# SATELLITE INTENSITY PREDICTIONS OF NORTH PACIFIC CYCLOGENESIS

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## 1. Introduction

The NOAA-5 and GOES infrared (IR) satellite imagery received at the Anchorage SFSS, called to my attention a particular cloud pattern associated with some of the most rapid developing cyclogenesis cases over the Pacific. I will refer to this particular cloud pattern as an S-C cloud system. It has been noted that these S-C systems almost invariably result in deepening surface low pressure centers, as long as the center stays over water and does not get captured by an upper low center. This fact seems to be almost independent of whether or not the center of the S-C system is behind or in advance of the 500-mb trough.

I thought of using this recurring satellite observed cloud pattern in conjuction with deepening prediction graphs once used in the Anchorage forecast office. The prediction graphs, published in the July 1959 AMS Bulletin by Snopkowski and Welch(1), were frequently used to help make hand drawn subjective surface prognostic charts. The prediction graphs had fallen into relative disuse by the 1970's, well before a steady flow of IR satellite imagery started here in 1976.

The objective surface low center deepening method used at Anchorage in the 1960's followed the conclusions in the Bulletin article, which recommended using for the Western Pacific, only the modal values from the earlier Project-AROWA(2) Atlantic graph (fig. 1), along with a modified Eastern Pacific graph (fig. 2).

The criteria for using these two graphs were:

1. Use between 30N to 60N latitude only.

2. The 180th meridian separates East from West Pacific.

3. For surface lows where centers are located under the 500-mb contours between the trough and down stream ridge, forecast decreasing central pressure.

4. For lows located directly under the 500-mb trough - i.e., within one degree longitude on either side, or located under the forward half (with respect to movement) of the closed 500-mb contours, forecast no change in central pressure.

5. For lows located elsewhere, forecast increasing surface central pressure.

6. Do not use these graphs for tropical storms which are in transition from typhoons to extratropical cyclones.

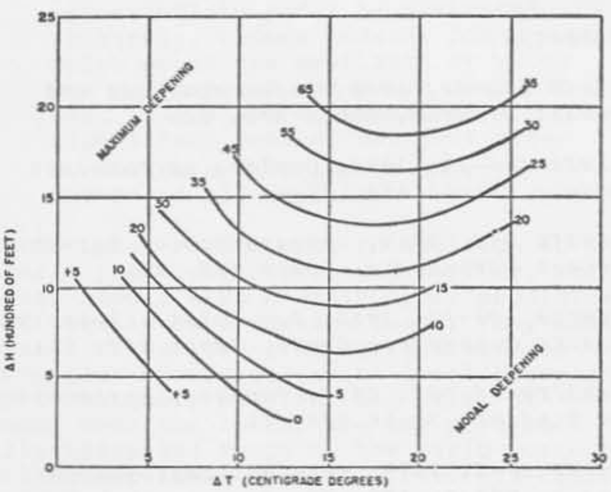


Figure 1. North Atlantic deepening prediction graph. Use only modal values for Western Pacific. (Snopkowski and Welch)

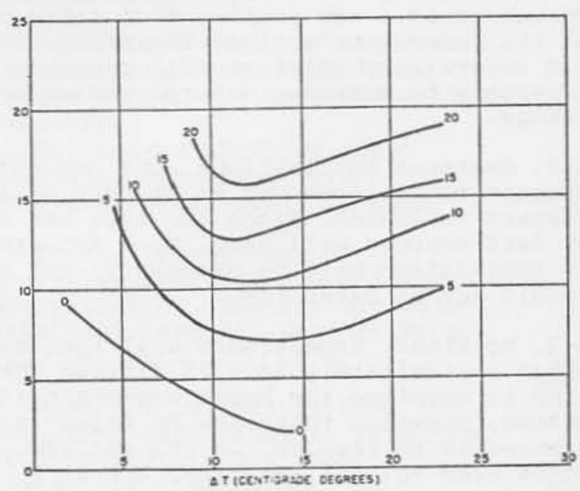


Figure 2. Deepening Prediction graph for Eastern Pacific, mb per 24 hr (Snopkowski and Welch)

Method of computation:

Measure the 500-mb height difference between points 7.5 degrees of latitude either side of the surface low position normal to the 500-mb contours. When closed contours lie in this range, measure only to the last open contour (fig. 3).

