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On the stratus cover in the neighbourhood of Baja California

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RESUMEN

A partir de fotografías de satélite del espectro visible, se analiza la variación del borde sureste de la cubierta de estratus californiano. Se combinan los bordes y se obtienen tres casos: los que se extienden de la Punta Sur de Baja California, los de Punta Eugenia y los de Punta Concepción hacia el suroeste respectivamente. En verano el punto de retorno del extremo noreste de este borde es Punta Eugenia. El desplazamiento hacia el oeste o norte del borde está asociado con la presencia de tormentas tropicales o huracanes que se aproximan por el suroeste de Baja California o bien por el paso de una vaguada en niveles superiores. Con lo anterior se repasan algunos estudios ya realizados.

ABSTRACT

From the visible satellite pictures of summer we have analized the variability of the southeast border of the Californian stratus cover. From the combination of the positions of the borders three cases are obtained: The borders towards the southwest, from south Baja California point, from Eugenia point and Conception point respectively. In summer the return point of the extreme northeast of this border is the Eugenia point. Shifting of stratus cover towards the north or west is associated with the presence of tropical storms or hurricanes which are near the southwest coast of Baja California, or also by the passage of an upper level trough. Also studies about this topic are reviewed.

Introduction

Observing the satellite images in Figure 1 of Miller and Feddes (1971) for the tropical or subtropical region, the most obvious extended sheet of clouds, that stands out, is the bright band of cloudiness associated with the intertropical convergence zone. The stratus cover is associated with the semipermanent subtropical highs as seen in Figure 2. It is also shown, in Figure 1 that the low level stratus are positioned east of the oceans, desert adjacent and over one oceanic coastal current categorized as follows (Schubert *et al.,* 1979):

Region	Coastal California	Coastal Ecuador, Perú and Chile	Coastal Northwestern Africa	Coastal Southwestern Africa	Coastal Northwester Africa
Desert	Sonora	Perú and Atacama	Sahara	Namib	Somalí
Ocean Current	California	Perú or Humboldt	Canaries	Bengüela	Somalí

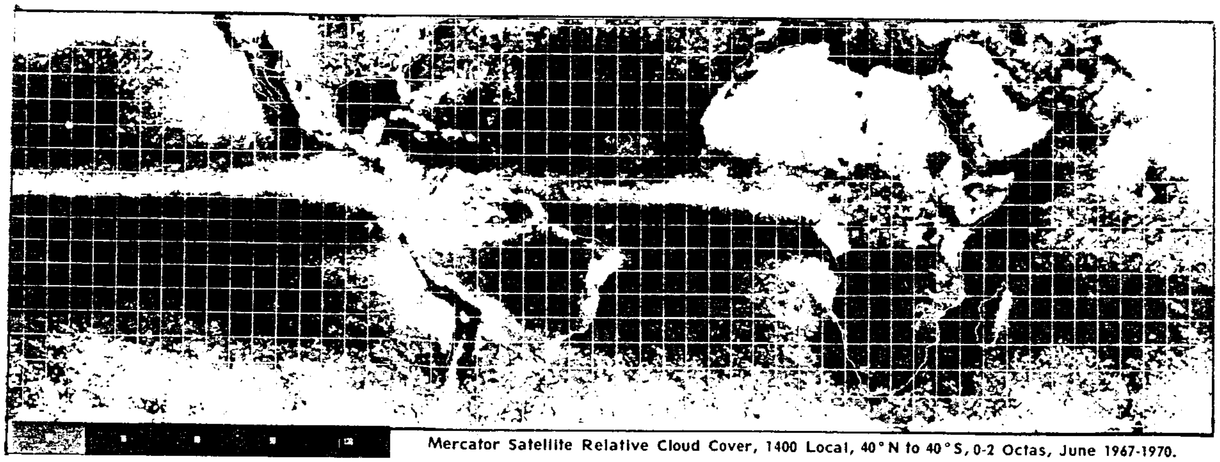


Fig. 1 Four-year average (1967-70) cloud brightness for June (from Miller and Feddes, 1971).

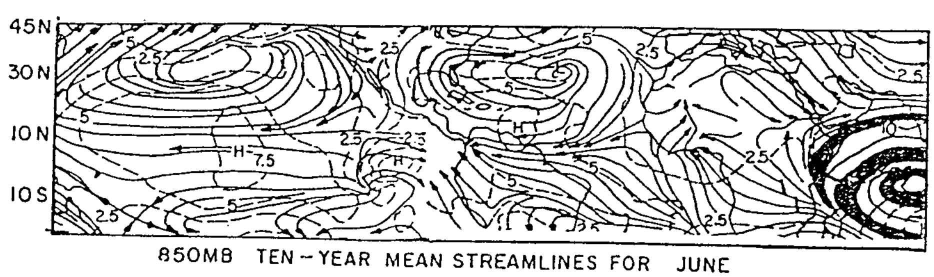


Fig. 2. Monthly mean streamlines and isotachs (ms^{-1}) for June, after Krishnamurti, 1986.

The presence of this extended sheet of stratiform clouds is the response to the air-sea interaction process, which has a profound effect on the shortwave and net longwave radiation reaching the sea surface. Winston *et al.* (1979) have published global charts of absorbed solar radiation, outgoing longwave radiation, albedo and net radiation for the month of June which are shown in Figures 3a - 3d. These maps reflect several features related with the cloudiness and circulation patterns from Figure 1 and Figure 2 respectively. Zones over South and Central America and Africa, as well as the Intertropical Convergence Zone, are associated with low outgoing long wave radiation and high albedo. Regions of high albedo and high outgoing longwave radiation to the east of the subtropical oceans reveal the persistent low-level stratiform clouds. The deserts are characterized by high outgoing longwave radiation and high albedo. Duynkerke and Driedonks (1987) indicated that the high albedo of the stratus cover, compared with the underlying Earth's surface, leads to a strong reduction of net incoming shortwave radiative flux, at the top of the atmosphere, in comparison with the cloudfree atmosphere (see Figure 3d). However, the infrared loss to space is not altered significantly, due to the low altitude of the clouds. Thus, an increase in stratiform cloud cover may lead to a global cooling of the atmosphere. Thus, in simulations of the climate such as Adem and Donn's (1981) with coupled ocean-atmosphere models, a correct position and frequency of ocurrence of this stratus cloud deck is required.

