FIRST YEAR FINAL TECHNICAL REPORT TO
CENTRAL WEATHER BUREAU

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Research-Development and Technology Transfer of Mei-Yu and Typhoon Long-Range Forecasting in Taiwan

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1. OBJECTIVES AND REMARKS

The purpose of this project is to develop the long-range (one month to one year) forecast scheme of Mei-Yu and typhoon in Taiwan. Specific technical objectives during the first year include:

1. To study the basic fields of variations in the Northern Hemisphere circulation with the long-term (1955-1986) upper air analyses and sea surface temperature (SST) analyses in terms of principal component analysis.

2. To obtain the teleconnection patterns of Mei-Yu and typhoon predictands with the Northern Hemisphere circulation and SSTs. The later updating of data to the present is utilized in this portion of the analysis.

3. To investigate the spectral characteristics of the Northern Hemisphere circulation in reference to the onset and recess of Mei-Yu.

4. To make proper arrangements and preparations for the second and third year projects which are respectively a qualitative forecast experiment in 1990 and qualitative regression forecast in 1991.

Before the commencement and during the progress of the first year project a close coordination has been maintained with Mr. Shih-Ting Wang and Dr. Beng-chun Lee to constantly review the technical objectives and also to monitor the progress. It is our belief that the first year objectives have been accomplished to the satisfaction of all parties concerned. This report describes the technical specifics of the research-development. Basic results of the principal component and teleconnection analyses have been forwarded to the Central Weather Bureau through Dr. Lee. The maps not previously forwarded are appended to this report as a separate volume. The voluminous maps previously forwarded are not repeated in this report. However, they are available at the Central Weather Bureau and we also can resupply those maps from our existing file. The figures utilized in this report are selected outputs for the purpose of description and discussion.

It is appropriate to note here that in this type of research-development, the results and progress may lead to a new scope of an addition to the technical objectives originally conceived. The third technical objective in the preceding paragraph (i.e., the spectral characterisitics associated with Mei-Yu onset and recess) is such an addition to the original plan. It is a positive, useful development which may be of significance in further research-development.

2. APPROACH AND METHODS

The data utilized include Mei-Yu and typhoon records in Taiwan, National Meteorological Center (NMC) octagonal grid analyses, and NMC and Comprehensive Ocean-Atmosphere Data Set (COADS) SST analyses (see Reynolds 1983 and Slutz et al. 1985). Original octagonal and SST analyses were previously forwarded to the Central Weather Bureau.

Before the teleconnection patterns of the Mei-Yu and typhoon predictands were examined, we proceeded to analyze the principal components of the Northern Hemisphere circulation and SSTs over the Pacific, Atlantic and Indian Oceans. Not only is it a necessary step before the teleconnection analysis, but also the obtained principal components may serve as predictors in formulating the forecasting scheme. One goal of the principal component analysis, which is also referred to as empirical orthogonal function or eigenvector analysis, is to reduce a large number of variables into a manageable set of components, while retaining the maximum variance of the original variables, enabling us to concisely describe patterns of interrelationship among observed variables. In the analysis of highly correlated meteorological fields, a limited number of principal components may effectively represent the fundamental modes of variations which are highly loaded on these components. It is appropriate to note that the empirical orthogonal functions have no predetermined forms, and only depend on the interrelationship within the analysis dataset. Thus, they are particularly suitable to investigate anomalous fields of the general circulation, for which no known analytical form exists because of complex boundary conditions and various scales of nonlinear interactions.

In this investigation pattern vectors and time coefficients are obtained for major principal components of monthly mean fields of the 700 mb temperature T(°C) and 500 mb geopotential height Z(m) in the Northern Hemisphere and for SST (°C) from 10°S to 60°N, all from 1955 to 1986. Variances of intra-annual seasonal variations are eliminated by defining the anomaly fields of monthly means in reference to long-term means of individual months. Spatial characteristic patterns of major components and corresponding time coefficients are compared among 500 mb Z, 700 mb T and SST, and for different seasons. The interrelationships among modes of variations of these three meteorological fields are examined through the comparison and correlation analysis of time coefficients of major components. The time coefficients are also utilized to compare the SST of the Pacific, Atlantic, and Indian Oceans, and also to compare the tropical and middle latitude SST.

