Case studies describing regional environmental analysis and forecast applications based on satellite data and conventional meteorological observations for the Indian Ocean area are presented. Topics include Northeast Monsoon, Southwest Monsoon, coastal zone phenomena, and ocean-atmosphere interaction. The studies provide insights into identifiable patterns of weather development that occur frequently, so that once the basic pattern is recognized at an early stage this information can be used for improved weather analysis and forecasting.
NAVY TACTICAL APPLICATIONS GUIDE

VOLUME 5

PART 1

INDIAN OCEAN
Red Sea/Persian Gulf

WEATHER ANALYSIS AND FORECAST APPLICATIONS

METEOROLOGICAL SATELLITE SYSTEMS

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Foreword

Volume 5 of the Navy Tactical Applications Guide (NTAG) series is devoted to regional weather analysis and forecast applications in the northern Indian Ocean. Part 1 of Volume 5 is dedicated to operationally important weather phenomena affecting the region surrounding and including the Red Sea and Persian Gulf. Part 2 extends the area of interest to the Arabian Sea and Bay of Bengal. The case study technique of relating weather satellite imagery to concurrent conventional weather data and analyses from the surface to the upper troposphere, along with available numerical guidance products, is continued, focusing on the unique weather characteristics of the Indian Ocean region.

Whereas the topics of blocking and cyclogenesis were emphasized in previous volumes, it is the powerful monsoon influences of winter and summer that become the dominant interest in the Indian Ocean. Duststorm generation is a subject of major interest because of its effect on operations throughout the northern portion of the Indian Ocean region. The ability to detect duststorms over land areas at the time of earliest inception in satellite data, and to forecast the areas most likely to be influenced by the dust, is given special attention.

The Indian Ocean volumes are intended as an evolving series which will be supplemented with additional material presently under development. The initial material is being distributed to the fleet to expedite access of completed work for operational use.

As with case studies developed for previous volumes, many of the principles derived for Indian Ocean weather analysis and forecasting are general in nature and equally applicable to similar weather events in other areas of the world.

It is anticipated that these guides will be useful supplements to other material available for the Indian Ocean region in their emphasis on new aspects of weather satellite interpretation for improved weather analysis and forecasts.

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INTRODUCTION
Introduction

Seasonal Circulation Patterns of the Indian Ocean

The northern Indian Ocean is located within the world’s most notorious monsoon regime. The term monsoon is a name for seasonal winds and is derived from the Arabic word *mausim*, meaning season. In general, the term describes a regime where there are highly persistent winds from nearly opposite directions in summer and winter and which are not the result of shifting migratory storm tracks. The basic cause of such a wind pattern is the differential heating and cooling of adjacent large land and sea areas. The land masses are warmer than the ocean areas in summer and cooler in winter, resulting in relatively lower pressure over the land in summer and higher in the winter. These pressure differences cause winds to blow primarily onshore (summer) and offshore (winter). The size, shape and orientation of the adjoining land/ocean areas play important roles in determining the specific monsoon characteristics of a given region.

The low-level circulation pattern for the Indian Ocean consists of southwest flow during the summer period and northeast flow during the winter period. When combined with the two intervening transitional periods it is convenient to use the mid-latitude convention of summer, autumn, winter, and spring season titles. It must be realized, however, that these terms applied to the tropics do not have the same connotations as when applied to the harsher extremes of mid latitudes. The approximate months of the four seasons are:

- Autumn Transition—October through November
- Winter Monsoon—December through March
- Spring Transition—April through May
- Summer Monsoon—June through September
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This section is under development and will be forwarded for inclusion in this volume.
Passage of an Upper-level Disturbance to the North of the Convergence Zone Cloud Band
Red Sea
January 1980

Key Points
1. A persistent convergence zone cloud band (CZCB) is located over the south-central Red Sea during the winter months.
2. The location of the CZCB is not disrupted by the passage of a short-wave upper-level disturbance to the north.
3. Baroclinic-zone cloud patterns in satellite imagery provide observational data on the extent to which disturbances penetrate the Red Sea region.

17 January

The early-morning DMSP picture (IC-2a) shows a typical convergence zone cloud band (CZCB) over the south-central Red Sea, extending from Port Sudan to Asmara. Fair weather conditions prevail, and the large-scale surface circulation features attending this convergence zone phenomenon are observed on the surface analysis (IC-3a and 3b), which shows the Sahara high, Sudan low, and Saudi Arabia high near their normal winter locations. (The Saudi Arabia high is an extension of the much larger Siberia high to the northeast.) Since the standard Northern Hemisphere NMC surface analysis provides only limited coverage of the Middle East, the NMC tropical surface streamline analysis (IC-3b) is included for more complete coverage of the area. Wind reports show light northerly winds directed toward the CZCB over the north-central basin, and light southerly winds over the southern basin. The streamline analysis over the Arabian Sea indicates a well-developed northeast monsoon, and the turning of a portion of this flow into the Red Sea, between the Sudan low and the Saudi Arabia high.

The surface analysis (IC-3b) shows that the CZCB consists primarily of stratocumulus, as reported at the coastal stations 01 and 02. In the satellite picture, broken stratocumulus is observed along the eastern shore, which becomes overcast with cumulus predominating along the western shore. The stratocumulus cloud deck extends inland south of Tokar, through a prominent break in the mountain barrier along the west coast called the Tokar gap. Inland, to the east of the CZCB, early morning convective clouds have developed along the higher elevations of the north-south Al Hajar mountain range.

Convective cloud lines, funneling through the Bab al Mandab (IC-2a) into the Red Sea, provide an excellent pictorial display of the turning of the surface easterlies over the Gulf of Aden to southerly flow over the Red Sea. The surface report at Aden (IC-3b), on the southwest corner of Yemen, shows cumulus and stratocumulus with bases at different levels. The bright clouds, a high-amplitude cloud deck banked up against the coastal mountains to the west and east of Aden, fair weather cumulus is observed along the coastal plains bordering on the gulf, where moisture is advected inland by onshore flow. At Ash Shihir, local winds are light and offshore, and reflect the remnants of the nighttime land breeze circulation.

Over the warm waters of the Persian Gulf (IC-2a), cloud lines are also observed where cold polar air (5°C) reported at 03 and 04 is channeled southward between the Saudi Arabia high and the low over central Iran (IC-3a and 3b). The presence of anomalous gray shades surrounding the convective cloud lines has a high aerosol/moisture content of the low-level air and a corresponding decrease in surface visibility in these areas over the water.

In contrast to the fair weather conditions prevailing over the central Red Sea region (IC-2a), an extensive low overcast area, indicating poor weather conditions, is observed to the north of Sinai along the eastern Mediterranean. The surface weather report (IC-3a) at Alexandria 05 shows overcast skies with openings, showers, and a temperature of 10°C. Intermittent light drizzle within the past hour and a temperature of 10°C is reported at Haifa 06. At Latakia 07, skies are overcast with low clouds, intermittent light rain is falling, and the temperature is 6°C. Nicosia 08, on the island of Cyprus, is also reporting overcast with openings, intermittent light rain, and a temperature of 12°C. These poor weather conditions are occurring in modified polar air which has had a westerly trajectory over the central Red Sea region (IC-2a), an extensive high over the central Red Sea, and the Sahara high over Africa.

