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POSITIONING TROPICAL CYCLONES IN SATELLITE IMAGERY.(U)
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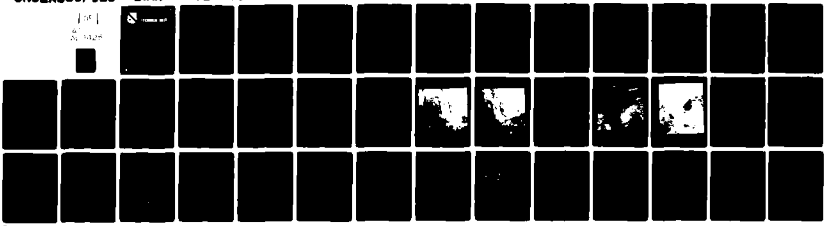

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1ST WEATHER WING

TECHNICAL NOTE

FIRST WEATHER WING

1ST WEATHER WING STAFF

POSITIONING TROPICAL CYCLONES

IN

SATELLITE IMAGERY

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A three step operational approach to positioning Pacific-based tropical cyclones in satellite imagery is presented. In the pre-analysis stage the image is acquired, selectively processed, and correctly gridded. During the analysis stage the circulation center of the cyclone is fixed based on cloud features in the image. In the third stage, post-analysis, quality control procedures assure optimum accuracy of the determined position fix.

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PREFACE

The threat posed by tropical cyclones to Department of Defense forces ashore and afloat in the Western Pacific led to the establishment of a tropical cyclone warning system for the Pacific Command. The key organization in the system is the Joint Typhoon Warning Center (JTWC). The JTWC is a joint Air Force and Navy tropical cyclone forecasting facility collocated with, and under the operational control of, the Naval Oceanography Command Center at Nimitz Hill, Guam. Today, with a greatly expanded area of responsibility, the JTWC provides tropical cyclone formation alerts and warnings for the western North and South Pacific and the entire Indian Ocean.

For accurate tropical cyclone forecasting, the JTWC must have accurate and timely fixes of cyclone position and intensity. Since conventional synoptic data is insufficient for these purposes, the JTWC depends on the Selective Reconnaissance Program (SRP). The SRP uses data from three primary sources: weather reconnaissance aircraft, land-based radar and meteorological satellites. The SRP attempts to exploit the peculiar capabilities of each of these platforms so as to produce the best possible forecasts.

The receipt of high resolution visual and infrared imagery from the Defense Meteorological Satellite Program (DMSP) polar-orbiting satellites beginning in 1971 was the key to developing the SRP. Since 1971, the JTWC has continuously increased its dependence on meteorological satellites. The reasons for this increase are twofold. First, the meteorological satellite has successfully demonstrated its reconnaissance value by providing accurate cyclone position fixes anywhere in the JTWC's vast area of responsibility. Second and equally important, the JTWC area of responsibility has expanded far beyond the present reconnaissance range of the radar and aircraft platforms. Both of these platforms are usually limited to use in the northern portion of the Western Pacific. Consequently, over the South Pacific and the entire Indian Ocean, the JTWC depends almost totally on meteorological satellites.

First Weather Wing maintains a network of DMSP readout sites that provide satellite-derived, cyclone position and intensity reports under the SRP. These sites, and the Air Force Global Weather Central at Offutt AFB, Nebraska, comprise the DMSP network. The key site in this network is Det 1, 1 WW, Guam. Collocated with the JTWC, Det 1 satellite analysts coordinate satellite reconnaissance requirements with the Director of the JTWC. Based on this coordination, Det 1 tasks the other sites in the network as appropriate.

Beginning in 1969 First Weather Wing distributed 1 WW Pamphlet 105-10, Tropical Cyclone Position and Intensity Analyses Using Satellite Data to these sites in an attempt to provide a timely, comprehensive treatise on how to support the JTWC. Technological evolution and methodological advances forced frequent revision and eventual (1981) rescission of the pamphlet. We believe this document was much too cumbersome to have received much field use. The pamphlet has been shortened, updated, simplified, and republished in individual packages each designed to address one aspect of the overall tropical cyclone support problem.

This tech note considers locating tropical cyclones in satellite imagery. It should be used together with all the other publications in the series but especially with TN-81/004 which discusses spacecraft geometry and resultant errors likely to affect positioning, and with FM-81/004 which discusses gridding images so as to compensate for these errors. Other publications in the series include: FM-81/003, Assessing Tropical Cyclone Development Potential Using Satellite Imagery, and this paper's companion volume Tropical Cyclone Intensity Estimation Using the Dvorak Technique with Visual Satellite Imagery, 1WW/TN-81/001.

Captains C.P. Arnold, C.C. Olsen, F. Wells, and T. Deemer all had input to 1WWP 105-10 but Major David C. Danielson has extensively revised large parts of this material. Earlier, the project was coordinated at 1 WW by Capt Rod Henderson. Major Don Cochran of 1 WW Aerospace Sciences Branch reorganized the format and did substantial editing. 1st Weather Wing welcomes identification of errors and suggestions for improvement to the final products.

INTRODUCTION. The role of meteorological satellites in tropical cyclone warning support expanded during the 1970s. Today, three major goals of satellite tropical cyclone support can be identified. These are:

a. To accurately identify those tropical disturbances that will develop to tropical cyclone intensity ($\geq$ 34 kts).

b. To accurately locate (fix) the cyclone's position for tracking and warning purposes.

c. To estimate the cyclone's current intensity and consider those environmental factors likely to influence the cyclone's future intensity and movement.

These three goals can be separated into two major roles of meteorological satellites in tropical cyclone warning support - surveillance and reconnaissance. The surveillance role encompasses the first of the goals while the reconnaissance mission incorporates the remaining two. This role distinction is significant since it defines the different operational modes employed by the DMSP network. In the surveillance mode, a continuous operation, the network sites monitor the satellite imagery covering their individual areas of responsibility for possible cyclone development. Disturbances showing development potential are identified to the typhoon duty officers (TDOs) of the JTWC for their analysis. If development then occurs and the JTWC issues a forecast or warning for the disturbance, the DMSP network shifts into its reconnaissance role providing position fixes, and cyclone intensity estimates and forecasts for use by the TDO in constructing the official bulletins.

This paper will discuss the techniques used by the DMSP network to position tropical cyclones in official fixes submitted to the JTWC. It is assumed here that the reader has a general grasp of the terms used in tropical cyclone analysis, such as those contained in AWS/TR-212.

CYCLONE POSITIONING.

The Goal. The goal of any cyclone fix is to accurately locate the center of the cyclone's surface wind circulation. Tropical cyclone fix accuracy using satellite imagery depends on two things: correctly choosing the point in the imagery which corresponds to the system's surface circulation center; and correctly gridding the image. Image gridding and attendant errors are complex problems discussed in 1WW/TN-81/003: Sources of Location Errors in Imagery from Plar Orbiting Meteorological Satellites, and in 1WW/FM-81/004; Gridding Images from Polar Orbiting Meteorological Satellites. Readers should be familiar with these works.

