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FORECASTING AND RELATED PROBLEMS IN CHINA

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(Air Weather Service
Tech. Rpt. 105-32)
~~REPORT NO. 805~~

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December 1944

05-5319-AF

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PREFACE

This report consists of a number of papers on various subjects related to weather forecasting in China.

These papers were selected from a group submitted for publication by U.S.A.A.F. forecasters who have been working in China, and represent a resume of the techniques and ideas they have gained by experience in that area. Minor editorial changes have been made and in most cases it has not been feasible to check completely the technical accuracy of the papers.

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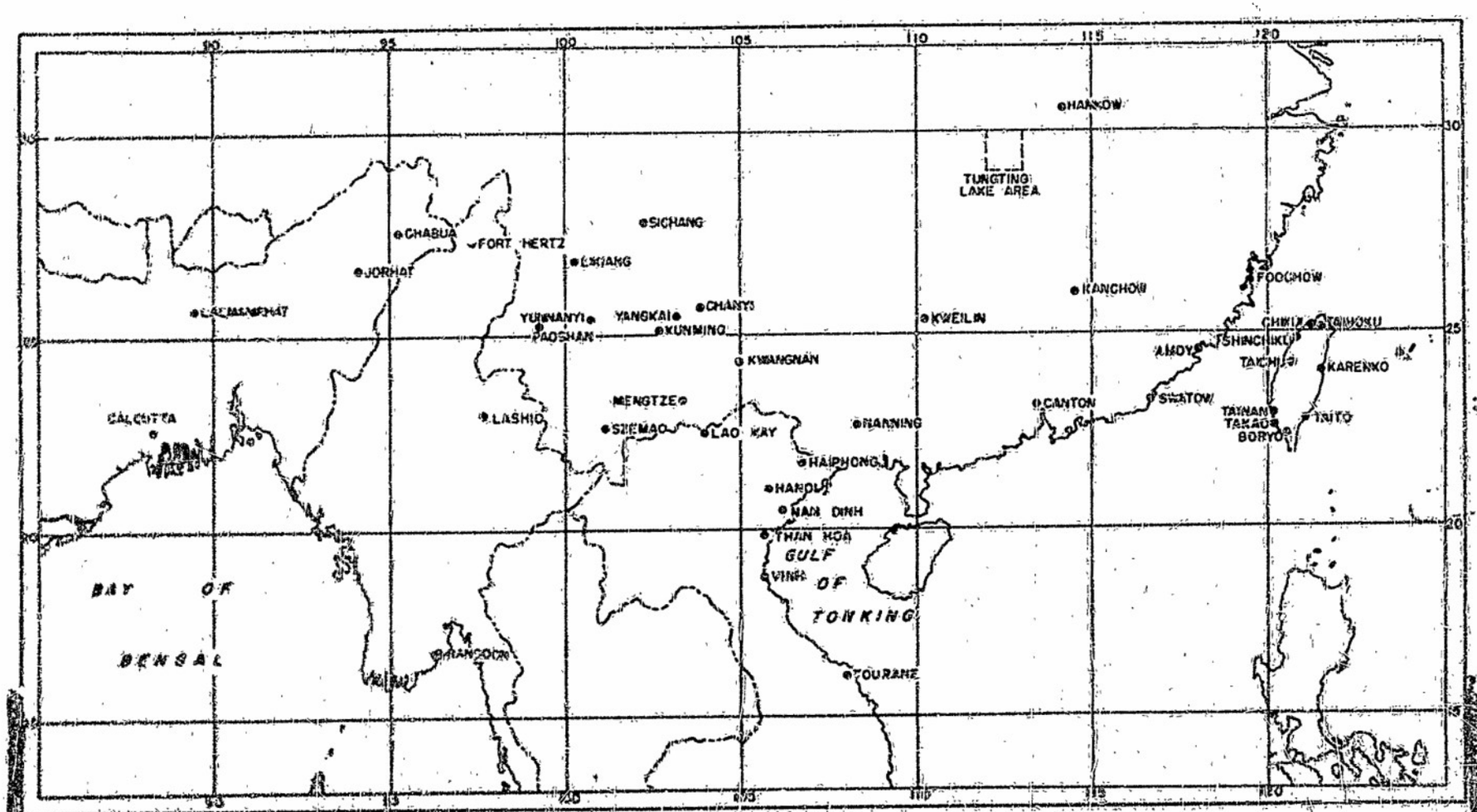

STATION LOCATION MAP

FORECASTING AND RELATED PROBLEMS

IN CHINA

CHARTS AND DATA

Synoptic charts are plotted by the Chinese for the 0500, 0900, and 1300 G.M.T. observations. The number of reports varies between 30 and 90, of which approximately 40 percent are instrumental reports.

Winds are expressed in kilometers per hour, temperature and dew point in degrees centigrade, and pressure tendency in whole millimeters. Relative humidities are also entered, and clouds are entered as 8Sk, 2.k, with no directions. Ceiling is not entered but visibility is given in hundreds of meters.

The mean altitude of Free China is, at an estimate, over 4,000 feet above sea level and very rugged, with extremely high peaks and several plateau areas. As in the Rocky Mountain area of the United States, winds under 15-20 m.p.h. are not usually representative. This condition applies to all of China; because it is shielded from all directions except the east and southeast by mountain ridges, the winds are usually light and variable.

Pressures in China can also be compared to those in the Rocky Mountains when reduced to sea level, where the addition of the weight of a fictitious air column to the station pressure proves to be inaccurate. In all of China, pressures are reduced to sea level from extreme altitudes, and by a much more inaccurate formula than the reduction formula used in the United States.

Naturally, cloud cover affecting surface temperatures will show a very marked effect on the pressure. Flat areas, such as the Yunnan Plateau, are very receptive to daytime heating and, as such, will show a marked pressure decline throughout the day when there is a large diurnal temperature change.

Pressure changes are highly inaccurate, but discounting the diurnal variation, they can be used with a fair degree of accuracy. Using pressure changes in areas of cloud cover where the surface temperature is fairly constant, one finds that they actually represent the true changes in pressure. Taking into account the diurnal pressure changes, which are fairly great in this country, we can determine the dynamic pressure changes without difficulty. For the same reason as above, pressure changes found over the plateau regions will be accurate when a cloud cover exists, but inaccurate when the sky is clear or scattered. However, knowing that with a large diurnal change in temperature the pressure will be at a maximum on the morning chart and at a minimum on the afternoon chart, and observing over a short period of time what the range between the two will be, we can, by observing departures from normal, predict

the intensity of this dynamic effect. For example, over Yunnan, which is an extensive plateau region, one would normally expect with clear skies a great fall in pressure from the 0900 to the 1500 map. If, however, this fall is only slight, we can say that a weak to moderate anticyclone is moving in. If the tendency is acutally a rise, we can say that a strong anticyclone is moving in. If the fall is much greater than normal, we can say that a strong cyclone is moving in, etc.

Temperatures can be used with a great deal of accuracy for locating fronts after correcting the temperatures for the differences in altitude between the various stations. This method is more practical in winter than in summer.

HUMP TROUGHS, RIDGES, AND RELATED PHENOMENA

It was noticed very early that there was a certain amount of correlation between the weather of Yunnan and Assam. It was independently noted by forecasters that correlation was greatest by "lag", that is, Kunming and Yunnanyi showed a significant change in weather following the change at Chabua, Jorhat, and Tezpur. Lag from Chabua to Yunnanyi was believed to be, roughly, 1 day, and from Chabua to Kunming, 1½ days, though no notes were made for more accurate determinations until this year (1944).