The 500-mb analysis (IC-4b) shows that the cloudiness over the eastern Mediterranean (IC-5a) is associated with a short-wave trough passing to the north of the Red Sea. This trough has a small amplitude because it is moving over a ridge of high pressure to the south. The presence of the stratified cloud band northwest of Alexandria, however, indicates that the baroclinic zone associated with this trough is strong and extends to lower levels.

At 200 mb (IC-4a), a broad band of subtropical westerlies is observed over northern Africa and Saudi Arabia. A double wind maximum structure is shown by a second wind maximum passing north of the Red Sea, south of Arabia and the Persian Gulf. The long sinus filaments (IC-5a) passing south of the Sinai and across Saudi Arabia reflect this double wind maximum structure.

continued on page IC-6
**Case 1  Red Sea/Persian Gulf—Winter**

*Red Sea Convergence Zone Cloud Band*

The Red Sea convergence zone cloud band (CZCB) is a persistent winter climatological feature over the Red Sea that is produced by large-scale circulation patterns. The cloud band forms along the convergence zone between northerly winds on the eastern periphery of the North African anticyclone over the Sahara, and southerly winds from the northeast monsoon over the Arabian Sea, which are turned northward between the surface anticyclone over Saudi Arabia and the equatorial trough over the Sudan (IC-1a).

The CZCB forms in the southern Red Sea in September and advances to about 18°-20°N in October where it generally remains until about February, when the convergence zone begins to retreat southward (NEPRF, 1980). During undisturbed weather conditions, day-to-day movements of the CZCB are small. However, when a synoptic-scale weather disturbance penetrates the Red Sea area, the CZCB may be temporarily displaced or completely disrupted until the weather event has passed and undisturbed weather conditions again prevail. The following case study is an example of the persistence of the CZCB during the passage of a short-wave disturbance across the northern region of the Red Sea.

Reference


![IC-1a. Typical Surface Streamline Map of January](IC-1)
IC-3a. NMC Surface Analysis. 0600 GMT 17 January 1980.

IC-3b. NMC Tropical Surface Streamline Analysis. 0600 GMT 17 January 1980
200 mb

1C-4a NMC 200-mb Analysis. 1200 GMT 17 January 1980.

500 mb

1C-4b NMC 500-mb Analysis. 1200 GMT 17 January 1980
18 January

The DMSP picture (IC-7a) on this day reveals that the CZCB has not moved from its location between Port Sudan and Asmara. As on the previous day (IC-2a), fair weather prevails over the Red Sea. The large-scale surface features (IC-7b and 7e) attending the CZCB are also identifiable: the Sahara high (which shows as a weak ridge of high pressure across North Africa), the Saudi Arabia high, the Sudan low, and the northeast monsoon flow over the Arabian Sea. The continued presence of cloud lines in the Bab al Mandab (IC-7a) shows that the northeast monsoon flow into the Gulf of Aden and the Red Sea has not been disrupted. Thus, there has been no major change in the surface circulation pattern over the southern Red Sea. This is not the case, however, along the northern border of the Red Sea region.

The cloud cover (IC-7a) associated with the upper-level disturbance passing to the north of the Red Sea has become more widespread, and a line of enhanced convection has developed over northern Saudi Arabia. At 500 mb (IC-6b), the short-wave trough (see IC-4b) has sharpened significantly during the past 24 hours and accounts for the enhanced convection observed over northern Saudi Arabia. The deepening of the 500-mb trough is due to increased cold air advection upstream. Note also that the trough is in phase with the sharp high-latitude trough to the north (50°N, 50°E). In the satellite picture, the comma-shaped cloud vortex over the Caspian Sea is located at the base of the high-latitude trough. The presence of this cloud vortex indicates that a deep baroclinic zone extends from the polar trough to Saudi Arabia.

At 200 mb (IC-6a), the broad band of zonal subtropical westerlies continues to show a double wind maxima structure. Only faint jet stream cirrus is observed over the north-central Red Sea in the satellite picture on this day, in comparison to the double jet cirrus streak pattern 24 hours earlier.

The line of enhanced convection (IC-7a) over northern Saudi Arabia indicates that the baroclinic zone associated with the 500-mb short-wave trough has reached to surface levels. This increases the potential for surface frontogenesis in the region. Although the surface pressure analysis does not show frontogenesis, a distinct wind shift line S1–S2 is in evidence as shown on the surface analyses (IC-7b and 7d). Note that showers are reported along the wind shift line. The Saudi Arabia high (IC-7c) has shifted to the southeast in response to the intrusion of the 500-mb trough to the north.

With the passage of the upper-level disturbance to the north of the CZCB, it is significant that the location of this band has not been disrupted. A pronounced deepening of the short-wave trough occurred; however, its influence remained well to the north of the CZCB region, as shown by the cloud patterns in the satellite pictures.
IC-6a. NMC 200-mb Analysis. 1200 GMT 18 January 1980.

500 mb

IC-6b. NMC 500-mb Analysis. 1200 GMT 18 January 1980.
**Case 2  Red Sea/Persian Gulf—Winter**

*Red Sea Convergence Zone Cloud Band Displacement from Normal Winter Location*

The Red Sea convergence zone cloud band (CZCB) is typically located near 18°–20° N during the winter. Under fair weather conditions, day-to-day variations in the position of the CZCB are small because the winds are generally light and variable along the Red Sea Convergence Zone (RSCZ). The displacement of the CZCB from this location indicates a change in the normal winter synoptic-scale circulation over the region. On occasion, a portion of the equatorial trough (Sudan low) will be observed over the northern Red Sea (1C-9a). This brings southerly winds around its eastern periphery which advance the RSCZ to the north of its normal position. A further evolution is for the Sudan low to move eastward, across the Red Sea to Saudi Arabia, in response to upper-level troughs or depressions crossing the eastern Mediterranean. Under such circumstances northeasterly winds appear over the northern Red Sea and the RSCZ recedes southward toward its normal winter location. When northeasterly flow is especially strong the RSCZ may be displaced southward to 13°–15° N for periods of several days.

**References**

Solot, Samuel B., 1950, General circulation over the Anglo-Egyptian Sudan and adjacent regions, Bull 41, S M, p 88

Pronounced Northward Displacement of the CZCB by a Low Pressure Development in the Equatorial Trough (Sudan Low)

Red Sea
January 1980

22 January

The DMSP picture (1C-10a) for 17 January 1980, from Case 1 (1C-2a), shows the Red Sea and adjacent land areas on a typical winter fair weather day. Except for the thin filaments of jet stream associated cores passing to the south of Sinai and across Saudi Arabia, the only major cloudiness over the Red Sea is the CZCB. The CZCB is at its normal winter position, near Port Sudan. Five days later, on 22 January, the DMSP picture (1C-11a) shows the CZCB near 25°N, almost 300 n mi north of its normal winter position. In addition, a band of cumuliform cloudiness, followed by dense stratus and fog, extends across the northern Arabian Peninsula which suggests the presence of a front.