Choosing the cyclone's apparent circulation center using satellite imagery is best accomplished using an implied cyclone development model. Dvorak's model is discussed in 1WW/TN-81/001. A 1WW technique for estimating the development potential of tropical cloud clusters is discussed in 1WW/FM-81/003. It would be beneficial, but not essential, to examine this paper before continuing.

The Model. The key to positioning a cyclone is an understanding of how tropical cyclones develop. When the eye of a mature cyclone is observed, the surface circulation is assumed to be coincident. It is likewise easy to fix the center when a well-defined low-level circulation is evident in swirls of shallow cumulus apart from convective clouds. But, to locate the surface circulation center when neither of these features is observed the analyst must investigate the cyclone's structure by analyzing three primary cloud features: low-level cumulus cloud lines, deep convective banding, and cirrus outflow. This analysis is based on an assumed cyclone model which has low-level cumulus lines and convective rainbands converging about the cyclone's surface center, and a cirrus-level anticyclone, positioned directly above the surface center.

While the analysis model is idealized, cyclones in nature are not. For example, in the early stages a cyclone may have multiple surface circulation centers. Further, upper-level wind shear may cause a significant displacement of the upper anticyclone. The analyst must always examine the environment of the cyclone to determine if and when these or similarly distorting conditions exist. For instance, multiple surface circulation centers are frequently encountered when the cyclone is imbedded in an elongated surface trough. Vertical tilt can be assumed when cirrus streaks indicate that there is significant unidirectional flow over the cyclone.

In many cases, particularly in the initial and weakening stages of cyclone evolution, individual analyses of the three separate cloud features mentioned above will result in disagreement as to the location of the cyclone's surface center. This is to be expected. When disagreement exists, surface features are assumed to be more representative and are weighted more in the analysis. Thus, when positioning a weak cyclone the analyst first concentrates the analysis on the extrapolation of cumulus lines, then on cumulonimbus rainbands, and considers cirrus outflow only as a last resort. Refer to 1WW/FM-81/003 for further details.

THE ANALYSIS APPROACH. The approach used in cyclone position analysis can be divided into three stages: pre-analysis, analysis, and post-analysis.

Pre-analysis. In the pre-analysis stage the analyst performs those functions which are necessary to prepare for the actual analysis of the imagery. These five functions include: past data review, data availability assessment, cyclone structure assessment, enhancement selection, and grid correction. They are listed in their approximate order of accomplishment.

a. Past Data Review. This is the first and perhaps the most important function to perform. The continuity of cyclone features and movement provided by a review of recent imagery covering the cyclone provides useful and often critical information for determining the present cyclone position. Each orbiter's pass should not be considered an independent entity for positioning purposes. Instead, individual satellite passes should be analyzed with due consideration given to the recent storm track, the preceding satellite pass, and the normal evolutionary cycle of a cyclone. Particular attention should be paid to subtle pass-to-pass changes of conservative cloud features.

As a minimum, the following questions should be answered... Has the convection increased or decreased? Is there more or less curvature to the banding? If a low-level circulation center is present, is it more or less exposed? Has an eye appeared/disappeared? And finally, is the upper-level anticyclone more or less aligned with the low-level circulation center? Answering these questions will not only improve fix accuracy, but increase the analyst's understanding of the cyclone's dynamics, as well.

Figure 1 illustrates how a review of previous images can help the analyst avoid a common positioning error. The pattern shows two small convective cloud areas merging with the larger convective area of a developing cyclone. The position of the low-level circulation center is indicated by the "+" at t_1. At time t_2 an analyst might easily misinterpret the gap formed by the merging clouds at "B" as the circulation center. By reviewing the imagery at t_1, the analyst would properly locate the center at "A" based on continuity.

Figure 1. Checking Imagery at Two Sequential Times

b. Data Availability Assessment. Data availability is of critical importance since it can ultimately dictate the required analysis approach. Fortunately, data availability can usually be assessed in advance and tentative decisions can be made regarding the types of data and enhancements to use in the analysis. There are two major factors to consider: first, the type of spacecraft which will be used and, second, whether the coverage will be from a daylight or nighttime pass.

The type of spacecraft used will determine the type and quality of imagery available for analysis. DMSP spacecraft use a pendulum-motion, scanning sensor called the Operational Linescan System (OLS). The OLS has the advantage of producing data or nearly uniform resolution throughout the field of view. In comparison, the NOAA Advanced Very-High Resolution Radiometer (AVHRR) uses a constant angular velocity (CAV) scanning mirror optics system. CAV sensors produce imagery of comparable resolution to the OLS at satellite subpoint but the resolution rapidly deteriorates toward the edges of the data.

Therefore, the DMSP OLS provides a significantly improved, more detailed image for analysis purposes relative to the NOAA AVHRR sensor. Further, the DMSP sensor can produce usable visual imagery in one quarter (or more) moonlight. The NOAA sensor lacks any nighttime visual capability. Figure 2 lists some comparative statistics for the OLS and AVHRR sensors.

The second factor to influence data availability is the time of day of the pass. Daytime passes provide optimum coverage because of the availability of visual imagery. In most applications, visual imagery is superior to infrared coverage because higher contrasts (cloud vs terrain) and finer resolutions are possible resulting in greater cloud detail for analysis purposes.

DMSP
(OLS)

Detector/Channel	Resolution (NM)	Spectral Interval (μm)
Light Fine (LF)	0.3 (0.6 km)	0.4 - 1.1
Light Smooth (LS)	1.5 (2.8 km)	0.4 - 1.1
Thermal Fine (TF)	0.3 (0.6 km)	10.8 - 12.5
Thermal Smooth (TS)	1.5 (2.8 km)	10.8 - 12.5

NOAA
(AVHRR)

Detector/Channel	Resolution (NM)	Spectral Interval (μm)
Channel 1	0.5 (1 km)	0.58 - 0.68
Channel 2	0.5 (1 km)	0.725 - 1.1
Channel 3	0.5 (1 km)	3.53 - 3.93
Channel 4	0.5 (1 km)	10.3 - 11.3*
		10.5 - 11.5
Channel 5	0.5 (1 km)	11.5 - 12.5

*(NOAA satellites using Channel 5 use this interval for Ch 4.)

Figure 2. DMSP and NOAA Sensor Characteristics

However, for daytime visual coverage the sun-angle of the pass must be considered. Midday passes provide the best data for intensity analysis and positioning purposes. Early morning and late afternoon passes are affected by the low sun-angle. A low sun-angle causes thin clouds, especially cirrus, to appear opaque making cyclones appear more intense than they actually are and obscuring low-level cloud details essential for positioning. In addition, the quality of low sun-angle visual coverage is frequently impaired by sun-glint (the reflection of the sun at a low angle off a water surface) and the terminator (the day/night or light/darkness line in the image).

