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中國東部空氣團之分析

趙九章

A Preliminary Analysis of the air Masses Over Eastern China

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內容:

(一) 導言

溯自挪威氣象學者勃奇朗T. Bergeron氏發表其"三度因次之氣候分析"一文後,舉世響應,各國氣象學界,先後採其方法,爲各種空氣團之分析,冀將研究之結果,利用於氣候分析及天氣預報。數年以來經各國氣象學者之努力與研究,此種希冀,已漸趨於實現之途。美國麻省理工學院教授羅氏 (C. G. Rossby) 曾發表論文一篇:"熱力學對於氣團分析之應用"此文除根據勃氏之意見外,並由熱力學理論推演之結果,得一實際應用之分析法。最近韋烈脫(Dr Willet)教授之"美洲空氣團之性質"及 Byers 氏之"北太平洋之空氣團"兩文,皆採用此法。作者於此文內,亦擬採用羅氏之方法,將我國近兩年半內,在北平南京兩地所測得之高空記錄,加以整理分析。然爲時既暫,記錄又少,故僅能視爲初步之分析,精密之研究,尙須待諸異日材料充足時也。

作者自去歲考取清華美庚款留學公費生後,卽奉學校當局之命,來京氣象研究所,在竺藕舫先生指導之下從事於實習及初步之研究工作。到所後,承竺先生熱誠之指導與夫在所諸先生之幫助,使作者得以完成此項工作,作者謹願於此機會,致其誠摯之謝意。

中國氣團之類別,作者於整理北平南京兩地高空記錄之後,依照韋氏之分法,暫分爲下列三種:

(1)極圈大陸空氣團 (Pc)

(2)極圈太平洋空氣團 (Pp)

(3)熱帶海洋空氣團 (Tm)

中國位於亞洲之東南,因受季候風之影響,氣候之變化,在一年中,軒輊甚劇,空氣團之分佈,亦隨季候而不同,冬季西伯利亞高氣

壓正在强盛之時,其範圍有時竟達我國東南,此時風向多爲北及西北,故氣團之來源亦多由西伯利亞,此種氣團,卽所謂極圈大陸氣團是也。洎乎春夏之交,霪雨正盛行於江南,高氣壓復移植於日本北部,此時到達長江下游之氣團多爲極圈太平洋空氣團。至夏秋之間,西南風盛行,則我國華南一帶,幾爲 Tm 氣團佔領之時期矣。

(二)分析方法概述

夫空氣團者,乃一大集團之空氣而有平面之均勻性(Horizontal homogencity) 質者也。換言之,卽在同一氣團之內,各地等高水平面之溫度,濕度,等均相等。故一氣團之形成必有一發源地,此發源地面之氣候應極一致,而所佔區域之必須極廣,如加拿大與西伯利亞,均爲極圈大陸氣團之發源地,因兩地在冬季,地面均爲雪所掩蓋,地面氣候在此廣闊之平原內極爲一致,所受日光之輻射,各地亦復相等,外來氣團在此停留稍久,卽形成一大集團之空氣,在各等高水平面之氣象要素必極一致,此空氣團形成之過程也。

空氣團之形成,既如上述矣,故一氣團之特性,當其未離發源地時,可由發源地之氣候情形,推知其大概。但氣團因大氣之流動,經其發源地後,因其所經地面氣候之不同,遂生種種之改變,行程愈遠改變愈大,故常有在北方爲乾燥穩定之氣團,行抵南方時,竟一改而爲既濕且極不穩定者,亦有初爲不穩定之氣團,受地面之影響,又變爲極穩定者,變化既如此複雜,吾人欲僅就地面測得之溫度,濕度,等,窺測空氣團之來源與其變化之歷程,幾不可能,故不得不利用高空之探測之記錄,爲氣團分析之重要根據,蓋在高空方面,距地面已遠,地面氣候之影響極微,故空氣團尙可保存其發源地之特性也。

一空氣團之特性與類別,常可由幾種富有保守性之要素 (conservatism) 如垂直減溫率 (lapse rate) 透視率 (visibility), 濕度,溫度而定,但最富有保守性者,非爲以上所述之可以直接測定者,而爲間接計算出之位溫(Potential Temperature),與比濕(Specific Humidity) 二種。

比濕 W,又名混合率(Mixing Ratio),其定義爲在一千克之乾空氣內所含水氣之重量,按其定義,W 應由下列公式表之:

$$W=1000\frac{\rho w}{\rho d}$$

式內 ρw 爲水氣之密度,ρd 爲乾空氣之密度,但水氣與乾空氣在平常情形,均合於氣體公式。故

$$\left.\begin{array}{ll} \rho w=\frac{MdRT}{e} & e=em\times f \\ \rho d=\frac{MdRT}{Pd} & Pd=P-e \end{array}\right\} \therefore W=1000\frac{Mw}{Md}\ \frac{e}{Pd}=622\frac{e}{P}$$

式內 e 爲水氣在溫度 T 時之張力,等于 em (最大張力) × f (相對濕度), pd 爲乾空氣之部份壓力(Partial Pressure), P 爲大氣壓力。

在羅氏分析方法中,所採用之另一要素爲部份位溫, (Partial Potential Temperature), 其定義爲:在高層之乾燥空氣,經絕熱變化,由其部份壓力 Pd 壓縮至標準壓力1000 millibars 時所應有之溫度。按柏桑氏之公式。

$$\theta d = T\left(\frac{1000}{Pd}\right)^{.2884} \qquad (2)$$

羅氏圖表之構造。其橫坐標代表W,縱坐標代表 log θd,其斜線則爲等準位溫線 (Equivalent Potential Temperature), 所謂準位溫者,卽各層濕空氣,經絕熱變化,凝結其全部之水氣而遺棄之,然後縮至1000 mb 標準壓力時應有之溫度。此外尙有兩種斜線,則爲露點溫度與露點壓力線,均爲圖 A 所示。

自公式 (1) 及 (2), 在地面及 500m, 100m, 1500m, … 等處,由高空所測得之記錄,計算 W 及 θ_d, 然後作點於羅氏圖表之上,此種點名爲

屬性點(Characteristic Point),聯各點爲一曲線,此曲線曰屬性曲線(Charcteristic Curve)由屬性曲線形狀之不同,而有下列之特性:

(1)如屬性曲線之坡度(Slope)爲負時,卽表明θ_d, θ_e同時因高度增加而遞減,則此氣團即在絕對不穩定狀態之中;一地空氣團有此性質時,則天氣必有劇變。

(2)如屬性曲線之坡度爲正,但較小於等位溫線之坡度時,卽θ_e因高度增加而減少,此種氣團,在對流性不穩定狀態之中(Convective Unstable Condition),如一經擡高,或由於高山之斜坡,或由於冷空氣之斜楔面(Cold wedge)則卽變爲絕對不穩定狀態。

(3)如屬性曲線坡度爲正且較準位溫線坡度爲大時,則θ_e與θ_d同時與高度俱增,則氣團絕對穩定狀態之中。(Absolute Stability)

(4)如屬性曲線中間之一段其比濕與高度俱增,而達於最大值時,復因高度增加而遞減,則表明此次所得記錄,已穿過一斷面。

(5)如屬性點密集一處,卽表明此氣團有上下均勻之性質,如屬性點疎散,則表示氣團各層之分別較大。

以上五則,係依羅氏原文,至其原理之根據其引證之步驟,因非本文範圍,故不詳述,作者當於異日,再爲文詳細介紹也。

(三)應用之材料與材料之整理

本文所引用之材料,共有五種:

(1)在南京用飛機測得之高空記錄。

(2)在北平用風箏測得之高空記錄。

(3)平京兩地測風氣球之記錄。

(4)氣象研究所刊佈之東亞天氣圖。

(5)氣象研究所刊佈之氣象月刊。

就中以(1),(2)兩種爲本文之基本材料,南京飛機之探測始民國二十一年七月,在過去兩年半中,共得有六十餘記錄,其中之二

十二記錄,已刊載於該所"高層氣流"第四卷。風箏之測取。高空記錄,則開始於同年九月,由清華大學氣象臺主任黃廈千先生主其事,去年七月黃先生赴美留學,故此項工作,暫告停頓,在此時期中,共得七十餘記錄,大部已載於上述刊物內,至所用儀器,在南京者,則爲一Flugmeteograph,在北平者爲Bosch氏之Meteorograph。所記之要素爲壓力,溫度,相對濕度與風速,在南京方面,因飛機本身亦有其速率,故風速一項所記者,爲飛機對於風之相對速率,而非真心之風速,故此項記錄,不予採用,但每日由測風氣球測得之風向與風速,可以借用,雖測取時間不甚一律,然相差尚不甚遠也。

至材料之整理與計算已述於上節中矣,茲不贅述。一屬性曲線既作成之後,首先工作卽爲確定此屬性因屬於何種空氣團,如氣團分析已有相當歷史,各種氣團之特性已經熟稔,卽可由屬性曲線本身之形狀地位,斷定其類別但此項分析工作,在我國尚在萌芽之期,故必須利用天氣圖及風向以爲鑑別之根據,試舉一例,如民國二十三年四月一號之飛機記錄(在第一表內第4頁),其最後兩行之風向與風速均取自當日由7時47分起測得之測風氣球記錄,是日開始飛行之時爲8:50,距測風球起飛之時,相差不過一小時零三分,故兩種記錄尚可合併應用。在飛行記錄中,自1000 m至2900 m,W之變化甚爲迅速,同時風向與風速變更亦極迅疾故由此可推知其爲兩種氣團,其移動於其他之上,同日六時之東亞天氣圖,一高氣壓正在華北,其中心約在山東省境內,此反旋風之流動,在下層將北太平洋空氣吸入,在高層則將我國西北之空氣旋入,又在第一圖中,(第一圖第16頁),屬性曲線在1.5km高度以下坡度甚小,過1.5km以上,則突見增加,此又足證明其代表兩氣團,其來自北太平洋者爲Pp一類,來自西北方者,則爲Pc一類。準此分析方法,作者曾將南京及北平之高空記錄,加以審慎之分析,每一次記錄均予以分類,如在一地某一氣團之記錄有相當次數時,

卽作一平均記錄,及平均屬性曲線,庶由此平均曲線可得稍正確之結果。

(四)極圈大陸空氣團

a, 冬季

極圈大陸空氣團導源於西伯利亞之北部,該處冬季,常爲深厚之冰雪所掩蓋,溫度旣低,濕度亦極微少,同時又爲高氣壓之領域,其勢力有時且伸達於長江下流,故在冬季,西北季候風盛行,南來之海洋氣團極難蓹止華北,卽華中華東亦莫不受其控制,故我國冬季東南及華北之氣候,均受有Pc氣團之影響。吾人自Pc之發源地,可推斷此Pc氣團之特性約有二端:

(1)溫度較低,比濕較小

(2)因氣團下層與地面寒冷之冰雪接觸,而稍高則高層氣流不受地面影響,故溫度反與高度俱增,而成爲逆溫層(Inversion level),氣團在此上熱下冷情形中,遂益穩定。

所惜我國北部僅在北平一處測取高空記錄而Pc氣團到達此平時,已經過西此之高山,遂因機械的渦動(Mechanical Turbulance 而成一團極均勻之空氣,故在北平冬季所測得之記錄中,逆溫層現象極少發現,而羅氏圖表上,屬性點多集一處,是可知已非純正之Pc氣團矣。按 Dr. Willet 氏之分法,應稱爲變性之Pc氣團,其符號爲Npc, 茲將過夫三冬在北平所測得之十三個 Npc 氣團記錄,得一平均,列於第二表(第 6 頁)。至關於北平氣團之詳細研究,黃廈千(現在美國加州理工學院)先生將有論文發表,茲不詳細討論。

在南京區域內,尤其當冬季天氣晴明,風向西北之日,氣團多爲Npc 一類。Pc氣團自西伯利亞經華北以達江南時,因經過各地,地面之溫度濕度均較Pc之發源地爲高,故到達南京時,溫度濕度已相當增高,此種氣團如按 T. Bergeron 氏之分法,應爲 cPK (在冬季),

茲將此種氣團在南京之平均記錄,列於第三表(第 6 頁),其屬性曲線則與北平者同如第二圖(第16頁),讀者觀此,對於 Npc 之特性,可以得一概念矣。由表三吾人可知減溫率在地面至五百米突內爲 −11.6, 是已較絕熱減溫率爲大 (Dry adiabatic lapse rate),同時 $d\theta_e/dH$ 爲負,故在500 m以下,正適合第二章第二條之條件,故在對流性不穩定狀態之中,此則因Pc之透視率甚大,在其經過之時,日光之輻射,大部地面吸收,故地面溫度較高,因之Pc氣團下層遂漸爲地面所炙熱,而成爲對流。但此種特性,不再向高繼續,蓋自500 m 以上,$d\theta_d/dH$ 與 $d\theta_e/dH$ 同爲正,已入於絕對穩定狀態之中矣。

b. 夏季

在夏季西伯利亞之冰雪已全溶化,長夏日永,受日光之曝曬,地面溫度,遂較高於高空,夏季 Pc 氣團已非如冬季之下冷而上熱,且一變爲上冷下熱,故常在不穩定狀態之中,所惜江南華北在夏季受西南季候風之控制,Pc氣團之記錄,測得不多,未能得較可靠之平均值,但在去年六月十二平京兩地之高空記錄,亦可舉爲代表,其記錄見第四表(第 7 頁),與第五表(第 8 頁),其屬性曲線,則同作於第三圖(第 17 頁),讀者於此,可發現夏冬兩季之 Npc 氣團之根本不同之點矣。在在下層兩地之屬性曲線的顯示其絕對不穩定之性質。兩地所測之時間,相差尙不遠,故兩地之記錄,似屬同一氣團,由此更可知 Npc 氣團自北平至南京途中所改變之情形。在南京記錄中,各500m 層之溫度均高於北平記錄,是能吾人所預料者。但比濕在南京反較低,此或因一部份之水分在進抵南京途中已凝結沉降,蓋查是日之天氣圖,華北華中均爲一羣低氣壓所佔領也。但無論如何改變,當其到達南京時,仍保留其低層之不穩定性質,是亦夏季極圈大陸氣團之一特性;在六月十二北平探測高空記錄時,陣雨常常發生,足徵其不穩定程度已臻極頂矣。