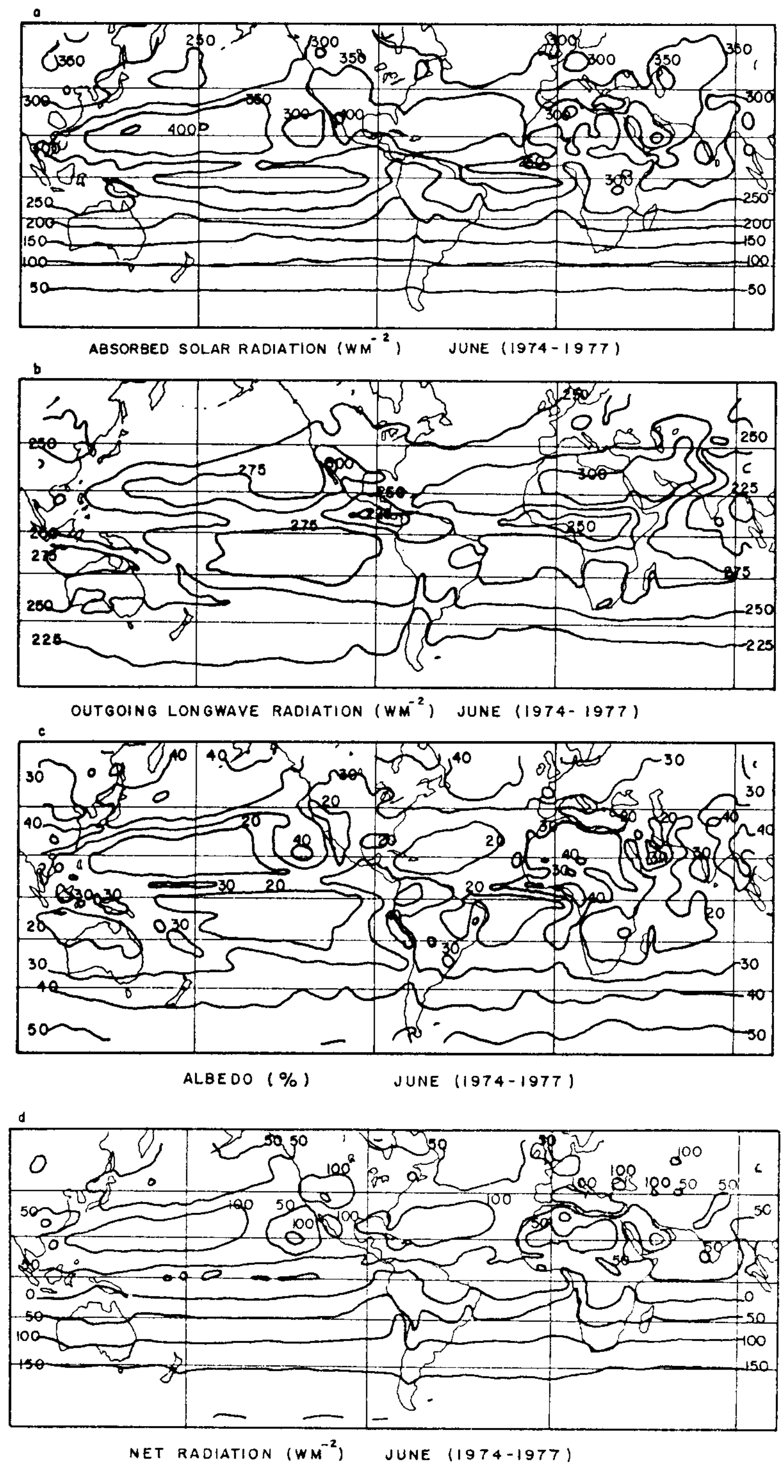


Fig. 3. Global charts of observed solar radiation a), outgoing longwave radiation b), Albedo, c), and net radiation d), from Winston *et al.*, 1979.

This first studies of temperature inversion generated by the large-scale subsidence of the subtropical high pressure system in the eastern North Pacific Ocean were made by Neiburger *et al.* (1961), during a Marine life Research Program of the University of California in the year 1950. They found temperature inversions in the whole tropical part, except in a small strip around the Intertropical Convergence Zone (ITCZ). This indicates the large-scale subsidence of the ITCZ. These areas of the temperature inversions will extend when the convergence in the ITCZ and the large-scale subsidence will be at its utmost (see Figure 17 of Neiburger *et al.*, 1961).

Neiburger *et al.* (1961) observed that the marine layer (H) has a diurnal oscillation, even 500 miles off the coast. In 52 out of the 68 instances in which such a comparison could be made, the morning H were higher than the average of adjacent evening ones. The diurnal oscillation of H in both coastal and long distances offshore was atributed to the convergence and divergence of the sea breeze. Recently in the Coastal Ocean Dynamics Experiment, Beardsley *et al.* (1987) noted that of the vertical sounding made at the Guadala Point site for the period from July 25th to August, 1982, the depth of the marine inversion base showed a clear diurnal cycle with a minimum elevation of less than 100 m occurring in the late afternoon local time, when the daytime acceleration along the shore has its maximum southeastward magnitude.

Recently Brost *et al.* (1982a, b), Hanson (1984) and Albrecht *et al.* (1985), have studied the turbulent structure of the atmospheric boundary layer of the Californian stratocumulus cover. Brost *et al.* (1982) noted that this cloud cover is observed, when a strong pressure gradient exist between

Fig. 4. Visible satellite image showing the Californian stratus cover and its southeastern border, at 1800 GMT, 20th September, 1988.

the subtropical high of the northeastern Pacific and the Arizona desert thermal low. This pressure gradient drives a strong and steady surface wind from the north or northwest along the Californian coast and generates upwelling. The presence of very cold water along the coast is thought to enhance the low level cloudiness and often provokes the formation of fog. However, an alternate source of the cold, nutrient-rich water is brought to the surface by the upwelling. McGowan (1983), Torres-Moyne and Alvarez-Borrego (1987), indicated that production of nutrient in the Californian current is high, when the transport of cool, low-salinity water from the north is strong, and low, when is weak. They also indicated that the periods of warming and low production in the Californian current tend to coincide with El Niño phenomenon, and that in 1982-1983, El Niño was still affecting the Californian current throughout 1984.

In Figure 4 the visible satellite photograph shows extended sheets of stratus clouds with its southeastern boundary marked to one side of the coast of Baja California. Around 300 visible pictures of this type were received in the National Mexican Meteorological Service for the months of May to August of the years 1981-1983; June to August of 1986, and May - July, 1984. Although interesting studies have been carried out over the Californian region, there are many questions concerning to the properties of the cool coastal dry climate, characterized by high albedo and extreme aridity, high frequency of fog, low stratus, small annual and diurnal temperature ranges.

The aim of this paper is to analize the variation of the southeastern border of the stratus cover, with the purpose of knowing the physical cause of their development and dissipation through the understanding of the summertime cloud climatology of this region.

The analysis method is to search the possible cause of the dissolution or displacement towards the north or south of the southeastern border, frequently induced by the arrival of tropical storms or hurricanes. Later the succession of analized borders is used to find the climatology of the stratus cover, which varies with respect to Figure 1. Finally some sinoptic analysis of surface pressure is presented which manifests the atmospheric circulation regimen, when a certain type of cloudiness is observed.