The greatest advantage of working with a daytime pass for positioning analysis is the availability of a "picture pair." A picture pair consists of the visual imagery plus a time-coincident infrared image. By working with a picture pair many interpretation ambiguities are eliminated. Also, the analyst can employ the full range of enhancement options on each type of data depending upon the cloud feature of interest.

At night the analyst is frequently limited to infrared coverage only. The main exception is DMSP light smooth (LS) imagery which can provide analysis quality imagery with illumination from a quarter moon or more. Further, the lack of a picture pair increases interpretation ambiguities and makes positioning analysis more difficult.

c. Cyclone Structure Assessment. The degree of development of a tropical cyclone affects position analysis since distinct cloud patterns are associated with each particular stage of a cyclone's evolution - developing, mature, or weakening. The analyst, by reviewing previous imagery and considering the past storm track along with "conventional" meteorological information, should be able to anticipate the degree of development and, therefore, the likely structure of the subject cyclone.

The structural assessment can be quite straightforward. It is sufficient at this stage of the analysis to determine whether upper-level (cirrus clouds or cloud top texture) or low-level (cumulus lines) features will be used to position the cyclone's low-level circulation center. Only in the mature stage is it relatively safe to assume that the cyclone is not tilted vertically. With a mature cyclone an analysis of upper-level features should be representative of the surface circulation center position. However, the analyst must be sure to include in the remarks section of his/her position report that the fix was based on an analysis of upper-level cloud features.

In both the developing and weakening stages, tropical cyclones tend to tilt with height such that the outflow center aloft may be significantly displaced from the actual surface circulation center. In these two stages the analyst must therefore concentrate his analysis on low-level cloud features. In those cases when tilt is present yet no low-level features are available for analysis, the analyst may have to resort to upper level features to support a fix. Even though these positions will not be representative of the actual position of the low-level center, experience indicates that a track based on such positions will often parallel the actual storm track and thus important information relative to the speed and direction of cyclone movement may be inferred. Again, it is essential that the analyst include appropriate remarks in the position report saying that the fix was based on upper-level cloud features.

Finally, in the weakening stage many cyclones shear apart and the analyst may have to rely on special thermal enhancements of the infrared imagery to resolve and position the surface circulation center.

d. Enhancement Selection. Upon completion of the data availability and cyclone structure assessments, the analyst is ready to work with the imagery he will use to position the cyclone. There are two tools which the analyst can use to modify this imagery and improve the analysis--scale expansions (image enlargements) and image enhancements.

Scale expansions are important since they enlarge the cloud features and make details easier to see and analyze. The analyst should always use expanded scale data, particularly in those cases where fine cloud details such as cumulus lines are critical to a successful analysis. The DMSP ground equipment can produce imagery in three different scales: normal (1:15 million), expand (1:7.5 million), and expand-expand (1:3.75 million).

An even more powerful analysis tool is the image enhancement. What can be seen on the imagery is a function of both resolution and contrast. While the analyst has no means for improving the resolution of the data, the DMSP ground equipment offers a wide range of image enhancement options to improve the contrast of the imagery.

The importance of contrast enhancements cannot be overemphasized. A simple illustration shows why. Given a white wall, one can paint a white line on the wall and no matter how wide the line is painted it will still be visible since there is no contrast. However, put a thin black pencil line on the same white wall and it can be seen from across the room.

The purpose, therefore, of image enhancement is simply to provide essential contrast to the data so that the critical cloud features are easily visible. This is done by concentrating the greatest number of grey shades into the albedo (visual imagery) or temperature (infrared imagery) "range of interest." This concentration of the grey shades increases the contrast of the imagery in the range of interest, thereby increasing the detail of the data features within the range. Note, however, that this concentration of grey shades into a particular range of interest always results in at least a partial loss of detail in all other ranges.

The actual enhancement selection is based on the information developed in both the data availability and the cyclone structure assessments. The data availability assessment identifies the type of platform (DMSP or NOAA) and the type of sensor(s) (visual and/or infrared) that will produce the imagery. The cyclone structural assessment identifies the range of interest in which increased detail is required.

As mentioned in the discussion on structural assessment, there are only two main ranges of interest--upper-level (cirrus clouds or convective cloud top texture) and lower-level (cumulus lines) cloud features. Once the type of imagery and the range of interest are determined, the specific image enhancement can be selected.

The DMSP ground equipment has separate enhancements for visual and infrared imagery; however, most units have been modified to permit the use of infrared enhancements on visual imagery, as well.

The two visual enhancements most frequently used in cyclone positioning are the low (LO ENH) and high (HI ENH) enhancements. As expected, these two enhancements can be applied to the imagery to selectively enhance either the low-level or upper-level cloud features. Figures 3 and 4 are different visual enhancements of the same imagery. The HI ENH image (Figure 4) brightens the cumulus cloud lines at "A" relative to those same clouds in the LO ENH image (Figure 3). Also, the convective area at "B" has much more cloud top detail in the LO ENH imagery compared to the same area on the HI ENH data which appears "whited-out" of any cloud detail. Finally, note how much more opaque the cirrus cloud band at "C" appears on the HI ENH image relative to the LO ENH data.

The DMSP equipment has two separate infrared enhancement modes--brilliance inversion (BI) and thresholding (THRESH). Specific details and capabilities of each mode are explained in AWSTR-250.