The NMC surface analysis (1C-12a) confirms the presence of a weak baroclinic zone T1 over the northern Arabian Peninsula. Note that the baroclinic zone does not extend across the Red Sea, but curves abruptly northward. This abrupt change in direction is important to recognize because in a cursory examination of the satellite picture a likely misinterpretation would be to include the CZCB as part of the baroclinic zone cloud band. The baroclinic zone is the location of a dissipating frontal system which had moved into the area from the eastern Mediterranean. Surface reports O1, O2, and O3 of rain and fog with obscured skies reveal that the baroclinic zone is an operationally important weather producer.

Further evidence that the two cloud bands are not part of the same baroclinic zone is provided by the NMC surface streamline analysis (1C-12b). This analysis shows the typical winter anticyclones over the eastern Arabian Peninsula and northern Africa. However, the equatorial trough over central Africa extends much further north than normal and shows a closed cyclonic circulation L1 over northern Sudan. Southerly flow around the eastern periphery of this low and the turning of the northeast monsoon from the Gulf of Aden northward through the Bab al Mandab produce a band of southeasterlies eventually extending to the northern portion of the Red Sea (1C-13b). This surge in the southeasterlies displaces the CZCB far to the north of its normal winter location, as shown on the satellite picture (1C-13a).

At upper levels, the NMC 300-mb analysis (1C-14a) shows a deep polar low L2 extending to lower latitudes over the eastern Mediterranean. A strong polar jet stream is located south of the low, with an elongated 110-kt jet streak PJS1 extending from northeast Africa to the Persian Gulf. At 500 mb (1C-14b), there is a short-wave trough T2 advancing toward the Red Sea in the strong westerlies across northern Africa. The minor trough T1, at 850 mb over the northern Arabian Peninsula (1C-14c), is the location of the baroclinic zone observed on the surface analysis (1C-12a). Note the packing of isotherms behind the trough T1, which defines the location of the baroclinic zone.

The presence of the ridge aloft at 850 mb (1C-14c) over the surface location of the Sudan low L1 confirms the thermal-low structure of this system. However, the strong cold air advection associated with the trough T2 to the west, and the fact that the trough extends almost to the latitude of the Sudan low, suggest that intensification of the low L1 may occur as the short wave crosses to the north. The NMC surface streamline analysis 12 hours later (1C-13b), near the daytime surface wind speed maximum, shows stronger winds around the northeastern periphery of the Sudan low L1, suggesting that this low is the primary influence in maintaining the CZCB at its northern location. In addition, numerous reports of dust (weather symbol S) raised by the surface winds, indicate that the low is deepening.

At 300 mb (1C-15a), 12 hours later, the polar low L2 has moved slowly to the southeast, and the jet streak pattern to the south has consolidated into a short, strong (110 kt) jet streak PJS1 over the Red Sea. The 300-mb short-wave trough T2 (1C-15b) advances across the Red Sea and is followed by a new short-wave trough T3. Note that the northern portion of T2 is located in the left front quadrant of the 300-mb jet streak PJS1 a favorable area for low-level cyclogenesis. These upper-air conditions have contributed to the formation of the closed low L3 at 850 mb (1C-15c). The Sudan low L1, at this time, is located just in advance of the 500-mb trough T2 and, as indicated on the surface analysis (1C-13b), shows definite signs of deepening.

A comparison of the FNOC 36-hi 500-mb prognosis (1C-17a) and the initial 500-mb analysis (1C-16a) shows that the strong polar westerlies (tight contour gradient) will be maintained across the northern Arabian Peninsula. The low L2 (1C-16a) is forecast to move to the eastern Mediterranean (1C-17a), and the short-wave trough T2 is replaced by the upstream trough T3, as it deepens and advances eastward. With the Sudan low L1 coming under the influence of increased southeasterly flow aloft, the stage is set for this low to advance across the Red Sea.

continued on page 1C-18
Pronounced Northward Shift of the CZCB

Red Sea/Persian Gulf Winter Case 2


IC-11
IC-12a. NMC Surface Analysis. 0600 GMT 22 January 1980

IC-12b. NMC Tropical Surface Streamline Analysis. 0600 GMT 22 January 1980.
Pronounced Northward Shift of the CZCB

EGYPT

ARABIAN PENINSULA

IC-13a F-4. DMSP LF Log Enhancement. 0732 GMT 22 January 1980 (Note this picture is a repeat of IC-11a.)

surface

IC-13b NMC Tropical Surface Streamline Analysis 1200 GMT 22 January 1980
300 mb

500 mb

850 mb

IC-14a. NMC 300-mb Analysis. 0000 GMT 22 January 1980.

IC-14b. NMC 500-mb Analysis. 0000 GMT 22 January 1980.

IC-14c. NMC 850-mb Analysis. 0000 GMT 22 January 1980.
Pronounced Northward Shift of the CZCB

Winter Case


IC-15
IC-16a. FNUC PE Initial 500-mb Analysis. 0000 GMT 22 January 1980.
Pronounced Northward Shift of the CZCB

Winter

Case

IC-17a FNOC PF 36-hr 500-mb Prognosis Valid 1200 GMT 23 January 1980.

1C-17
On the early morning DMSP picture (1C-19a), the spiral cloud pattern L1 shows that the Sudan low has crossed the Red Sea and is located over central Saudi Arabia. Note also that the CZCB has been displaced southward to a position just north of 20°N. This represents a movement of the CZCB of about 240 n mi in 24 hours (see 1C-11a). An examination of the NMC surface streamline analysis (1C-18a) reveals the reason for the pronounced displacement. (Note: the NMC surface streamline analysis for 0600 GMT was not available.) As the Sudan low L1 crossed the Red Sea, northwesterly flow developed over the northern Red Sea and, by 1200 GMT (1C-18b), strong northwesterlies (20-30 kt) are reported over the Red Sea down to 20°N. Twenty-four hours earlier (1C-13b), southeasterlies extended as far north as 26°N over the same area. The development of numerous convective cloud lines north of the CZCB (1C-19a) indicates the advection of colder air over the warmer sea surface and serves as an indicator of the northwesterly flow advancing southward over the Red Sea.

At 300 mb (1C-20a and 21a), the polar low L2 advances to the eastern Mediterranean, as forecast (1C-17a), and strong polar westerlies are located across the Arabian Peninsula. At 500 mb the short wave T2 (1C-20b) is replaced by the new trough T3 (1C-21b), as forecast. During this period the Sudan low L1 advances across the Red Sea (1C-18a and 18b) in response to the southwesterly flow aloft. With the persistence of the jet streak PJS1 over the Red Sea region, the northern part of the trough T3 is located in the front left quadrant of the jet streak at 300 mb (1C-21a), and deepening to lower levels is enhanced, as reflected by the persistence of the 850-mb low (1C-20e and 21e). As a result, northwesterlies develop over the northern Red Sea and, by 1200 GMT, they extend to 20°N.

continued on page 1C-22
IC-18a. NMC Tropical Surface Streamline Analysis. 0000 GMT 23 January 1980.