More accurate determinations of time lag were hampered by the obvious possibility for entry of personal judgment, since correlations seemed to be longer-range (2- to 6-day) trends of weather. Thus, the onset of a protracted period of bad weather in Assam was usually followed by the later onset of the same weather in Yunnan. It was likewise possible to note this lag with respect to clearing weather in the two provinces. Agreement as to what limits should delineate "good" from "bad" weather cannot, naturally, be perfect among various forecasters. Widespread rain and clouds below 3,000 feet and over 8/10 cover throughout the day would probably be considered bad by most forecasters. Conversely, good weather would ordinarily consist of lack of showers (other than a few scattered ones), and ceilings never below 4,000 feet (except for fog). Such criteria, however, are merely extremes. What must be used in any given case is a marked change in cloud amount, cloud type, or weather, as compared with the preceding and following few days. Thus, a detailed examination of the weather at Yunnan in the "dead of winter", when cloudless weather is frequent for a number of days, will show that high, broken cirrus, and later scattered cumulus or stratocumulus, followed again by cloudless weather, can apparently be best attributed to a Hump trough. Examples can be found on December 12, 13, 19, 24, and 25, 1943. It is interesting to note that in the case of the trough passage in Yunnan on December 25, 1943, an entirely new regime was ushered in, with scattered stratocumulus until December 31, when another trough passed. It is obvious, then, that no hard and fast rules can be used in determining by weather conditions alone when, or whether, a Hump trough has occurred, and the entire range of experience of the forecaster must be utilized. Since, however, we are here postulating that one of the most common types of significant change in weather is due to troughs, their existence or lack of effect is not thereby decreased.

The existence of such Hump troughs has led to much discussion of their theoretical nature. The term "trough" has been used purposely in this article, since the author rejects present explanations involving surface or upper fronts.

It is hard to see how a surface phenomenon would be able to traverse the terrain involved, particularly the continuous 14,000-foot Kaolikung Range immediately west of the Salween (the Hump proper). On the other hand, the clouds usually associated with the trough in the lower levels are hard to attribute to an upper trough or upper front. There is, however, one explanation recently advanced that seems to fit the known facts. Evidence has recently been found that surface fronts moving from the northeast through Yunnan do not dissolve nearly as rapidly, if at all, in the south and west as was formerly thought. If one postulates a frontogenetical sector in the general area of the Mekong River for the upper trough to act upon, the problem is immediately solved. The appealing thing about this explanation is that it fits a further observed fact--that during the past winter, a number of cases have been noted wherein troughs produce their characteristic effects in Assam and on the Hump (where the trough is marked, as on the Pathai Range, by a large increase in cloud tops, thunderstorms, etc.), but absolutely no weather in Yunnan. This is apparently due to the absence of a frontogenetical sector in the western part of Yunnan for which the upper trough can act as a trigger, cold front passages from the northeast having been unusually rare in 1944 until May. This explanation is not startling, since it is a common occurrence in the Rockies, where an upper front migrating across will intensify a stationary front on the east slopes.

The hypothesis of an upper front has been advanced in the past, but it did not find general favor, probably because of the old tendency to deny the presence of all frontal systems, surface or upper, in India. In view of the recent trend to reclassify the so-called "Western disturbances" into certain types of frontal systems, the possibility of existence of upper fronts on the Hump was investigated more thoroughly through the use of raob data. The two most marked trough passages of the year, both in May, 1944, were examined in detail with this purpose in mind, and it appears that in those two cases, at least, the phenomenon under consideration was not of a frontal nature aloft. The case of May 26-28 indicates heating in the lower layers, but cooling at an average of 20-30° C. above about 12,000 feet at Chabua and Yunnanyi, while Ft. Hertz shows continued heating aloft after the trough passage. The case of May 8-10 more conclusively indicates heating after the trough passage, being definite at Ft. Hertz and Yunnanyi to over 20,000 feet but remaining constant at Chabua above 6,000 feet. In both cases there is a tendency toward cooling at both low and high levels with the approach of the trough, and toward heating, sometimes to "normal" and sometimes above "normal", following passage. As can be seen, this is a general tendency only, and subject to exceptions where least expected. Since that regularity of temperature trend appears is found in these cases at the lower levels, it seems unlikely that a front passed aloft. More cases will, however, have to be studied in the future to be certain that the anomalies are not due to instrument error.

While the raobs do not indicate any significant criteria in temperature or stability, they do show a very definite decrease in moisture content following the trough passage in all cases. Unfortunately for forecasting, detection is limited to after passage or during passage. It has been found that there is a frequent lag of clearing weather behind a trough, etc., probably, to

such factors as amount of solar radiation available, previous history of the locality (particularly with respect to amount of precipitation and existence of upper cloud decks), and intensity of trough. Thus, both Chabua and Ft. Hertz show decreasing moisture above 10,000 feet on the night of May 27-28, 1944, and Yunnanyi is known to have cleared quickly on May 28, indicating that at the time of the soundings (1700Z, May 27), the trough was between Ft. Hertz and Yunnanyi.

Lag in clearing in Yunnan may be due to more than the simple phenomena associated with the trough, for it has been observed in a number of cases that the semi-stationary front ("Lai-U") usually found north of Chanyi will be drawn south, without any strengthening of the high cell to the north in the Red Basin with the approach of a Hump trough. This does not mean that every trough "sucks in" the southeast front, for such is not the case. Apparently, southward migration is merely aided by the approach of the trough aloft.

In following Hump troughs, either the trend in weather or the upper winds may be used as an index. Since there is so much room for personal opinion on "significant changes in weather", and since there may be a lag in clearing, pibal data is used more in practice because it is easy to follow when it is available. Few, if any, serious exceptions have been noted to the rule that at Yunnanyi and Kunming, winds at middle altitudes veering from southwest to northwest mark the passage of a trough (middle altitudes in this case means the zone from 10,000 or 12,000 feet to 16,000 or 18,000 feet). Surface winds are seldom from the northwest, and then usually only at the onset of a cold front passage from the northeast, a case which must obviously be excluded. The winds at high levels seem to be more constant in any given month (except for the case of the Tibetan wedge, which is to be considered below), and hence are also excluded in this rule of thumb. When it is recalled that broken to overcast stratus in the morning and showers in the afternoon during certain seasons are common with southeast winds, and that clear to scattered morning conditions and lack of afternoon showers are characteristic of northwest winds, it is readily seen how the two criteria of change in general weather and upper wind direction may be used interchangeably in Yunnan.

The pibal of Likiang does not seem to show the same characteristics as those south of that station. For one thing, flow is disturbed by the high mountain to the west; furthermore, sufficient runs have not been received for final decision. Nevertheless, there seem to be several cases of northerly winds at Likiang which were not observed either simultaneously or shortly afterward at Yunnanyi, Chanyi, or Kunming. It is now believed this may be associated with the north-south oscillation of the zone of convergence which lies, generally, east-west between Likiang and Sichang. This zone of convergence is an extension of the semi-stationary front usually found north of Chanyi and which extends southeast towards the Gulf of Tonking. Where formerly it was believed that because of the height of the terrain, the front dissolved to the west of the Chungking Road, some evidence now appears that, instead, it is at times subject to marked frontogenesis. It has been noted that numerous cases of weather similar in effect to troughs occur in Yunnan

with an increase in wind speed at middle altitudes, particularly in winter. At Paoshan, Yunnanyi, or Kunming, a westerly wind of 50 m.p.h. or over at 14,000 feet, or 60 m.p.h. or over at 17,000 feet is definitely of this type, while in winter, winds under 35 m.p.h. cannot be associated with this type. This phenomenon has been attributed to a zone of convergence lying east-west along the normal Hump route. It would appear that ordinarily this zone of convergence is weaker than formerly thought, and another lies 150 to 200 miles north of the first zone. It may then be assumed that a low aloft (probably migratory) has strengthened in Sikang and Szechwan. Here again, what evidence there is seems to point to the fact that a massive mountain system does not necessarily inhibit well-developed (or upper) pressure systems.

