Minimum Temperature Forecasting at Naha, Okinawa by Statistical Techniques

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Isao NAKAMURA *

Abstract

Both a linear multiple regression method and a graphical method were tested to forecast the minimum temperature at Naha, Okinawa during the winter. The predictors, observed at 0900 local time of the previous day, were selected very carefully according to certain criteria. Due to the characteristic features of predominated northeast monsoon around Okinawa during the period, the predictors associated with large circulations were preferable to the local parameters themselves. Though the resultant prediction equation and prediction diagram showed no apparent difference of forecast accuracy, both were considerably better than the method of persistence. Large error-producing synoptic situations during the use of the methods were also revealed.

1. Introduction

Recently, in England, Freeman (1959, 1961) developed a statistical forecasting technique in meteorology. The method, which is called the graphical method, requires the use of a composite forecasting diagram drawn by fitting a curved surface to the basic data by the method of least squares. It has been used to forecast visibility three and six hours ahead and very encouraging results have been obtained, indicating some capability of the method for forecasting some other meteorological elements for some other forecasting time range.

Use of a linear multiple regression equation is one of the most frequently adopted methods in statistical forecasting. It works fairly well especially when applied to short period (2 to 7 hours) forecasts. Many investigators have also tried this method for long time range (24 hours or more) forecasts and gotten very hopeful results. But their data for both predictors and predictands comprise averages of meteorological variables (Aubert et al., 1959;

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* General Education Division, University of the Ryukyus.

Klein et al., 1959; Stidd, 1954).

The present paper describes a study to test the forecast accuracy of these two techniques applied to instantaneous meteorological variables (directly observed variables) for a relatively long forecasting time range. Limited predictors carefully selected according to certain criteria were fed into the test. The minimum temperature at Naha, Okinawa was treated as the predictand for both techniques, because I wanted to try to improve, if it were possible, the operational minimum temperature forecasting methods for Naha which have been considered unsatisfactory. Brief explanations of the present minimum temperature forecasting techniques at the Ryukyu Weather Bureau are given in Chapter 2.

The investigation covered only the winter-months, December to February. The characteristic climatological features around Okinawa during the winter are the strong northeast monsoon associated with a high on the continent and a low southeast of Japan such as seen in Fig. 1 and very frequent formation and passage of cyclones often accompanied by fronts. It therefore seems natural to associate the variation of minimum temperature over the area

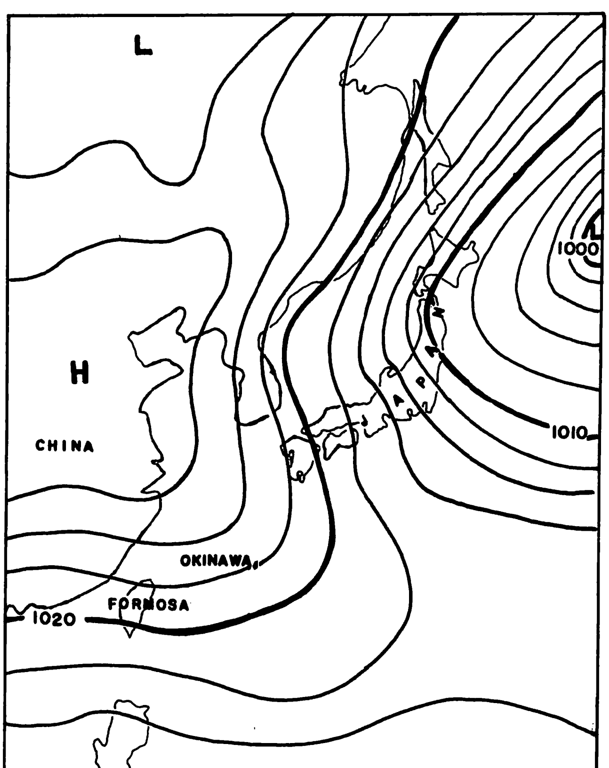

Fig. 1 Typical winter-time pressure distribution around Okinawa. (After Takahashi, 1957)

mostly with these large scale circulations rather than with local effects, when a relatively long forecasting time range is concerned.

In addition to surface parameters, some parameters at 700 mb. height were taken into consideration for the predictors because of an expectation of a lag relation between the surface minimum temperature and the upper level circulation. The observation time for all the predictors used here were 0000 GMT (0900 local time) of the previous day. The data used for the study consisted of six winters of dependent data, from 1958–59 to 1963–64, and two winters of independent data, 1964–65 and 1965–1966. All are available in "Daily Weather Maps" and "Aerological Data of Japan", both prepared by Japan Meteorological Agency in Tokyo.

2. Operational minimum temperature forecasting methods at the Ryukyu Weather Bureau

The Ryukyu Weather Bureau uses three techniques operationally to estimate minimum temperature at Naha. The first one is a simple statistical or climatological method using the diurnal variation of temperature. For each month, they classify the diurnal variation of temperature in the past records according to weather conditions and wind directions and determine the mean diurnal range of temperature for each class. Then, observing the maximum temperature with weather and wind direction they determine the appropriate value of minimum temperature for the following morning by simply subtracting the value of the diurnal range from the maximum temperature.

The second technique uses the temperature (T_{18}) and wet-bulb temperature (T_{18w}) at 1800 local time to forecast the minimum temperature (T_{min}). From past data for the particular month, they have determined a regression line on a ($T_{18}-T_{18w}$) versus ($T_{18}-T_{min}$) graph. Several regression lines are prepared by considering various weather conditions at the forecasting time and the conditions forecasted for the morning. In the case of Fig. 2, for example, the regression line is used when the 1800 local time weather is cloudy or rain and the expected morning weather is fair. Knowing $T_{18}-T_{18w}$ for the given regression line, the forecaster finds $\triangle T=T_{18}-T_{min}$ and obtains the minimum temperature by $T_{min}=T_{18}-\triangle T$.

The third way of estimating minimum temperature is based on the assumption that, if the meteorological situations at the forecasting time are the same for any two cases, the deviation of the forecast minimum temperature from the previous day's minimum temperature will be the same. For every possible synoptic situation for a particular month the occurrence frequency of some range of the deviation is examined from the past records (see Fig. 3, for example) and the most representative value of the deviation ($\overline{\triangle T_{min}}$)

is determined in such the way that the most frequent occurrence is found between $\overline{\Delta T}_{min}-1.5°C$ and $\overline{\Delta T}_{min}+1.5°C$ (this corresponds to the shaded area in the figure). This method should forecast the minimum temperature within ±1.5°C for the given meteorological situation. In Fig. 3, for example, the appropriate value of $\overline{\Delta T}_{min}$ is −1.6°C, thus the expected morning minimum temperature is 1.6°C higher than the previous day's minimum temperature when a front is situated north of Okinawa.