Analysis method

Figures 5a - 5t show the southeastern border (with the corresponding days and months) of the stratus cover, 1800 GMT. During the days 9th - 12th of May, 1981, the behaviour of the southeastern boundary of the stratus cover was very variable. A very extended sheet of stratiform cloud was observed from 22nd of May - 1st of June, 1981. Comparing June, 1981 with June, 1982, the latter had little variability. Also the semi-monthly means of sea surface temperature of June, 1981, in the southwestern Baja California was more variable than June, 1982, which can be seen in figures 6a - 6d. The Highest sea surface temperatures of June were observed in 1983 and 1984 (see Figures 6a - 6h), mainly south of 25° N latitude, due to the El Niño phenomenon of 1982 - 83, which still affected the Californian current throughout 1984.

Also in the Figures 5a - 5t we can follow the positions of some tropical storms, which were close to the region of the stratus cover. For example, hurricane Beatriz (29th June - 4th July, 1981), labeled with symbol ∮Bl for the 1st of July and with ∮B3 for the 3th July, moving towards the northwest dissipated the stratus cloud as can be seen in figure 5c. Similar to this, was the tropical storm Calvin (July 4th - 9th, 1981), which arrived near 22°N, 110°W on the 9th of July. During the days 6th - 11th of July, 1981, stratus clouds close to the south Baja California Point were observed with a tongue of cloudless air towards the southwest of Conception Point. The "synoptic maps" that contain this case are shown in Figure 9j. In this Figure we can observe a high covering the low pressure over the State of Sonora, which causes a flow of dry air from the continent towards the southwest of Conception Point. During August of 1981 the tropical depression Hilario (Aug. 21st - 28th) moved to the southwest of Baja California (see Figure 5q). On 25th of August the stratus cover shifted towards the west of Baja California. Another tropical storm that arrived in the stratus area was Irwin (August 27th - 31st) passing Cabo San Lucas at 1200 GMT on August 30th, then turning to the northwest.

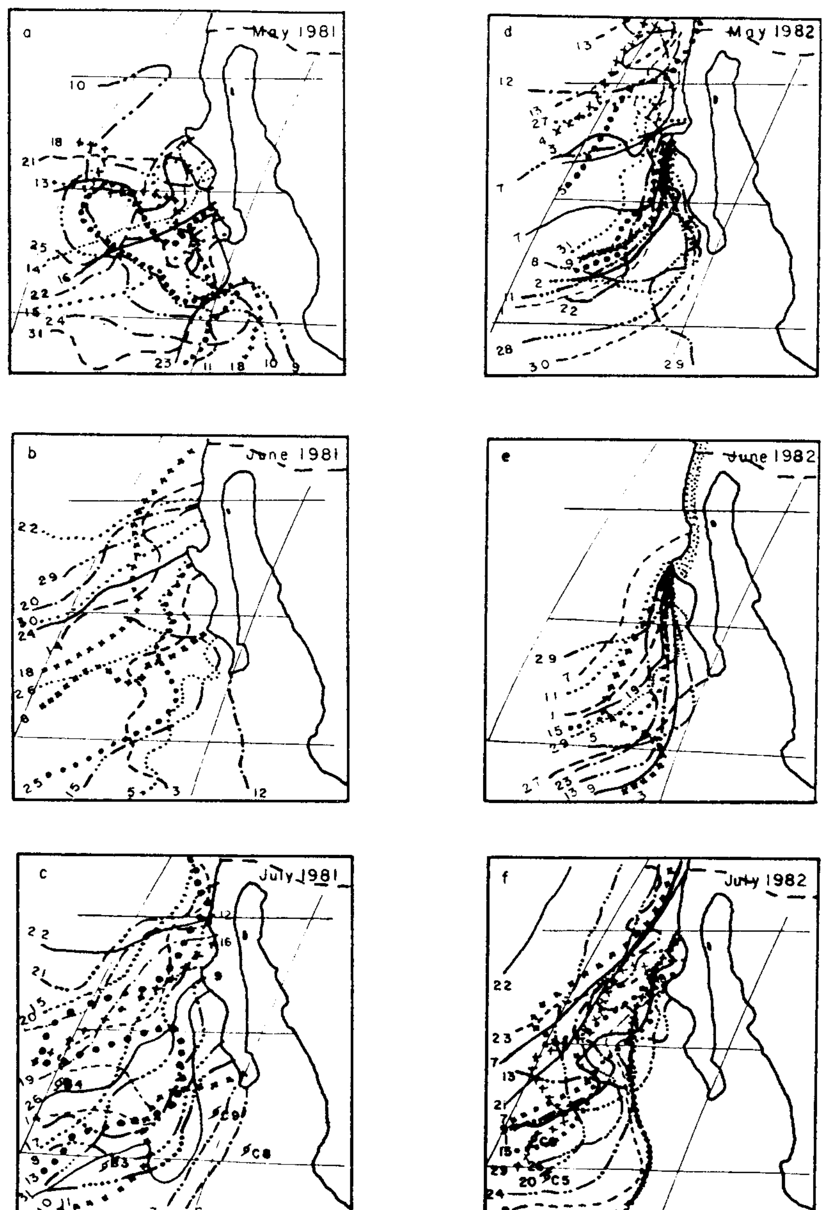


Fig. 5. Plot of some southeastern borders of the stratus cover for five "summers". The cases shown are for May - August of 1981 (a - c and q), 1982 (d - f and r), 1983 (g - i and s), May- July, 1984 (j - 1), and June- August of 1986 (m - p and t).

During the first days of May, 1982, scattered stratus were observed and shifted towards the northwest of Eugenia Point. Later, the behaviour of the southeastern contour was more uniform, as well as could be seen in June (Figures 5d - 5e).

During the first days of July, 1982, a cloudless sky in the neighbourhood of Baja California is noticed, which indicates that a hurricane is being developed in the southeast. Effectively, on July 6th the tropical storm Carlota arrived in the stratus region, as can be seen in Figure 5f.

Similarly, the previous situation was repeated during the days 18th - 22nd of July of the same year, which also indicated that another hurricane was moving in the southeast. From 20th - 22nd the sheet of stratus clouds shifted towards the west. On the 23rd the stratus cover returns weakly and the clouds that the hurricane carried are transformed into stratus clouds.