Criteria from pibal data in Assam also varies with locality. In winter, there is a general northeast light drift down the Brahmaputra River, extending to 7,000-8,000 feet at Chabua and 3,000-4,000 feet at Jorhat. For Chabua, troughs have been detected by lowering of the level at which westerlies or southwesterlies set in (4,000-6,000 feet), by northwest winds from 12,000-20,000 feet, and by increase in speed of the westerlies (usually associated, however, with the case of westerlies at low levels). Pibal data for Jorhat and Tezpur accurately reflect the directional shift and the increase in speed associated with troughs, but data for Lalminar Hat does not. Cases of marked northwest circulation aloft have been noted at Lalminar Hat, without clearing in upper Assam in the next several days. It must be borne in mind, in using data for regions to the west of Assam, that the bad weather there may be due to systems to the south as much as those to the west.

So-called "Western disturbances" seem, however, to be the result of the same migratory waves that farther east are termed Hump troughs, at least in winter. Their detection at such stations as Agra and Delhi is reminiscent of that at Yunnan, for in the winter they frequently cause only cirrus lowering to altocumulus, and sometimes stratus in the morning. Certain Indian forecasters have also identified the disturbance with high cirrus at Peshawar, and lately raob data has confirmed passages by decrease in moisture at high levels at Peshawar, and at middle altitudes at Agra and Lalminar Hat. Nor is the wave traceable only this far. It is said to be found at Karachi and, before that, as an occlusion in the southern than from the Mediterranean migrating across Arabia and the Persian Gulf.

Just as the effects of upper waves causing the Hump troughs is detected far to the west, their effects to the east of Yunnan are also evident. To this date, little effort has been made by forecasters to follow Hump troughs beyond recognizing that they must exist, but it is believed that most, if not all, of the apparently anomalous weather of southeast China (Kweichow, Kwangsi, Kwangtung, Hunan, and Kiangsi) can be explained and anticipated by the use of Hump troughs. By "anomalous occurrences" are meant those cases which are not readily accounted for by the regular migration of polar highs and cold fronts from the north, nor the apparent strengthening of the western lobe of the Pacific high. These cases are most noticeable in fairly flat pressure fields in which the forecaster is hard put to find any definite characteristics, and ends by forecasting "more of the same." In summer, this is often the case when a weak zone of frontogenesis is found lying northeast-southwest on a line near Kweilin-Kanchow (as opposed

to north in the Tungting Lake area or south off the coast). The two marked troughs of May, mentioned before, caused sudden and otherwise unexpected clearing through southeast China, the zone where frontogenesis is driven off-shore without any apparent change in the situation to the north of the Yangtze. Likewise, the experienced forecaster, looking for the return of the zone of frontogenesis from off the coast and expecting it to migrate to the Yangtze, may be fooled by the passage of the upper trough, which acts to deter the otherwise expected south-to-southeast flow aloft at 5,000-15,000 feet.

The southern limit of Hump troughs is unknown. However, this winter it was found that Hump troughs, when causing clearing weather from Kunming through Mengtze to Lao Kay, also cause clearing weather in the Hanoi-Haiphong region, though only in the period 24-48 hours after clearing at Kunming. Advantage of this observation was taken February 1[illegible], 1944 (following a Hump trough passing Kunming February 11) to send a mission to Vinh, the weather being good the entire route and at the target, whereas the previous day and in several reconnaissance flights in the preceding week it had been low overcast with drizzle over the entire area. It appears probable that if the reasoning was correct for this case, the effects of Hump troughs are manifest as far as Tourane, at least in the case of well-defined troughs.

If Hump troughs are thus valuable for forecasting for all of south China, they should be watched as closely as possible, and their effect taken into consideration. To this end, a general knowledge of their rate of movement is of great help. It is reported to be 2-3 days from Peshawar to Assam, though it must be borne in mind that not all such disturbances may come through, and that others (from the Bay of Bengal) may. By observation it has been found that the trough requires 1½ to 2½ days from Chabua to Kweilin, with an average rate of movement of nearly 500 miles a day or 20 m.p.h. Variation from this figure will depend upon intensity and season. It will be recalled that the more intense all upper waves are, the more slowly they move, and that the general westerly wind is strongest in winter. From the critical altitudes found through the use of pibal data, it appears that in winter or in periods of what may be called "high index", the wave is propagated at approximately 40-50 percent of stream velocity (the average winter winds at 15,000 feet being west at 50 m.p.h.

From known cases in May, it is apparent that Hump troughs cannot be entirely of a seasonal nature, despite the low latitude and nearness to the equatorial easterlies. Since the thermal equator in July is as far north as the path of the troughs, it is felt a more definite check should be made on the possibility of a slight decrease in summer, though it is remembered that periods of high index and definite westerlies occur frequently through the summer at 25° N.

One final aspect of Hump troughs should be considered. Some evidence of periodicity exists. The cases of December 7, 13, 19, 25, and 31, 1943 and of May 8, 16, 22, and 28, 1944 indicate a recurrence, roughly, every 6 days. The extreme northerly flow following May 8 was apparently responsible for extension of this period temporarily, and it seems likely that variation from high to

low index may interrupt the cycle completely, initiating it again with no correlation to the previous cycle.

While the existence of Hump troughs has been widely acknowledged, its natural corollary, the wedge, seems to have been overlooked. If purposely sought for, the more well-developed cases become evident and some rather startling concepts emerge. In connection with the so-called "intensity trough", or apparent east-west line of convergence, northerly winds at middle levels in Sikang may be attributed either to a well-developed trough aloft in Szechwan, or to a high farther to the west in eastern and central Tibet. More probably, both will be found simultaneously. The series of troughs ending May 28, 1944 were followed by northeast circulation aloft over Assam and western China (Szechwan and Yunnan) simultaneously, and later in eastern China. The same phenomenon occurred June 24, 1944, although it was apparently not initiated by a trough. During 1943, several cases of relatively clear weather, which were initiated and ended anomalously, were noted over all China. The only criteria for these 10-day periods were northerly or easterly winds at middle and high levels. In cases studied (June 6-16, September 13-23, and December 6-16, 1943), surface pressures were average, and the situation must not therefore be confused with the case of intense surface high such as occurred October 1-10, 1943 shortly after one of the preceding cases of the ridge aloft.

The existence of the ridge aloft is demonstrated best by consideration of the winds aloft in Yunnan and Szechwan. With the onset of the clear period, upper winds are northerly or easterly, and usually continue so for about 4 days. Thereafter, they veer to south, with the eastward movement of the high cell aloft. (In these pronounced cases, of course, the cells are completely closed and they cannot be properly termed ridges, which remain open.)

It is apparent from the cases cited that the phenomenon is not confined to any one season, particularly since the case of September 1943 followed closely (on September 6) the onset of winter. Nevertheless, there is apparently a greater frequency in summer, probably because of the fact that the existence of easterly circulation is more common in this period, and the cells, therefore, are noted more often.

This paper has been an attempt to point out the great significance of upper pressure systems, the extent to which they modify surface phenomena, and the reorientation that appears necessary, in the forecaster's mind, with respect to the present "blank spot" occupied by Tibet and the Hump. Present knowledge on these points is admittedly scant, and it is hoped that the indications and conjectures set forth herein will serve to develop more fully the knowledge of forecasting for China.