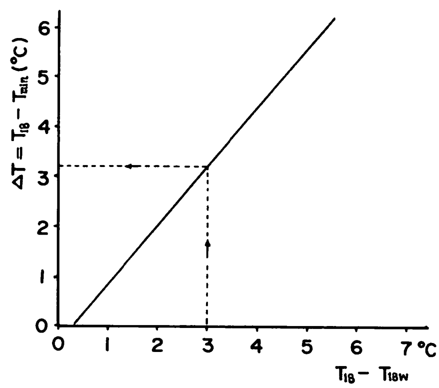

Fig. 2 The regression line for the case when 1800 local time weather is cloudy or rain and verifying time weather is fair.

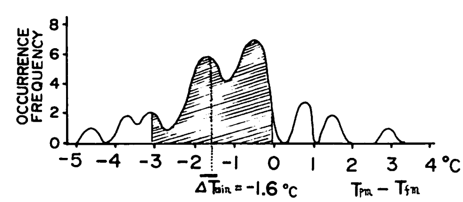

Fig. 3 Occurrence frequency of the deviation of forecasted minimum temperature (T_{fm}) from the previous day's minimum temperature (T_{pm}).

All these three methods (i. e., the use of a diurnal temperature range, a regression line, and a minimum temperature deviation) are statistical approaches, and the success of each method, aside from the merit of the method itself, depends heavily on the forecaster's choice of the synoptic situation at forecasting time and his ability to accurately predict the situation at verifying time. Thus, one's erroneous judgements obviously cause large errors in the forecast minimum temperature. Although the forecast was made at 1800 local time every day, unfortunatately none of the forecasts have been stored, so that the quantitative comparison of their methods with the two techniques I have used was not possible.

3. Selection of predictors

Like all other techniques of statistical forecasting, the selection of predictors was one of the most important parts of the study. The criteria for selecting predictors were:

1) difference chart of a meteorological variable,
2) scatter diagrams of minimum temperature versus any other meteorological variable,
3) previous studies of the same nature,

4) personal meteorological experience, and

5) regularity of data reporting.

In order to see the tendency of the lag relationship between the predictand, the minimum temperature at Naha, and other possible meteolorogical variables the winter of 1963–1964 was examined for criteria 1) and 2) above.

(a) Difference chart of a meteorological variable

Ideally, for a meteorological variable to be a good predictor it has to show wide range of variation at the forecasting time with the subsequent change of the predictand. This feature of the variable is easily found by using a difference chart of the variable. Associated with extreme high value of the predictand, a set of contour lines of a variable at the forecasting time was prepared, and associated with an extreme low value of the predictand, another set of contour lines for the same variable at the forecasting time was also prepared. By the graphical subtraction between these two sets of contour lines, one can obtain a difference chart of the variable. The resultant chart shows the distribution of the variation range of the variable associated with the extreme change of the predictand. Thus, the portion of the chart over which the difference is large indicates the area in which the variable may be employed as a good predictor.

In this investigation, difference charts for surface pressure, surface temperature, surface dew point, 700 mb. height, and 700 mb. temperature were constructed. Two situations were randomly selected. One pair of extreme high and low minimum temperature at Naha was observed on January 23, 1964 and January 20, 1964 and the other pair of high and low was on February 9, 1964 and February 13, 1964. Since the forecasting time for all the four cases was 0000 GMT on the previous day, the graphical subtractions were done by subtracting the 0000 GMT variable on January 19, 1964 from the same variable on January 22, 1964 and the 0000 GMT variable on February 12, 1964 from the same variable on February 8, 1964. The resultant difference charts are shown in Fig. 4 to Fig. 13.

From the pressure difference charts (Fig. 4 and Fig. 5) it was found that surface pressure over the Tohoku area of Japan is possibly positively correlated with the minimum temperature. The same variable over the southeast part of China is also possibly correlated negatively.

In the same way, the temperature difference charts (Fig. 6 and Fig. 7) suggest that in the area near Shanghai the temperature may be a good predictor. A very similar statement can also be made for the dew point (Fig. 8 and Fig. 9).

The 700 mb. height difference charts (Fig. 10 and Fig. 11) clearly indicate that 700 mb. height over mid-Japan has a wide range of variation

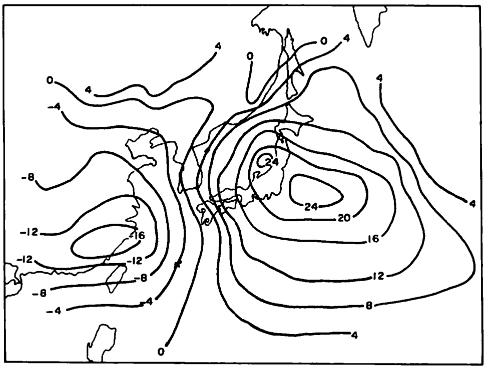

Fig. 4 0000 GMT surface pressure difference chart (January 22, 1964 —January 19, 1964).

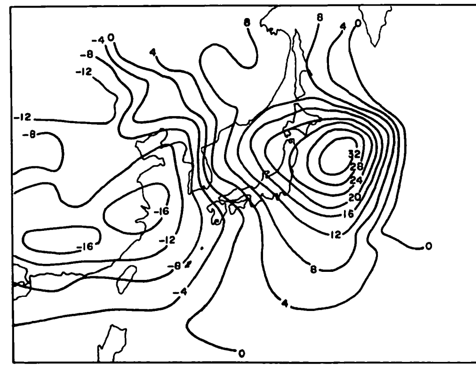

Fig. 5 0000 GMT surface pressure difference chart (Februry 8, 1964 —February 12, 1964).

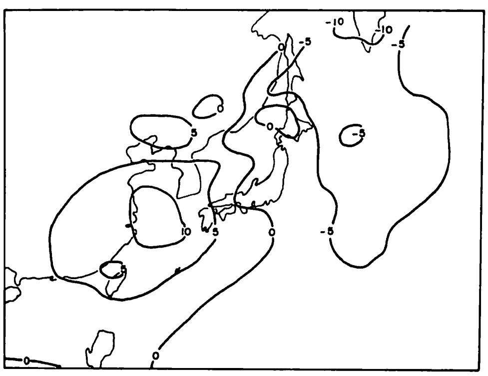

Fig. 6 0000 GMT surface temperature difference chart (January 22, 1964—January 19, 1964).

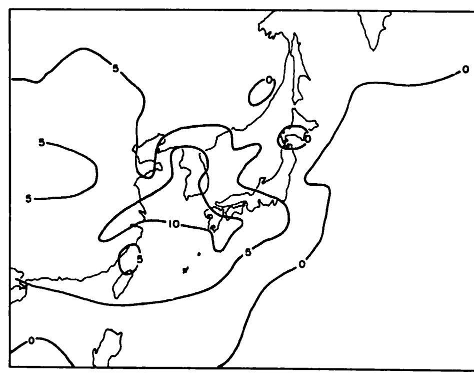

Fig. 7 0000 GMT surface temperature difference chart (February 8, 1964—February 12, 1964).

