一、天氣學(synoptic meteorology,又稱綜觀天氣學)簡介

一、A. 何謂天氣學

a. 簡介

Although the adjective ‘**synoptic**’ comes from the Greek word ‘**synoptikos**’, meaning "**affording a general view of a whole**", the adjective synoptic in the meteorological lexicon has taken on somewhat restrictive meaning. One usually refers to it in the context of the horizontal dimensions and length of time of atmospheric phenomena such as extratropical cyclones and anticyclones, troughs and ridges in the baroclinic westerlies, and to some extent frontal zones and jets. synoptic scale : space ~10**3 km, time ~ 1 week

synoptic: (syn- 同時的，綜合的； -optic：視覺的)
: taking a general view of the principal part of a subject.

本課程要探討的主要課題有：

1. 如何收集是’視為同時的’大範圍天氣資料？
2. 如何分析這些資料，以得知綜觀尺度天氣系統之結構及演變特性？
3. 大氣的平均結構為何？
4. 綜觀尺度天氣系統的演變過程及其物理機制為何？
5. 如何利用天氣學的分析，以及各種氣象學的知識（如動力學、熱力學），來預測未來天氣系統的變化，甚至於天氣現象的變化？

b. 天氣學的演進及歷史回顧

450 BC	Aristotle's "Meteorologica"
ca. 1440	Rain gauge used in Korea---雨量記錄
ca. 1595	First Thermometer (Galileo)—溫度記錄
1643	Torricelli invents of mercury barometer---氣壓記錄
1650	Cloud motion determined by trigonometry---上層風場
1660	Compressibility of air discussed (Boyle)
ca. 1670	Suggestion that pressure should decrease with height (Halley)
1674	Observations of pressure decreasing with height (Pascal)
1686	Description of winds and monsoons (Edmund Halley) and first "Climatological" map of winds
1687	Description of winds at sea (Dampier)
1735	Explanation of winds that involves effect of Earth's rotation (Hadley)
1749	Upper air temperatures measured on kite (A. Wilson flies the kite)
1765	Ben Franklin suggests that storms are rotary vortices
1773	Invention of balloon (Charles)
1784	Upper air temperatures measured on balloon (Jeffries, Blanchard)
1780 etc.	Manned balloon flights in France establish temperature lapse
1800 etc.	Basic research on gas laws, chemical nature of air (Priestley)
1801	First cloud classification scheme devised (Lamarck)
1803	Cloud classification scheme, basis for current one, devised (Howard)

1809	Wind measurements made above ground (Foster)
1816	First synoptic maps draw (Brandes)---第一張天氣圖
1835	Coriolis force described mathematically (Coriolis)---科氏力
1840	Invention of telegraph (Morse)---摩斯電報
1840	Identification of "polar current" and "equatorial current" (Dove)
1849	Smithsonian Institution starts cooperative natwork w/ telegraphs
1850	Heinrich Wilhelm Dove -- storms form due to colliding air masses
1852-90	Upper air measurements of pressure, temperature, and humidity in a manned balloon (Welsh, Glaisher, Assman)
1857	Buys-Ballot Law: stand with back to wind, lows to the left---白貝羅定律
1860	Dove's "currents" found on synoptic maps (Fitzroy)
1861	Cyclone model (based on marine observations) that has wind-shift lines (Jinman)
1862-66	Glaisher's balloon flights probe temperature structure of atmos.
1863	Le Verrier 首度分析等壓線分佈圖—為最早的每日天氣圖
1865-78	Improvement of Howard's cloud classification scheme (Ley)
1870	Invention of cup anemometer (Robinson)
1878	First model of what later becomes a cold front (Ley)
1883	Cyclone model based on pressure distribution on synoptic maps (Abercromby)
1890	Model of cyclone showing relationship between divergence (convergence) at surface and aloft and pressure distribution at surface (Van Bebber)
1890	First "balloon-sonde" (unmanned, recording balloon) (de Bort)
1893	First kite network (Rotch and Fergusson)
1898	Bjerknes Circulation Theorem
1899-1902	Assmann and de Bort discover stratosphere
1900	Invention of radio (Marconi)
	Radio telegraphy developed, permits weather reports from ships
1901	Discovery of tropopause (de Bort)
1903	Invention of airplane (Wright brothers)
1903	Hypothesis that kinematic energy of storms comes from total potential energy,and is associated with horizontal temperature contrast (Margules)
1906	Study of Dove's "currents"using trajectory analysis (Lempfert and Shaw)
1909	First theodolite used to get upper air winds, invention of pilot balloon (Rotch)
1909-11	Streamline analysis first used (Sandstrom, Bjerknes)
1917	First airplane soundings
1917	First telegraphy from instrumented kite (Herath and Robitzsch)
1918-28	Polar front theory--the "Bergen school" (J. Bjerknes, Solberg, Bergeron)
1922	L.F. Richardson tries first numerical weather forecast - & fails.
1923-35	Invention and improvement of radiosonde (Blair, Idrac, Bureau, Moltchanoff, Vaisala, Duckert, Lange)
1928	Theory of kinematic of frontogenesis (Bergeron)
	The teletype replaces the telegraph in weather data transmissions
1930	Introduction of concept of isentropic analysis (Shaw)
1933	First upper air maps at constant height levels
1933	First upper air maps at constant pressure levels (Scherhag)
1937	First routine use of radiosonde data
1937-40	First isentropic analysis of upper air data (Rossby, Namias)
1939	Rossby's Theory of the General Circulation of the Atmosphere
1941	"Father of climatology" Helmut Landsberg: "Physical climatology"
1941	First routine isentropic analyses in USA

	Inventation of radar
1943	First aircraft penetration of the eye of a hurricane
1944	First detection of precitation by radar
1945	International adoption of constant-pressure analysis
1945	First use of reference states
	Discovery of the jet stream and jet streaks, The "Chicago School" (Palmen, Newton, Rossby et al.)
	First use of quasigeostrophic assumption (Charney, Eliassen)
	Mathematical justification for quasigeostrophic theory (Charney)
1946	First computerized weather forecasts (Charney & Van Neumann)
1949	The Thunderstorm Project (Byers, Braham)
1950	Invention of the computer
	First numerical forecast by computer
	Discovery of upper level fronts (Reed)
	Discovery of the dryline (Fujita, Beebe)
1957	First satellite (Sputnik I)
1959	First meteorological satellite (Explorer VII)
1960	First communications satellite
	TIROS I launched (a meteorological staellite)
	First pulsed Doppler radar
	First infrared sensors on satellite
	First geosynchronous satellite
	First satellite soudings using infrared spectrometers
1960s	New high speed computers come into general use
1967+	Project Stormfury begins hurricane modification experiments
1969	Nimbus Satellite SIRS experiments: temperature soundings from space
1967-70	ATS Stationary satellites launched
1970	Analysis of coastal fronts
	First detailed documentation of mesoscale organization of precipitation systems
	First multiple-Doppler observations
	Introduction of semigeostrophic theory and its application to the study of fronts and jets (Hoskins)
	First Doppler radar observations in clear air
	First use of minicomputers
	First interactive computer system for meteorologiacl analysis (McIDAS)
	First pulsed Doppler lidar observations
	First automated surface networks (NCAR)
	Theory of conditional symmetric instability and rainbands in cyclones (Emanuel, Bennetts, Hoskins)
1974	SMS-1 launched (geostationary), GOES-1 follows in 1975
1978	Fujita discovers downbursts, micro- and macrobursts
1979	Mesoscale Convective complexes discovered using GOES imagery
1980	First use of wind profilers (Wave Propagation Laboratory)
	First dual-polarization radar for hail detection
1983	NOAA-8 launched with buoy data collection monitors
1990	CWB installs Cray Y-MP4
2000's	You take Synoptic Meteorology coursework...

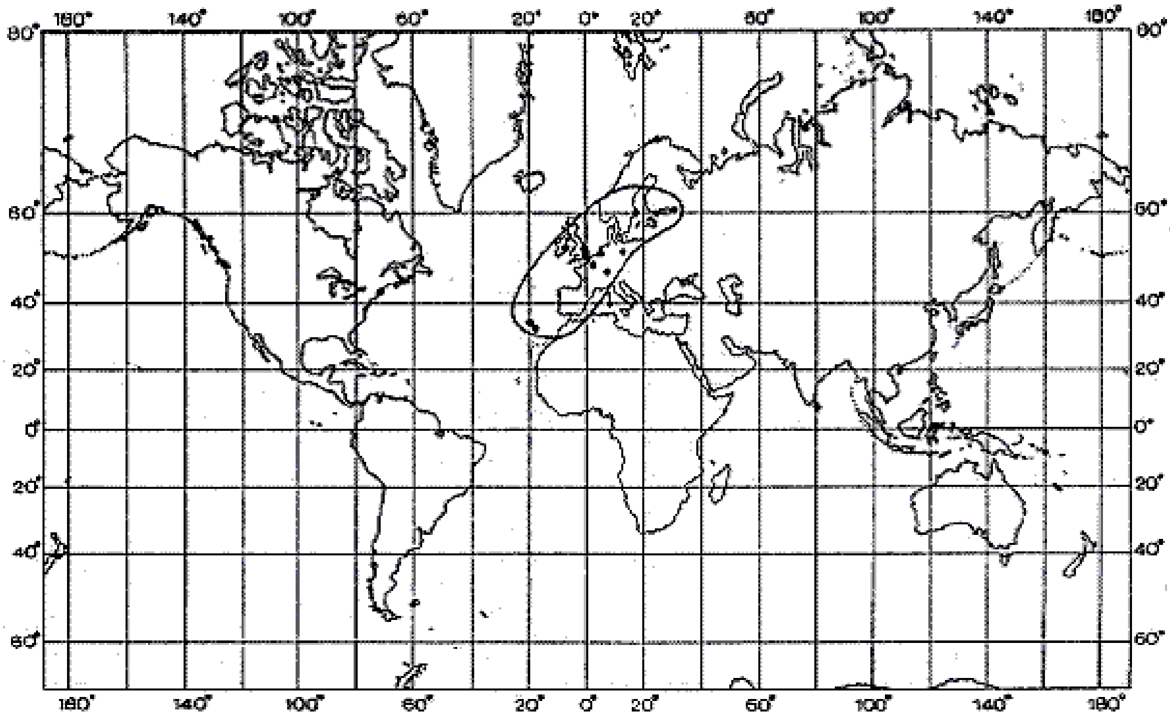
Results: circulation maps and indices since 1750

The growth of the network of observations and of the area for which 10-year mean isobars can be shown is seen in Fig.1 A–C.