Pronounced Northward Shift of the CZCB

Red Sea/Persian Gulf
Winter
Case 2


IC-19
Pronounced Northward Shift of the CZCB
Summary
The movement of the Sudan low from Africa across the Red Sea to central Saudi Arabia, in response to the eastward progression of upper-level troughs extending to lower latitudes, has been shown to be associated with a sudden northward and then southward shift of the CZCB. The weather occurring with this movement was the result of a complex interaction of flow patterns extending from the surface to upper levels.

Through satellite analysis, a shift from the normal position of the CZCB provided the clue to an important change in weather affecting a large portion of the Middle East. The charts on page 1C-22 and satellite picture on page 1C-23 are useful in reviewing some of the significant features. Fog and stratus that had developed over the northern Arabian Peninsula as the moist Mediterranean air moved in behind the original baroclinic zone (1C-13a) was further enhanced on 23 January (1C-23a) by southerly flow around the eastern periphery of the Sudan low L1 as it advanced to central Saudi Arabia. From a larger perspective, the 850-mb flow (1C-22b and 22c) produced warm air advection over Iran which was overrunning cold arctic air, streaming southward from the surface anticyclone north of the Black Sea (1C-22a). This produced the widespread poor weather conditions with low ceilings and heavy snow over that region. Evidence of the intensity of the cold, cross-isobaric arctic flow can be seen in the closely-spaced convective cloud lines over the Caspian Sea (1C-23a). Moist air from the Persian Gulf and the Arabian Sea has also resulted in thunderstorm and shower reports (1C-22a) over the higher elevations of the Zagros Mountains bordering on Iran.

To the east, the 850-mb low (1C-22b and 22c) produced northerly winds which combined with the flow around the Sudan low (1C-18a and 18b) to produce strong northerlies in the Red Sea, driving the CZCB southward.

850 mb

Pronounced Northward Shift of the CzCB

Winter

Case 2

R: < (S> stratus/fog

SAUDI ARABIA

Persian Gulf

Zagros Mountains

IRAN

IC-23a 1-4 DMSP LI 1 og Enhancement 0712 GMT 23 January 1980. (Note this picture is a repeat of IC-19a.)
Case 3  Red Sea/Persian Gulf—Winter

Subtropical Jet Streams and Surface Anticyclones

The mean meridional circulation in the Northern Hemisphere during winter (IC-25a) shows two prominent jet stream systems: the polar-front jet stream and the subtropical jet stream. At mid latitudes, the polar jet stream is characterized by strong horizontal mixing at mid levels and weak subsidence at low levels. Since the subtropical jet stream is located over the descending branch of the Hadley cell, horizontal mixing at mid levels, as observed with the polar jet, is absent and the development of deep baroclinic zones below the subtropical jet are inhibited.

Subsidence in the descending branch of the Hadley cell accounts for the subtropical high-pressure belt along 30°N. The subtropical high-pressure belt is a persistent climatological feature at low latitudes. From a forecast point of view, however, it is important to recognize that high-pressure centers in the subtropical belt can undergo dissipation and new formation because of the dynamics associated with the subtropical jet stream flow (Reiter, 1963). These effects are most pronounced when deep polar troughs in the westerlies extend to low latitudes.

References
18 December

The NMC surface streamline analysis for 0000 GMT (IC-26c) shows the typical winter anticyclone over the Arabian Peninsula. The surface high is weak and the areal extent of the anticyclonic circulation is outlined by the pattern of the surface winds. Fair weather prevails over the Arabian Peninsula under the influence of this surface anticyclone.

Although the surface high over the Arabian Peninsula is weak, the height contour pattern at 700 mb (IC-26b) shows a distinct ridge aloft. This ridge is located ahead of a deep polar low LI, which extends to the 200-mb level (IC-26a). On the 200-mb analysis, note that the polar jet associated with the low LI has apparently merged with the subtropical jet to the south. A single 110-kt jet streak PJS/SJS appears over the northern Arabian Peninsula where the two jets have merged. Jet stream cirrus on the DMSP infrared picture (IC-27a), however, reveals the double structure of the merged jets. The polar jet cloudiness is situated in appearance with numerous small-scale transverse cloud bands. The subtropical jet cloudiness shows cirrus cloud streaks and filaments oriented parallel to a denser band of cirrus along the northern edge. This is an excellent example of the appearance of subtropical jet stream cirrus in satellite imagery.

An examination of the location of the ridge at 700 mb over the Arabian Peninsula (IC-26b) with respect to the PJS/SJS at 200 mb (IC-26a) shows that the ridge is under the right-front quadrant of the 110-kt jet streak, which is an area of upper-level convergence and lower-level divergence. As a result, subsidence associated with the low-level divergence under the merged polar subtropical jet acts to enhance the ridging observed at 700 mb; however, the subsidence is not pronounced because only a weak anticyclonic circulation is observed at the surface (IC-26c).

By 1200 GMT, the 110-kt jet streak PJS/SJS at 200 mb (IC-28a) has advanced eastward over the Persian Gulf, and the central and southern Arabian Peninsula is no longer under the influence of the right-front quadrant of this jet streak. The consequences of this change aloft are the sharp reduction in the amplitude of the 700-mb ridge (IC-28b) over the southern Arabian Peninsula and a corresponding weakening of the surface anticyclone (IC-28c). The enhancement of the low-level ridge and its subsequent weakening is in accordance with Reuter’s comments (see page IC-25) on the change in intensity of surface anticyclones because of changes in the dynamics associated with the subtropical jet stream.

On the satellite picture (IC-29a), the cirrus over the central Arabian Peninsula has increased in response to a new 110-kt polar jet streak crossing the Red Sea at 200 mb (IC-28a). The dense cirrus shield observed on the satellite picture is typical of polar jet cirrus. Intermittent high rain at 01 (IC-28c) indicates that baroclinic instability and deep convection extend to low levels beneath the jet.

19 December

On the NMC 200-mb analysis at 0000 GMT (IC-30a), a broad, merged jet stream system extends from northeast Africa to India. Prominent 130-kt jet streaks PJS/SJS are located over the Arabian Peninsula and northwest India. The deep polar low LI has become stationary over the eastern Mediterranean. The NMC surface streamline analysis (IC-30c) shows a very weak anticyclonic circulation and a flat high-pressure gradient over the eastern and southern Arabian Peninsula—the center of the surface high over this area is located to the northeast over Afghanistan. This indicates that there is no localized area of subsidence extending through a deep layer of the atmosphere over the southern Arabian Peninsula to enhance surface high pressure, as occurred on the previous day (IC-26b and 26c). There is a ridge at 700 mb (IC-30b) over the southern Arabian Peninsula; however, it is a reflection of the general anticyclonic pattern which extends to 200 mb in advance of the upper low LI.

Fair weather prevails over the southern Arabian Peninsula, which is under the influence of the general anticyclonic flow aloft. On the satellite picture (IC-31a), the isolated cirrus band located over central Saudi Arabia is anvil cirrus. The general southwest-northeast orientation of the cirrus streaks is in response to the 200-mb (IC-30a) SJS (J1-J1) which extends from Africa, across the Red Sea, to central Saudi Arabia. Note also the development of the low-level convergence zone cloud band (CZCB) over the central Red Sea (see Case 1).