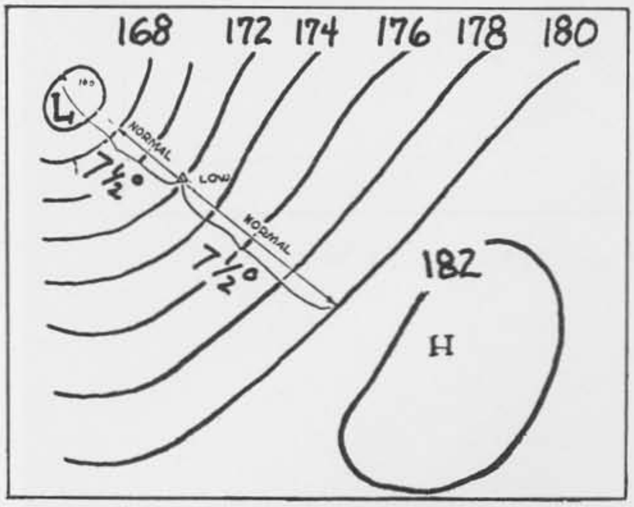


Figure 3. Method for determining 500mb height difference for computation. (Snopkowski and Welch)

Measure the 500-mb temperature difference from the surface low position within the sector extending 15 degrees of latitude northwest of the low (fig. 4).

With the above two parameters, use either the Western Pacific deepening-prediction graph (fig. 1) or the Eastern Pacific graph (fig. 2), or a combination of both, in order to obtain the 24 hour deepening prediction.

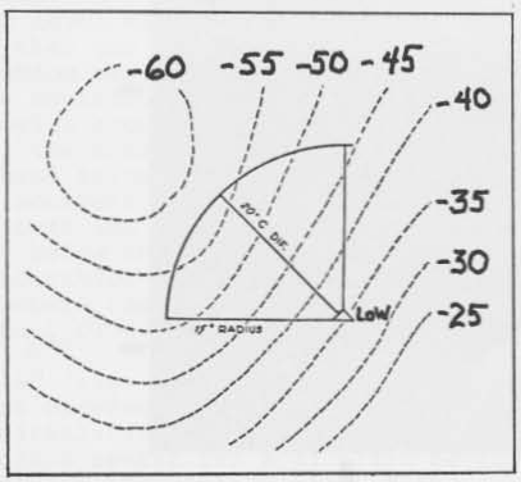


Figure 4. Method for determing 500mb temperature difference for deepening computation. (Snopkowski and Welch)

To use these deepening-prediction graphs, the forecaster had to be aware of the existence and position of a surface low pressure center along with its central pressure. In addition, the Anchorage forecasters found that they did not feel secure enough to rely solely on this technique. The statistical results in the Bulletin article indicated deepening forecast cases for the Western Pacific were overforecast by 10 percent in the winter and 33 percent in the summer, and overforecast for the Eastern Pacific 7 percent in the winter and 9 percent in the summer. The added assurance needed to avoid this over-forecasting by Anchorage forecasters was the surface evidence of deepening in successive analyses. Consequently, computes were not frequently used on surface lows in their initial stages of development.

Since the often observed S-C cloud pattern seemed to identify the position of impending cyclogenesis up to 12 hours before a low was analyzed at the surface, and thus well before significant deepening had occurred, it was hoped that a combination of these deepening-prediction graphs with S-C cloud patterns would give objective forecasts up to 24 hours earlier than previously obtainable. The purpose of this paper is to show the encouraging results of this marriage.

2. Identification of S-C cloud systems and their associated cloud circulation center positions

The diagrams (fig. 5) are what I refer to as S-C cloud structures. The letters S and C refer to the cloud shape on the cold side of the baroclinic zone or wind maximum. Instead of looking at upward vertical motion induced cloudiness, I focus more attention in these cases on the cloud structure that appears to be a direct result of sinking motion aloft. It seems that this sinking motion over or to the rear of a deep cloud circulation center is a more timely clue for cyclogenesis over the North Pacific.

