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THE TYPHOONS OF OCTOBER 1970 IN THE SOUTH CHINA SEA:

INTENSIFICATION, DECAY AND OCEAN INTERACTION

by

C. S. RAMAGE

JUNE 1973

ENVIRONMENTAL PREDICTION RESEARCH FACILITY
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by

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ABSTRACT

In October 1970, the South China Sea experienced three typhoons. Meteorological and oceanographic data were examined in an attempt to explain why the typhoons underwent intensity changes while over the South China Sea. The clearest relationship was found with troughs in the upper tropospheric westerlies -- intensification accompanied development of a middle and high cloud plume streaming northeastward from the storm area.

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I. INTRODUCTION

In October 1952, three typhoons moved rapidly westward across the South China Sea at 5-day intervals, the latter two on nearly coincident tracks (Ramage, 1972). The first two typhoons decreased the sea-surface temperature up to 4.5°C ahead of the third typhoon. Even with this temperature decrease the third typhoon neither veered away from the cold water nor was weakened by it. In turn, it further cooled the surface waters by 2.5°C.

Lack of ocean soundings, weather satellite data and a paucity of aerological soundings and aircraft reconnaissance prevented detailed study. The physical processes by which the typhoons cooled the sea, and other factors besides sea-surface temperature which could affect their intensity and movement, could not be evaluated.

In October 1970, the South China Sea experienced three typhoons (Figure 1). Numerous aerological soundings, detailed weather satellite pictures, aircraft reconnaissance data and more than 200 ocean soundings have been analyzed for this month and the tentative conclusions of the earlier study evaluated.

In this paper each typhoon is discussed and reasons are sought for intensity changes. The paper ends with a discussion, ideas on future research, and forecasting suggestions.

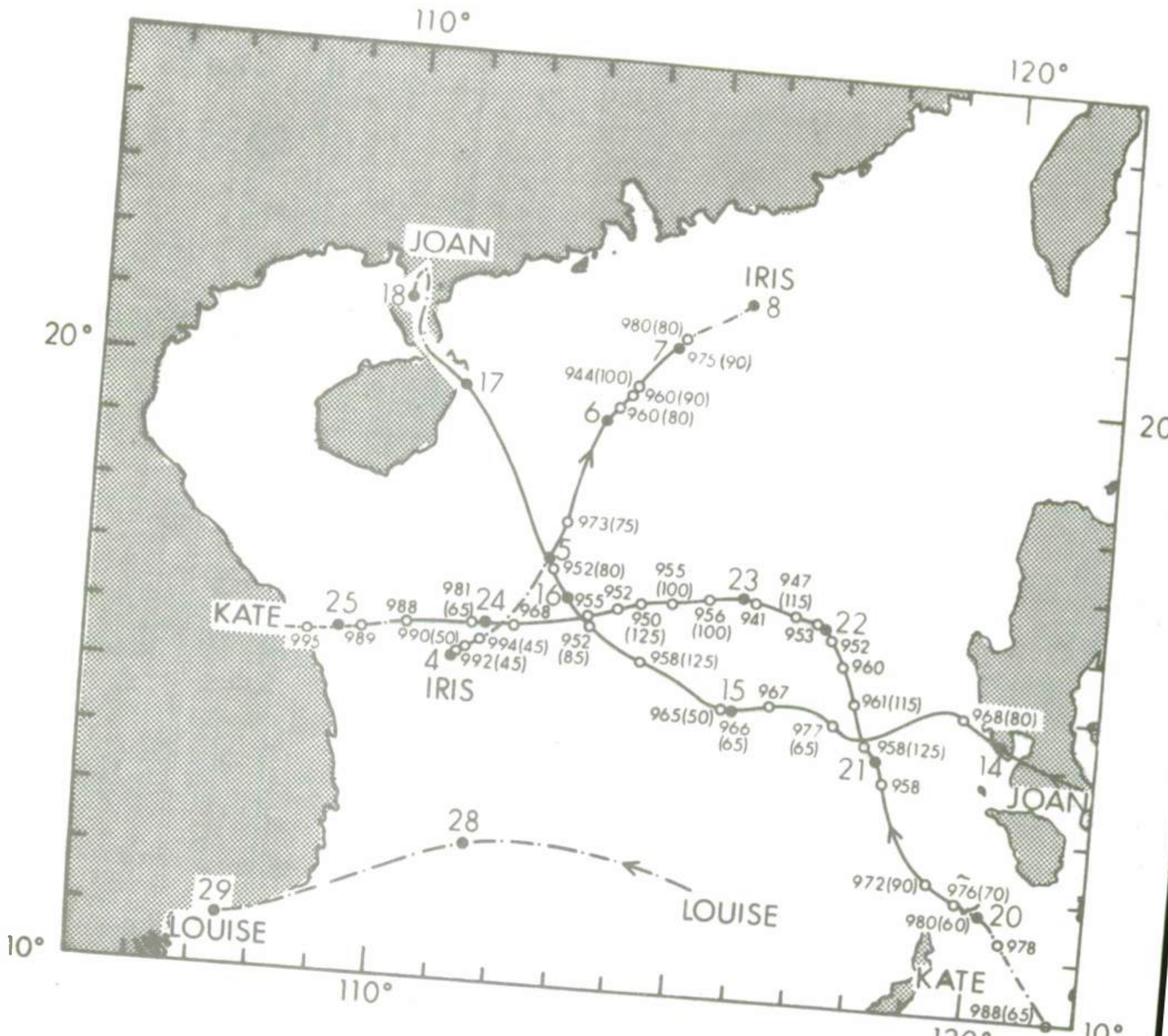

Figure 1. Tracks of October 1970 South China Sea tropical cyclones. Daily positions (large black dots) are given at 0000Z. Full lines denote typhoon intensity, dot-dashed lines denote tropical storm or depression intensity. Reconnaissance-determined, sea-level pressure in the eye (mb) and maximum estimated surface winds (kt, in parentheses) are entered at circled positions.

2. TYPHOON INTENSIFICATION, MOVEMENT AND DECAY

Of the three typhoons whose tracks and intensities[1] are shown in Figure 1, Iris developed in the South China Sea; Joan and Kate developed and became intense over the Philippine Sea, weakened while crossing the Philippines and then reintensified over the South China Sea.

Cold, dry polar air failed to approach the surface circulations of the typhoons and was never a factor in their intensity changes. It also was apparent that none of the typhoons moved to avoid cool water.

2.1 TYPHOON IRIS

As it moved slowly north-northeast, Iris intensified rapidly and filled even more rapidly while still over the open sea (Figure 2). A brief period of intensification took place over water where sea-surface temperatures were 1-2°C cooler than those previously encountered by Iris. As Iris came under the influence of the eastern portion of a shortwave trough in the upper-tropospheric westerlies on the 5th, a plume of middle and high cloud spread from the center northeastward toward the subtropical jet, and the eye pressure fell rapidly.

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[1] Sea-level pressure measured in the typhoon eye by reconnaissance aircraft is used as an objective indicator of intensity.

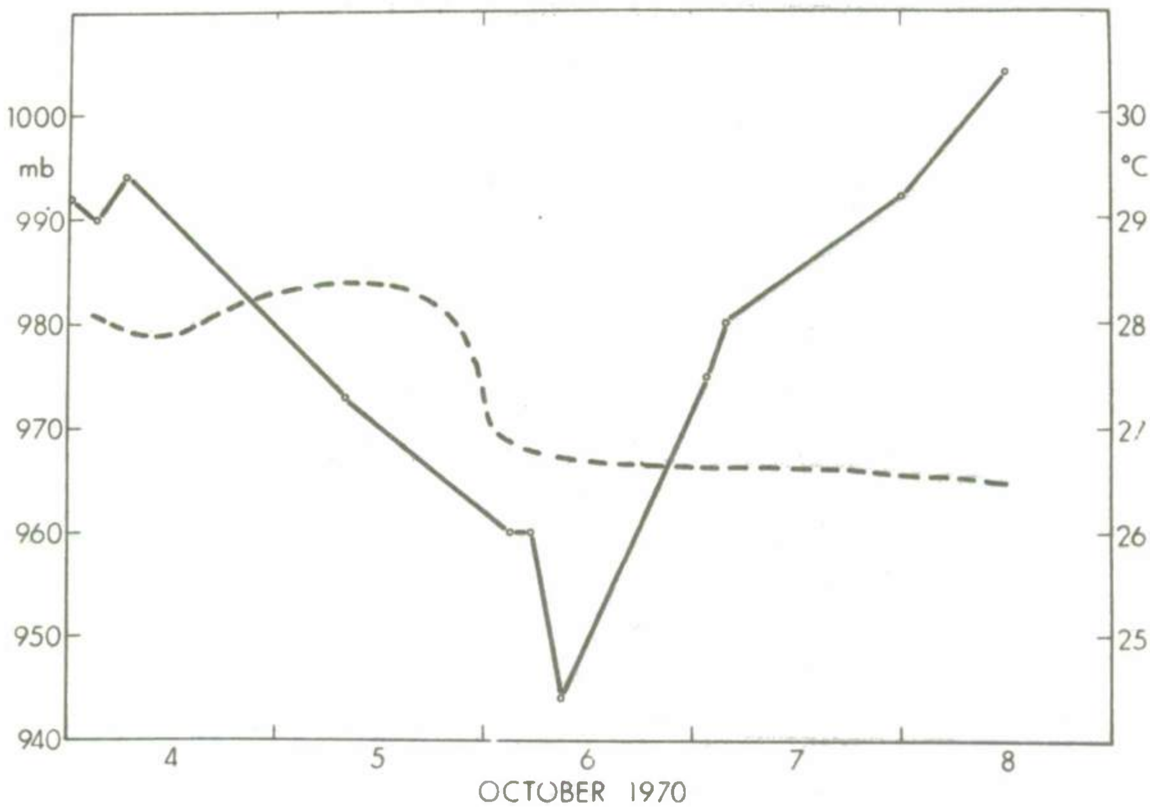

Figure 2. Sea-level pressure in the eye (full line) and prior sea-surface temperature (dashed line) along the track of Typhoon Iris.

A simplified form of the vorticity equation can be written as follows:

$$\nabla \cdot \vec{V} = -\left[\frac{\vec{V} \cdot \nabla\zeta + w\frac{\partial\zeta}{\partial z} + \frac{\partial\zeta}{\partial t} + \beta v}{(\zeta + f)}\right] \qquad [1]$$

where $\nabla\cdot\vec{V}$ is the divergence, $-\vec{V}\cdot\nabla\zeta$ is the horizontal advection of relative vorticity, $-w\frac{\partial\zeta}{\partial z}$ is the vertical advection of relative vorticity, $\frac{\partial\zeta}{\partial t}$ is the local change of relative vorticity with time, βv is the Beta (Coriolis) term, and $(\zeta+f)$ is the absolute vorticity.

Equation [1] was applied to the 200-mb level to a 450 km diameter circle enclosing the surface low. Between 1200Z on the 4th and 0000Z on the 5th, $-\vec{V}\cdot\nabla\zeta = 2.1 \times 10^{-10}$ sec^{-2}. Since $\frac{\partial\zeta}{\partial t} = -0.6 \times 10^{-10}$ sec^{-2} nearly balanced $\beta v = 0.7 \times 10^{-10}$ sec^{-2}, and with $(\zeta+f) = 1.89 \times 10^{-5}$ sec^{-1} the net result was upper tropospheric divergence ($1.2 \times 10^{-5} sec^{-1}$) and intensification of the surface low.