(五)極圈太平洋空氣團

a, 冬季

極圈太平洋空氣團發源於太平洋之西北,隣近日本北海道之東及白令海,其發源地之特性,頗類似極圈大陸氣團發源地西伯利亞。在冬季,白令海常結深厚之冰塊故此種氣團在其發源之性質,亦爲溫度低而比濕小。惟當其離開發源地,而移動於溫暖之海面以上,其低層受溫暖海面之炙熱,溫度漸增,而高層仍保持其固有之低溫,於是上冷下熱,低層遂在絕對不穩定狀態之中。溫度旣高比濕亦增,故到達長江下流時,常在不穩定狀態中降連綿雨,此種氣團按Dr. Willet之分法應爲Npp 而按T. Bergeron 氏之分類則在冬季應爲 mPW, 在夏季應爲 mPK。

在中國探測氣球雖已試用,但氣球一去,永無回音,故此種探測方法, 目下尙未達實行時期。當天雨之時, 飛機旣不能飛行. 氣球又未能應用, 故在 Npp 氣團到達南京時, 因多雨之故, 記錄甚少, 不能得一平均記錄爲討論之根據,卽求一次足以代表者,亦屬無有,蓋當 Npp 氣故到達南京時,其上層常爲Pc氣團所驅排。第三節中所擧之例(民國二十三年四月一日), 卽此種記錄之一也。但其低層之性質,尙可於此種記錄窺測一二,如二十二年十二月五日南京之飛行記錄(列在第六表,第 9 頁)是日適無測風氣球記錄,但是日天氣圖,西伯利亞高氣壓之中心已移至內蒙古與滿洲之交界。在西北太平洋及日本之北部又有一低氣壓。故按照旋風與反旋風之轉動,吾人可推斷到達南京之氣團應爲 Npp 一類,此由天氣圖上各氣候站之風向尤易證明。由此記錄之屬性曲線,第四圖(第 17 頁)其低層自500m以下,在對流性不穩定狀態之中,過此至 1500m, 則坡度稍大,已爲絕對穩定性質,再上坡度幾等於零,屬是溫率正等于絕熱變化減溫率矣(Dry Adiabatic Lapse Rate)。在

2000m至3000m 之間,比濕有一最大值,按第二節所述,此應代表一極面,其上則爲pc氣團所佔領。如吾人將此記錄與上節之南京Npc氣團平均記錄相比較,吾人易知 Npp 氣團之比濕,溫度,準位溫均較高於NPc 氣團,但在 3000m 以上,則情形一變。兩記錄中之溫度極相接近,是又可證明此氣團之上爲Pc氣團矣。

此外一例,爲民國三十四年二月十八日之飛行,(記錄暫略), 其屬性曲線則同作於第四圖,在此兩次飛行記錄,雖有差異之處,但其中有一共同之點,卽其上層均爲Pc氣團所佔領也。因Pc氣團較冷,上冷下暖,故到達中國海岸,均在不穩定狀態中矣。

b. 夏季

在春夏之交,霉雨期內之Npp 氣團,可以二十三年五月二十五日作一代表,其記錄列於第七表,其低層之絕對不穩定性質,極易由其屬性曲線(第四圖)窺出。是日,高層氣流之風向,自地面至3500 m 均爲東比,過 3500 m 則突變爲西北,故其高層亦爲Pc氣團,查是日之天氣圖,高氣壓之中心在中國中部,低氣壓之中心,則在日本之北,故空氣之旋動,適將西北太洋平之氣團吸入於我國領域,是爲 Npp 一類無疑,惟此時低層之不穩定性質,非由於高層之Pc氣團,因在夏季Pc氣團之溫度當較高於Pp氣團之溫度也。在春夏之交,Pp氣團較冷於地面,故其低層之減溫率常超過絕熱變化減溫率,如二十三年五月二十五日,卽爲一例,故氣團遂有絕對不穩定之性質矣。

總上所述, Npp氣團對於長江下流之雨量,有極大關係,尤其在霉雨期中,風向多自東北,亦一確切之根據,惟是否卽爲主要原因,在材料尙未充足之今日,尙不敢驟予斷定,蓋照昔日對霉雨之解釋,謂爲熱面之停留於長江下流,此熱面之形成,爲東北冷空氣團與西南熱空氣團相遇,熱空氣循冷空氣尖楔面上升,體積澎張,溫度減低,至凝結層時,遂將水分凝成雨珠下降,是說亦有其理論與

事實之根據,作者對此問題,甚願於異日材料稍多之時,再爲研究也。

(六)熱帶海洋空氣團

a, 冬季

冬季西北風盛行於我國,故南京來之 Tm 氣團,甚難到達南京一帶,故其對於冬季長江下流之氣候無甚重大關係,去年三月十八日在南京之飛行記錄(第八表第12頁)可舉爲代表,其低層之絕對穩定狀態爲與夏季之 Tm 根本不同之點。蓋當冬令,海洋溫度較高於大陸地面,故當其北來時,低部與地面接觸,較冷於上層,此種氣團,按下 Bergeron 氏之類别,應爲 mTW, 而到達南京時,絕對不能致雨,此與Npp 氣適相反也。

b. 夏季

夏季西南風盛行, Tm 氣團影響於我國氣候者至巨,當六月之末至九月初旬,我國東部莫不在 Tm 氣團控制之下。因其發源地遠在爪哇島及赤道,當其到達長江下流時,已經過長距離之海面,故其溫度與比濕均較他種氣團爲高大,在第九表中(第13頁),作者將去年六月至八間之十三個 Tm 氣團記錄,得一平均值,其屬則性曲線,作於第六圖。

自 500m 以上, $d\theta_e/dH$ 均爲負數, $d\theta_d/dH$ 爲正,故 Tm 氣團在對流性不穩定狀態之中,此種性質,繼續至 4000m 高度。此種氣團。雖挾有大量之水分,但本身未在絕對不穩定狀態之中,必須經高山之斜坡,或冷空氣斜楔面之擡高,方能降雨,應擡高之高度,可用Babinet 氏公式

$$Z=1600[1+2(to+t)/1000]\frac{Bo-B}{Bo+B}$$

計算之,式中 Bo, to 爲凝結層 (Condensation's level) 之壓力與溫度,

B, t, 則爲地面之壓力與溫度,Bo與to之數值可於羅氏圖中求出之,其值爲 22°C 與 890mb, 代入上式,則得 Z=1180meters

夏季西南風强盛,北方之冷空氣不能到達南方,極面遂移植於華北,故北方在夏季常多雨量,而在西南各省,因高山環列, Tm 氣團經擡高後,亦常多雨。

如以南京之夏季Tm 氣團與美國者相較,作者覺美國Due West 城之 Tm 氣團記錄,與南京者甚爲接近,(見第10表與第9表,第13, 14頁)此或因 Due. West 城與南京所處緯度甚近,而地理的環境亦甚相彷也。

在北平之 Tm 氣團記錄,作者僅舉去年六月二十三日之記錄(第十一表第14頁),以爲比較,其屬性曲線則附於第六圖,其低層1000m, 在絕對不穩定狀態之中, 1000m 以上,則入於對流性不穩定狀態,準位溫 θ_e 則在 315 與 323 之間,較南京稍低,W 之數值,亦較南京爲小,此則或因 Tm 氣團經過華中一帶高山,因擡高而降落一部份之水是也。此種氣團到達北平時,亦可稱爲Ntm。

(七) 結論

高空氣象要素之測取,在我國僅有兩年半之歷史,且祇有北平與南京二處,過去兩年半之材料,尙未足爲得確定結果之根據;中國氣團之分析工作,尙須繼續進行,測量地點必須增加,測量時間,亦須規定,過去測取之時刻,多未能按日均有,或一週一次,或一月祇有一二次,故極難知一地逐日氣團之變化與氣候之關係;同時地點太少,如北平以北,南京之南,均無記錄,前者爲Pc氣團距發源地較近之區,設有高空之探測則吾人對Pc氣團之特性,更可得一較有根據之結論;後者爲 Tm 控制之區域,如兩廣及西南各省,吾人可預料其全年均爲 Tm 氣團所佔領,設於兩廣有一高空測候站,則 Tm 一年中之變化亦可以詳細研究,最近航空學校當局

頗有先在杭州開始逐日探測高空氣象要素之議,且擬推行於洛陽南昌各處,此則作者所引領而望者也。

在本文中所論之氣團之特性,須有精密之改正,但亦可藉以窺其概況,及其於我國氣候之關係,此或於(Synoptic Meteorology)不無小補也。

A PRELIMINARY ANALYSIS OF THE AIR MASSES OVER EASTERN CHINA.

By Jaw Jeou-jang

A PRELIMINARY ANALYSIS OF THE AIR MASSES OVER EASTERN CHINA.

CONTENTS:

1. INTRODUCTION

Since T. Bergeron, the Norwigan meteorologist, published his famous paper: "Über die Dreidimensional Verknüpfende Wetter-analyse.", the meteorological circles of the world have soon adopted his method to investigate the characteristic properties of the principal air mass types with the object of rendering some assistance to the diagnosis in synoptic meteorology and forecasting. During the past several years, and under the successive investigation of various meteorologists of the world, this hope seems to have been realized. Prof. C. G. Rossby of Massachusetts Institute of Techology, has recently published a paper: "Thermodynamics Applied To Air Mass Analysis." in which he, following the ideas of T. Bergeron, has proposed a practical means for the analysis. Dr.Willet's paper: "American Air Mass Properties." and more recently, Byer's "The Air Masses of North Pacific" all followed his method of attack. In the present paper, the author will endeavor to apply this same method for a preliminary analysis of the air masses that invade the Chinese territory.

The author, as a fellow of Tsing Hau University in preparation for a course of further study in aeronautical meteorology abroad, was ordered by the University to do some resarch work at the National Resarch Institute of Meteorology, Nanking, under the directorship of Dr. Co-Ching Chu. By his valuable suggestions, and the kind assistance of the members of the Institute, the author was able to complete a preliminary study of the aerological data of Nanking and Peiping, part of which is still unpublished. To them the author wishes to take this opportunity to express his thanks.

The air masses that invade China, according to Dr. Willet's notation, are clsasfied as:

1. Polar Continental Air Mass (Pc).
2. Polar Pacific „ „ (Pp).
3. Tropical Maritime „ „ (Tm).

Since China occupies the entirely south-eastern part of Asian continent where monsoon winds are well developed, the weather condition varies much with the seasons. In the winter half year, the Siberian high extends its domain to the northwestern part of China, the wind directions over all China are always northerly, so that the air masses are mostly of the Pc type. During the spring, particularly, in the rainy season of the later part of spring, when a high has developed at the north of Japan, the air masses that reach the lower Yangtze valley are to a large extent of the Pp type. During the summer time, the winds come mostly from the south so at this time of year Tm air mass prevails.

3. THE MATERIALS USED.

The materials used in this paper are:

1. The aeroplane sounding data of Nanking.
2. The kite flight data of Tsing Hua University, Peiping.
3. Pilot balloon data of Nanking and Peiping.
4. Monthly Meteorological Bulletin of the National Research Institute of Meteorology. (N. R. I. M.)
5. Daily weather charts of Eastern A519 (N. R. I. M.).

Among which, the first two are the basic materials used in the study. The aeroplane sounding of Nanking started in July 1932, and during the past two years and half more than 60 ascents were made, among which 22 of them have been published in the "Bulletin of the Upper Air Current" Vol. 4. The kite sounding began in the month of

September of the same year in Tsing Hua University, Peiping, and was temporaily suspended in July 1934. During this period there were 76 ascents, and 58 of them have been published in the same Bulletin. The instrument used in aeroplane ascents of Nanking is a Flugmeteograph of R. Fuess make, while meteorographs of Bosch and Bosch construction are used in kiteflight in Tsing Hua University. Owing to the movement of the aeroplane, the wind velocity data are not reliable, hence in order to determine wind direction and velocity at different levels during the time of aeroplane ascents, the pilot balloon data are used. Although the ascensions were not in general at the same time, yet the interval between the two ascents is not great.

3. TREATMENT OF THE MATERIALS

For the treatment of the materials, formulae of Rossby are used, they are:

$$p_d = P - e, \text{ where } e = e_m f. \tag{1}$$

$$W = \frac{m_w}{m_d} \cdot \frac{e}{p_d} \times 1000 = 622 \frac{e}{p} \tag{2}$$

$$\Theta_d = T \left(\frac{1000}{pd} \right)^{\cdot 2884} \tag{3}$$

$$\Theta_E = \Theta_d \, e^{\frac{L_{o\omega}}{Cp\,To}} \tag{4}$$

in which W is the Mixing ratio, expressed in terms of numbers of grams of water vapor in 1000 grams of dry air; e_m the maximun water vapor pressure of dry air. The notation Θ_d, appeared in the formula 3, is called the partial potential temperature which is defined as the temperature the air element would have if it is compressed adiabatically from the pressure Pd to 1000mb. The formula 4 gives an another term, Θ_E, the equivalent potential temperature, is defined as the temperature of the air element would have if it is compressed pseudo-adiabatically to 1000mb. and L_0, the heat of codensation, is taken at the temperature T_0 which is the temperature at the condensation level.