In both the S and C cases sketched in Figure 5, the low clouds to the right of the dashed lines tend to be near the same temperature (same shade of gray on the Z curve display) as that of the underlying water. Consequently, it is often difficult, in Z curve imagery, to distinguish whether this area is clear or covered by a low overcast. The southern end (point L) of the S and C cloud structure is also frequently indistinguishable, since these clouds are low. There must be a gradual increase in brightness from the southern or lower portion of the S or C cloud structure to the northern or upper portion (L to U) without a leaf or layered appearance. Additionally, clouds in the L and U band of Figure 5a become colder towards the western edge. These features can be seen in the IR pictures of Figures 6 and 7.

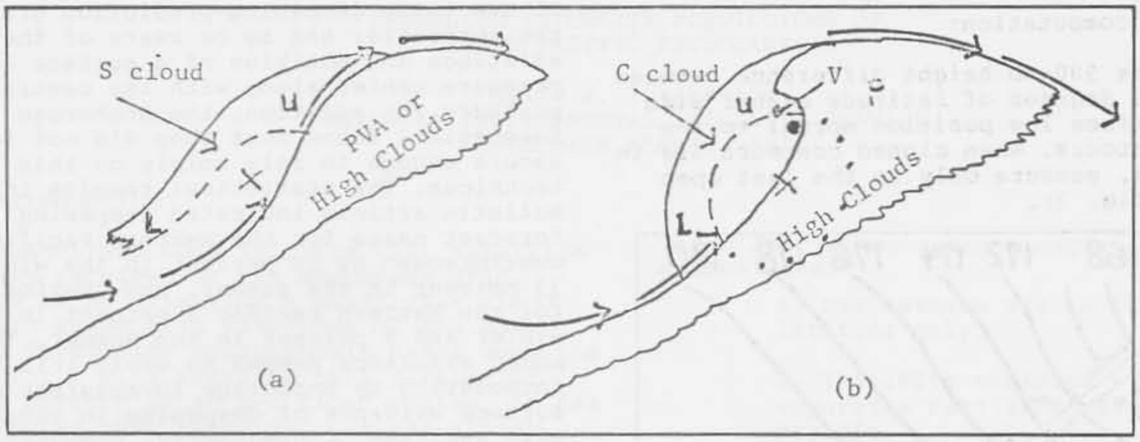


Figure 5. Schematic showing "S" and "C" cloud patterns.