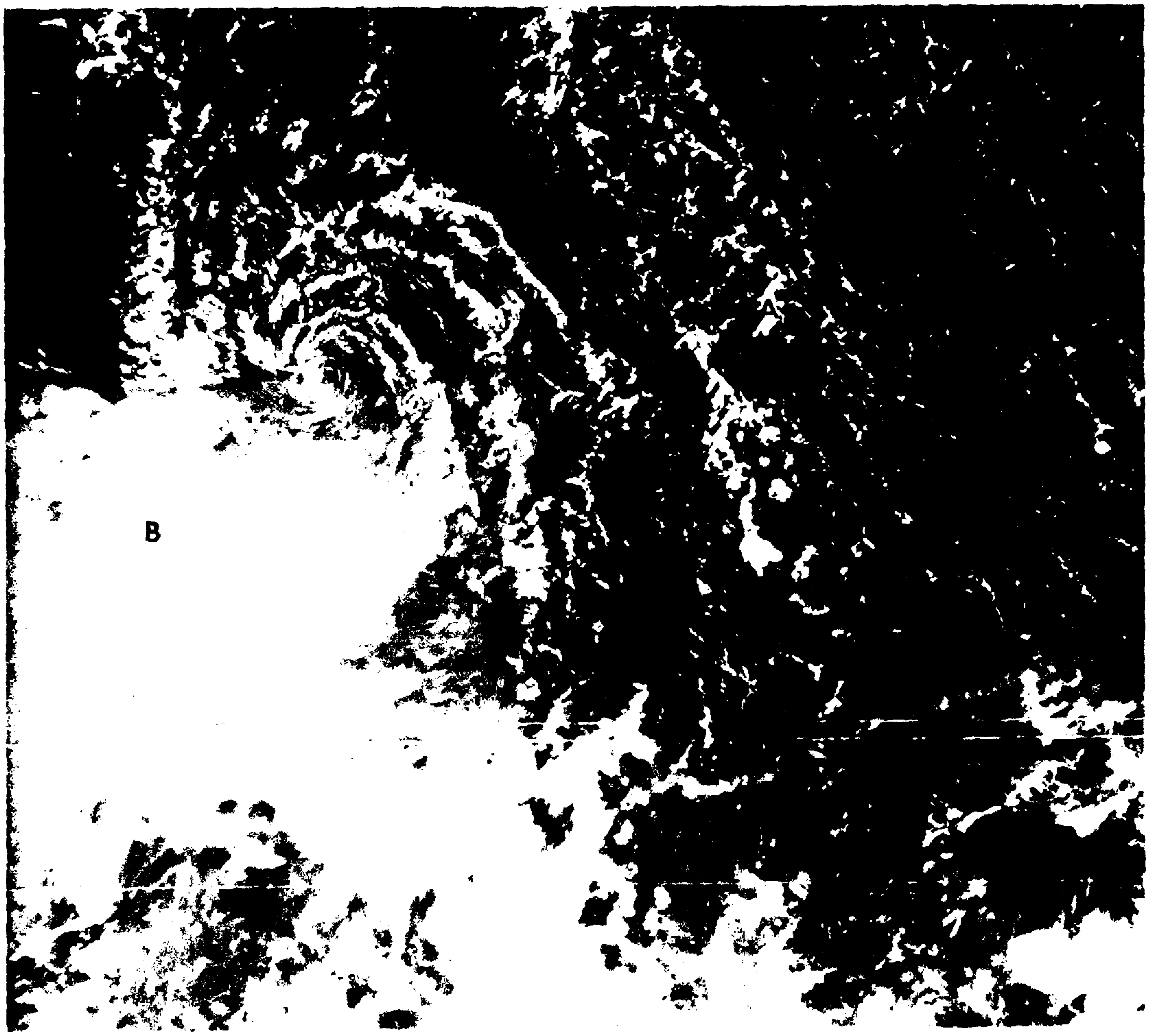

Figure 3. Daytime DMSP Imagery (FTV 13536/2232Z 24 Sep 79/Orbit 11930) (L0 ENH).

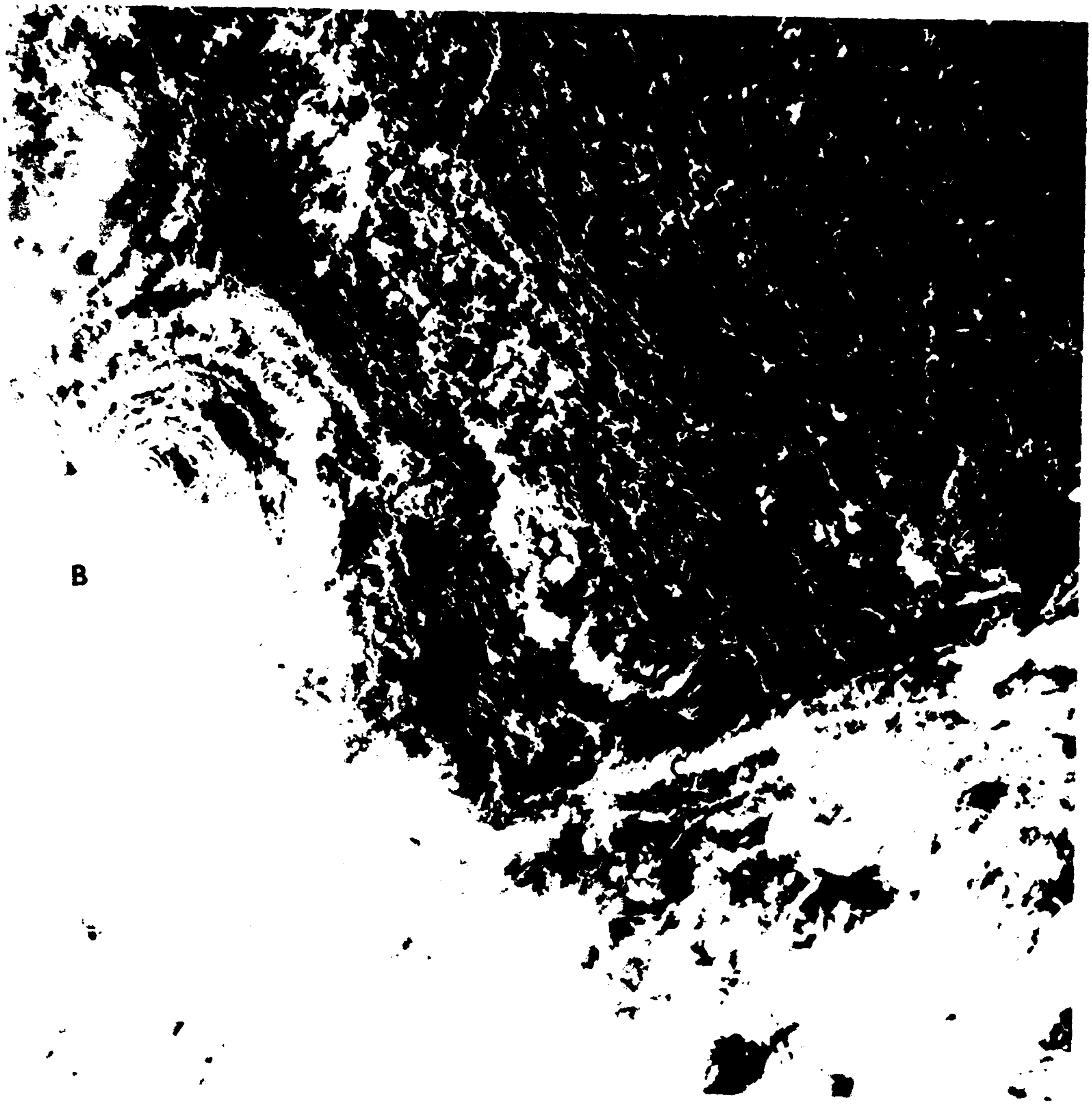

Figure 4. Daytime DMSP Imagery (FTV 13536/2232Z 24 Sep 79/Orbit 11930)(HI ENH).

The BI mode is the more useful of the two. It offers the analyst a means for selecting thermal ranges of 100, 50, and 25 degrees Kelvin in which to linearly distribute 16 grey shades of detail--the smaller the range, the finer the thermal detail. The employed range is determined by specifying a "base" temperature setting which defines one limit of the thermal range. Commonly the analyst will use the 25°K range and a base temperature setting either near the sea-surface (290°K) or cloud top (250°K) to improve the low-level or upper-level cloud detail, respectively. The first setting is useful for locating exposed or partially exposed low-level circulation centers. The latter setting will result in increased detail in the cloud top canopy, which is necessary for locating anti-cyclonic outflow centers and banding or cloud-covered eyes.