Fig.15A shows the average pressure in January over quite a large part of the Northern Hemisphere for one of the earliest 40-year periods (1790–1829) which can be reconstructed within the required limits of error. It may be compared with Fig.2 B, the average for another 40-year period (1900–1939), the earliest for which most—but not yet all—of the world can be covered.

It may be considered surprising that it is possible to present the average pressure distribution across the Atlantic, at least in temperate latitudes, in the absence of observations from the Azores—though there was occasional information from Madeira and Iceland in the period covered by Fig.1 A. Yet this is the verdict of the tests. It is useful at this point to consider how far such a test procedure takes one. Since the test chart series really measured the analyst's ability to produce the average pressure patterns of 1920–1939 from skeleton data, and the early charts were also drawn with the modern "normal" chart on the desk, any untested bias in the analysis is likely to be towards minimizing differences from the twentieth century. Of course, there are also smoothing errors: wherever the real pressure distribution is intricate and the isobars sinuous, the isobars on any small-scale map are always too smooth. But the localized details that are smoothed out are seldom of much interest in the dynamics of the large-scale circulation.

Intricate isobar patterns are rarer over the oceans than over the land, and it is one of the virtues of the map method that pressure gradients can be measured over the oceans, where the main windstreams are best developed and most regular in their occurrence.



A

Fig. 1 Growth of the world network of observations of barometric pressure used and of the area that can be covered by reliable 10-year average isobars: A. 1750–1759. B. 1850–1859. C. 1950–1959.

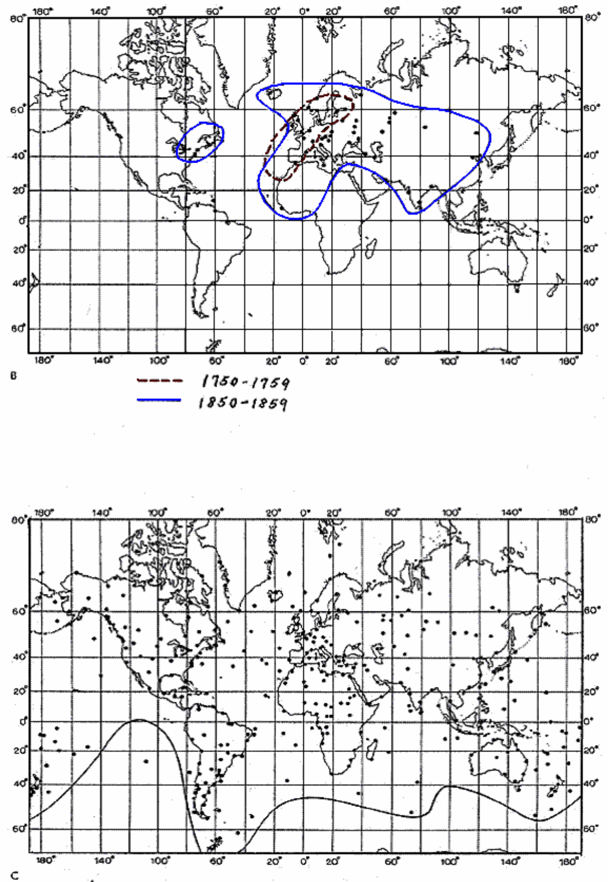


Fig. 1 B, C. (Legend see p.210.)

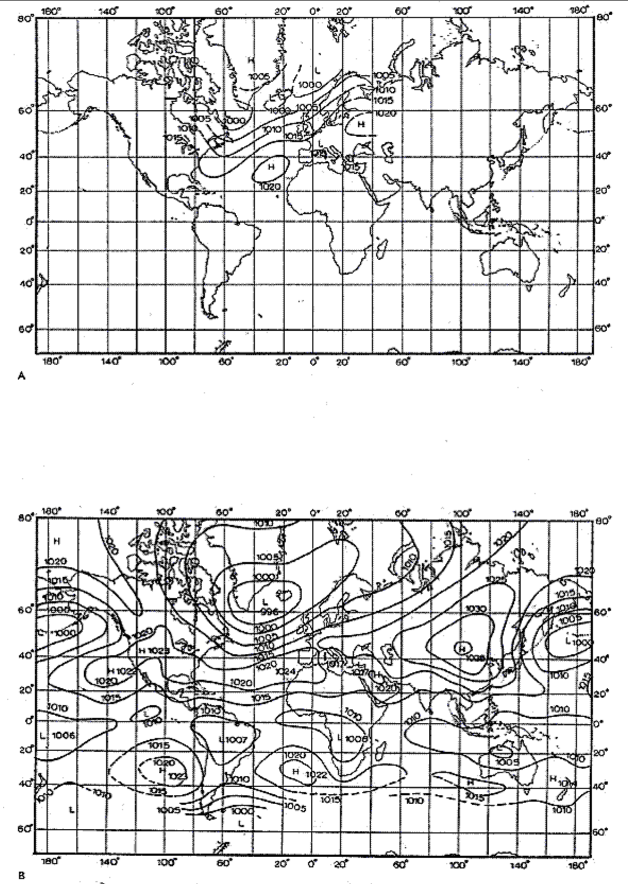
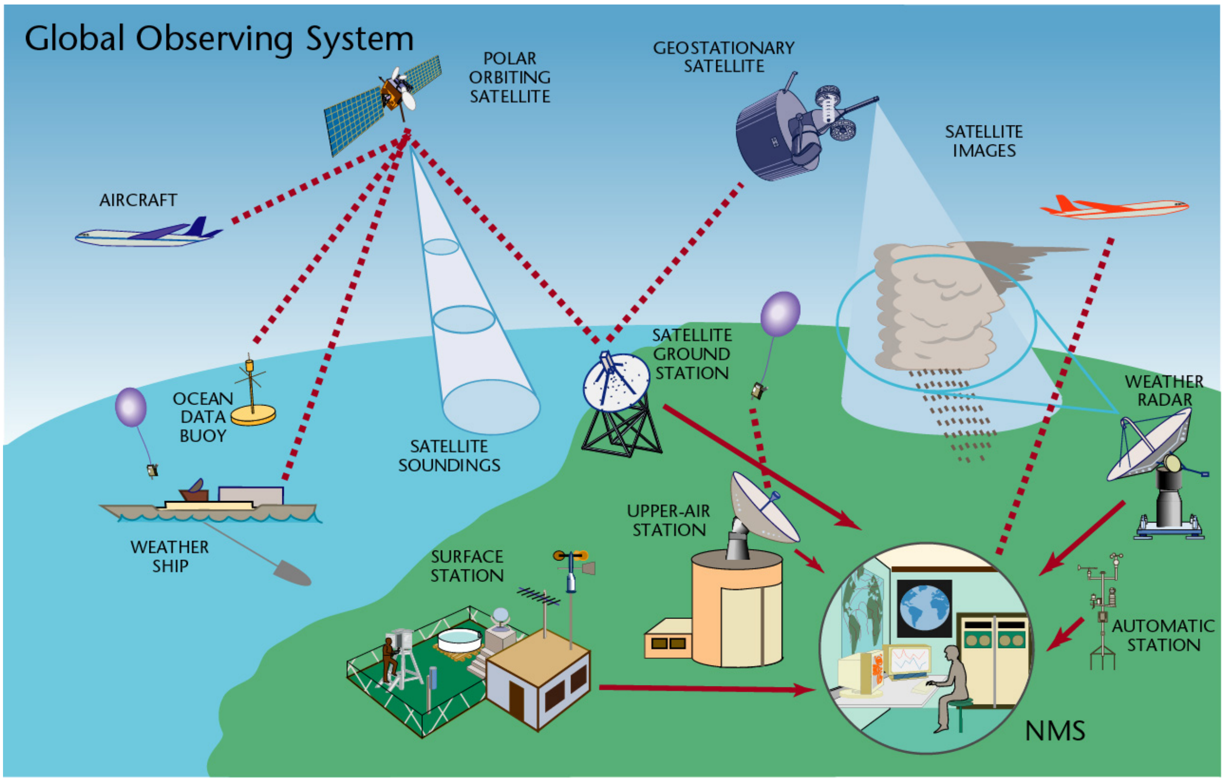
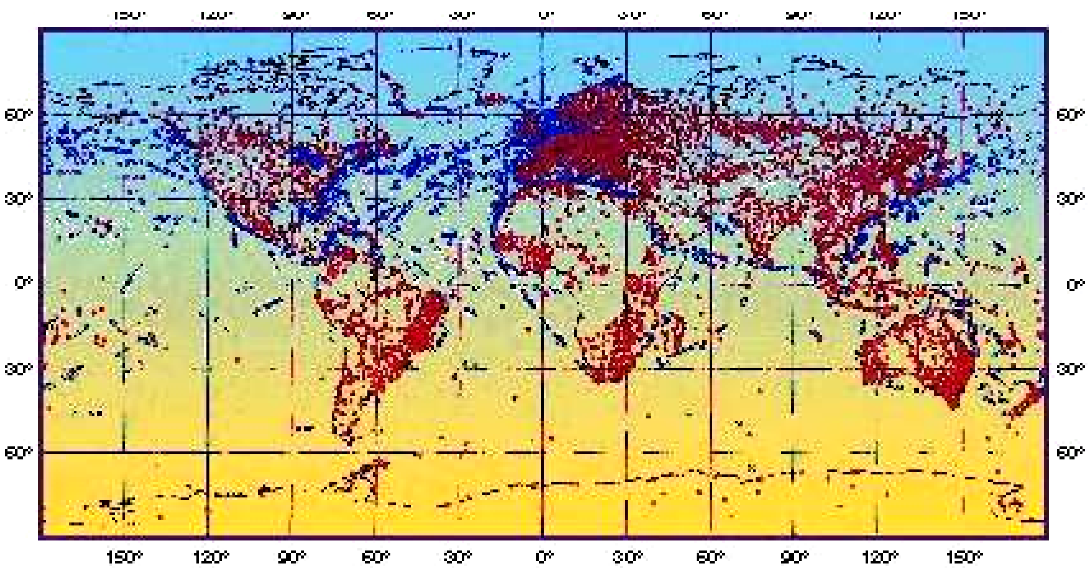


Fig. 2 Average atmospheric pressure (mbar) at sea level in January: A. 1790–1829. B. 1900–1939.