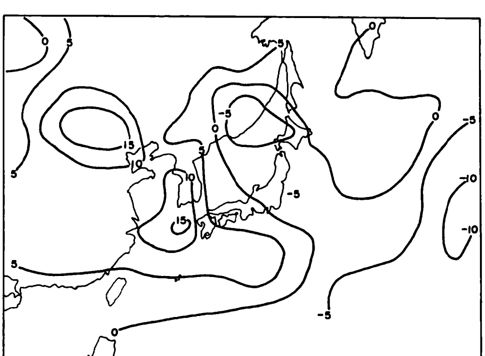

Fig. 8 0000 GMT surface dew point difference chart (January 22, 1964—January 19, 1964).

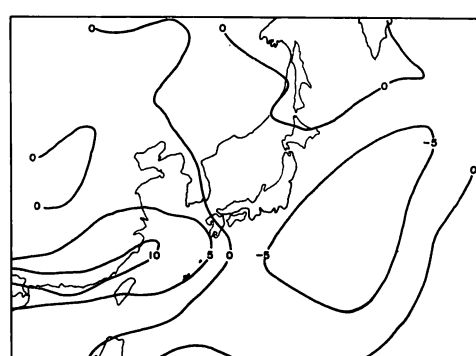

Fig. 9 0000 GMT surface dew point difference chart (February 8, 1964—February 12, 1964).

associated with minimum temperature change at Naha. It is positively correlated. This is due to an upper level trough over the area at the time of extreme low temperature at Naha. Fig. 12 and Fig. 13 suggest that the 700 mb. temperature over Chugoku or northern part of Kyushu, Japan could be used as a forecasting parameter.

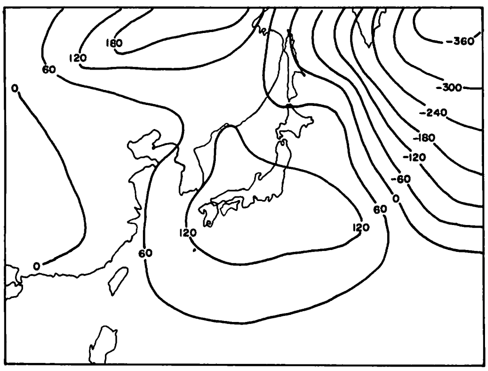

Fig. 10 0000 GMT 700 mb. height difference chart (January 22, 1964 –January 19, 1964).

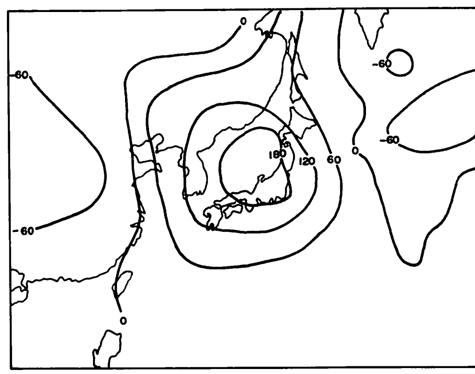

Fig. 11 0000 GMT 700 mb. height difference chart (February 8, 1964–February 12, 1964).

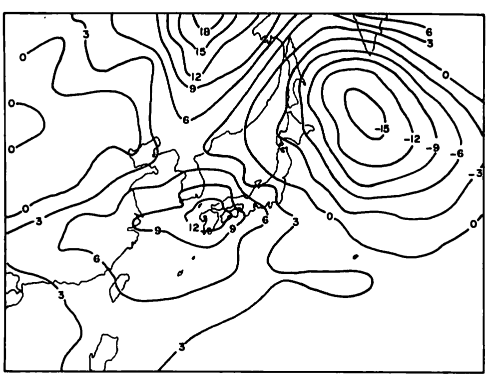

Fig. 12 0000 GMT 700 mb. temperature difference chart (January 22, 1964–January 19, 1964).

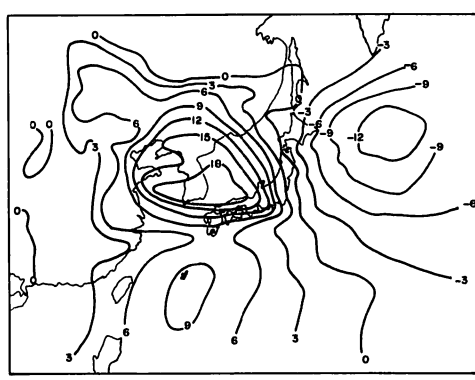

Fig. 13 0000 GMT 700 mb. temperature difference chart (February 8, 1964–February 12, 1964).

(b) Scatter diagram

Numerous scatter diagrams of the minimum temperature versus many meteorological elements were made not only to check the results obtained from the difference charts but also to select other possible predictors. These diagrams revealed that most of the variable suggested by the difference charts were useable as the predictors. Two typical diagrams for these variables, 700 mb. temperature at Yonago and surface temperature at Shanghai, are shown in Fig. 14 and Fig. 15. One particular disagreement with difference charts was the pressure over the Tohoku area of Japan. Although large difference of pressure around the area was seen in the two difference charts, a scatter diagram of the pressure at a particular station did not show a corresponding close relation with Naha minimum temperature. This may be due to the very quick movement of cyclones over the area. As an example, the

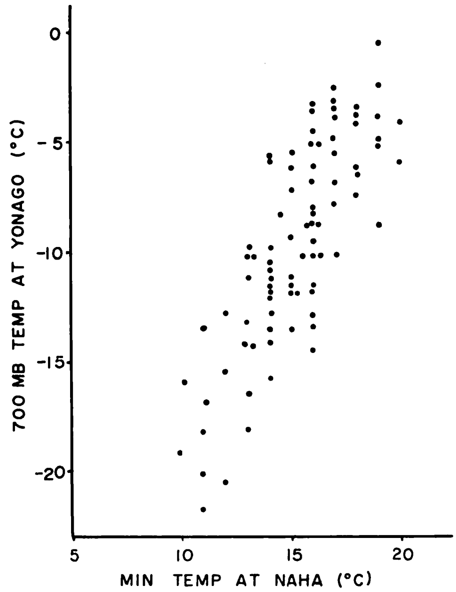

Fig. 14 Scatter diagram of the min. temp. at Naha versus 0000 GMT 700 mb. temp. Yonago.

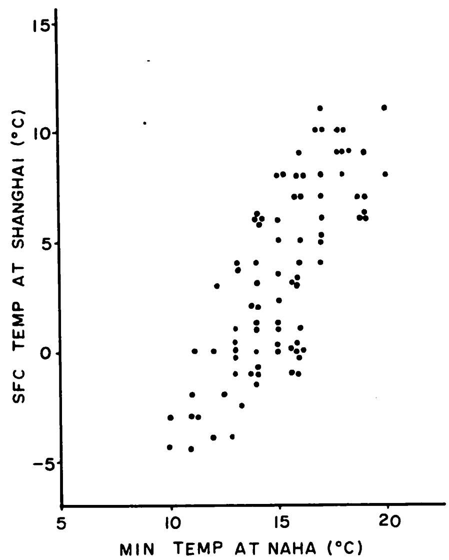

Fig. 15 Scatter diagram of the min. temp. at Naha versus 0000 GMT temp. at Shanghai.