Important Conclusions
1. High-pressure centers in the subtropical belt undergo changes in intensity because of the dynamics associated with jet streaks in the upper atmosphere.
2. The changes in intensity of surface high-pressure centers are most pronounced when the subtropical jet is associated with deep polar troughs in the westerlies extending to low latitudes.
3. On satellite imagery, cirrus cloudiness provides details on jet streak structure in areas of polar subtropical jet stream surface anticyclone teleconnections.
IC-26a. NMC 200-mb Analysis. 0000 GMT 18 December 1979.

700 mb

IC-26b. NMC 700-mb Analysis. 0000 GMT 18 December 1979.

surface

IC-26c. NMC Tropical Surface Streamline Analysis 0000 GMT 18 December 1979.
Subtropical Jet Stream and Surface Anticyclones

Winter Case 3

IC-27a 1-4 DMSP TI: Normal Enhancement. 1745 GMT 17 December 1979

700 mb


surface

IC-28c. NMC Tropical Surface Streamline Analysis. 1200 GMT 18 December 1979
IC-29a F-4. DMSP IF: Normal Enhancement. 1725 GMT 18 December 1979
Case 4 Red Sea/Persian Gulf—Winter

Winter Storms over the Arabian Peninsula

During the cooler season, depressions which affect the Arabian Peninsula enter the region from the Mediterranean. Most of these depressions tend to fill and weaken as they progress inland and, in general, they follow an easterly track. Fronts associated with the disturbances may show sharp changes of wind direction and have heavy squalls, but as a rule there is very little or no rain. Downdrafts from thunderstorms along squall lines often generate vigorous dust storms at the surface.

The following case study covers part of the same period, 18–19 December 1979, as the previous case (Case 3). In the previous case, the emphasis was on the changes in intensity of the surface anticyclone over the southern Arabian Peninsula in response to dynamics of the subtropical jet stream flow. This case examines a winter storm development in a Mediterranean depression that moves inland over the northern Arabian Peninsula. Rapid intensification of the depression occurs following the movement of a jet streak around the base of the upper-level trough in which the depression is located. Of particular interest is the development of a squall line in response to the dynamics of a merged polar jet and subtropical jet in advance of the trough aloft.

Since the supporting baroclinic zone with the subtropical jet stream exists only in the upper troposphere beneath the jet core, the wind field at middle levels is only barely affected and the potential for instability and growth of deep convection is inhibited. However, a polar jet stream with its characteristic deep tropospheric baroclinic zone in close proximity to the northern border of a subtropical jet can provide the mechanism for convection to develop through a deep vertical layer. Convection is sharply inhibited south of the subtropical jet core beginning in the region where wind speeds decrease abruptly.
17 December
The NMC 200-mb analysis for 1200 GMT (IC-34a) shows an upper-level trough LI in the westerlies extending to low latitudes, and a strong subtropical jet stream to the south with a jet streak maximum over the Red Sea and one further east over the Persian Gulf. An examination of the DMSP infrared picture (IC-35a), acquired about 6 hours after chart time, shows typical anticyclonically curved subtropical jet stream cirrus over the south-central Arabian Peninsula. In addition, the presence of the stratified band of cirrus over the north-central Arabian Peninsula is characteristic of the polar jet stream. The proximity of these cirrus bands indicates that the polar westerlies from the Mediterranean have merged with the subtropical flow over the central Arabian Peninsula. This accounts for the analyzed single PJS/SJS1 wind maximum over the Red Sea. Upstream of the trough LI at 200 mb (IC-34a), a 90-kt polar jet streak PJS2 in the westerlies is digging southward toward the subtropical jet. At 300 mb (IC-34b), this wind maximum increases to 150 kt.

At lower levels over the eastern Mediterranean, there is a closed low LI at 850 mb (IC-36a) and at the surface (IC-36b). Although the surface low is not particularly deep (1008 mb), the satellite picture (IC-37a) shows a squall line, exhibiting the characteristic line of global convection clouds, in progress ahead of the surface cold front. This indicates strong convective instability aloft in the flow in advance of the upper-level low which is strongly diffusive in the mid through upper troposphere (IC-34a, 34b, and 36a). In the satellite picture, the decrease in cloud cover inland reveals that the surface warm front (IC-36b) is weak and dissipating. Note also the southerly winds on the surface streamline analysis (IC-36a) over the southern Red Sea and the advection of warm, moist air at 850 mb (IC-36a) northward along the western periphery of the high over the Arabian Peninsula. This is a primary source of moisture for convective developments over the central Arabian Peninsula.

18 December
On the early morning DMSP visible picture (IC-39a), the absence of organized cloudiness over western Iraq, which showed baroclinic zone clouds 12 hours earlier (IC-37a), indicates that the surface low LI over the eastern Mediterranean has not intensified. This is confirmed by the 0600 GMT surface analysis (IC-38d) which shows that the surface low LI has remained weak (1008 mb) and advanced slowly eastward during the preceding 12 hours. On the satellite picture, the overcast area south of the Caspian Sea is upslope fog and stratus along the Elbur Mountains produced by the southerly flow around the eastern periphery of the surface low LI. The most significant weather change in the region has occurred over the central Arabian Peninsula, where local areas of deep convection have been initiated and cumulonimbus have developed.

The convective instability is occurring in the region under the merged polar westerlies and subtropical jet stream at 200 mb (IC-38a), where the moist, warm air has advanced over the Arabian Peninsula at 850 mb (IC-38c). Note that the location of the jet streak core, as superimposed on the satellite picture (IC-39a), is not the dividing line between the convectively unstable region to the north and the mostly clear region over the southern Arabian Peninsula, as might be expected. The separation is more precisely defined by the axis of maximum anticyclonic vorticity, that is, where the jet force winds at 200 mb decrease in speed to the south of the jet core most rapidly. This occurs near 20 °N, or about 5 degrees south of the jet core, and is roughly where the change from deep convection to mostly clear occurs on the satellite picture. At 300 mb (IC-38b), the polar jet streak PJS2 continues to move southward in the westerlies that have merged with the subtropical jet over the Arabian Peninsula.

On the late afternoon DMSP infrared picture (IC-41a), jet-associated cirrus covers the central Arabian Peninsula from the Red Sea to the Persian Gulf. This jet cirrus has developed in the newly formed 110-kt jet streak PJS2/SJS2 at 200 mb (IC-40a). The new jet streak developed as the polar jet streak PJS2 in the westerlies advanced around the base of the 200-mb low LI and merged with the subtropical jet over the central Arabian Peninsula. The merger is more clearly evident from a comparison of the isotach analysis over the Red Sea at 300 mb (IC-40b) and the corresponding isotach analysis (IC-38b) 12 hours earlier. Note that the jet streak PJS/SJS1 has moved eastward beyond the Persian Gulf.

On the satellite picture (IC-41a), cirrus debris from convective activity below the jet extends across the Persian Gulf. Intermittent light rain from convective buildups beneath the jet was reported at 1200 GMT (not shown). However, the surface report 01 on the 1800 GMT surface streamline analysis (IC-40d) shows dust in suspension. In all probability, the dust was raised by mesoscale convective activity in the region.