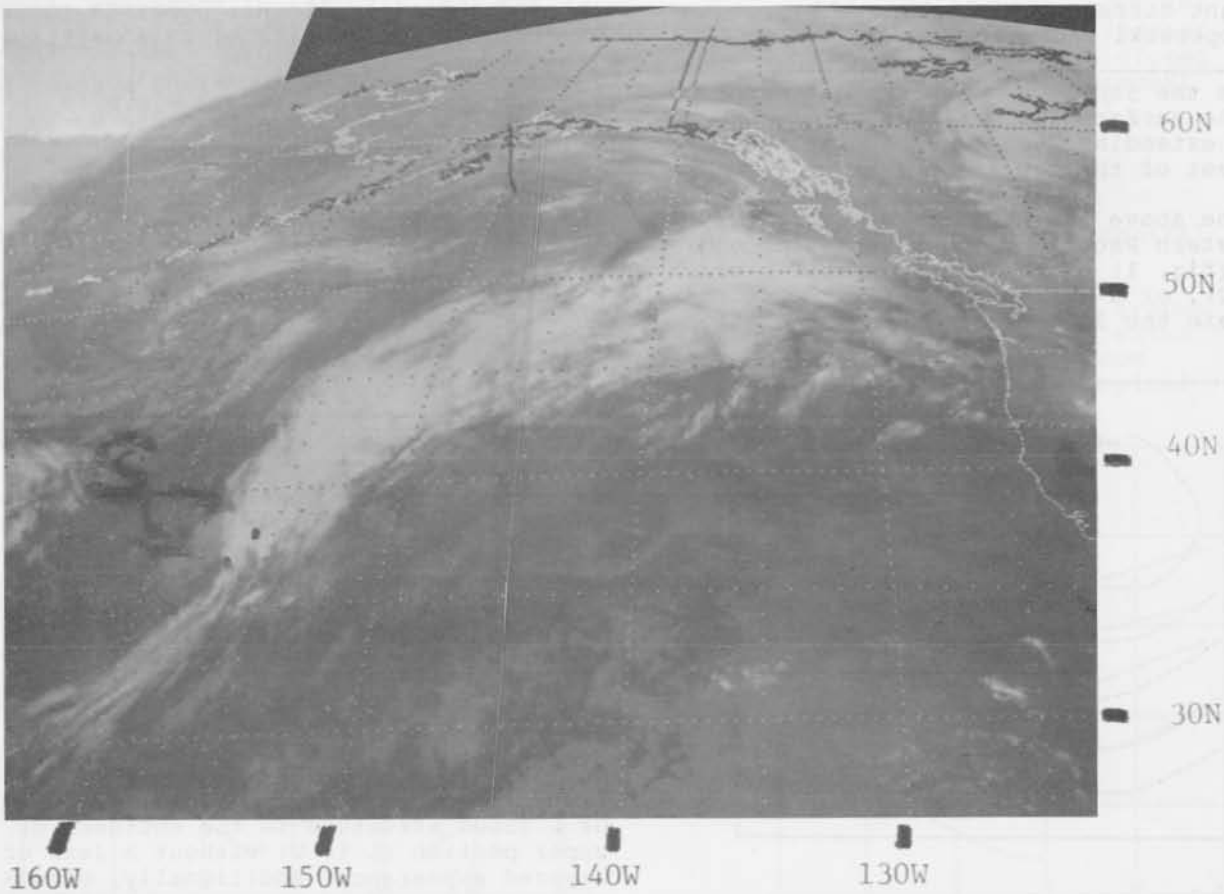


Figure 6. GOES-3 IR imagery 1145 GMT 1 October 1978.


Figure 7. GOES-3 IR imagery 0745 GMT 12 October 1978.

It is known that the S stage is an early stage in the development of circulation. The C stage is a later stage which ocurs when the rotational component of the wind around the low level circulation center becomes faster than the speed of translation of the circulation center with respect to the earth's surface. At this time when return flow begins around the rear of the cloud system, the southern portion (L) of the S cloud band turns to become the cyclonicly curved southern portion of the C cloud. Since these low level cloud tops are often near or below the 850-mb level, they are a good indication that a surface wave with open isobars has changed into a closed low once the C cloud stage is reached.

The "X's" (fig. 5) represent the most frequent observed position of the lower cloud circulation centers. In case b, this lower cloud center can most often be located by imagining the continuation of the curvature of the inside of the dark cloud band (L to U) around in an oval shape under the PVA comma tail (indicated by dots). The center of this oval is the position (X) of the lower cloud circulation center. Notice that this point is well to the rear of the upper cloud vortex "V" which is the position of the upper cloud circulation center. Of all strong cyclogenesis cases over the North Pacific, this large slope by as much as 200 miles between upper and lower circulation centers seems to be restricted to this C cloud pattern. It is important to use this lower cloud circulation position in these C type cloud cases to obtain the best estimate of the surface low position.

Experience has shown that a definite relationship exists between positions of cloud circulation centers and surface lows over the Pacific from 25N to 65N during the cooler months of October through May. Surface low pressure centers will be about one degree of latitude to the left of the direction of translation of significant cloud circulation centers with a 30 kt speed of movement, and within 2 degrees latitude at 60 knots. This relationship is the same for both the more common upper cloud circulation centers that reflect down to the surface without exposing a middle or lower cloud center, and the lower cloud circulation centers of the S-C type systems. This rule does not work well over the North Pacific from June through September apparently due to the lack of enough vertical extent in the circulation patterns.

The accuracy in determining the surface low pressure center position from S-C cloud patterns using this displacement rule is dependent on skill in finding the lower cloud circulation center position. Even though the easier to see upper cloud circulation center in IR pictures will give the general location, the better related lower cloud circulation center is often hidden in more uniform dark grey low clouds. When a visual picture is available, the location of the lower cloud circulation center is often simplified since high clouds are usually not masking this center. A good example of this problem appears in the left hand portion of the UC-2 sector of Figure 8. Test yourself by looking at this IR picture and guessing what part, if any, is free of clouds in the vicinity of this storm, and also try to estimate the position of the lower cloud circulation center. Then refer to the visual picture (fig. 9) of this same storm to find the answers. This extra-tropical low is experiencing frontogenesis just prior to intense deepening. Note that the clouds associated with the PVA comma (P) in Figure 8 slope down on the inside edge, in a funnel shape, to the lower cloud circulation center apparent in Figure 9. This evidence of sinking air results in the same shading (change in brightness on the inside edge of the high clouds) as that normally seen in the S and C clouds bands previously discussed.

