THE METEOROLOGICAL PICTURE 1957-1958

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This particular problem of change, climatic change, is really quite an old and familiar one. It arises in many branches of geophysics, and in meteorology it is especially common. As John Isaacs said, the correspondence from the public on this subject is quite amazing, and the Weather Bureau gets more than its share of these letters. People want to ascribe abnormal weather to almost anything one can think of. Each generation seems to espouse some theory as to the changing climate. Of course, the present vogue is to blame things on nuclear tests. I have one personal correspondent—a one-way correspondence—who makes it a habit to ascribe each and every extreme weather phenomenon to bomb tests. Of course, his reasoning is entirely *post facto*.

Actually, from the standpoint of meteorology, the weather is always changing, never static. The atmosphere is a restless medium undergoing all sorts of transitory variations—not only on an hourly or daily scale, but also on a weekly, monthly, yearly, decadal, and greater scale up to the ice ages. Those of us engaged in modestly attempting to detect and predict some of these variations work with periods of the order of a week to a month. We would indeed be surprised if there were no major changes taking place —even of the order of a year, two years, or even a decade. This does not mean to say that we have illusions about the ease of interpretation or explanation of these climatic changes. We simply do not know the answers now, although there are a few tantalizing leads. I was particularly gratified to be invited to this Symposium because I believe that we can no longer ignore transitory fluctuations of the oceans in treating atmospheric motions. Normally, most meteorologists are content to treat ocean and land surface as fixed and unchanging terrain, which modify the air masses in transit above. It is usually assumed that the only oceanic variations that affect atmospheric motion are the normal seasonal changes of the ocean temperature; and all surface temperature variations are more or less tossed aside as being small or insignificant—meteorologically insignificant, that is. The relatively large variations in air temperature, pressure, and wind tend to make meteorologists feel this way. However, to me the ocean temperature fluctuations or anomalies seem striking and important for it is conceivable that they may exert rather important feedbacks on the atmosphere.

I will mention one example of such a feedback. In 1955 New England had two hurricanes, Connie and Diane. Normally a hurricane produces very heavy precipitation as it moves inland, but these two storms produced over some areas precipitation equalling almost one-half the normal annual total. Now in examining that particular summer's weather, one finds that the early summer was characterized by marked stagnation and warmth of the atmospheric circulation over Northeastern United States and adjacent waters. This was also associated with a positive temperature anomaly of the ocean surface off the East Coast. As the two storms moved northward off the coast they were imbedded in tropical air from a tropical source region essentially displaced northward because of the higher ocean temperatures. The storms were fed by increased moisture, and I believe this had something to do with the increase of precipitation over and above the amount one might normally anticipate. This case may be an example of a feedback mechanism where atmospheric conditions set up over a long period of a summer season influenced the ocean, which in turn had a subsequent effect on atmospheric behavior. It is quite conceivable that similar events proceed on a larger scale. Therefore, I hope the material brought to light in these meetings will encourage further studies of ocean temperatures, so that meteorologists also might be able to study them in relation to atmospheric phenomena.

While the central problem at this meeting is oceanic variations, I would like to make a few preliminary remarks about the character of persistent recurrences that take place in atmospheric phenomena, because it is likely that this sort of thing also occurs in the oceans. In the first place, whether or not events are highly correlated from day to day, from week to week, and even from year to year, this correlation makes for long-period trends. This sort of thing is not a simple serial correlation, but one where a regime established during one period comes back in much the same form later on. The period of recurrence is not fixed; it may be a few days, a week, or perhaps two weeks, but with some consistency. For example, last winter recurrent cold waves into Southeastern United States were the rule. Recurrence accounts for a lot of the persistence observed in meteorological events, and this, of course, has its influence on the ocean. Figure 3 highlights the nature of this recurrence tendency.

From forty years of historical daily-weather maps, the standard deviations of daily and monthly mean pressures averaged by latitude were computed for the forty Januarys. The striking feature of the figure is that standard deviations of the daily values are about the same as those of monthly means (between the forty Januarys). We get variations between Januarys that are fully as great as between individual days during a given January. This points up the nature of the problem we are up against, and the answer to this riddle will go far toward solving the long range problem. A second point is that weather is not only correlated in time but also in space. If a large scale aberration in atmospheric circulation is happening in one area, say over the Northeast Pacific, it will soon influence circulation in other even remote areas both up and down stream. Each time that an event happens, whatever the cause, it will set off a series of disturbances down stream, and will also have

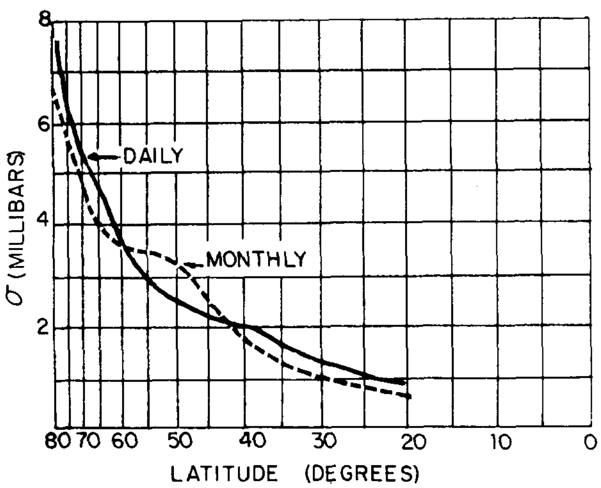


FIGURE 3. Standard deviation of mean sea level pressure along latitudes for daily (solid) and monthly mean (dashed) values for the Januarys from 1899 to 1939; from data prepared by G. W. Brier.

certain up-stream propagating effects. Thus in meteorological phenomena there is a high degree of interdependence in space as well as in time. We understand much more about the interdependence in space than in time.

