Improvements in the Seasonal Forecasting of Tropical Cyclone Activity over the Western North Pacific

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ABSTRACT

A recent scheme to predict tropical cyclone (TC) activity over the western North Pacific partially failed in 1997 and 1998, during which a warm and a cold event of the El Niño–Southern Oscillation (ENSO) occurred, respectively. This paper presents results of two approaches to improve on such predictions. The first is to include new predictors that are related to ENSO based on some recent research, and the second is to provide an updated prediction by incorporating monthly values of predictors in April and May of the current year.

The results suggest that new predictors related to ENSO can indeed be identified, which include temporal changes in the Southern Oscillation index, strength of the Australian monsoon, and intensity of the subtropical high in the South Pacific. These predictors, together with those selected from the original prediction scheme, are combined to form a modified scheme that in general gives better forecasts of TC activity. The updated scheme that includes April and May predictors further improves the accuracy of the predictions. Real-time predictions from both schemes for the year 2000, which were made in April and June, are found to be largely accurate. Both schemes show better skill compared with the original one.

1. Introduction

It has long been recognized that tropical cyclone (TC) activity in most ocean basins has a strong interannual signal (see, e.g., the review in Landsea 2000). Over the western North Pacific (WNP), many studies have related this signal to the warm phase of the El Niño–Southern Oscillation (ENSO) phenomenon (Chan 1985; Dong 1988; Lander 1993, 1994) and the quasi-biennial oscillation (QBO) in the stratosphere (Chan 1995). Chen et al. (1998) extended these studies by comparing the locations of TC formation over the WNP between warm and cold phase years. Chan (2000) further identified variations in TC activity over different regions of the WNP the year before, during and after either a cold or a warm episode of ENSO. Since both ENSO and the QBO have periods exceeding a year, the results of such studies suggest that TC activity must have some type of interannual signal and therefore it should be possible to predict the interannual variability of TC activity. This has actually been performed for the Atlantic (Gray et al. 1992, 1993, 1994; Elsner and Schmertmann 1993; Hess et al. 1995) and the Australian regions (Nicholls 1984, 1992). However, it was not until recently that a real-time prediction scheme has been developed for the WNP (Chan et al. 1998, hereafter CSL).

The CSL scheme is based on the projection-pursuit regression (PPR) technique (Friedman and Stueltzle 1981; see also Chan and Shi 1999, and a description in CSL). Three sets of predictors were chosen:

- sea surface temperature anomalies over the central and eastern Pacific (as a proxy for the ENSO signal),
- indices that represent the characteristics of the circulation over Asia and the western Pacific from April of the previous year to March of the current year, and
- trend of the interannual variations in TC activity (the so-called climatology and persistence).

The predictands include annual number of TCs (TCA), annual number of tropical storms and typhoons (TSYA), annual number of typhoons (TYA), as well as three corresponding numbers for the period May to December (i.e., the main active TC season). Two other predictands are also defined for the South China Sea (SCS, defined as the area bounded by 0°–23°N, 100°–120°E) alone: annual number of TCs (TCS) and annual number of tropical storms and typhoons (TSYS).

Since this study represents an update of the CSL scheme, it is useful to review briefly the statistical procedure used in the CSL paper and the current study. For each of the eight predictands, CSL applied the PPR technique using the 12 predictors (one for each month,

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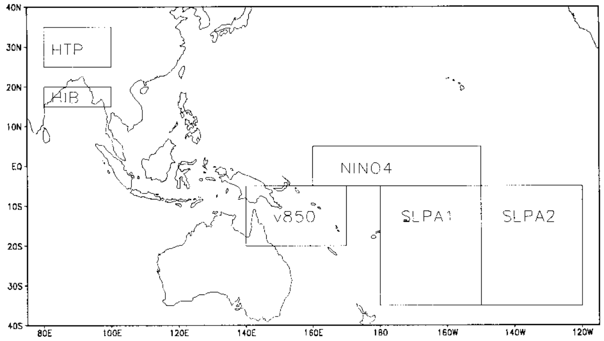

FIG. 1. Regions within which the various predictors are averaged. See text and appendix for details of the descriptions of the predictors.

