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Stabilization of atmospheric circulation patterns by sea surface temperatures[1]

by Jerome Namias[2]

ABSTRACT

Although the atmosphere and the underlying sea surface temperatures are usually well coupled so that quantitative specification of one medium by the other is quite successful, there are occasional periods when no such coupling exists. A case of this kind occurred during the cold months of 1957–58, when the atmosphere transitionally went off track, only to return later on to its original abnormal regime (negative height anomalies in the east central North Pacific). This paper describes the breakdown and restoration of the large scale coupling mechanism and poses a problem of major concern to those hoping to predict climatic fluctuations for seasons or years ahead.

1. Introduction

It has for some years been known that sea-surface-temperature patterns, when averaged over periods from a month upward, are associated with atmospheric flow patterns. Conceptually, mean atmospheric pressure anomalies, and hence wind anomalies, imply anomalous temperatures and humidities of air masses, resulting in variations in heat exchange. Anomalous winds also produce different from normal Ekman drifts, and these may advect warmer or colder water into an area. Organized anomalous mean wind systems, cyclonic or anticyclonic, may also affect open ocean upwelling and oceanic vertical mixing. All the above factors can influence sea-surface-temperature (SST) patterns.

Several quantitative attempts to devise methods of specifying SST from atmospheric parameters have been made. For example, Clark (1972) showed that some success could be obtained by employing the so-called bulk heat exchange formulas. Namias (1965) showed that anomalous mean wind components could be objectively related to contemporaneous SST patterns by employing Ekman advection concepts. More recent studies by Namias and Born (1972) have used stepwise multiple regression techniques to specify SST from circulation or vice-versa, and they believe that until better physical understanding is achieved, these statistical specification methods are best suited to the problem.

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Usually time-averaged atmospheric and SST patterns are highly correlated so that the specification of one field by the other is quite successful. Occasionally, however, there is little agreement between specified and observed patterns. The purpose of this paper is to describe and suggest an explanation for one such striking case, in December, 1957, which was preceded and followed by a three-month series of good specifications. The case study has important ramifications regarding not only the role of SST in stabilizing atmospheric patterns, but also regarding other factors which may transitionally overwhelm SST influences.

2. Observed monthly mean 700 mb and SST anomaly patterns for the period September, 1957, through March, 1958

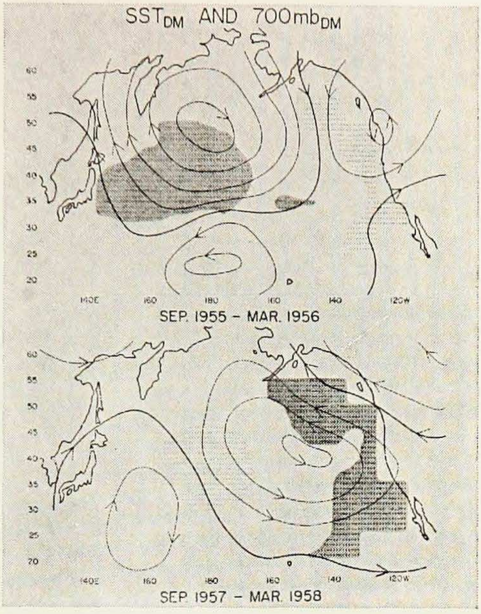
The period 1956 to 1958 was one of major change in the thermal structure of the upper layers of the ocean and of circulation of the troposphere. This period of upheaval led to the now famous Santa Fe conference, (Marine Research Committee, 1960), and to numerous subsequent papers. An example of the remarkable change in atmospheric (midtropospheric) anomalies and the associated SST anomalies during the cold seasons of the two years spanning a "break" in climatic regime is shown in Fig. 1, where isopleths of 700 mb anomaly are drawn for each 15 m, and shading and stippling represent SST anomalies greater than ± 1° F. Not unexpectedly, colder than normal SST's generally underlie northerly components of mid-tropospheric flow, while warmer than normal SST's underlie southerly (or easterly) anomalous components. To give an idea of magnitude, the anomalous geostrophic east to west component between 30°N and 40°N at 180° in the upper chart of Fig. 1 is of the order of 6–8 mps.

When the data from September, 1957, through March, 1958, are broken down into individual monthly means (Figs. 2 and 3 where isopleths are drawn for 30 m intervals) several interesting features come to light:

1. With the exception of December, all months show a large observed negative 700 mb height anomaly center in mid- or eastern North Pacific with a vast cold pool to its west and a warm pool to its east.
2. The center of the negative 700 mb height anomaly lies close to the border zone between SST anomalies.
3. December's anomalous circulation is the opposite of the others—*anticyclonic* rather than cyclonic.