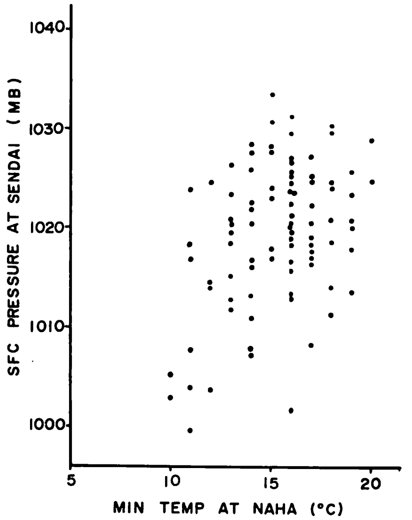

Fig. 16 Scatter diagram of the min. temp. at Naha versus 0000 GMT pressure at Sendai.

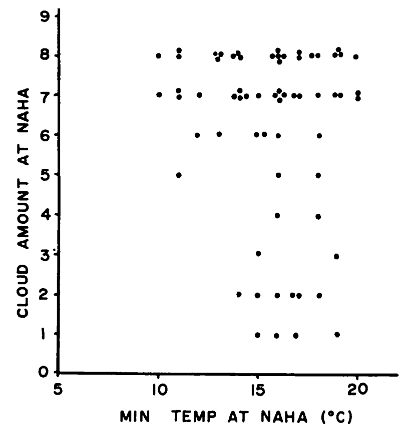

Fig. 17 Scatter diagram of the min. temp. at Naha versus 0000 GMT cloud amount at Naha

scatter diagram for the station of Sendai is shown in Fig. 16.

In Fig. 17, the scatter diagram for the cloud amount at Naha is shown to indicate that there is no clear lag relationship between morning cloudiness and the subsequent minimum temperature. This is one indication that prediction parameters associated with large scale circulations (mentioned in the first chapter) are preferable to the local parameters for forecasting day to day variation of minimum temperature at Naha for the time range considered.

(c) Previous studies

A review of many previous studies of statistical forecasting indicated that, with few exceptions, the same type of parameters as the predictand itself are very good predictors. Thus, in this study the previous minimum temperature and 0000 GMT temperature at Naha were especially taken into consideration.

(d) Personal meteorological experience

In the winter-time, Naha usually experiences very low temperature associated with the strong northeast monsoon over Okinawa. Hence, it is reasonable to postulate that the wind upstream could be a good predicoter. But it may be better to use pressure gradient rather than wind itself, because observation of wind is comparatively inaccurate while pressure can be observed accurately. The pressure difference (P. D.) between Shanghai and Fukuoka was selected as a predictor.

(e) Regularity of data reporting

Only the southern part of China was a problem in the data collection. It was difficult to prepare the basic data over the area, especially for the early part of the sampling period because of the irregular reporting. Thus, in spite of high usability of the pressure over the area, as indicated by the difference charts, all the stations there except Hong Kong, Taipei, and Shanghai were disregarded.

As a result of the above evaluation, I decided to choose the following predictors for the present study. All the stations involved here are shown in Fig. 18.

List of predictors

Pressure at Shanghai
Pressure at Taipei
Pressure at Hong Kong
Pressure difference (P. D.) between Shanghai and Fukuoka
Temperature at Shanghai
Temperature at Naha
Minimum temperature at Naha
Dew point at Shanghai
700 mb. height at Wajima, Japan
700 mb. temperature at Yonago, Japan

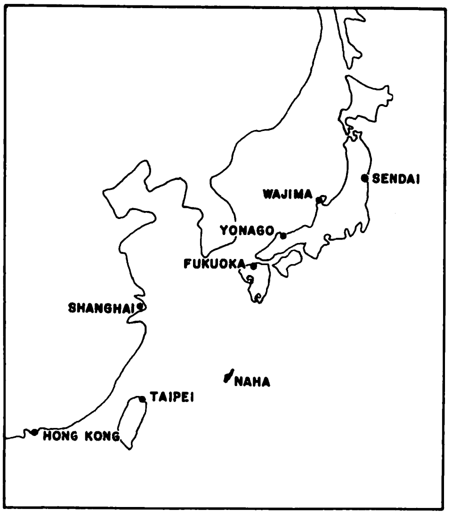

Fig. 18 Distribution of predictor stations.

4. Mathematical procedure of the methods

(a) Linear multiple regression method

When the minimum temperature at Naha is forecasted using a linear multiple regression equation in the form

$$T_f = A_o + \sum_{i=1}^{i=n} A_i X_i \tag{1}$$

where n is the number of the predictors X_i, and A_o and A_i are the regression constants, the least square method requires

$$D^2 = \sum_{k=1}^{k=M} (T_{fk} - T_{ok})^2 = \text{minimum}$$

$$k = 1, 2, 3, 4, \cdots\cdots, M$$

where T_{fk} and T_{ok} are the forecasted and observed minimum temperature for the case k, and M is the total number of observation. By equating $\frac{\partial D^2}{\partial A_o} = 0$ for the best A_o and $\frac{\partial D^2}{\partial A_i} = 0$ for the best A_i, the following $n+1$ order simultaneous equations are obtained:

$$
\begin{array}{llllll}
A_0 M & + A_1\sum_k X_{1k} & + A_2\sum_k X_{2k} & + \cdots\cdots + & A_n\sum_k X_{nk} & - \sum_k T_{ok} = 0 \\
A_0\sum_k X_{1k} + & A_1\sum_k X_{1k}^2 & + A_2\sum_k X_{1k}X_{2k} & + \cdots\cdots + & A_n\sum_k X_{1k}X_{nk} & - \sum_k X_{1k}T_{ok} = 0 \\
A_0\sum_k X_{2k} + & A_1\sum_k X_{2k}X_{1k} & + A_2\sum_k X_{2k}^2 & + \cdots\cdots + & A_n\sum_k X_{2k}X_{nk} & - \sum_k X_{2k}X_{ok} = 0 \\
\vdots & \vdots & \vdots & & \vdots & \vdots \quad \vdots \\
A_0\sum_k X_{nk} + & A_1\sum_k X_{nk}X_{1k} + & A_2\sum_k X_{nk}X_{2k} & + \cdots\cdots + & A_n\sum_k X_{nk}^2 & - \sum_k X_{nk}T_{ok} = 0
\end{array}
$$

Thus, the coefficient A_0, A_1, A_2, $\cdots\cdots\cdots$ A_n in equation (1) are determined by solving this set of equations.

Following the screening procedure described by Klein et al. (1959), I made a computer program for IBM 7040 to select suitable predictors for the minimum temperature at Naha. First, n in equation (1) was set equal to 1 and all the predictors selected in the previous chapter were correlated one by one with the minimum temperature. The predictor giving the highest correlation coefficient was chosen as the first predictor X_1. Next n was set equal to 2 and the rest of the predictors, with X_1, were multiple correlated in order. The predictor which contributed to make the highest multiple correlation was chosen as the second predictor X_2. The number n was increased, and the process was repeated step by step until the stage when the addition of a new predictor did not contribute to increase the correlation coefficient. Then a complete forecasting equation was established.