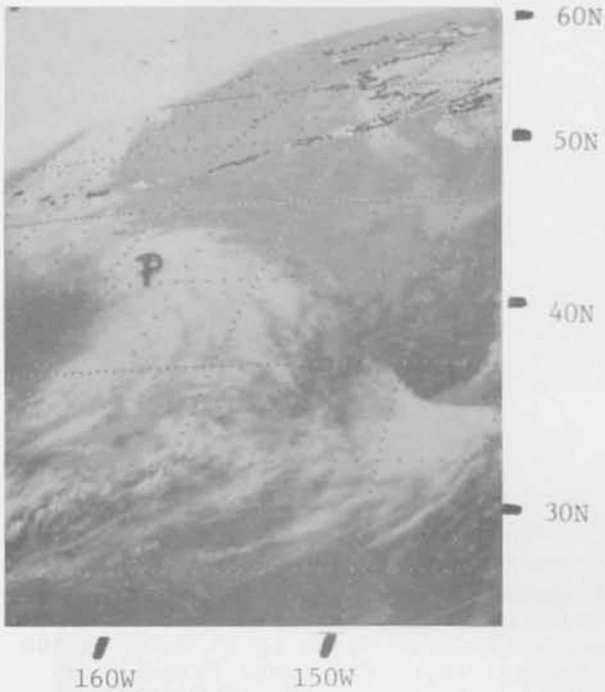


Figure 8. GOES-3 IR imagery 2245 GMT 5 October 1978.

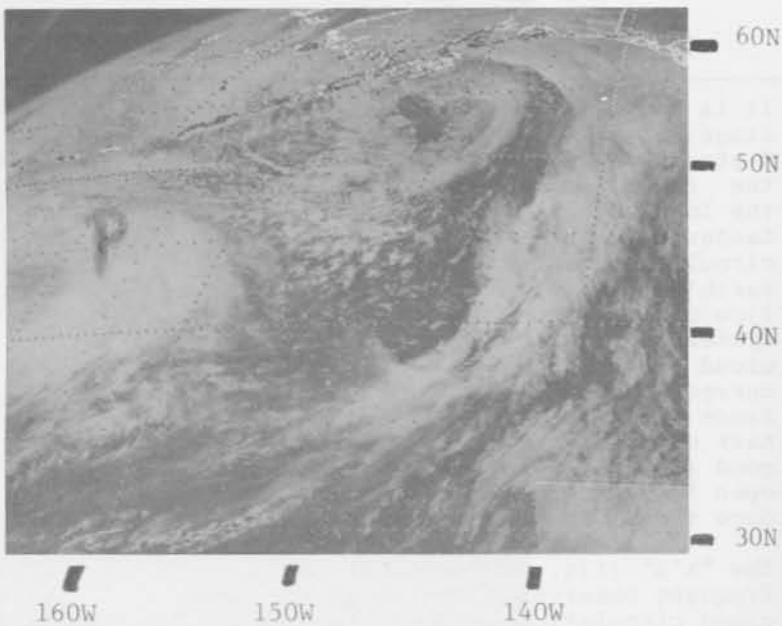


Figure 9. GOES-3 Visible imagery 2315 GMT 5 October 1978.

3. Technique of making 24-36 hour surface low central pressure predictions

After tracking an S-C type cloud circulation center to obtain the speed and direction of translation for at least 8 hours, the previously mentioned displacement rule was used to estimate corresponding surface positions of the impending or already formed and intensifying low center. After obtaining the surface pressure from an NMC or Anchorage WSFO analysis at a 00 GMT or 12 GMT position along with the corresponding NMC 500-mb temperature and height parameters (figs. 3, 4), one or both the deepening-prediction graphs (figs. 1, 2) were used to arrive at a final 24 or 36 hour objective central pressure prediction. In cyclogenesis cases in which a surface low was expected to remain over water and not become captured by an upper low or move through a long wave upper ridge position, the forecasts were extended to 36 hours using the 24 hour deepening rates indicated by the graphs.