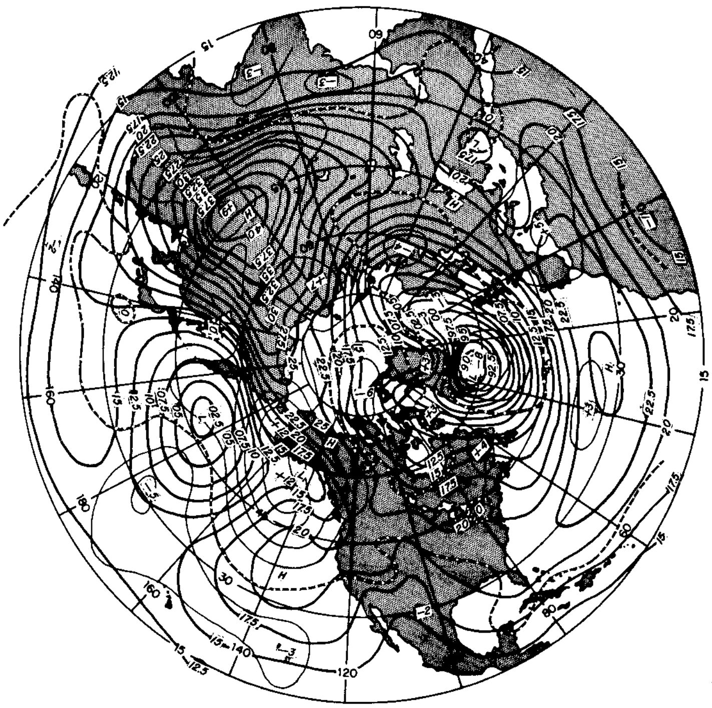
This special interdependence means that if some abnormal form of circulation and weather is occurring in one area, we cannot attribute it solely to peculiarities in that general geographical region. While it might be associated with some abnormality in ocean temperatures of the region, it could be a completely resonant phenomenon due to something which has happened thousands of miles away. More likely, it could be due to several events in several remote areas, each ganging up or reinforcing one another so as to produce specific abnormalities in the concerned zone. Unfortunately, no one so far has been able to determine which circulations are forcing which others in climatic fluctuations of the order of a month or more. When we add to this complex the oceanic system, things must become even more difficult.

In spite of all this confusion, I feel that the water-temperature fluctuations over the Pacific to be discussed here can be rather definitely associated with large-scale atmospheric systems. The scale of systems of which I speak are very large—several thousands of miles—and the energies involved are tremendous. Small-scale patterns like cyclones and anticyclones are superimposed and transitory. The large-scale systems are the great centers of action which are coupled with so-called planetary waves in the upper-level westerlies of the general circulation. An easy way to shed light on these is to average over a long time interval, purposely suppressing the small scale "noise." This has been done for the seasonally-averaged charts for sea level and 700 mbs (Figs. 4-9). These figures are three month means. Winter is considered as December, January, and February; while spring is March, April, and May; summer, June, July and August; and so on. On these charts are also shown (as light solid lines) the departures from normal—that is, deviations from seasonal averages of many years. These isopleths indicate the anomalous component of the total mean flow, which, of course, is composed of the normal flow plus the anomalous component. We also have the departures from normal of thickness between 700 and 1,000 mbs. These charts essentially indicate the mean departures from normal of temperature in the lower troposphere.

Let us now review the highlights of the general circulation of the atmosphere during 1957 and 1958 with the help of these mean charts. The most consistent abnormality of the general circulation since the beginning of 1957 seems to have been the remarkable tendency for weak westerly winds in temperate latitudes. In fact, in only one month since the beginning of 1957 have the temperate latitude westerlies (zonal component between 35°N and 55°N) been appreciably above normal. Weak westerlies or low index conditions are not associated with the same displacements of the centers of action in summer as in winter. In the cold season pressure distributions accompanying low index generally involve an excess mass of air (with respect to normal) over northern latitudes with a more or less compensatory deficit at low latitudes. In such cases the peak strength of the westerlies is usually found farther south than normal, a condition which can be seen from the winter and spring wind-speed profiles at the lower left of the 700 mb figures 8 and 9. In these for half the hemisphere lying between the Greenwich Meridian and 180° we have plotted the zonal component of observed mean and normal wind as a function of latitude. Also in low-index cases during winter the subtropical anticyclones are weak or absent and displaced south of their normal positions. This was especially noteworthy during the winter and spring of 1958. In summer, on the other hand, low index is frequently accompanied by northward displacements of the subtropical anticyclones and a corresponding northward shift of the westerlies.

If we examine in greater detail the anomalous features of the mean seasonal circulations over the North Pacific we see that central and eastern areas have been dominated by a large negative anomaly during the period from summer 1957 through spring of 1958. Moreover, the East Pacific high-pressure area during this period has been much weaker than normal. Note especially the pronounced anomalous southerly components over the Eastern Pacific during winter, 1957-58 (Fig. 8).

Now, if we turn to the water temperature anomalies that Mr. Murphy's Bureau of Commercial Fisheries laboratory have prepared (see Figs. 14-30 McGary paper) we might try to relate them to our meteorological anomalies. At first glance the surface water



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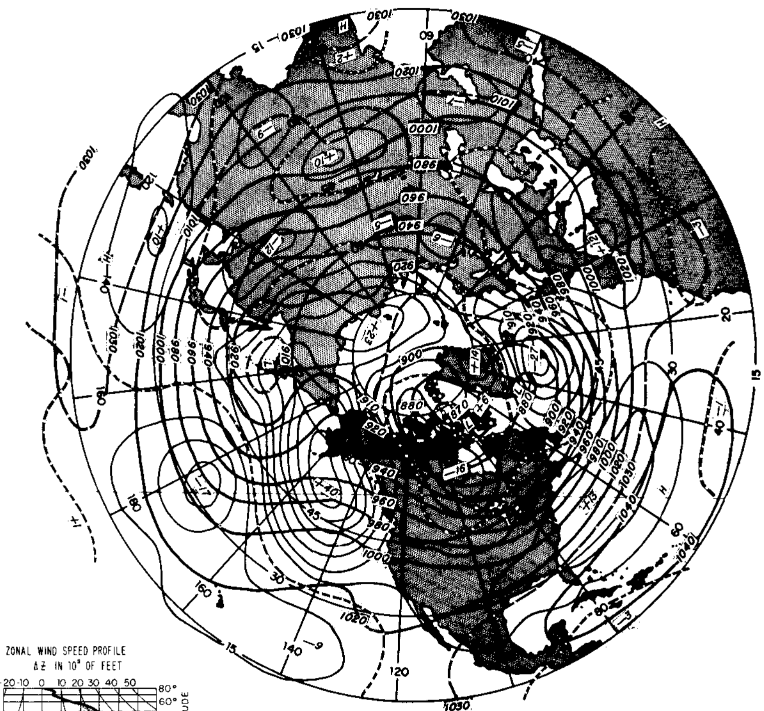

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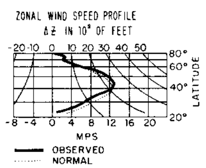
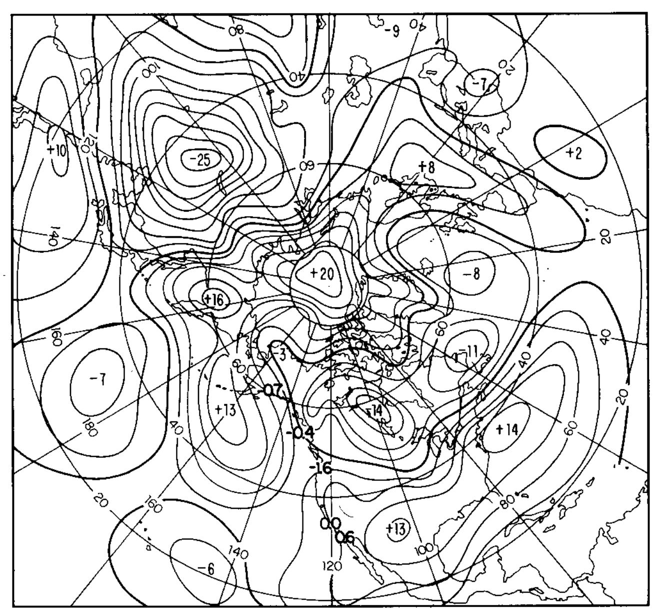