In the following discussion I shall try to make the point that the prevailing cyclonic pattern preceding and subsequent to December was, in fact, stabilized by the underlying SST pattern and that December was a "freak" transitional month during which other factors tried to destroy the SST pattern, *but did not last long enough to do so*. Hence, the atmosphere was brought back on track to the cyclonic pattern by the long lasting SST pattern after an abortive attempt at change.

In the first place, one may question the association between the anomalous cyclonic center which appears on the charts for September, October and November with that which appears on the charts for January, February and March, because on the latter series the center lies east of 160°W while on the former it lies at around 170°W. This eastward displacement is not uncommon in monthly mean 700 mb charts (Namias, 1953). It frequently takes place with the transition from fall to winter and is partly associated with two meteorological factors: the increasing strength of the westerlies and the "anchoring" of the Asiatic coastal trough. Thus given a roughly fixed Asiatic trough, as it is from year to year (Stark, 1965), and an increase in the westerlies, the next downstream trough is more apt to be found farther to the east in winter than in fall. But this obviously does not explain the quasi-permanent existence of the negative *anomaly* center. Here we introduce the concept of enhanced atmospheric baroclinicity which arises because of differential heating of air masses over the warm and cold water pools. Such an anomalous contrast seems to intensify fronts and cyclones and thereby create a statistical mean negative anomaly as described by Bjerknes (1962) and the author (1959, 1974).


SST$_{DM}$ AND 700mb$_{DM}$

SEP. 1955 - MAR. 1956

SEP. 1957 - MAR. 1958

Figure 1. Isopleths of 700 mb height anomaly (drawn for intervals of 15 m with zero isopleth heavy) and sea surface temperature (SST) anomalies (heavy shading for greater than +1°F and stippled for greater than −1°F) over the North Pacific for the two periods indicated. Arrows give direction of geostrophic anomalous component of flow.

The above discussion may not be the sole explanation for eastward displacement of the anomaly, for if water masses conserved their thermal anomalies in being transported by the North Pacific gyre, the zone of strong SST gradient would move, and with it it the baroclinic source of enhanced cyclogenesis. At present, it is not possible to separate out the primarily meteorological from the primarily oceanographic effects. However, some objectively computed kinematic displacements of anomalies, and some studies of other cases, (Namias, 1972, 1974) suggest that the oceanically produced displacements of anomalies cannot be dismissed – as indeed Favorite and McLain, (1973) have indicated.

We shall now return to item 3 above. The December pattern in Fig. 3 is completely at variance with the other six charts in that it is dominated by a large positive (anticyclonic) anomaly rather than a negative one. The abnormal nature of this situation is vividly demonstrated by specification computations as displayed in Figs. 2 and