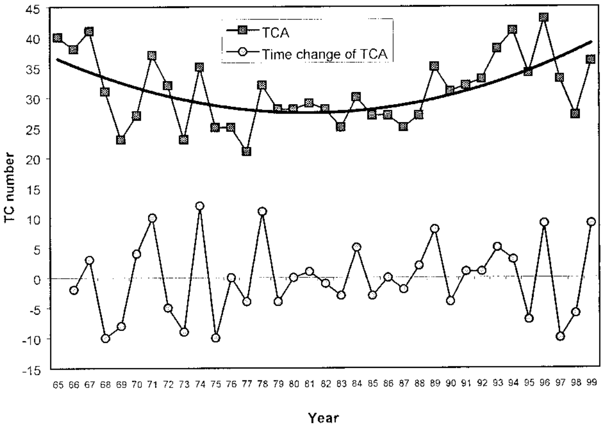

FIG. 2. Annual number of tropical cyclones over the western North Pacific (TCA) and the time change of TCA (i.e., first difference) for the period 1965–99. The thick solid line indicates a second-order polynomial fit to the TCA series.

from April of the previous year to March of the current year, except for the climatology–persistence type, which has only three predictors) of each parameter. Those predictors (up to five) that explained the largest amounts of variance were retained. The PPR technique was then applied to these selected predictors to derive a prediction equation. Thus, for each predictand, a number of prediction equations could be derived (i.e., one equation for one predictor).

To determine the number of prediction equations to be retained, CSL applied the jackknife technique (Miller 1974) to each equation to make ‘‘independent’’ predictions, which were then correlated with the observed numbers. Only those equations with significant (95% or above) correlations were kept. The final prediction was then a linear, weighted combination of these forecasts, with the weights being the absolute value of the correlation coefficients estimated through the jackknife technique.

Real-time predictions of the 1997 and 1998 TC seasons were made using the CSL scheme. The results (Table 1) show that in 1997 the scheme predicted the total activity quite well although it overpredicted TC activity over the SCS. Almost the reverse is true in 1998 (Table 2), with the predictions being generally accurate for the SCS but an underprediction of TC activity over the entire WNP.

Since 1997 (1998) was a strong warm (cold) ENSO year, these predictions suggest that perhaps the scheme could not capture the precursor signal of either a strong cold or warm event. It is also possible that such signals do not exist prior to April of the current year. Indeed, Webster and Yang (1992) have proposed the existence of a predictability barrier during the boreal spring. However, recent studies by Chan and Xu (2000) and Xu and Chan (2001) have suggested that some parameters in the Southern Hemisphere may provide clues as to when and whether a cold or warm event might occur. In other words, it might be possible to identify new predictors that can serve as better proxies for ENSO, which could then be used to modify the original scheme. However, if the signal that relates to an ENSO event does not appear until after March, this approach may not yield any improvements. An alternative is to provide an updated forecast after such signals have appeared in early

TABLE 1. Verification of the 1997 TC activity forecasts made by the CSL scheme. The boundaries are defined as follows: WNP, 0°–40°N, 100°E–180°; and SCS, 0°–23°N, 100°–120°E. The observed numbers are from the Joint Typhoon Warning Center and the ‘‘normal’’ is the average for the years 1959–94.