FIGURE 4. WINTER 1956-1957

① *Sea Level*—Isobars (heavy solid) are drawn at intervals of 2.5 mbs. Departures from normal are shown by isopleths (light solid) drawn for every 2½ mb for winter and 1¼ mb for other seasons. The broken line represents zero departures. Numbers represent highest and lowest values in centers.

② *700 mb*—Contours (heavy solid lines) are generally drawn for 200-foot intervals. Isopleths of departure from normal are drawn as light solid lines for each 50 feet, the centers of maximum and minimum being labeled in tens of feet. The broken line represents zero departures. At the lower left of the 700 mb chart is a zonal wind speed profile where the zonal wind speed (for 0° westward to 180°) is plotted against latitude as a heavy solid curve, and the normal as a dotted line.

③ *1000-700 mb Thickness Anomaly*—Isopleths are drawn for every 30 feet, with maximum and minimum values shown by numbers at center. Large numbers along North American West Coast show seasonal departures from normal of surface sea water temperatures (°F).



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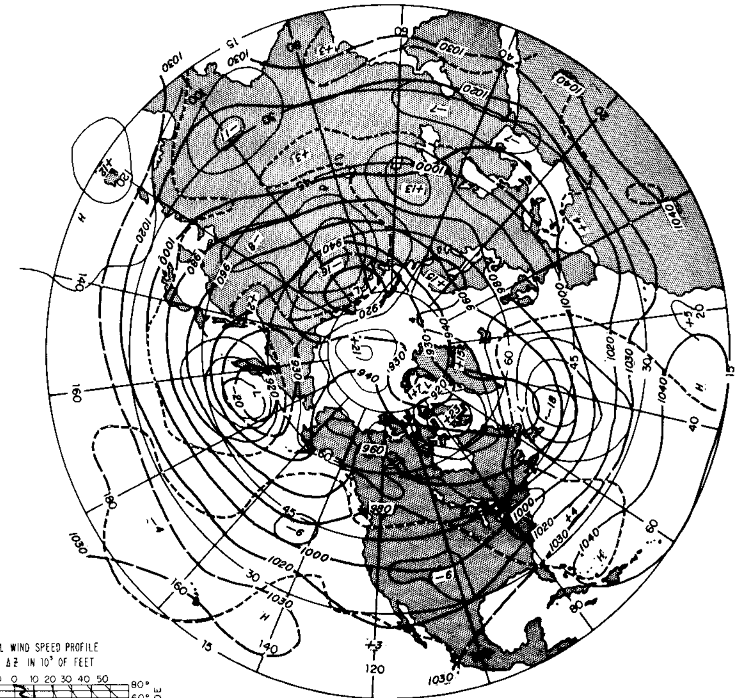

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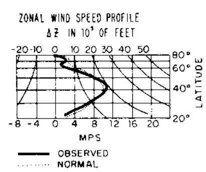

FIGURE 5. SPRING 1957.

① *Sea Level*—Isobars (heavy solid) are drawn at intervals of 2.5 mbs. Departures from normal are shown by isopleths (light solid) drawn for every 2½ mb for winter and 1¼ mb for other seasons. The broken line represents zero departures. Numbers represent highest and lowest values in centers.

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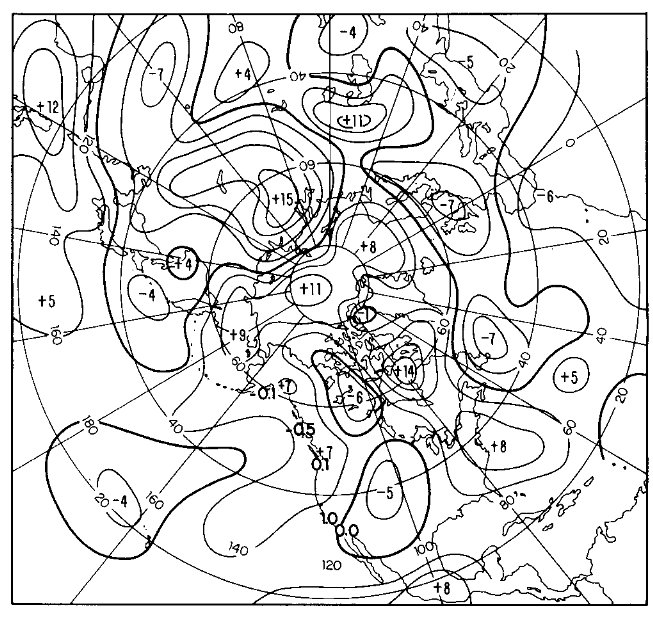

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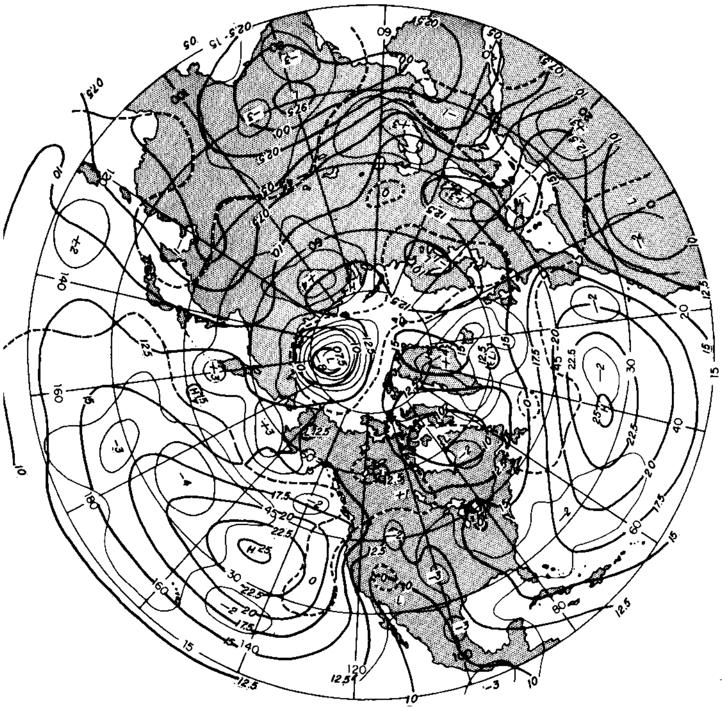

