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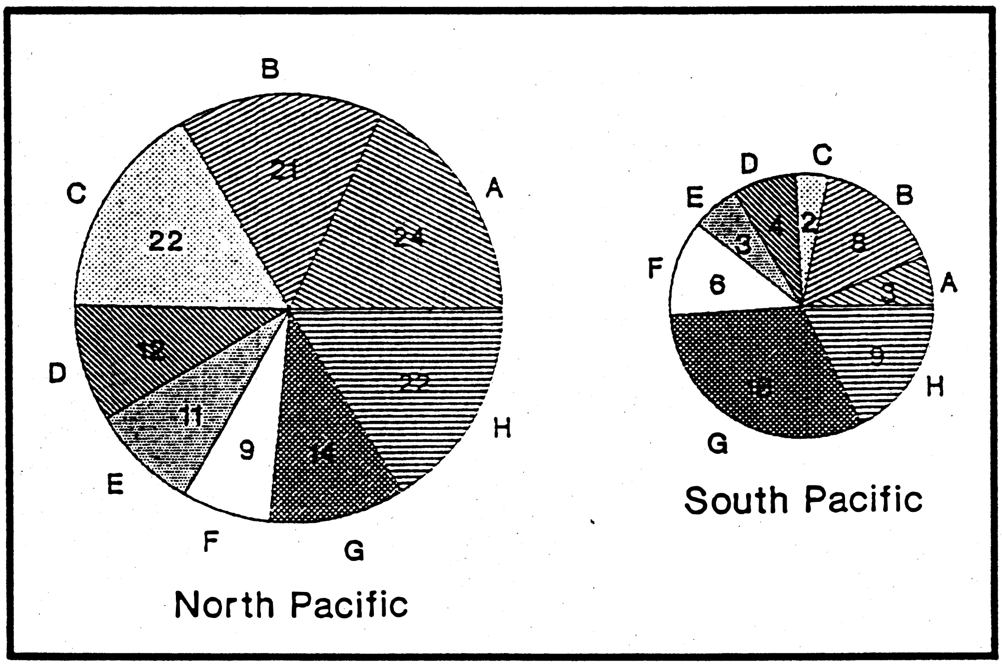

THE PHASE OF THE 30- to 60-DAY OSCILLATION AND THE GENESIS OF TROPICAL CYCLONES IN THE WESTERN PACIFIC

by

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The Phase of the 30- to 60-Day Oscillation and the Genesis of Tropical Cyclones in the Western Pacific

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Abstract

The relationship between the genesis of tropical cyclones in the Western Pacific and the phase of the tropical 30- to 60 day oscillation (MJO) is analysed using 5 years of data. The phase of the MJO is described by the POP index of the MJO.

A statistically significant signal is identified for both the North and South Pacific: More (less) cyclones than on average occur when the MJO is causing negative (positive) regional outgoing long wave radiation (OLR) anomalies.

The signal is considerably better defined in the Southern Hemisphere than in the Northern Hemisphere. In the Southern (Northern) hemisphere the expected number of cyclones formed in the convectively active MJO-phase is 4 (2.25) times the expected number in the inactive phase.

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1. INTRODUCTION

The tropical 30 to 60 day oscillation, or the Madden and Julian oscillation (MJO; Madden and Julian, 1972) is known to be a global scale disturbance that is associated with significant regional anomalies of convection (in terms of outgoing long wave radiation (OLR)) (e.g., Knutson and Weickmann, 1987; Storch and Xu, 1990). It is generally believed that reduced vertical stability and the presence of organized convection is favorable for the generation of tropical cyclones (for an overview see Evans (1990)). It is thus reasonable to hypothesize that the regional low-frequency modifications of the tropical mean state might associated with the MJO influence the frequency of tropical cyclones (Nakazawa, 1986).

In this short contribution we are pursuing this hypothesis by stratifying the dates of formation of lows that became tropical cyclones after the phase of the MJO. This phase is defined by the complex POP index of the MJO (Storch and Xu, 1990)

The paper is organized as follows: First the POP index of the MJO is briefly introduced, with particular emphasis on its appearance in terms of OLR (Section 2a), and then some information on the tropical cyclone data is given (Section 2b). In Section 3, frequency distributions are derived displaying the dependence of evolving cyclones on the phase of the MJO. These frequency distributions are obtained separately for the northern and southern summers, as the signature of the MJO-related OLR signal in these seasons is markedly different.

