado's path can be seen clearly in this panchromatic image acquired on May 1 by the Advanced Land Imager (ALI), flying aboard NASA's EO-1 satellite.

1-3 中尺度運動的一般特性 (General Characteristics of Mesoscale Motions)

Synoptic weather chart showing airflow roughly follows isobars (blue contous)



HEIGHT(m), WIND(kts), TEMPERATURE(°C) AT 700 hPa

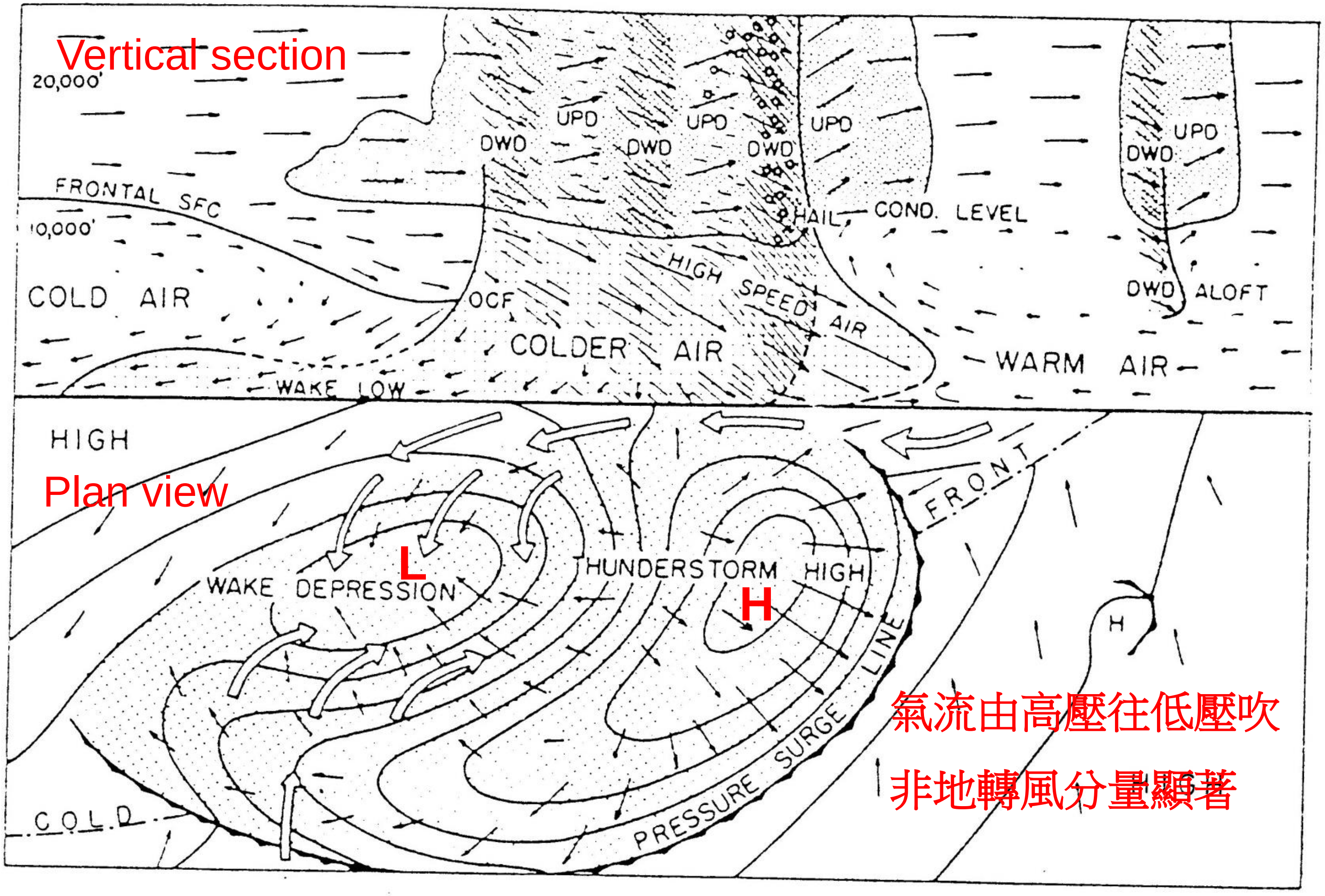
Adapted from CWB

Valid at 09 SEP 2014 00UTC

GFS (T319)