	Forecast	Observed	Normal
Annual for the WNP			
No. of TCs	33 ± 3	33	31
No. of TCs with at least tropical storm intensity	30 ± 3	31	27
No. of typhoons	19 ± 2	23	17
May–Dec for the WNP			
No. of TCs	30 ± 3	30	28
No. of TCs with at least tropical storm intensity	27 ± 2	30	25
No. of typhoons	18 ± 2	20	16
Annual for the SCS			
No. of TCs	12 ± 2	7	13
No. of TCs with at least tropical storm intensity	9 ± 2	6	10

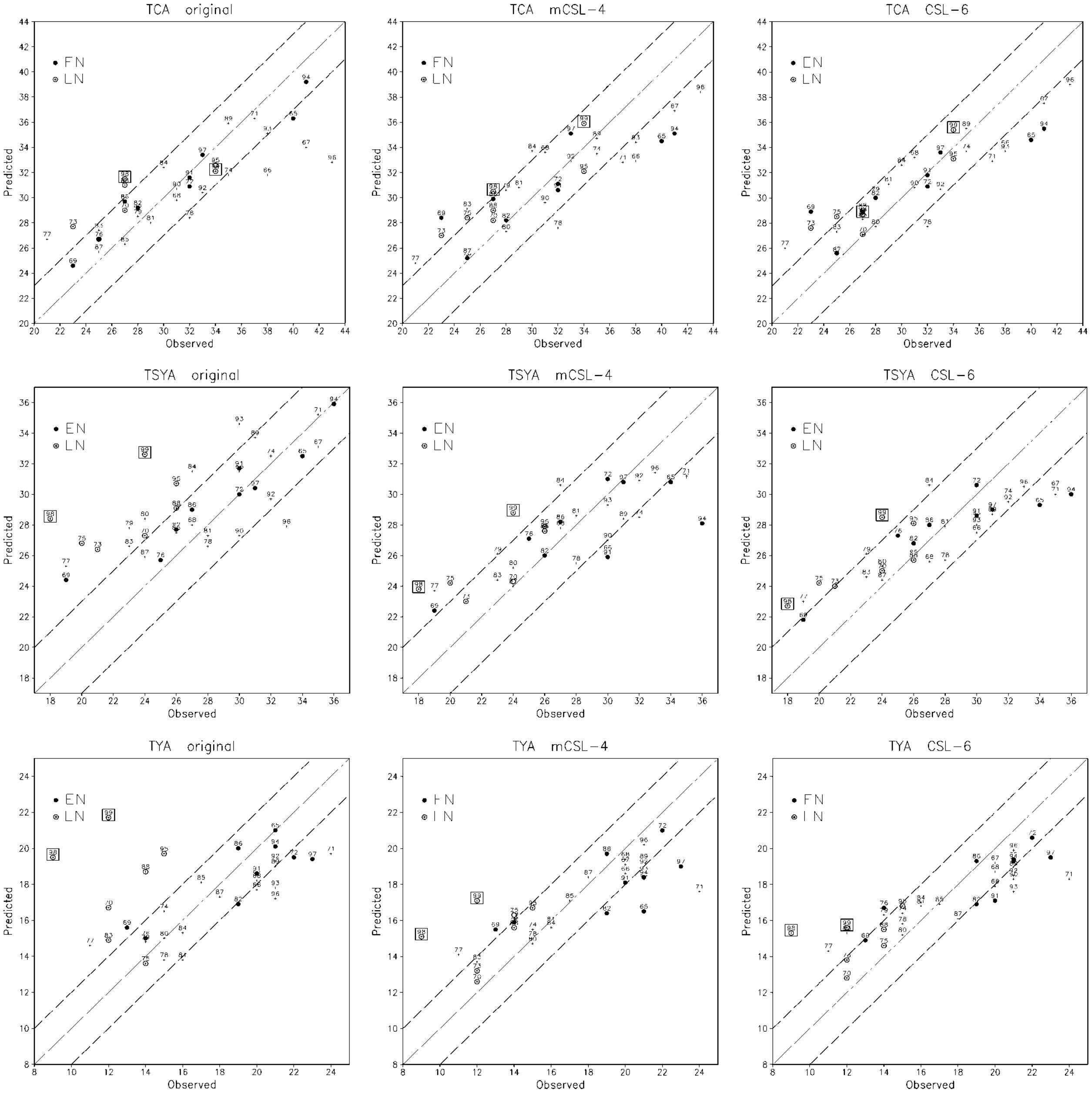

FIG. 3. Scatterplots of the predicted vs observed values for the three series TCA, TSYA, and TYA for the original, mCSL-4, and CSL-6 schemes. In each plot, the solid line represents the perfect prediction and the two dashed lines are parallel to the solid line and deviate from it by a value that corresponds to the standard error of the predictions. The number yy beside each symbol is the value for the year 19yy. Solid dots, El Niño years; circles with plus sign, La Niña years; plus sign, other years. Predictions for the years 1998 and 1999 are boxed.

summer. Indeed, Gray et al. (1993, 1994) also make such updates for the Atlantic on 1 June and 1 August.