Near the time of maximum intensity (Figures 3(a) and 3(b)), the cloud plume was still evident and coincided with strong upper-tropospheric divergence and possible heat flux divergence.

Between 1200Z on the 6th (Figure 3(a)) and 0000Z on the 7th (Figure 4 (a)), while Iris drifted northeastward, the 200- mb trough moved eastward at over 20 m sec^{-1} to the longitude of the typhoon center. Rapid filling ensued and the eye

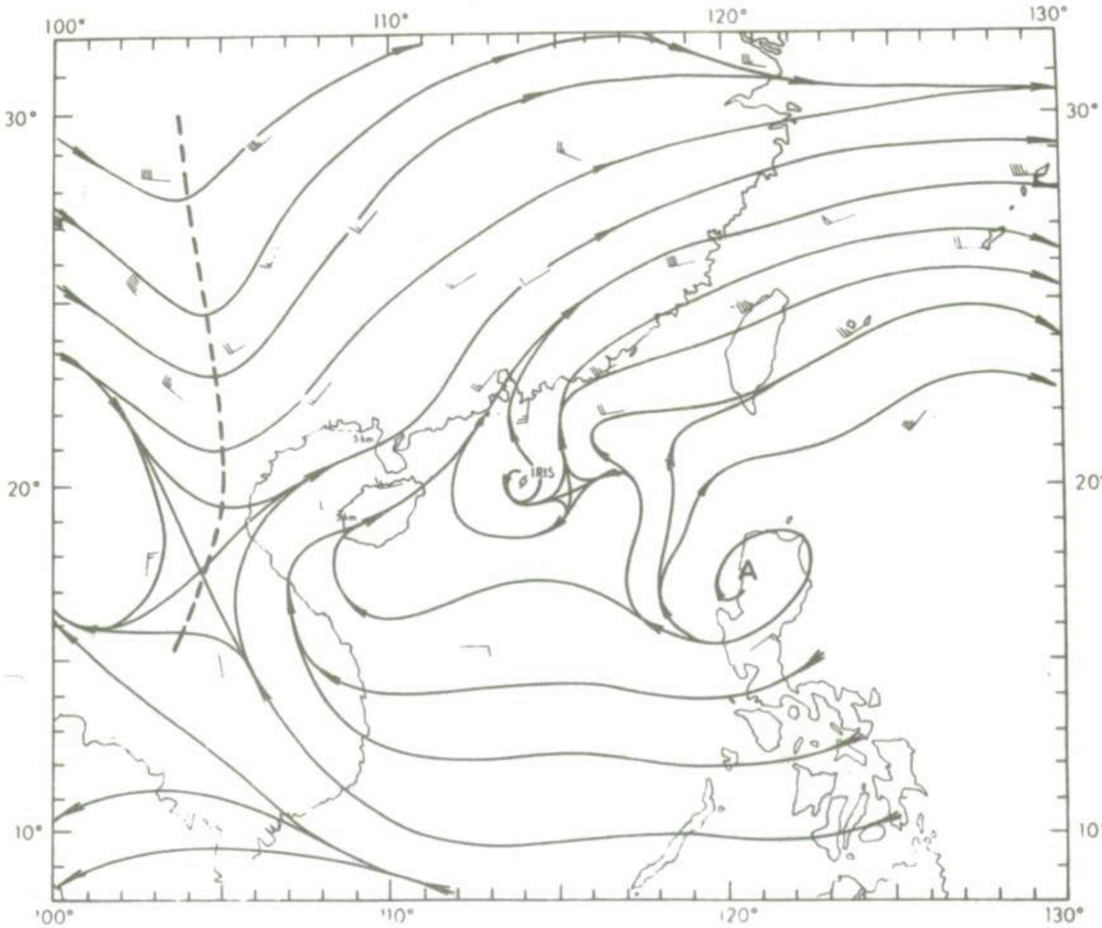

Figure 3(a). 200-mb chart for 1200Z, 6 October 1970. Over-ocean analysis is based on cirrus recorded in Figure 3(b).

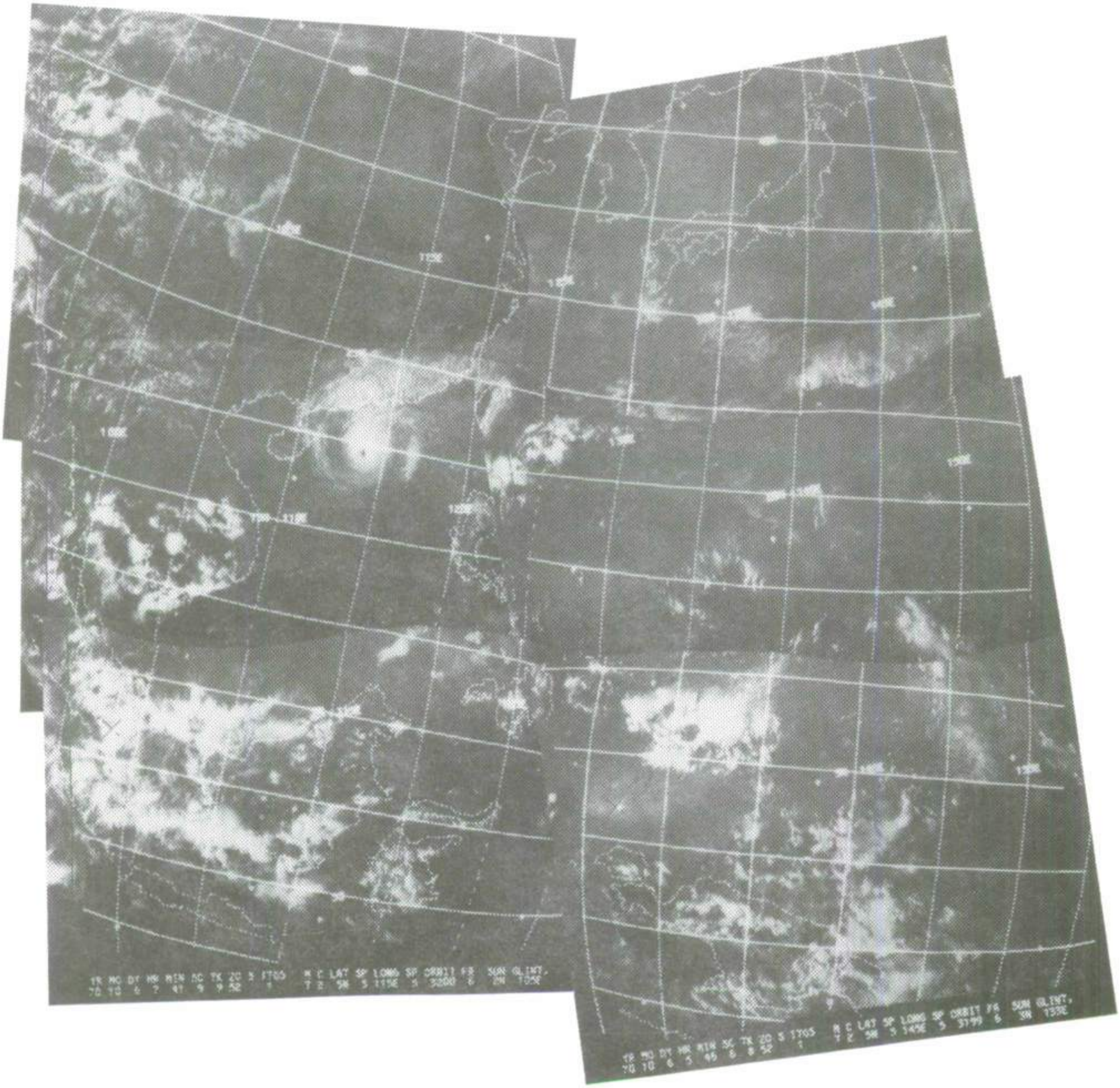

Figure 3(b). Satellite (ITOS1) photograph of Typhoon Iris at 0746Z, 6 October 1970.

pressure rose 31 mb in 16-1/2 hours. The Annual Typhoon Report for 1970 (U. S. Fleet Weather Central/Joint Typhoon Warning Center, 1971) ascribed both intensification and subsequent filling to the influence of the upper trough. The satellite picture for 0647Z on the 7th is shown in Figure 4(b). By this time the surface center lay west of the upper trough.

From Figures 3(a) and 4(a) the terms of Equation [1] for a 450 km diameter circle centered on Iris were computed:

$$\vec{V} \cdot \nabla\zeta = -\ 2.0 \times 10^{-10} \text{ sec}^{-2}$$

$$w \frac{\partial\zeta}{\partial z} \doteq 0$$

$$\frac{\partial\zeta}{\partial t} = 16.7 \times 10^{-10} \text{ sec}^{-2}$$

$$\beta v = 1.4 \times 10^{-10} \text{ sec}^{-2}$$

$$(\zeta + f) = 5.2 \times 10^{-5} \text{ sec}^{-1} \text{ with:}$$

$$\nabla \cdot \vec{V} = -3.1 \times 10^{-5} \text{ sec}^{-1}.$$

This convergence if applied to the layer between 200 and 150 mb, and uncompensated, would result in a pressure rise of 11.1 mb hr^{-1}, compared with the 2 mb hr^{-1} observed.

It is assumed that $\frac{\partial\zeta}{\partial t}$ controlled the sign and magnitude of $\nabla \cdot \vec{V}$ because of the trough's very rapid movement. Had the trough moved only slowly eastward, Iris would probably have accelerated northeastward, keeping east of the troughline where vorticity advection would have maintained moderate upper-tropospheric divergence. As it was, sudden development of convergence aloft could not be readily accommodated within the air column and lower-tropospheric convergence would have