Analysis

A vertical section and a plan view of a mesofront (Fujita, 1955)



氣流由高壓往低壓吹

非地轉風分量顯著

A convective line developed offshore in southeastern Taiwan during TAMEX (Jorgensen et al. 1991)

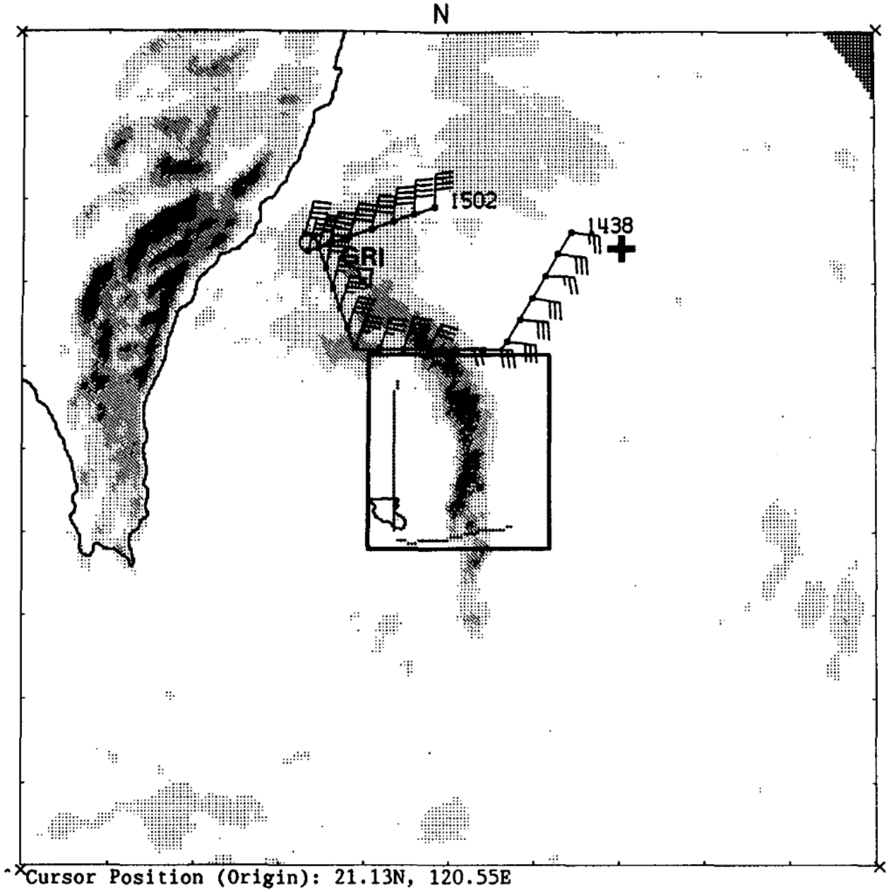
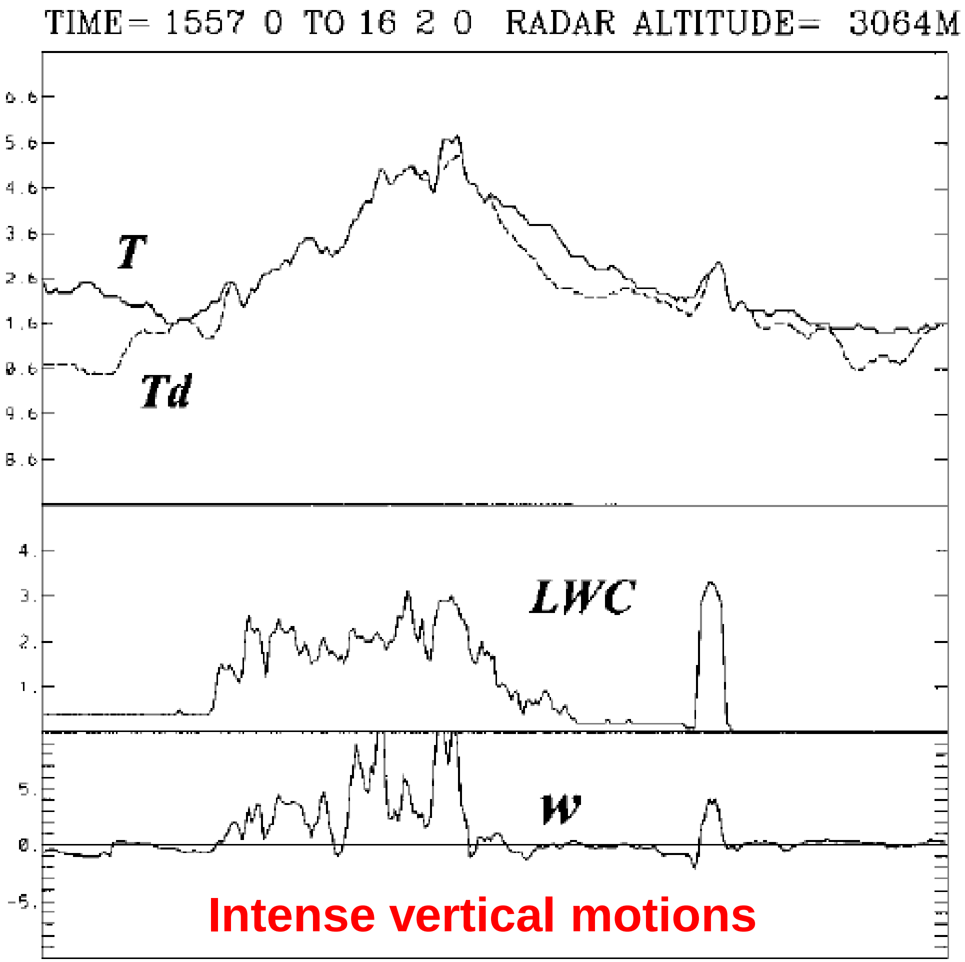