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SOME ASPECTS OF EQUIVALENT-POTENTIAL TEMPERATURES IN RELATION TO WESTERN TROUGH PASSAGES IN YUNNAN PROVINCE

Before attempting to explain the correlation between θ_E (equivalent-potential temperature) values and western trough passages, it is necessary to explain the method of obtaining the θ_E values and the general characteristics of a "normal" θ_E map in China. By normal conditions are meant those in which the station concerned is neither under the direct influence nor just recovering from the influence of any frontal systems.

The values of θ_E are determined from the surface observations and are subject to some error. The standard pressure of each station is calculated from its elevation, also an approximate value. Then, using the pseudo-adiabatic diagram, the surface temperature and dew point are plotted at the station pressure, which is the standard station pressure plus or minus the difference between the sea level pressure and standard sea level pressure (1,013.2 mbs.). θ_E is then determined by the intersection of the mixing ratio line and the potential temperature line given by the temperature and dew point. Thus, θ_E varies directly with the temperature and dew point, although it varies more with a given change in the former than with the same change in the latter.

As for the "normal" map, the southwestern portion of China (that part of the map including Yunnan Province and the Gulf of Tonking) is all that concerns this paper. Under normal conditions, a warm tongue seems to extend northwestward from the Gulf of Tonking, through Yunnan Province, and thence northwards towards Szechwan Province. The equivalent-potential temperature at Mengtze is usually higher than that at Yunnanyi by about 10° C., and approaches that of Lunchow and Nanning. The value at Yunnanyi is, in turn, usually somewhat lower than that of Kunming and Chanyi. If one assumes that these calculations are based on correct station data and elevations, the axis of the warm trough lies somewhere near Mengtze and east of Yunnanyi.

The day preceding the passage of a western trough, the axis of the warm tongue seems to migrate westward. The value of θ_E at Mengtze either falls slightly or remains stationary, while that at Yunnanyi rises from 10° to 20° C., resulting in a value which is often higher than that of the stations to the east. This apparent shifting of the tongue of warm air toward the west might indicate that the warm air is no longer coming from the Gulf of Tonking but is now, at least partially, from the Bay of Bengal. This may or may not be true, since it is impossible to tell with the amount of data available. The fact remains, however, that a rise of 10°-20° C. occurs in Yunnan Province.

A rise of 5°-10° C. in summer is not ordinarily significant in the Yunnan Province, as the θ_E varies that much with no apparent reason during that season. Also, since the value of θ_E is higher in the summer, a 5° change does not represent as great a percentage variation as it does in the winter, a fact which may be more significant than the absolute value of the change.

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Associated with this rise in equivalent-potential temperature is a considerable rise in the mixing ratio which also indicates that more moisture has been sucked in ahead of the trough by the southwesterly trajectory.

After the trough passage from the west, there is an initial drop in θ_E, usually slightly less than the previous rise, so that the equivalent-potential temperature is either normal or slightly above normal. The mixing ratio, however, drops well below the former value. This may be accounted for in two ways: (1) the flow of warm moist air no longer continues because of the northwest trajectory, (2) the downslope motion of the air from the west has a drying effect. This change of θ_E and of the mixing ratio differs from the change following a cold front passage from the northeast. Behind these fronts the θ_E falls considerably below the previous 48-hour value and the mixing ratio falls somewhat lower, but never as much as after the passage of a western trough. Also, the marked rise in θ_E in Yunnan Province is not observed before a frontal passage from the northeast.

In the 24 hours following a trough passage, the values of θ_E in Yunnan Province again experience a slight rise, on the order of 5° C. Although this in itself is not significant during the summer, it is observed as well during the winter season. During this period the mixing ratio also rises to a nearly "normal" value, with the result that stations in Yunnan Province have a θ_E somewhat higher than normal and a mixing ratio which is about the same as under normal conditions.

These variations in θ_E and mixing ratio can be readily explained by studying the trajectory of the air over the station. Although equivalent-potential temperature is one of the most conservative properties of air, the surface layers especially are subject to some change by heating, etc., and since all values are calculated from surface data entirely, this change must be taken into consideration. On fair days during the summer, a rise of a few degrees over the previous 24-hour value is the rule. This rise is probably due largely to this surface heating, neglecting the continued flow of warm, moist air from the Gulf of Tonking. However, this rise is of only a few degrees and could not account for the rise of 10°-20° C. just previous to a trough passage, as would the southwesterly trajectory. Even though this might be purely an upper air phenomenon, the surface layers would be affected by mixing.

The fall in θ_E following or during the passage of the trough might be explained by the cooling which is caused by the overcast conditions that often accompany the trough, but this would not account for the drop in mixing ratio to well below a normal value. A trajectory from the northwest, on the other hand, would cease to bring up from the south the warm, moist air which, along with the foehn effect, would cause a drying of the air. There is also heating due to this latter downslope motion, which is probably the reason that the θ_E does not fall below the "normal" value.

The slight rise in both equivalent-potential temperature and mixing ratio during the 24 hours following the passage is easily explained by the renewed trajectory of the air out of the Gulf of Tonking.

To summarize, the changes that take place with the passage of a western trough are:

(1) the day previous to the passage there is a considerable rise in both θ_E and the mixing ratio to values well above "normal".

(2) during or just following the passage the θ_E value drops back to near normal, while the mixing ratio falls below its former value.

(3) during the 24 hours following the passage there is a gradual return to the normal mixing ratio, while the value of the θ_E rises a few degrees, probably because of the rise in mixing ratio.

RADIOSONDE AND PILOT BALLOON DATA AS USED IN WEATHER ANALYSIS AT YUNNANYI, CHINA

Meteorological conditions of the atmosphere as observed by radiosonde and pilot balloon ascents are of considerable diagnostic value, but it is only after careful diagnosis of a series of flights that their features can be formulated and be of prognostic value. A single flight is usually of little value to a forecaster, but a series of flights will reveal certain changes in the atmosphere which will enable him, in many instances, to analyze and foresee changing weather conditions.

In order to better interpret the features of the flights, some knowledge of the location of the station and the general character of the surrounding terrain is essential. The location of the Yunnanyi observation station is approximately 100.5° E. longitude and 25.5° N. latitude. It is situated in a narrow valley orientated northeast-southwest, with an elevation of 6,452 feet. Surrounding the valley are rolling hills for 50-75 miles, while farther away are higher mountains in all directions, with the lowest terrain to the east and northeast.

On April 12, 1944 an accurate aneroid barometer was installed in the station, giving a different station pressure reading. Therefore, in order that an accurate comparison of raobs can be made, those observations taken between April 12 and June 10 will be discussed.

Comparison was made between several raobs taken at approximately 1330 L.S.T. and the observations taken the night before, the time of release having been 2230 L.S.T. This revealed that diurnal changes occurred even as high as the 20,000-foot level. (It should be noted that the different levels referred to will be mean sea level; therefore, the 10,000-foot level will be approximately 3,500 feet above the valley floor, and the 20,000-foot level at about 13,500 feet.) Air mass thunderstorms were forecast numerous times because of the large positive area found on the raobs after energy diagrams were constructed, but a study of the afternoon soundings indicated why they did not develop. All of these soundings showed an increase of temperature at all levels. At the 10,000-foot level the increase was found to be as much as 10° C., and at 20,000 feet the maximum increase was 6°. Other diurnal variations were in relative humidity, which showed a sharp decrease as high as 45 percent at 10,000 feet, and the mixing ratio, which showed only a small decrease at times but more often showed an increase. Heating should normally increase the mixing ratio at the surface because of the added moisture picked up from the numerous rice paddies and water reservoirs throughout the valley. It is readily understood why the relative humidity decreases, however, when it is noted that this is a ratio of the amount of water vapor in the air to that which it would hold if saturated, and the diurnal heating would thus increase its capacity.