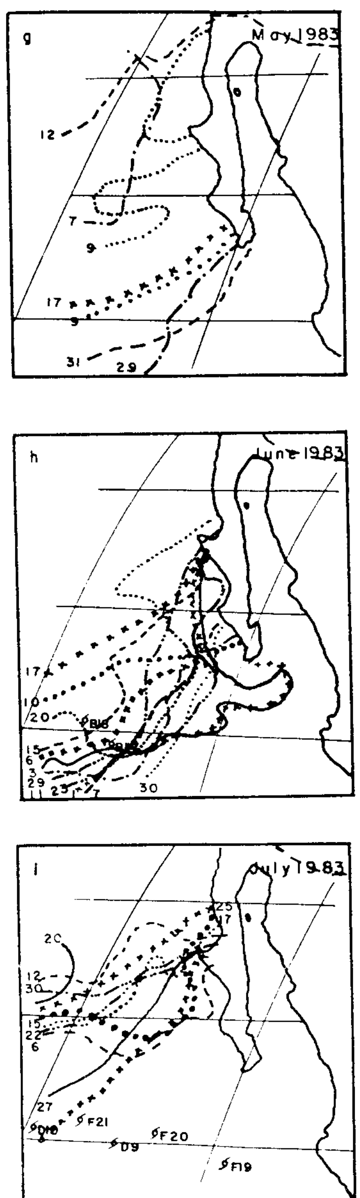


Fig. 5 g-i

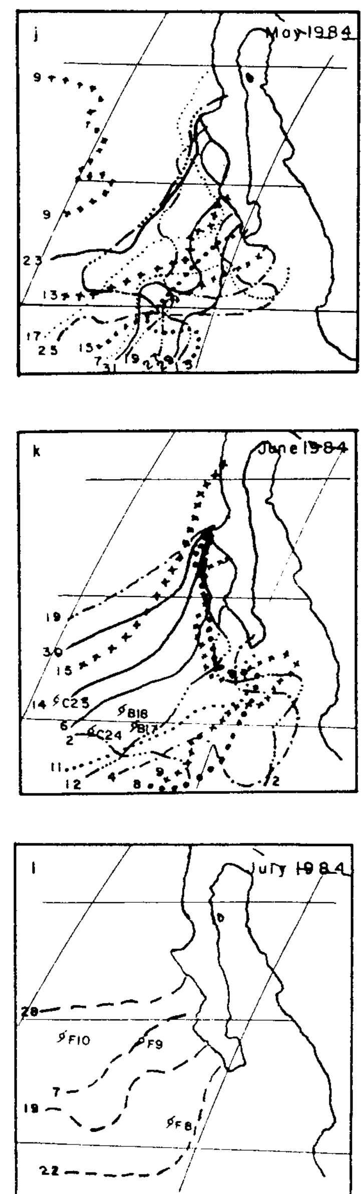


Fig. 5j-l

From 26th - 28th the stratus cover shifted slightly towards the west (see Figure 5f), due to a cloud cluster located in the south of the Californian Gulf. On 29th the stratus clouds return weakly and are strengthened on the 31st.

By August 3rd, 1982 the satellite pictures show that the stratus cover is still strong. On the 5th it is weakened and moves westwards (see Figure 5r). From the 6th to 7th it returned and was reinforced. From the 8th to 10th the stratus cover shifted towards the west of the shore of Baja California probably due to the presence of a hurricane that was being developed in the southeast. For the 11th once again the stratus cover returns slowly and is intensified from 12th -16th (see Figure 5r). By the 19th a "cloud cluster"is centered over La Paz and a sky clear of stratus clouds is observed towards the southwest of Baja California. On the 22nd, stratus clouds are not observed in the neighbourhood

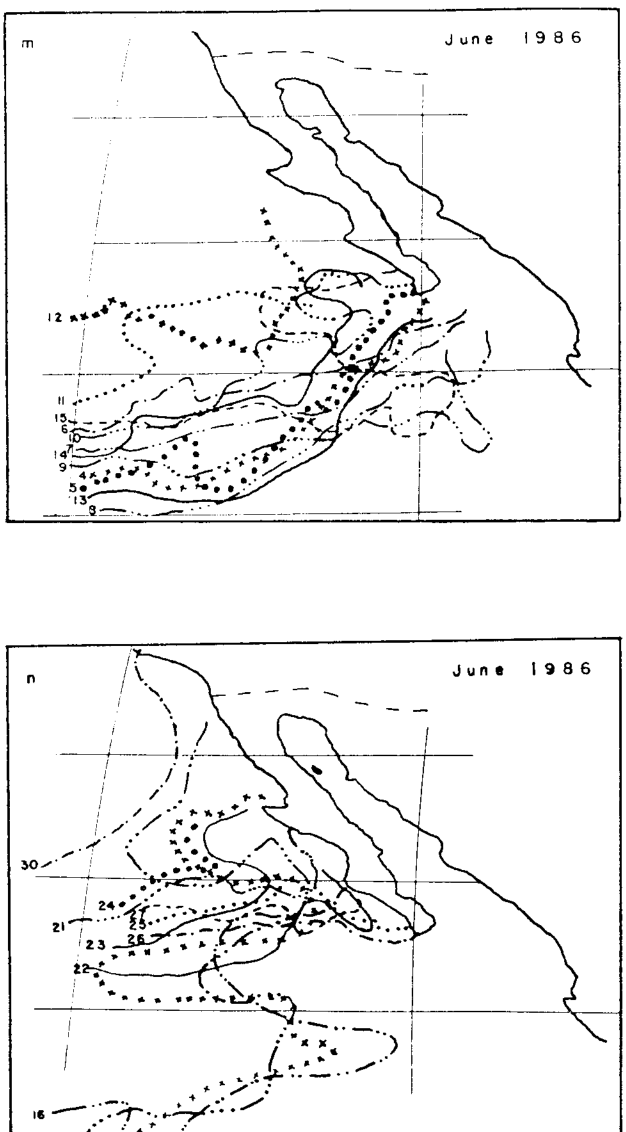


Fig. 5m-n

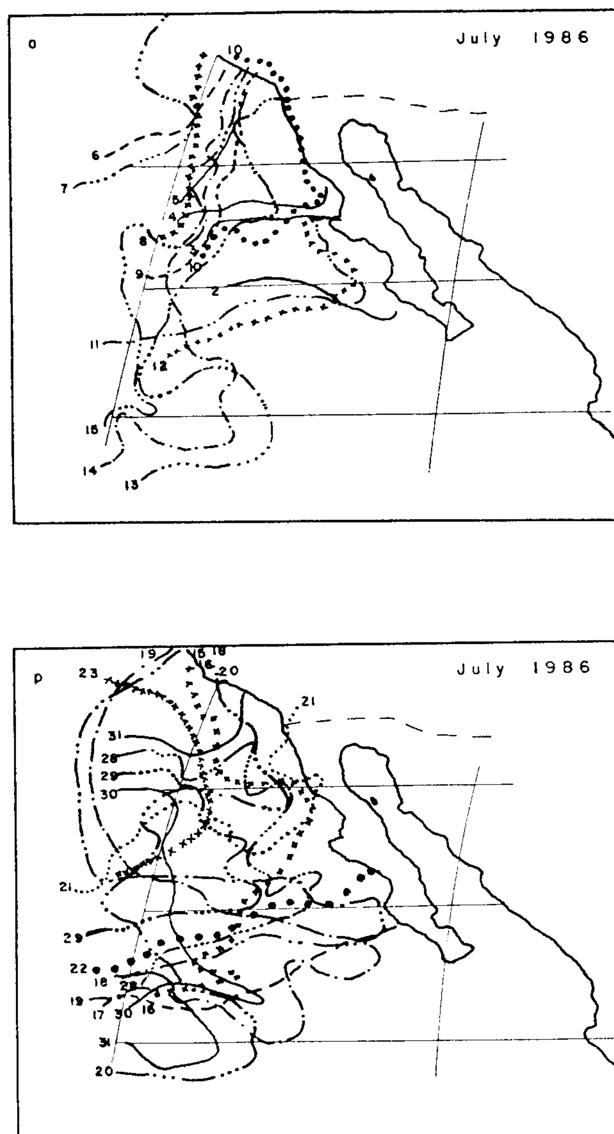


Fig. 5 o-p

of Baja California, but on the 25th again, we have the stratus cover. By August 30th another tropical disturbance was beginning to develop in the southeast, moving west - northwest. From August 31th to September 4th, 1982, no stratus cover is observed west of the coast of Baja California.