In this paper, results from both approaches will be reported. That is, atmospheric and oceanic parameters not currently in the CSL scheme will be examined using the same regression scheme to determine whether other precursor signals can be identified. The other approach is to use all available parameters up to May of the current year to develop an update scheme that will be run in mid-June. The objective is to develop prediction schemes that can improve upon the original CSL scheme.

An evaluation of the original CSL scheme is first made in section 2. Possible new predictors are then identified in section 3. The performance of the modified scheme developed from a combination of these predictors and those from the original CSL scheme is also presented. The development of an updated scheme is described in section 4 together with an evaluation of its skill. Both the modified and updated schemes are then

TABLE 2. Verification of the 1998 TC activity forecasts made by the CSL scheme. The boundaries are defined as follows: WNP, 0°–40°N, 100°E–180°; and SCS, 0°–23°N, 100°–120°E. The observed numbers are from the Joint Typhoon Warning Center and the ‘‘normal’’ is the average for the years 1959–94. The verifications are all for the annual activity since no TC formed before May.

	Forecast	Observed	Normal
WNP			
No. of TCs	32 ± 3	27	31
No. of TCs with at least tropical storm intensity	28 ± 3	18	27
No. of typhoons	20 ± 2	9	17
SCS			
No. of TCs	13 ± 2	13	13
No. of TCs with at least tropical storm intensity	11 ± 2	8	10

TABLE 3. Correlations between observed TC activity and that predicted using each of the predictors from the original CSL scheme. Two sets of correlations are shown, one with predictions for 1965–94 (30 yr) and the other for 1965–99 (35 yr). Correlations significant at 95% (99%) are indicated with an asterisk (double asterisk). Correlations that are insignificant in both sets are not shown.

	Niño-4	SOI	WP	HSCS	HWNP	HPV	HTP	HIB	HC	CLIPER
Annual TC activity										
30 yr	0.66**		0.38*	0.52**	0.59**	0.38*	0.70**	0.70**	0.53*	
35 yr	0.57**		0.35*	0.27	0.47**	0.16	0.18	0.67**	0.15	
Annual no. of tropical storms and typhoons										
30 yr	0.59**		0.41*	0.51**	0.41*	0.55**	0.71**	0.67**		
35 yr	0.36*		0.50**	0.36*	0.54**	0.21	0.31	0.54**		
Annual no. of typhoons										
30 yr			0.19	0.26	0.37*		0.76**	0.54**	0.20	
35 yr			0.58**	0.40*	0.44**		0.24	0.34*	0.37*	
Annual no. of TCs over the South China Sea										
30 yr		0.34	0.35*			−0.02	0.48**	0.4*		0.67**
35 yr		0.40*	0.25			0.37*	0.40*	0.63**		0.48**
Annual no. of tropical storms and typhoons over the South China Sea										
30 yr	0.46**	0.47**	0.36*				0.40*	0.23	0.48*	0.56**
35 yr	0.42*	0.32	0.00				0.30	0.73*	−0.14	0.42*

used to predict TC activity in the year 2000 in section 5. Verifications of the predictions are also presented. A summary of the results is given in section 6 together with a discussion on possible future improvements.