2. The Index of the MJO and the Cyclogenesis Data

a) The POP index of the MJO

The POP index of the MJO (Storch and Xu, 1990; Storch and Baumhefner, 1991) is used to describe the state of the MJO. This index z is complex, $z = \rho\ e^{i\phi}$. The phase ϕ indicates the longitudinal position of the minimum of the MJO wave number 1 in the upper air velocity potential (Fig 1.), and ρ measures the strength of the MJO. In this study, the z-plane is split into eight 45^0 sectors. Sector A covers the angles 0^o-45^o in Fig. 1, sector B the angles 45^o-90^o, and so forth with H representing the sector 315^o-360^o. Note that the POP index is defined to propagate clockwise so that the system tends to migrate from B to A, and then from A to H, to G and so forth.

The distribution of the phase ϕ is, to a good approximation, uniform (Storch and Baumhefner, 1991) so that no longitudinal sector is preferred by the MJO, and the a-priori chance of hitting any of the sectors A to H on a randomly chosen day is 1/8.

As a rule of thumb, the minimum of the velocity potential wave 1 pattern is associated with maximum anomalous upper air divergence, but not necessarily maximum extra convection; also, the corresponding maximum of the velocity potential wave, and the anomalous upper air convergence, are approximately 180^o out of phase with the minimum.

Applying the "associated correlation pattern technique" (Storch et al., 1988) it is possible to derive the OLR anomaly patterns that are typically associated with the eight sectors A to H. The A (B,C,D) pattern is the same as the E (F,G,H) pattern, but with reversed sign. The associated correlation patterns can be derived for subsets of the data, e.g., for different seasons.

In Fig 2. the four sectors with a signature in the West Pacific are shown, separately for northern and southern tropical cyclone seasons, JJASO and DJFMA. In accordance with Knutson and Weickmann (1985) and Storch and Xu (1990), the OLR-signal exhibits a distinct annual variation. The signal is very well defined in the western part, but less well organized in the central part.