The reason for this diurnal change through such a deep layer is believed to be the thin atmosphere found at this altitude. Thus, the surface air heats very quickly, causing a very steep lapse rate, even temporarily super-adiabatic. This extreme instability causes rapid mixing and carries the heat to higher and higher altitudes as heating continues. On April 15, May 2, and June 2 and 6, 1944, mild convective thunderstorms developed and in all cases, positive areas capable of producing thunderstorms existed even after diurnal effects were taken into account. In considering those effects, the amount of cloud cover at all levels must be carefully noted, because even a low layer of clouds would prohibit insolation, thus preventing the formation of the instability layer necessary to carry the heat to higher levels.

Of several thunderstorms developing at Yunnanyi, the one occurring on the afternoon of June 2 will be discussed as an example. After an energy diagram had been constructed, it was found that a large positive area existed all the way from the surface to 400 mbs. Then after the curve due to diurnal heating was reconstructed, a very small negative area was present with positive area above that all the way up to 400 mbs. Even then it was thought that too much diurnal heating was anticipated because the skies were broken to overcast on June 2, and a study of the previous afternoon soundings revealed that on days when the sky was broken to overcast, as little as 1° C. increase took place, while on the day when maximum increase took place, less than 1/10 cloud cover existed the entire day. In addition to this favorable analysis of the raob, the nibal, on the morning of June 2, veered steadily from the surface to 16,000 feet, showing advection of warm air, then turned counterclockwise from that level to 20,000 feet, indicating advection of cold air. This situation is ideal for the development of thunderstorms, since it would tend to steepen the lapse rate, and it is entirely possible that a much larger positive area actually existed than that found after the curve was reconstructed. The thunderstorms developed at 1350 L.S.T., and although very little thunder was heard, convective showers occurred before the thunder and rain continued to fall for 4 hours afterward.

On June 5 a frontal thunderstorm and showers occurred intermittently between 1530 and 2030 L.S.T. An examination of the Rossby diagram from the sounding of the night before revealed that the air was convectively unstable, the equivalent-potential temperature having decreased more than 6° between the top of the surface isothermal layer and 20,000 feet. The front did not pass the station until between 1730 and 1830 L.S.T., but the thunderstorms began at 1530 L.S.T. Lifting, therefore, had taken place before the actual frontal passage. During other frontal passages in May and June, the air ahead of the fronts was convectively stable, and no thunderstorms developed.

Fronts rarely passed Yunnanyi during the winter months, but during May and June they became more frequent and passed on May 4, May 9, June 5, and June 9. No method of forecasting the passage of these fronts by the raobs has yet been determined, but the soundings taken behind the front have given valuable aid on explaining the type of front and the consequent weather. In fact, it was not until after study of the raobs that the fronts could be followed with any degree of success on the synoptic chart, because little was known about them.

These fronts are cold fronts moving from the northeast against the southwest flow of air and are usually very weak and shallow at Yunnanyi. Overrunning takes place, giving warm front type clouds and rain behind the front. Instead of the usual low accompanying a front, there seems to be nothing more than a cold, and consequently shallow, high pressure area behind the front, the forward portion of which is made very indistinct by mixing. A shallow system should be a fast-moving one, but in this case it is slowed down, not only by its abnormal movement against the southwest flow, but also by the uphill movement towards Yunnanyi and the friction caused by the rugged terrain over which it passes. It may also be that the air mass farther behind it to the northeast is very deep, although it usually does not move as far southwest as Yunnanyi. These same factors which cause the front to move slowly also cause mixing to take place, and the part of the front which passes Yunnanyi is frontalyzed within 50-100 miles to the southwest. An examination of the Rossby diagrams, drawn from raobs taken just before the front passed and again 24 hours later, show a definite change in air mass, a sharp decrease in equivalent-potential temperature having occurred. The relative humidity and mixing ratio may vary according to the amount of precipitation following the front; that is, it is entirely possible that the relative humidity may increase with a decrease in mixing ratio. This can be understood when it is considered that these observations were taken in two different air masses, one being colder, and consequently the mixing ratio may be even lower, though the air is saturated. These changes are completely wiped out in 18-36 hours by mixing with the mt air from the southwest.

Although only four fronts passed Yunnanyi during the months of May and June, they were responsible for much of the non-flyable weather and by far the greatest amount of rainfall. One frontal passage may cause nearly as much rainfall as in the combined months of January, February, March, and April.

The use of radiosondes in detecting monsoon flow and consequent weather has been valuable, as yet, only in following the changes in moisture content. The changes in height of the tropopause have not been studied because of the infrequency of soundings at that height. From the few soundings which have reached the tropopause and from other flights which have gone to considerable distances without reaching it, the height of the tropopause is believed to be approximately 19 km.

Pilot balloons were valuable during the winter months for forecasting Hump weather. Winds aloft having a northerly component were associated with cloudless skies, both at Yunnanyi and over the Hump. This can best be illustrated by specific examples. On February 27, 1944, the Hump was overcast with tops which built up to about 18,000 feet. The pibal observation on the morning of the 28th was as follows:

12,000 ft.	100°	12 knots
15,000 "	340°	27 "
18,000 "	320°	41 "

Yunnanyi was clear all day and only a few cirrus clouds were observed over

the Hump. On March 5 the winds did not have much northerly component:

12,000 ft.	250°	8 knots
15,000 "	290°	45 "
18,000 "	280°	55 "

Broken clouds were observed over the Hump, with tops about 15,000 feet. It may be noted also that a very strong advection of warm air existed between 12,000 and 15,000 feet with advection of cold air above, making a favorable condition for cumulus development. On March 6, winds aloft and clouds remained about the same, but on the 7th, they had lost their northerly component:

12,000 ft.	260°	36 knots
15,000 "	270°	42 "
18,000 "	270°	45 "

The Hump was overcast, with tops at 18,000 feet.

These northerly winds show that a high pressure area existed in the direction of the Hump. The approximate position of this high could be placed by the northerly component of the winds. If the high was far enough north, upper Assam often had practically cloudless skies, but if it was farther south, upper Assam and the first ridge had large cumulus build-ups, while clouds over the Hump itself remained scattered.

Even better weather existed in the Lashio area and central Burma. This is readily understood when it is noted that the high must necessarily be located in the general area southwest of Yunnanyi, that is, central Burma. Even though the high exists in northern Burma, a high pressure area would still exist aloft over central Burma, since the axis of a high must tilt toward the warmer air which would be towards Lashio and south-southwest over Thailand. Winds aloft during the greater part of the winter are from 2500 to 270°, placing a high pressure area to the south of Yunnanyi. Lashio would still be under the influence of this high and would continue to have good weather. These conclusions were substantiated by numerous mission reports over these areas.

During the transitional period from winter to the monsoon season, pibals are used mainly to detect the direction of the air flow aloft. One significant fact is that southwest and south-southwest winds bring in early morning stratus around the mountain tops, while no stratus formed with winds from a more westerly direction. The explanation of this seems to be that higher terrain exists to the west than to the southwest, and therefore more adiabatic heating takes place on the downward flow of the air towards Yunnanyi--enough to prevent formation of stratus.

WEATHER OF FORMOSA AND THE FORMOSA STRAITS

Location and Topography

Formosa (Taiwan) extends from 21°55' N., 120°50' E. at its southernmost point to 25°13' N., 121°33' E. at its northern tip. The island runs parallel to the east coast of China from 23° N., 120°05' E. to 25°18' N., 121°33' E., and forms the eastern edge of the Straits of Formosa. Formosa is located approximately 120 miles from Foochow, and about 140 miles from Amoy. It is 90 miles at its widest point, and is approximately 240 miles in length.