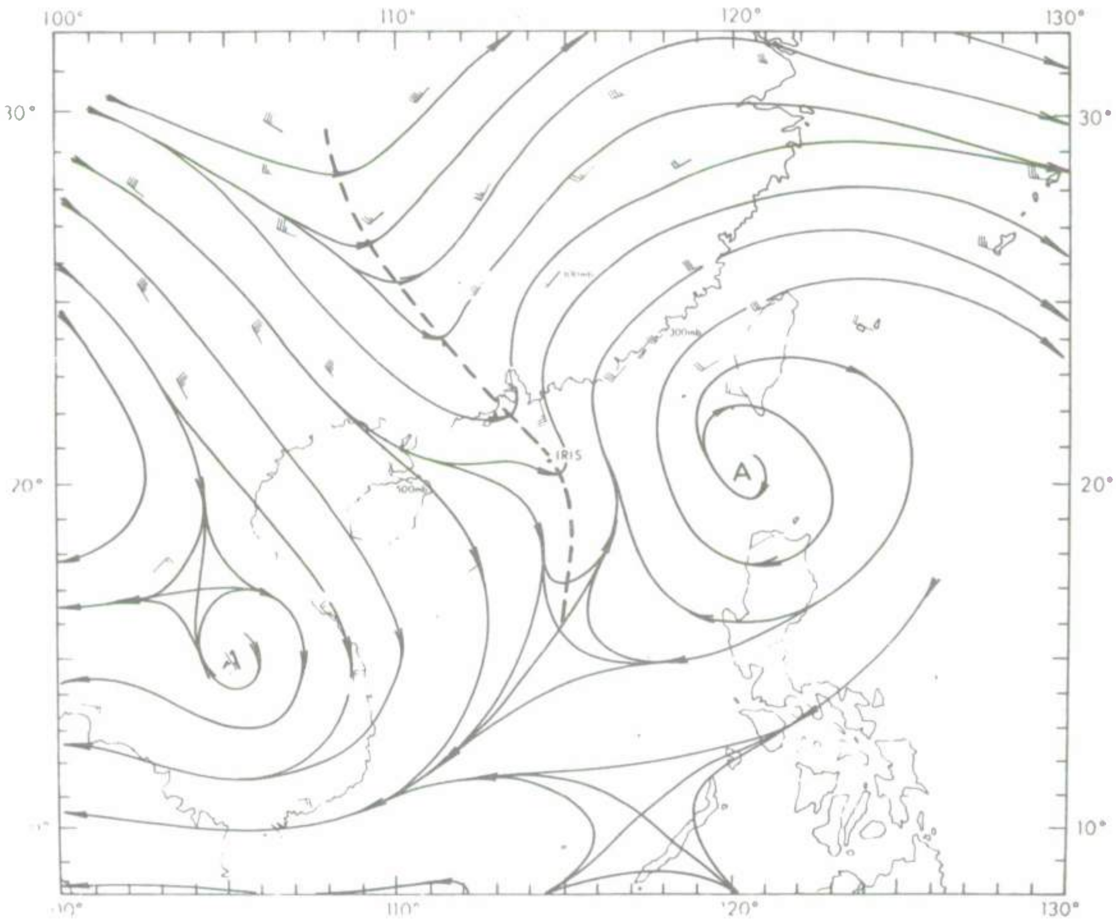

Figure 4(a). 200-mb chart for 0000Z, 7 October 1970. Over-ocean analysis is partly based on cirrus photographed by ESSA 8 (APT) at 0035Z.

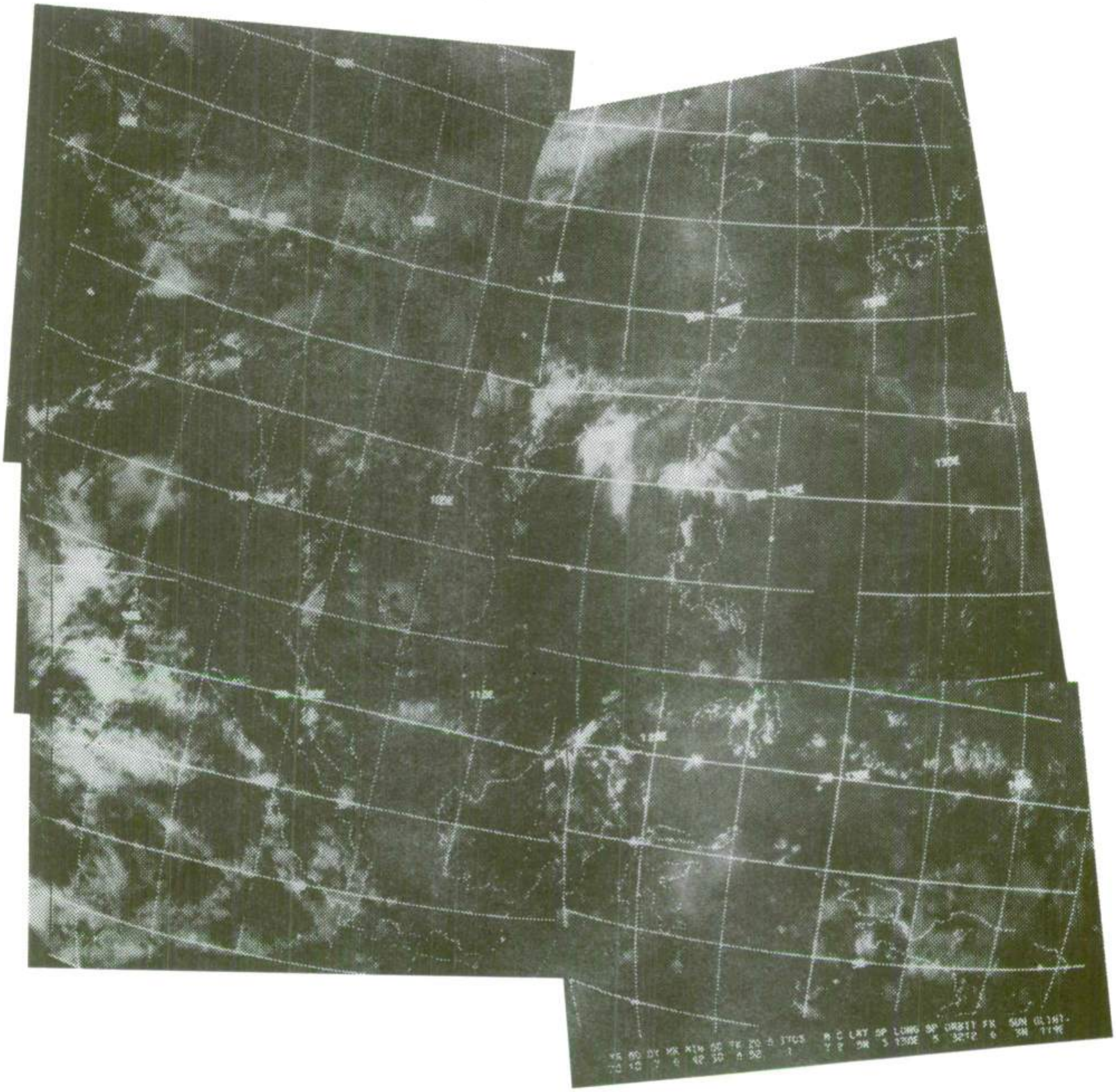

Figure 4(b). Satellite (ITOS1) photograph of Typhoon Iris at 0647Z, 7 October 1970.

continued into the surface low under pressure and frictional forces even as the surface pressure began to rise. Thus, it appears as if upper- and lower-tropospheric convergence suddenly dissipated Iris. By the 8th, nothing remained of the circulation. The satellite picture for 0743Z of 8 October is shown in Figure 5.

Conditions in October over the South China Sea often resemble hurricane season conditions over the Caribbean, in which a semi-permanent northeast-southwest trough (cyclonic shear line) in the upper troposphere affects tropical disturbances. According to Simpson and Sugg (1970),

> "As a system approaches the wind-speed maximum in the upper troposphere south of the shear line, the vorticity advection enhances the mass outflow from the disturbance. Beyond this wind maximum and across the shear line to the wind-speed maximum on the opposite side of the line, the vorticity advection in the upper troposphere inhibits the divergent outflow of the disturbance or cyclone. This well-developed circulation feature may have influenced the development of a number of disturbances, while accounting also for the dissipation or sharp loss of intensity of some hurricanes over warm tropical waters...."

On 17 October 1962 a tropical storm in the North Atlantic centered between Georgia and Bermuda, changed direction from west-northwest to north-northwest and intensified beneath divergent flow on the east side of a trough in the upper-tropospheric westerlies. According to Dunn and staff (1963),

> "There is little doubt that in this instance the cyclogenesis began under (near) a cold trough and that the upper-tropospheric anticyclonic pattern developed during or subsequent to the surface intensification."

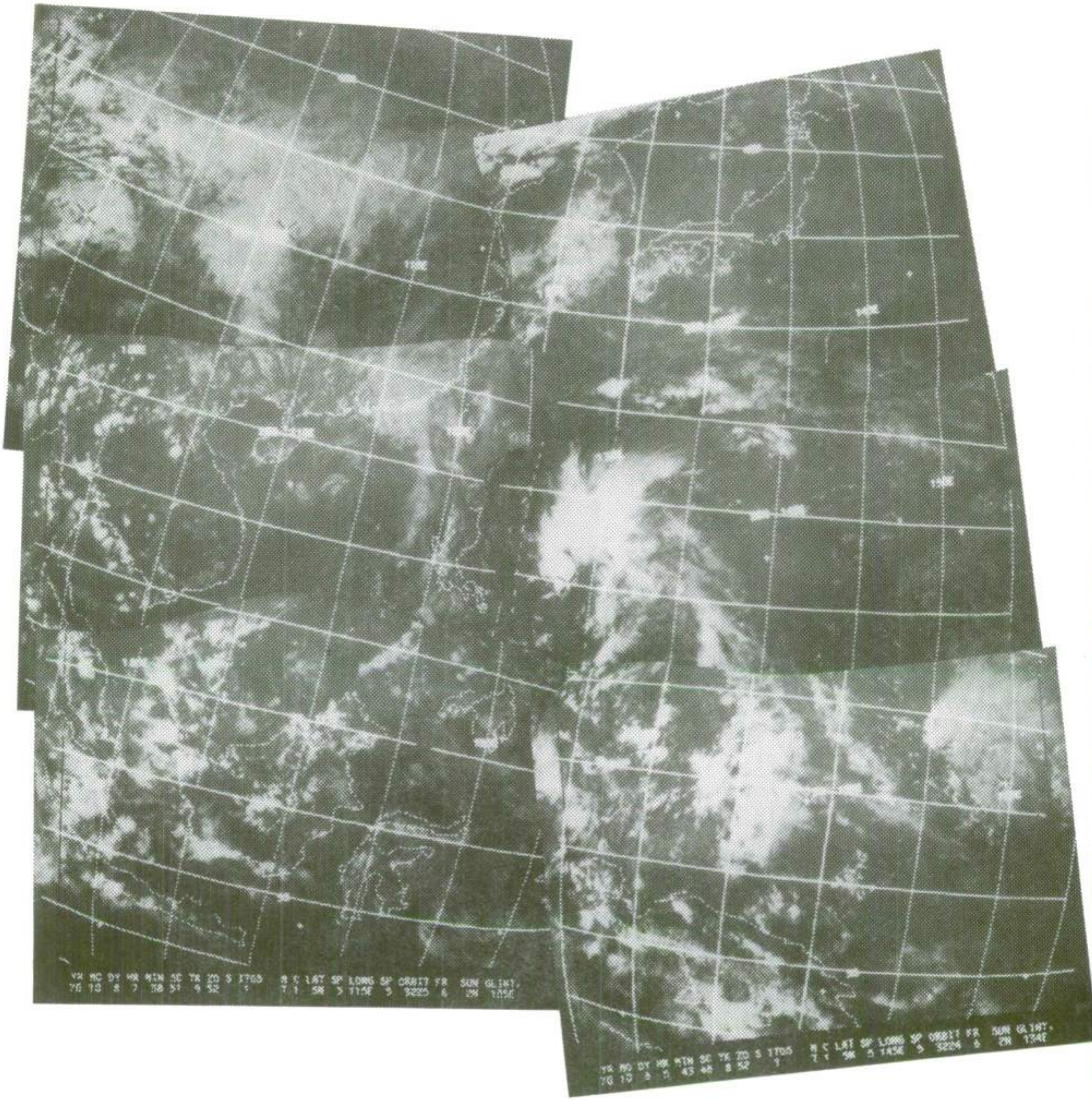

Figure 5. Satellite (ITOS1) photograph of the remnants of Typhoon Iris at 0743Z, 8 October 1970.

2.2 TYPHOON JOAN

Typhoon Joan began reintensifying about 12 hours after the eye had moved over the South China Sea (see Figures 1 and 6). Until the 15th, Joan lay south of the 200-mb ridge and outflow was confined to the upper-tropospheric easterlies.