4. Results of first 40 predictions using only S-C cloud centers

Of the 40 deepening predictions made through November 10, 1978, the last 36 were issued in Satellite Interpretation Messages (SIM's) well in advance of their verifying time. Several of them were extended forecasts for 36 hours; however the lead time in the SIM's were only 15 to 27 hours primarily due to th 7 hour delay in reception of the NMC 500-mb analysis. Thirty-nine of these 40 predictions were based on the Eastern Pacific graph. Of these 40 cases, 39 deepened and verified better than the latest machine progs that were available at the time the computes were made. The only non-deepening case was one of earliest attempts in this technique. This error was due to a premature classification of the cloud system in the distorted area at the picture edge. When this cloud system moved into better view just 2 hours after the SIM had been transmitted, it was then obvious that this was not the S-C cloud pattern it was previously thought to be. If this one mistake were thrown out, the frequency of deepening indicated by this technique would have been 100 percent instead of just 98 percent.

It was found after verification that the forecast depth of the low centers was within 2 mb of the actual central pressure in 93 percent of the 40 predictions. If the non-deepening case were disregarded, 95 percent of the computes were within 2 mb of the actual central pressure. The results through November 10, 1978 were:

| computes | results |
|---|---|
| 32 | within 1 mb |
| 5 | within 2 mb |
| 1 | underforecast 6 mb, but 8 mb better than the LFM forecast |
| 1 | underforecast 10 mb, but 10 mb better than the LFM forecast |
| 1 | non-deepening case |

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The following example is one of these extended forecast cases that also needed to be interpolated between the 24-hour and extended 36-hour deepening predictions from the graphs, because the S-C cloud center was expected to deepen beyond 24 hours but only remain offshore 33 hours from its 00 GMT position. This information was included in the following portion of the October 14, 1978 SIM.

ANC W TBXX6 PANC 140900 SFSS ANC SIM.
IMAGERY THRU 0745Z

WIND MAXIMUM WELL DEFINED NORTHEAST PACIFIC BY SHARP EDGE TO PVA SOUTHEAST OF WIND MAXIMUM NOW ALONG ARC 50/152-59/145-61/135 EASTSOUTHEAST. NO BUILDING NORTHWARD OVER SOUTHEAST ALASKA YET APPARENT THE PAST 6 HOURS ALTHOUGH MOISTURE IS INCREASING. WELL DEFINED SHORT WAVE TROUGH UPSTREAM SOUTHEAST ACROSS THE BAROCLINIC ZONE 43/152-39/142 MOVING NORTHEAST 40-45 KNOTS. PROBABLE SURFACE LOW ABOUT 90 MILES NORTHWEST OF APPARENT LOW CLOUD CIRCULATION CENTER 42/148. DEEPENING GRAPH GIVES 3-4MB DEEPENING IN 24 HOURS FROM 00Z...THUS EXPECT ABOUT 1004MB CENTER AT 00Z TOMORROW ENTERING THE SOUTHEAST PORTION OF THE GULF OF ALASKA. EXTENDING THE TRACK AT THE PRESENT RATE OF MOVEMENT GIVES 51/140 POSITION FOR THE CIRCULATION CENTER...THUS A SURFACE LOW JUST NORTHWEST NEAR 52/141 IS FIRST GUESS FOR 00Z. THIS IS VERY CLOSE TO THE POSITION OF AN INVERTED SURFACE TROUGH ON LFM AT THAT TIME...BUT 12MB DEEPER. FASTER DEEPENING EXPECTED AS FORECAST BY LFM THEREAFTER UNTIL THE LOW HITS THE COAST LINE...THUS CENTRAL PRESSURE OF 8MB DEEPER THAN LFM AND PE LIKELY WHEN THE CENTER IS EXPECTED TO HIT SOUTHEAST ALASKA COAST ROUGHLY 09Z...AND POSSIBLY 12MB DEEPER. THIS COMES OUT TO A 996MB TO 1000MB CENTER TO HIT COAST WHEN TRYING TO EXTEND THE DEEPENING GRAPH PREDICTION OUT BEYOND THE 24 PERIOD IT WAS DESIGNED FOR.