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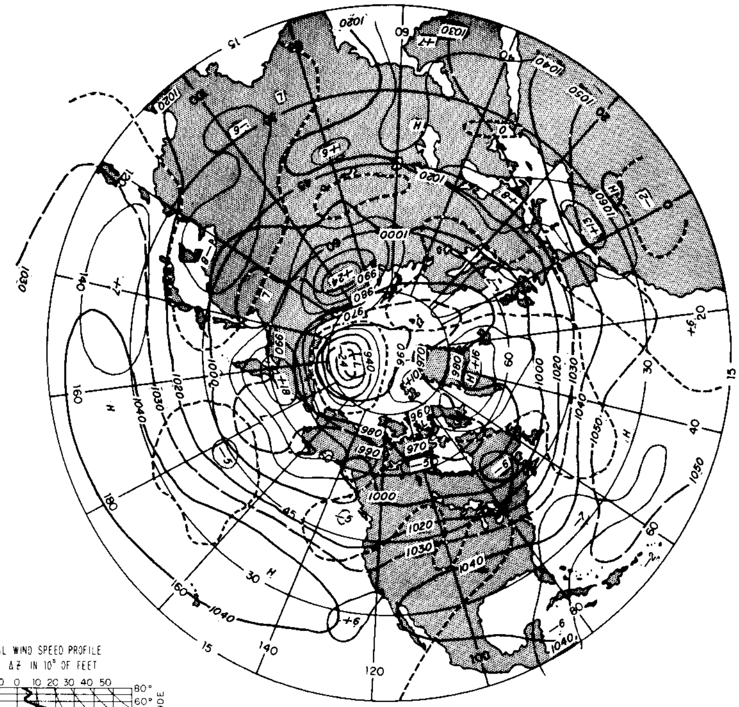

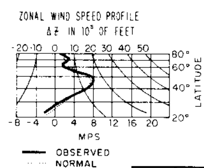

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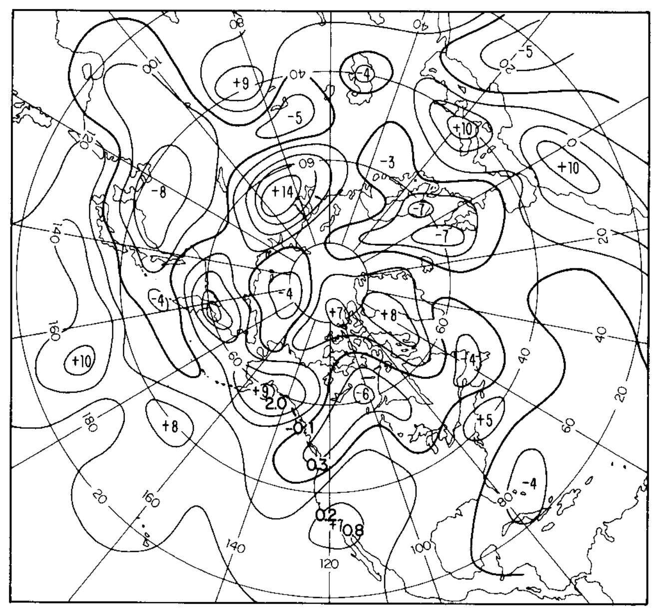
FIGURE 6. SUMMER 1957.

① *Sea Level*—Isobars (heavy solid) are drawn at intervals of 2.5 mbs. Departures from normal are shown by isopleths (light solid) drawn for every 2½ mb for winter and 1¼ mb for other seasons. The broken line represents zero departures. Numbers represent highest and lowest values in centers.

② *700 mb*—Contours (heavy solid lines) are generally drawn for 200-foot intervals. Isopleths of departure from normal are drawn as light solid lines for each 50 feet, the centers of maximum and minimum being labeled in tens of feet. The broken line represents zero departures. At the lower left of the 700 mb chart is a zonal wind speed profile where the zonal wind speed (for 0° westward to 180°) is plotted against latitude as a heavy solid curve, and the normal as a dotted line.

③ *1000-700 mb Thickness Anomaly*—Isopleths are drawn for every 30 feet, with maximum and minimum values shown by numbers at center. Large numbers along North American West Coast show seasonal departures from normal of surface sea water temperatures (°F).



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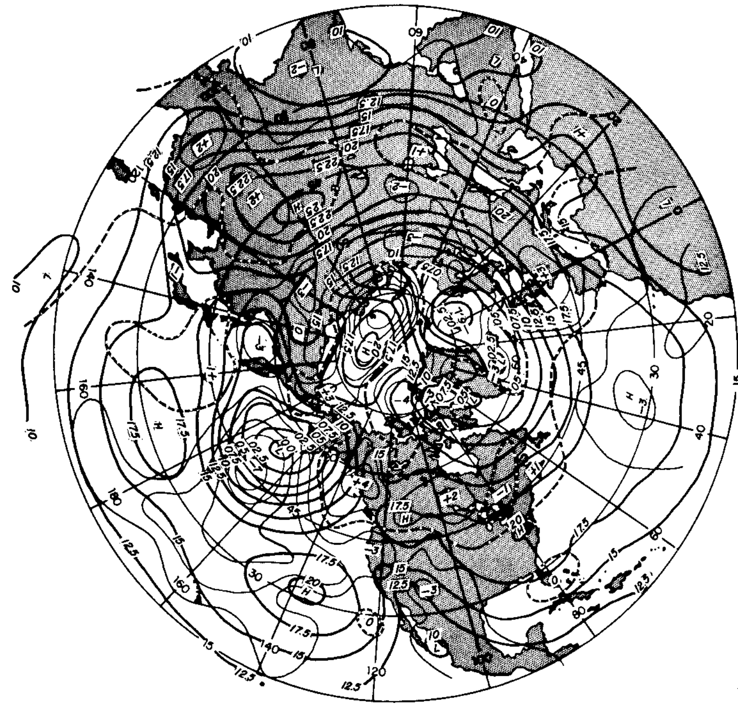