By 1200Z on the 15th, the upper ridge had weakened and strong divergent southerlies developed west of Joan. The effect was dramatic -- a huge mass of cloud now streamed out of the system toward the north and northeast and joined with subtropical jet and frontal cloud. Intensification continued despite the fact that the storm was now passing over progressively cooler water. Even where the mixed layer prior to passage was shallow and conditions favored cold water being brought to the surface, the typhoon remained intense. Massive outflow persisted until Joan struck northeastern Hainan Island (see Figures 7(a) and 7(b)), where observations indicated a landfall eye pressure of no more than 960 mb.

2.3 TYPHOON KATE

Typhoon Kate moved out of the Philippines beneath a 200-mb anticyclone and across a sea surface with a temperature of 30C. In the first 24 hours (see Figures 1 and 8) the eye pressure fell from 980 to 958 mb. Then, after little change for another 18 hours, the typhoon began moving over progressively cooler water. At the same time, intensification

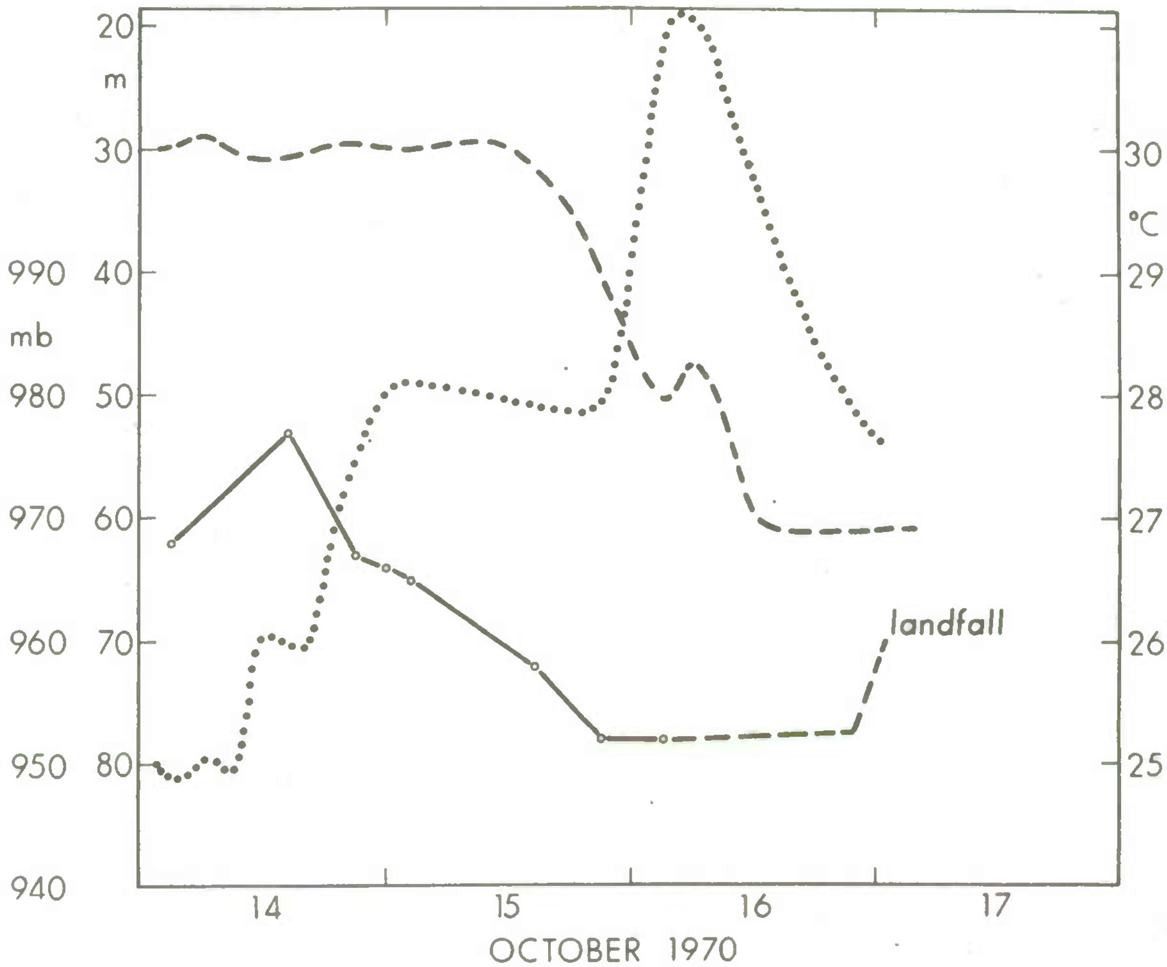

Figure 6. Sea-level pressure in the eye (full line), prior sea-surface temperature (dashed line), and mixed-layer depth (dotted line) along the track of Typhoon Joan.

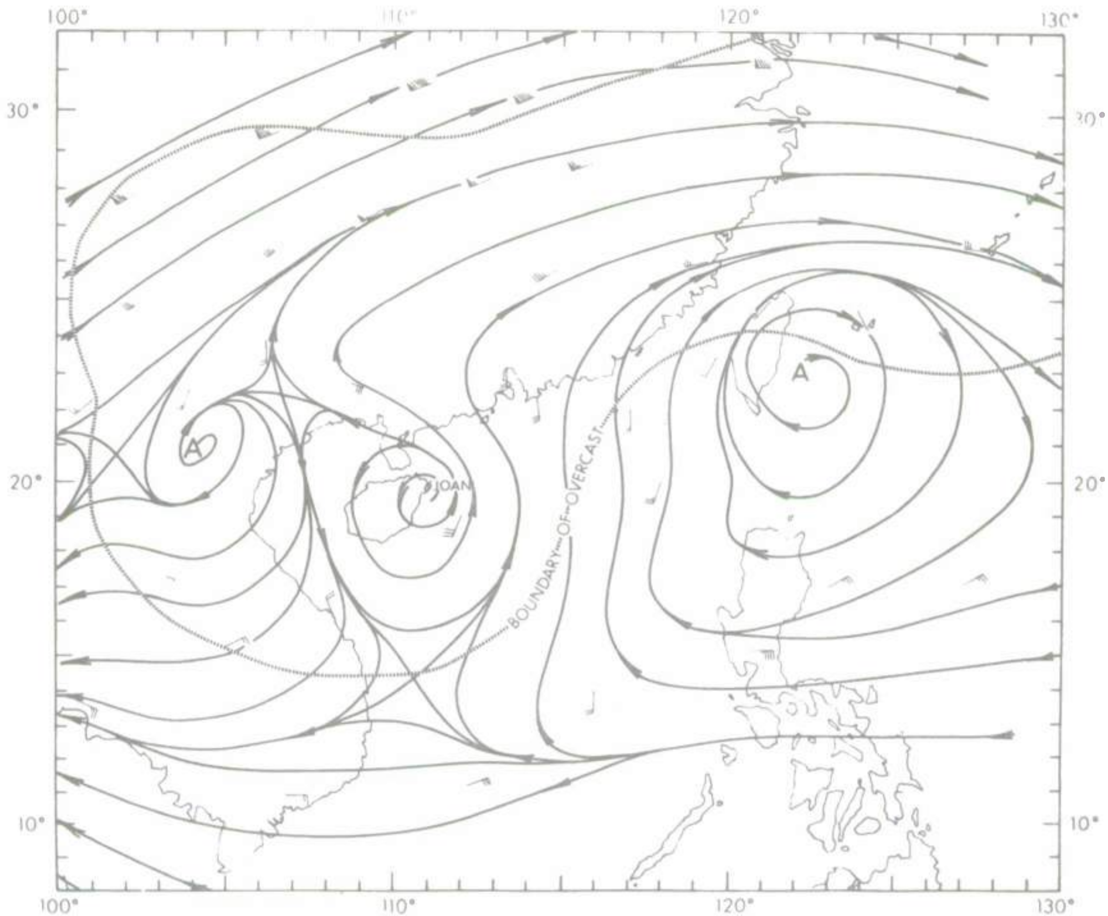

Figure 7(a). 200-mb chart for 0000Z, 17 October 1970. Over-ocean analysis is partly based on cirrus photographed by ESSA 8 (APT) at 0225Z. Stippling outlines the area of overcast as observed from surface stations.

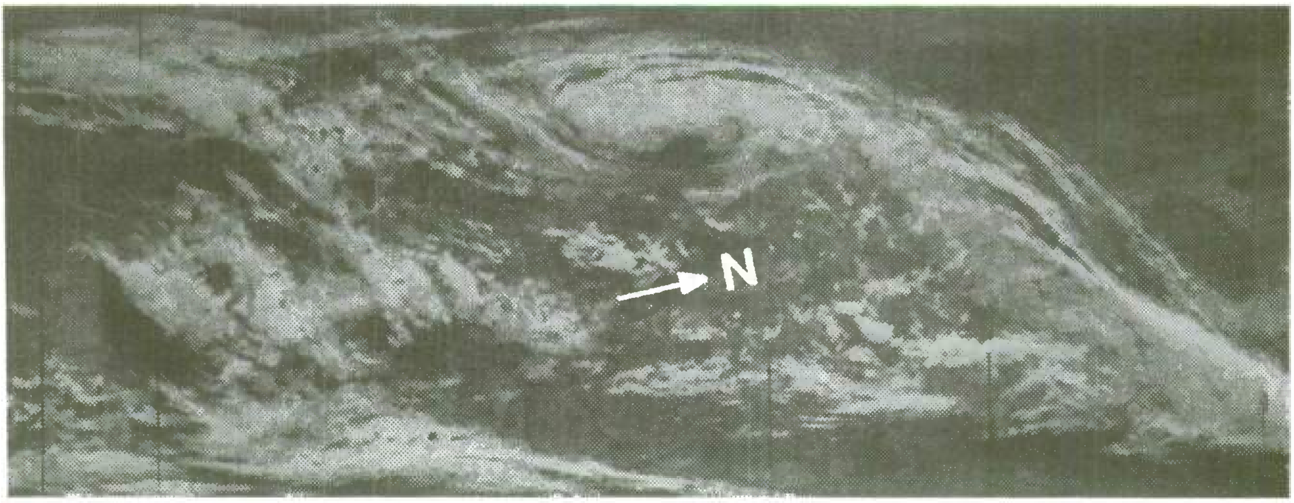

Figure 7(b). Satellite (ITOS1) IR photograph of Typhoon Joan approaching landfall near Hainan Island at 1940Z, 16 October 1970.