FIG. 2. Composite radar reflectivity map over a 10-min period from 20 scans of the P-3's lower fuselage C-band radar. During the composite period, the aircraft executed an L-shaped flight pattern (solid line). The composite was constructed by maximizing the radar reflectivity from each sweep at each grid point. The radar echoes over Taiwan are ground clutter. The domain of the map is 240 × 240 km^2. The small box centered on the line is the 54 × 54 km^2 Doppler analysis domain. The wind observations (1 full barb = 5 $m\ s^{-1}$) were determined from an earlier 300-m track and show the cyclonic shear across the band.

Flight-level data collected as the aircraft penetrated the line (Yu et al. 2001)



Intense vertical motions

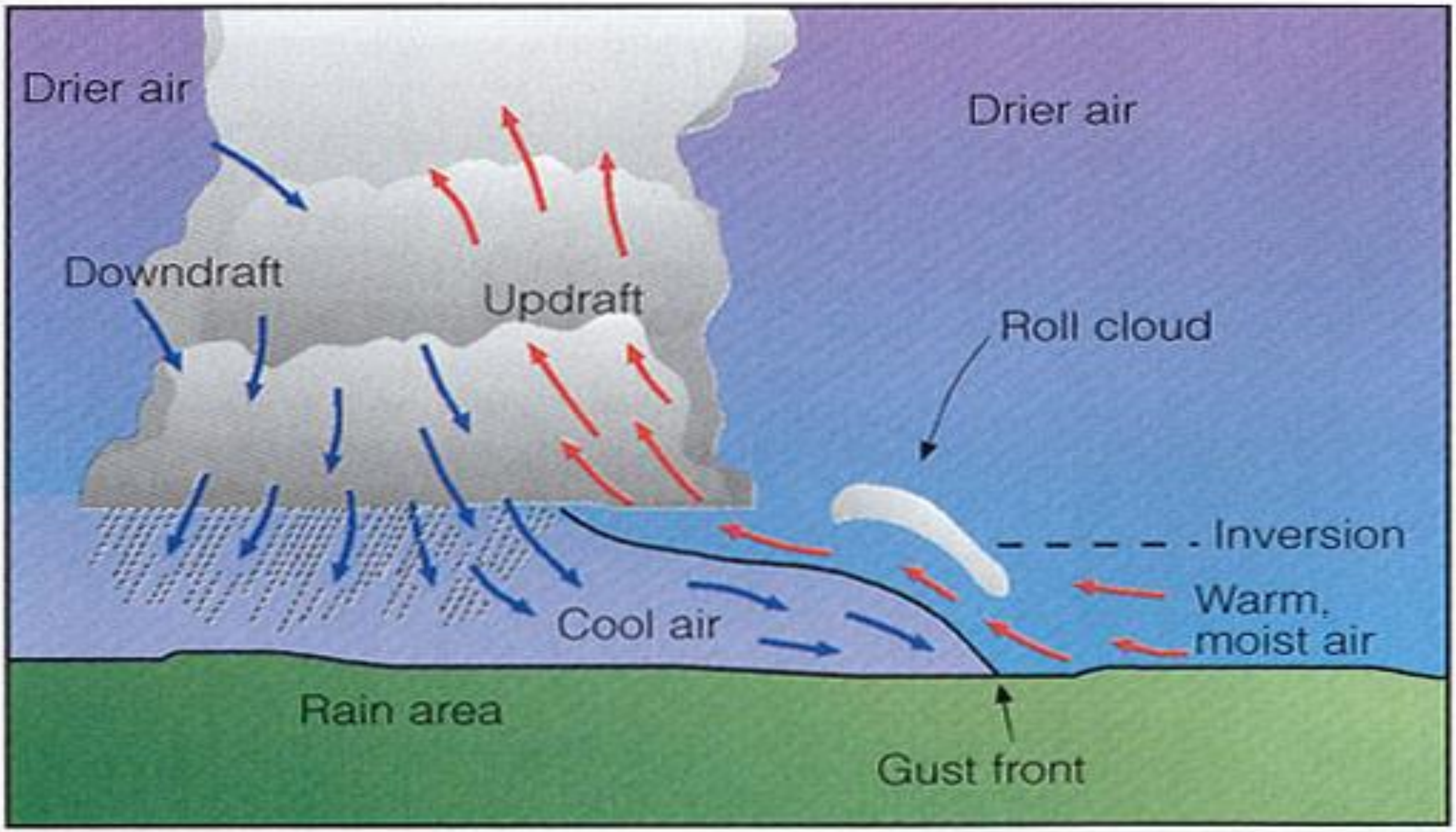


Figure 10.5
The lower half of a severe squall-line-type thunderstorm and some of the features associated with it.