The surface low center just missed Southeast Alaska as it moved inland at Yakutat AK. The aviation hourly reports on October 15, 1978 at that time were:

08 GMT 14 OVC 5R-L-F 951/43/42/1012
09 GMT 4 BKN 12 OVC 5R-L-F 943/44/43/1015
10 GMT 7 OVC 5R+F 981/42/39/3018G26

These reports along with other data show that an approximate 994-mb low moved northeast over Yakutat about 33 hours from the 140000 GMT NMC 500mb analysis and corresponding IR satellite imagery used to make the prediction. This was just 2 mb deeper than the low estimate of 996 mb made in the Anchorage SIM, but was 14 mb deeper than the machine prognostic charts indicated.

Only one compute using the western Pacific deepening-prediction graph was made, and included in this initial test group of 40 predictions. It was not initially identified as a S-C cloud system since we still did not have satellite coverage of the western Pacific at that time. It was included however because it was identified as a well defined S-C cloud system as soon as it came into our satellite viewing area. The compute on this system consequently was based on surface continuity instead of satellite positioning like the others. This compute was made to check out the LFM forecast of deepening of an already existing surface wave. The 24 hour deepening of 30 mb on this 998 mb wave was obtained from both western and eastern Pacific graphs proportional to the time the wave was expected in these different areas. An extra 12 mb deepening was indicated from the eastern Pacific graph for a 36 hour total deepening of 42 mb to a 956 mb low for October 1978. This compute was so much deeper than indicated by the LFM model that I was reluctant to refer to it in a SIM without the satellite evidence that it was a S-C cloud system. The SIM of 280900 GMT did forecast a deepening low to move northeast into the eastern Pacific near Nikolski at 290600 GMT, thus giving the expected deepening trend along with the direction of movement and speed. Although I did not refer directly to the objective forecast depth, I did add the comment that I would not be surprised to see a 956 mb surface low center by 291200 GMT.

The 998 mb wave did deepen into a 956mb center as it continued to move northeast to the southwest coast of Alaska near Cape Newenham at 291200 GMT, and continued to deepen another 4 mb as it moved onshore near Bethel at 291800 GMT before stalling and beginning to weaken. This observed 956 mb pressure was an impressive 44 mb lower than the 1000 mb pressure forecast by the LFM model for Cape Newenham at 291200 GMT.

## 5. CONCLUSIONS FROM FIRST 40 PREDICTIONS

Well defined S-C cloud patterns are extremely well correlated with intensifying surface lows. When the S-C cloud pattern is used in conjunction with the deepening-prediction graphs, a high degree of accuracy can be obtained on the resultant 24- to 36- hour central pressure of a surface low. The previously needed evidence that a surface low is already in existence with possibly the added assurance that it is also intensifying is not as timely or as important a consideration as to when to apply the deepening-prediction graphs. Since several intensifying S-C cloud systems were located behind the upper trough position at the time the computes were made, the previously used rules relating the 500 mb trough position to surface low position are not an important consideration on which to base a deepening compute.

## 6. USE AND VERIFICATION BY ANCHORAGE SFSS STAFF OF OTHER SATELLITE CYCLOGENESIS FEATURES

On November 10, 1978, the Anchorage SFSS staff to routinely issue objective cyclogenesis advisories based on the success of the earlier 40 satellite based deepening predictions. We now have an additional 81 deepening predictions along with verification data up through June 3, 1979. In 12 of these cases, the P.E. model forecast did not show any indication of a trough, pressure weakness, or separate low center in the neighborhood of these developments in order to obtain a pressure value for comparison with our forecasts. In 27 of these 81 cases, the LFM model likewise did not catch this development, or did not provide coverage for the area of development.

The majority of the 81 deepening computes were based on satellite support whereby cloud circulation centers and their positions were apparent. Fewer than half of these had S-C cloud patterns that verified so well in the prior cases studied, but most had shading characteristics in the IR imagery that indicated sinking air on the upstream side of the upper cloud circulation centers. A few of the deepening computes however had no initial satellite support; incidentally, most of the 81 forecast with the poorest verification were in this group. Nevertheless, these surface lows were deeper at the end of the forecast period in 80 out of the 81 cases, resulting in 99 percent accuracy of selection of deepening low situations. The one case that did not deepen had the same central pressure at the end of the forecast period as it did initially.