The terrain is rugged with the exception of the west coast -- central Formosa, southwestern Formosa (Gosei to Boryo) and northwestern Formosa (Shinchiku to Chikui), where there is a plain from 10 to 30 miles in width. There are three large mountain ranges on the island, the most important being the Niitaka Range, which is on the eastern section of the island and runs north-south. Paralleling this range is the Taito Range, which runs from Taito to Karenko along the eastern coast of the island, and the Sankui-rei Range, which is west of the Niitaka Range. Another range, the Daiton Range, lies in the northern section of the island. The mountains rise gradually from the western edge of the plain to the east, where they reach their peak about 30 miles from the eastern coast of Formosa. The highest mountains are in the Niitaka Range and reach a maximum at Mt. Miitoka (13,075 feet). The mountains reach a secondary maximum height at Mt. Tsugitoka (12,972 feet). Along the northeast coast is a small valley approximately 20 miles long and 10 miles wide at its widest point, Tai to Suo. Farther south along the eastern coast is another valley beginning at Karenko and extending to Taito. This valley is but a few miles in width and lies between the comparatively low Taito Range (1,651-3,518 feet) and the Niitaka Range, which rises abruptly along the west side of the valley to 5,000-7,000 feet, and a few miles farther west, to 10,000-12,000 feet.

In approximately the center of the island is Lake Jitsugetsutan, which is comparatively small and drains into the Seira River on the west coast of Formosa. There are a number of rivers on the island but none are of appreciable size. The drainage is primarily to the west; the line of demarkation is approximately 20-30 miles from the east coast of Formosa and extends southwest-northeast. The larger rivers are on the west coast; they are the Tamsui, Taiko, Seira, Sobun, and Hilmo Tamsui Rivers. The most prominent rivers on the east coast are the East Dakusui and the Lokka.

In the Straits of Formosa are the Pescadores Islands, which are small barren islands about 35 miles west of Formosa. They are low, and do not reach a height greater than 200 feet.

The terrain along the southeast coast of China from Foochow to Swatow is quite irregular. Approximately 40 miles inland from Foochow are mountains 4,625 feet in height. These extend southwest with decreasing height and are approximately 3,095 feet high 40 miles north-northeast of Amoy. The mountains southwest of Amoy are nearer the coast of China and are about 3,300 feet in height. There is no extensive range which reaches any appreciable height

in this section of southeast China. There are mountains north of Amoy which reach a height of about 6,000 feet, and they constitute the highest in this section of China. The terrain in general is quite irregular, with a number of small valleys interspersed in this area. There are no large rivers in this sector. The two most prominent are the Min River, which drains at Foochow, and Feitsian River, which drains into the Formosa Straits at Swatow. There are, however, a number of smaller rivers.

The terrain at some of the more important cities on Formosa may be described as follows:

Taihoku lies about 18 miles from the northern tip of Formosa and is bordered on the north and southeast by mountains about 4,000 feet high. The mountains to the southwest of the city are about 1,400 feet in height, as are those near the city; those to the west of the city are 2,000 feet in height. The river drains to the northwest.

Shinchiku lies in a plain on the northwest coast of Formosa, approximately 3 miles inland. The terrain is flat to the west and north, while to the northeast and east there are mountains which rise to 1,500 feet, and a short distance eastward, to 1,000 feet. To the southeast and south, several miles from the city are small hills which rise to 700 feet, and to the southeast are mountains which rise to 6,000 feet.

Takao is located on a plain on the southwestern coast of Formosa. To the north of Takao close to the city is a flat-topped hill 1,170 feet high. To the northeast are the foothills of the Niitaka Range, which extend north and south. To the east of these foothills and 10 miles from Takao is the Shimo Tamsui River. Takao is approximately 25 miles west of the Niitaka Range.

Tainan is located on the southwestern coast of Formosa and is approximately 3 miles inland. It is on the western plain of the island and is about 10 miles from the Niitaka foothills, which are about 1,000 feet in height.

Taichu is about 13 miles inland from the western coast of Formosa and lies in a valley separated by a range of low hills, which are west and south of the city and rise to 1,000 feet, and mountains to the east which are about 4,000 feet high. The city lies on one of a number of small rivers which drain this valley.

Karenko lies on the east coast of Formosa on a narrow plain about 5 miles east of the Niitaka Range, which rises abruptly to 6,000 feet. To the southeast of the city and along the east coast of Formosa is a range of low mountains. Close to the city is the Lokka River, which drains into the Pacific.

The Kuroshio (Japan Current)

The Kuroshio flows northeast from Formosa to the Ryukyu Islands as far as 35° N. The continuation of the current as it flows east is known as the Kuroshio Extension. Its flow reaches 180° E. and from there it is known as the North Pacific Current.

Another current flows southwest along the coast of east China through the Straits of Formosa and is known as the East China Current.

The salinity of the Kuroshio is less than 35 percent. During the summer, the salinity along the east coast of China to Foochow is 30 percent; it increases through the Straits of Formosa to approximately 33 percent and reaches 34.5 percent at the southern and northern tips of Formosa. The isotherms of the surface water in the Straits of Formosa run in a southwest-northeast direction throughout the year. A considerable temperature gradient is noted in the winter. In winter the isotherms to the east of Formosa run uniformly in an east-west direction. The temperature gradient in the Straits of Formosa is from approximately 15° C. on the east coast of China to 20° C. on the west coast of Formosa. During the summer season the difference is about 1° C., the temperature being 27° to the west of the straits to 28° farther east. The temperature variation with depth of the Kuroshio is quite uniform. This situation is perhaps due to the heating and cooling at the surface and to transmission below by conduction.

During the summer season the Kuroshio does not emit much energy, while during the winter season, 300 to 600 g. cal. /cm²/ per day are emitted.

Air Masses

The island of Formosa is under the influence of several air masses. During the winter the polar continental air mass, which has its origin in the Siberian High, and the modified polar continental air mass, which has been influenced by its trajectory over the Pacific, are dominant. During the Southwest Monsoon period (the summer season) the tropical maritime and the equatorial air masses are predominant.

Winds

Formosa is affected by the Northwest and Southwest Monsoons. During the winter, northeast winds are dominant, flowing from the Siberian High and converging into the Equatorial Low. The wind is from this direction most of the time from September to May. The average velocity of the wind is greater during this season and reaches its maximum in the Straits of Formosa as a result of the compression of the air as it passes through the channel formed by the Formosa mountains and the mountains along the southeast coast of China.

During the summer there is a general reversal in the direction of the wind; the dominant direction is southerly. These winds converge into the Tibetan Low. In addition to the monsoonal effect, Formosa is at this time of the year also under the influence of the trade winds, which change direction from southeasterly to southwesterly as they cross the Equator and enter the Northern Hemisphere. The winds in the Formosa Straits are southwesterly at this time of year. The average wind velocities are lower during this season, but the maximum velocities have been recorded during this period, since it is at this time of the year that typhoons are present and it is not uncommon for the wind to exceed gale velocities with the passage of one of the phenomena.

There is little information other than pilots' reports concerning the upper winds over Formosa. From November 1943 to April 1944, the winds aloft from 25,000 to 30,000 feet were predominantly from the northwest and at times reached velocities greater than 150 m.p.h. There were, however, several instances in the spring when the wind was from the southwest, and at times its velocity was less than 50 m.p.h. The intensity of the wind during the spring seldom exceeded 75 m.p.h. The direction of the winds aloft during the fall and winter quite closely follows the mean isobaric 4-km. pressure chart. Excessive wind velocities from the northwest have been noted during the fall and winter from Hankow to Shanghai.

During the summer season the winds aloft above 25,000 feet are from the south to the southwest from Canton to Swatow and do not reach high velocities. The winds again follow the mean 4-km. pressure map.