An example showing the hydrostatic and nonhydrostatic pressure observed at a gust front

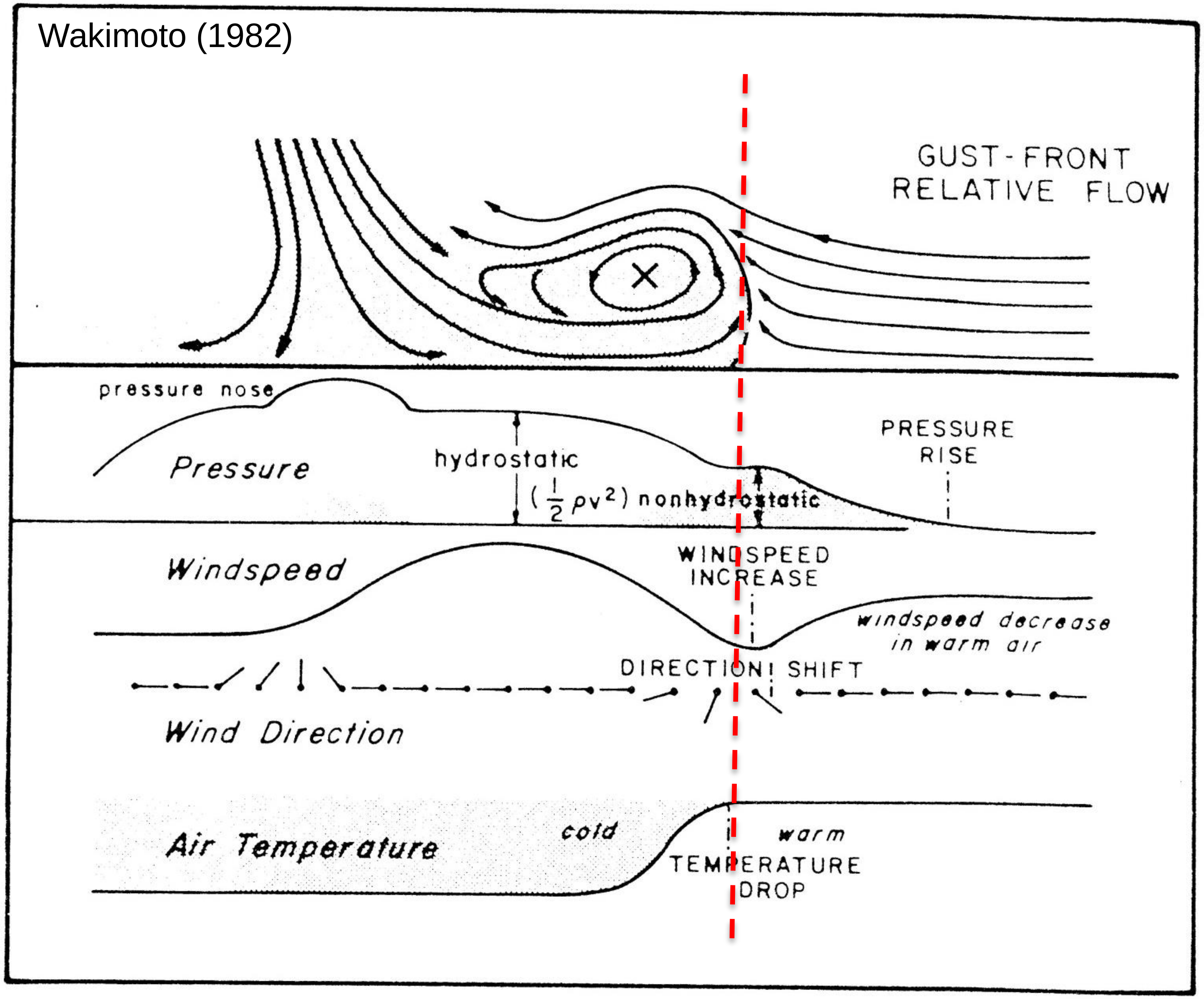
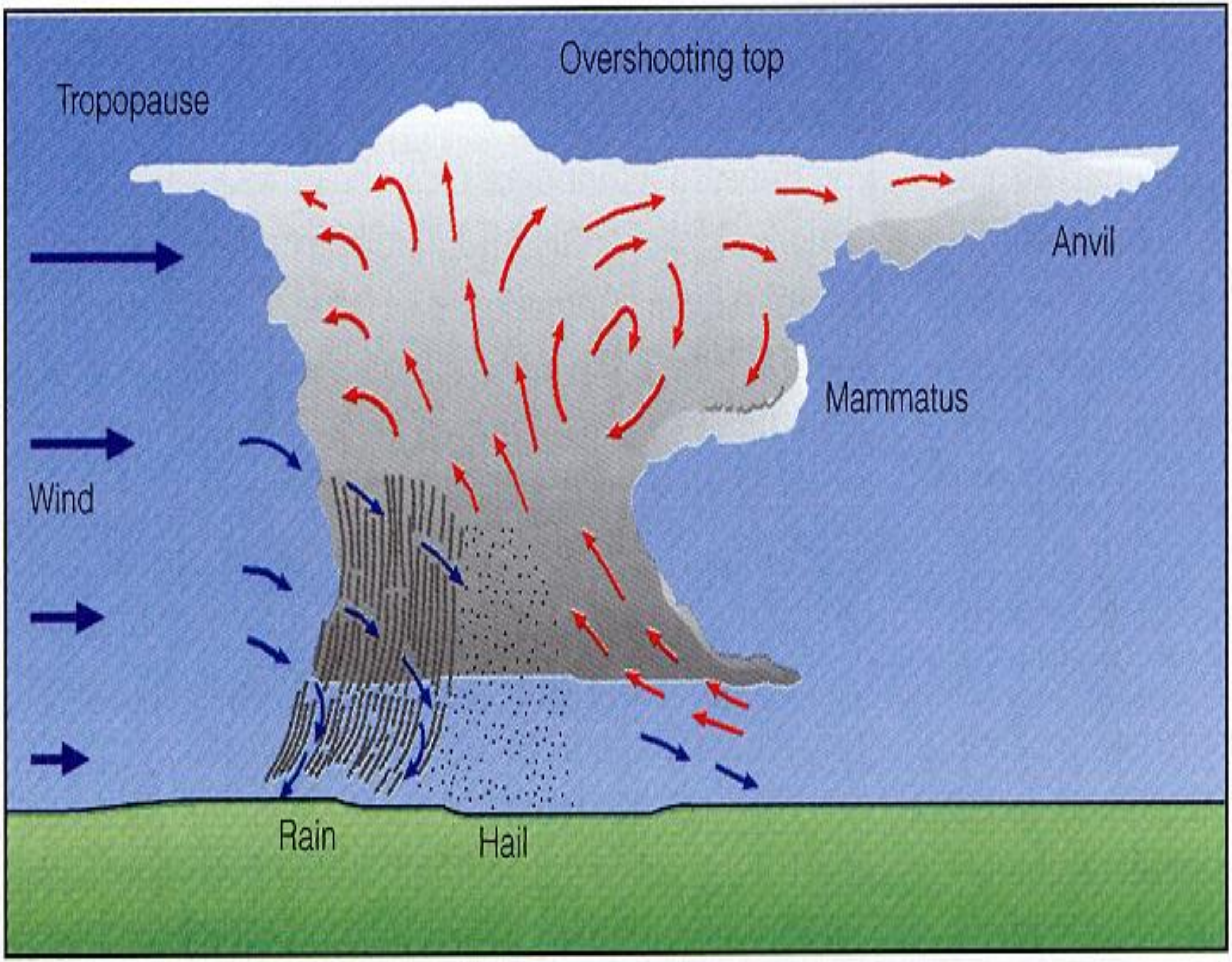