For May of 1983 we received few data and the bahaviour of the southeastern border was as follows (see Figure 5g). During the first days, from 5th - 9th, it was weak and variable. From 10th - 12th it moved towards the north and by May 29th to June 3rd it is observed the satellite pictures a very extended stratus cover with its southeast border from La Paz towards the southwest.

On June 4th - 12th we still have an extended stratus cover, which now slowly returns to the northwest (see Figure 5h). However, the hurricane Barbara (9th - 18th of June, 1982) on the 9th was beginning to develop in the southeast. By 12th - 15th the interaction between the stratus cover and the hurricane began, with the result that in the neighbourhood of the southernmost point of Baja California it remains clear of stratus clouds. On the 16th a clear sky is observed south - southwest of Eugenia Point. Correlating the southeastern border of the stratus cover on the 15th and 17th of June, with the position of Barbara on the 17th, we can affirm that this system dissipated the stratus cover. From the days 20th - 27th of June the stratus cover returns slowly towards the southeast as far as Eugenia Point and by the 30th reaches close to the southernmost point of Baja California (see Figure 5h).

During the first days of July, 1983, the stratus cover returns to Eugenia Point. Apparently because the tropical storm Dalilia (July 5th - 12th), that begins to develop in the southeast, arrives in the stratus region on the 10th, as shown in Figure 5i.

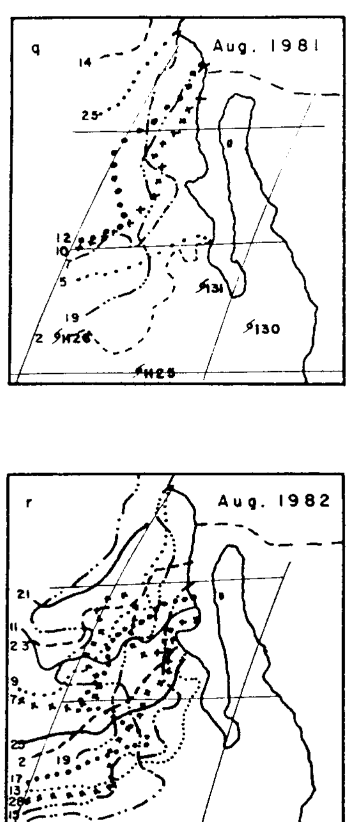


Fig. 5q-r

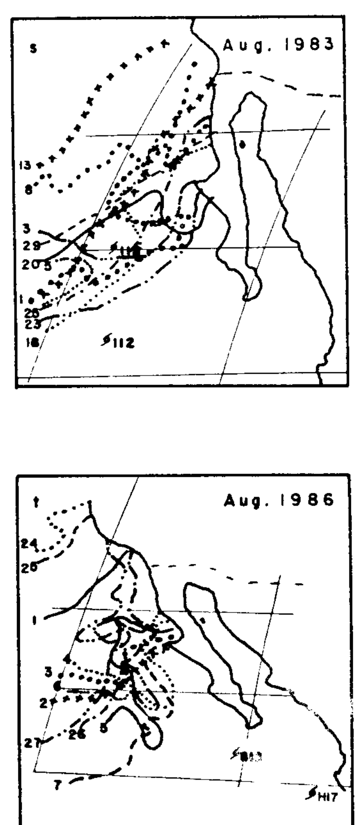


Fig. 5s-t

Another tropical storm is developing and the previous situation is repeated. This one is called Flossie (July 17th - 21st). On the 17th a clear sky is observed south of Eugenia Point. By the 19th the stratus cover shifts towards the west, and from the 20th to 21st the satellite pictures show a cloudless sky west of the California coast, as can be seen in Figure 5i. After the 22nd the stratus cover returned as far as Eugenia Point.

On the 22nd - 26th another hurricane was moving towards the southwest of Baja California and by the 28th a cloudless sky was observed west of Baja California and once more on the 30th the stratus returned to Eugenia Point.

On August 1st, 1983 we have stratus clouds near Eugenia Point shifting slowly towards the south, which again return to Eugenia Point by the 3rd (see Figure 5s). However, the hurricane Ismael (August 8th - 16th) begins to develop in the southeast. From the 5th - 7th no stratus clouds are observed in the neighbourhood of Baja California. By the 8th they weakly return to Eugenia Point. On the 11th the interaction between the hurricane cloudiness and the stratus cloud is initiated. By the 13th and 14th this hurricane remains surrounded by stratus clouds towards its western and southern borders. The hurricane Ismael was the one that drifted to the highest latitude.

From the 18th to 19th the southeastern border of the stratus cover returns to Eugenia Point and shifts slowly towards the south. From the 27th - 31st of August very small stratus clouds are observed west of the Baja California coast. This situation continues until the first days of September, 1983. Also during the first day of September the hurricane Kiko (August 31st - 9th September) was moving south - southwest of Baja California.

During the first days of May, 1984 (1st - 7th) there were stratus clouds close by south Baja California Point, but with a tongue of cloudless air towards the west - southwest of Conception Point. From 8th - 9th no stratus clouds are observed in the neighbourhood of Baja California. From 13th - 28th of May an extended stratus cover is observed as far as Cabo San Lucas with a cloudless tongue southwest of Conception Point (see Figure 5j).

On the 30th hurricane Boris (May 28th - June 18th, 1984) begins to develop in the southeast. From May 30th to June 7th a very extended stratus cover is observed (see Figure 5k), and on the 8th a slightly cloudless sky is seen in the neighbourhood of half of south Baja California. On the 11th the interaction between the stratus cover and hurricane is initiated and by the 15th the hurricane remains surrounded towards the west by stratus clouds. Afterwards the effects of the hurricane were still felt until the 18th. On the other side hurricane Cristina (June 17th - 26th) developed in the southeast of Baja California and so the south Baja California Point remains covered by cirrus clouds. On the 25th another tropical perturbation is developing in the southeast and moves towards the west. Also a cloud system reaches the southwest of Sonora State and very strong convective activity is observed on the 26th at 2100 GMT. The previous situation is repeated on the 28th and 29th.