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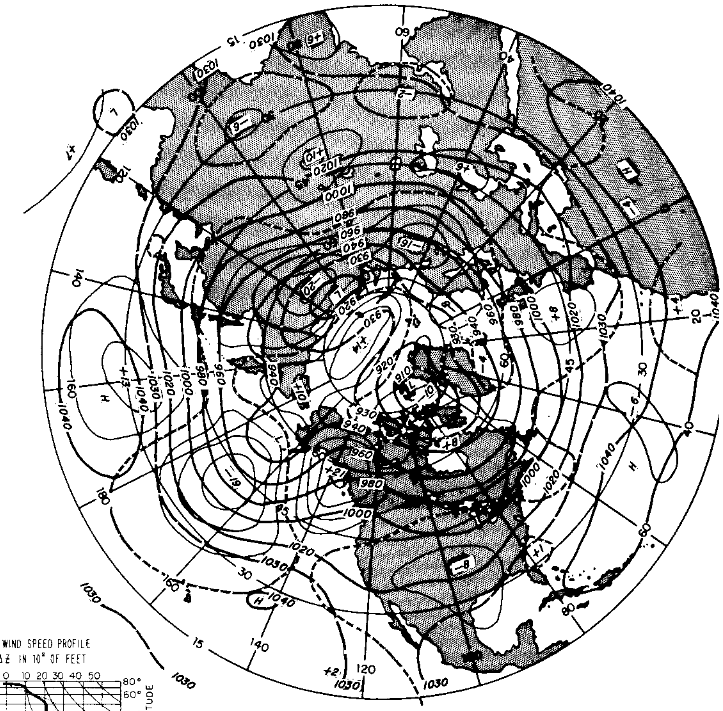

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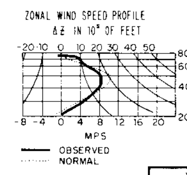

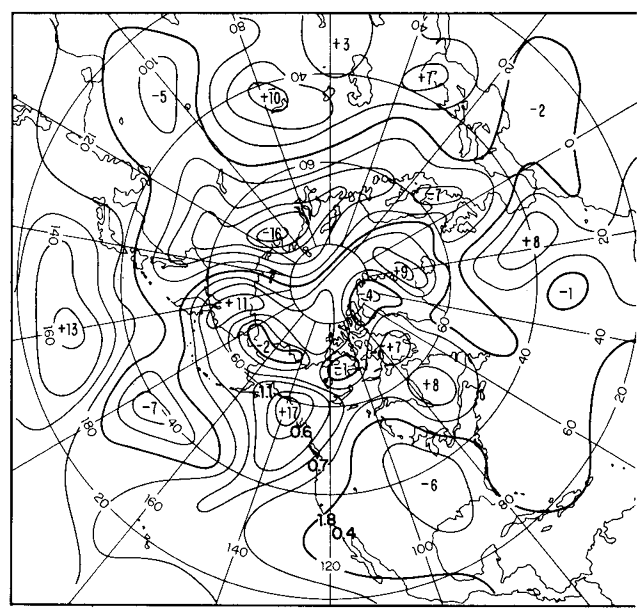

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FIGURE 7. FALL 1957.

① *Sea Level*—Isobars (heavy solid) are drawn at intervals of 2.5 mbs. Departures from normal are shown by isopleths (light solid) drawn for every 2½ mb for winter and 1¼ mb for other seasons. The broken line represents zero departures. Numbers represent highest and lowest values in centers.

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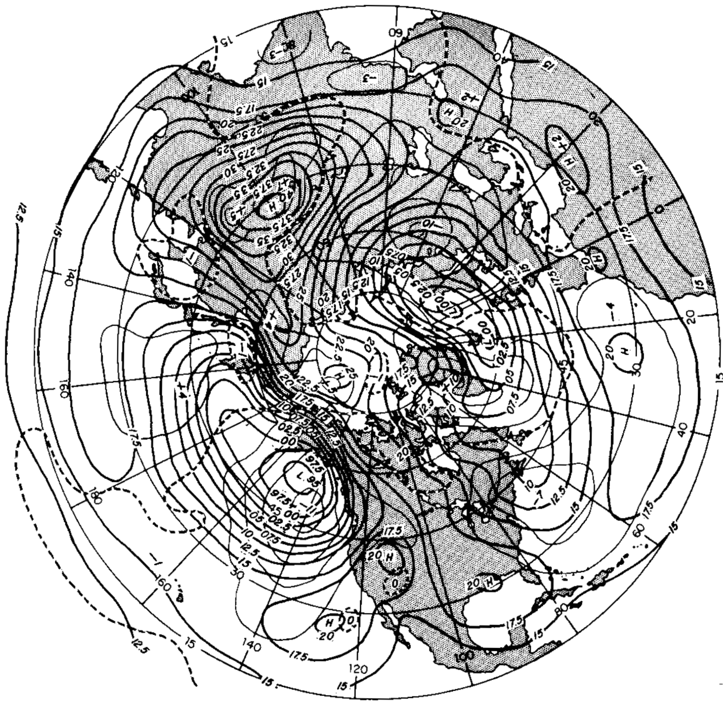
③ *1000-700 mb Thickness Anomaly*—Isopleths are drawn for every 30 feet, with maximum and minimum values shown by numbers at center. Large numbers along North American West Coast show seasonal departures from normal of surface sea water temperatures (°F).



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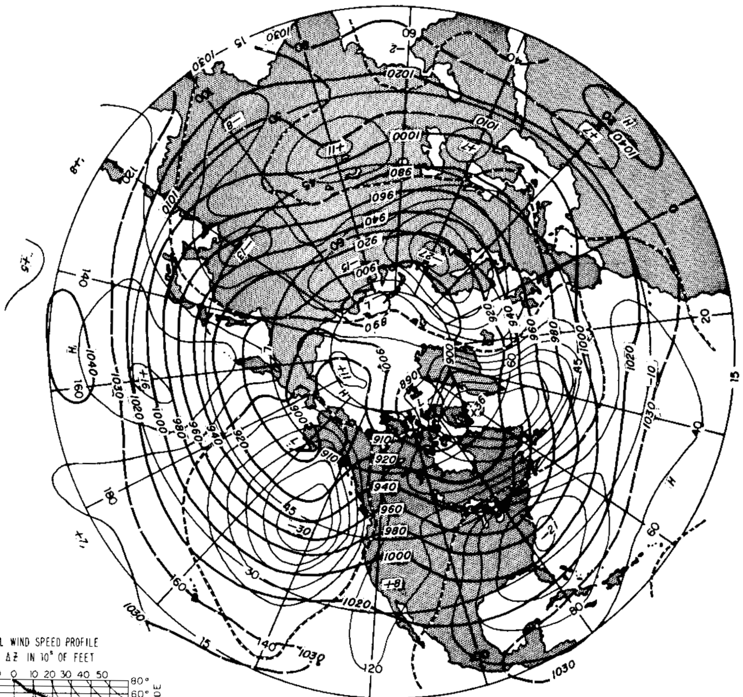

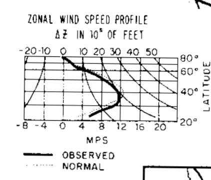

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FIGURE 8. WINTER 1957-1958.