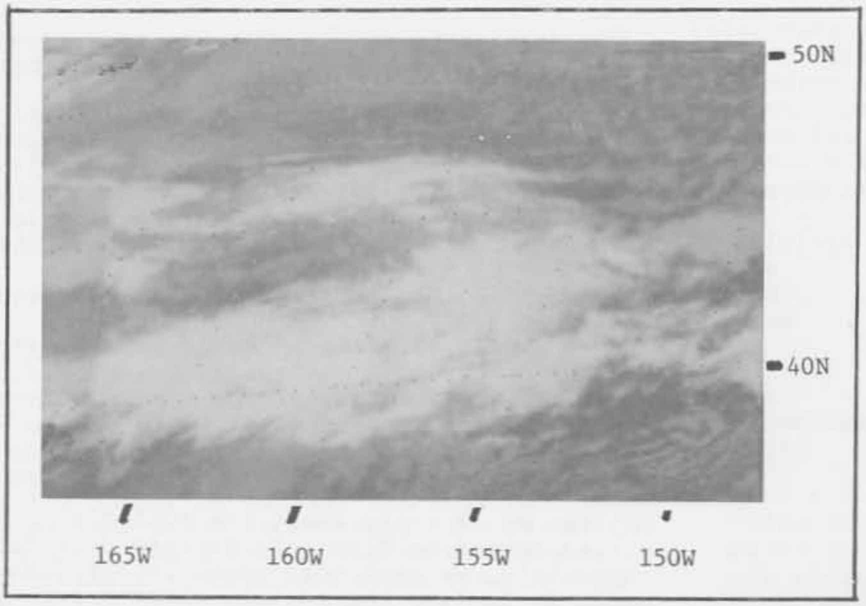


Figure 10. GOES-3 IR imagery 1245 GMT 19 October 1978.

7. Statistics on 81 deepening forecasts of surface lows

| Cases | SFSS 81 of 81 | LFM 54 of 81 | P.E. 69 of 81 |
|---|---|---|---|
| Hits (Observed central pressure equalled forecast central pressure) | 11 | 1 | 0 |
| Total mb overforecast | -245 | -1 | -3 |
| Total mb underforecast | +141 | +1040 | +1097 |
| Mean | -1.28 mb | +19.24 mb | +15.86 mb |
| Standard deviation | 6.48 mb | 9.81 mb | 8.50 mb |

A hit occurred whenever the observed central pressure equalled the forecast central pressure. Also in this list, O is the total amount of mb overforecast, and U is the total of mb underforecast. SD is the standard deviation in mb.

8. Final conclusions

Computes have been consistently successful on other than perfect S-C cloud structure systems. Apparently, the most important feature as when to use the deepening-prediction graphs is not just whether the S or C cloud structure is present, but just if the IR pictures show the steady slope of cloud tops down into low clouds. Since this feature is present on the rear side of many other upper cloud circulation centers, they also can be used in conjunction with the deepening-prediction graphs. This sinking evidence in the cloud tops must not be confused with baroclinic zones in which the high clouds taper off, or end at a sharp edge to expose a low cloud band in a PVA comma cloud tail. The definite slope from the high clouds down into the low clouds must be present. Figure 10 is an example of one of these deepening cases that does not have a perfect S or C shaped cloud structure, but shows some evidence of sinking air even though it has a somewhat layered appearance.

The nearly steady slope in cloud tops in a downward left-handed screw configuration in the northern hemisphere into the lower cloud circulation center is evidence of an intensifying surface system. This downward motion seems to precede the upward motion ahead, thus it is an earlier indication of surface deepening than deepening associated with PVA comma cloud patterns. This evidence of sinking type cloud systems is associated with cyclogenesis cases that are most often missed or underforecast by the machine prognostic charts over the North Pacific.

Since this technique of combined IR satellite imagery with deepening prediction graphs has added so much value to the satellite program in the Alaska area, the one designed for the North Atlantic in Project-AROWA might prove just as valuable.

*1. Snopkowski, E.L. and P.R. Welch, 1959: "Evaluation of an Objective Method for the Prediction of Central Pressures of North Pacific Cyclones" Bulletin, American Meteorological Society Vol 40, No. 7 July 1959. pp 336 - 339.*

*2. George, J.J., and Cdr. P.M. Wolff, 1955: "The Prediction of Cyclonic Intensity over the North Atlantic." Res. rep., U.S.N.*