WORLD METEOROLOGICAL ORGANIZATION (WMO)
http://www.wmo.ch/web/www/OSY/GOS.html
Global Observing System (GOS)



Surface Observations

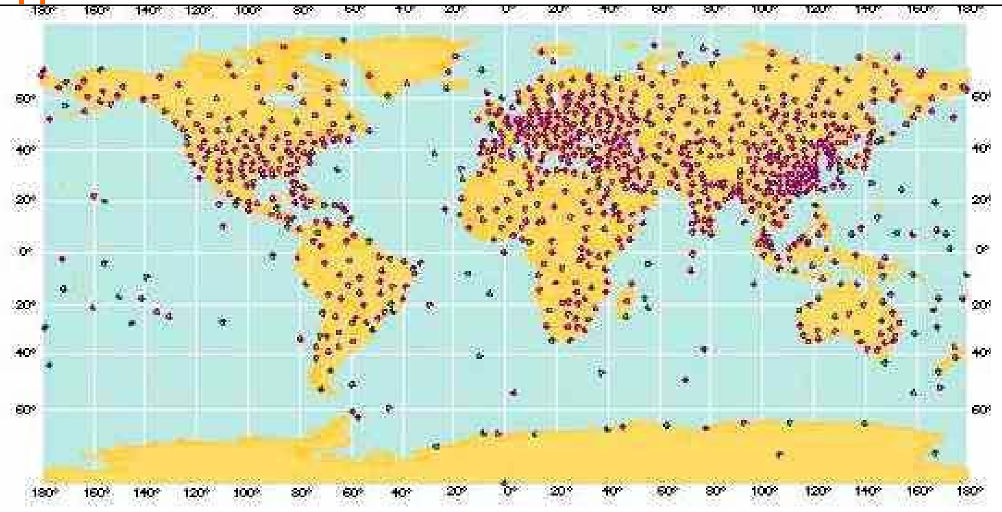


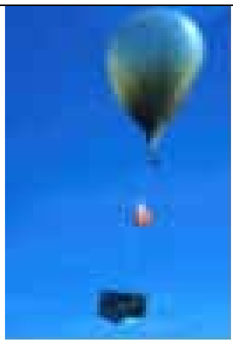
about 11,000 surface-based stations (2007)

at least every three hours and often hourly

Some 4000 of these stations comprise the Regional Basic Synoptic Networks (RBSNs) drawn up by the six WMO Regional Associations. Data from these stations are exchanged globally in real time.

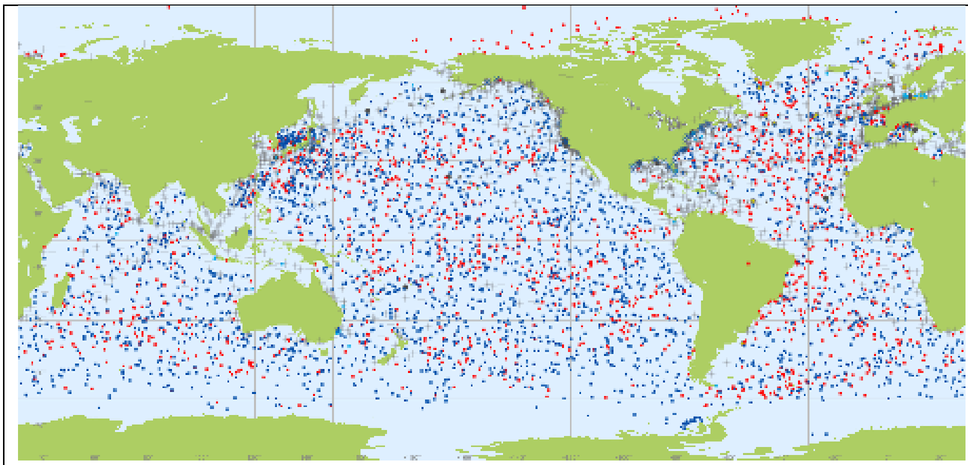
Upper-air Observations





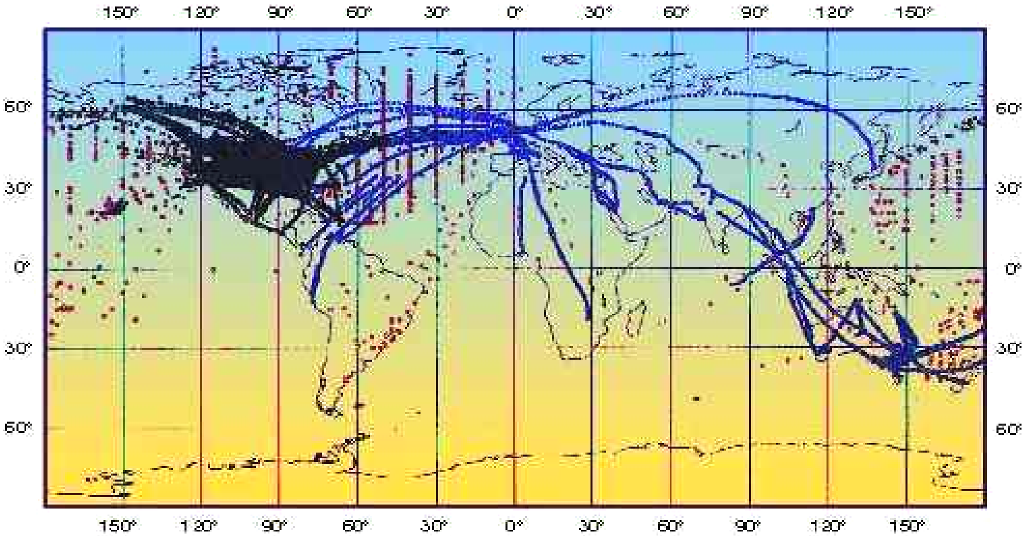
roughly 900 upper-air stations, radiosondes, attached to free-rising balloons, make measurements of pressure, wind velocity, temperature and humidity from just above ground to heights of up to 30km. Over two thirds of the stations make observations at 0000UTC and 1200UTC.

Marine Observations



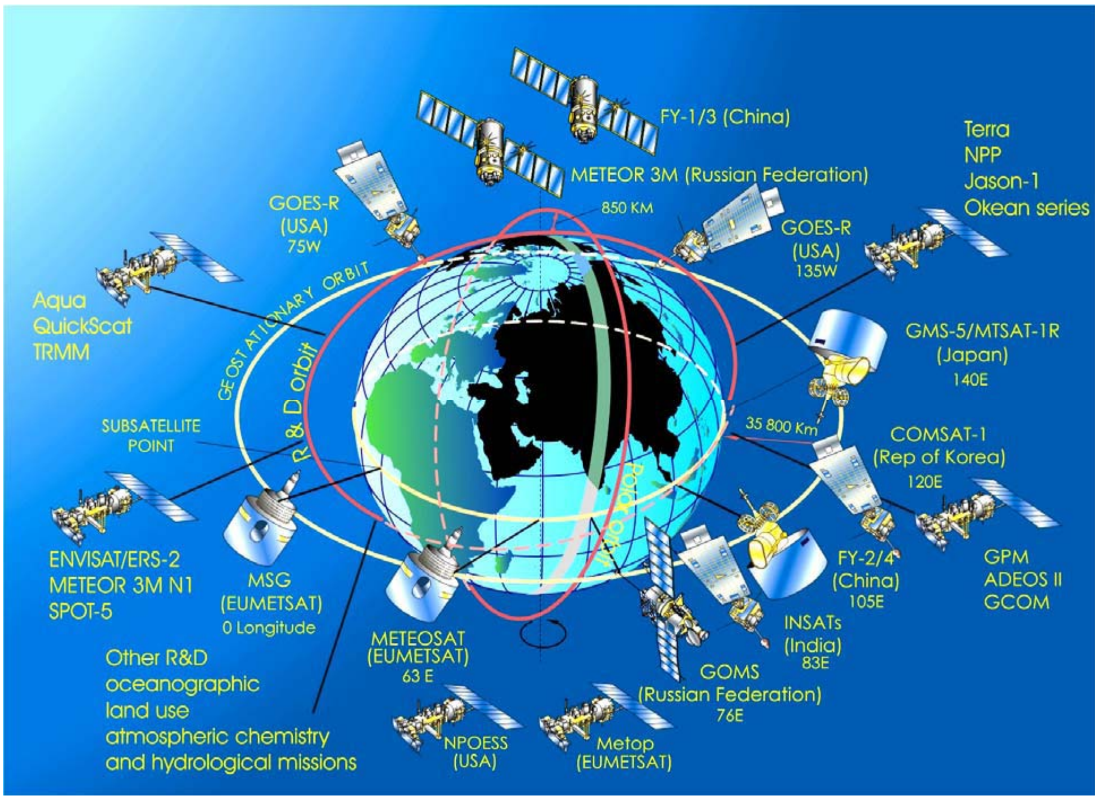
The number of observing ships is around 4,000. About 1000 of them report observations every day. The operational drifting buoy programme comprised of about 1,200 drifting buoys provides over 27,000 sea surface temperature per day. Half of the drifters also report sea level pressure providing about 14,000 reports per day.