The process of evaluation is firstly to obtain the value e_m for the temperature T from water vapor pressure table, thence substitute it in (1) and (2) to obtain Pd and W, and finally from (3) the value Θ_d is calculated. This same process is carried for each 500m interval of altitude and the results are plotted on the Rossby diagram with log Θ_d as ordinate, and W as abscissa.

Since the air mass analysis in China is still in its infancy, we are not acquainted with the characteristic properties of the different types of air mass, hence the first step of the analysis is to identify what type of the air mass coresponding to each particular characteristic curve in the Rossby diagram. For this purpose, the pilot balloon data and the weather charts are of the primary importance. As for an example, the aeroplane ascent of April first, 1934 over Nanking has the following data:

Table 1.

H	T	W	θ_d	W. D.	W. VEL.
Surf.	282.0	4.24	280.6	NE	6.9
0.5	276.0	1.96	281.3	,,	10.4
1.0	273.5	1.52	281.4	,,	9.4
1.5	271.0	1.27	283.9	NNE	14.2
2.0	266.0	.97	284.3	NNW	13.9
2.5	,,	.93	289.0	NW	16.4
3.0	,,	.80	294.5	,,	18.8
3.5	,,	.72	300.0	,,	21.8
4.0	,,	.76	305.6	WNW	22.0
4.2	264.5	.63	306.4	,,	,,

The last two columns W.D. and W. Vel. are taken from the pilot balloon data of the same day starting in the morning from 7:47, while the aeroplane sounding began from 8:50. From the abrupt change of the mixing ratio W between 1.5 to 2.0 Km level, one would at the first sight expect that there must be two kinds of air masses, one ran over the other. This expectation is strengthened when we consider that the wind directions as well as the wind velocity both change abruptly at the same level. Again, from the daily weather charts of Eastern Asia (made by the Institute of Meteorology), we find that a high of 768mm was developing in North China, with its center at Shantung province, so that the circulation of the anticyclone would draw in the air mass of the Pacific at the lower levels over Nanking, while the air at higher levels came still from north-west. In the Fig. 1 the characteristic curve is plotted in which we see that the slope of the curve changes rapidly between 1.5 and 2.0 Km level, which fact confirms the expectation stated above. In the lower levels below 1.5 Km, the slope of the curve shows the condition of convective instability, while above 1.5 Km the curve becomes so steep that both θ_d and θ_e increase with altitude which is known as the absolute stable condition. From the above analysis we know that the air mass at the lower level is of the Pp type, while that of the higher level is of the Pc type.

By this procedure, the author has studied all the data of the aeroplane soundings of Nanking and a large part of the kite soundings of Peiping. Each data was carefully analyzed and classfied. For a particular type of air mass, if sufficient data were available, an average was taken for each station, and the mean characteristic curve was plotted so that we can draw certain conclusions from it.

3. THE POLAR CONTINENT AIR MASS (PC)

a. The winter type

The polar continental air mass originates from northern Siberia where snow covers the ground for the entire winter. As the Siberian high rules over that land during the winter half year, and extends its influence to the greater part of China, the winds all over China come mostly from the north and north-west. Since the north and north-west winds are predominent in the winter, the air masses of southern origin play only an insignificant rôle, especially in North China. For this reason, the air masses that appeared in the vicinity of Peiping in winter are practically all of the Pc type. According the source properties of the Pc air mass, one would expect its characteristic properties in the winter will be:

1. Very low surface temperature and small W,

2. Owing the cooling of the lower air by coming into contact with the ground, which is snow covered, a temperature inversion is established to a certain height so that the air column becomes absolute stable.

But unfortunately, we have no aerological stations further north of Peiping, so that we can not show these properties by a practical example. The polar continental air mass that reached Peiping has largely been transformed, particularly owing to the loft mountains in the north and north-west. It is thoroughly mixed by the mechanical turbulance set up by the relief of the country so that the temperature inversion is seldom observed below 3 Km. The average temperature and water content of Pc air mass obtained from 13 ascents in the winter of the past three years in the vicinity of Peiping are given in the following table:

Table 2

H	T	W	θ_d	θ_e	dT/dH	$d\theta_d/dH$	$d\theta_e/dH$
Surf.	275.8	1.69	274.6	278.5			
0.5	271.8	1.39	274.4	278.2	–8.0	–0.4	–0.6
1.0	268.0	1.16	275.4	278.7	–7.6	2.0	1.0
1.5	263.5	.93	276.1	278.7	–9.0	1.4	0
2.0	260.4	.82	277.9	280.0	–6.2	3.6	2.6
2.5	258.3	.71	280.5	283.0	–4.2	5.2	6.0

For a detailed analysis of the Peiping air masses, my teacher Mr. H. C. Huang, lecturer on meteorology at Tsing Hua University, now at California Institute of Technology, has already written a paper which will be published in the near future, so the present author will not go into this subject.

As to the district around Nanking, particularly during fair weather in winter, the air masses appeared are mostly of the Pc type. Since they reach Nanking after having travelling a long distance, they are considerably modified by the warm ground over which they travel. In the first place, the temperature of the surface level is increased since they are heated by the ground through radiation and conduction, and in the second place, the water content is much increased. This type of air mass, which is denoted by Dr. Willet as the transitional polar continental (Npc), should be classfied as cPK in the winter by the differential notation of T. Bergeron. The average temperature and water content of this type of air mass over Nanking are as follows:

Table 3.

H	T	W	θ_d	θ_e	dT/dH	$d\theta_d/dH$	$d\theta_e/dH$
Surf.	282.9	4.16	280.3	292.0			
0.5	277.0	3.06	280.7	288.7	–11.8	0.8	–6.6
1.0	273.9	2.72	281.8	289.3	–6.2	2.2	1.2
1.5	271.1	1.94	284.2	290.4	–5.6	4.8	2.2
2.0	269.3	1.69	287.6	292.3	–3.6	6.8	3.8
2.5	268.7	1.43	291.8	296.0	–1.2	8.4	7.4
3.0	267.1	1.18	295.4	299.0	–3.2	7.2	6.0
3.5	265.0	.92	298.7	301.2	–4.2	6.6	4.4
4.0	261.9	.76	300.7	303.0	–6.2	4.0	3.0
4.5	259.9	.53	303.8	306.0	–4.0	6.2	6.0

From the above table and the accompany characteristic curve (Fig. 2), we can easily get a general idea of the properties of Npc air mass in the vicinity of Nanking. Since the lapse rate of the first half Km is greater than the dry adiabatic, and the value $d\theta_e/dH$ is –6.6, hence the lower level is in the convective unstable condition. This is because of the fact that the visibility of Pc air mass is always so good that insolation raises the temperature of the stratum of air near the ground, which is heated from below in the course of their journey southward. The lower level become warmer and warmer until the convective instable condition is finally reached. But this heat effect does not go very far up, since both $d\theta_d/dH$ and $d\theta_e/dH$ are positive above 500m, so that the air there is in the absolute stable condition. Therefore the Npc air mass when it arrives at Nanking, is characterized by fair cold day, good visiblity and north-west wind.

b. The Summer type

In the summer time, since the south-west wind is then prevailing, the Npc air masses reach Nanking only occasionally, so we have not sufficient data to take an average; but the ascent of June 12, 1934 both at Nanking and Peiping will show some fundamental difference from that of the winter type:

Table 4

Kite-flight at Tsing Hua University, Peiping.

19h June 12 to 3h June 13 1934. (G. M. T.)

H	T	W	θ_d	W. D.
Surf.	296.2	7.80	297.3	WNW
0.5	291.6	7.09	296.8	NW
1.0	286.1	6.88	296.2	NNW
1.5	282.4	7.47	297.5	N
2.0	276.9	5.74	296.7	NNE
2.5	273.7	5.12	298.4	NE
2.86	271.2	4.46	299.5	NE

Table 5

Aeroplane Ascent at Nanking.

June 12, 1934, 6:52 to 8:32 (G. M. T.)

H	T	W	θ_d	W. D.
Surf.	301.8	6.45	302.0	WSW
0.5	293.5	4.35	298.2	WNW
1.0	288.7	3.40	298.2	NW
1.5	283.7	2.41	298.0	"
2.0	279.5	1.98	298.7	"
2.5	——		——	WNW
3.0	273.5	——	——	
3.5	271.5	0.78	306.0	"
4.0	267.0	0.38	306.4	"

The characteristic curves of there two ascents are plotted on the same diagram (Fig. 3). The contrast between the winter and summer type of Npc is striking. At the lower levels, the air mass of both places are in the absolute unstable condition, as can be seen from the characteristic curves. These two data seem to represent the same air mass since the time interval between these ascents at these two places are not very great. From them we can perceive the manner of transformation as it moves from Peiping to Nanking. The temperature of each 500m levei over Nanking is higher than that over Peiping, as we would expect. But the value of W is less over Nanking at each 500m level, this may be due to the fact that part of the water content had been precipitated on its way to Nanking, since from the weather chart of that day, we find a series of low pressure areas in the central and south-eastern China. Although by the transformation during their passage from Peiping to Nanking, their properties are greatly modified, but they still retain the condition of absolute instability. During the warm season the source properties of Pc air mass are very different from the characteristic of the cold season. The snow cover no longer exists over Siberia and the bare ground becomes very warm in long summer days. Consquently, instead of being cold from beneath as in the winter, they are heated from the ground so that they are always in the absolute unstable condition. During the ascent of June 12, 1934, at Peiping, passing showers are observed, which shows that the instability of the Pc air mass in summer is quite pronounced.

5. THE POLAR PACIFIC AIR MASS (PP).

a. The Winter Type

The polar Pacific air mass originates in north-western part of Pacific, somewhere from east of Yezo Island of Japan to the Bearing Sea. This type of air mass plays a dominant rôle in the weather of the rainy season at lower Yangtze valley. The source properties in the winter of the Pp air mass are to a certain extent resemble to that of the Pc air mass; for the Bearing Sea is always covered by ice and snow during the winter, so the Pp air mass is characterized by low surface temperature and small water content W at its source region. But as soon as it leaves its source reigns and moves over the warm sea to the lower latitudes, it is heated below so that its properties are transformed when it reaches the Chinese coast. This type of air mass comes to the lower Yangtze valley as a fair warm and moderately moist air with its lower levels in the absolute unstable condition. This type of air mass is denoted by Dr. Willet as Npp and should be classfied as mPW in winter and mPK in summer.

Unfortunately, the balloon soundings have not been used in China, while in the presence of the Pp air mass, the weather condition is always so bad that the ascent of the aeroplane is infeasible. Consquently during the past two years and half, there were only a few numbers of ascent made in this type of air mass so that we can not take an average, even a fair representative datum is not available. For those data which we have obtained always represent a Pp air mass over run by a Pc air mass at higher levels, and hence we do not know the characteristics of the vertical structure of Pp air mass. However, the general properties of the Pp air mass at the lower levels can be seen from some of these data. As for an example, the aeroplane ascent of December 5, 1933 over Nanking had the following data.

Table 6.

H	T	W	θ_d
Surf.	287.8	8.20	286.0
0.5	283.0	6.33	286.9
1.0	282.5	5.26	291.3
1.5	278.0	4.36	291.6
2.0	275.0	4.41	293.6
2.5	272.0	4.35	295.6
3.0	268.5	3.56	297.0
3.5	265.0	2.89	298.5
4.0	263.0	2.63	301.6

No pilot balloon ascent was made on that day, so we have no record of the wind direction and velocity. But on the weather chart of that day, made by the Institute, we find that the Siberian high had developed with its center near the border of Inner-Mongolia and Manchuria. Over the north-west Pacific there was a low centering near the north part of Japan. In conformity to the general circulation around the cyclone and anticyclone, one would expect that the air masses that reached Nanking should be of the Pp type. This is proved by the surface wind direction of those stations shown in the weather chart. From the characteristic curve (Fig. 4), we see that the lower level (from surface to 500m) is in the convective unstable condition, and that the curve goes steeper above, until a condition of absolute stability is reached at the altitude 1.5 Km, from whence its slope equal to zero, i.e., the lapse is of the dry adiabatic. Between the level 2.0 to 3.0 Km., there is a maximun of W, which shows the crossing of a front above which the Pc air mass lies. If we compare this curve with the mean characteristic curve of Npc of Nanking, we will find easily the contrast between these two types of air mass: in the first place, the value of W of Npp air mass is greater than that of Npc, in the second place, the θ_e of Npc is around 290 at the lower levels, while for the Npp air mass this value varies between 307 and 303, or even more. The temperature at each level in the Npp air mass is always higher than that of the corresponding levels of the Npp air mass. In the present case, this is true until the level of 3.0Km is reached, above which the temperature seems to be very near to that of the mean for Npc air mass. This seems to verify the fact that Npp air mass is over run by the Npc air mass.