① *Sea Level*—Isobars (heavy solid) are drawn at intervals of 2.5 mbs. Departures from normal are shown by isopleths (light solid) drawn for every 2½ mb for winter and 1¼ mb for other seasons. The broken line represents zero departures. Numbers represent highest and lowest values in centers.

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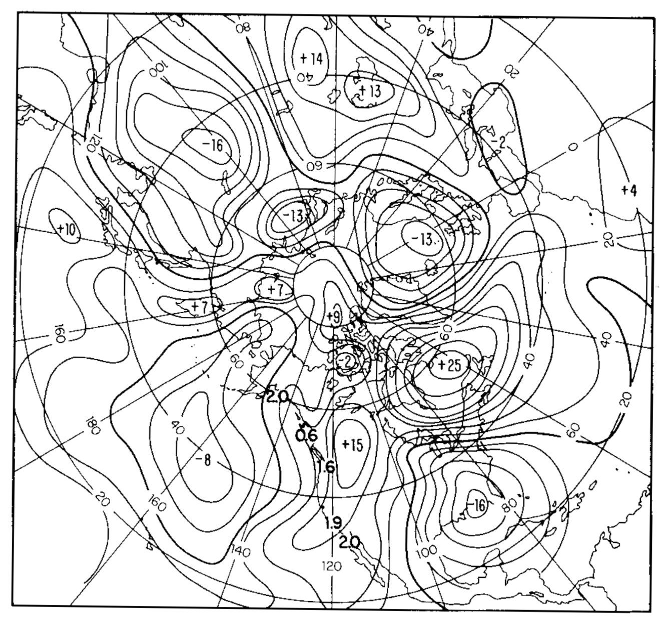
③ *1000-700 mb Thickness Anomaly*—Isopleths are drawn for every 30 feet, with maximum and minimum values shown by numbers at center. Large numbers along North American West Coast show seasonal departures from normal of surface sea water temperatures (°F).



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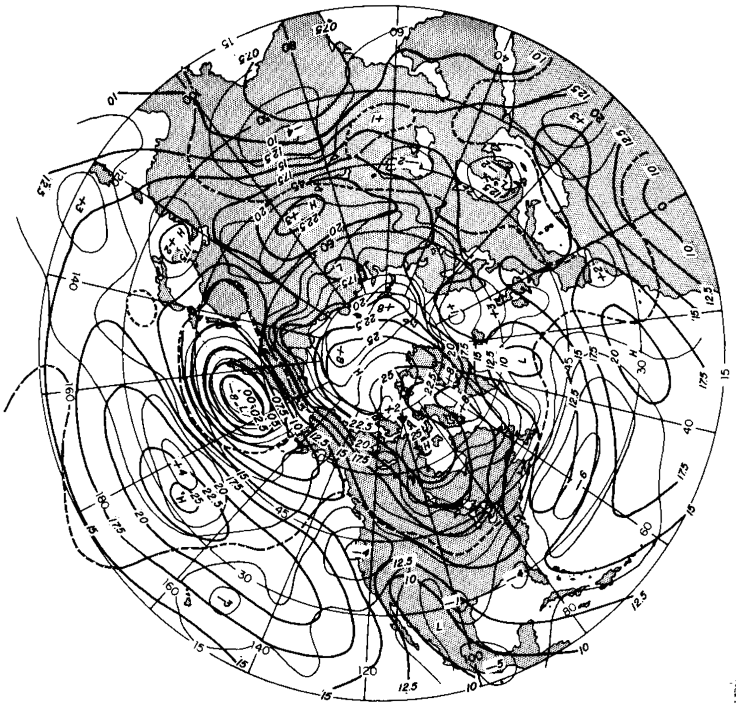

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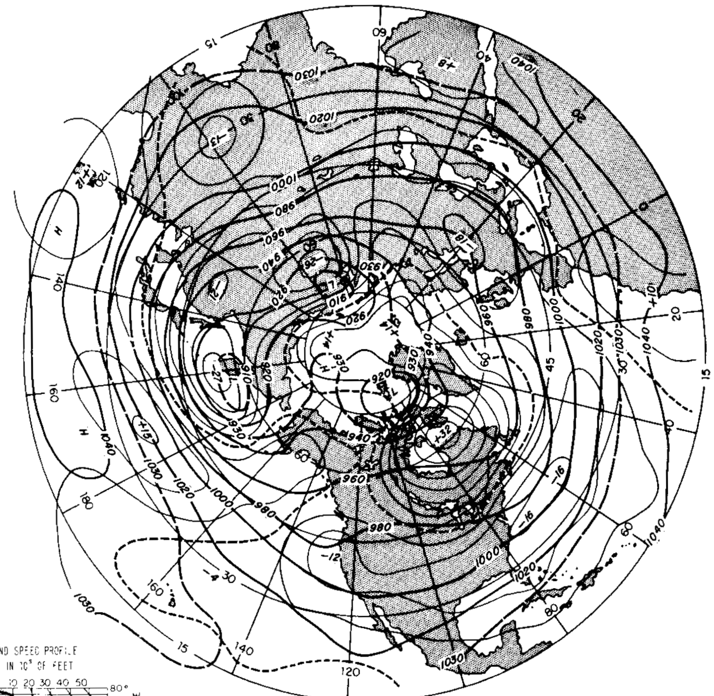

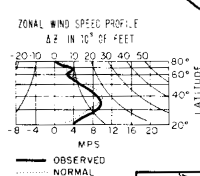

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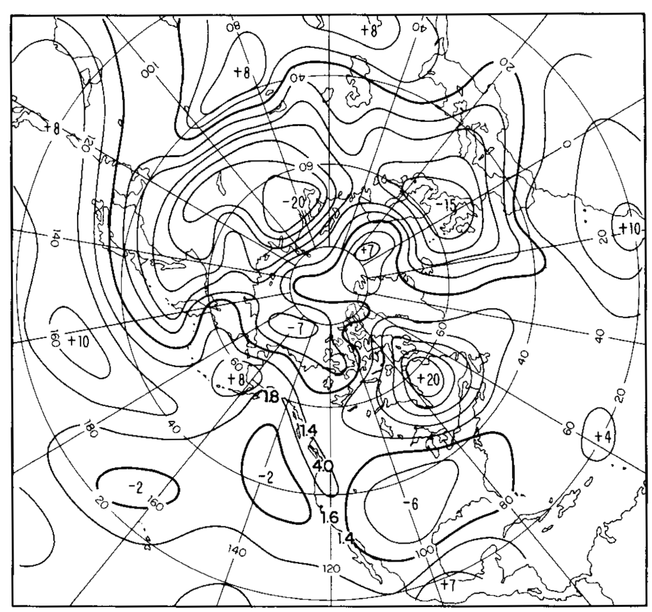

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FIGURE 9. SPRING 1958.