2. Temporal variations of the predictive skill

In the CSL scheme, the regression equations were derived based on 30 years of data (1965–94). If the same predictors used in these original equations for the period 1995–99 were included and the entire 35 years of predictions were made, again using the jackknife technique, these predictions have different correlations with the observed activity (Table 3). In most cases, the correlations decreased although some of these did increase. In fact, in some cases, the decrease is rather significant. This result suggests the possible existence of a decadal variability of the predictors, which may be out of phase with that of TC activity [see Chan and Shi (1996) for a discussion of the latter].

As mentioned in section 1, the CSL scheme predicts annual TC activities as well as those for the months of May to December. However, it has been found that in some years, the two sets do not quite agree with each other. To avoid the subjectivity in deciding which prediction to choose, only the annual activities will be discussed for the remaining parts of this paper, as in Table 3. The five predictands are therefore TCA, TSYA, TYA, TCS, and TSYS.

A consequence of the decadal variability of TC activity and/or the predictors is that the predictive skill of the original CSL scheme decreases for the latest 5 yr (Table 4). These results suggest two important points. First, the interdecadal variations in both the predictors and TC activity need to be removed before the prediction equations are derived. Second, because of these variations, the regression equations should be rederived every few years to reduce their influence on the accuracy of the predictions.

3. Possible predictors from the Southern Hemisphere

As mentioned in section 1, Chan and Xu (2000) found that sea level pressure anomalies in the Southern Hemisphere (SH) are apparently related to the onset of cold ENSO events. Xu and Chan (2001) also identified the summer monsoon circulation over Australia as an im-

TABLE 4. Performance of the original CSL scheme using 30 and 35 yr of data.

	Correlation		Absolute error		Rms error		Measurement of agreement	
Predictand	30	35	30	35	30	35	30	35
TCA	0.89	0.84	2.3	2.6	2.9	3.4	0.5622	05166
TSYA	0.86	0.73	2.3	3.1	2.6	3.9	0.4892	0.3643
TYA	0.75	0.57	2.0	2.5	2.5	3.2	0.4378	0.3391
TCS	0.77	0.71	2.4	2.3	2.7	2.8	0.3402	0.3305
TSYS	0.75	0.69	1.4	1.5	1.9	2.0	0.3860	0.3537

portant ingredient for the occurrence of warm events. The following indices [all computed from monthly values in the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis dataset] are therefore defined to represent these features:

- Australian monsoon circulation index (V850): 850-hPa meridional winds averaged over the region (5°–20°S, 140°–170°E),
- SH sea level pressure anomaly 1 (SLPA1): mean sea level pressure anomaly averaged over the region (5°–35°S, 180°–150°W), and
- SH sea level pressure anomaly 2 (SLPA2): mean sea level pressure anomaly averaged over the region (5°–35°S, 150°–120°W).

These areas, together with those for the other predictors listed in Table 3 and the appendix, are shown in Fig. 1. However, it was found that a simple correlation between each of these three indices and TC activity does not yield any significant result. Recall from section 2 that interdecadal variations in TC activity exist (see also Nicholls 1992; Chan and Shi 1996). In addition, Wang (1995) has shown that ENSO events possess an interdecadal signal. In other words, these time series are nonstationary, which may be the reason for the low correlation among the series.

To remove this condition, the first difference of the time series is computed (Box et al. 1994). That is, for a variable z at time t (z_t), the quantity

$$\delta z_t = z_t - z_{t-1}$$

is calculated for all times $t > 1$. The new series $\{\delta z\}$ then becomes nearly stationary, as is evident from the example given in Fig. 2 for the TC activity. This procedure is then applied to all the TC series, the three new indices, and the (monthly) Southern Oscillation index (SOI). Most of the correlations among the series then become statistically significant (Table 5). Note further that δ(SOI) also correlates significantly with TC activity. This is consistent with Nicholls' (1992) result for TC activity in the Australian region. However, it needs to be pointed out that this procedure still does not yield any significant correlation between the indices and TC activity over the SCS.

TABLE 5. Correlation coefficients between the time series of the first difference of the four new predictors and that of TC activity. See text for the definition of the predictors.