There are few data for July, 1984 (see Figure 5l). By July 3rd the hurricane Fausto (July 3rd - 10th, 1984) begins to develop in the southeast. The position of Fausto on the 5th permits the formation of a cloud system located between Cabo San Lucas and Nayarit State. This cloud system affects the south part of Baja California. By the 8th the hurricane Fausto reaches the stratus region. On the 9th another tropical system arrives in the southeast affecting the south Baja California Point on the 10th. This system arrives to Cabo San Lucas by the 13th affecting all the neighbourhood south of Baja California and then weakened. The remanents of this system provoked cloudiness over all Baja California from the 14th - 18th. On the 22nd of July, 1200 GMT, a cloud cluster suddenly appears west of Jalisco State, which dissipates stratus in the neighbourhood south of Baja California. On the 24th 600 GMT, the previous situation repeats itself, but now the system is located between La Paz and Nayarit State.

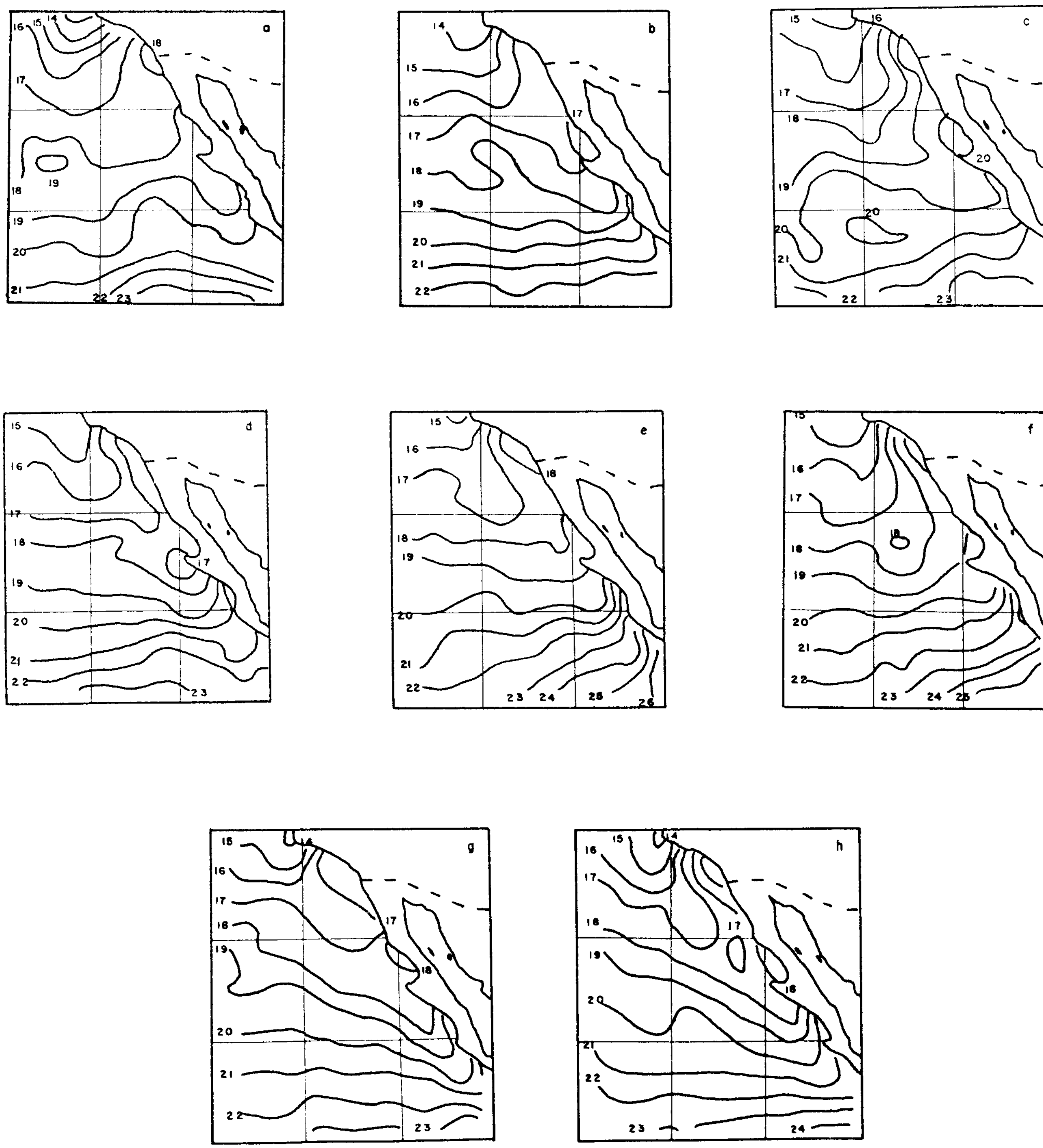


Fig. 6. Semi-monthly means of sea surface temperature compiled by the National Meteorological Center of the National Weather Service, U. S. A. The cases shown are for June 1st - 15th, 1981 (a), June 1st - 15th, 1982 (b), June 16th - 30th, 1981 (c), June 16th - 30th, 1982 (d),June 16th- 30th, 1984 (f), and June 1st - 15th, 1986 (g) and June 16th - 30th, 1986 (h).

During the summer of 1985 we received no data. Figures 5m - 5p and 5t show the analysis of the southeastern border of the stratus cover corresponding to the summer of 1986. During the first days of June (1st - 3rd) the stratus cover is extended more to the south of the southernmost point of Baja California and then it returns by the 4th, such as it is shown in Figure 7a. This behaviour