The cumulonimbus buildups and precipitation observed are along the eastern Mediterranean coast (IC-40d) indicate that the surface low LI is intensifying as it moves eastward. The bright, dense overcast (baroclinic zone cloudiness) over the eastern Mediterranean and northwest Iraq (IC-41a) is associated with the convective developments along the coast and the short-wave trough TL which has developed along the southeastern periphery of the 850-mb low LI (IC-40c).

continued on page IC-42
IC-34a  NMC 200-mb Analysis. 1200 GMT 17 December 1979.

300 mb

IC-34b  NMC 300-mb Analysis 1200 GMT 17 December 1979
I.C.-37a. 1-4. DMSP TI Normal Enhancement. 1745 GMT 17 December 1979. (Note this picture is a repeat of IC-35a.)

IC-39
Mediterranean Sea

Polar frontal zone

Cloudiness

toward Peninsula

Cirrus debris

ARABIAN PENINSULA

Caspian Sea

19 December

The surface streamline analysis at 0600 GMT (IC-42d) shows that the low LI over the eastern Mediterranean has moved inland, and southerly flow extends from the southern Red Sea to the northern Persian Gulf ahead of the surface low. At 200 mb (IC-42a), the wind speed maximum PJS/SJS2 has advanced eastward, and cyclonically-curved southwesterly flow has developed ahead of the low LI over Iraq. Pronounced cyclonic flow is also occurring in this area at 300 mb (IC-42b). The most pronounced cyclonic flow, however, occurs over southern Iraq at 700 mb (IC-42c). As the surface low LI advances inland, it is in a favorable location (southwesterly cyclonic flow aloft) for further development. The reports of showers and rain along the northern portion of the surface low LI (IC-42d) indicate that development may already be occurring.

The strong southwesterly flow ahead of the upper-level low LI at 700 mb (IC-42e) has resulted in an increase in the amplitude of the ridging over the southern Arabian Peninsula. On the DMSP visible picture (IC-43a), early morning convective activity is observed over central Arabia; however, it is suppressed compared to the early morning convective activity observed on the DMSP picture 24 hours before (IC-39a). The reduced convective activity is due to the increased ridging and anticyclonic flow aloft over the region.

By late afternoon, a major change in the weather has occurred over the Arabian Peninsula. The DMSP infrared picture (IC-45a) shows that a large, winter storm spiral cloud vortex has developed over Iraq, and deep convection (Cb's) is occurring along a sharp baroclinic zone which extends to the southwest over the Arabian Peninsula. The 200-mb analysis for 1200 GMT (IC-44a) shows that the low LI has become a mobile trough; however, closed centers are observed at 300 mb (IC-44b) and 700 mb (IC-45b) which indicate an intense disturbance at mid-tropospheric levels.

The reason for the rapid development can be inferred from the change in the arrangement of the merged jet streaks PJS/SJS2. A separate polar jet streak PJS2 is observed at 300 mb (IC-44b), and the subtropical jet streak SJS2 at 200 mb (IC-44a) has advanced eastward relative to the jet streak PJS2. A close examination of the arrangement of these two jet streaks shows that the right rear quadrant of the jet streak SJS2 is superimposed over the left front quadrant of the jet streak PJS2. It is well known that the right rear quadrants and the left front quadrants of jet streaks are cyclogenetic areas. Therefore, the superposition of the cyclogenetic area of the SJS2 at 200 mb over the cyclogenetic area of the PJS2 at 300 mb accounts for the rapid development of the disturbance over northwest Iraq which was located in this favorable cyclogenetic region.

The absence of a deep closed low LI on the surface analysis (IC-45c), which would be expected with the pronounced spiral cloud vortex on the satellite picture, reveals that the storm is primarily a mid- to upper-tropospheric disturbance. There is a well-defined wind shift line SI at the surface across central Arabia associated with the baroclinic zone aloft, as indicated on the surface contour analysis (IC-45c) and the surface streamline analysis (IC-45d), however, there are no corresponding sharp surface temperature gradients which would indicate a polar front-type surface frontal zone development. Surface reports show that the most pronounced temperature changes occur around the northern periphery of the surface low LI, where the disturbance borders on the colder air masses to the north. In addition, the sharp, ragged rear edge of the cloudiness over central Arabia, on the satellite picture (IC-45a), is more characteristic of the appearance of squall line development in a baroclinic zone aloft than of a surface cold front.

Important Conclusions
1. Polar jet streaks in the westerlies (300 mb) need to be monitored as they progress in the flow around major troughs in which short-wave disturbances are located, because they can trigger the rapid development of short-wave disturbances into significant weather producing storms.

2. Convection through a deep layer is not normally associated with the subtropical jet when it is well to the south of the polar jet; however, a merger of the two jet systems can produce ideal conditions for deep convection.

3. When deep convection is observed south of the core of the subtropical jet stream, convection will be sharply inhibited equatorward of the axis of maximum anticyclonic vorticity associated with the jet. This axis is located in the region where the jet-force winds decrease most rapidly to the south of the jet core.
surface
This section is under development and will be forwarded for inclusion in this volume.
Case 1  Red Sea/Persian Gulf—Summer

Development of Convection in Southwest Monsoon Flow over the Southern Arabian Peninsula

As the sun advances into the Northern Hemisphere in summer, a major change occurs in the surface pressure pattern over the Red Sea/Persian Gulf region. The winter anticyclone over the Arabian Peninsula is replaced at lower levels by a thermal low (1E-la). This thermal low is capped by an anticyclonic circulation aloft which effectively inhibits the development of deep convection. The Saharan anticyclone over northern Africa (1E-la) shifts eastward and its long axis is oriented north-south over the eastern Sahara. As a result of the northerly circulation between the Saharan anticyclone and the Arabian thermal low, hot, dry northerly winds penetrate to the Gulf of Aden during the summer months.

By late June, the southwest monsoon is established over the Arabian Sea. As the southwest monsoon advances northward over East Africa, the intertropical convergence zone (ITCZ) moves into the Northern Hemisphere (1E-1b). North of the surface ITCZ there is the northerly current composed of hot, dry air between the Saharan anticyclone and the Arabian thermal low. South of the ITCZ, the southwest monsoon brings warm, moist air across Somalia and the Arabian Sea. Generally the southwesterlies across Somalia do not contain much moisture because most of it is lost in the long meridional trajectory over the uplands of East Africa and further south. In addition, the flow over the Kenya-Somalia area is strongly difflluent so that low-level subsidence prevails. On occasion, however, moist air is advected across the southern Arabian Peninsula land mass, and heavy showers are experienced.

Reference
Solot, Samuel B. , 1950 General circulation over the Anglo-Egyptian Sudan and adjacent regions Bull AMS, 31, pp 91
Convective Buildups in the Southwest Monsoon Flow
Southern Arabian Peninsula
June 1979

29 June

The DMSP visible picture at 0809 GMT (IE-2a) shows the typical cloud-free summer view of the Arabian Peninsula and adjacent areas, and provides an unusually clear display of the major rivers and desert regions. In Egypt, the Nile River stands out prominently against the adjacent land, from the Nile Delta on the Mediterranean to the Sudan. Similarly, the Tigris and Euphrates Rivers in Iraq are readily identified in the imagery. Where the rivers stand out in marked contrast to the land areas, the desert regions, such as the Libyan Desert, the Syrian Desert, the plateau region of the An Nafud, and the Empty Quarter Desert, are displayed as uniform light tone areas. Finally, the land areas to the west and east of the Red Sea show irregular patterns of light and dark tones, which reveal the large variations in soil, rock formation, and vegetation of the region, in the visible mode.