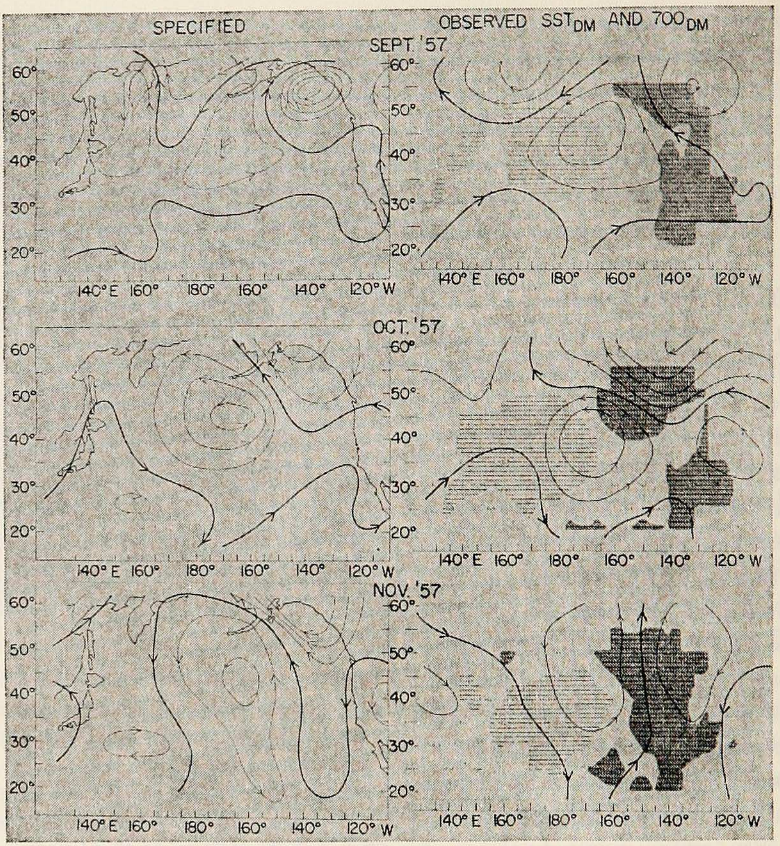


Figure 2. Isopleths of 700 mb height anomaly (drawn for intervals of 30 m with zero isopleth heavy) and SST anomalies (heavy shading for greater than + 1°F and stippled for greater than −1°F) for the months indicated. Observed anomalies are on the right side of the figure, while 700 mb height anomalies specified from observed SST anomalies are shown on the left.

Essentially, these charts show the SST anomaly pattern that should accompany the contemporary *observed* 700 mb pattern and also the 700 mb anomaly pattern that should accompany the *observed* SST pattern. The method used for making these specifications is a stepwise multiple regression technique (called "screening") described in earlier work (Namias and Born, 1972). Based on a series of historical data extending over 25 years, the method explains about $90\,^0/_0$ (median value) of the variance of seasonal mean patterns. For the present work, I have used the seasonal regression equations for individual months. These are believed suitable for our purpose, since no comparable formulas have been worked up for monthly data.

From comparison of the 700 mb anomaly specifications with observed 700 mb anomalies it is clear that a high correlation exists between all contemporary pairs of monthly maps except that of December. Pattern correlations for the individual months are shown in Table 1.

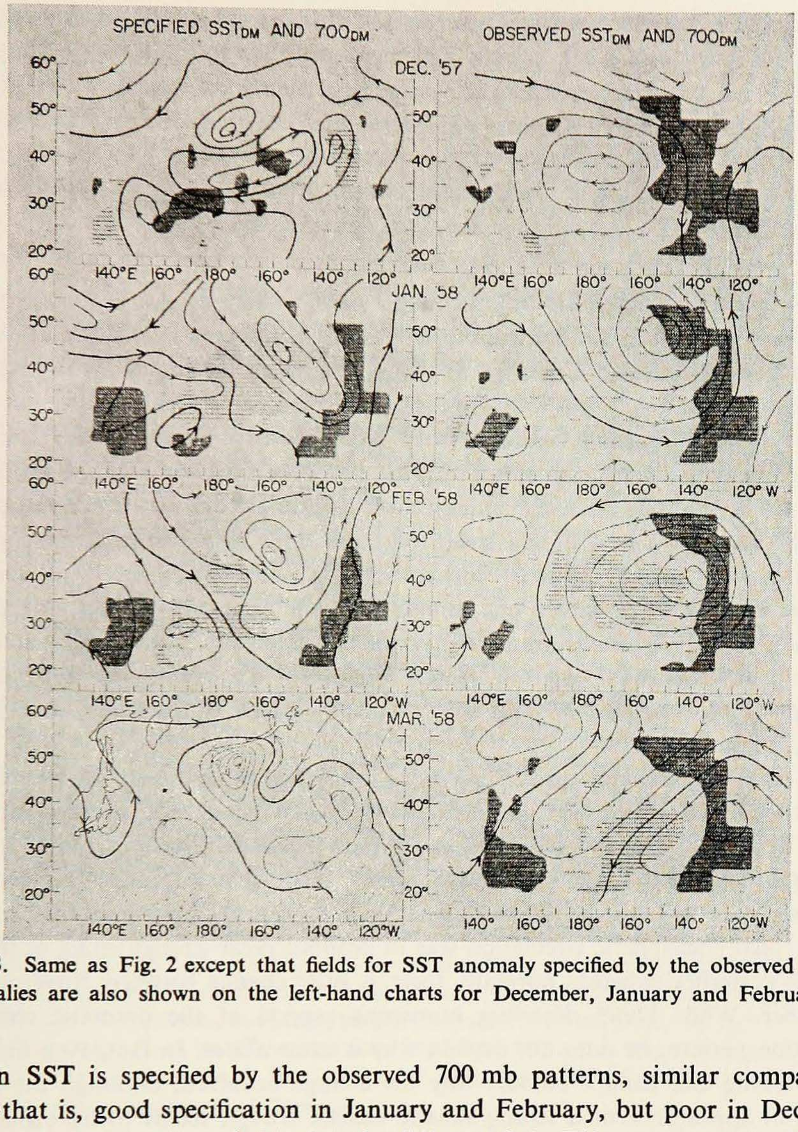


Figure 3. Same as Fig. 2 except that fields for SST anomaly specified by the observed 700 mb anomalies are also shown on the left-hand charts for December, January and February.