	δ(SLPA1)	δ(SLPA2)	δ(V850)	δ(SOI)
δTCA	0.65	0.74	0.63	0.63
δTSYA	0.40	0.55	0.43	0.56
δTYA	0.06	0.45	0.56	0.33

These four new predictors [i.e. δ(SOI), δ(V850), δ(SLPA1), and δ(SLPA2)] are then combined with the predictors used in CSL to rederive the prediction equations using 35 yr of data (hereafter referred to as the modified CSL scheme to be issued in April, or mCSL-4) by applying the same procedure used by CSL (see section 1). A maximum of six final predictors can be chosen. The cross-validation results show the mCSL-4 scheme to be superior to the original CSL scheme (Table 6). Because the new predictors are all related to the ENSO phenomenon, the mCSL-4 scheme should perform better in ENSO years. A comparison between the two schemes shows that this is indeed the case (Table 7).

These improvements can be better illustrated using scatterplots of the predicted versus observed values for all the three series (Fig. 3). A prediction can be considered to be correct if it falls within the dashed lines, which are parallel to the 45° line and constructed using the standard errors from the final prediction scheme (± 3 for TCA and TSYA and ± 2 for TYA). For the TCA series, although the number of years that fall outside the dashed lines in the mCSL-4 scheme is actually larger, the errors are in general much smaller (see also rms errors listed in Table 6), especially for the underpredictions. More importantly, the mCSL-4 scheme improves significantly on the predictions of both TSYA and TYA especially for La Niña years. In both cases, the overpredictions made by the original CSL scheme for these years have been much reduced, although a slight increase in errors occurs for a few El Niño years.

4. The updated prediction scheme

The CSL scheme uses data up to March of the current year. However, since precursors of the ENSO (or other phenomena) may not occur or be detected until later in the year, it might be possible to provide an updated (and better) forecast by utilizing data from later months. Gray et al. (1993, 1994) have shown that by including data from more recent months, the predictive skill for TC activity in the Atlantic can be improved.

TABLE 6. Performance of the original CSL (O) and mCSL-4 (M) schemes using 35 yr of data. Both schemes are based on 35 yr of data.

	Correlation		Absolute error		Rms error		Measurement of agreement	
Predictand	M	O	M	O	M	O	M	O
TCA	0.88	0.87	2.6	2.8	3.0	3.4	0.5206	0.4674
TSYA	0.80	0.77	2.5	2.7	3.0	3.2	0.4371	0.3889
TYA	0.84	0.74	2.0	2.3	2.5	2.8	0.4966	0.3391

To do this, the prediction equations are rederived using the same technique as described in CSL but using monthly data from June of the previous year to May of the current year. This was done separately for three sets of predictors: those described in CSL, the four ‘‘ENSO predictors’’ described in section 3, and a combination of these two sets. The correlation coefficients from the cross-validation tests show that the combination yields the best results in almost all the categories (Table 8). However, a comparison of these correlations with those of mCSL-4 (see Table 6) shows that improvement only occurs in the TSYA category. In the other categories, the correlations are about the same. A similar result is found for the ENSO years (see Table 7). This result suggests that by including April and May predictors, the regression procedure might exclude some predictors from earlier months that correlate better with TC activity.

To circumvent this problem, the following procedure is adopted. The predictors selected in the mCSL-4 scheme are each used to make the predictions and the correlation coefficients calculated. These are then compared with the coefficients obtained from the late predictors (i.e., those from the previous Jun to the current May, and including the SH predictors). Note again that all the correlation coefficients are derived through the cross-validation (jackknife) procedure. Six predictors with the highest correlation coefficients within these two sets are then chosen to obtain the final (weighted) forecast, again using the coefficients as the weights. This is then termed the CSL-6 scheme. The results (Table 9) show that this scheme gives higher correlations than the mCSL-4 scheme (Table 7), the one utilizing only the late predictors, or a combination of the two sets (i.e., columns N and C, respectively, in Table 8).