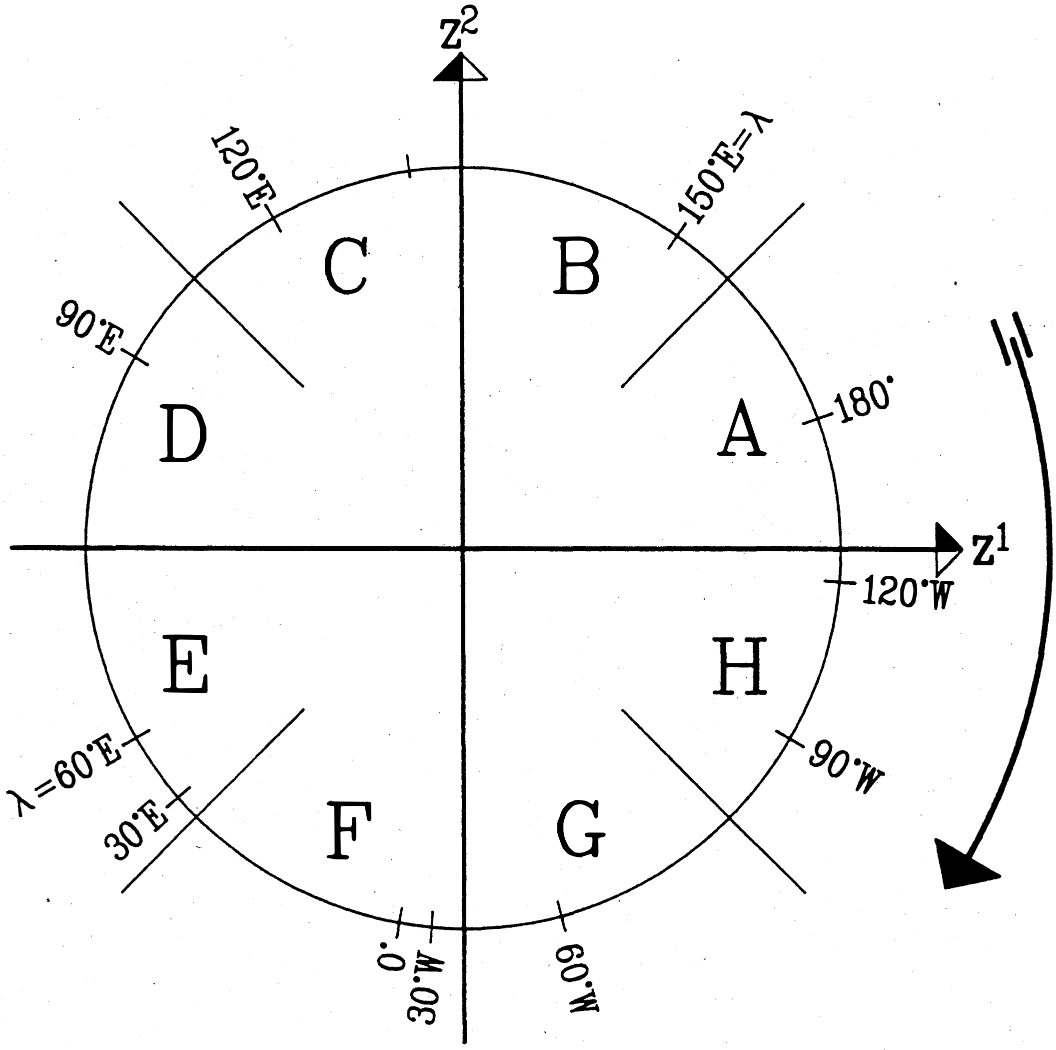


Figure 1:
Schematic of the phase of the complex POP index of the MJO and the longitudinal position of minimum of the MJO wave 1 pattern of 200 hPa velocity potential. The eight sectors A to H are used to form the frequency distributions shown in Fig 4. Note that the POP index is defined so that the MJO is described as propagating clockwise, from A to H, then H to G, and so forth.