(b) Graphical method

As was already mentioned, the method requires the use of a composite diagram which is drawn by fitting a curved surface in the form of a Nth order polynomial

$$T_{fk} = \sum_{i+j=0}^{i+j=N} A_{ij} X_k^i Y_k^j \tag{2}$$

where X_k and Y_k are two predictors and T_{fk} is the forecasted minimum temperature for the case k. The coefficient A_{ij} of the polynomial may be determined from the following normal equations which were derived by the principle of the least square.

$$\sum_{k=1}^{k=M} \left(\sum_{i+j=0}^{i+j=N} \mathrm{A}_{ij} X_k^{i+p} Y_k^{j+Q} \right) - \sum_{k=1}^{k=M} T_{ok} X_k^p Y_k^Q = 0 \qquad (3)$$

$$k=1.\ 2.\ 3,\ \cdots\cdots,\ M$$

where T_{ok} is the observed minimum temperature, M is the total number of observations, and $0 \leq P + Q \leq N$. Since for each pair of P and Q between $P+Q=0$ to $P+Q=N$, i and j varies from $i+j=0$ to $i+j=N$, the order of the normal equation is equal to the number of combinations of P and Q or that of i and j (e.g. when $N=3$, the order of the normal equation is 10) . Once A_{ij} is determined, some contour lines of Y are drawn on an X and T rectangular graph. T is read from the given X and Y.

The actual procedure in making a composite prediction diagram is explained next. Since there are numerous combinations of any two of the predictors suggested here, some method of selecting predictors for the diagram is required. In the present study the following procedure, deriving from Freeman (1961) , was used. The complete arithmetical process was performed by an electronic computer.

First, with $j=Q=0$ in equation (2) and (3) the single curvilinear correlation of fifth power between the individual predictors and the minimum temperature was examined, and the predictor giving the highest correlation coefficient was chosen as the first X predictor (X_1) for the first prediction diagram. Then the remaining predictors were substituted for Y predictor one by one and they, with X_1, were correlated to the minimum temperature by use of the polynomial. The predictor that gave the highest correlation coefficient was selected as the first Y predictor (Y_1) for the first prediction diagram. The first approximation of the minimum temperature obtained by the first two predictors, X_1 and Y_1, was then used as the value of the second predictor (X_2) for the second prediction diagram. A new Y predictor was introduced by the same procedure that selected Y_1, and the minimum temperature was predicted. The predicted minimum temperature was used as the next X predictor. A new Y predictor was added into each step, and the procedure was continued until the correlation coefficient obtained by the new step becomes less than that in the previous. It was necessary to control the order of the polynomial for each predictor and each step in order to avoid the phenomenon of overfitting – the curved surface represents the particular sample of data rather than the general population (Freeman, 1961; Jack, 1966) .

(c) Correlation coefficient

The formula used to calculate the correlation coefficient (R) was

$$R^2 = 1.0 - \frac{(RMS)^2}{(STD)^2}$$

where RMS is the root mean square error of the forecast and STD is the standard deviation of the minimum temperature to be forecasted.

5. Preliminary test

Before long range data were collected, a preliminary test of the methods was performed considering only the one winter data from December 1963 to February 1964 (sampling size $M=90$) . Table I shows the correlation coefficient (R) and the root mean square error (RMS) of the individual predictors obtained by both single linear and curvilinear correlation.

Table I Correlation of individual predictors with the minimum temperature at Naha based on one winter ($M=90$)

STD=2.95 °C

Predicror	Linear		Curvilinear	
	R	RMS (°C)	R	RMS (°C)
700 mb. temp. at Yonago *	0.75	1.56	0.76	1.54
700 mb. height at Wajima	0.72	1.64	0.73	1.62
Pressure at Taipei	0.71	1.68	0.71	1.67
Temp. at Naha	0.68	1.73	0.71	1.67
Temp. at Shanghai	0.67	1.77	0.68	1.74
Dew point at Shanghai	0.63	1.85	0.64	1.82
Pressure at Shanghai	0.62	1.87	0.62	1.86
Pressure at Hong Kong	0.59	1.91	0.59	1.92
P.D. (Shanghai−Fukuoka)	0.56	1.97	0.58	1.93
Minimum temp. at Naha	0.53	2.01	0.53	2.02

(Sign of correlation is omitted)

* 700 mb. temperature at Yonago was not included in the preliminary test because of the delay of data preparation, but its single correlation coefficient calculated later was shown here to display the reasonableness of the selection of predictors in Chapter 3.

As expected, all the predictors showed very high correlation with the minimum temperature at Naha. According to the methods described in the previous chapter, 700 mb. height at Wajima was selected as the first predictor for both methods.

The resultant linear multiple regression equation was

$$\text{MIN TEMP AT NAHA} = 175.327 + 0.0095X_1 - 0.1877X_2 + 0.2286X_3 - 0.0993X_4$$

where

X_1 = 700 mb. height at Wajima

X_2 = Pressure at Taipei

X_3 = Temperature at Naha

X_4 = P.D. (Shanghai−Fukuoka).

The correlation coefficient and the root mean square error were 0.83 and 1.31 °C for the basic data.

For the graphical method the computation was kept with the same order of the polynomial through each predictor and each step, because it was considered to be sufficient to look at the tendency of the usefulness of the graphical forecasting technique, saving considerable computation time. Thus, here, only fifth order was used and the following sequence of predictors was found to give the highest correlation coefficient of 0.88 and the least root mean square error of 1.12 °C.

X_1 = 700mb. height at Wajima
Y_1 = Pressure at Taipei
⋮
X_2 = First approx. of min. temp.
Y_2 = Temperature at Naha
⋮
X_3 = Second approx. of min. temp.
Y_3 = Dew point at Shanghai
⋮
X_4 = Third approx. of min. temp.
Y_4 = Temperature at Shanghai
⋮
Forecasted min. temp. at Naha

Both techniques were used to forecast the minimum temperature at Naha during the two independent winters, 1964 – 1965 and 1965 – 1966. The standard deviation of the minimum temperature for the period was 2.95 °C.

The linear multiple regression equation gave the correlation coefficient of 0.79 and the root mean square error of 1.80 °C and the graphical method gave 0.75 and 1.96 °C. In both cases considerable decrease of correlation coefficient was found. This indicated that the two techniques were not stable. The reason was obviously because the prediction equation and the prediction diagram were based upon a small amount of data.

Although the independent tests failed, the root mean square error of 1.31 °C for the linear multiple regression equation and 1.12 °C for the graphical method obtained from the basic data encouraged further study of the methods.

6. Prediction equation and prediction diagram for minimum temperature at Naha, Okinawa

Since it was decided that one winter's data were not sufficient to give a stable forecasting equation and prediction diagram, six winters, from 1958–1959 to 1963–1964, were taken into consideration. The results of the initial step for both methods are given in Table II.

The interesting feature seen in the table is that predictors of the same general type as the predictand give a relatively high correlation coefficient while the pressure predictors tend to show a lower correlation. In contrast to the result based on one winter data in Table I, the order of predictors found by single linear correlation was slightly changed by curvilinear correlation.