Aircraft Observations



Over 3000 aircraft provide reports of pressure, winds and temperature during flight. observations of winds and temperatures at cruising level as well as at selected levels in ascent and descent.

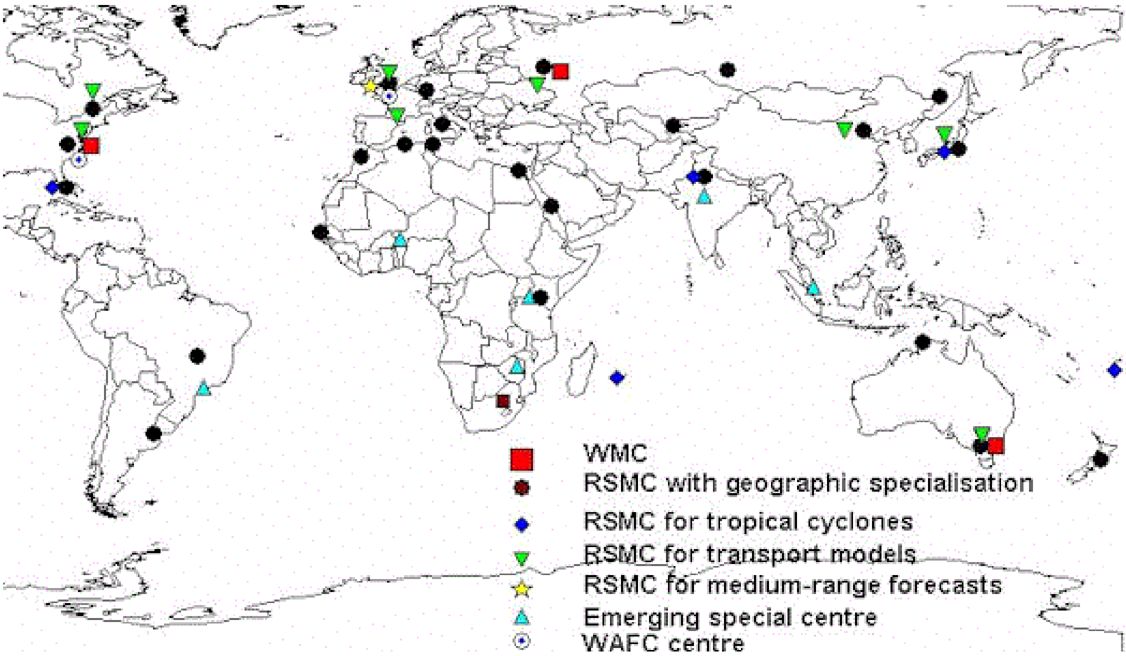
Satellite Observations



Other observation platforms

GOS also includes solar radiation observations, lightning detection, and tide-gauge measurements. In addition, wind-profiling and Doppler radars are proving to be extremely valuable in providing data of high resolution in both space and time, especially in the lower layers of the atmosphere.

World and Regional Meteorological Centers



WORLD METEOROLOGICAL CENTRES (WMCs)

MELBOURNE
MOSCOW
WASHINGTON

REGIONAL SPECIALISED METEOROLOGICAL CENTRES (RSMCs) WITH GEOGRAPHICAL SPECIALIZATION

ALGIERS	JEDDAH	OFFENBACH
BEIJING	KHABAROVSK	PRETORIA
BRACKNELL	MELBOURNE	ROME
BRASILIA	MIAMI	TASHKENT
BUENOS AIRES	MONTREAL	TOKYO
CAIRO	MOSCOW	TUNIS/CASABLANCA
DAKAR	NAIROBI	WASHINGTON
DARWIN	NEW DELHI	
	NOVOSIBIRS K	

RSMCs WITH ACTIVITY SPECIALIZATION FOR TROPICAL CYCLONE FORECASTING:

MIAMI - HURRICANE CENTER
NADI - TROPICAL CYCLONE CENTRE
NEW DELHI - TROPICAL CYCLONE CENTRE
SAINT DENIS, LA RÉUNION - TROPICAL CYCLONE CENTRE
TOKYO - TYPHOON CENTRE
HONOLULU - HURRICANE CENTRE

一、B. 大氣尺度畫分與大氣變數

B. 大氣變數

物理變數：　壓力、溫度、密度、溼度
運動變數：　風場（u, v, w）
獨立變數：　x, y, z, t

C. 天氣系統的尺度畫分

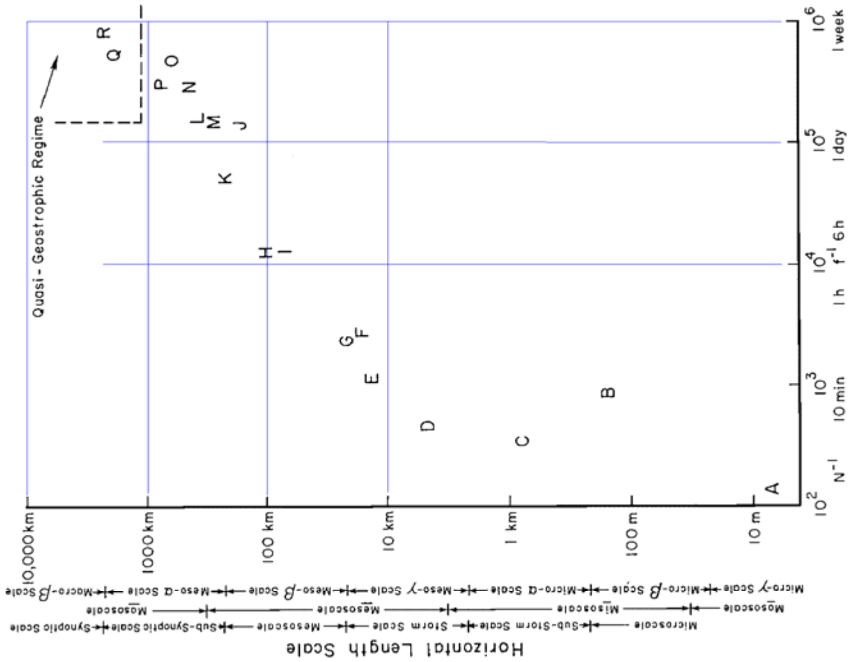


Figure 5a. Horizontal-length scales and time scales for the following atmospheric phenomena: A, dust devils; B, tornadoes and waterspouts; C, cumulus clouds; D, downbursts; E, gust fronts; F, mesocyclones; G, thunderstorms; H, sea/land/lake breezes, mountain–valley circulations, and meso-highs and meso-lows; 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.

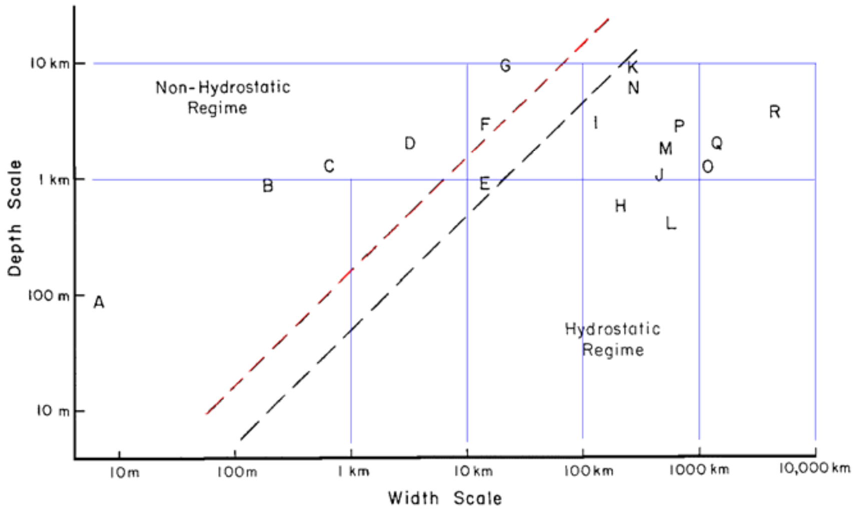


Figure 5b. Depth and width scales for the atmospheric phenomena shown in Fig. 1.1. (By *width* we mean the characteristic horizontal scale; some features such as fronts are elongated and therefore are characterized by two different length scales. In this case we refer to the longer of the two scales as the *width*.)