The scatterplots (Fig. 3) further illustrate the improvements from the CSL-6 scheme over both the original and the mCSL-4 schemes especially for the TSYA and TYA predictions. Some of the errors for ENSO years have been further reduced. One of the motivations of this study is the failure of the CSL scheme in predicting TC activity over the entire WNP in the La Niña year of 1998 (failure of the scheme in 1997 was for the SCS but no new predictors can be found). Both the mCSL-4 and CSL-6 schemes give much better predictions. The same can be said for 1999. Further, predictions from the CSL-6 scheme are better than those from the mCSL-4 scheme.

TABLE 7. Correlations between observed TC activity and that predicted using the original CSL and the mCSL-4 schemes for the ENSO years.

	Original CSL	mCSL-4
TCA	0.80	0.88
TSYA	0.79	0.79
TYA	0.80	0.85

5. Predictions for 2000

In April 2000, forecasts based on the original CSL scheme were issued (Table 10), which called for a slightly above-normal season for the entire western North Pacific but close to normal over the SCS. However, using the mCSL-4 and CSL-6 schemes, the predictions are for a slightly above-normal season but with slightly below-normal number of typhoons. Verification of the forecasts shows that if all those TCs that were considered by the Joint Typhoon Warning Center (JTWC) as having reached tropical storm intensity are counted, the predictions from both the mCSL-4 and CSL-6 schemes are all correct. Even if the three relatively weak TCs (16W, 27W, and 28W) are discounted, these revised predictions are still better than the original ones. In particular, the predicted number of typhoons is much reduced, as observed.

6. Summary and discussion

a. Summary

This paper presents an improved [over the Chan et al. 1998 (CSL) scheme] seasonal forecast scheme for TC activity over the western North Pacific. Such im-

TABLE 8. Correlations between observed TC activity and that predicted using three sets of predictors from Jun of the previous year to May of the current year: those from the original CSL scheme (O), the four new ENSO predictors (N), and a combination of the two sets (C). The correlations are shown for all 35 yr in the dataset as well as for the ENSO years only.

	All years			ENSO years		
	O	N	C	O	N	C
TCA	0.85	0.70	0.86	0.87	0.72	0.87
TSYA	0.85	0.62	0.85	0.88	0.70	0.88
TYA	0.64	0.69	0.78	0.71	0.78	0.77
TCS	0.67	0.63	0.77	0.69	0.51	0.80
TSYS	0.70	0.60	0.78	0.76	0.48	0.73

TABLE 9. Correlations between observed TC activity and that predicted using the CSL-6 scheme for all 35 yr and for the ENSO years.

	All years	ENSO years
TCA	0.91	0.92
TSYA	0.89	0.90
TYA	0.87	0.87
TCS	082	0.80
TSYS	0.84	0.83

provements became necessary after the partial failures of the CSL scheme for the 1997 and 1998 forecasts (see Tables 1 and 2). Because these two years correspond to warm and cold phases of the ENSO phenomenon, respectively, it appears logical to seek predictors that would be better indicators of the occurrence of these phases. The scheme thus makes use of recent results of Chan and Xu (2000) and Xu and Chan (2001) that relate the onset of these phases with sea level pressure anomalies associated with the subtropical high in the southern Pacific and the meridional flow in northeastern Australia, respectively. Further, because these indicators might not be present in the earlier parts of the year (the original CSL scheme utilizes data from Apr of the previous year to Mar of the current year), the predictors in April and May of the current year are also examined.

The methodology used by CSL is adopted in selecting the best predictors. The results suggest two schemes. The first one can be issued in April [the modified CSL-April (mCSL-4) scheme] that makes use of some the original CSL predictors and some of the new ones related to ENSO. An updated forecast is then issued in June [the CSL-June (CSL-6) scheme] that incorporates information up to May of the current year. Both schemes are found to perform better than the original scheme, especially for La Niña years. Predictions for the 2000 season were issued in April and June. Verifications of the predictions show that indeed both the mCSL-4 and CSL-6 schemes gave more accurate, and indeed correct, forecasts.

b. Discussion

While the mCSL-4 and CSL-6 schemes do show improvements over the original scheme, two points should be noted. First, the current sample size of 35 yr is still relatively small. Stability of the prediction equations still needs to be further substantiated in the future. This has been demonstrated in section 2 of this paper when comparing the predictions using 30 and 35 yr of data. In other words, the prediction equations should be rederived after a few years. Second, the problem of interdecadal variations needs to be taken into consideration. Removal of such variations is likely to produce better predictions, as has been shown in section 4.