A less frequently used infrared enhancement mode is the THRESH product. The THRESH mode permits the analyst to select three temperatures with which to divide the imagery into four grey shades. Each temperature setting is a division point between two grey shades. If two or all three of the temperature settings are set to the same temperature, then the imagery will display only three or two grey shades, respectively.

The THRESH mode is usually used to analyze the coldest cloud details of the cyclone center. Compare the THRESH mode imagery in Figure 5 with the brilliance inversion mode enhancement (settings 310°KX1) of the same pass in Figure 6. Although the THRESH enhancement can readily locate the coldest portions of the cloud system, the loss of thermal resolution (degrees per grey shade) results in a tremendous degradation in important cloud texture and detail. It is the fibrous wispy texture of cirrus that makes it distinguishable from convective clouds of the same grey shade. Thus, the

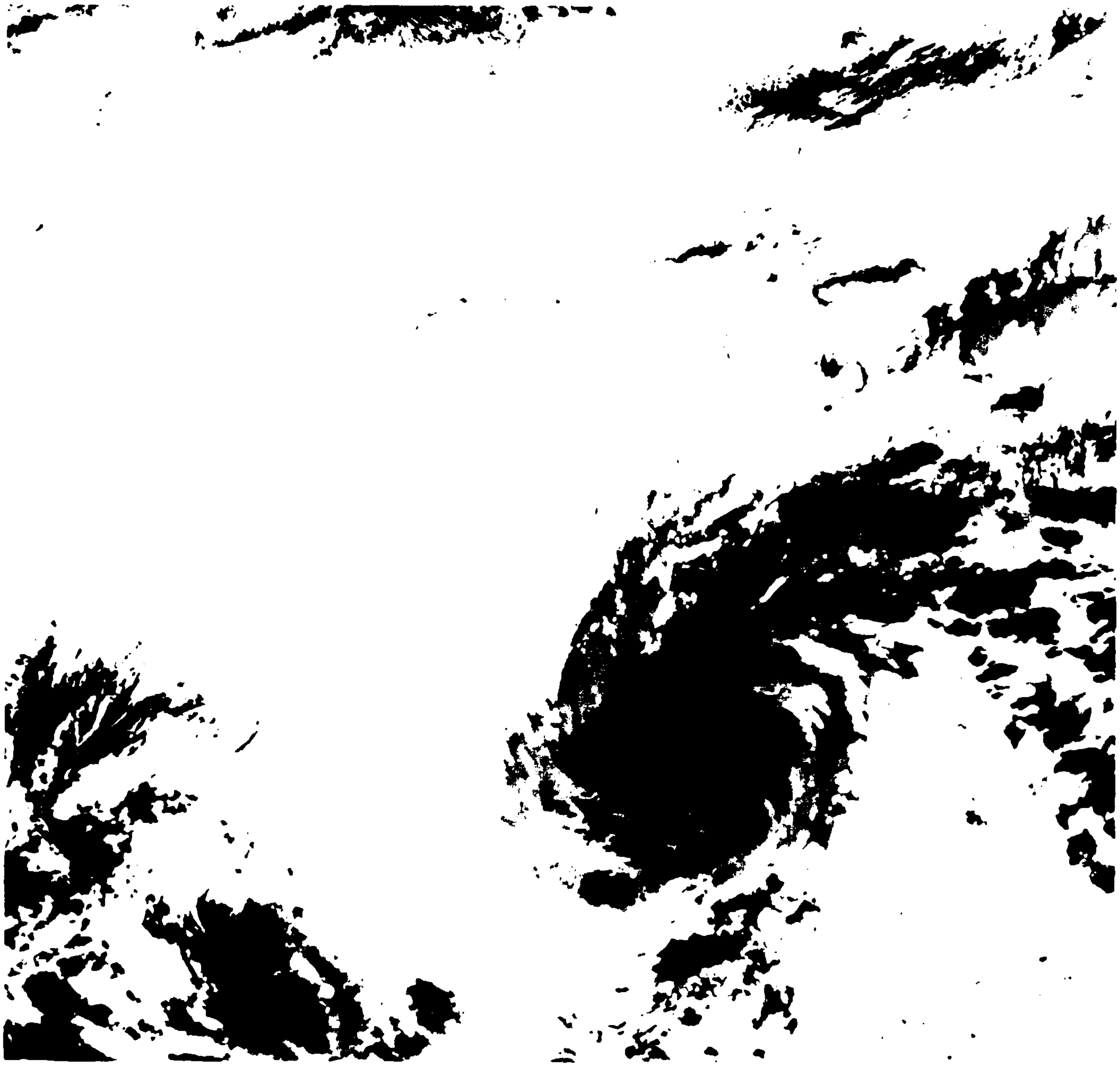

Figure 5. Nighttime DMSP Imagery (FTV 15539/1356Z 21 Dec 79/Orbit 2807). This termal fine (TF) imagery illustrates the THRESH mode. The different shades of grey indicate temperature regions. In the above example, TI=$273^{\circ}K$, T2= $253^{\circ}K$ and T3=$213^{\circ}K$. The white or clear area represents temperatures warmer than $273^{\circ}K$, light grey represents temperatures between 253°-$273^{\circ}K$, the dark grey between $213^{\circ}K$ and $253^{\circ}K$ and the black represents cloud top temperatures colder than $213^{\circ}K$.

Figure 6. Nighttime DMSP Imagery (FTV 15539/1356Z 21 Dec 79/Orbit 2807). This imagery comes from the same pass as Figure 5 but uses different settings. A 310°K X 1 brilliance inversion mode enhancement obtained the above results. Note the better cloud texture detail in Figure 6 when compared to Figure 5.

analyst can easily confuse patches of cirrus with convective areas and mis-analyze the THRESH imagery. Further, the outflow or convective cloud pattern shown on the THRESH product may not be representative of the cyclone's surface circulation center if a vertical tilt exists. Therefore, the increased opportunities for mis-analysis make the THRESH enhancement an inferior product for positioning analysis.

e. Grid Correction. The final step of the pre-analysis stage is gridding the image. Data location errors and techniques of proper geographic gridding are thoroughly discussed in the DMSP user's guide and in 1WW/TN-81/003 and 1WW/FM-81/004.

The pre-analysis stage of the procedure is now over.

ANALYSIS. The second part of the analysis approach is the analysis stage. After completing the pre-analysis stage, the analyst should be thoroughly familiar with the cyclone's structure and should have identified the choices of imagery and enhancements which will best display the cyclone. The enhanced imagery should be properly gridded and is now ready for analysis.

Depending on its degree of organization, a cyclone's surface circulation center can be positioned based on one of the following: an exposed low-level circulation center or eye; extrapolation of the curvature of well-defined cloud features to an implied center; or by relating the center to other conservative cloud features. These procedures are discussed in order from the easiest and most accurate to the most difficult and least accurate.

a. Exposed Low-Level Circulation Center or Eye. The surface circulation center is assumed to be coincident with the position of an exposed low-level circulation center (LLCC) in a weak cyclone or with the eye of a mature cyclone. Therefore, minimum analysis is required to obtain a very accurate fix once a cyclone develops either of these two features. However, there are still four points to consider when fixing such a cyclone.