The general mathematical procedures for computation of orthogonal pattern vectors and their coefficients are as provided in Kutzback (1967). The grid values of monthly mean fields were standardized to zero mean and unit variance so that each grid point can have normalized significance in describing the spatial variation. Since the departure fields are obtained with respect to the multi-annual means of respective monthly mean fields, the variance of the seasonal cycle has been eliminated. The variable matrix, which has normalized departures from time means, is used to compute the corresponding correlation matrix, whose elements are the correlation between grid points. The eigenvectors of such a correlation matrix represent a set of normalized departure fields. The eigenvectors are not rotated in order to retain the maximum variance in the first few components (see Walsh and Richman 1981). The characteristic pattern vector is described by the eigenvector multiplied with the standard deviation of its corresponding principal component. Thus, characteristic patterns represent the simple correlations between respective components and meteorological fields.

As a basic measure of teleconnections between predictands and antecedent oceanic and atmospheric conditions, a comprehensive cross-correlation analysis was performed. The Mei-Yu predictands utilized for this purpose were the onset date, recess date, total precipitation during

Mei-Yu season, and the days of Mei-Yu season. The onset and recess dates are expressed in reference to April 1 (April 1 is 1, and May 1 is 31 for instance). These are average values of Northern and Southern Taiwan. The applicable areas of predictands must be as large as possible. The predictands for smaller regions tend to be more unstable in use, but the prediction in small areas can be easily derived from large areas with proper climatological parameterization. The typhoon predictands included frequencies of typhoons invading Taiwan, and typhoons and tropical cyclones in the northwestern Pacific. The antecedent atmospheric conditions for the teleconnection analysis included 500 mb Z and 700 mb T in the Northern Hemisphere and SST from 40°S to 60°N.

The spectral functions of 500 mb Z were computed daily from 1956 to 1986. For the composite Mei-Yu period from day-100 to day 60 for the 31-year period, the spectral functions were averaged for the latitudinal band of 46°N-62°N and presented in terms of trough-ridge diagram. The days of the composite Mei-Yu period are expressed in reference to the onset date. Thus the onset date is day 0, day-100 is the 100th day prior to the onset, and day 60 is the 60th day after the onset. After examination of gross characteristics of the composite spectrum, spectra of individual years of the period may be further examined.

3. PRINCIPAL COMPONENT ANALYSIS

The percentage variance and cumulative percentage variance of the first ten components of 700 mb T and 500 mb Z of the Northern Hemisphere and Pacific SST are shown in Tables 1 and 2 for January and July. The distributions of variance over these components show the magnitude which we may expect from previous analyses without involving the seasonal cycle (e.g., Kutzback 1970, Weare et al. 1976; Weare 1977; Park and Kung 1988). The first three to four components account for approximately one-half or more of the total variance, although there exists some differences among the three fields and between winter and summer months. As discussed by Overland and Preisendorfer (1982), it is important to determine if the principal components obtained in the analysis are statistically significant, so that the geophysical interpretation of results will be meaningful. As shown in pattern vectors of major components (Figs. 1-5), large-scale characteristic patterns are described by large correlation coefficients of $|0.4|$ to $|0.8|$, which are significant at the 98 to 99.9% confidence level for 700 mb T, and at the 96 to 99.9% level for SST fields according to the respective lengths of time series. The higher components also show some significance in limited areas, but the level of significance in large areas drops sharply.

Monthly patterns and interannual variations of time coefficients have been previously forwarded and figures related to this section are merely for the purpose of description in this report. Characteristic patterns of the first three components of the monthly mean 700 mb T are shown in Figs. 1-3 for every other month through the year. A clear winter pattern is recognized in Fig. 1 for the first component, as seen in January and March. Large "centers of action" are recognized in all quadrants of the Northern Hemisphere. The centers over eastern Asia and the western Pacific, and over the eastern Pacific and Europe, are particularly dominant and stable. The configuration deteriorates through the late spring and summer months, when the centers of action are recognizable over the eastern Pacific and western Atlantic. In the fall, as seen in September, a transition from the summer pattern to the winter pattern occurs, and as early as November, the winter pattern reappears. The second component in Fig. 2 also shows a distinguishable large-scale winter pattern in the Pacific and Atlantic. Although the pattern is clear, it is less intense than that of the first component. It is noteworthy that the large-scale pattern completely disintegrates and becomes fragmental in the summer, as seen in July. The third component in Fig. 3 has winter centers of action in the Pacific and Atlantic, with the former being much stronger than the latter. In the summer the pattern is greatly weakened, but not as fragmental as that of the second-component.