Another example of Npp air mass in winter taken from the ascent of aeroplane on Feberary 18,1935 is plotted in the same diagram. For these two cases cited, although some variations may be found in the data, but there is one thing in common to both, i.e., the Npp air masses were all over run by Npc air mass, so that the coldness of the Npp air mass in winter at the upper levels made the Npp air mass reaching the lower Yangtze valley always in the unstable condition.

b. The Summer Type

For the Npp air in summer during the rainy season of lower Yangtze valley, the data of the ascent on May 25, 1934 over Nanking may be taken as an example:

Table 7

H	T	W	θ_d	W. D.
Surf.	302.6	9.91	303.4	calm
0.5	294.8	7.60	300.4	NE
1.0	288.3	6.32	298.2	ENE
1.5	281.8	5.03	296.3	NNE
2.0	280.0	4.33	299.6	NE
2.5	——	——	——	ENE
3.0	275.3	1.32	304.8	NE
3.5	271.8	1.05	306.3	NE
4.0	267.8	0.92	307.3	NW
4.5	263.3	0.93	307.8	NW
4.9	261.8	0.80	310.7	NW

The absolute instability of the lower levels is clearly shown in the characteristic curve (Fig. 5). Since the wind directions are prevailingly from north-east up to 3.5 Km. and then change suddenly to north-west, it is evident that the Npp air mass is overrun by the Pc air mass. From the weather chart of that day, we find that a high was developing in the central China and a low to the north of Japan. The circulation of air would lead the Pp air mass coming directly from the north-west Pacific. But now the cause of the instability of the lower levels is not due to the Pc air that moves at the higher level, for the temperature of the Pc air mass in the summer may even be higher than that of Pp air mass. In late spring and early summer the Pp air mass is colder than the land over which it is travelling, the lapse rate at lower levels often exceeds the dry adiabatic as in the case of May 25, 1934 over Nanking, and hence the air mass is absolute unstable. But whether this is the main cause for the continuous rain in the lower Yangtze valley or not, we can not say definitely before sufficient number of these type of air masses have been analyzed. For, according to the old interpretation, the continuous rain of the late spring is due to the stagnation of a warm front produced by the interaction of Pp from north-east and Tm from south-west, the latter being lifted and slowly climbed ober the former. To settle this question, the author will go into the subject at a later date when more aerological material is available.

5. THE TROPICAL MARITIME AIR MASS (TM)

a. The Winter Type.

Since, as has been stated in the above sections, the north-west wind prevails in winter, the Tm reaches Nanking only occasionally, so it plays only an insignificant rôle to weather condition of Nanking during the winter half year. The ascent on March 18, 1934 will show a fair example charasteristic of Tm in the winter half year.

Table 8

H	T	W	Θ_d	W. D.
Surf.	286.0	4.99	285.2	SW
0.5	„	4.01	290.1	WSW
1.0	„	3.85	295.1	W
1.5	281.0	2.61	294.9	WSW
2.0	277.0	1.84	295.7	„
2.5	271.5	1.50	295.0	„
3.0	266.5	1.23	„	
3.5	262.0	1.02	295.4	
4.0	260.2	0.94	299.0	
4.5	257.5	0.80	301.5	

The absolute stability of the lower 1000m shows the fundamental difference between Tm in winter from that of summer. Since during the winter, the temperature of the sea is higher than that of land, hence they are cooled at the surface layer from below as they progress from the source reign northward. They should be denoted as mTW in the winter season and do not yield any precipitation owing to their absolute stability at the lower strata. This is just opposite to the Npp air mass that reaches Nanking during the same season.

b. The Summer Type

During the warm season, the tropical maritime air mass plays an important rôle to the Chinese weather. Usually from the later part of June to the beginning of September, the wind directions at surface as well as at the upper levels over Nanking are all from the south or south-west, which shows that the Tm air mass now rules this part of China. Since it comes from the South Sea somewhere arround Java near the equatorial regions, and reaches the continent after travelling a long

distance over the sea, it is characterized by higher temperature and large value of W. From 13 ascents made in this air mass during 1934, from June to August, an average has been taken as follows:

Table 9

H	T	W	Θ_d	Θ_e	dT/dH	$d\Theta_d/dH$	$d\Theta_e/dH$
Surf.	302.8	18.41	305.0	355.6			
0.5	300.8	16.88	307.1	356.0	-4.0	4.2	0.8
1.0	296.6	13.76	308.0	347.0	-8.2	1.9	-11.0
1.5	292.3	11.24	308.5	340.3	-8.6	1.0	-13.4
2.0	288.0	8.83	308.5	333.7	-8.6	0	-13.2
2.5	283.2	7.48	308.4	330.0	-9.6	-0.2	-7.4
3.0	280.0	6.14	310.1	329.4	-6.4	3.4	-1.2
3.5	276.3	5.26	311.4	327.4	-6.8	2.6	-4.0
4.0	273.2	4.17	313.4	326.0	-6.4	2.0	-2.8

From 0.5 km upward the value $d\,\Theta_e/dH$ is negative, and $d\,\Theta_d/H$ positive, hence the air mass is in the convective unstable condition. This condition continues up to 4.0 Km. level. For this type of air mass, rain can only fall by a lifting of 1180 meters or more through a cold wedge or by passing over a high mountain range. The value 1180, the height that the Tm air mass over Nanking should be lifted in order to yield rain, is calculated by Babinet's formula:

$$Z=16000[1+2(t_0+t)/1000]B_0—B/B_0+B.$$

in which t_0 and B_0, the temperature and pressure of the condensation level, are found from the characteristic curve to have the value 22°C and 890mb respectively. The value t, the mean temperature of the surface layer, is 29.8 and the mean surface pressure B is 1020. Substitute these values to the above formula, we get Z as equal to 1180 meters.

Since, in the summer half year, the south-west wind is always so predominant that the cold air masses seldom come to the lower Yangtze valley, hence the front system moves to North China. This explains why the amount of rain-fall in Peiping is even heavier than in Nanking in the month of July, and orographic rainfall is quite heavy in south-western China.

A comparison with the tropical maritime air mass of America, will show that the Tm air mass at Due West in summer has properties quite similar to those of Nanking. The data is taken from Dr. Willet's paper: "American Air Mass Properties".

Table 10

H	T	W	θ_e
Surf.	301.8	18.4	356
1.0	298.2	12.8	345
2.0	291.0	10.3	430
3.0	283.0	8.1	336
4.0	276.6	5.9	333

The correspondence of properties of the two air masses at each level is striking. This is due the fact that Due West and Nanking are located practically on the same latitude and similar in their geographical situation.

In order to make a comparison of Tm data of Nanking with those of Peiping, the data of kite-flight of June 22, 1934 are given in the following table:

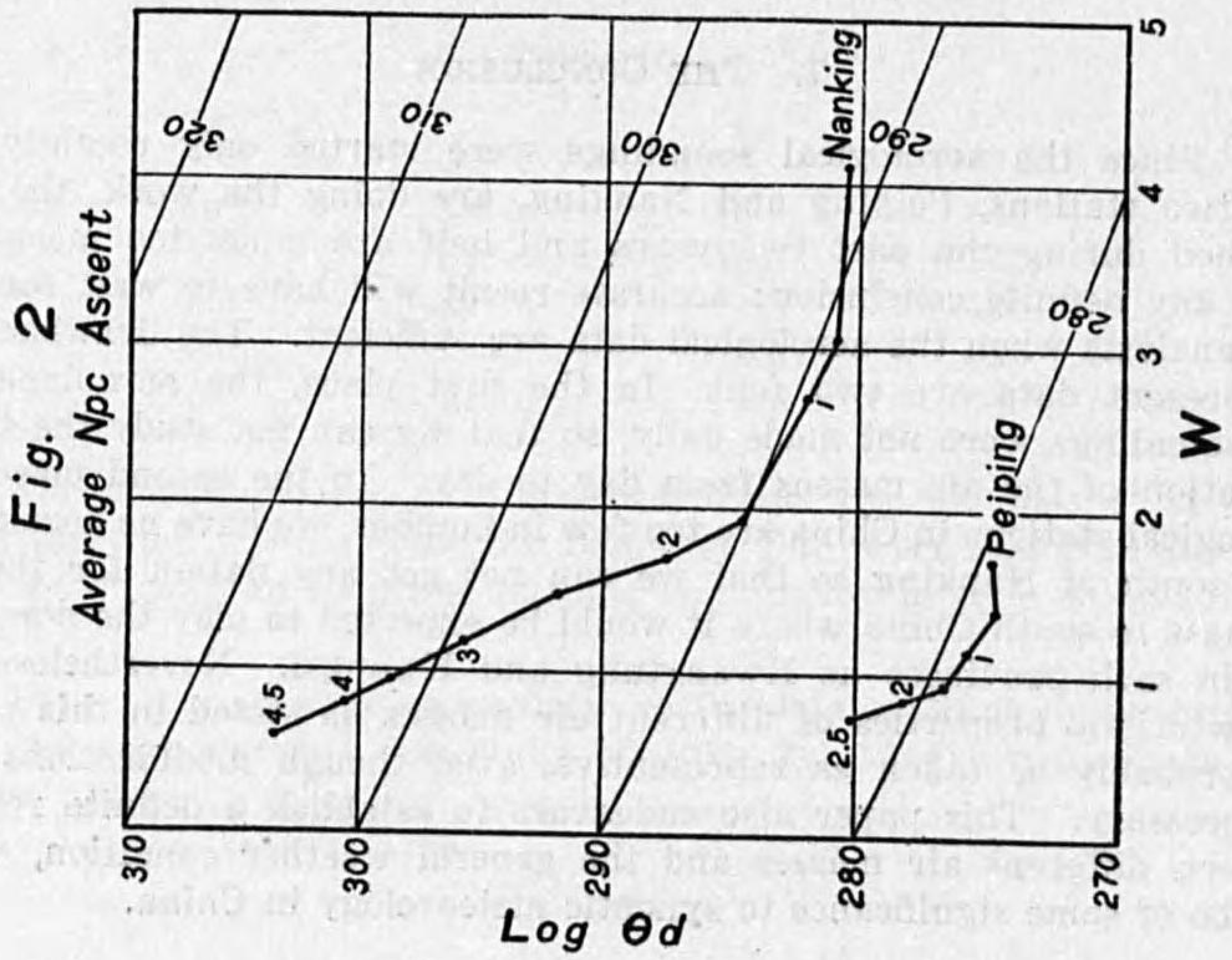
Table 11

H	T	W	θ_d	W. D.
Surf.	303.4	11.23	304.9	SSE
0.5	298.1	9.52	303.6	,,
1.0	293.0	8.19	303.2	,,
1.5	288.3	7.09	303.3	,,
2.0	284.4	6.35	304.1	S
2.5	280.6	3.47	304.9	SW
3.0	277.1	3.97	306.5	,,
3.22	275.8	4.29	307.3	,,

From the characteristic curve (Fig. 6), we find the lower 1000m level is in the absolute unstable condition, but as the decrease of θ_d with altitude is not very large, it will not give precipitation during its presence over Peiping. From 1000m up to 2000m it is in the convective unstable condition, and the θ_e of that level is around 315 to 323 which is lower than the value over Nanking (see table 9.). Again the water content W at Peiping is much lower than that of correspondent level over Nanning. This may be due to the precipitation by lifting when the Tm air mass passes across the high mountain ranges in south and central China, so this type of air mass can be denoted as Ntm according to Dr. Willet's notation.

7. THE CONCLUSION

Since the aerological soundings were started only recently and only two stations, Peiping and Nanking, are doing the work, the data obtained during the past two years and half are much too meagre to draw any definite conclusion; accurate result will have to wait for further analysis when the aerological data are sufficient. The drawbacks of the present data are two fold. In the first place, the aeroplane and kite soundings were not made daily, so that we can not study the transformation of the air masses from day to day. In the second place, the aerological stations in China are too few in number, we have no aerological data south of Nanking so that we can not get any datum for the Tm air mass in south China where it would be expected to play the dominant role in sach provinces as Kwangtung and Kwangsi. Nevertheless, the characteristic properties of different air masses as stated in this paper, can probably be taken as representive, even though modifications may be necessary. This paper also endeavors to establish a definite relation between different air masses and the general weather condition, which may be of some significance to synoptic meteorology in China.