各種大氣運動系統的數量級及所屬尺度

尺度等級	運動系統	典型數量級（公尺/分鐘）	備註
微 (micro)	分子平均自由路徑 微小湍流性渦流 小渦流	10^{-7} 0.01 ~ 0.1 0.1 ~ 1	turbulent eddies
小 (small)	塵捲 陣風 龍捲風、積雲	1 ~ 10/2 10 ~ 100/5 100/10	dust devils
中 (meso)	雷暴、積雨雲 鋒、颮線、海陸風	$10^3/40$ 10^4 ~ 10^5/天	meso γ meso β
大 (large or synoptic)	颱風 氣旋、反氣旋	10^5 10^6	有人以較小熱帶風暴列入 meso α 尺度 有人建議以 1~2x10^6範圍的系統，如小高壓、梅雨等系統，另稱「間尺度」(intermediate or medium)
巨 (marco)	行星級波動 大氣潮汐 大氣環流	10^7 10^7 10^7	

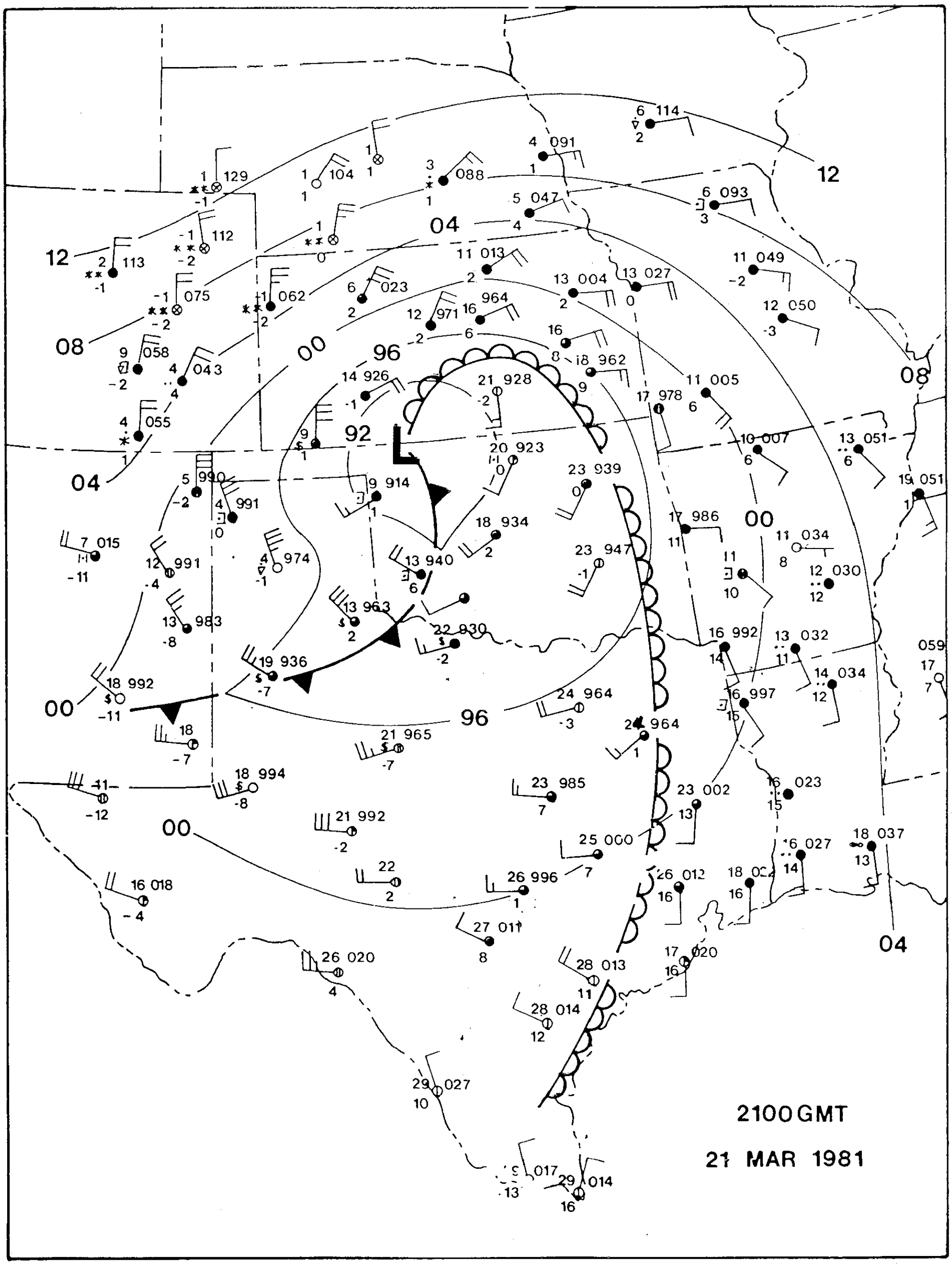


Figure 2.40 Example of a dryline (scalloped line) being advected far to the east by a strong synoptic-scale system 2100 UTC (GMT), March 21, 1981. Temperature and dewpoint in °C. Sea-level pressure in tens of mb, without the leading 9 or 10. Whole wind barb = 5 m s^{-1}; half wind barb = 2.5 m s^{-1}. Sea-level isobars in mb (solid lines), without the leading 9 or 10. Blowing dust is often observed when strong surface winds are found behind the dryline (from Carr and Millard, 1985). (Courtesy of the American Meteorological Society)

1. 鋒面：ΔT 大，(ΔT_d 小或等)

2. dryline：ΔT_d 大 (ΔT 小或等)

乾線（dryline），在春天或初夏，最常發生之位置有美國中西部、印度（季風前）、及西非中部。

對氣塊的熱力性質，如：靜穩定度、水氣凝結高度、自由對流、絕熱過程等描述，就需要藉熱力圖來分析。

若針對某特定時間的氣象資料分析：

（1） x , y 當固定，z 為自變數時，即探空熱力圖；

（2） z 當固定，x , y 為自變數時，即高空天氣圖；

（3） x （或 y） 當固定，（z , y） 或 （z , x ） 為自變數時，即剖面圖。

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§ 2－2 大氣的變數

大氣分析的物理變數包括溫度、氣壓、水汽含量、和其它導出量；而運動變數包括風速的三個分量。

（A） 溫度（T）

在氣象學中，氣溫有三種不同的刻度表示法：

1. 攝氏溫度 （°C）
2. 華氏溫度 （°F）

$$°F = \frac{9}{5}(°C) + 32°$$

$$°C = \frac{5}{9}(°F - 32°)$$

3. 絕對溫度 （°K）

$$°K = (°C) + 273.16°$$

（B） 氣壓（P）

所謂靜力壓力（ Hydrostatic Pressure ）是指單位面積的空氣柱的總重量，它的單位：

1. c . g . s . 制 － dyne / cm^2 Pascal
2. m . k . s . 制 － Nt / m^2 （即 Pa ）

$$100\ \text{Pa} = \cancel{100\ \text{Hpa}}\ 1\ \text{hPa} = 1\ \cancel{\text{Mb}}\ \text{mb} \quad \text{hecto Pascal (百帕)}$$

$$= 1000\ \text{dyne}/\text{cm}^2 = 10^{-3}\ \text{bar}$$

由於靜力壓力隨高度而呈對數遞減，故可以選擇氣壓為垂直坐標。

(C) 密度 (ρ)

假設大氣為理想氣體，則

$$\rho = \frac{P}{RT}$$

對乾空氣而言，R = 287.05 Joul / ^{0}K / Kg，定義比容為密度的倒數。由於水汽含量的不同，氣體常數會有少量的改變。

(D) 濕度

大氣濕度的表示法有多種：

(1) 水汽壓 (Vapor Pressure, e) ：空氣中存在水汽所佔有的分壓，叫水汽壓。對特定的氣壓與氣溫狀況下，所能容納的最大水汽壓力，叫飽和水汽壓 (e_s) ，依經驗式知，

$e_s = 6.11 \times 10^{(at/(t+b))}$ (mb) $10^{\frac{at}{t+b}}$

其中，在水面上 a = 7.5 , b = 237.3； 在冰面上 a = 9.5 , b = 265.5。

(2) 絕對濕度 (Absolute Humidity , ρ_w) ：空氣中存在水汽的密度，叫絕對濕度 。假設大氣為理想氣體，水汽壓為 e，水汽分子量為 m_w ，氣體常數為 R^*，則 $\rho_w = \frac{m_w}{R^* T} e$，

若濕空氣的密度為ρ，乾空氣的密度為 ρ_d，則

$$\rho = \rho_d + \rho_w$$
$$= \frac{m_d}{R^* T}(P - e) + \frac{m_w}{R^* T} e$$

其中，$m_d = 28.966$ ，$m_w = 18$ 。

$$故\quad \rho = \frac{m_d}{R^* T}(P - 0.378\,e)$$

$$= \frac{1}{R_d T}(P - 0.378\,e)$$

其中，$R_d = \dfrac{R^*}{m_d} = 287\ \text{Joul} / {}^0\text{K} / \text{Kg}$。

由此可見，在同溫同壓下，乾空氣要比濕空氣的密度大一些。

(3) 比濕 (Specific Humidity , q) ：空氣中存在水汽的質量對濕空氣質量的比，叫比濕。即，

$$q = \frac{\rho_w}{\rho} = \frac{0.622\,e}{(P - 0.378\,e)} \ ,$$

而飽和比濕 (q_s) 可寫成

$$q_s = \frac{0.622\,e_s}{(P - 0.378\,e_s)} \ 。$$

(4) 混合比 (Mixing Ratio , r) ：空氣中存在水汽的質量對乾空氣質量的比，叫混合比。即，

$$r = \frac{\rho_w}{\rho_d} = \frac{0.622\,e}{(P - e)} \ ,$$

而飽和混合比 (q_s) 可寫成

$$r_s = \frac{0.622\,e_s}{(P - e_s)} \ 。$$

故，混合比略小於比濕，兩者應無單位，但其值甚小，一般採用 (g/kg) 。

(4) 相對濕度 (Relative Humidity , U％) ：空氣中存在水汽的混合比對飽和混合比的比，叫相對濕度。故，

$$U\% = \frac{r}{r_s} \times 100\ \% \ ;$$

$$\approx \frac{q}{q_s} \times 100\ \% \ ;$$

$$\approx \frac{e}{e_s} \times 100\ \% 。$$

(E) 風速

一般而言，垂直風速分量遠小於水平風速，垂直風速分量不從觀測直接得到，而需經由診斷分析計算獲得。

風速的單位：　Why?