Table II Correlation of individual predictors with the minimum temperature at Naha based on six winters (M = 534)

STD = 2.96 °C

Predictor	Linear		Curvilinear	
	R	RMS (°C)	R	RMS (°C)
Temperature at Naha	0.79	1.81	0.80	1.79
Temperature at Shanghai	0.72	2.06	0.73	2.03
700 mb. temp. at Yonago	0.70	2.10	0.79	1.84
Min. temp. at Naha	0.69	2.16	0.69	2.10
Dew point at Shanghai	0.61	2.35	0.74	1.98
700 mb. height at Wajima	0.60	2.36	0.73	2.03
Pressure at Taipei	0.59	2.40	0.59	2.40
Pressure at Hong Kong	0.54	2.49	0.54	2.49
P. D. (Shanghai–Fukuoka)	0.54	2.49	0.55	2.48
Pressure at Shanghai	0.44	2.66	0.44	2.66

(Sign of correlation is omitted)

Starting with the temperature at Naha, that showed the highest single linear correlation, I obtained the following prediction equation for the minimum temperature at Naha. It gave a correlation coefficient of 0.85 and a root mean square error of 1.55 °C for the basic data.

$$\text{MINIMUM TEMP AT NAHA} = 7.2459 + 0.5290X_1 - 0.1174X_2 + 0.0864X_3 + 0.0391X_4$$

where

X_1 = Temperature at Naha

X_2 = P. D. (Shanghai–Fukuoka)

X_3 = 700mb. mb. temp. at Yonago

X_4 = Dew point at Shanghai.

In the case of the graphical method, the order of the polynomial was carefully controlled as was mentioned before. As we saw when visibility was predicted by Freeman (1961) and Jack (1966), the overfitting of polynomial (producing very complicated diagram) was found for the present case with relatively high order of polynomial. The correlation coefficient increased with increasing the order of polynomial. However high order polynomials were undesirable because they produced more complicated diagrams. Thus, it was necessary to adjust the order of polynomial in order to get the highest correlation coefficient with a simple and usable prediction diagram. This adjustment was done for every predictor of every diagrm by controlling N in equation (2) during the computer process.

For the minimum temperature at Naha, the third order polynomial for the first and second diagrams and the second order for the third diagram were suitable to obtain the following sequence of predictors that gave the highest correlation coefficient with a useable composite forecasting diagram.

X_1 = Temperature at Naha

Y_1 = P. D. (Shanghai–Fukuoka)

⋮

X_2 = First approx. of min temp.

Y_2 = 700 mb. temp. at Yonago

⋮

X_3 = Second approx. of min. temp.

Y_3 = 700 mb. height at Wajima

⋮

Forecasted min. temp. at Naha

The actual prediction diagram for the above sequence is shown in Fig. 19. A dashed line in the figure shows the method of using the diagram for predicting minimum temperature at Naha when the temperature at Naha at the forecasting time is 15.0°C, the pressure difference between Shanghai and Fukuoka is 8.4 mb., 700 mb. temperature at Yonago is −19.2 °C, and 700 mb. height at Wajima is 2838 meters. The forecast minimum temperature at Naha is 11.8 °C. The correlation coefficient and the root mean square error obtained by the diagram for the dependent data were 0.86 and 1.50 °C.

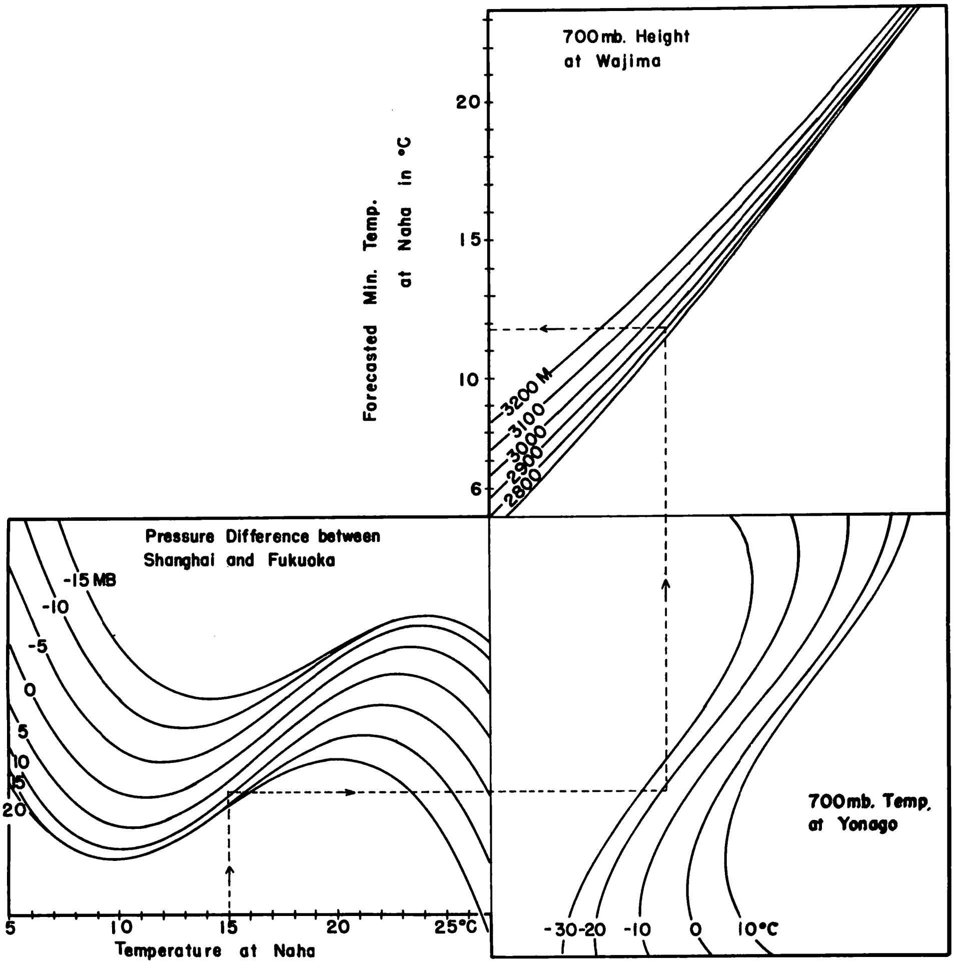

Fig. 19 Minimum temperature prediction diagram for Naha. The dashed line indicates the method of using the diagram.

7. Verification and discussion of results

As mentioned in the earlier chapter it was not possible to prepare any forecast value of the minimum temperature at Naha for any forecasting time by the methods the Ryukyu Weather Bureau uses, so that no attempt was made to compare them with the current two techniques. But the usefulness of the techniques may be partially determined by their ability to surpass a persistence forecast – which uses the present value of the minimum temperature as the forecast value for the following day.

Table III Independent data results and comparisons with the persistence forecast

STD = 2.95 °C

Method	R	RMS (°C)	AAE (°C)
Linear	0.86	1.48	1.26
Graphical	0.87	1.43	1.13
Persistence	0.64	2.26	1.80

Table III shows the results when these three techniques were tested on independent data of two winters, 1964 – 1965 and 1965 – 1966. Beside the correlation coefficients and the root mean square errors, the average absolute errors (AAE) were shown to convey the magnitude of the errors involved in the minimun temperature forecasting. It was seen that the two forecasting techniques performed considerably better than the persistence forecast indicating the potentially practical use of both techniques. Although the figures in the table show that the graphical method is better than the linear multiple regression method, the difference between the two is very small.