When SST is specified by the observed 700 mb patterns, similar comparisons result–that is, good specification in January and February, but poor in December (equations are not yet available for the fall months). This agreement in January and February relative to December is shown in Fig. 3 where SST anomalies greater than ± 1 are shaded as described in the legend. It is also shown by the pattern correlations of specified vs observed SST anomalies listed in Table 2.

From the above material it is clear that something highly unusual transpired in December so that the sea and atmosphere were uncoupled and were not behaving in the systematic collaborative manner usually found. The lack of coupling implies that either the atmosphere or the ocean underwent a major change that produced little response in the other medium. Since the ocean retained its general anomalous

Table 1. Pattern correlation between specified and observed 700 mb deviations from normal.

September, 1957	0.57
October	0.57
November	0.70
December	0.01
January, 1958	0.74
February	0.49
March	0.21

SST pattern from November to December—warmer than normal in the eastern and colder than normal in the central North Pacific, it appears it was the atmosphere that underwent a dramatic change to which the ocean thermal structure had little response. It will be noted, however, that the central Pacific cold pool underwent a slight anomalous warming from November to December of from more than −1°F to slightly less than −1°F. This was apparently an attempt on the part of the sea to respond to the changing atmospheric circulation. Since the positive anomaly was also strong at sea level, the anomalous SST warming was probably associated with several factors: reduced sensible and latent heat losses from the water because of the deflection of cyclones (and cold arctic air masses), downwelling associated with horizontal water convergence below the anticyclone, and some surface drift of warmer waters from the south. But the change did not annihilate the general SST pattern of cold west of warm which by February had become strongly reestablished.

The remarkable change in atmospheric circulation pattern over the Pacific from November to December was accompanied by major changes in other components of the general circulation. These changes have been described in some detail by Dunn (1957) who showed that a large change to positive anomalies also occurred over the Atlantic and over the southwestern U.S. The net impact of these changes on the zonal hemispheric circulation was to produce great strengthening of the mid-latitude westerlies, whereas normally there is little change between November and December. While Dunn describes numerous aspects of the dramatic change in circulation pattern, he does not explain why it came about. In fact, even in further retrospect we still cannot be sure *why* the change occurred, although the sudden (and late) appearance of a strong Asiatic coastal trough seems to have played an important role in altering the hemispheric flow pattern downstream. Whatever the cause, the atmospheric readjustment was so strong over the Pacific that it was out of conformity with the contemporary SST pattern. While there was a slight change in the anomalous SST gradient (cold west of warm), the high month to month

Table 2. Pattern correlation of specified vs observed SST anomalies.

December, 1957	−0.11
January, 1958	0.64
February	0.66

coherence (0.55) found in historical SST patterns, (Namias and Born, 1970) operated in this period to keep alive the November SST pattern. Of course, this coherence is primarily due to the great oceanic heat reservoirs which are not soon depleted. The persistence of the SST pattern, in spite of the atmosphere's abortive attempt to destroy it, seems ultimately to have succeeded in reestablishing the North Pacific atmospheric cyclonic circulation, as seen in the January, February and March charts (Fig. 3), when the Asiatic coastal trough weakened and retrogressed. The reestablishment may have occurred because of the atmospheric baroclinicity imposed by the differential heating provided by the adjacent cold and warm pools, as described earlier.

If the above hypothesis is correct it raises some serious questions about large-scale air-sea interaction as it relates to long range forecasting as practiced with the "statistical aggregate" technique. In the first place, one may ask, "How long must a large atmospheric adjustment last before the new flow pattern destroys or makes a substantial change in the SST Pattern"? This is the "response time" problem. In the second place, if, in our case, the SST pattern has been altered materially, would a new climatic regime have been ushered in? If so, long range forecasting for several seasons done by statistical methods becomes harder than many have supposed. Fortunately, for intervals up to a season, statistics indicate that SST patterns are fairly coherent, and gross statistics, such as the mean SST of the entire North Pacific display remarkable month to month serial correlation (Namias and Born, 1970). But the great breaks between coherent regimes extending over several years may elude attempts at prediction until the problems to which we have alluded are solved. The solution could arise from very advanced general circulation models in which atmosphere and ocean are properly coupled. Such models could handle transients as described with no loss of predictability. Unfortunately such sophisticated models require rigorous physical understanding of both ocean and atmosphere.

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