The NMC surface streamline analysis for 1200 GMT (IE-3b) shows a well-developed thermal low over the Persian Gulf and northeasterly flow across the Arabian Peninsula to the southern Red Sea. The limitation of the thermal low to the lower troposphere with an overlying anticyclone over the Arabian Peninsula is illustrated by comparing the distribution of the pressure centers at upper levels with respect to the surface heat low and trough positions. At 850 mb (IE-3a) a trough T1 extends over the Persian Gulf to northern India, and a weak anticyclone is located over the Arabian Peninsula. At 700 mb (IE-3d) the anticyclone over the Arabian Peninsula is more intense and the trough T1 is weaker. At 500 mb (IE-3c) the region from the Red Sea to western India is dominated by the anticyclone circulation aloft.

This summer large-scale circulation pattern aloft and at the surface is generally unchanging. The extreme surface heating typical of the land areas adjacent to the Red Sea during the summer is revealed by the temperature reports (IE-3b), which range from 33° to 39° C (91° to 102° F). Strong local effects, such as dust storms, tend to be the dominant phenomenon observed in the vicinity of the Red Sea. Note the numerous reports of suspended dust and haze to the west of the Red Sea.

Suspended dust occurs regularly over the southern Red Sea. In the satellite picture (IE-2a), suspended dust (light gray shades) is observed south of 20° N. On the western coastline, a plume of dust extends from the Tokar gap over the Red Sea. This break in the terrain along the western shore is where dust generated inland can move freely over the Red Sea. Typically, the suspended dust moving out over the Red Sea through the Tokar gap is dust raised by convective activity to the west over the northern Sudan and advected eastward by the prevailing flow. Observations of suspended dust (S) raised by convective activity over the Sudan are indicated by surface reports (IE-3b). There are also surface reports of suspended dust to the north and west of the Persian Gulf. The satellite picture shows several long, narrow, northwest to southeast oriented dust plumes just north of the Persian Gulf and an accumulation of dust over the central Persian Gulf. This dust is not raised by convective activity; it is the result of strong prevailing northeasterlies (shanal) over the area.

As a result of the northerly circulation between the Saharan anticyclone and the Arabian thermal low, hot, dry, northerly winds penetrate to the Gulf of Aden during the summer months (see schematic IE-1b). On occasion, however, the southwest monsoon flow extends northward across the Gulf of Aden and the southern Arabian Peninsula. This brings warm, moist air with thunderstorms and showers to the southern Arabian Peninsula region. The southwest monsoon flow rarely penetrates more than several hundred kilometers (150-250 n mi) inland.

On the satellite picture (IE-2a), cumulus clouds are observed over the Yemen Highlands and along portions of the elevated topography of northern Oman. Patches of early morning fog and stratus are also located off the coasts of Yemen and Oman. These are signs of an incursion of moist southwest monsoon air over the southern Arabian Peninsula. The satellite picture also shows an extensive area of convective clouds from the Sudan, across Ethiopia, to the Somalia coast, which is additional evidence of the advance of moist southwest monsoon air over East Africa.

Although the surface streamline analysis (IE-3b) does not show direct airflow from East Africa across the Gulf of Aden to the southern Arabian Peninsula, such a flow pattern did exist during the preceding 24 hours (not shown). A close examination of surface reports along the southern Arabian Peninsula, which are about 4 hours after the picture time, reveal that cumulonimbus and showers have developed over the Yemen Highlands. The strong, gusty winds produced by these synoptic-scale convective systems are responsible for numerous dust storms and the advection of dust over the Gulf of Aden during the summer.

Important Conclusions
1. Over the Arabian Peninsula the anticyclone of winter is replaced in summer at lower levels by a thermal low. Above the thermal low an anticyclonic circulation continues to persist.

2. Strong local effects, such as dust storms, tend to be the dominant phenomenon observed.

3. Convective clouds and showers over the Yemen Highlands and elevated terrain of Oman are indicators of an incursion of moist southwest monsoon air over the southern Arabian Peninsula. This flow is strictly a low-level phenomenon (850 mb and below).
Convection over the Southern Arabian Peninsula

850 mb

I-E-3a. NMC 850-mb Analysis 1200 GMT 29 June 1979

Surface

I-E-3b. NMC Tropical Surface Streamline Analysis 1200 GMT 29 June 1979
Case 2  Red Sea/Persian Gulf—Summer

Red Sea Region Duststorms

The Haboob, a regional term which originated in the Sudan of East Africa, is a duststorm produced by convective (thunderstorm) activity. Downbursts and gust fronts from these storms generate dust plumes that have a distinct leading edge and appear as a wall of dust. Haboobs are primarily a summer phenomenon, with a maximum in June, and they occur most frequently in late afternoon. The average wind speed accompanying Haboobs is 25-50 kt. Dust may be carried upwards to form a cloud of dust often extending from the ground to 15,000 ft or higher.

Under certain large-scale thunderstorm-generating weather patterns over the Sudan, such as a tropical disturbance, dust raised by complexes of convective activity associated with the disturbance may evolve into a widespread duststorm. This occurs when a deep polar trough in the westerlies passes to the north of the tropical disturbance, and the raised dust is picked up in the southwesterly flow ahead of the trough. The raised dust forms a huge cloud of dust which is then advected over the Red Sea. As a result, visibilities can be severely reduced over a large area of the Red Sea.
12 June
The NMC 300-mb analysis at 1200 GMT (1E-6a) shows a polar trough T1 extending over the eastern Mediterranean to Africa. The mid-latitude westerlies along the base of the trough T1, just north of the Red Sea, appear to have merged with the subtropical jet stream SJS extending across the northern Arabian Peninsula. At 500 mb (1E-6b), the base of the trough T1 is farther advanced over the eastern Mediterranean than at 300 mb, and northwesterly flow is directed over northeast Africa and across the northern Red Sea.

The surface streamline analysis (1E-7c) shows reports of suspended dust, under clear sky conditions, in the northerly flow over Egypt and northern Sudan. This is where the upper-level trough T1 at 850 mb (1E-7b) has moved across the northern Red Sea in advance of the trough T1 at 500 mb (1E-6b), bringing northerly upper-level flow over the region. Northerly winds of 20–30 kt, behind the trough T1 at 850 mb, are superimposed over northerly flow at the surface and are sufficient, under unstable daytime (1500 LST) conditions, to result in the turbulent transfer of momentum from aloft to raise dust, as indicated by the surface reports. The report of suspended dust to the southwest of Khartoum is probably associated with convective activity (note the report of a thunderstorm in progress at Kadugli, station 62810).