Some interesting features of the 700 mb T patterns may be noted. It is reasonable to expect that the configuration of the first component represents the planetary-scale variation of the lower boundary (see Budyko 1974), including that of land-sea contrast. Time coefficients as exemplified in Fig. 6 indicate that the interannual variation (as shown over the entire date period) and intra-annual variation (as shown in the difference between months) of the first component are both smaller than those of the second and third components. This may be due to the stability of the largest-scale variation of the surface boundary, which is responsible for the first component.

When we compare the winter and summer time coefficients of the second and third components in Figs. 4 and 5, the interannual variations are more clearly observed during the summer than in the winter. Although coefficients of winter months involve more noise, it is still possible to see a general interannual variation which is consistent with those of summer months. The characteristic patterns in Figs. 2 and 3 suggest that those two components are likely the result of the ocean surface heating (see Figs. 4 and 5). In the second component the east-west contrast over the ocean stands out, whereas the third component indicates a north-south contrast over the ocean. It is noted here that the basic planetary-scale variation of the first component also involves the effects of the ocean through the land-sea contrast. The ocean apparently acts in different distinguishable modes of the large-scale climatic variations. Following the interannual variations of time coefficients of the second and third components (Figs. 6), three distinct periods seem identifiable over the entire data period: periods prior to 1962, between 1962 and 1978, and after 1978. Given a steadiness of the first component, the second and third components are important indicators of the oceanic effects in the interannual climatic fluctuations.

The 500 mb Z patterns are not explicitly discussed here, but they clearly follow those of 700 mb T, and the utilities may be made from the figures previously forwarded. The characteristic patterns of the first component of Pacific SST in winter show an east-west contrast, which is particularly distinguished in the winter (Fig. 4) when the western and eastern Pacifics have the largest temperature difference between the warm (Kuroshio) and cold (California) currents. During the summer (Fig. 5) the variations of the first component are more localized in smaller scales. This is apparently related to the fragmental summer pattern of the second component of 700 mb T as we have seen in Fig. 1. The second component of

SST is more dominated by the north-south contrast than the east-west contrast. The spatial pattern distributions of the first and second components in tropical areas, particularly those of the second component in the winter and the first component in the summer, underscore the preferred scale and locations of appearance for the El Niño/Southern Oscillation interhemispheric variations. The third and fourth components, as shown in Figs. 4 and 5, also portray distinct spatial distributions of pattern vectors. However, the scale of variation and contribution to the total variance (Tables 1 and 2) are smaller than those of first and second components. It is reasonable to assume that the higher order principal components represent the finer aspects of physical processes, whereas the lower order components describe more of the basic features of the physical environment, such as large-scale temperature contrasts. It is important to point out, however, that the higher components of SST (also 700 mb T and 500 mb Z) could bear considerable importance for Mei-Yu and typhoon predictands, as indicated by the scale of cross-correlation patterns in Figs. 7-9. In any case, the SST anomalies may be related to the anomalies in the mid-tropospheric circulation through the heating of the lower troposphere. It should be pointed out that, although they contain large fluctuations, the three distinctive climatic periods identifiable in the second and third components of 700 mb T (Fig. 6) are also traceable in the time series of the first and second components of 500 mb Z and SST.

4. CROSS-CORRELATION ANALYSIS

Cross-correlation analyses of the Mei-Yu and typhoon predictands vs. 700 mb T, 500 mb Z, and SST, of the preceding 12 months were completed, and correlation maps have been forwarded to the Central Weather Bureau. General noteworthy characteristics of the correlation patterns include the following. (Figures 7-9 only exemplifies characteristic patterns, and previously forwarded maps must be referenced.)

1. The characteristic patterns are statistically very significant and useful in long-range prediction.

2. Cross-correlations are significant up to 12 months, indicating the long-range predictability of Taiwan Mei-Yu and typhoon from a season

to a year.

3. Significance of cross-correlation is quasi-cyclic. Thus the use of appropriate predictors should be found through detailed examinations of all preceding months.

4. In general, among examined predictors, the Mei-Yu onset, precipitation, and typhoon frequency show better cross-correlations than Mei-Yu recess. However, a proper combination of Mei-Yu onset and Mei-Yu days may overcome the weakness of recess prediction.

From each of the cross-correlation charts (previously forwarded) of preceding months, areas of high cross-correlation were selected. Each area, except for limited cases, involve several to more than 10 degrees of latitudes and longitudes. Grid values of 500 mb Z, 700 mb T and SST are overaged for each area as a predictor. A total of 312 such predictors (97 for 500 mb Z, 103 for 700 mb T, and 112 for SST) in reference to Mei-Yu predictands are examined. Cross-correlations with typhoon predictands are to be completed during the second year.