① *Sea Level*—Isobars (heavy solid) are drawn at intervals of 2.5 mbs. Departures from normal are shown by isopleths (light solid) drawn for every 2½ mb for winter and 1¼ mb for other seasons. The broken line represents zero departures. Numbers represent highest and lowest values in centers.

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temperature anomalies appear to have little or no organization. In fact, if we look at them too closely we might get the impression that they consist of completely chaotic islands of anomalous warmth or cold. However, if we stand back and try to get the big picture there are undeniable macro-scale features which embrace large portions of the ocean. For example, during September, October, and November 1957, the entire southern portion of the Eastern Pacific (east of 170°W) south of about latitude 40°N was above normal (Figs. 22, 23, 24 McGary paper). North of here the ocean was characteristically warm over eastern portions but with marked changes over the west. In December (Fig. 25 McGary paper) a pattern similar to September arises although with larger departures. In January 1958 (Fig. 26 McGary paper) the field becomes chaotic but by February a more organized state seems to emerge with relatively cool temperatures in central and western portions and marked warmth in the east.

Now the seasonal meteorological picture for fall indicated especially by the 700 mb mean contours and anomalies shows a deep trough with an anomaly of —190 feet over the Central Pacific with ridges and positive anomalies on either side (Fig. 7). The form of these isopleths means that over much of the area east of 165°W the prevailing and resultant wind was composed of stronger south-to-north components than normal. West of here the reverse anomalous components are implied. These mean anomalous components are composed of persistently-recurrent northward (east of 165°W) and southward (west of 165°W) thrusts of air in advance and to the rear of rapidly-developing cyclones moving into a central Aleutian Low, and with sharp polar-front systems persistently found in mid-Pacific during this particular season. It is likely that on each occasion when the southerly-wind component sets in, surface water is set in motion and a general east to northeastward drift becomes established.

If we consult an atlas of maps of normal sea-surface isotherms during winter over the North Pacific, it looks to a non-oceanographer that it does not require much of an anomalous southerly-wind component operating for an extended period of time to effect a material local warming, particularly if we assume that the water conserves some of its heat as it moves. At any rate, it is conceivable that sustained anomalous transports of water might have been induced by the anomalous winds and thereby help to explain the broad-scale sea-temperature anomalies reflected in the U. S. Bureau of Commercial Fisheries charts. Of course, all of this is rather vague and is really more of the nature of a suggestion for further investigation.

An alternative explanation might involve deeper phenomena brought about by some sort of mutual adjustment process between induced current and pressure field and involving density changes of consequence. It seems that this long-period wind-ocean interaction problem is a beautiful one for the dynamic oceanographer. The relationship between anomalous wind and ocean temperature seems to be even clearer after the circulation has settled down in winter of 1957-1958 (Fig. 8). Here the negative air-circulation anomaly is very strongly developed and somewhat farther east than in fall. Note the strong southerly anomalous fetch over the Eastern Pacific. In this case, a strong prevailing southerly wind is represented. I believe that this persistent and recurrent condition was responsible for the extreme warmth of water masses found off the West Coast during February 1958.

Another peak in the curve of surface-water temperature just off the West Coast occurred during the summer of 1957. However, we cannot employ the same reasoning that was used to account for the winter warming. This is so because the mean circulation anomalies are too weak to effect much change. The Pacific anticyclone was not appreciably weaker than normal and the strength of the offshore northerly components upon which upwelling depends do not appear to be much weaker than normal, although they are slightly so. Experience with other summers' maps suggests that there was no great aberration in the northerly-wind component, and possibly the reduced upwelling may account for only a small part of the positive water anomaly. On the other hand, there is a striking anomaly in the upper level trough off the West Coast. For example, there is a +60 foot anomaly off Southern California during summer 1957 (Fig. 6), implying failure of the West Coast upper-level trough to develop in a normal fashion. This was also associated with a summer that was characterized by pronounced warmth along the entire California Coast.

Now it is well known that positive anomalies imply less cyclonic vorticity and less ascent of air than normal. Therefore, it is possible that the stratus cloud deck was somewhat thinner and more disintegrated than is normally the case in this area. I understand that during calm conditions in summer the uppermost layers of the ocean respond more than at other seasons to solar radiation and I propose that some of the warming here may have been associated with increased absorption of enhanced radiation through weaker screening by the poorly-developed stratus cloud-deck. Here again I am merely tossing out a suggestion for further study where numbers must be employed.

At any rate, the implication is that the long period of warm water off California may result from a combination of different mechanisms. The summer and early-fall warmth might have been associated with increased absorption of solar radiation, diminished evaporation, and diminished upwelling, while the late fall and winter warmth may have been produced by some sort of a surface-transport process as I indicated.

If we now make a rough comparison between mean-thickness fields and the corresponding charts of sea-surface temperature anomaly, it seems that a definite positive correlation exists. For example, during winter the warm water off the West Coast of North America can be associated with warm air in the lower troposphere, whereas in the Central Pacific anomalously cool air is found over anomalously cool water (Fig. 10). Then again, positive correlation exists in fall, especially in the Gulf of Alaska, the Central and

Eastern Pacific. Of course, some postive correlation might be anticipated, first, because low layers of air are in contact with the sea and are modified by the underlying supply of heat especially in the free ocean.

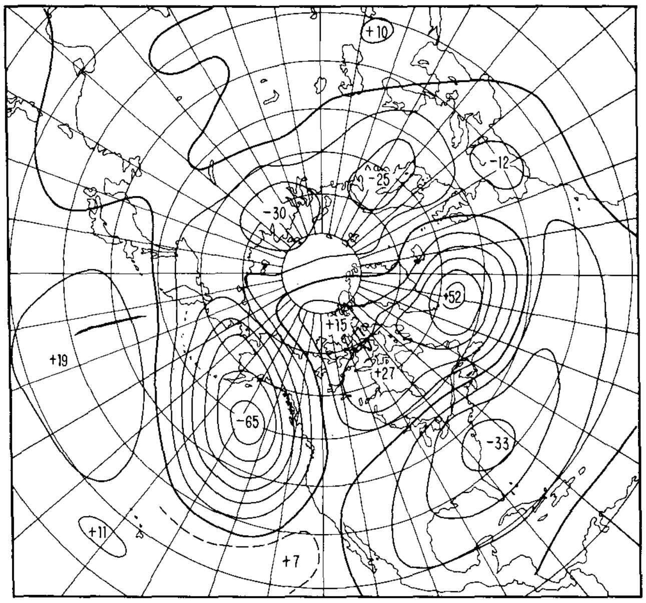

FIGURE 10. 1000-700 mb thickness anomaly change chart. Change of Winter 1957-1958 from Winter 1956-1957 in tens of feet.