First, the analyst must confirm that the feature is real and is actually the cyclone's surface circulation center. Sometimes a shadow or break in the clouds can be mistaken for an eye. Also, eddies in the broad surface circulation pattern may be confused with the actual surface circulation center. Many ambiguities can be eliminated by comparing the visual and infrared imagery and by considering past cyclone movement.

Second, if an eye or an exposed LLCC has not first appeared in visual imagery, be suspicious. Try special enhancements to resolve the "invisible" eye or LLCC.

Third, apply a second positioning technique to confirm the position of an apparent eye or LLCC. The position should still be consistent with other cloud features associated with the cyclone.

Finally, if doubt still exists and the feature cannot be confirmed, report the position at a lower confidence limit (less fix accuracy) than the feature would normally warrant and include the comment "POSITION BASED ON APPARENT EYE (or LLCC)" in the remarks section of the Position report.

b. Extrapolating Cloud Feature Curvature. In the majority of cases a cyclone will not have an exposed LLCC or an eye which is visible to the analyst. In these cases the analyst must consider the cyclone in terms of the assumed development model described earlier and, if possible, extrapolate the existing curvature of the cloud features to an implied--but not visible--circulation center. If there is well-defined curvature in any of the three cyclone-associated cloud features--cumulus lines, convective bands, and cirrus outflow--then the analyst can extrapolate from these features to estimate the cyclone's surface center.

There are two types of extrapolation techniques--those using spiral overlays and those done free-hand. The spiral overlay technique can employ several spiral pattern overlays--logarithmic, hyperbolic, Archimedian, or parabolic. These patterns can be used with either the low-level cumulus cloud lines or cumulonimbus rainband features of the cyclone. The analyst attempts to maximize the alignment of the spiral pattern with the cyclone's cloud features as in the technique employed in radar positioning. The center of the spiral overlay pattern is assumed to be representative of the cyclone's surface circulation center. To confidently employ this technique the alignment of the cloud feature with the spiral overlay should be very good for at least 90 degrees of arc and preferably more than 180 degrees.

Early post analysis studies conducted at Det 1 showed that the logarithmic spiral was less satisfactory than the hyperbolic, Archimedian, or parabolic spirals. Other investigators have promoted particular spirals. In recent years the spiral overlay technique has been largely replaced at Det 1 by free-hand extrapolation.

Freehand extrapolation can be done on all three cyclone-associated cloud features if present. However, the analyst should remember that in order to obtain the most accurate surface position fixes, one attempting curvature extrapolation should attempt to employ cumulus cloud lines the most often, convective rainband features less frequently, and cirrus outflow patterns the least. The extrapolation technique is illustrated in Figure 7.

Initially, the surface circulation center is obscured by an overcast cloud canopy with surrounding cumulus cloud lines paralleling the convergent low-level flow. Using a grease pencil and acetate, the analyst extends the cumulus lines into the cloud mass. Each line is extended a little bit at a time smoothly extrapolating the curvature pattern. Tightly curved clouds lie close to the circulation center and are weighted more in the analysis. Other cloud features such as cumulonimbus rainbands and cirrus streaks should be extrapolated in a similar manner.

Significant cloud features such as breaks in the cloud canopy, radial patterns in the convective cloud tops, or a notch in the central cloud mass should be considered in the final analysis. The process may have to be repeated several times before the analyst is satisfied with the fit. Eventually, a final extrapolated position can be obtained.

c. Continuity of Conservative Cloud Features. When the surface circulation center cannot be readily determined by other means, the analyst should fix the center based on some conservative cloud features of the cyclone.

The conservative features technique assumes that the analyst knows where the surface circulation center lies relative to some cloud features which persist over a period of time. The technique is most useful when the time interval between consecutive observations is less than six hours and is especially useful with geosynchronous data, if available. Over an interval less than 12 hours the movement of the conservative feature may not be representative of the cyclone's true movement; beyond twelve hours