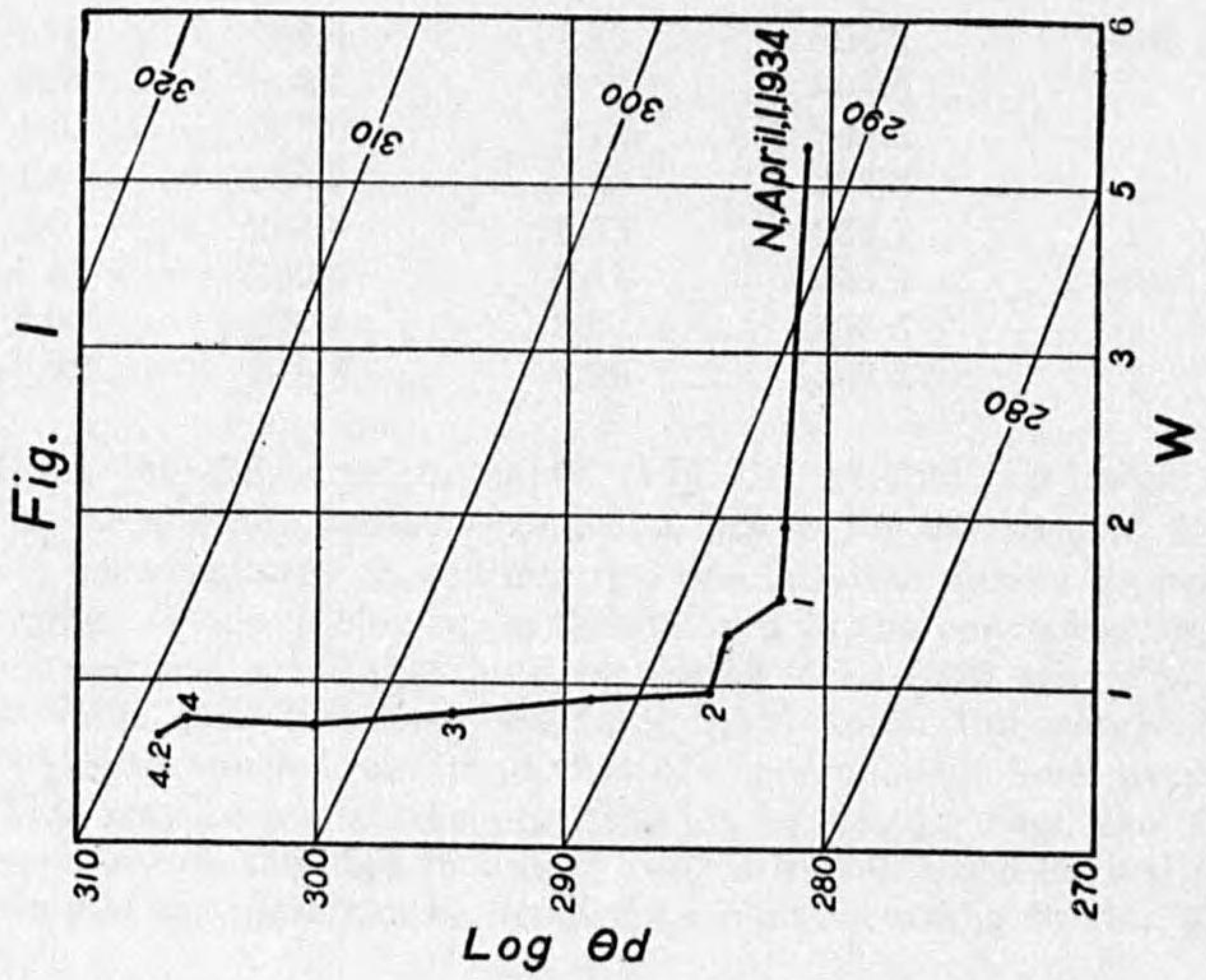
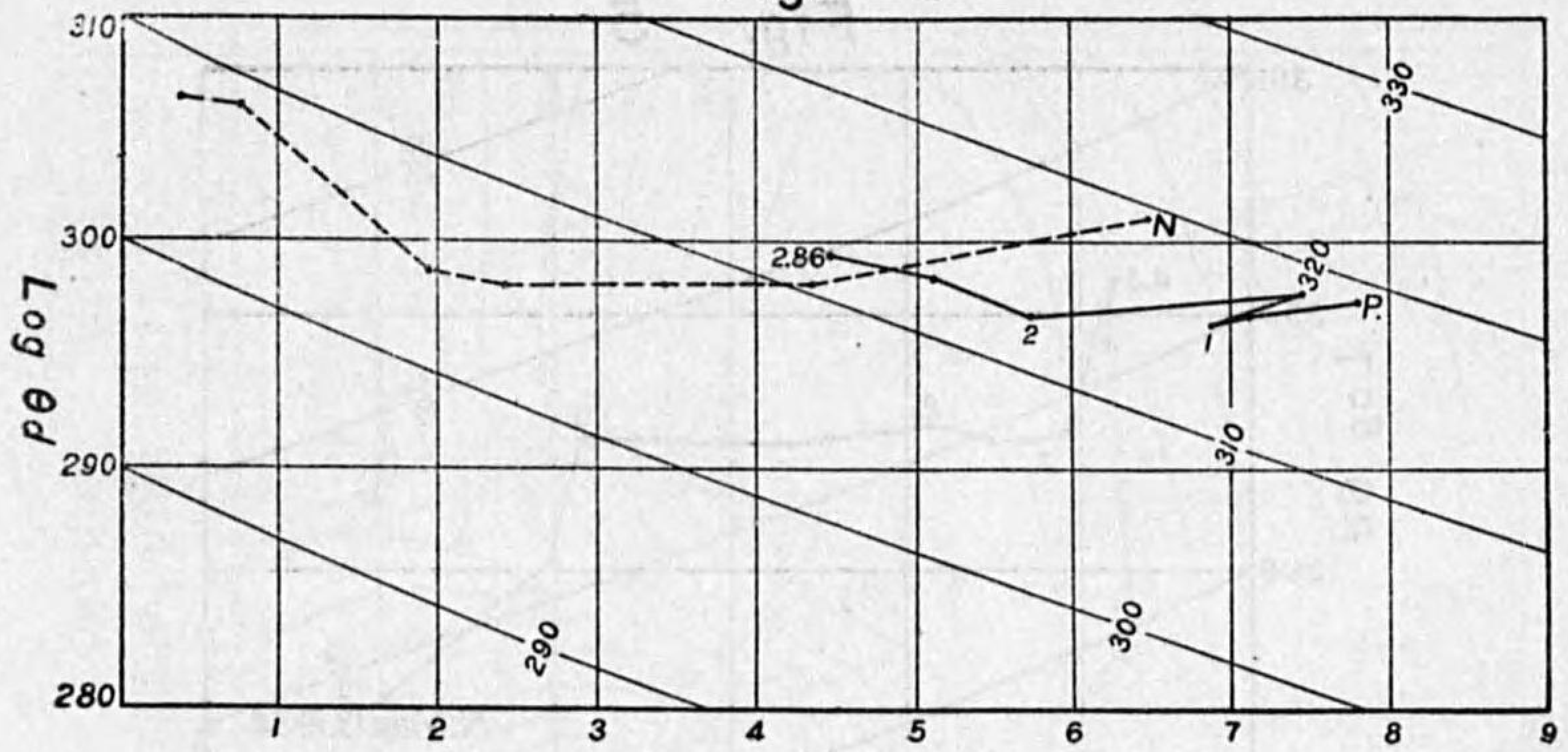