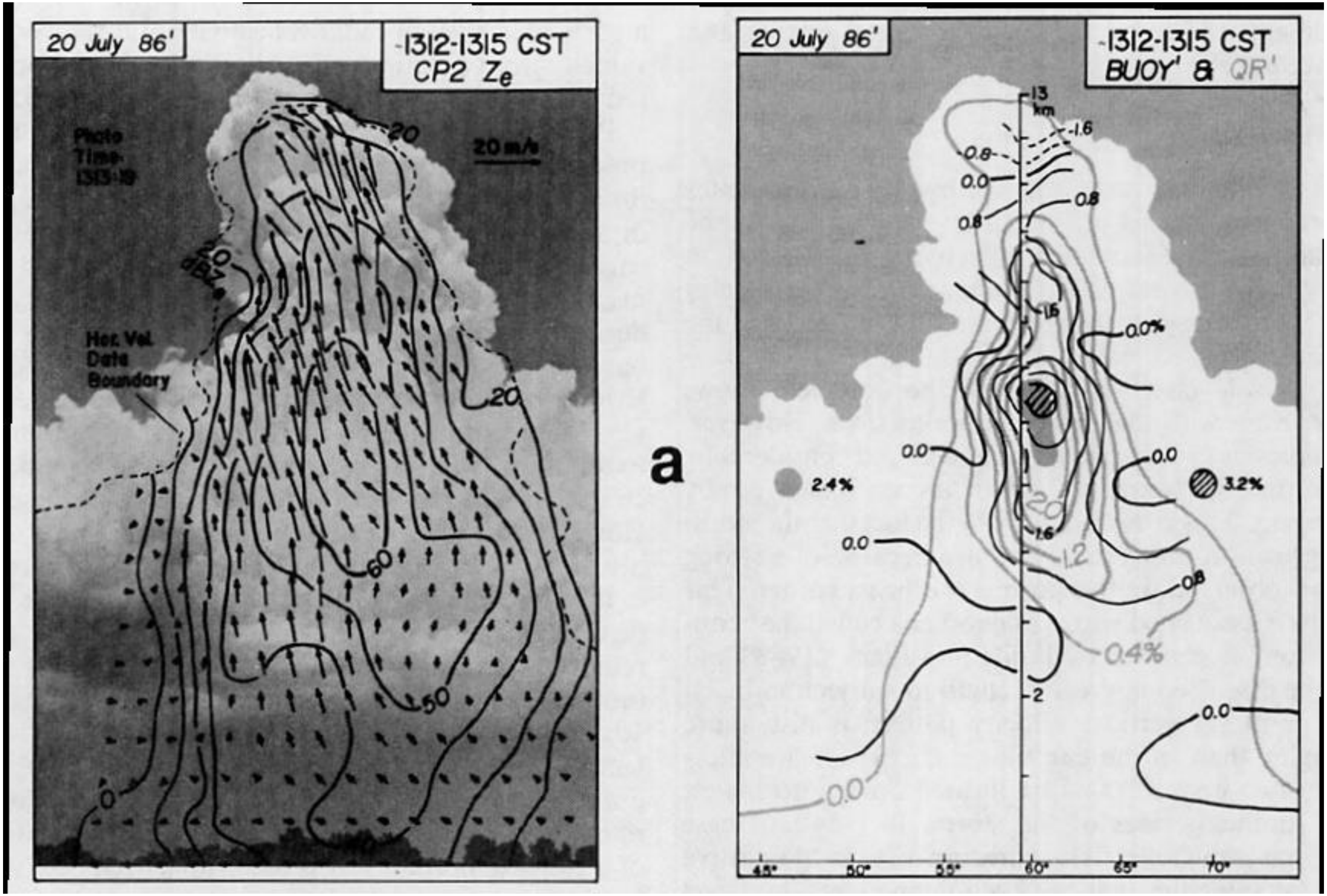
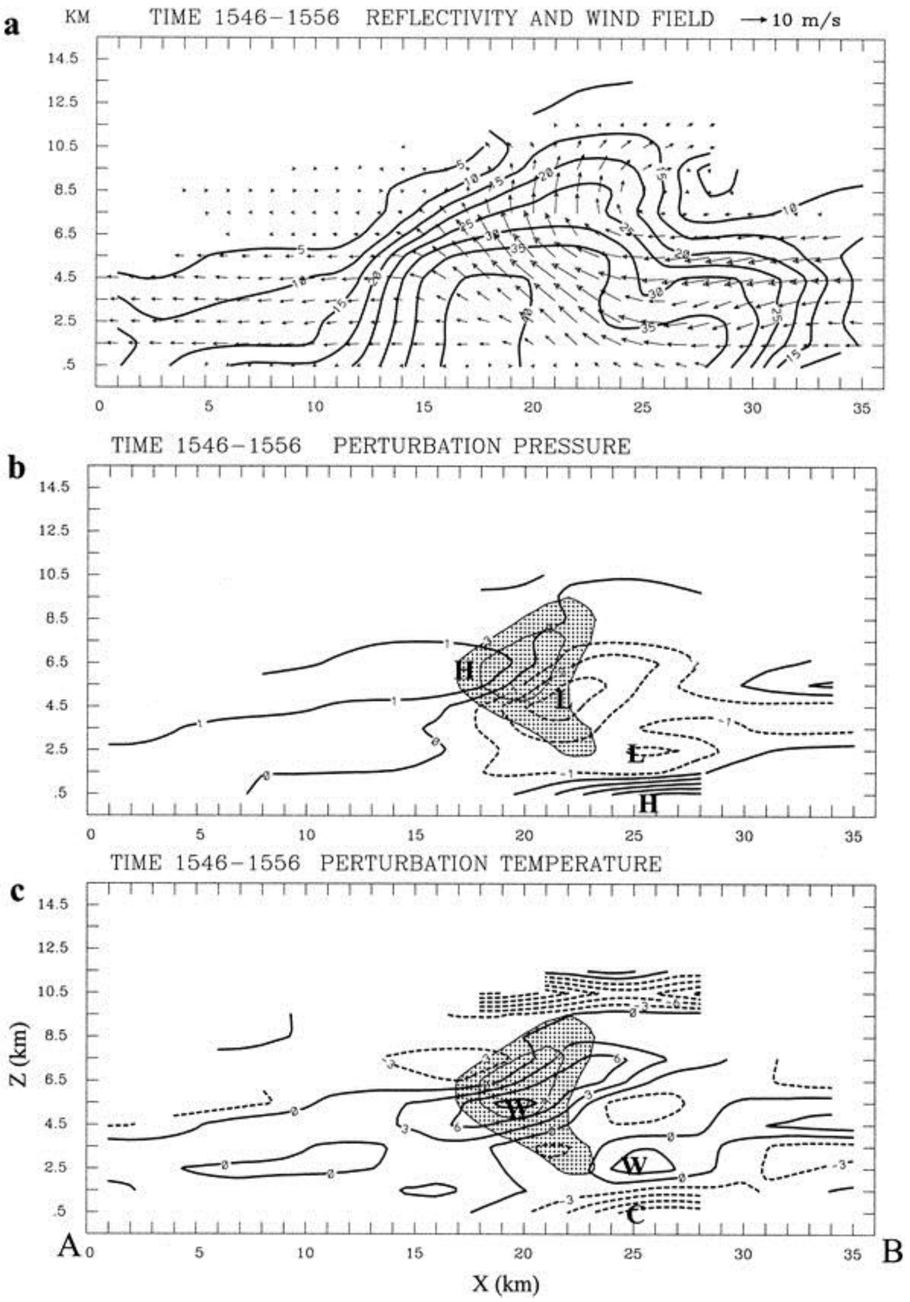

Wakimoto (1982)

FIG. 29. Conceptual model of the surface observations during the passage of a gust front in stages II and III.


Overshooting top
Tropopause
Anvil
Mammatus
Wind
Rain
Hail

Significant in-cloud warming associated with storm updrafts and a relatively weak cooling near the cloud top (Kingsmill and Wakimoto 1991)





Vertical cross sections of a convective line showing pressure and temperature perturbations within the convective cloud (Yu et al. 2001)