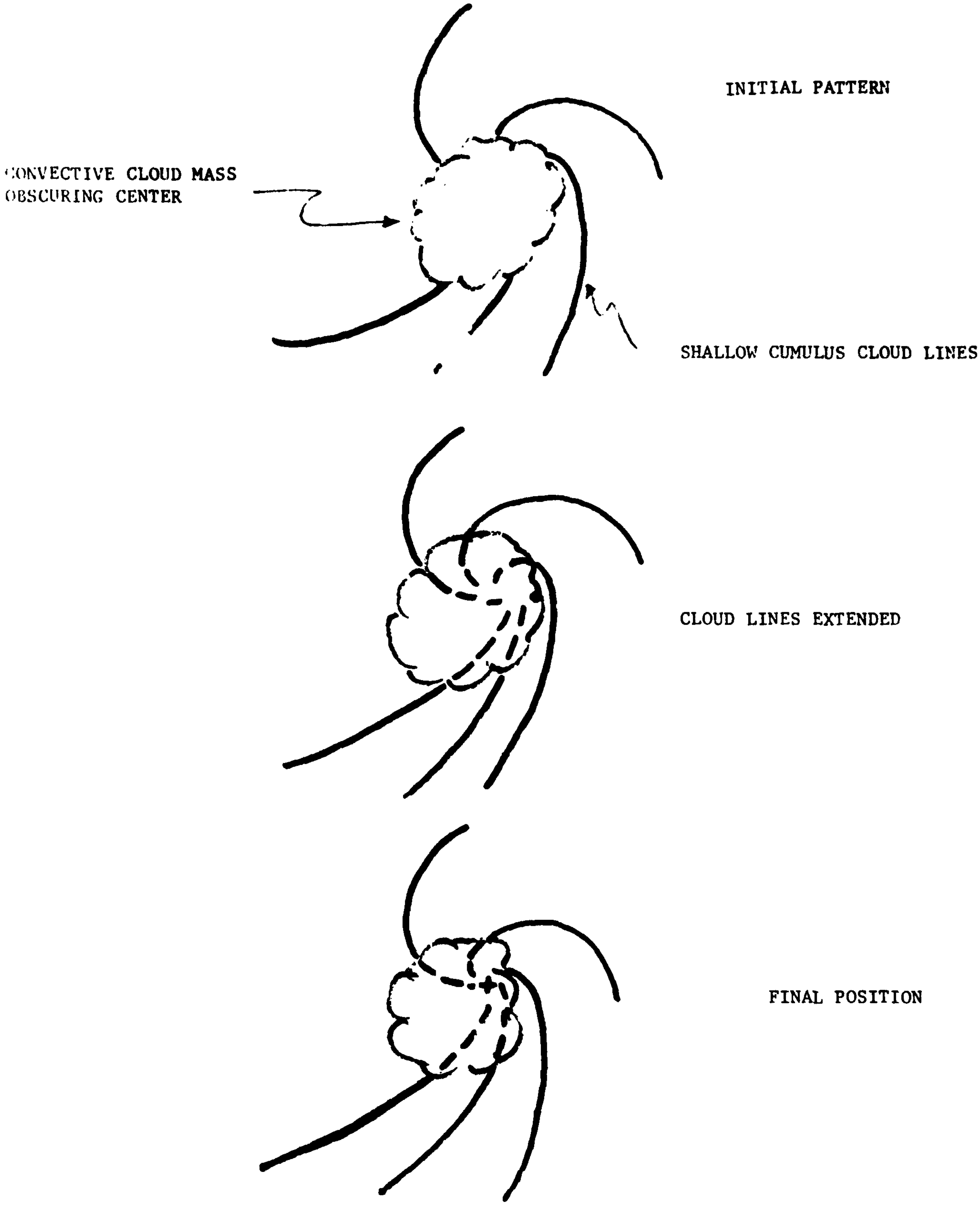

Figure 7. Extrapolating Cloud Curvature

structural changes may destroy conservative features entirely.

The conservative features technique is frequently used to provide continuity between daytime fixes based on visual and infrared data and nighttime fixes based on infrared imagery alone. Infrared imagery cannot provide the finer cloud detail contained in visual data. Thus, the common blackout of visual coverage at night may result in eight to twelve hours of degraded support based on more poorly-defined, lesser-confidence position fixes. The use of the conservative features technique can significantly improve this situation.

When making a conservative features fix after a day/night transition, the recommended procedure is to sketch the details from the daytime infrared imagery onto an acetate overlay. The sketch should include any features which might persist such as the edge of the cirrus canopy, rainbands, cirrus plumes, and small convective areas which are part of the cyclone cloud mass. The relative position of the surface circulation center is also plotted on the overlay. The overlay can then be placed on the nighttime infrared imagery and aligned relative to those features which remain identifiable. Based on the best fit of the applicable cloud features, the new position of the circulation center on the overlay becomes the preliminary fix position for the nighttime imagery.

Analysis has now determined the point in the imagery which best represents the cyclone's surface circulation center.

POST ANALYSIS. At this point the analyst has located the cyclone's surface circulation center on the gridded image. The preliminary fix position will have the latitude/longitude coordinates measured off the grid.

However, several significant tasks remain before the fix can be finalized for transmission to the JTWC. These tasks include: grid correction recheck, PCN determination, and continuity verification.

a. Grid Correction Recheck. Generally during the gridding process two correction factors will have been added to the preliminary fix position to obtain the final fix: a geographic correction factor and the beta angle correction. Since an error in either could have substantial impact on the JTWC forecast track, recheck both factors now with particular attention to the algebraic sign of the correction factor.

b. PCN Determination. Each satellite-derived cyclone fix is assigned a position code number (PCN). The PCN tells the typhoon duty officer how the image was gridded and how clearly defined the cyclone's center appeared. The code is shown in Figure 8.

DEGREE OF CYCLONE ORGANIZATION	GRIDDED USING	
	GEOGRAPHY	EPHEMERIS
Eye	1	2
Well-defined circulation center	3	4
Poorly-defined circulation center	5	6

Figure 8. Position Code Numbers (PCN)

In general, the lower the PCN, the greater confidence the analyst places in his position fix. Therefore, PCN 1 fix is assumed to be the most accurate, whereas, a fix with a PCN 6 carries the least confidence and accuracy.

The ordering of the PCN indicates that geographically gridded fixes are more accurate than those based solely on ephemeris gridding. While this should be expected, actual verification statistics do not always support this conclusion. The reason for this statistical anomaly lies in the method used to assess fix accuracy.

Based on position reports from a variety of platforms (aircraft, radar, satellite), the TDO constructs an average track called the "best track." The best track represents the officially construed "true" movement of the cyclone throughout its life cycle and all position and intensity observations and forecasts are then "verified" against the best track.

As equitable as this may seem in the absence of other ways of constructing "ground truth," the best track is obviously not independent of the very components used to construct it. For instance, most ephemeris gridded fixes are reported at night due to the lack of terrain detail in the infrared data to allow geographic gridding. In addition, aircraft fixes are traditionally flown in the daytime to afford the weather reconnaissance officer a view of the sea surface upon which cyclone wind speed estimate is based. Therefore, at night the TDO will usually draw the best track quite close to the ephemeris-gridded satellite fixes since these are commonly the only fixes available. However, in the daytime the TDO will generally constuct the best track closer to the usually-available aircraft position reports than to the geographically gridded satellite fixes. (Aircraft reports are generally accepted to be more accurate than satellite-derived position reports regardless of the method of gridding.) Thus, when using the best track as ground truth, any statistics comparing the accuracy of geographically gridded versus ephemeris gridded satellite fixes are probably inconclusive as are similar statistics debating the relative accuracy of aircraft versus satellite fixes.

The actual method of selecting the PCN involves several steps. First, the analyst selects a preliminary PCN based on the definitions shown in Figure 8. Next, the analyst draws the PCN's 90 percent confidence circle as defined in Figure 9.

PCN	RADIUS OF 90% CONFIDENCE CIRCLE IN NAUTICAL MILES
1, 2	27
3, 4	40
5, 6	56

Figure 9. Confidence Circles vs PCN

The nominal radii of these confidence circles were calculated in 1972 and have been used ever since as standards for fix accuracy. The circle is drawn centered on the fix. The analyst then examines the area outside the 90 percent circle and decides whether the cyclone's surface circulation center could possibly be located there. If the analyst subjectively judges that there is a 10 percent or greater chance that the circulation center could lie outside the 90 percent circle, then he/she should select a higher numbered PCN (or larger circle). Otherwise, the preliminary PCN should be retained.

Experience indicates two common pitfalls in PCN selection. The first involves the selection of PCNs 3 and 4. These fixes are supposedly based on well-defined circulation centers. In practice, an analyst will fix many systems that have well-defined circulations. These fixes are not automatically candidates for a PCN 3 or 4. The well-defined circulation must represent a single, unambiguous cyclone center to qualify as a PCN 3 or 4. Many well-defined circulations do not do so and thus should be assigned PCNs 5 or 6.

The second pitfall involves the arbitrary selection of a lower (more accurate) PCN to convey a higher degree of confidence than the data actually supports. This is a somewhat natural temptation that should be resisted. The definitions of Figure 9 should be strictly observed.

c. Continuity Verification. The final step in cyclone positioning is sometimes the most crucial. Continuity or past movement is extremely important to the forecast track of a cyclone. The TDOs at the JTWC plot each fix as it is reported. A significant deviation from their forecast storm track causes the TDOs to be concerned, particularly if the fix is a higher confidence fix than the previous fixes from the same observation site. Therefore, each site must carefully consider its own past positions before releasing a current fix.