Fig. 3



Npc air mass in Summer
June 12, 1934

Fig. 4

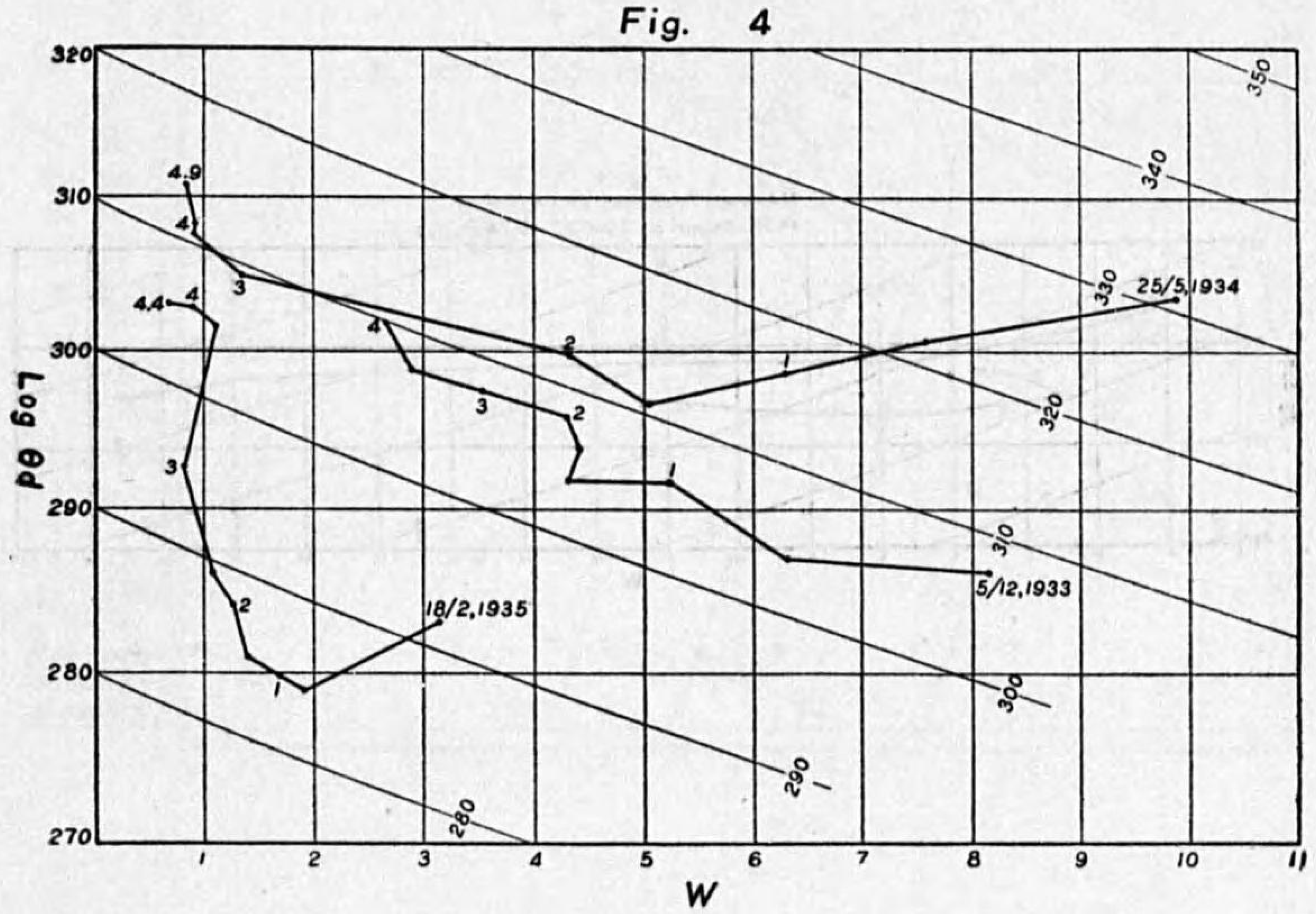


Fig. 5

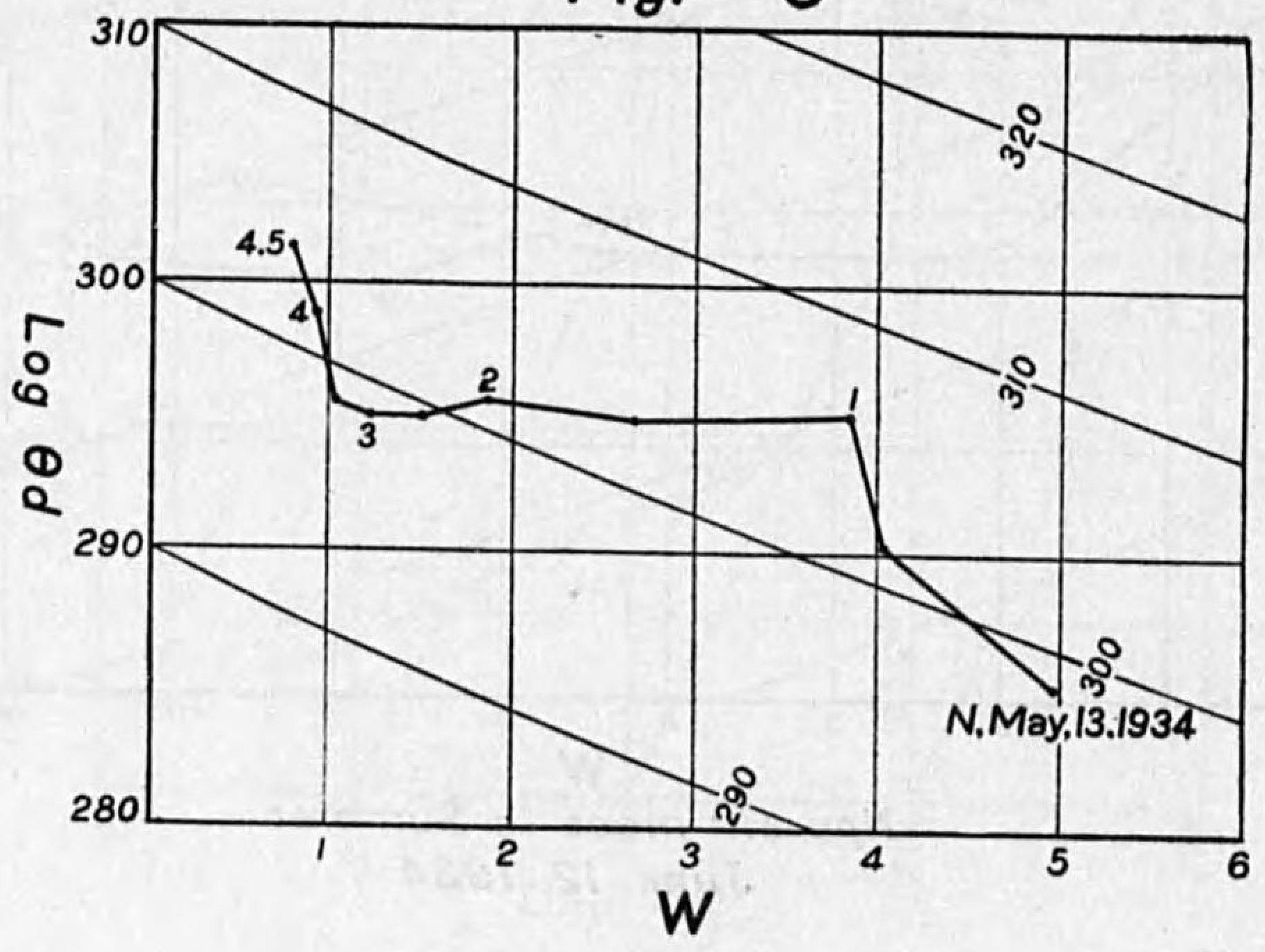
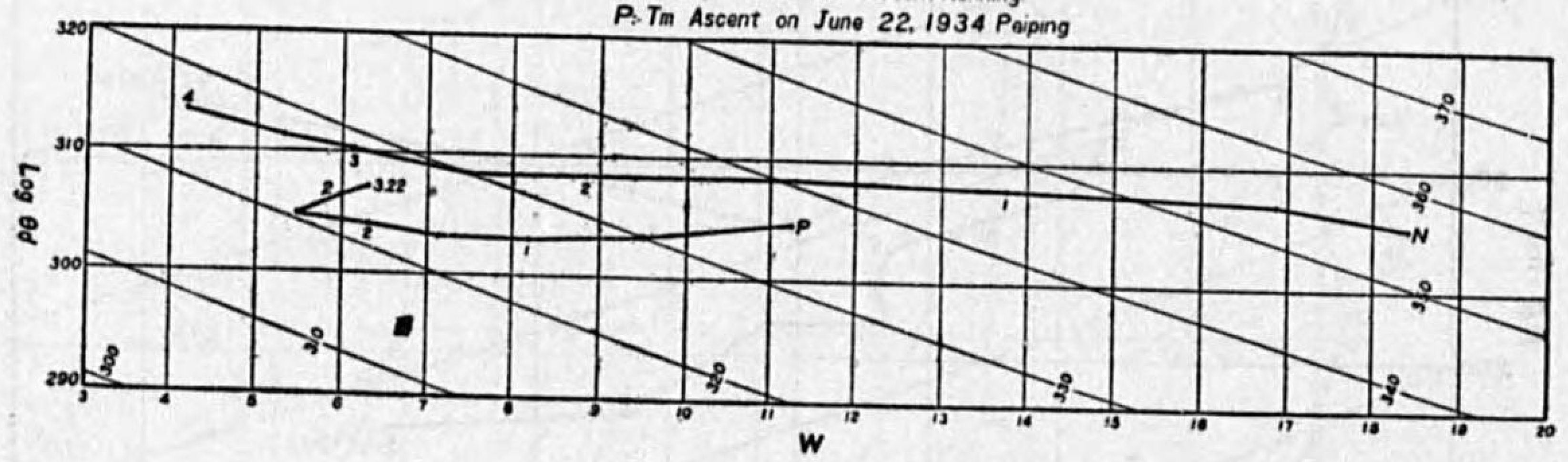
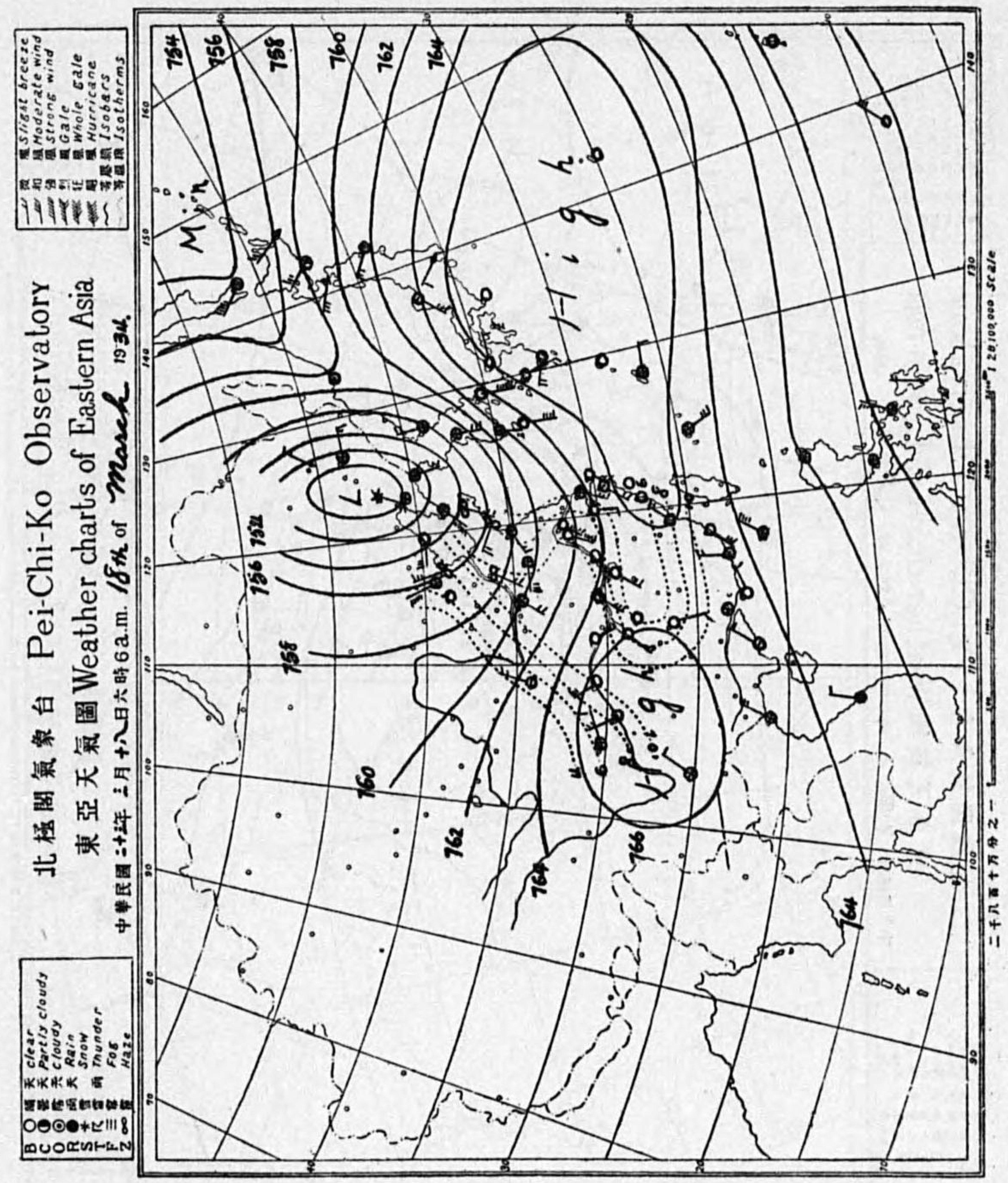
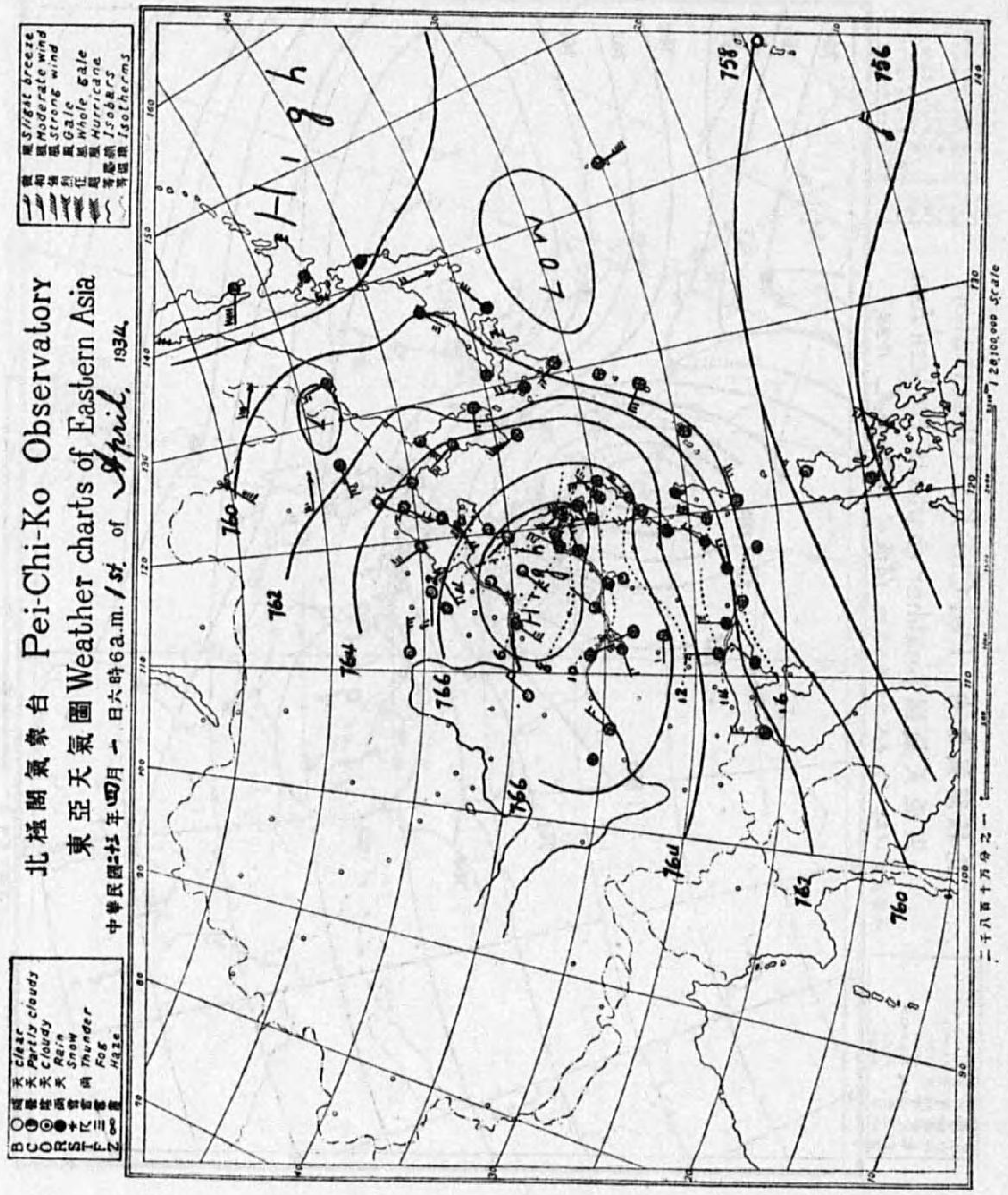


Fig. 6.
N: Average Tm (Summer) Ascent Nanking
P: Tm Ascent on June 22, 1934 Peiping