1. c . g . s . 制 − cm / sec
2. m . k . s . 制 − m / sec
3. 英制 − Knot

1 Knot = 0.51479 m / sec

1 m / sec = 1.942 Knots

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§2−3　天氣資料的傳送

分別

北半球與南半球的地面測站和高空測站的分布情形如圖六與圖七所示，觀測的資料編成電碼後，經電報或點間通訊系統傳送至各國氣象管理單位（如氣象局或氣象中心），經編審後在以無線電報對外發送，各使用單位即可接收，經譯碼後供天氣分析與數值預報作業使用。

比較先進的國家對氣象資料的觀測、資料傳送與接收，甚至於解碼、錯誤檢定、填圖分析，都採用自動化電腦處理，除了提高處理速度之外，還可減少人為的錯誤。

§2−4　地面天氣圖與高空天氣圖

地球是個球體，要把地面的狀況在一張平面圖上描述，就要考慮地圖的投影方式，為求得投影後地圖所表示的面積、方向等要素，沒有太大的變形，一般而言，北半球地圖與高緯度地區地圖採用Stereographic Projection（如圖八所示），中緯度地區地圖採用Lambert Conformal Conic Projection（如圖九所示），低緯度地區地圖採用Mercator Projection（如圖十所示）。

一、C. 氣象觀測與資料傳送

（ppt, pdf 檔）
ch1-b.ppt
ch1b-gos.pdf
ch1b-www.pdf

一、D 天氣圖與地圖投影

A. 各種圖

天氣圖為二維平面圖，但獨立變數有 x, y, z, t 四個，所以要固定其中兩個變數。一般是對同一時間之觀測資料做分析，所以時間是固定的，另外若：

1) Z (or P) = constant, 則為一般之天氣圖，包括等高面圖(constant-level charts, 現已不常用) 及等壓面圖(constant-pressure charts, since 1945)

☆ 地面圖類似等高面圖，圖上填有海平面氣壓(定高)及其他的地面觀測資料。

* **The surface chart**, commonly called the sea-level chart or simply the synoptic map, is really ***NOT*** a constant-level chart. Pressure is the only element reduced to sea level. Temperature, dew point temperature, and wind refer only to the ground level; other elements of surface observations are visible phenomena in the free atmosphere.

☆ 高空圖採用定壓面 --- 如 500 mb, 1000 mb, ... 等
定壓面圖為一等特性面圖(constant-property charts),；另外尚有等位溫面圖（isentropic charts)等。

* The most common of the constant property charts is that of constant pressure. Charts of mandatory pressure surfaces, with observations of temperature, humidity, wind, and also computed height above sea level, are prepared from data in the radiosonde reports.

* One soon learns that the dynamics factors in the weather, and therefore the basis for forecasting, are the **PATTERNS** which these variables describe in space, considered either individually or together.

未填入天氣資料之天氣底圖，稱為「白地圖」，圖上有經緯度，海岸線，河川，湖泊，及測站等。平面圖是由地球之球面投影到平面上而成。其時間（ 年 月 日）以格陵威治（東經0度）時間(GMT 或 Z)為準，現在又稱環球時間(UTC, Universal Time Coordinate)；亦可用地方標準時(Local Standard Time)，台灣在東經120度，比東經0度 (00Z) 早了八小時 (08L)。

2) 若 x and y = constant，只 Z 變化，則為探空圖（the sounding charts）；包括風向圖(the hodograph diagram)，風向隨高度的變化及熱力圖（the thermodynamic diagrams）。 熱力圖不只描繪各變數隨高度變化情形，也代表大氣之流體靜力穩定度等特性。一張完整的熱力圖包括五組線：溫度、壓力、乾絕熱、假（溼）絕熱、及飽和水氣線。

3) 若僅x (或y)固定，而y-z (或x-z)變化，則為垂直剖面圖（the cross-section charts）；常用

的有天氣剖面（synoptic cross section）及航線剖面圖（route cross section）

時間剖面（time sections）

4) 若隨時間變化，如 X-t (longitude-time or Hovmöller diagram),
Y-t (latitude-time diagram), and
Z-t (探空之時間序列圖)

* The Z-t chart is particularly useful for analysis in regions of spare data where a great deal of emphasis must be placed on the weather history at one station to determine the synoptic analysis in the vicinity.

5) 只有時間變化，如測站之壓力變化曲線（barograph chart, P-t)及溫度變化曲線(thermograph chart, T-t)等。

B. 地圖之投影法

(Ref.: Saucier, 1955: Principles of Meteorological Analysis.)

地球為一球形，但天氣圖是一平面圖，所以要想辦法將球面上之地圖投影到平面上，此即地圖之投影法。其方法有多種，氣象上常用之投影法有下列三種（均為conformal projection，保角投影）：

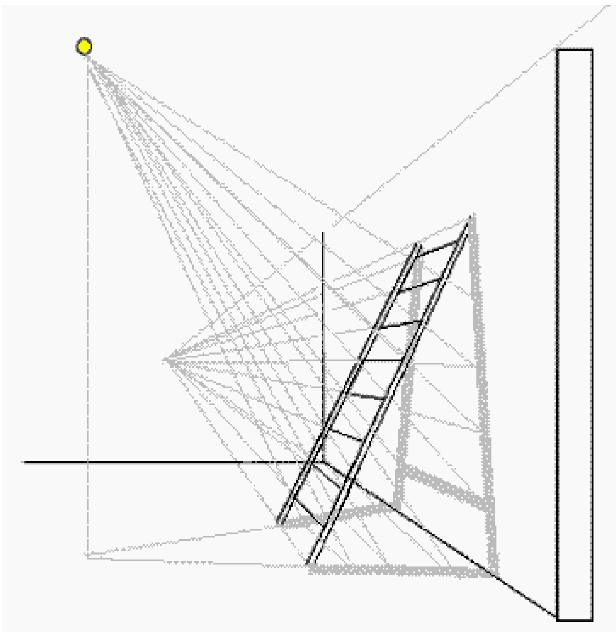
1) Polar stereographic projection – 半球與高緯度通用（切在60N or 60S）
2) Lambert conformal conic projection –中緯度通用(切在30 and 60N; or 10 and 30S)
3) Mercator projector (cyclindric projection) – 低緯度適用（切在 23.5度）

* Three-step processes of map-making

   1. projected upon fictitious geometric surface---image surface (投影，要確定燈光位置)
   2. flatting the image surface into a plane surface (擺平)
   3. reduced in scale to a size as desired (縮圖)

* Principal properties of map projections are:

   1. Areas are exactly comparable anywhere on the map -- equal-area .
   2. Correspondence between angles on the map and angles on the earth: **conformal**, isogonal, or orthomorphic maps.
      Conformality is also defined by equality of scale in all directions about a point, thus preserving the **shapes** of small geographical features at the expense of varying the area and scale over the map.
   3. Conservation of azimuths or bearings from the center of the map to any other point.
   4. Straight rhumb lines (羅盤方位線)
   5. Straight great circles (e.g., polar gnomonic projection,燈光在球心，日晷投影法)



跟畫透視圖一樣，要確定燈光的位置。

* Desire properties on each element of projected surface

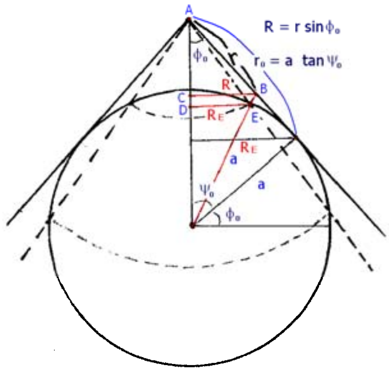
  1. Correct shape and area
  2. Correct scale
  3. True direction and azimuths (方位角)
  4. Shortest distance between two points (the great circles)

* For climatic charts conservation of areas is often required, but that property is of secondary importance for meteorological charts. We are primarily concerned with representation of atmospheric patterns, necessitating preservation of true angles and shapes as far as possible, and , consequently, conformal projections are recommended.

Conic conformal projection satisfies 2. and 3.

  1. Tangent projection (相切)

  2. Secant projection (相割)



* σ (image scale) = L_I / L_E = (distance on image) / (distance on earth)
  σ = 1: standard latitude, right on the tangent (or secant) point(s)
  > 1: outside the earth (cone)
  < 1: inside the earth (only secant projection) (cone) $\sigma_\phi = \frac{\mathcal{L}}{\mathcal{L}_E}$ (緯度圈上), $\sigma_\lambda = \frac{dr}{dr_E}$ (經度圈上)

* m (map scale) = L_M / L_E @ standard latitude = constance (i.e. 地圖之比例尺)
  = (distance on map) / (distance on earth) = the reduction scale.

* S (actual map scale) = m σ = (L_M / L_E) * (L_I / L_E)
  S is the linear error of the map and the areal error of the map is S^2.

* n = the constant of the cone = cos ψ_0 = sin ϕ_0

東西方向上之距離

$L_E = 2\pi R_E$, $R_E = a\cos\phi = a\sin\psi$ = the radius of a lat. circle on the earth.

$L = 2n\pi r = 2\pi R$, R = 圓錐上之半徑 $= r\cos\psi_0 = rn$; r = the radius of an arc of lat. on the image sfc.; $R = r\cos\psi_0$

∴ the scale along a circle of lat. $\sigma_\phi = \frac{L}{L_E} = \frac{2n\pi r}{2\pi R_E} = \frac{nr}{R_E} = \frac{R\ (\text{圓錐上半徑})}{R_E}$

$$\sigma_\phi = \frac{nr}{a\cos\phi} = \frac{nr}{a\sin\psi}$$

∴ at the std. lat. ϕ_0, $\sigma_\phi = 1 = \frac{n\,a\tan\psi_0}{a\sin\psi_0} = \frac{n}{\cos\psi_0} \Rightarrow n = \cos\psi_0$.
$r_0 = a\tan\psi_0$

4

南北方向上之距離

Along a meridian an increment of arc on the earth is given by 3.

$$dr_E = a\,d\psi$$

On the image sfc. $dr = \sigma_\lambda\, dr_E = \sigma_\lambda\, a\, d\psi$, λ denotes const. longitude.