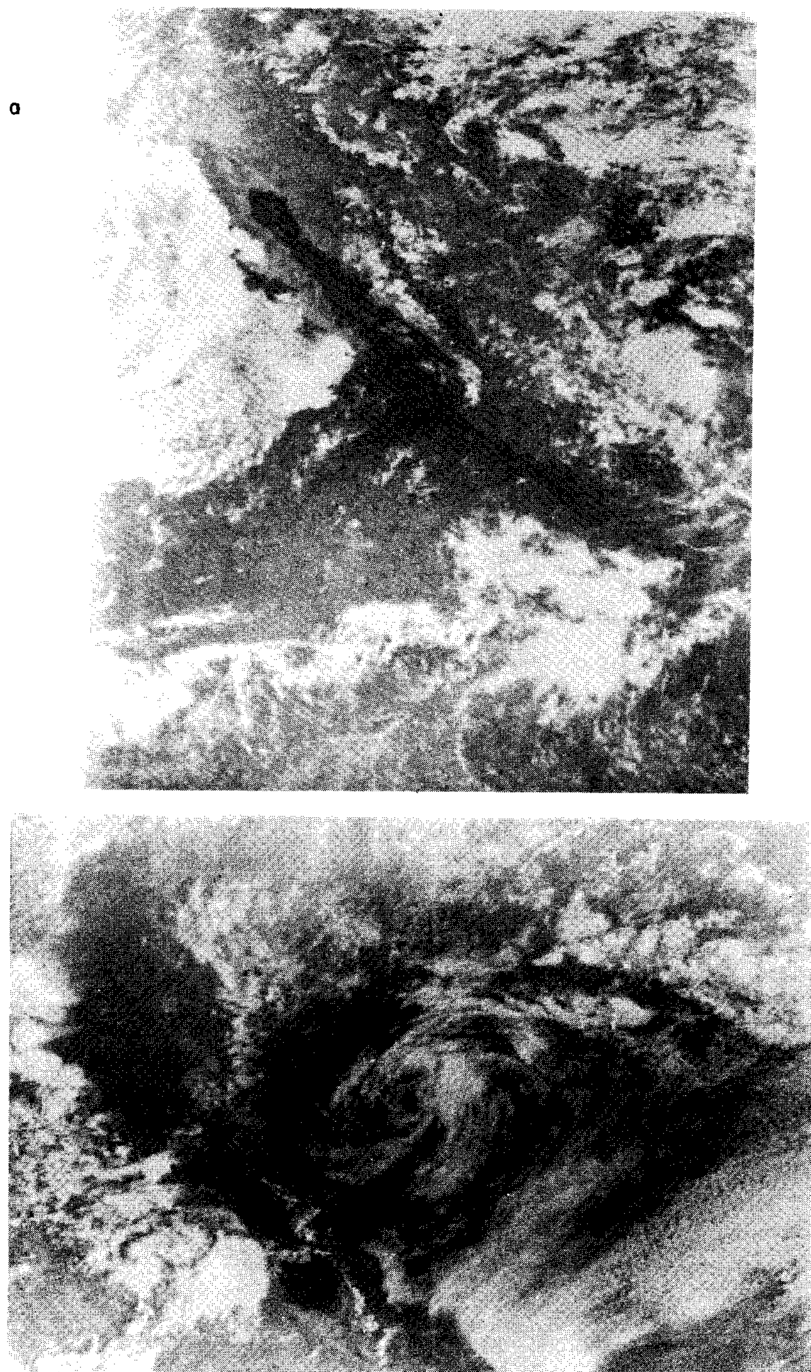


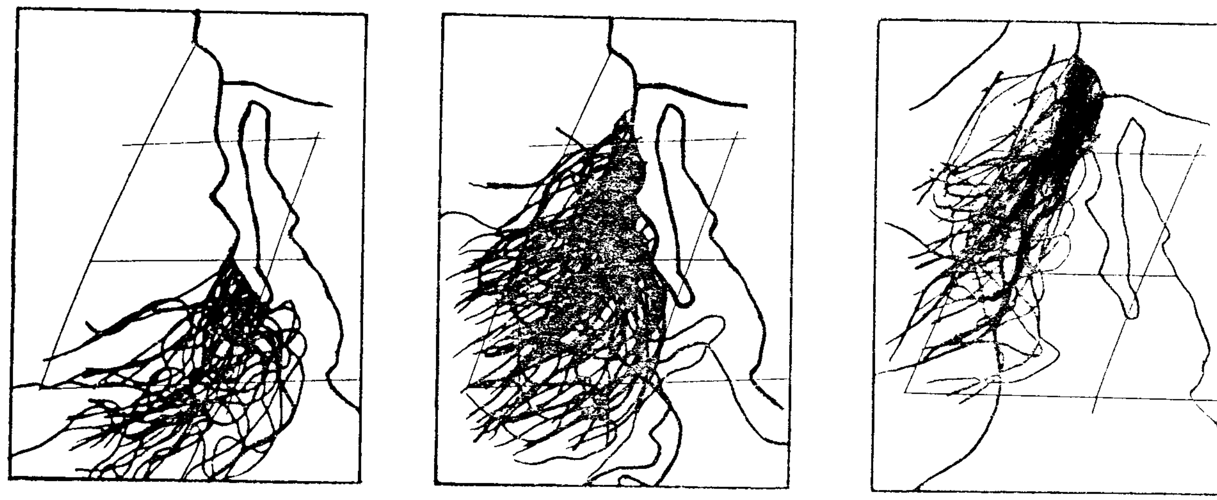
Fig. 7. Visible satellite image showing stratus cover southwest of Baja California at 1800 GMT 4th June, 1986 (a),and hurricane Celia at 1800 GMT 29th June, 1986 (b).

is sustained throug the 9th, (see Figure 5m). From the 10th - 16th it remains slightly clear at the south point of Baja California, which is reinforced in the afternoons. By the 17th and 18th the whole coast near the region of Baja California is cloudless, and from the 19th - 20th stratus cover is not observed except one small portion located north of Eugenia Point. However, the hurricane Blas was moving in the south by June 18th - 19th. On the 21st the stratus cover returns to Eugenia Point. This is sustained until the 24th with diurnal oscillation (see Figure 5n). By the 25th we have stratus close to Cabo San Lucas and the tropical perturbation Celia moving in the southeast. By the 27th the stratus returns to Eugenia Point and on the 28th the cumulus and cirrus clouds of the hurricane Celia begin to invade half of the south of Baja California. On the 29th the whole southwest of Baja California is being invaded by the hurricane Celia, such as it is shown in Figure 7b.

During July 1st - 3rd, 1986, the Celia depression continues to weaken in the southwest of Baja California with stratus clouds towards the north and as far as Eugenia Point. Another tropical perturbation develops in the southeast by the 3rd. On the 5th we have stratus clouds as far as Eugenia Point and the effects of the tropical storm Darby are initiated. From the 6th - 7th the tropical storm Darby affects the whole southwestern part of Baja California (see Figure 5o). Also in the satellite picture stratus are observed towards the northwest and on the 8th no stratus can be seen in the southwest. However, there is much convective activity between La Paz and the Jalisco State. By the 9th no stratus exists in the southwestern part of Baja California, but one vortex is located over the southernmost part of Baja California causing overcast. On the 10th stratus clouds as far as Eugenia Point are prevalent moving slowly towards the south. By the 12th another tropical perturbation occurs in the southeast and moves close to Cabo San Lucas. Part of the cloud that the perturbation transports is transformed into stratus clouds by the 15th, as can be seen in the satellite picture. On the 17th the stratus cover is extended as far as the south point of Baja California and there are stratus scatters south of Conception Point. By the 18th a slightly clear tongue of air invades the north and west of Eugenia Point. So on the 19th the whole southwest of Baja California remains clear (see Figure 5p). On the 20th stratus clouds cover the northwest of Baja California and on the 21st - 22nd they reach as far as Eugenia Point it is being cloudless near the coast in the afternoons. The previous situation prevails until the first days of August, 1986 (see Figure 5t).