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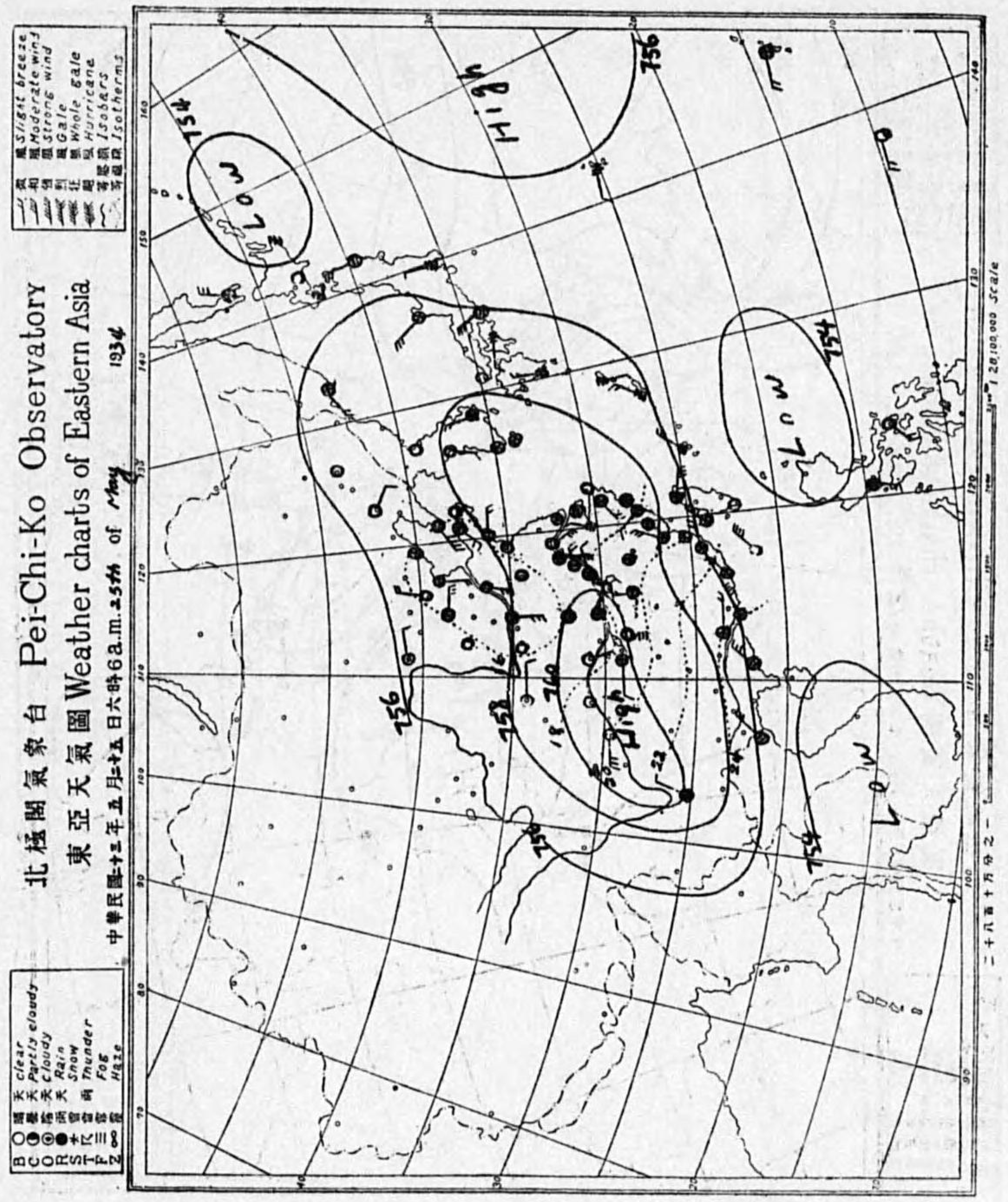
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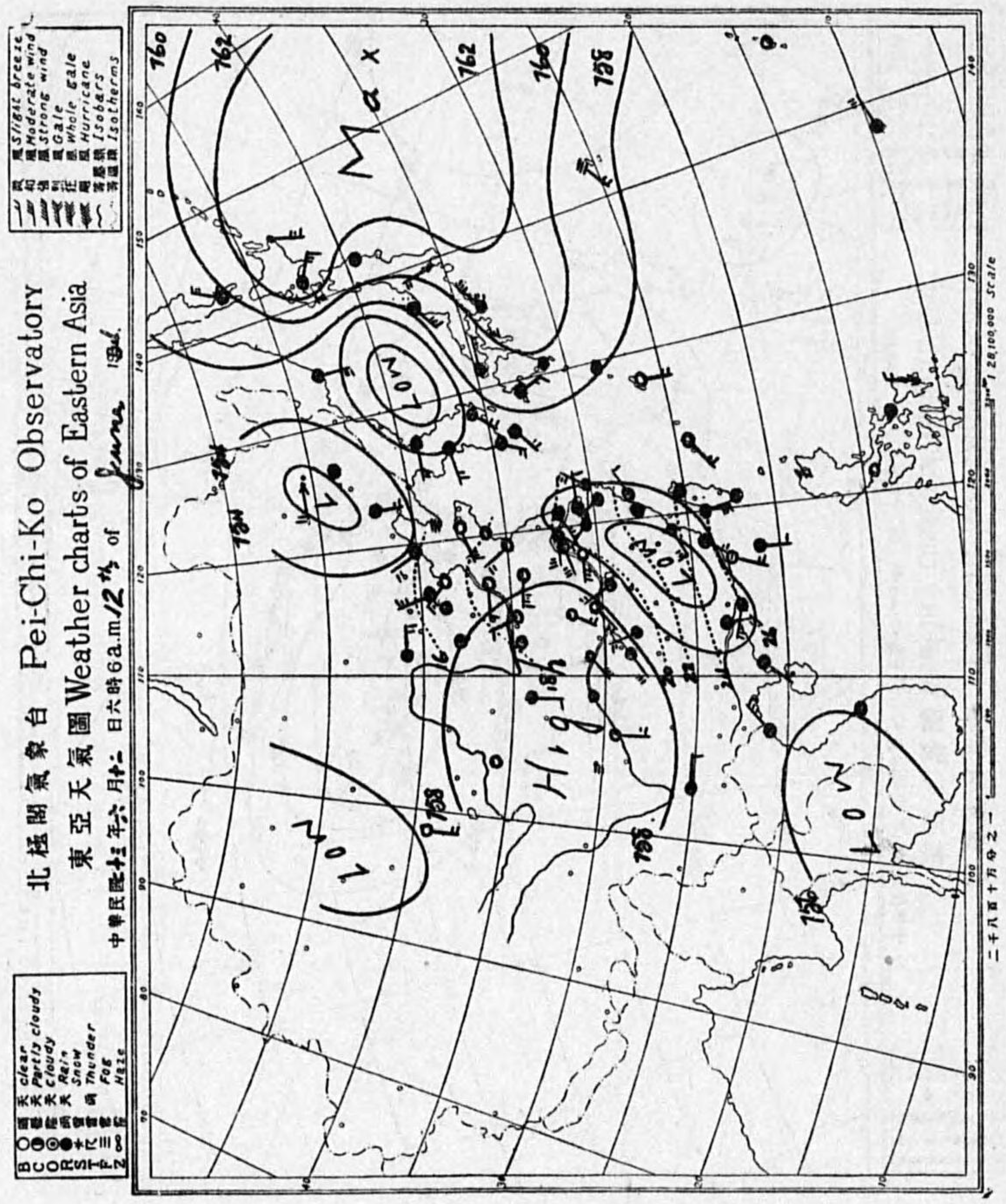
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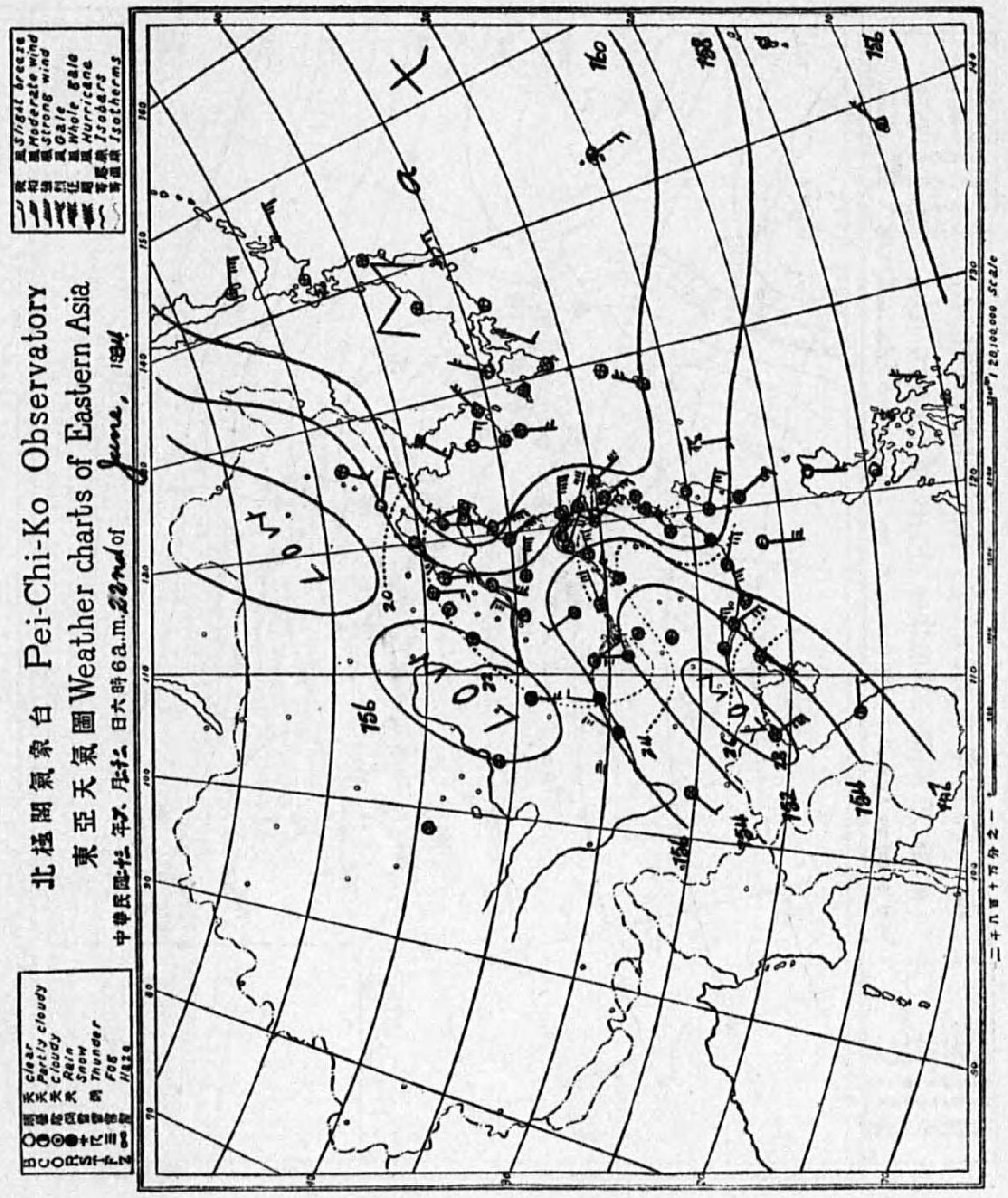
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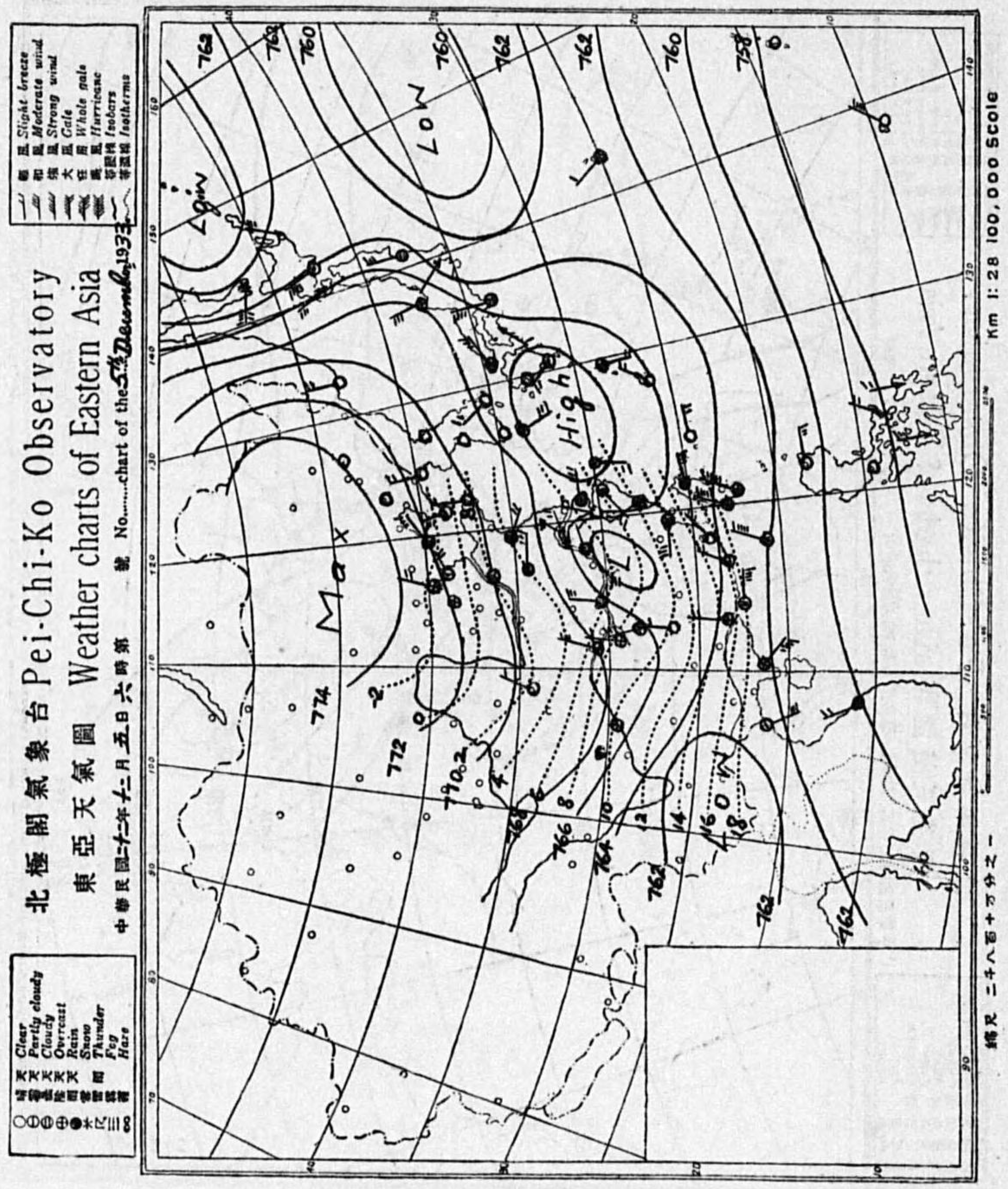
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東亞天氣圖 Weather charts of Eastern Asia
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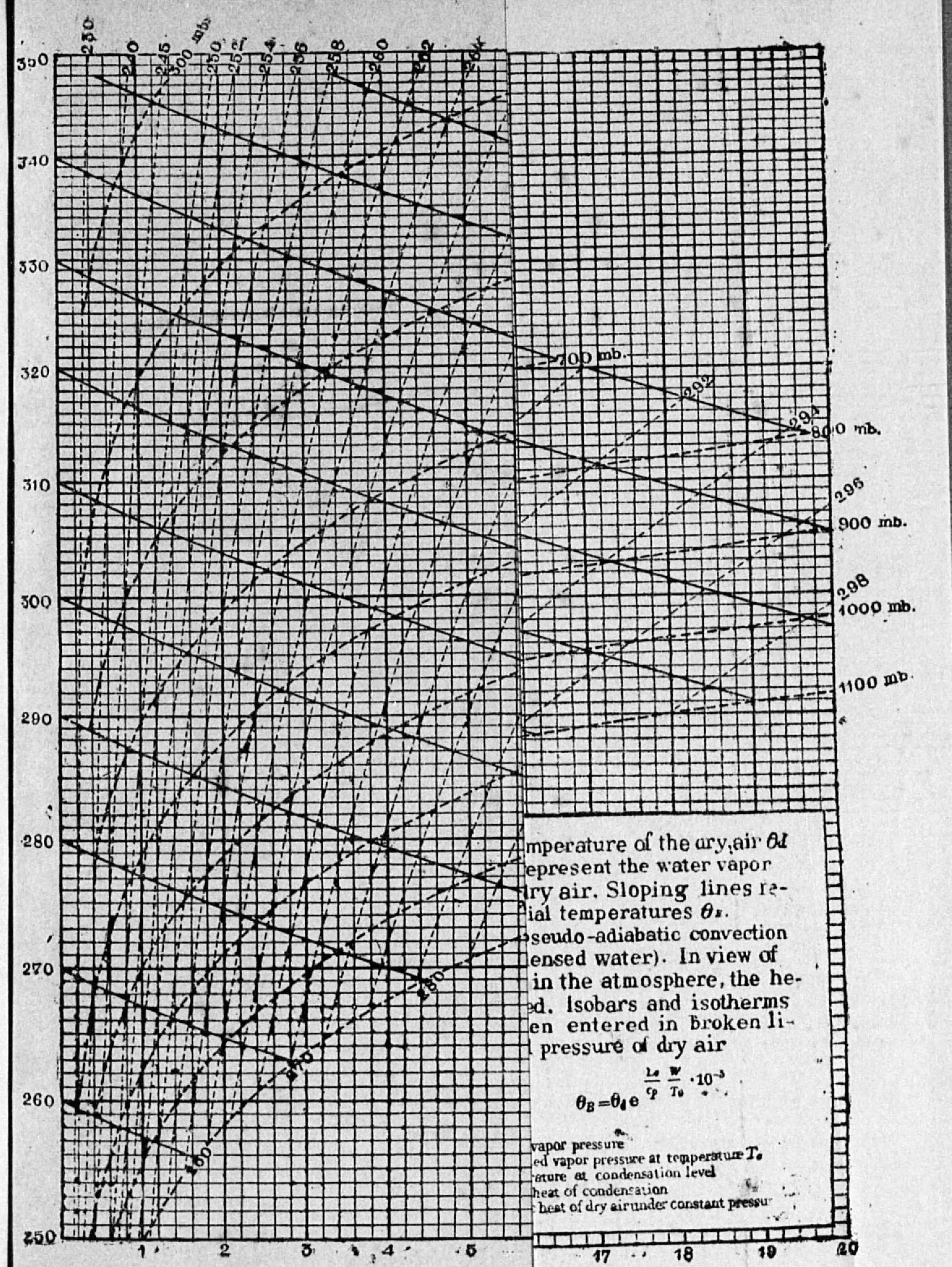
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mperature of the dry air θd
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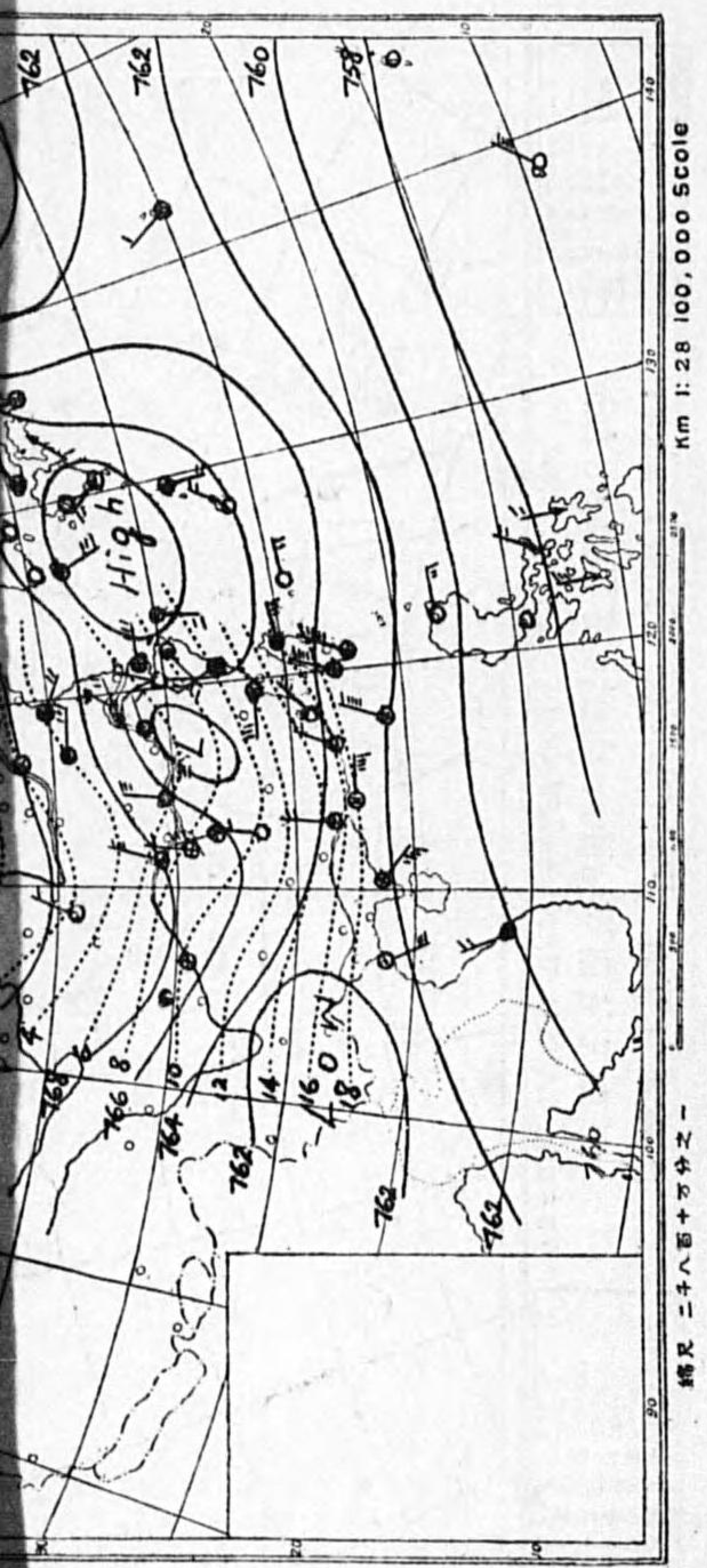
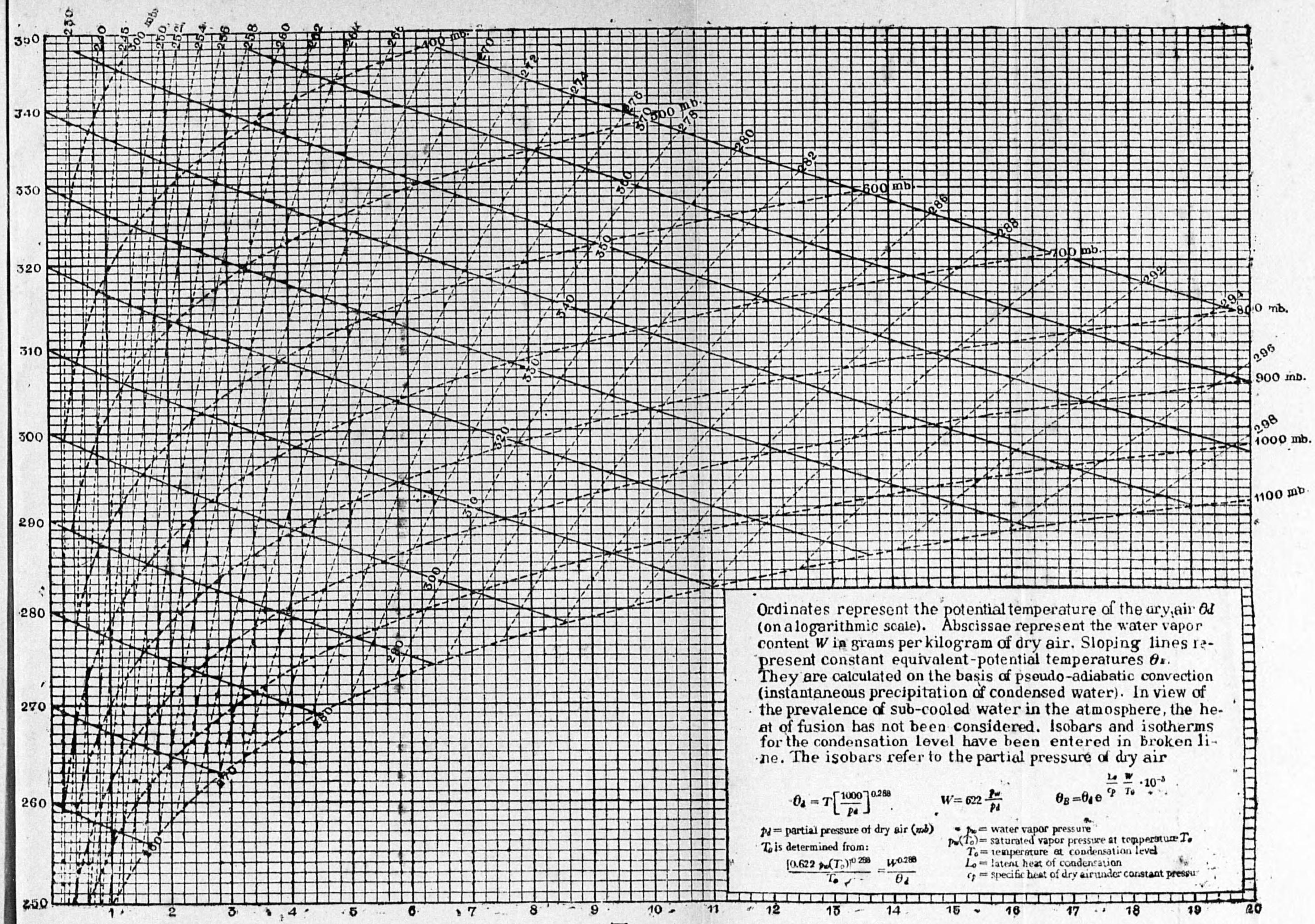
Y ANALYSIS OF THE