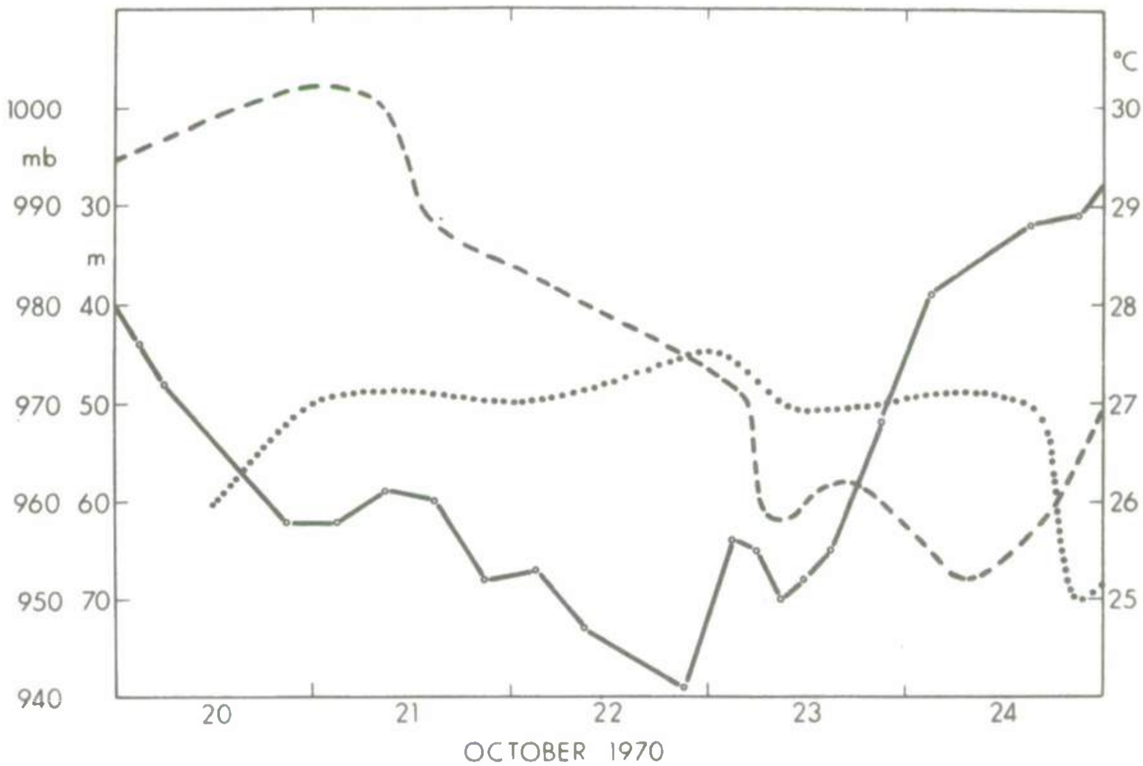

Figure 8. Sea-level pressure in the eye (full line), prior sea-surface temperature (dashed line), and mixed-layer depth (dotted line) along the track of Typhoon Kate.

resumed. At least part of the pressure fall might be attributed to an upper-tropospheric shortwave trough which temporarily linked with Kate on the 21st and 22nd (Figure 9(a)). Kate moved very slowly north-northwest under the influence of the trough and, near the time of maximum intensity, middle and high cloud streamed out of the circulation toward the northeast (see Figure 9(b)). Presumably the trough moved too rapidly eastward for Kate to complete recurvature; the intense ridge west of the trough moved over Kate on the 23rd, cutting off northward outflow and changing the typhoon's movement from north-northwest to west-southwest. By the 24th (Figures 10(a) and 10(b), the transformation was complete. Kate's eye pressure rose sharply with outflow to higher latitudes cut off. Higher sea-surface temperatures and a deeper mixed layer near the coast failed to reverse the trend. At landfall early on the 25th, Kate had diminished to weak depression strength.

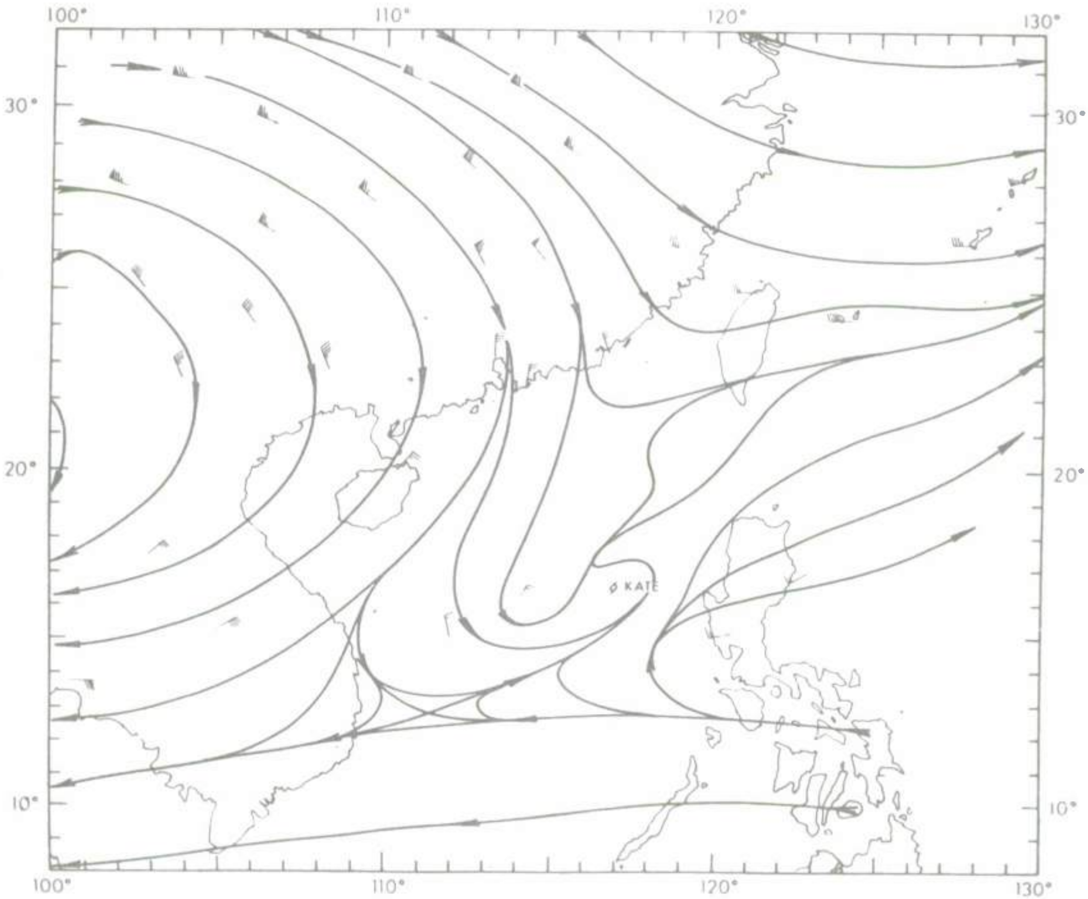

Figure 9(a). 200-mb chart for 1200Z, 22 October 1970. Over-ocean analysis is partly based on cirrus photographed by ITOS1 at 0728Z.

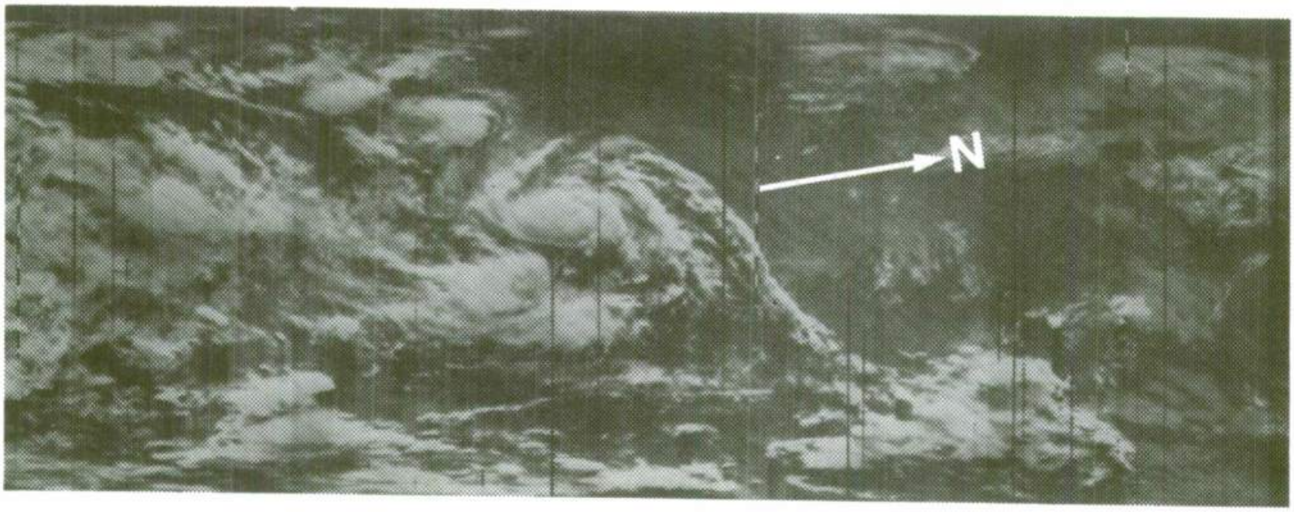

Figure 9(b). Satellite (ITOS1) IR photograph of Typhoon Kate near maximum intensity at 1934Z, 22 October 1970.

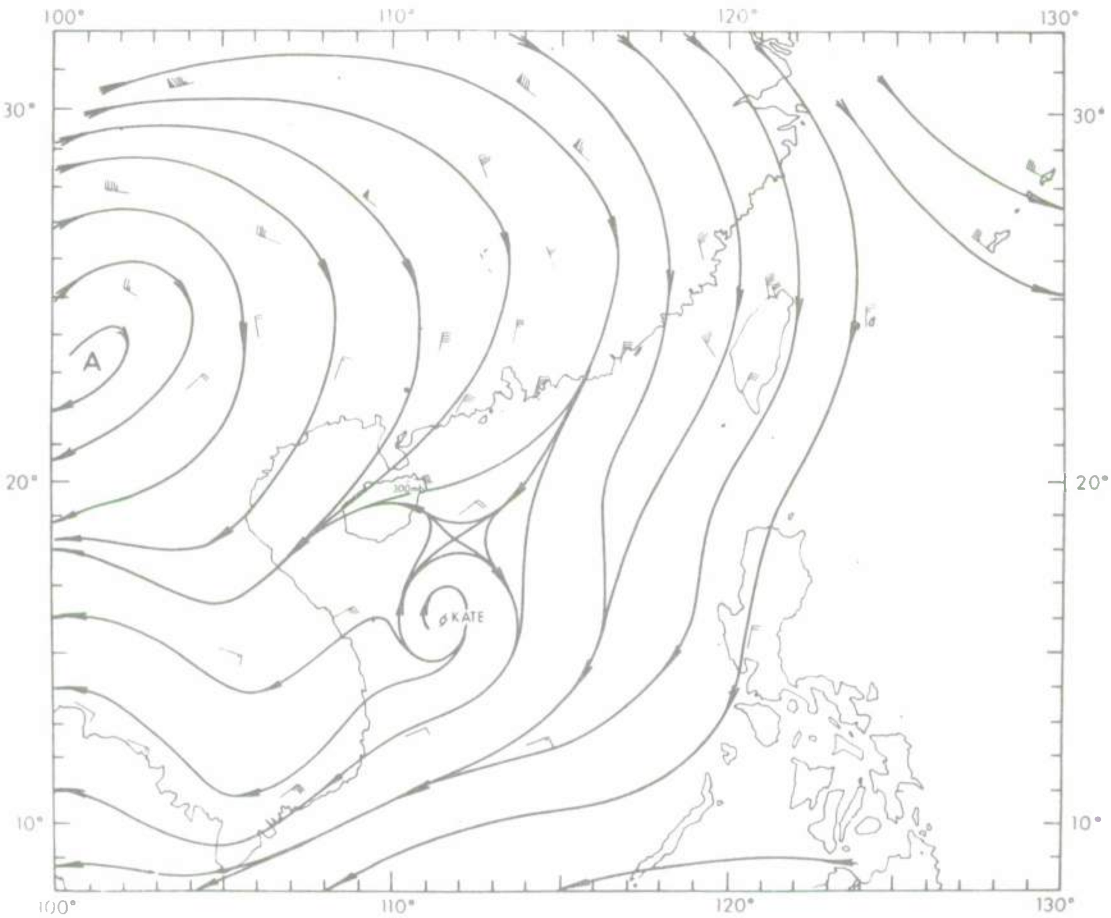

Figure 10(a). 200-mb chart for 0000Z, 24 October 1970. Over-ocean analysis is partly based on cirrus photographed by ESSA 8 at 0139Z.