All scatter diagrams and time series diagrams of these predictors will be forwarded separately to the Central Weather Bureau. Figures 10-13 are arbitrary examples of such diagrams at different locations of the predictors. Some predictors show clear simple regression with predictands, but some only indicate a general trend. In any case we should not base the prediction on any single predictor or on only a few predictors. Collectively, however, the fowarded diagrams will be very useful in forecasting Mei-Yu and typhoon predictands when we use many predictors in different locations during different months. An intercomparison of indications from different predictors in reference to a specific predictand for their consistency and general trend, will be critical in a qualitative-synoptic forecast. This will further be the basis to develop the multiple-regression schemes.

5. PLANETARY WAVES

It is important to note that Mei-Yu is an ingredient of the hemispherical planetary wave activities despite its customary treatment as local phenomena in eastern Asia. Figures 14-17 are trough-ridge diagrams of 500 mb Z for the latitudinal band of 46°-62°N from day-100 to day 60 of the Mei-Yu composite (day 0 is the onset) for 1956-1986. The average onset date (day 0) is 47.7 days from April 1 with the standard deviation being 9.5 days. The average recess date is 79.7 days ± 9.6 days. Thus the average recess date should fall at day 32 of the composite Mei-Yu.

It is obviously difficult to associate zonal wavenumbers $n=1$ and 2 (Figs. 14 and 15) with the Mei-Yu period. However, $n=3$ and 4 in Figs. 16 and 17 clearly can be associated with the onset and recess of Mei-Yu, and these are the expected scale ranges of of Mei-Yu or summer monsoon activities in eastern Asia. Prior to the onset, the activities of $n=3$ disappear. Some level of activity is restored with the establishment of Mei-Yu, which disappears again after recess. Activities of $n=4$ also diminish prior to the onset. It shows a characteristic move of phase at the time of recess.

Currently, we are processing daily trough-ridge diagrams which will be completed during the second year project. Preliminary indication from the individual year's diagrams is that the variations of $n=3$ and 4 are indeed observed annually in association with Mei-Yu onset and recess. However, strength and contrast of $n=3$ and 4 are also related with Mei-Yu variation in individual years. The subject will be further pursued through the contrast of annual $n=3$ and 4 patterns and variations of Mei-Yu during the data period.

It is noted that Mei-Yu is a stationary frontal system that moves gradually from southern China to northern China and Japan. The onset as defined in this investigation is the onset as observed in Taiwan. Thus it is possible to calibrate the trough-ridge diagrams in Figs. 3 and 4 against different onset and recess dates in various latitudes of eastern Asia.

6. LINKAGE WITH THE SECOND AND THIRD YEAR PROJECT (CONCLUDING REMARKS)

The investigation reported in this document is the basis of the qualitative and quantitative forecast of Mei-Yu and typhoon in the second and third year of the investigation.

In the second year the principal components, cross-correlations at grids, and large-scale teleconnection patterns as obtained in this study will be adequately utilized with the real-time data to generate 1990 long-range forecast with lead time of one month to one season. The spectral characteristics of $n=3$ and 4 will be subject to detailed investigation to give supplementary semi-quantitative forecasts in the range of one to two weeks.

During the third year, multiple regression equations will be established utilizing the numerous predictors examined in the first and second year. The quantitative long-range forecast then may be expected for 1991.

7. TECHNOLOGY TRANSFER

A close collaboration with the Central Weather Bureau was maintained during this year's investigation, and will be maintained through the second and third year in qualitative and quantitative (multiple regression) forecasts.

During this first year investigation the following volumes of documents have been forwarded to the Central Weather Bureau:

1. Monthly principal components of 700 mb T
2. Monthly prinicpal components of 500 mb Z
3. Monthly principal components of SST
4. Cross-correlations of Mei-Yu predictands and 700 mb T
5. Cross-correlations of Mei-Yu predictands and 500 mb Z
6. Cross-correlations of Mei-Yu predictands and SST

*7. Scatter diagrams and interannual variation of Mei-Yu predictands and 700 mb T

*8. Scatter diagrams and interannual variation of Mei-Yu predictands and 500 mb Z

*9. Scatter diagrams and interannual variation of Mei-Yu predictands and SST

*These three volumes are being forwarded under a separate cover.

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