TABLE 10. Forecasts of TC activity in 2000 using the original CSL scheme, the mCSL-4, and the CSL-6 schemes. The asterisk in the TSYA row indicates that three TCs were classified by JTWC as tropical storms (16W, 27W, and 28W) but they were not named by any other center. Similarly, the double asterisks in the TSYS row indicate that one TC was classified by JTWC as a tropical storm (28 W) but not named by any other center. In the TYA row, the number sign indicates that the 15th typhoon (Soulik) did not intensify to typhoon strength until 3 Jan 2001 (but formed on 29 Dec 2000). The observed and normal (1959–94) numbers are also included in the last two columns.

	Forecast				
	Original	mCSL-4	CSL-6	Observed	Normal
TCA	30 ± 3	32 ± 3	33 ± 3	34	31
TSYA	29 ± 3	26 ± 3	28 ± 3	23/26*	27
TYA	22 ± 2	14 ± 2	16 ± 2	14/15#	17
TCS	13 ± 2	11 ± 2	13 ± 2	12	13
TSYS	10 ± 2	9 ± 2	9 ± 2	7/8**	10

The next step in this investigation would be to understand the physical reasons for the correlations. This may not only lead to even better predictions but also to a better understanding of the mechanisms that determine the seasonal TC activity.

Acknowledgments. The authors would like to thank the National Climate Center of the China Meteorological Administration for providing the indices necessary for the predictions. Other indices were extracted from the Web site of the U.S. Climate Prediction Center. Computations of the atmospheric wind and pressure anomalies are based on the NCEP–NCAR reanalysis dataset. Comments from the two anonymous reviewers, which have led to improvements in the manuscript, are gratefully acknowledged.

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APPENDIX

Detailed Description of the Parameters Listed in Table 3

Predictor	Description	Source
Representing the El Niño–Southern Oscillation		
SOI	Standardized Southern Oscillation index	NOAA/CAC
Niño-4	SST anomalies in the Niño-4 region	NOAA/CAC
Representing the large-scale flow over Asia and the Western North Pacific		
WP	West Pacific pattern index that describes a primary mode of low-frequency variability over the North Pacific (see Barnston and Livesey 1987)	NOAA/CAC
HSCS	Mean latitude of the northern flank of the 5880-gpm contour (characteristic height of the subtropical high) on the 500-hPa monthly mean chart between 110° and 120°E	NCC
HWNP	Area enclosed by the 5880-gpm contour (characteristic height of the subtropical high) on the 500-hPa monthly mean chart within the area (10°–50°N, 110°E–115°W)	NCC
HPV	Area enclosed by the characteristic geopotential height contour of the polar vortex (which varies from 5480 m in Jan to 5720 m in Jul and Aug) on the 500-hPa monthly mean chart within the longitude band 150°E–120°W.	NCC
HTP	Average 500-hPa geopotential height minus 5000 gpm within the area (25°–35°N, 80°–100°E)	NCC
HIB	Average 500-hPa geopotential height minus 5800 gpm within the area (15°–20°N, 80°–100°E)	NCC
HC	Frequency of cold-air intrusion into China during Sep–Dec and Jan–May; an occurrence of a cold-air intrusion is defined as when 8 out of 15 stations over China (evenly spread around from north to south) have a temperature drop of ≥5°C within the same 3 days	NCC
Representing the climatology and persistence		
CLIPER	Trend and 3–7-yr variations of the predictand	Derived from data

NOAA/CAC: National Oceanic and Atmospheric Administration/Climate Analysis Center.
NCC: National Climate Center, China.

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