Cloud Coverage

The cloud coverage on the western side of the island (about 5.8 tenths) is much less than that on the eastern side (7.5 tenths).

During the period of the Northeast Monsoon, modified polar continental air invades the island. Polar continental air is dry and stable as it leaves the continent; when it passes from colder to warmer water as it travels over the Pacific and the Sea of Japan, it picks up moisture and becomes convectively unstable. This air, as it approaches the island from the northeast and east, gives a great deal of cloudiness as it rises over the mountain ranges in the northeastern and eastern section of the island. As a result of this orographic lifting, there is an almost permanent cloud coverage on the mountains of eastern Formosa, while the western side of the island has few clouds because of the foehn effect. It is during the fall that the best weather is prevalent in western Formosa. However, clear skies often prevail after the passage of a cold front in east Formosa.

During the summer season, the mean cloudiness increases on the west side of the island and tends to decrease on the east side. It is at this period that the island is under the influence of tropical maritime and equatorial air masses.

Thunderstorm activity is most frequent from June to September and reaches its maximum at Tainan during July and August, when there are 10 or 11 thunderstorms a month. Due to the nature of the topography and air masses, thunderstorms and orographic showers are naturally frequent during this season.

Typhoons, which are most frequent from June to August, affect the weather and give low ceilings, precipitation, and strong winds for a period of 1-5 days

John Lee, in his article, "Dynamical Effect of Eastern Chinese Coastal Winds", has set forth a theory concerning the cause of cloudiness in the Straits of Formosa. He explains that there is a channel formed by the terrain of eastern China and Formosa through which the air must pass. As the air is blown through the channel its velocity increases and the air expands and rises;

thus it is cooled adiabatically and clouds are formed. The cloud coverage in the Straits of Formosa is from 6/10 to 8/10 and is usually altocumulus or altostratus, with tops at 8,000 to 10,000 feet. According to pilots' observations, there is always a layer of clouds in the straits which is generally broken, ending at the western end of the island. There is little information concerning ceilings on Formosa. Reports from pilots indicate that the semipermanent clouds over the mountains of eastern Formosa are several thousand feet thick during the winter, fall, and spring periods.

Icing

The icing level during the summer will be greater than 20,000 feet and will be found in cumulonimbus clouds. During the other months of the year the icing limits in feet are as follows:

Jan	Apr	Oct
15,000-7,000 ft.	13,000-20,000 ft.	12,000-20,000 ft.

Visibility is usually good over the island and in the Straits of Formosa. Pilots have reported unlimited visibility during the fall, winter, and spring seasons. It must be noted, however, that these observations were made under ideal conditions. The restriction to visibility caused by haze on the mainland of China is not as pronounced over Formosa. Fog is present from October to May and is found mainly on the western side of the island. This is because the colder air passes over the warm water.

Forecasting for Formosa

During the fall season of the year, weather conditions are very good on Formosa and cloud coverage is a a minimum on the western side of the island. During this period the weather on the island will be affected a great deal by frontal systems which have their origin in northwestern China. The characteristics of frontal systems must be studied while they are on the mainland of China in relation to their velocity, intensity, height, etc., since the mountains on the eastern side of the island will have a tendency to retard them and leave a great deal of cloudiness on western Formosa after the system would be expected to be beyond the island. During this period, typhoons occur and greatly affect the weather.

During the winter period, the cloud coverage is again quite low on the western side of the island but increases on the eastern side. At this time of the year there is a well-developed high over China, which is under the influence of the polar continental air mass, a dry, stable air mass. When the pressure field is flat and the isobars have a short sea trajectory, good weather may be expected on western Formosa, for the air has had little opportunity to pick up moisture. When the center of the high is farther northeast and the isobars assume a west-northwest east-southeast pattern, the polar continental air becomes influenced by its trajectory over the warmer water and picks up a great deal of moisture. When this air is lifted over the island from the east or northeast, clouds form, thus accounting for the greater cloudiness on the eastern side of Formosa during the winter. Because of the foehn

effect, cloudiness is less on the western side of the island. However, when the air has had a long sea trajectory, broken to scattered clouds will often be found on the western side of Formosa while the eastern side will be practically overcast. During this period, clear to scattered conditions can be found on the eastern side of Formosa immediately after the passage of a fast-moving cold front. When there is a frontal system on the mainland of China but quite close to Formosa, weather will usually be very good on the island. Fog is most frequent on the western side of the island during this, and, to a lesser degree, during the preceding period, since with a west wind, the cold air is passing over the warm water which has a large temperature gradient across the straits. During this period, the best weather will be encountered during the late morning, for at that time the fog will have dissipated. Winds aloft during this and the greater part of the preceding period are invariably northwest and reach excessive velocities above 25,000 feet. Velocities greater than 150 m.p.h. have been noted.

During the spring, cloudiness tends to increase as a result of the breaking down of the high pressure system over China, and frontal activity. A flat pressure field will tend to give good weather over Formosa. With a good southwesterly flow aloft and a strong flow into the low on the continent, bad weather can be expected while the front is some distance from the island. Good weather will also prevail over the island when it is in the warm sector of a cyclone. The island is still under the influence of the Northeast Monsoon at this time and cloudiness is greatest on the island, especially on the northeastern and eastern sides. During spring, the winds aloft are variable between northwest and southwest above 25,000 feet. Fog also occurs during this season.

At the summer season, cloudiness increases on the western side of the island and decreases on the eastern side. At this time, the island is under the influence of the equatorial and tropical maritime air masses. The continent of China is dominated by a low pressure area. When this pressure field is flat, good weather prevails over Formosa. When the Pacific High increases and pushes on to the continent or when this high breaks into two cells and pushes into China, the weather of Formosa is usually bad and showers prevail along the southwest periphery of the high. Typhoons are most prominent at this season and, since they usually have a sea trajectory before entering the mainland or Formosa, it is quite difficult to forecast their position with limited data. The presence of a typhoon might be forecast by closely observing the pressure field, the stations near the coast, and the winds on the surface and aloft. Irregular wind shifts and unusual velocities are a hint to the presence of a typhoon. Typhoons in many cases follow each other closely, and may be only two days apart. Weather in many cases clears up rapidly after the passage of a fast-moving deep low pressure area. Typhoons tend to dissipate soon after they reach the continent. Thunderstorm activity is prominent during this season and early fall. Because of the topography and air masses present, most of the thunderstorm activity would be orographic. Many stations have two maxima of clouds during this season, the first being in the early morning and the other during the middle of the afternoon when convective activity is at its greatest. In general, weather will be best during the late morning hours. Fog is not very frequent during summer. Winds aloft will be south to southwesterly during the greater part of this season.

C5-5119,AF

SOUTHERN EXTENT OF THE CHINA HAZE

The phenomena which have been observed to limit visibilities in southwest China, the Gulf of Tonking, northern French Indo-China, Thailand, and Burma would probably more correctly conform to the international definition of mist than to that of haze. However, the name of "haze" for this condition has gained common usage among both air crews and weather men.

According to Petterssen*, mist consists of microscopically small water droplets or of highly hygroscopic particles suspended in the air. The droplets in mist are smaller and more scattered than in fog, and as a result, the horizontal range of visibility is greater than 1 km., which was fixed by international agreement as the limit of visibility between fog and mist. Haze consists of finely divided dust particles from arid regions or of salt particles which and dry and so extremely small that they cannot be distinguished individually by the eye but which diminish the visibility and give a characteristic smoky (haze opalescent) appearance to the air. Haze produces a uniform veil over the landscape and subdues its colors. The veil has a bluish tinge when viewed against a dark background, but a yellowish orange tinge when viewed against a white background. This distinguishes it from the grayish-white mist.