∵ $\sigma_\lambda = \sigma_\phi$ in conformal projection.

$$\therefore\ dr = \sigma_\phi\, a\, d\psi = \frac{n r \csc\psi}{a}\, a\, d\psi$$

$$\Rightarrow \boxed{\frac{dr}{r} = n \csc\psi\, d\psi = \underline{\cos\psi_0 \csc\psi\, d\psi}}.$$

$$\therefore \begin{cases} r = a \tan\psi_0 \left[\dfrac{\tan\frac{\psi}{2}}{\tan\frac{\psi_0}{2}}\right]^{\cos\psi_0} & \text{: the image radius of any lat. circle.} \\ \sigma = \sin\psi_0 \csc\psi \left[\dfrac{\tan\frac{\psi}{2}}{\tan\frac{\psi_0}{2}}\right]^{\cos\psi_0} & \text{: for Lambert projection} \end{cases}$$

* The angular spacing of unit meridians on the map is n compass degrees about the pole. ∴ For the 45° std. lat., the spacing unit meridians is $n = \cos 45° = 0.707$ compass degrees.

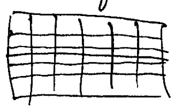
∴ 绕一纬度圈 $= 360n = 254.5°$

* 一般 Lambert proj. 之光源在球心。但例外的是 polar stereographic proj. 要在 s.p.; 若光仍在球心, 则称为 polar gnomonic proj. (日晷投影) — 图上之直线均为大圆弧, 而赤道在 ∞ 远处。

特例

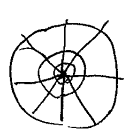
① Mercator proj. (Cylinder proj).: for the std. parallel is at equator.

$$\psi_0 = 90°,\ n = 0 \Rightarrow \begin{cases} r = \infty \\ \sigma = \csc\psi \end{cases}$$



其经、纬度均为直线, 而間隔随纬度增加而增大, 赤道 1, N.P. ∞.

② For polar stereographic proj., $\psi_0 = 0$, $n = 1$



$$\begin{cases} r = 2a \tan\frac{\psi}{2} \\ \sigma = \dfrac{2}{(1+\cos\psi)} = \dfrac{2}{1+\sin\phi} \end{cases}$$.#

(間隔 N.P.=1, 随纬度减少而增大)

5 ~~4~~

* The International Meteorological Organization recommends use of the so-called <u>secant</u> projection instead of tangent proj.

$\therefore \frac{dr}{r} = n \csc\psi \, d\psi$

$$\Rightarrow r = \frac{a}{n} \sin\psi_1 \left[\frac{\tan\frac{\psi}{2}}{\tan\frac{\psi_1}{2}} \right]^n$$

$$= \frac{a}{n} \sin\psi_2 \left[\frac{\tan\frac{\psi}{2}}{\tan\frac{\psi_2}{2}} \right]^n , \quad \text{where } n = \frac{\log\sin\psi_1 - \log\sin\psi_2}{\log\tan\frac{\psi_1}{2} - \log\tan\frac{\psi_2}{2}}$$

$\therefore$ for $60°, 30°$, $n = \underline{0.716}$.

and $$\sigma = \frac{\sin\psi_1}{\sin\psi} \left[\frac{\tan\frac{\psi}{2}}{\tan\frac{\psi_1}{2}} \right]^n$$

$$= \frac{\sin\psi_2}{\sin\psi} \left[\frac{\tan\frac{\psi}{2}}{\tan\frac{\psi_2}{2}} \right]^n .$$

$\therefore$ ① For Mercator (cylinder) proj.

$n = 0$, $r = \infty$, $\sigma = \sin\psi_1 \csc\psi$

It is unity at the std. parallel, less than 1 between std. parallels, greater than 1 where $\phi > \phi_1$, and infinite at the poles.

② For polar stereographic, $n = 1$ with std. parallel ϕ_0.

$$\begin{cases} r = a(1 + \cos\psi_0) \tan\frac{\psi}{2} \\ \sigma = \dfrac{1 + \cos\psi_0}{1 + \cos\psi} = \dfrac{1 + \sin\phi_0}{1 + \sin\phi} . \end{cases}$$

The recommended std. parallels for the Lambert proj are $30°$ and $60°$ in the N.H. and $10°$ and $40°$ in S.H..

* 在 Mercator proj. 中 $r = \infty$, ∴ 無法由 pole 來求距離, ∴ 反向由赤道來求.

$\therefore$ along a meridian $ds_E = a\,d\phi$, $ds = \sigma_\lambda ds_E$

$dL_E = a\cos\phi \, d\lambda$, $dL = a\cos\phi_1 d\lambda$

$\Rightarrow ds = a\cos\phi_1 \sec\phi \, d\phi$

$\Rightarrow s = a\cos\phi_1 \ln\left[\tan\left(\frac{\pi}{4} + \frac{\phi}{2}\right)\right]$: image distance along meridians, measured from the equator.

6.

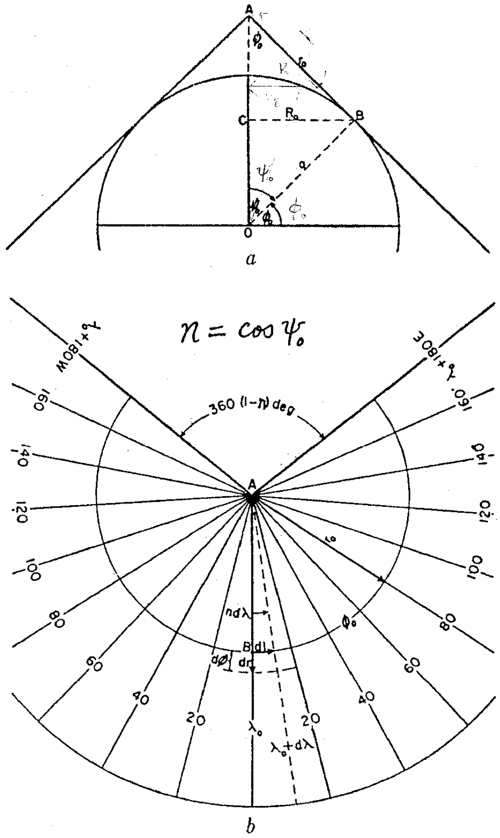


FIG. 2.111.—Scheme of the conic polar projection (tangent cone).

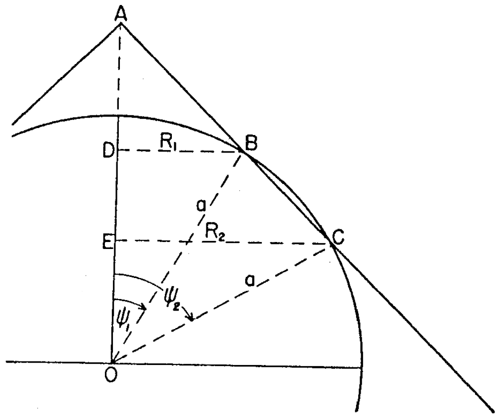
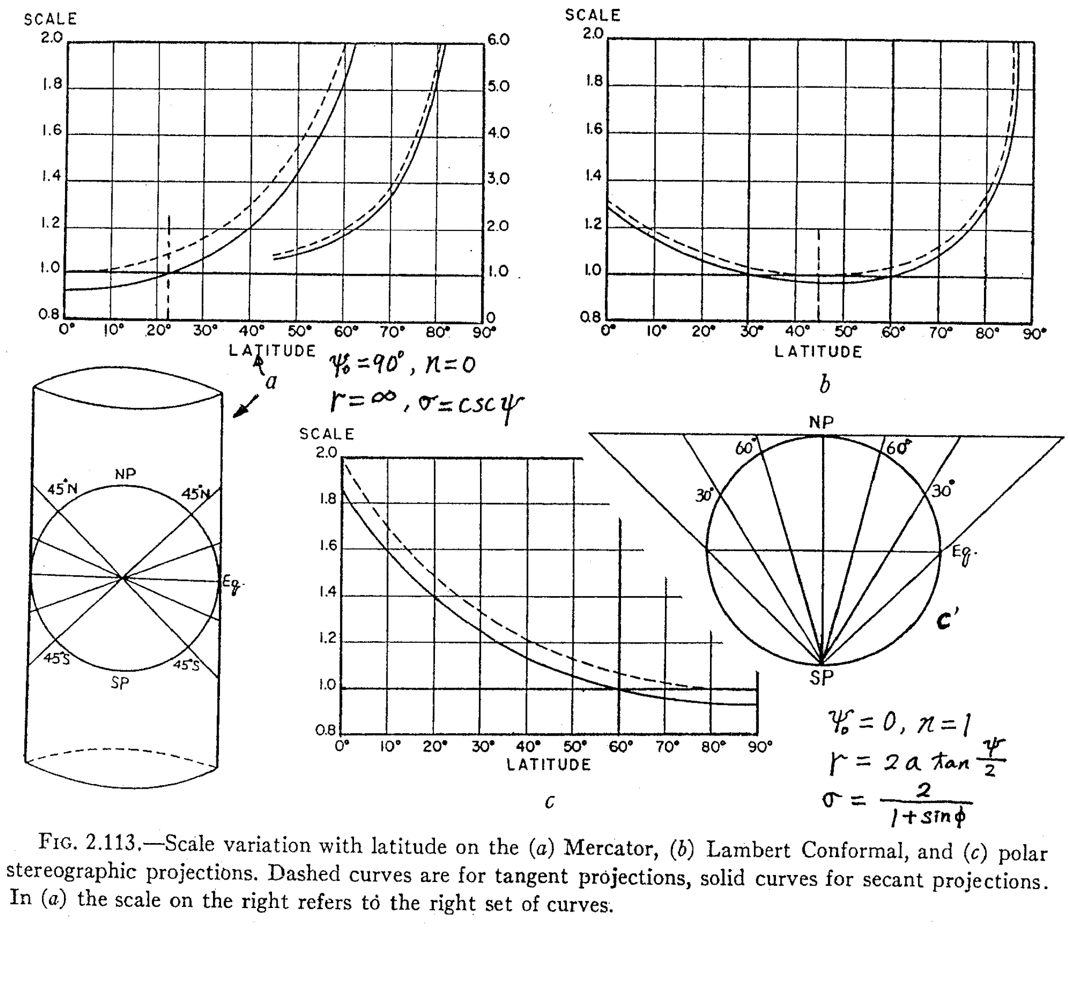