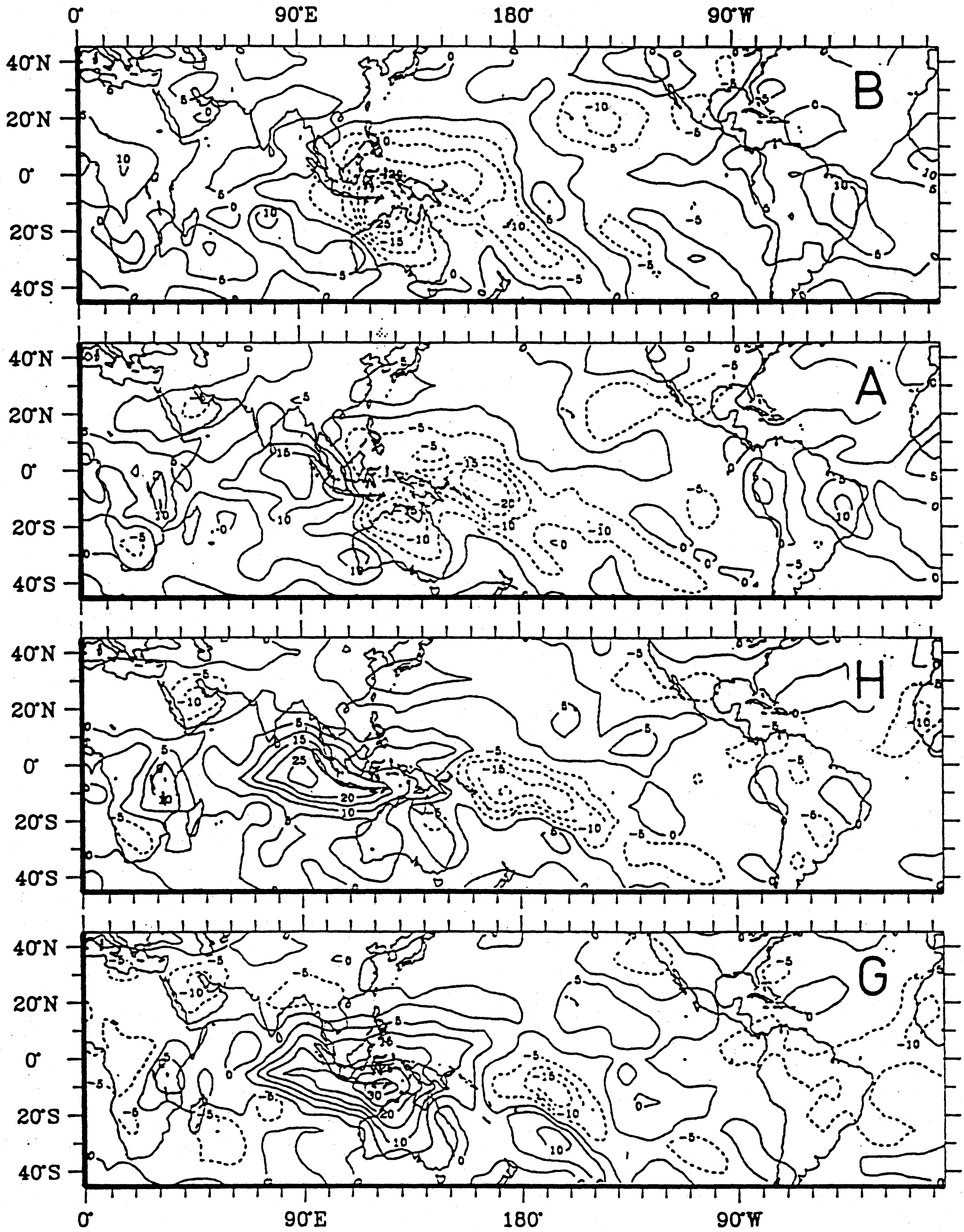


Figure 2

Negative OLR anomalies connected with the MJO prevail in the Western Pacific

• in the SH storm season DJFMA in the POP coefficient sectors B, A, H and G.

The patterns shown are the expected fields if the POP coefficient is in the respective sector and if its modulus is 1 standard deviation. The POP coefficient sectors are defined in Fig. 1.

Units: Wm^{-2}.