The forecast values of the minimum temperature by both techniques during the independent test period were plotted with the observed minimum temperature. These are shown in Fig. 20 for the winter 1964–65 and in Fig. 21 for the winter 1965–66. Although there are disagreements between the forecast and observed values in some cases, the general trend of forecast values is fairly good. One important feature found from the graphs is that the error appearances in the forecasting equation and in the graphical method were quite similar to each other in both magnitude and sign. Thus it is very difficult to tell which method is superior. Since the first three predictors used in both techniques were the same, it may be concluded that the main factor which increases the forecasting errors would be attributed to the

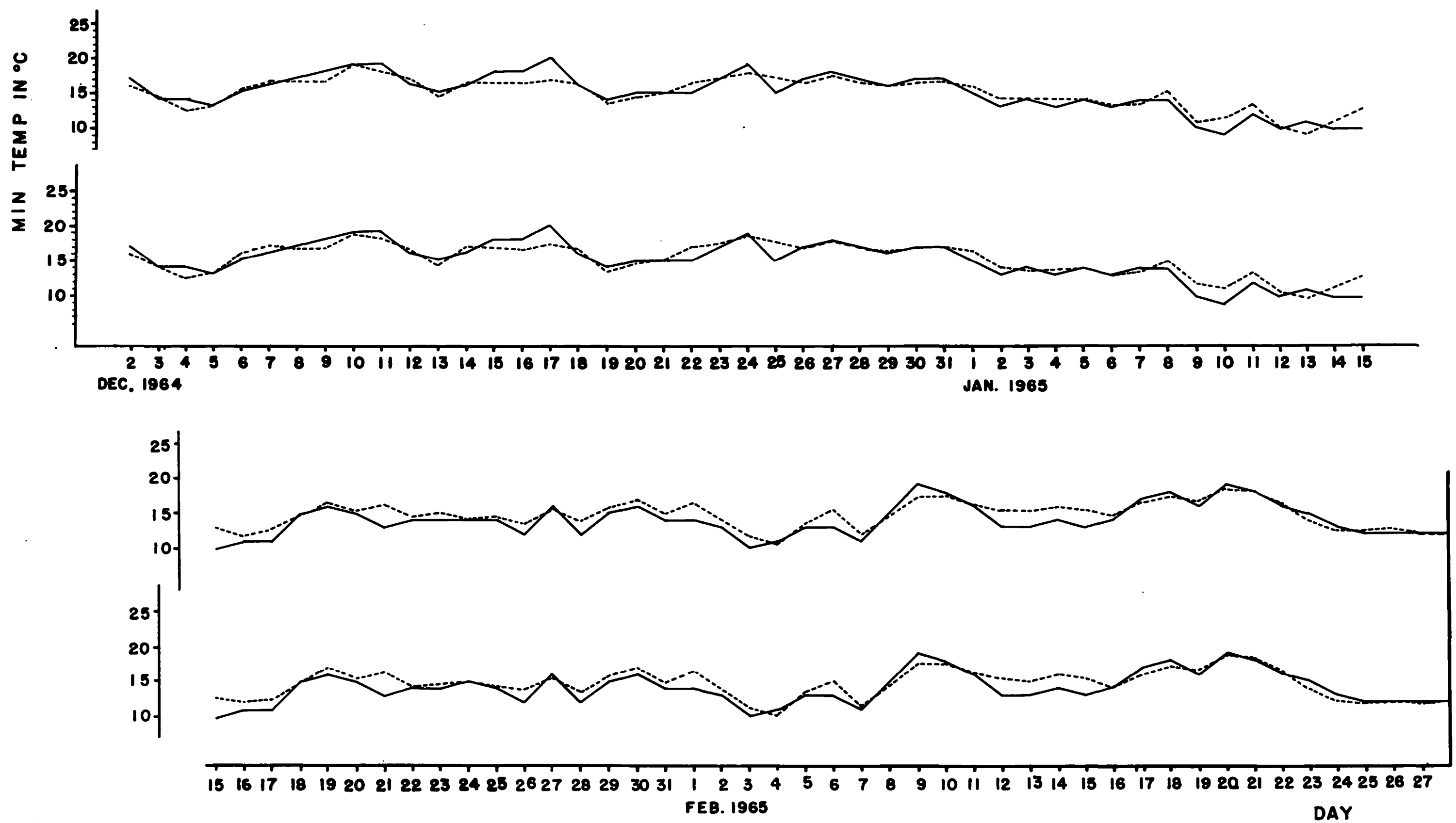

Fig. 20 Comparison of predicted minimum temperature (dotted line) with observed minimum temperature (solid line) for the prediction equation (above) and for the prediction diagram (below) during the winter 1964—65.