FIG. 2.112.—Scheme for conic polar projection (secant cone).

$$r = a \tan\psi_0 \left[\frac{\tan\frac{\psi}{2}}{\tan\frac{\psi_0}{2}}\right]^{\cos\psi_0}$$

$$\sigma = \sin\psi_0 \csc\psi \left[\frac{\tan\frac{\psi}{2}}{\tan\frac{\psi_0}{2}}\right]^{\cos\psi_0}$$



$\psi_0 = 90^\circ,\ n = 0$

$r = \infty,\ \sigma = \csc\psi$

$\psi_0 = 0,\ n = 1$

$r = 2a \tan\frac{\psi}{2}$

$\sigma = \frac{2}{1+\sin\phi}$

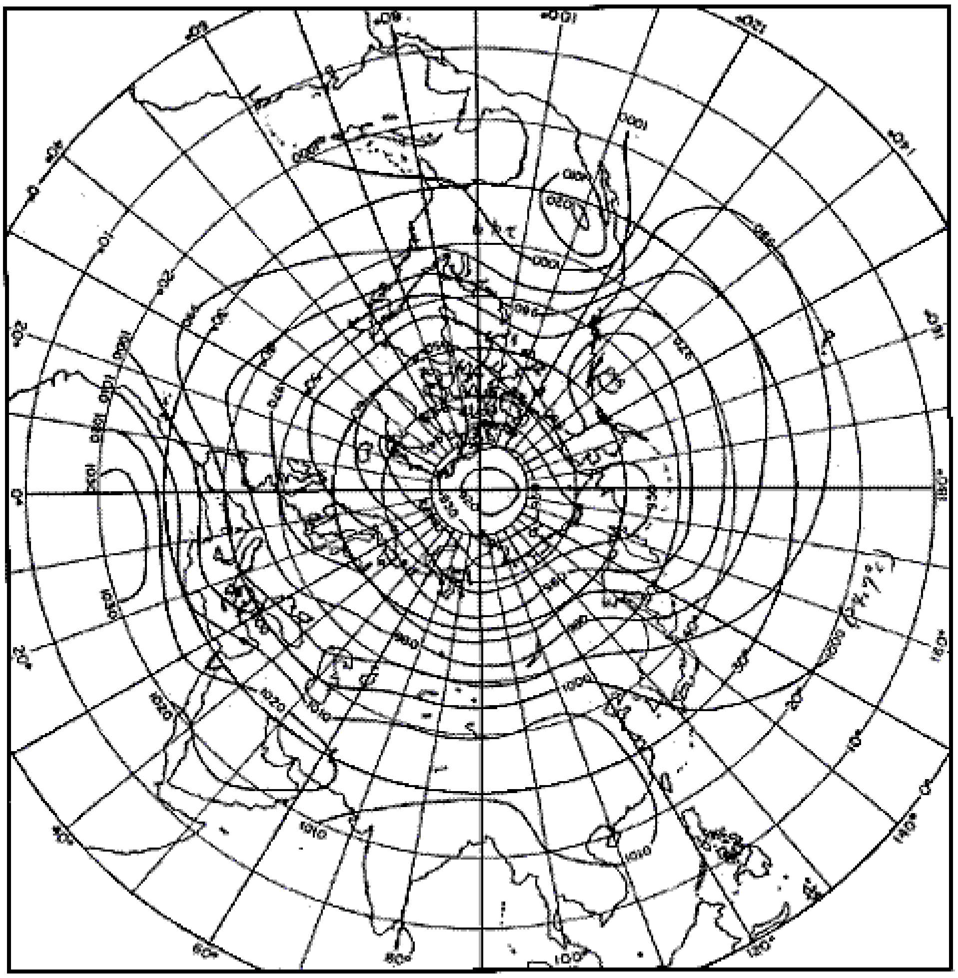
FIG. 2.113.—Scale variation with latitude on the (a) Mercator, (b) Lambert Conformal, and (c) polar stereographic projections. Dashed curves are for tangent projections, solid curves for secant projections. In (a) the scale on the right refers to the right set of curves.

習題一、(a)試以流體靜力平衡假設導出兩層空氣間之厚度與其平均溫度之關係。

(b)下圖為七月份1000 hPa及700 hPa間之平均厚度圖，以10英尺為單位。試求出每條等厚度線之對應溫度(°C)值？並算出每100英尺厚度間隔相當於幾°C，及每10m厚度相當於幾°C？

(c)試沿著30°N，討論其厚度值大小的原因，即其動力特性為何？

（註： 1 m = 3.28 ft;　Rd = 287　J/K/Kg　）　　　　Due:　1　week

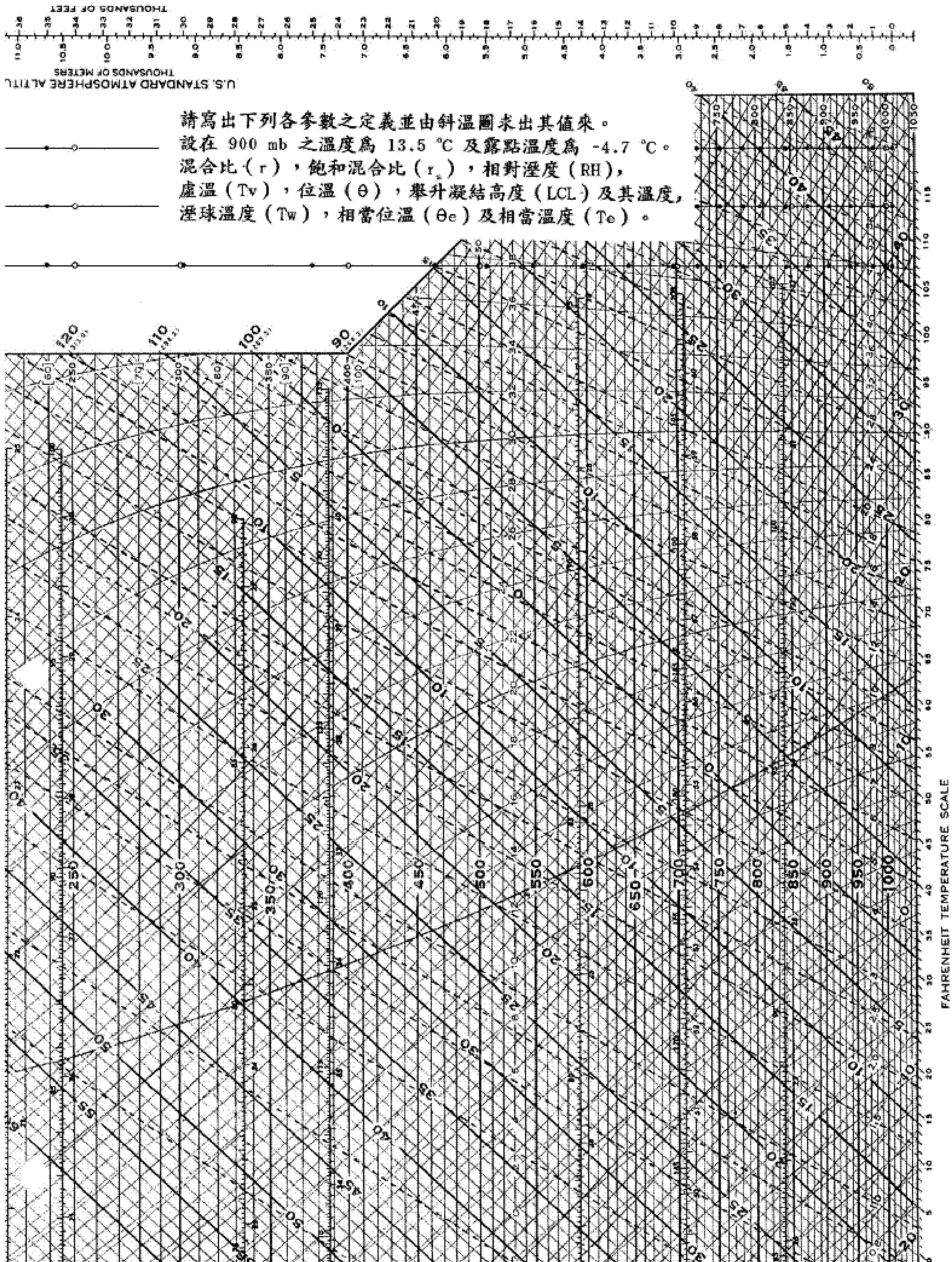


大動複習：

1. 尺度分析 （水平及垂直運動方程式）。
2. 垂直座標：等高、等壓、等位溫座標之優缺點。

習題二、斜溫圖之應用

請寫出下列各參數之定義並由斜溫圖求出其值來。
設在 900 mb 之溫度為 13.5 ℃ 及露點溫度為 -4.7 ℃。
混合比（r），飽和混合比（r_s），相對溼度（RH），
虛溫（Tv），位溫（θ），舉升凝結高度（LCL）及其溫度，
溼球溫度（Tw），相當位溫（θe）及相當溫度（Te）。



習題三、地圖投影之應用　　　(due　1　week)

有一東亞地區之地圖，其比例尺為1:5,000,000，此圖為Lambert投影，標準圓切在30°N(故圓錐角為30度)。試問在台灣附近120°E, 25°N之位置上，

(i)在地圖上一個經度為幾公分? 而在地球上應為幾公里？

(ii)在地圖上一個緯度為幾公分? 而在地球上應為幾公里？