The lack of uniformity of visibilities, the characteristic mist color, and the necessity that the air be over a region of high humidity before the visibilities greatly decrease indicate the nature of the particles in the air with which we are concerned. However, maritime modification of air does not alone cause this mist or haze, since air crews have never reported bad visibilities in the maritime tropical air in the southern half of the French Indo-China-Thailand peninsula. In fact, traveling south, the end of the haze is always rather sharply defined and takes place at a weak but unmistakable front. Therefore, this haze must be produced by a combination of certain characteristics of the polar continental air present at the time it reaches those southern regions and must be characteristic of the regions themselves. The air itself originally must contain a large quantity of hygroscopic impurities, since the evolution of the haze is so rapid. The fine dust from the desert source region in north China may be a partial explanation of this phenomenon, but since this dust is not especially hygroscopic, it can not be the complete explanation. It is more probably the smoke from fires in millions of villages all over China, passed by the air on its southward journey, which furnishes the necessary hygroscopic materials. This, together with the subsidence inversions which would form as the newly arrived air mass begins to age, produces perfect conditions for the haze if the stagnation takes place in a region of high humidity.

In order to demonstrate this theory satisfactorily, it should be shown first that every time heavy haze was encountered in the Tonking Gulf, north Indo-China, or Thailand, there was evidence of a front to the south; i.e., the hazy air mass did not extend indefinitely to the south, thus was not part of the maritime tropical air mass but rather modified air of continental origin. Second, on those occasions when the weak front to the south was passed, visibilities become unlimited, i.e., this haze is not found in

*Petterssen, Sverre. "Weather Analysis and Forecasting"; McGraw-Hill, 1940.

the maritime tropical air. Third, when there are two hazy air masses which would be separated by an east-west front lying approximately along the south coast of China, the more recent outbreak is less hazy than the older air which is just to the south and also above the newer air; i.e., when there is no activity along the fronts, the strength of the haze is proportional to the time the air has stagnated over the region of high humidity.

The following information was obtained from air crew and personnel observations on bombing missions from the first of February 1944 until the rainy season virtually ended the haze conditions, about June 1.

During the period February 17-19, 1944, a new air mass had passed south over the Gulf of Tonking until the front, reported as a heavy build-up of clouds extending eastward, was in the region of Vinh. A secondary front extended past Wanshan eastward, just south of the coast, resulting in low ceilings and fog, with visibilities reported less than 2 miles on all 3 days. North of the northern front, slight haze may have been present but was not reported. North of the southern front, on the first day when the air mass was new and conditions unsettled, ceilings were low and visibilities were bad. However, on the second and third days, overcasts began to break and haze with visibilities 6-8 miles resulted.

During the period from February 27 to March 6, 1944, a front lay along the Indo-China border south of Kunming, extended in the direction of Haiphong, and then continued eastward just south of the China coast. A second front was found again extending east from Vinh. On the 27th, visibility over the Gulf of Tonking between the two fronts was 4 miles with haze, while visibility over land in Indo-China was somewhat better. No mention was made of near-surface visibilities north of the northern front, but the haze from the south was reported to extend above the frontal clouds near Hanoi. On the 28th, frontal positions and visibilities were reported unchanged. On March 2, reports were again collected, but only for the northern part of the gulf. According to these, frontal conditions had not changed, except that the northern front had progressed south 10-15 miles. By now the synoptic situation in this region had been stagnant for some time. Visibility at the south China coast was reported 6-7 miles, but much worse above the clouds, which extended from the surface front slightly farther south. On March 4, more explicit information was gained. The region from Kaoning to the coast had visibility 8-10 miles, and just off the coast near the small islands the visibility was 6-8 miles. Farther south in the region of Nam Dinh, Than Hoa, and South, visibility was 3-5 miles. Conditions on the 6th were unchanged, except that visibility aloft had dropped to approximately 1 mile.

On March 22 and 23, information was not complete, but a line of frontal weather was reported along the Indo-China border south of Kunming, turning south and lying along the coastal ranges toward Vinh, and from there moving out to sea. Visibility on land had decreased to 6 miles with haze, and over the gulf, was reduced to 2-3 miles.

March 28-29 had continued reduced visibilities from haze up to 12,000 feet, the only difference being a new cold front moving down onto the gulf, which gave frontal weather to a depth of 4,000 feet over the southern part of the gulf.

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During the period April 7-15, the synoptic situation had again become relatively stationary. There was a weak front lying along the Burma border, continuing along the Indo-China border, looping south through Indo-China, and back north along the Indo-China coast and the east side of Yunnan. During this period it moved southeast onto the gulf and began to retrograde, without influencing the haze situation. On the 6th, only slight haze was present in the morning over China and the gulf to central Hainan, but the afternoon haze reduced visibility to 2 miles. On the 7th and 8th, haze had increased so that from approximately 25° latitude to south of Hainan, visibilities were 1 mile up to 11,000 feet, being somewhat improved to 4 miles as a result of turbulence between the surface and 3,000 feet. Up until this time there had been no evidence of a front to the south acting as a southern boundary to the hazy air. However, the winds in this region had been persistently southerly, and at approximately 0500 on the morning of the 9th, the high altostratus of a warm front was observed above the southern coast of Hainan Island. This front continued to move up, reaching its most northerly position some time on the morning of the 13th, when the frontal clouds consisted of broken altocumulus, with bases at 16,000 feet near Kwanghan, thickening to overcast altostratus with bases at 14,000 feet at the coast. This continued to thicken and lower until at Hainan Island it was observed to touch the mountain peaks, which are 6,000 feet high. On the 14th, the system had already moved some distance south, and altocumulus at 14,000 feet over Hainan was the only remaining sign. The last report of this period on the 15th came from the region of Hanoi. This territory was covered by the newer polar continental air behind the northern front described above. Visibilities near the surface were from 9 to 10 miles, but aloft they were still reduced to 1½ miles, with the heavy previously observed farther south.

The above information places the haze in the air at the latitudes of the Tonking Gulf, bounded on the south by a front. Information was available on visibilities south of this front on and after April 24.

On April 24, a weak but unmistakable front running west-northwest from the Gulf of Tonking was encountered south of Szemao (at 21° latitude). To the north of this line, visibilities were, in general, 4 miles, but decreased sufficiently in the vicinity of Szemao to cause instrument conditions. South, visibilities were unlimited, as before.

On May 25, a weak front was observed lying along and just south of the Red River, a second, stronger one crossing the course just south of Wan Pa Hsa (at 21° latitude). From Yangkai to the Red River, visibilities were 9-10 miles with haze, and decreased to 6 miles in late afternoon. Between the Red River and Wan Pa Hsa, visibilities averaged 7-8 miles with haze, while south of 21° latitude to the latitude of Rangoon, unlimited visibilities were observed. From that date (May 25, 1944), instability accompanying the rainy weather practically ended haze in the southern area, and operations were too limited for complete information.

It is not intended to convey the impression that the haze is confined to the southern coastal region of China, since on February 28, 1944, the haze was reducing visibilities in the gulf to from 3 to 5 miles, another

haze area was observed in the Tungting Lake region, also reducing visibilities to approximately 3 miles.

No accurate information is available on the northerly extent of the haze, which spreads from south of Kunming but it is apparently brought inland by the prevailing southerly winds, gradually moving northward during a period of frontal activity. As regards its upward extent, reports have always indicated a definite top to the layer at an average of 12,000 feet. Undoubtedly, it may have risen higher on unusual occasions, but the highest it was recorded during the season was 15,000 feet on March 29, 1944. As a practical conclusion from this pilots should be instructed before take-off in such conditions that if the haze interferes with operation, they can probably climb above it very easily.

Finally, the clearing of the haze seems to be dependent only on frontal activity, which increases the circulation and brings down new polar air.