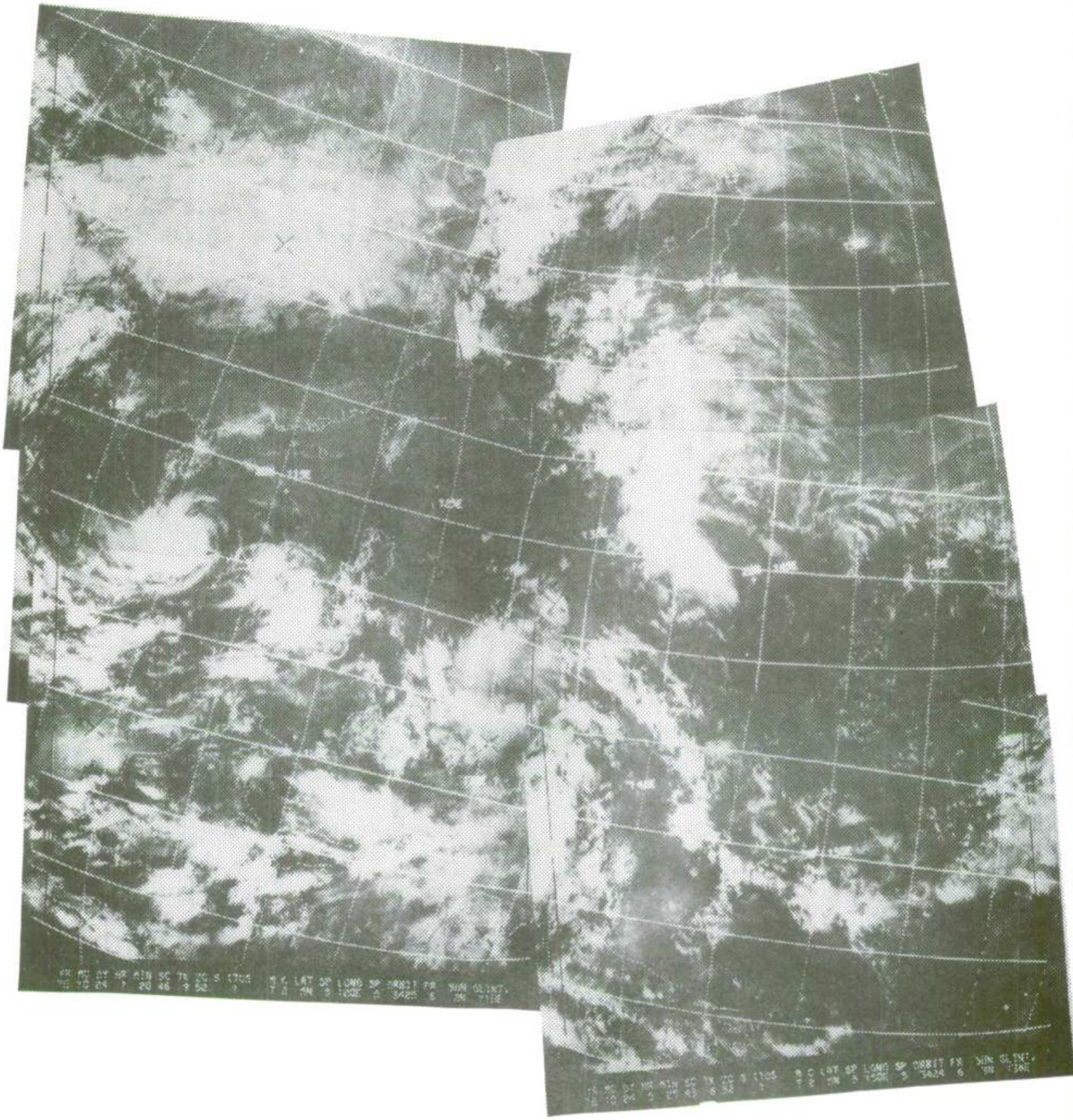

Figure 10(b). Satellite (ITOS 1) photograph of Typhoon Kate at 0725Z, 24 October 1970.

3. EFFECT OF TYPHOONS ON THE SEA

Between 10 and 13 September 1970, Typhoon Georgia moved northwestward across the northeastern South China Sea which then remained free of typhoons until Iris developed.

The sea-surface temperature distribution in the South China Sea for the period 1-3 October 1970 (Figure 11), closely resembles the long-term mean. Information on the mixed-layer depth[1] is inadequate for comparison with the long-term mean. Surface temperature of the sea over which Iris had passed at typhoon strength fell about 1°C (see Figure 12). Near-track soundings before and after passage revealed a decrease in mixed-layer depth and temperature as well as a cooling of the thermocline. A combination of upwelling and surface-layer mixing associated with Typhoon Iris probably accounts for much of the difference.

Sea-surface temperature changes associated with Typhoon Joan (Figure 13) reveal no consistent pattern. Cooling of 3-4°C and a decrease in mixed-layer depth occurred over the central sea, again suggesting upwelling and surface layer mixing, but toward Hainan Island slight warming is evident.

Only slight sea-surface temperature falls were associated with Typhoon Kate (Figure 14), reaching 2°C east of Hainan. The mixed-layer depth increased somewhat over the central sea.

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[1] That depth at which temperature became 1°C less than the surface temperature (see Wyrtki, 1971).

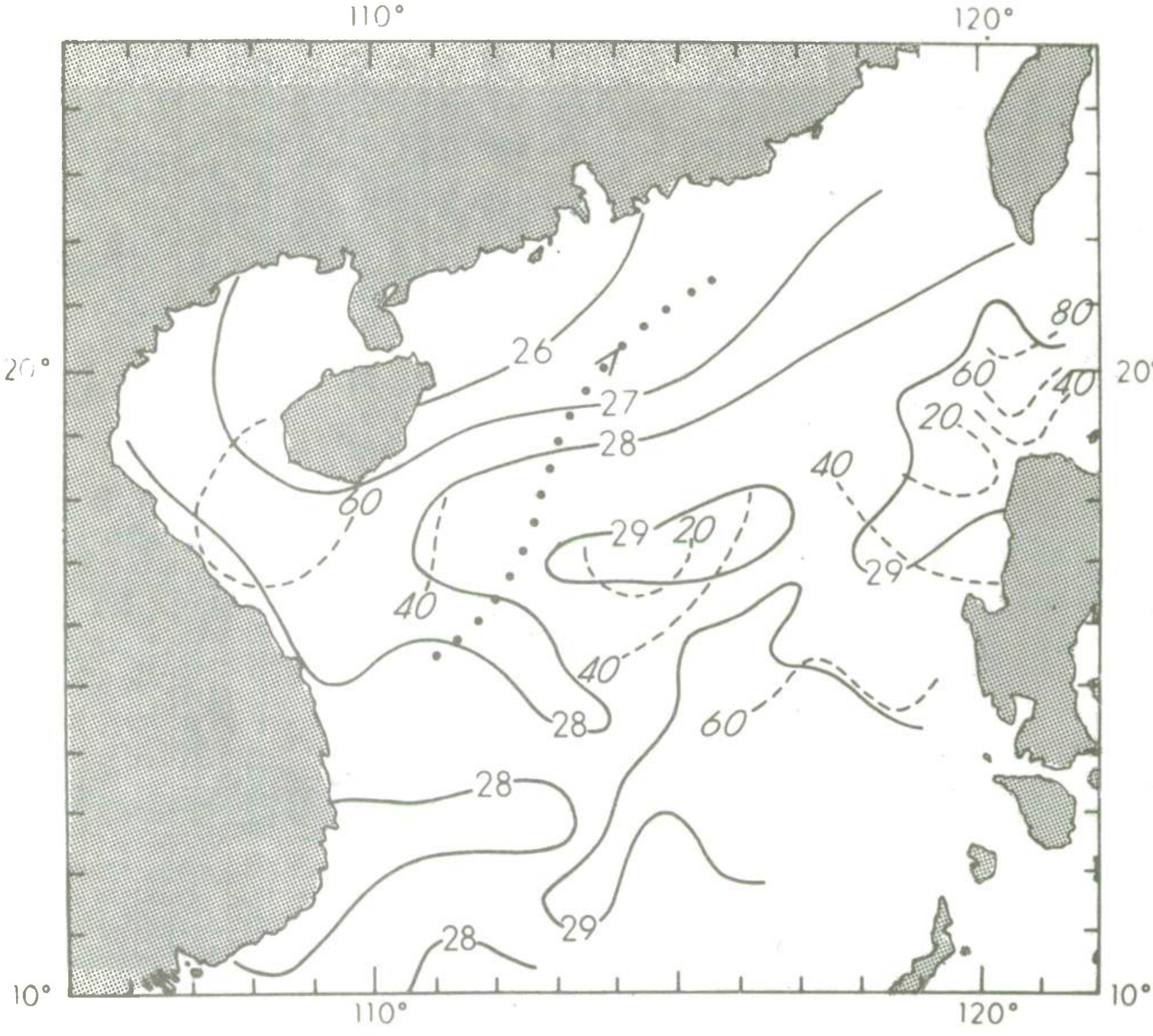

Figure 11. Sea-surface temperatures (°C, full lines) and mixed-layer depths (m, dashed lines) for the period 1 through 3 October 1970 prior to development of Typhoon Iris. The dots show Iris' track.