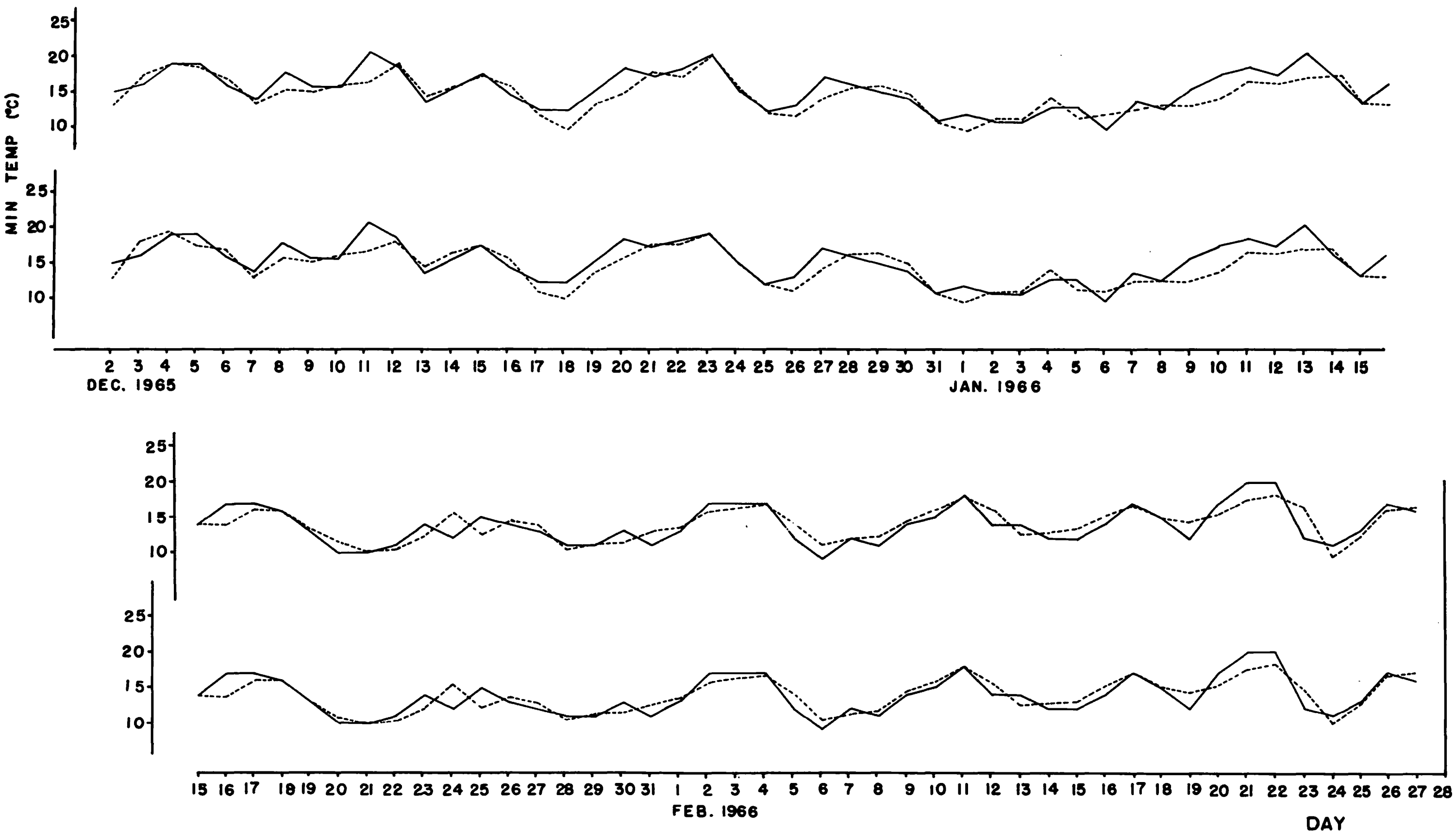

Fig. 21 Comparison of predicted minimum temperature (dotted line) with observed minimum temperature (solid line) for the prediction quation (above) and for the prediction diagram (below) during the wintere 1965—66.

predictors' defects not to the forecasting methods. Thus increasing of forecast accuracy by both techniques is mostly achieved by selecting more proper predictors. A similar result was obtained when a factor analysis forecatsing technique and linear multiple regression method were compared by Aubert et al. (1959) .

Day to day synoptic situations were studied during the independent test period in order to find out the possible explanations for the errors found in the two techniques. Two main situations were found to be associated with large forecast errors.

When a small low pressure system (cyclone) appeared between Taipei and Okinawa or its vicinity and moved very quickly along the Ryukyu Islands, the forecast value of minimum temperature tended to be lower than the observed minimum temperature. The cyclone usually brought a southerly wind at Naha during the period. Thus it may have happened that the actual rise of minimum temperature at Naha was faster than evaluated by the present methods. This situation corresponded to the periods December 15 to 17, 1964; December 7 to 8, 1965; December 10 to 11, 1965; December 26 to 27, 1965; January 9 to 13, 1966 (2 cyclones) ; January 16, 1966; and February 19 to 21, 1966 (2 cylones) .

A large forecast error also occurred when an intense front originating from the cyclone formed between Shanghai and Kyushu influenced the Ryukyu Islands. While the front approached the islands, the temperature there rose rapidly due to southerly wind, and again the forecast value of minimum temperature was lower than the observed one. But when the front was very weak or the cyclone was accompanied by no front, good agreement between forecast and observed minimum temperature at Naha was found even with rising temperature. The former situation corresponded with the period December 18 to 20, 1965, and the latter with the periods January 17 to 19, 1965; January 29 to 30, 1965; February 7 to 9, 1965; December 2 to 5, 1965; and February 24 to 26, 1966.

In the case of the typical winter-time synoptic situation (Fig. 1) the forecasting techniques showed fairly good results. When the continental high was week, sometimes another small high appeared over Japan, which caused a southerly wind at Naha with associated higher temperature. The forecasts at this time were also good.

8. Summary and conclusions

No apparent difference of forecast accuracy between the linear multiple regression method and the graphical method was found, when they were used to forecast the minimum temperature at Naha by using limited numbers of

0900 local time predictors. The predictors were selected very carefully according to the criteria mentioned in Chapter 3 and they are all directly measurable.

For each technique the same first three predictors were selected, and the error appearances on both were quite similar in magnitude and sign. This may lead to the conclusion that the main factor which increases the forecasting errors could be the predictors' defects, not the forecasting methods. Thus increasing of the forecast accuracy by both techniques is mostly achieved by selecting more proper predictors.

When the resultant prediction equation and prediction diagram were used to forecast the minimum temperature at Naha, during the independent test winters, 1964 – 65 and 1965 – 66, both showed considerably better results than persistence forecasts. The correlation coefficient and the root mean square error obtained were 0.86 and 1.48 °C for the prediction equation and 0.87 and 1.43 °C for the prediction diagram, while those obtained by persistence were 0.64 and 2.26 °C.

Large error-producing synoptic situations were found. One was when a cyclone appears between Taipei and Okinawa or its vicinity and is moving northeastward along the Ryukyu Islands. Another was when an intensive front originating from a cyclone between Shanghai and kyushu influenced Okinawa. In both cases the forecast minimum temperature tended to be lower than actually observed minimum temperature due to quick warm air advection from south.

Although a quantitative comparison of the techniques presented in this paper with those used by the Ryukyu Weather Bureau was not possible, it can be said that the former are superior to the latter in the respect that fewer subjective considerations by the forecaster are involved.

For the further study of minimum temperature forecast for Naha by the present two techniques it is suggested that the introduction of predictors which can detect the large error-producing synoptic situations mentioned above will improve the methods considerably.

References

Aubert, E. J., I. A. Lund and A. Thomasell, Jr., 1959: Some objective six-hour predictions prepared by statistical methods. *J. Meteor.*, 16, 436–446.

Ezekiel, M., 1956: *Methods of correlation analysis*. John Wiley and Sons, Inc., New York, 531 pp.

Freeman, M. H., 1959: Objective prediction of local forecasting. *Met Mag.* London, 88, 207–218.

Freeman, M. H., 1961: A graphical method of objective forecasting derived by statistical techniques. *Quart. J. R. Meteor. Soc.*, 87, 393–400.

Jack, V. D., 1966: Further work on objective forecasting of visibility. *Met. Mag.* London. 95, 114–121.

Klein, W. H., 1959: Objective prediction of five-day mean temperature during winter. *J. Meteor.*, 16, 672–682.

Panofsky, H. A., and G. W. Brier, 1965: *Some Application of Statistics to Meteorology.* The Pennsylvania State University, 223 pp.

Russo, J. A., I. Enger and E. L. Serenson, 1964: A statistical approach to the short-period prediction of surface winds. *J. Appl. Meteor.*, 3, 126–131.

Stidd, C. K., 1954: The use of correlation field in relating precipitation to circulation. *J. Meteor.*, 11, 202–213.

Takahashi, K., 1957: *Climatology (in Japanese)*, Iwanami Shoten, Tokyo, 315 pp.

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Tables

Illustrations