Results and concluding remarks

From the visible spectrum satellite pictures of summer we have presented the variability of the southeast border of the Californian stratus cover. The behaviour of the southeastern border of this stratus cover in June of 1982 and 1986 was more uniform than in 1981, 1983 and 1984. The sea temperature was also lower. The combined analysis from May to August of 1981 to 1984 leads to three cases: First, the borders are extended towards the southwest of Cabo San Lucas, Figure 8a, the majority of these borders being from the last days of May and the first two weeks of June. Second, the vecinity of Eugenia Point towards the southwest, the major parts are presented in May and June respectively (see Figure 8b). Third, these contours, which begin near Conception Point towards the southwest, generally are observed in July and August (see Figure 8c).



a b c

Fig. 8. Joint analysis of the southeastern borders of the stratus cover that are extended from Cabo San Lucas towards the southwest (a), from Eugenia Point towards the southwest (b), and from Conception Point towards the southwest (c).

In figures 9a - 9o is shown some of the analyses of the 5-day mean surface pressure (mb the solid line) and 5-day mean 500 mb height (x 100, thin dashed line), compiled by the Japan Meteorological Agency, which correspond to some of the 3 cases. Figures 9a - 9e show the synoptic field that corresponds to the case, when there is an extended sheet of stratiform cloud, where the majority are from the last day of May and the first days of June. In each square the existence of a strong pressure gradient is shown between the subtropical high and low pressure that almost covers the Mexican Republic. In 500 mb height a high to the east and a low towards the south of Alaska is observed with a stronger gradient southwards. The surface pressure analysis and 500 mb height of the following four pictures (see Figures 9f - 9i) correspond to some cases from figure 8b, as well as for the climatology of June shown in Figure 1. Still a strong pressure gradient is observed between the thermal low of the Sonora or Arizona deserts and the Pacific semipermanent high.

The following 5 squares, figures 9k - 9o, correspond to the cases, where the stratus cover has shifted much towards the north and westwards. The weakness of the pressure gradient is observed, due to the shift towards the continent of the Atlantic high. This causes a continental flow towards the coast west of Baja California. However, still in some cases a strong pressure gradient exists between the high and low pressure, but now it has moved very much northwards. The shift of stratus cover towards the north or west is related to the pass of a trough in upper levels, 500 mb, as well as with the shift towards the west of the semipermanent subtropical high of the east Pacific. The elements of the weather that contribute to the dissipation of stratus are the presence of tropical storms or hurricanes approximating closely to the Baja California coast. These tropical systems are moving towards higher latitudes, when the semipermanent high shifts northwards. Out of the summers for the period from 1981 to 1986, the years 1983 and 1984 were the ones, where most tropical storms arrived in the stratus cover region.

In some visible satellite pictures fog was observed along the coastal mountains west of Baja California, mainly in the northern part. In Figure 5e the fog zone is shown (dotted), observed in June 1982, 1400 GMT. This fog is an important element of sustaining the vegetation, since the plants can intercept some fog water. Later an attempt will be made by means of satellite pictures to analyse the fog cover.

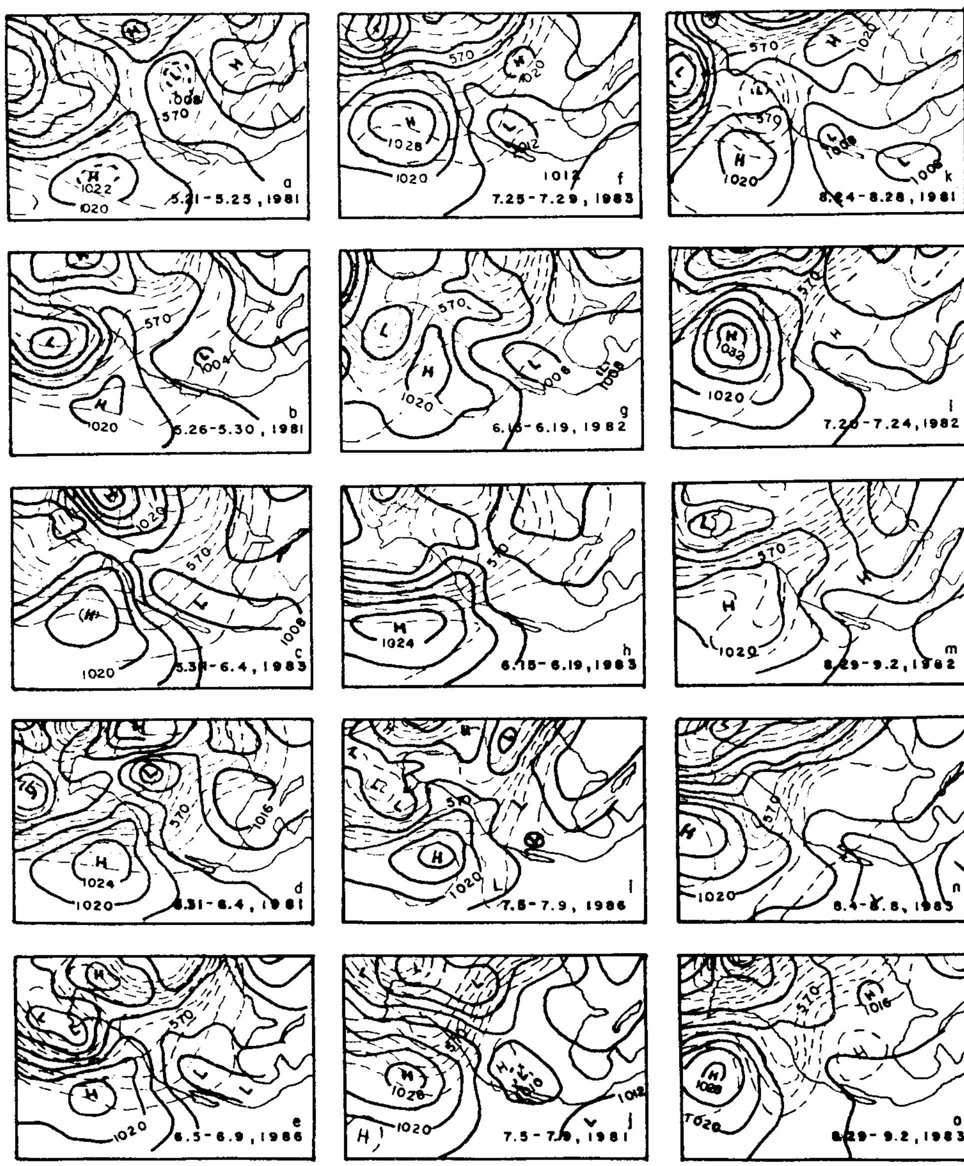


Fig. 9a-e Fig. 9f-j Fig. 9k-o

Fig. 9. 5-day mean surface pressure (mb, the solid line) and 5-day mean 500 mb height (x 100, dashed line), a - e corresponding to any case from figure 8a, f - i from figure 8b, and k - o from figure 8c respectively.

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