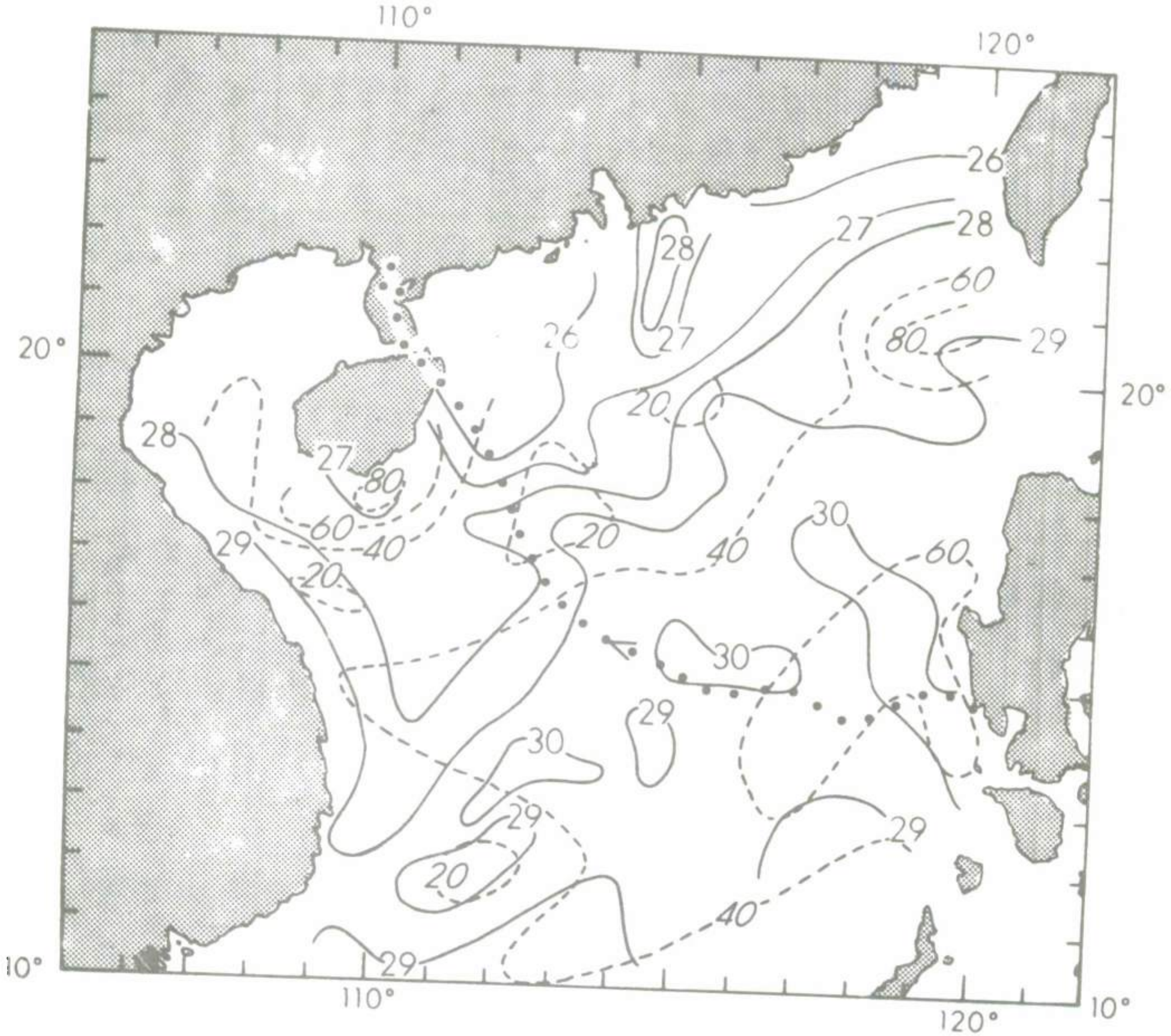

Figure 12. Sea-surface temperatures (°C, full lines) and mixed layer depths, (m, dashed lines) for the period 8 through 13 October 1970 following Typhoon Iris and prior to the appearance of Typhoon Joan in the South China Sea. The dots show Joan's track.

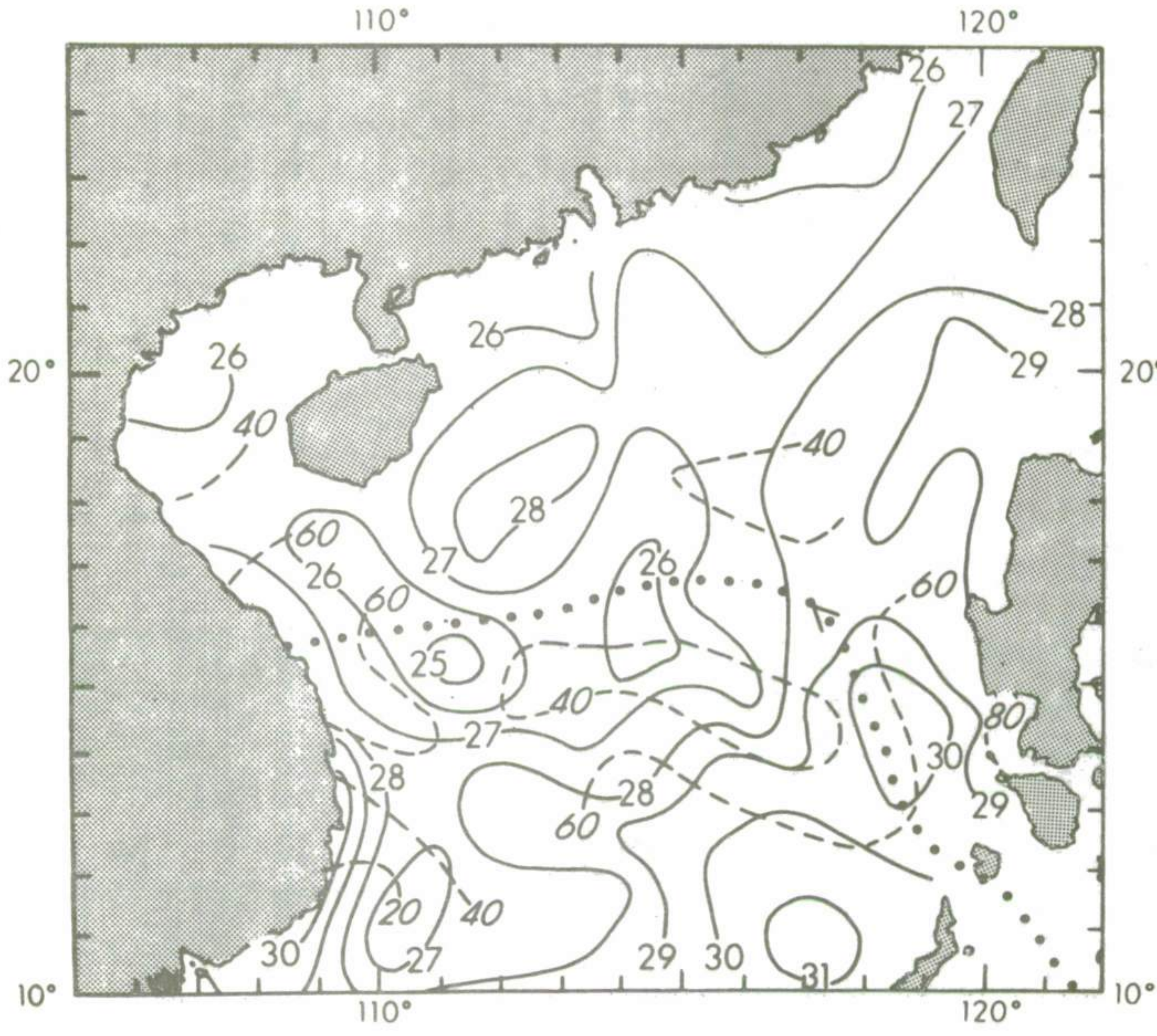

Figure 13. Sea-surface temperatures (°C, full lines) and mixed layer depths (m, dashed lines) for the period 16 through 19 October 1970, following Typhoon Joan and prior to the appearance of Typhoon Kate in the South China Sea. Dots show Kate's track.

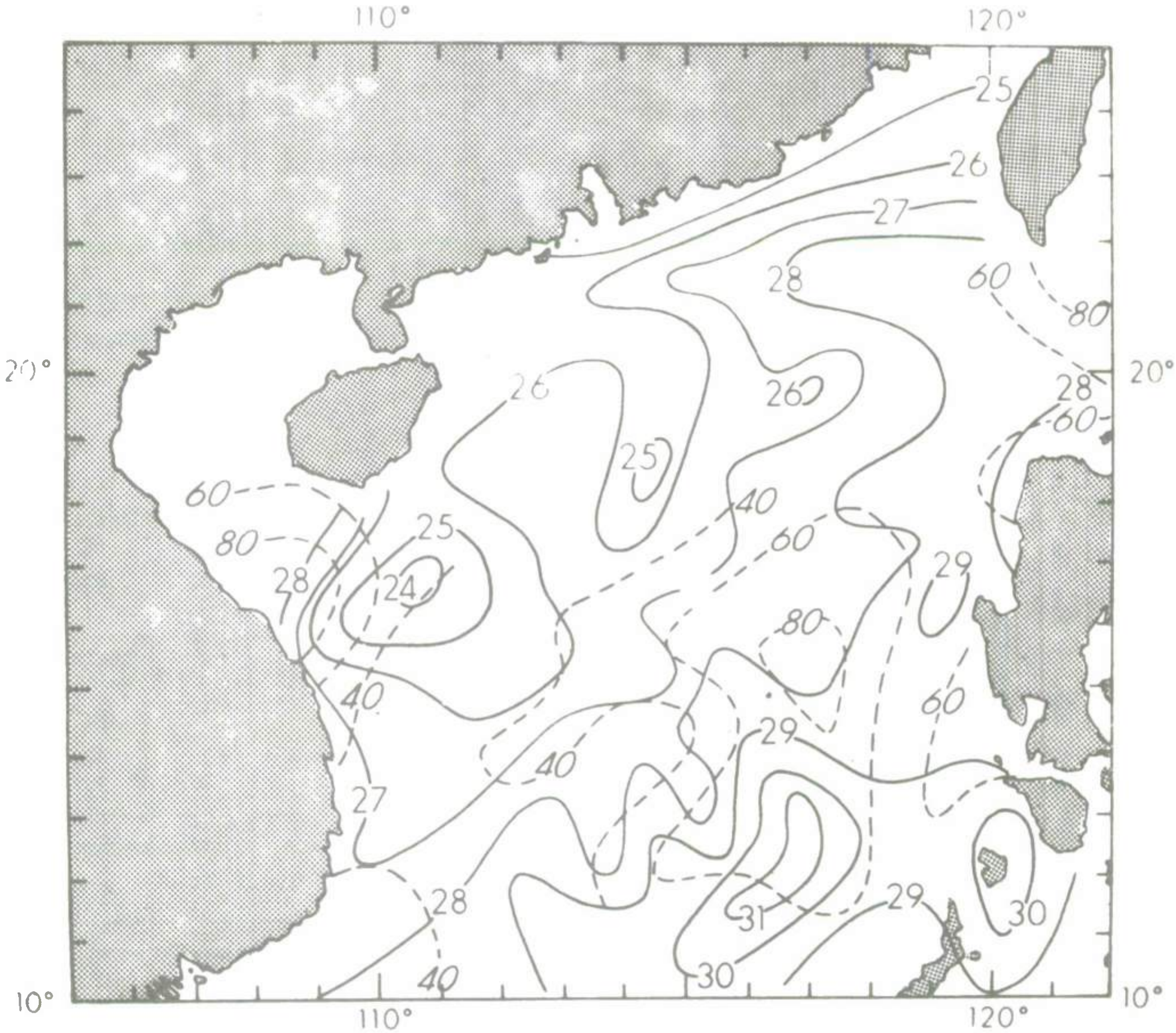

Figure 14. Sea-surface temperatures (°C, full lines) and mixed layer depths (m, dashed lines) for the period 25 through 31 October 1970 following Typhoon Kate.

Figure 15 shows the typhoons produced little change in sea-surface temperature near the Philippines, where the mixed-layer depth remained greater than 50 m and presumably cold thermocline water was beyond the influence of mixing and upwelling. The greatest temperature falls occurred slightly north of where the typhoon tracks were concentrated.