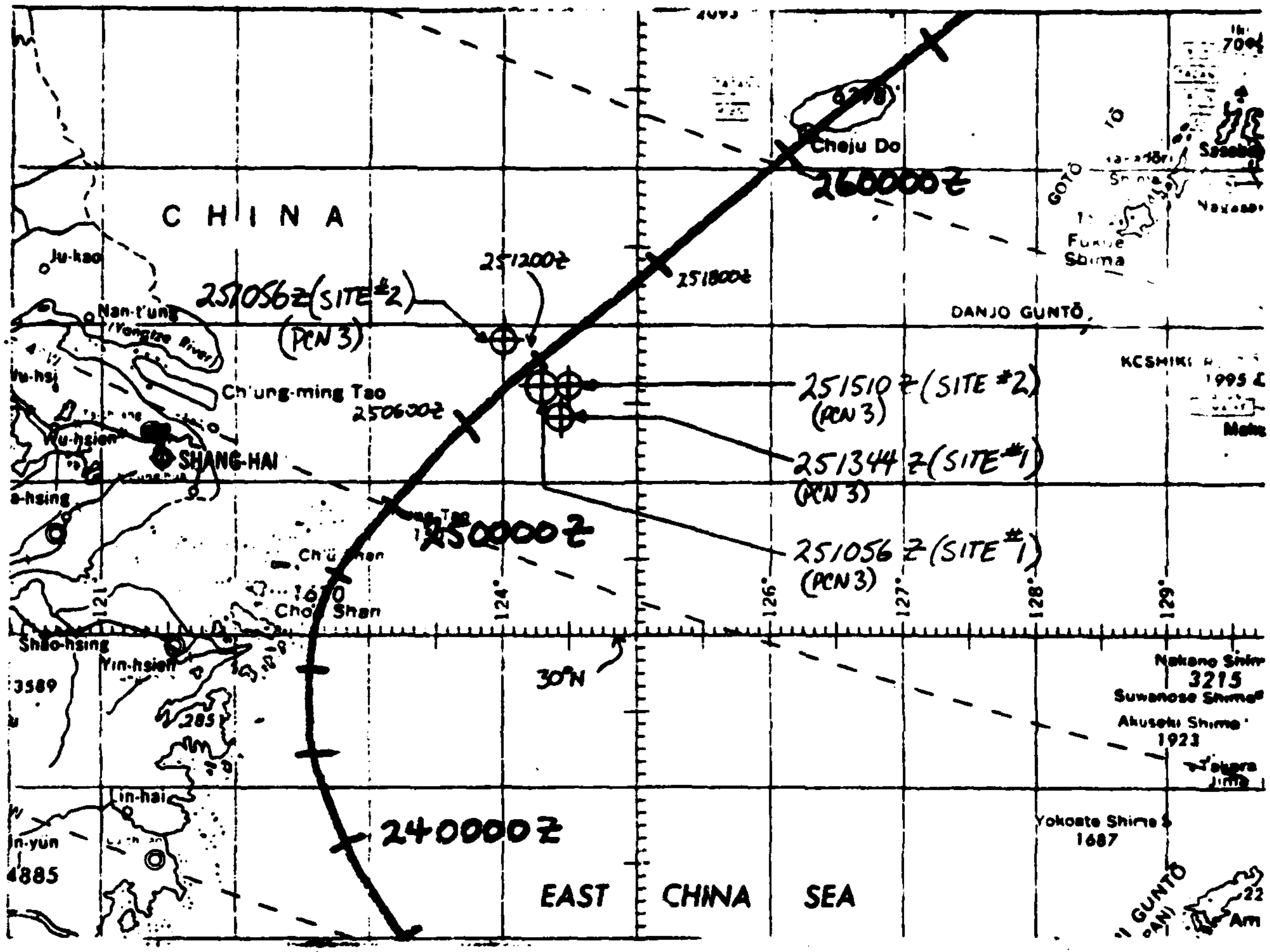

Figure 10. Positions of Typhoon Judy (1979)

Figure 10 illustrates the importance of continuity. The figure shows the actual position reports and portions of the best track for Typhoon JUDY in August 1979. Four fixes are plotted: two from each of two DMSP sites. All the fixes are PCN 3 or high confidence fixes. Note that continuity at both sites suggests a southeast movement of the cyclone, which is at right angles to the actual storm track. When questioned neither analyst was immediately aware of his own site's past fix positions. Neither the JTWC forecast track nor the site fixes were being plotted. If they had been, the break in continuity would have been immediately obvious. Fortunately in this case, positions derived from other platforms and fixes from other sites confirmed the northeastward movement of JUDY and the JTWC forecast track was not needlessly amended.

Maintaining continuity at each DMSP site is very simple and fast. Analysts should plot the current JTWC forecast track along with each fix his/her particular site originates during the life cycle of the cyclone. Exact agreement of a newly-made fix with the JTWC forecast track is not essential nor should the forecast track unduly influence the analyst. However, if large deviations occur, particularly from the expected position based on extrapolation from the site's previous position, the analyst has reason for concern. In these cases he/she should initiate a reanalysis to confirm the accuracy of the fix. If a large deviation is still indicated, then the analyst should transmit the fix with a remark noting an awareness of the break in continuity. This informs the TDO that continuity has been considered but that the analyst stands by the present fix with the confidence stated.

This concludes the post-analysis procedure.

SUMMARY. Tropical cyclone positioning is best accomplished using a three step approach incorporating actions in a pre and post-analysis sequence with the procedures of the actual analysis.

During the important pre-analysis stage the analyst considers the cyclone's recent past characteristics--its size, cloud structure, environment, speed and direction of movement, and growth rate. Combining this knowledge with his/her awareness of the type, time, quality, and availability of upcoming satellite imagery, the analyst can then decide how to display and process the received image so as to produce the best available data for the task of fixing the cyclone's position. After correctly gridding the image the meteorologist is ready to begin the actual analysis, i.e., the fixing of the cyclone's center based solely on the satellite image.

He/she will accomplish this in one of three ways. The center will be placed in an exposed well-defined low level circulation center or eye (the easiest and most accurate method); extrapolating existing curvature of cloud features to an implied but not visible circulation center is the second choice (a method of intermediate ease and accuracy); or if neither of the above two procedures is possible, the analyst must fix the center by relating it to some conservative or persistent feature(s) of the cyclone. This technique is probably the most difficult and least accurate of the fix methods.

After the cyclone's actual latitude/longitude is determined, the analyst must recheck the corrections applied for gridding errors; select the appropriate position code number or confidence factor to accompany the fix; and, lastly, must perform a continuity check, prior to transmission of the finalized position report to the typhoon duty officer.

By studying these procedures along with gridding techniques presented elsewhere, forecasters throughout the Pacific should be able to acquire the necessary skills to effectively accomplish the critical task of tropical cyclone position fixing in support of the Joint Typhoon Warning Center.

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AFGWC/NESS LIAISON	10

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DATE
FILME