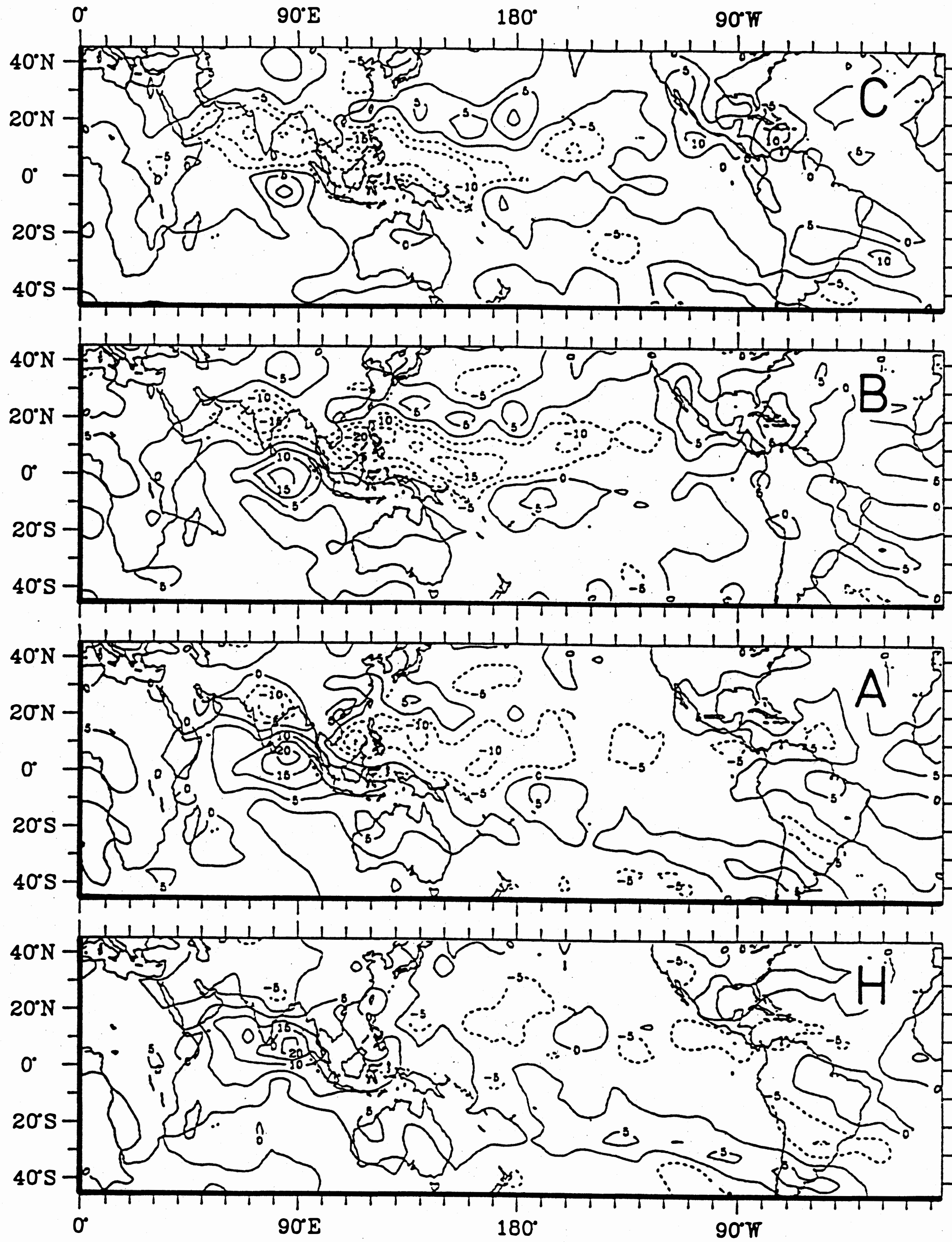


Figure 2

Negative OLR anomalies connected with the MJO prevail in the Western Pacific

• in the NH season JJASO in the sectors C, B, A and H.

The patterns shown are the expected fields if the POP coefficient is in the respective sector and if its modulus is 1 standard deviation. The POP coefficient sectors are defined in Fig. 1.

Units: Wm^{-2}.

The POP index is extracted from NMC analyses of equatorial velocity potential at 200 hPa. These analyses were available for this project from 1982 until April 1989. They are reasonably statistically stationary from May 1984 onward; before that the quality of the analyses is somewhat questionable. The present analysis is therefore limited to the interval May 1984 till April 1989.

b) The tropical cyclogenesis data

In the following we are concerned with the location of lows which develop into tropical cyclones, and the time of their first appearance. These intense storms do not develop everywhere in the tropics, but only over the warm water pools (Fig. 3). Those in the Northern (Southern) Hemisphere form predominantly in the northern (southern) summer.

Two collections of dates of the occurrence of tropical cyclones in the West Pacific have been used, which are named "NH" and "SH" data sets. They describe the formation of storms in the Northern and Southern Hemispheres. The NH data set has been compiled by Gray and coworkers at Colorado State University, Ft. Collins, and the SH data set by Smallegange of the Queensland Regional Office of the Bureau of Meteorology, using data held by that office and preliminary reports issued by the Fijian Meteorological Office.

Most of the storms in the NH data set are from June to November, and only very few are from the northern winter months. The SH data set contains only storms from the months November to May.

All NH storms have originated from longitudes between 105°E and 170°W, and all SH storms have formed between 135°E and 145°W. Eight of the SH storms formed west of Torres Strait. During the considered 5 year interval, from May 1984 through April 1989, 135 tropical NH storms have been identified. One of these storms is disregarded because it occurred when the MJO-index was not available for a short period. 51 storms are included in the SH data set.