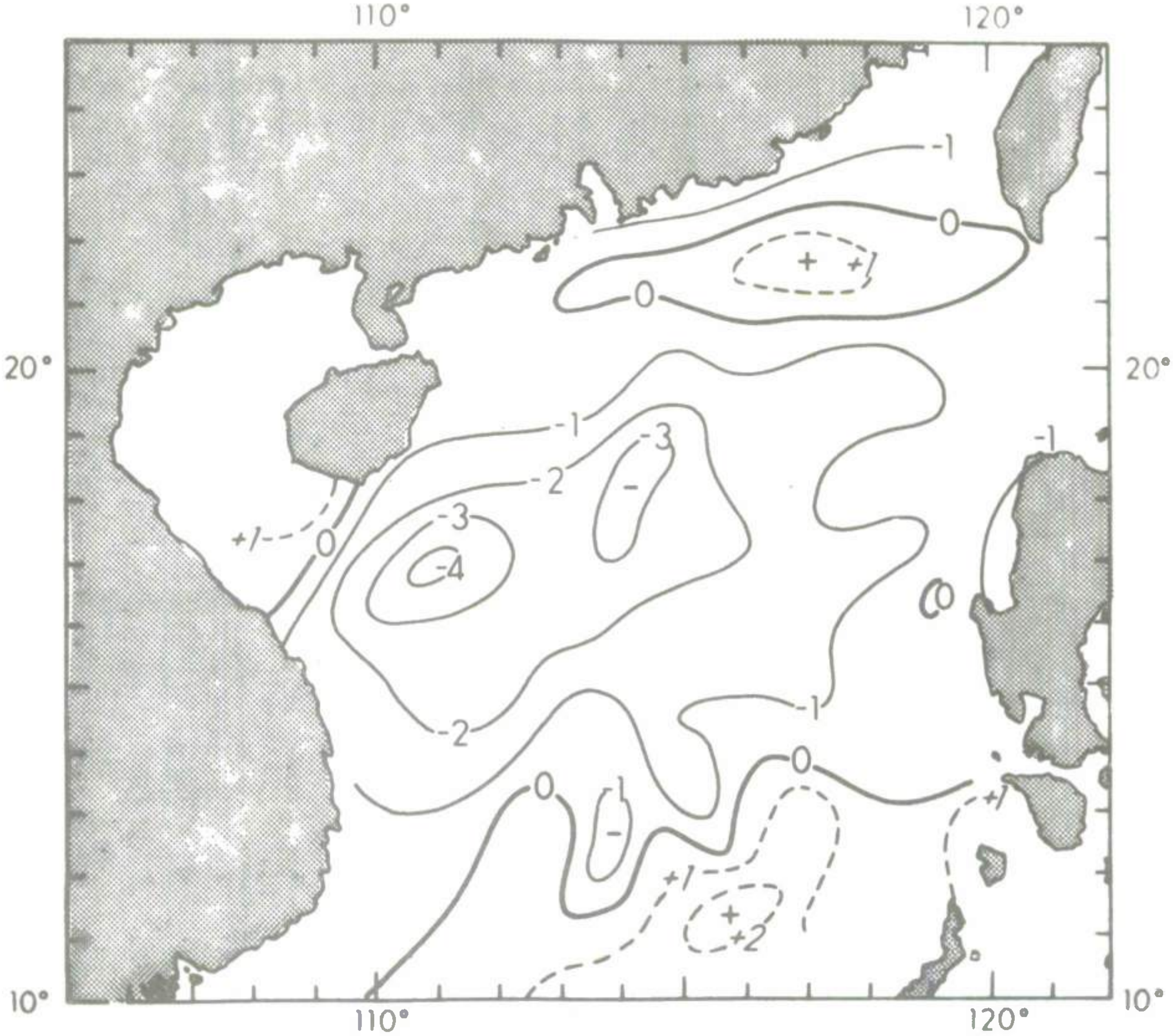

Figure 15. Change in sea-surface temperature (°C) between the periods 1 through 3 October (Figure 11) and 25 through 31 October 1970 (Figure 14).

4. DISCUSSION

4.1 SEA-SURFACE TEMPERATURE CHANGES

Near the typhoon tracks, upwelling probably contributed to the cooling of the sea surface. However, mixing stemming from the strong winds seems to have been the prime surface cooling mechanism.

The typhoons of 1970 were more intense than the typhoons of 1952 and moved at only about half the speed. It is surprising then, that they cooled the surface waters only half as much.

In the regions where the sea-surface temperature rose, meager data suggest that the mixed-layer depth increased in agreement with Leipper's (1967) model in which the changes are associated with advection and downwelling. The effects of instrumental inaccuracies and unrepresentative measurements on the conclusions, based on comparisons of individual soundings, cannot be assessed but they may be a factor.

4.2 TYPHOON INTENSITY CHANGES (Refer to Table 1)

As in October 1952 (Ramage, 1972), the temperature of the sea surface over which the typhoons moved bore no apparent direct relationship to the typhoon intensity changes. Eye pressure sometimes fell and sometimes rose as the center moved over colder water, while movement over warmer water did not guarantee intensification.

Table 1. Summary of events associated with the typhoon intensity changes

Name	TYPHOON INTENSIFYING					TYPHOON WEAKENING				
	Rate of change of eye pressure (mb day^{-1})	Speed of eye movement (kt)	Prior sea temperature along track	Prior mixed-layer depth along track	Upper-tropospheric outflow toward north	Rate of change of eye pressure (mb day^{-1})	Speed of eye movement (kt)	Prior sea temperature along track	Prior mixed-layer depth along track	Upper-tropospheric outflow toward north
IRIS	-23.7	5.6	Steady and then lower 14 hours prior to weakening	?	Yes	+28.2	3.1	Steady	?	No
JOAN	-14.1	6.0	Steady and then lower 12 hours prior to intensity leveling off	Steady	Yes	Hit land				
KATE	-13.5	5.8	Slightly higher and then lower	Steady	Yes	+23.7	8.0	Lower and then higher	Steady	No

Since it appeared that other factors predominated in the determination of typhoon intensity for these storms, it was impossible to isolate the effect of sea-surface temperature gradient. The intensity apparently, in these cases, responded more to troughs in the upper-tropospheric subtropical westerlies.

East of the trough line vorticity advection enhanced divergence above the typhoon. Divergence of heat flux apparently also occurred, being made visible by a mass of middle and high cloud streaming toward the subtropical jet.[1] Thus surface pressure in the eye decreased, heat generated by the typhoon was rapidly exported and the circulation intensified. Notice from Table 1 that upper-tropospheric outflow toward north is present for all storms during intensification.

Conversely, west of the trough line negative vorticity advection increased surface pressure in the eye and prevented rapid export of heat.

The intensity of the trough and its location with respect to the typhoon determines the sign and magnitude of the vorticity advection ($-\vec{V}\cdot\nabla\zeta$), which in turn determines the sign and magnitude of the upper-tropospheric divergence.

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[1]Erickson and Winston (1972) examined the cloud bands extending from 14 North Pacific tropical cyclones into the middle latitudes and found large scale circulation changes resulting from the energy injection from tropical storms into middle latitudes.

However, should the trough be rapidly changing intensity or should there be rapid relative movement of the trough and the typhoon (as with Iris), the local change of vorticity ($\frac{\partial \zeta}{\partial t}$), may predominate to produce very sudden typoon intensity changes.

From 23 to 25 October, Typhoon Kate moved westward south of the upper-tropospheric ridge (circumstances in which summer typhoons intensify or remain intense); yet eye pressure in Kate rose more than 50 mb. Differences between the large-scale circulations of the summer and autumn might account for part of this apparent paradox.

During July, August, and September the Asian monsoon circulation dominates the South China Sea and upper-tropospheric easterlies prevail south of 30N. The thermal influence of Himalaya-Tibet (Ramage, 1971), causes the easterlies to be persistently divergent, and thus favorable to maintaining or intensifying typhoons. By early October the upper-tropospheric ridge has moved south with establishment of the wintertime subtropical westerly jet stream along the Himalayas. As a consequence, divergence of the mean resultant 200-mb winds over the central South China Sea decreases from 4.0×10^{-6} sec^{-1} in August and September to 2.0×10^{-6} sec^{-1} in October, and the climate becomes distinctly less favorable to typhoon intensification. Rather scanty statistics seem to support this. Typhoons moving west or west-northwest across the

South China Sea in summer frequently deepen rapidly; in October, eye pressure more frequently remains steady or rises.

Another factor that tends to produce the same effect is the sea-surface temperature. This is uniform over the South China Sea in August and September, but in October the sea surface over the western portion of the South China Sea is 1-2°C cooler than in the eastern portion.

5. POSSIBLE FUTURE RESEARCH

In this study, the role of cold dry surface air in filling a typhoon could not be evaluated. Case studies are needed to determine its importance in comparison with troughs in the upper-tropospheric subtropical westerlies. However, since most cold outbreaks occur west of an upper trough, one would expect reinforcement and consequent typhoon filling to be very rapid indeed. Typhoons remaining under the influence of, and to the east of, upper troughs usually recurve and outrun the surface cold air.

In a statistical study of 66 recurving typhoons, Riehl (1972) reported that 43 reached maximum intensity within 12 hours of the point of recurvature. Typhoons almost always recurve close to the east of troughs in the upper-tropospheric westerlies, and the fact that greatest intensity is attained near this point provides indirect support for the conclusion that the divergent upper flow east of the trough intensifies the typhoon. Also, a plume of upper cloud streaming northeastward from the typhoon would indicate that a more northward or recurving track was being followed; whereas sudden disappearance of the plume would indicate backing of the direction of movement toward the west. Absence of a northward-extending plume would appear to preclude early recurvature. Hopefully, there are sufficient weather satellite data to enable these ideas to be tested statistically.

Occasionally in autumn east of the Ryukyu Islands, and even rarely over the South China Sea, a typhoon is "trapped" beneath an upper trough. Middle and high cloud may stream toward the northeast but the typhoon weakens, probably because it practically ceases to move. Cold surface air can reach the center, while mixing and upwelling acting for some time below a near stationary storm can result in significant surface cooling -- both effects tend to weaken the typhoon.

Characteristics of outflow plumes in the upper-tropospheric easterlies of the summer monsoon should also be studied to determine relationships to tropical cyclone intensity changes.

6. SUGGESTED FORECASTING PROCEDURES FOR AUTUMN TYPHOONS OVER THE SOUTH CHINA SEA

Typhoons usually weaken when crossing the Philippines and reintensify over the South China Sea (Brand and Blelloch, 1972). The sequence occurs as land temporarily reduces sensible and latent heat supply to the circulation (Miller, 1964). Other factors which may affect the intensity, modify but do not reverse the land effect and cannot be separately evaluated. Within 24 hours of reaching the South China Sea the typhoon is no longer influenced by the Philippines and is responding to other factors.

Large scale numerical forecasts should be carefully monitored for troughs in the upper-tropospheric westerlies. Should typhoon and trough be approaching each other, then a more northerly movement of the center and intensification should be expected. The first sign could be sudden development of a cloud plume streaming northeastward from the center. As long as the plume persists and the upper trough remains west of the center, the typhoon should not weaken (even though it may be moving over cooler water) and it should not revert to a more westerly course. It may even continue to veer and finally to recurve. Cutting off the plume occurs when the trough moves east of the typhoon center and the storm would then begin to follow a more westerly course. Eye pressure would begin to rise and cold surface outbreaks should be carefully tracked for now they could reach the center and sharply accelerate the filling. If the typhoon is moving over cooler water, filling would be further accelerated; if it is moving over warmer water, the rate of filling might be retarded.

These ideas are probably applicable to autumn tropical cyclones in the Bay of Bengal region as well (World Meteorological Organization, 1971).

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13. ABSTRACT

In October 1970, the South China Sea experienced three typhoons. Meteorological and oceanographic data were examined in an attempt to explain why the typhoons underwent intensity changes while over the South China Sea. The clearest relationship was found with troughs in the upper tropospheric westerlies -- intensification accompanied development of a middle and high cloud plume streaming northeastward from the storm area.

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