Secondly, patterns of thickness anomaly are related to the anomalous atmospheric flow—that is, anomalous southerly currents of air not only drive water northward and eastward but they also reflect advection of warm air masses from the south (or they diminish the northerly component) and this almost always results in positive air temperature anomalies. If you take time to look at these thickness charts and compare them with the circulation anomalies you will see this general relationship. In other words, warm-air temperatures frequently accompany warm-water temperatures because both may be responses to abnormal forms of the general circulation. I prefer to believe this is the primary reason why it has been so warm along the West Coast during the past winter, rather than to ascribe the air warmth chiefly to the sea warmth. Apparently, there is a three-way relationship between anomalous patterns of mean height, or pressure, mean thickness, and mean sea-surface temperatures. This relationship could be helpful in oceanographic-atmospheric analysis. I should think that the analysis of sea-surface temperature fields could be done much more efficiently if the atmospheric thickness fields were considered. In other words, the use of the thickness field might help detect errors in sea-surface temperature observations and it might help in constructing smoother temperature patterns, thereby eliminating some of the apparent chaos.

So far I have talked only about the passive role the ocean plays in atmospheric-ocean interactions. However, one of the chief reasons why this general topic fascinates me is the possibility that, once disturbed in its thermal structure for a long period, the ocean surface may play an active role in modifying or even generating atmospheric-circulation anomalies. This is an old idea that has been resurrected and dusted off on many occasions, and I do not have much new to add to the inconclusive scraps of evidence presented up to now. However, in studying over the figures presented here, a sliver of light appears regarding the long-period evolution of mean patterns from summer of 1957 through spring of 1958. This is hopeful since it is usually impossible to detect continuity of features on mean maps for consecutive seasons. In this case it seems we can follow the course of the negative anomaly in the 700 mb circulation from its initial summertime position at about 180° south of the Aleutians, gradually eastward in the following fall, winter and spring, arriving off California in spring. These negative anomalies and associated troughs are almost invariably associated with increased cyclonic activity. If the long-period continuity suggested is real, two questions arise: (1) What accounts for the long lifetime of such systems? and (2) Why should such an area move with some sort of regularity in seasonal means?

Let us take the second question first. As summer goes into fall there are two climatological phenomena over the North Pacific and adjacent areas that are very highly probable—that is, they take place almost every year. (1) the westerlies increase in strength, and (2) an upper level trough along the east coast of Asia becomes established. Both these phenomena are associated with the increased cyclonic activity developed off the Asiatic Coast with the onset of the Asiatic cold season monsoon, and with increased baroclinic developments of these cyclones as they approach the Aleutians. Now, if we first assume that some factor imparts a long lifetime to the negative anomaly we may roughly explain its eastward motion like this: The trough found in the vicinity of Korea and Eastern Asia in summer becomes more or less locked into position along the Asiatic Coast in fall. As the westerlies increase in strength in fall, the preferred position for the next downstream trough would be expected farther to the east than in summer. This reasoning qualitatively employs Rossby's idea of the stationary wave length of planetary waves which, as is well known, increases with the zonal wind speed. A similar trend in winter may explain the further progression of the trough and negative anomaly. However, the continued eastward motion in spring is not so readily explained, although certain studies of so-called blocking phenomena (where a low latitude trough is surmounted by a high latitude ridge) indicate a preference for the Eastern Pacific area in spring, especially when a fast westerly current exists upstream as it does in this case off the east coast of Asia.

Now, we come to the first question; namely, why such an anomaly center should enjoy a long lifetime. Here we speculate that in this case it is possible that the warm water developed to the east of the negative anomaly and the general contrast between this water and cooler water to the west might be of consequence. The warmer water would provide a better heat and moisture supply for cyclones to feed on and the horizontal contrast might assist in developing thermal asymmetries favorable to cyclone development. But since the stationary wave length is in itself changing, the area of influence would itself be changing position and might be expected to shift.

Of course, this is the sketchiest type of hypothesis and it is only the delightful informality of this meeting that encourages me to suggest it. But the history of meterology and perhaps oceanography indicates that such imaginative excursions are probably initially required for progress. Perhaps some dynamic meteorologists and oceanographers may explore such a simple hypothesis and formulate mathematical models that could either expand upon it or completely negate it.

DISCUSSION

Isaacs: Can you say from the historical maps how often these anomalous situations arise?

Namias: That question puts me on the spot. It seems easy to break records in meterology, so I will say this: I have not found any circulation of this kind as persistent as this one has been. In other words, in about 25 years of record, I have not seen as strong a long-period aberration of this precise kind and strength over the North Pacific.

Question: Do 1931 and 1940 stand out?

Namias: Yes, looking over past maps over the North Pacific, the winter of 1940-41 seems to have had some marked similarities, but it is not as intense. It also had similar characteristics when viewed as the general circulation from the Eastern Pacific on to the Eastern Atlantic. In 1931 adequate upper air data were lacking, but perhaps the sea-level weather charts could be studied.

Saur: They show it to be similar.

Stewart: These similarities also show up on some long-range monthly charts of sea level.

Schaefer: Do you know whether there are internal oscillations in this system?

Namias: I think Charney can answer that better than I. It is rather difficult to conceive of internal oscillations with this time period. We have been able to disentangle some internal oscillations of the order of a week or possibly up to a few weeks, but this latter seems pretty long. Sometimes one can follow something that suggests a general redistribution of vorticity over a week or so. Anything longer than that, nobody really understands. There is some evidence that there can be long-period trends such as the so-called index cycle in which the position of the westerlies migrate southward and then northward over a period of roughly four weeks. Anything longer than that we simply have little idea about. But certain interactions between circulations over widely separated areas, as between the eastern North Pacific and the Western Atlantic are fairly well recognized. For example, the intense cyclonic activity off the East Coast of United States and the cold waves in Florida last winter can be associated with the abnormal East Pacific trough.

Stommel: How does the Atlantic meteorological abnormality compare in magnitude with this? As I remember it, it would be almost of this order.

Namias: Yes, it would.

Question: Was it connected with the Pacific, or was it in the Atlantic alone?

Namias: It was associated with the Pacific, but in the Atlantic case there was a great blocking anticyclone. No two cases are identically alike.

Charney: Everyone is concerned with the catastrophic importance of this change. Is that really very important? Is it not important to try to explain changes whether they are catastrophic or not?

Schaefer: Certainly these things do have a certain recurrence. These same periods that you have mentioned tally with the abnormalities off Peru in 1941, for example, almost exactly. One interesting thing was that 1953 was an abnormal year in the Peruvian situation though not so extreme as this last year.

Namias: It would seem to me logical that there was some interconnection between the abnormal wind systems of both hemispheres, but no one has been able to document this idea. Maybe with the help of IGY data we can piece things together.