In the SH data set a measure of the storms' strengths is also included, namely a category, ranging from 1 (weakest) to 5 (strongest). For the Queensland data, the storms' categories were determined mainly from the lowest estimated pressure, but also from the wind estimates. For the Fijian data, the storms' categories were derived from the maximum estimated wind or gust speed. Due to

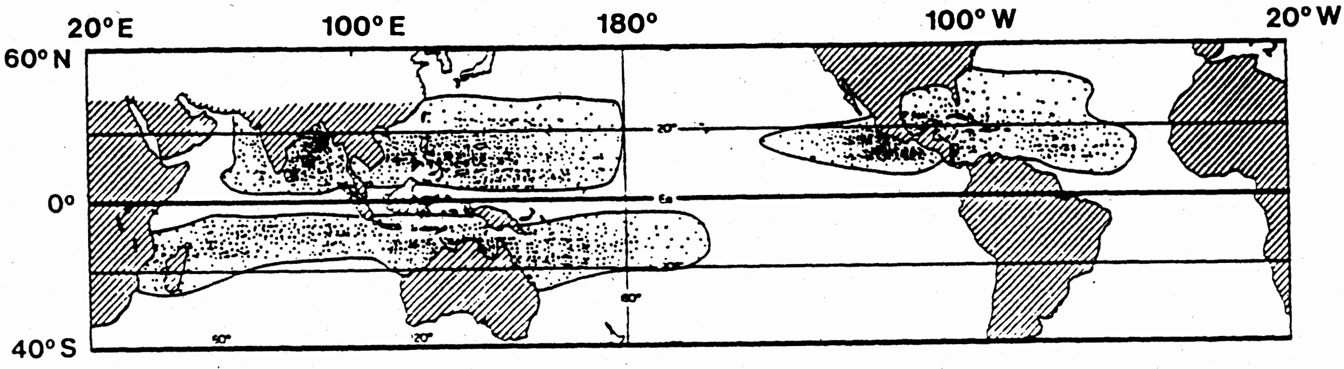


Figure 3
Global tropical cyclogenesis locations for a 20 year period (after Gray, 1975).

errors in determining these values there must be some errors in the cyclone category determination, however, it is believed these errors generally would not be greater than one category.

Two of the SH storms are rated only as depressions, nine are rated as category 1, seven as category 4 and only one as category 5 (Hina, formed on the 10.3.85).

3. RESULTS

In this Section we consider first the SH data set.The resulting statistic of the SH cyclogenesis is compared with the MJO-typical OLR patterns representative of the southern storm season (DJFMA). Similarly, the results obtained with the NH data set are compared with the typical OLR anomalies in JJASO.

Each tropical cyclone is associated with one of the sectors A - H, namely the one in which the POP index z(t) is located on the day t of the storm's genesis. In this way a frequency distribution is obtained which may be displayed in a pie-diagram. We have derived pie diagrams for southern and northern storms separately (Fig. 4).

As mentioned before, the MJO is uniformly distributed on the eight sectors A to H so that, if there were *no relation between the phase of the MJO and the cyclogenesis*, the number of storms per sector would be one eighth of all storms. If n is the total number of storms, f(X) the frequency of storms in sector $X \in \{A,B,C,...H\}$, and $\mathcal{E}$ the expectation operator, the no-relation is formally equivalent to

$$\mathcal{H}_o: \mathcal{E}(f(X)) = n/8 \qquad \text{for all } X \in \{A,B,...H\}$$

If $\mathcal{H}_o$ is true, then the statistic $\gamma = \sum_{X=A}^{H} \left[f(X)/(n/8) - 1\right]^2$ is asymptotically χ^2 distributed with 7 degrees of freedom (Lindgren, 1968). Thus, we can reject the null hypothesis $\mathcal{H}_o$ with a risk of α if γ is larger than the (1-α) quantile of the χ^2 distribution with 7 degrees of freedom. Statistical textbooks (Lindgren, 1968) indicate that the asymptotic approximation is useful if the number n is four or more times the number of categories. Here, this condition is satisfied, as we have n = 135 storms in the NH data set and n = 51 in the SH data set while 8 categories (A to H) are considered.

The (1-α) quantile of the χ^2 distribution with 7 degrees of freedom is 14.1 for α = 0.05 and 20.3 for α = 0.005.

a) Southern Hemisphere

For the SH data set, which contains 51 storms, the null hypothesis $\mathcal{H}_o$ is strongly rejected, with a risk of less than 0.5%, as γ = 23.5 > 20.3. Thus, the data support the existence of a link between the phase of the MJO and the frequency of the formation of tropical storms.