Ordinates represent the potential temperature of the dry air θ_d (on a logarithmic scale). Abscissae represent the water vapor content W in grams per kilogram of dry air. Sloping lines represent constant equivalent-potential temperatures θ_E. They are calculated on the basis of pseudo-adiabatic convection (instantaneous precipitation of condensed water). In view of the prevalence of sub-cooled water in the atmosphere, the heat of fusion has not been considered. Isobars and isotherms for the condensation level have been entered in broken line. The isobars refer to the partial pressure of dry air

$$\theta_d = T\left[\frac{1000}{p_d}\right]^{0.288} \qquad W = 622\frac{p_w}{p_d} \qquad \theta_E = \theta_d\, e^{\frac{L_0}{c_p}\frac{W}{T_0}\cdot 10^{-3}}$$

p_d = partial pressure of dry air (mb)

T_0 is determined from:

$$\frac{[0.622\, p_w(T_0)]^{0.288}}{T_0} = \frac{W^{0.288}}{\theta_d}$$

p_w = water vapor pressure

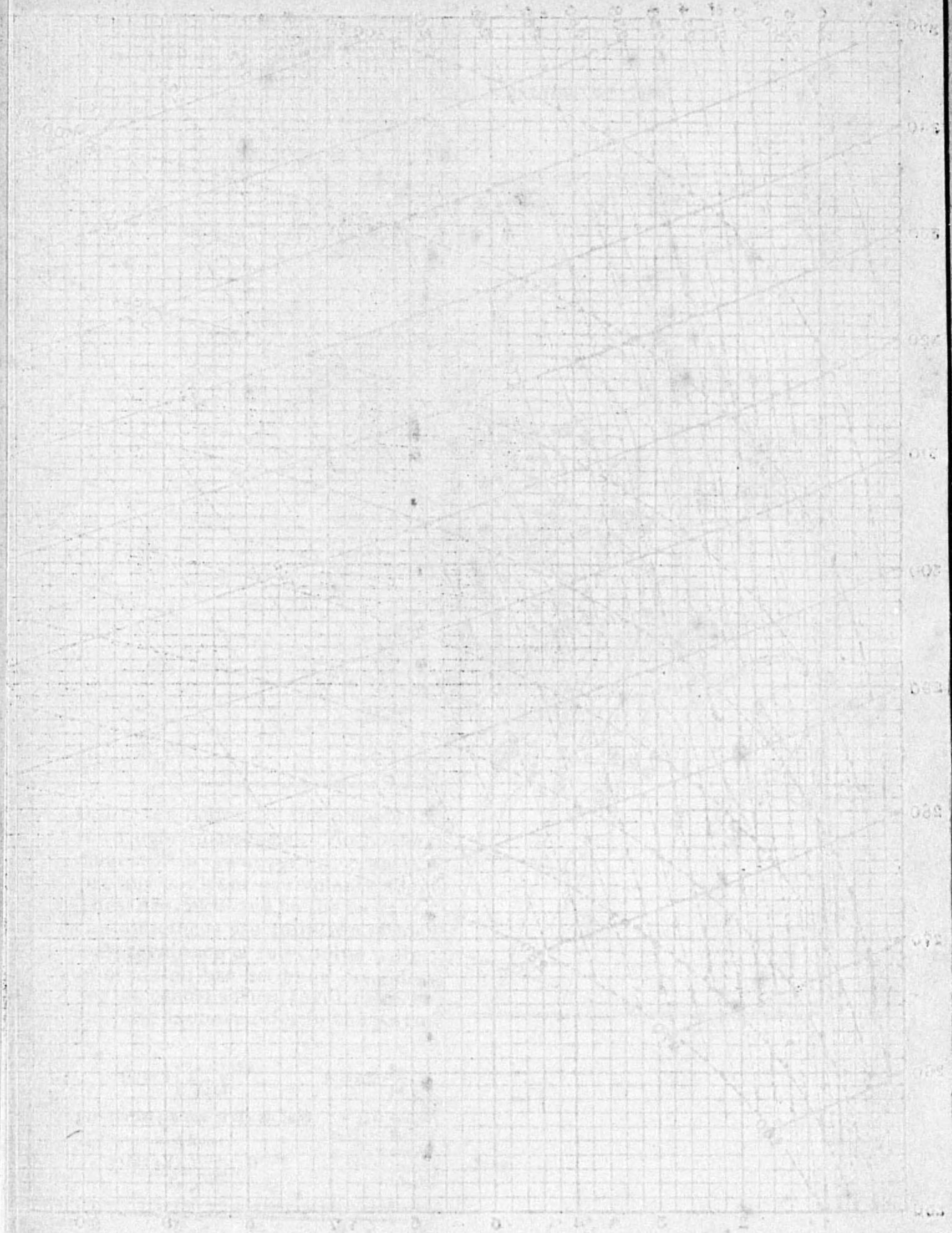
$p_w(T_0)$ = saturated vapor pressure at temperature T_0

T_0 = temperature at condensation level

L_0 = latent heat of condensation

c_p = specific heat of dry air under constant pressu

圖 A



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