About 50% of the 51 tropical cyclones in the West Pacific area develop while the MJO is in the sectors G and H (Fig. 4). If there were no relationship between the phase of the MJO and the cyclone formation, one would expect a rate of 25% for the two sectors, or about 6 cyclones per sector. In Fig 2a, the typical DJFMA OLR anomalies connected with the MJO-phases B, A, H and G are displayed. While the MJO phase passes along the sectors H and G negative OLR anomalies, i.e. intensified convection, prevail in the central Pacific. Thus, storms develop more frequently in the tropical South Pacific if the MJO is destabilizing the central Pacific troposphere.

In the opposite phase of the MJO, in the sectors C and D when positive OLR anomalies are in the central Pacific, only 6 cyclones are counted. Thus if a vortex is present while the MJO is in G and H the probability that this vortex will form a tropical cyclone is four times larger than if the MJO is in C and D.

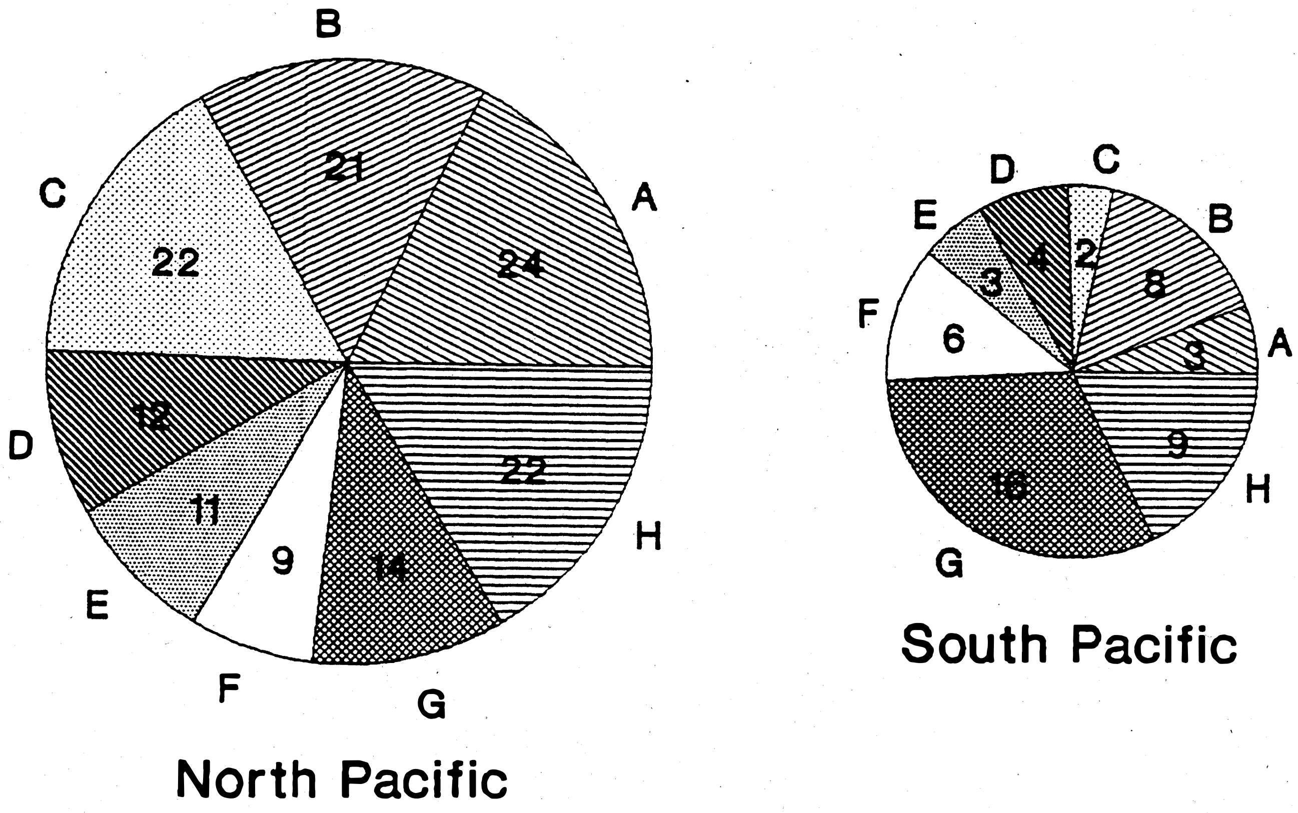
In Table 1, the frequency distribution of all SH tropical storms is stratified after the category of the storms. The category 1 storms prefer the sectors when the MJO is causing negative OLR anomalies in the west or central Pacific (sectors G, H, A and B). Surprisingly, no preference can be determined for the category 2 storms. The preference for sector G in the categories ≥ 3 is statistically significant, even if the above mentioned asymptotic approximation is questionable in view of the too small sample sizes. The results suggest that the deepening of storms to category 3 or more is more likely to occur in the convectively active MJO phase.

b) Northern Hemisphere

For the NH data set, which contains 135 storms, the null hypothesis $\mathcal{H}_o$ is rejected, with a risk $\alpha < 5\%$, since $\gamma = 14.7 > 14.1$. Thus, in the Northern Hemisphere there is also a statistically significant link between the phase of the MJO and the genesis of tropical storms.

89, or 66%, of the 135 NH tropical cyclones are formed while the MJO is in C, B, A and H (Fig. 4). Minimum frequency is in the sectors F, E and D, when the

The Phase of the MJO and the genesis of tropical cylones in the West Pacific



May 1984 through April 1989

Figure 4
Pie diagrams of the frequency of tropical cyclogenesis in the Western Pacific, sorted after the same day's POP coefficient. The POP coefficient sectors A, B to H are defined in Fig. 1.
Right: the Southern Hemisphere cyclones.
Left: the Northern Hemisphere cyclones.
The size of the pie is proportional to number of cyclones in the area.

Table 1

Frequency of SH tropical storms in the eight POP coefficient sectors A, B, to H, stratified after the category of the storms. If $\gamma > 14.1$ (20.3) the null hypothesis $\mathcal{H}_o$ that the distribution is uniform may be rejected with a risk of less than 5% (0.5%)

	POP coefficient sector								number of	
category	A	B	C	D	E	F	G	H	samples	γ
1	1	4	-	-	-	1	2	1	9	18
2	1	2	2	1	2	2	3	4	17	5
3	-	2	-	3	-	3	6	3	17	23
≥4	1	-	-	-	1	-	5	1	8	31

MJO-related OLR anomalies are the opposite of those in the sectors B, A and H. Clearly, the sectors C, B and A represent the phases of the MJO when its negative OLR anomalies prevail in the Western Pacific. During H the negative anomalies are in the central part of the ocean (Fig. 2b).

The probability of a tropical cyclone forming in the two sectors B and A is 2.25-times the probability of a cyclone in E and F.

4. CONCLUSIONS

The main conclusion to be drawn is that Nakazawa's (1986) suggestion of a link between the formation of tropical storms and the phase of the MJO is supported.

The other conclusion is that the phase lock between MJO and tropical storm formation is not strong. This finding is not unexpected since the formation of cyclones is not directly linked to the dynamics of the MJO. Instead as it passes by, the MJO modifies the tropical large scale environment in a favorable, or unfavorable, way to amplify vortices. But the MJO, even if it is the dominant actor on the sub-annual time scale in the tropical theater, is not the only one able to modify this environment. Other processes include ENSO, SST anomalies, the activity of the monsoon trough, cold air outbreaks and meso-scale disturbances. These other processes appear in the present analysis as noise.

Our analysis depends on the reliability of the POP index of the MJO. We take this for granted because this index reproduces the typical features of the MJO which have been identified previously by conventional techniques (Storch and Xu, 1990). The results presented in this study have been obtained with the unfiltered index, i.e., the index z(t) depends only on the velocity potential field at day t. Because of the low frequency character of the MJO the use of a band-pass filtered index might be more appropriate. When this was done, however, the results did not change significantly.

Another problem of our study concerns the date of the initial formation date of a low. Some lows develop quickly, others slowly. If a low develops slowly in a data sparse area, its "formation date" could be given as one of a range of dates. Also, a low might exist for a week or two but not deepen until conditions become more favorable for the development into a tropical cyclone. The time of significant deepening of a low might be a more adequate parameter than the time of the initial development.

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