A METEOSAT infrared picture at 1155 GMT (1E-7a) shows that skies are generally cloud-free over northeast Africa. Subtle changes in tonality (gray shades) can be detected, however, over the desert areas. Water vapor absorption is unlikely to be a factor in producing such gray shade changes under dry desert conditions. The changes over the area are due to dust in the atmosphere which radiates as a black body at the temperature of the air in which it is located. Since dust can be lifted to high altitudes, its presence will be indicated in satellite infrared data as a lighter shade of gray (cooler temperature). For this reason, satellite infrared data should be viewed as a primary tool for duststorm detection.

On the satellite picture (1E-7a) light gray shades, indicating dust in the atmosphere, should be apparent over Egypt and the northern Sudan which is the region of the numerous surface reports of dust (1E-7c). The dust is not heavy and is probably only at low levels so that it is too faint to be recorded in the imagery. There is a tropical disturbance located south of Khartoum showing large clusters of convective activity. At this time there is no indication of dust (areas of light gray shades) spreading outward from the storm. In the tropical disturbance over western Africa, however, the irregular shaped, light tone area along the northern border is dust in suspension raised to high elevations. This is the characteristic appearance of suspended dust associated with a Haboob in progress at the surface. The large geographical extent of the Haboob indicates that it is being generated by a complex of thunderstorms, rather than by an isolated storm.

13 June
A casual examination of the late morning 0759 GMT (1059 LST) DMSP visible picture (1E-8a), reveals no apparent obscurations of geographic features due to dust over the central Sudan. However, dust is not heavy and a duststorm in progress in its earlier stages, can be identified in visible satellite imagery. In general, only by comparison with imagery acquired in previous cloud-free conditions, can a duststorm be identified. The suspended dust area (light gray shade) in the infrared picture (1E-11a) is elongated in a southwest to northeast direction, suggesting that winds in the dust layer are southerly or southwesterly. Verification of the duststorm and southerly flow is obtained from a time sequence of surface reports (1E-10c) which show a duststorm in progress at Atbara at the time of the METEOSAT picture. Reports from two additional stations provide evidence of a trough line or low-pressure center just to the north of the duststorm. The surface streamline analysis (1E-7c) shows the trough T2 and reports of dust in the vicinity of Khartoum. The trough T2 is clearly revealed at the 500-mb level (1E-10a) and the 850-mb level (1E-10b), with Khartoum reporting a 30-kt southwesterly wind.

The suspended dust area (light gray shade) in the infrared picture (1E-11a) is elongated in a southwest to northeast direction, suggesting that winds in the dust layer are southerly or southwesterly. Verification of the duststorm and southerly flow is obtained from a time sequence of surface reports (1E-10c) which show a duststorm in progress at Atbara at the time of the METEOSAT picture. Reports from two additional stations provide evidence of a trough line or low-pressure center just to the north of the duststorm. The surface streamline analysis (1E-7c) shows the trough T2 and reports of dust in the vicinity of Khartoum. The trough T2 is clearly revealed at the 500-mb level (1E-10a) and the 850-mb level (1E-10b), with Khartoum reporting a 30-kt southwesterly wind.

The FNOC 500-mb analysis (1E-12a) shows that the northern Sudan is under the influence of southwesterly winds ahead of the trough T2. This is favorable for advecting the dust over the Red Sea that has been raised by the thunderstorm complexes south of Khartoum. There is also a new trough T3 which has developed upstream of the trough T2.

The FNOC 36-hour 500-mb prognosis (1E-13a), valid at 1200 GMT on 14 June, shows that the trough T2 dissipates, and the new trough T3 advances to a position over the eastern Mediterranean. This will continue to provide favorable conditions for the advection of dust at this level from Sudan into the Red Sea region.

continued on page 1E-14
In the western part of the chart, there is a dust plume that has been moving towards the north. This dust plume is expected to be cleared by the wind. The shaded areas in the chart indicate regions with high pressure systems. The shaded areas are also marked with a dark green color.

In the southeastern part of the chart, there is a low-pressure system that is expected to move towards the east. The low-pressure system is marked with a light blue color.

In the western part of the chart, there is a high-pressure system that is expected to remain stationary. The high-pressure system is marked with a dark green color.

In the central part of the chart, there is a large area of low pressure that is expected to move towards the north. This area is marked with a light blue color.

In the northeastern part of the chart, there is a high-pressure system that is expected to remain stationary. This area is marked with a dark green color.

In the southwestern part of the chart, there is a large area of high pressure that is expected to move towards the west. This area is marked with a dark green color.

In the southern part of the chart, there is a low-pressure system that is expected to move towards the east. This area is marked with a light blue color.

In the northwestern part of the chart, there is a high-pressure system that is expected to remain stationary. This area is marked with a dark green color.

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In the southwestern part of the chart, there is a large area of high pressure that is expected to move towards the west. This area is marked with a dark green color.

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In the northwestern part of the chart, there is a high-pressure system that is expected to remain stationary. This area is marked with a dark green color.

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Dust Storm over the Red Sea
Summer
Case 2
Dust Storm over the Red Sea
### Table of Surface Weather Reports

<table>
<thead>
<tr>
<th>STATION</th>
<th>62414 (Aswan)</th>
<th>62641 (Port Sudan)</th>
<th>62680 (Atbara)</th>
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<td>6 1006 7 miss</td>
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<tr>
<td>14/12</td>
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<td>1006 2 34/06</td>
<td>6 1004 3 08/17</td>
</tr>
</tbody>
</table>

Surface observations for stations 62414, 62641, and 62680 located in the vicinity of the 13-14 June 1979 Haboob originating over the Sudan

**Surface wind (dd/ff)**

**Sea level pressure (SLP)**

**Present weather (ww)**

- 6 Widespread dust in suspension in the air, not raised by wind, at time of observation
- 31 Slight or moderate duststorm or sandstorm, no appreciable change during past hour

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**Notes:**

- Dust Storm over the Red Sea
- Summer Case 2
- Inset of the Haboob
- Inset of the Haboob
- Table of Surface Weather Reports
- Image of enlarged view infrared picture
- Image of enlarged view visible picture
- Station information:
  - 62414 (Aswan): 24 0N 32 0E
  - 62641 (Port Sudan): 19 5N 37 2E
  - 62680 (Atbara): 17 7N 34 0E
Dust Storm over the Red Sea

Summer

Case 2

500 mb

IE-13
The DMSP visible picture at 0239 GMT (1E-15a) provides an excellent view of the suspended dust which has been advected over the Red Sea from the Sudan. The light gray shade area in the simultaneous DMSP infrared picture (1E-15b) precisely outlines the duststorm area as a region of moderately cold temperature, indicating that the dust extends vertically to mid-tropospheric altitudes.

The 500-mb analysis for 1200 GMT (1E-14a) shows a generally good correspondence of the circulation features as indicated by the FNOC 36-hour 500-mb prognosis (1E-13a). Note the anticyclonic turning of winds around the high, bringing southerly flow over Khartoum at the 500-mb level. However, evidence on the 850-mb analysis for 0000 (1E-14b) and 1200 GMT (1E-14e) reveal a complexity not captured at the 500-mb level. These latter analyses show that the original trough T2, associated with the duststorm development, has merged with the low pressure belt over southern Saudi Arabia, and that a new trough T3 has moved to a position over the northern portion of the Red Sea. This places the dust source area, near Khartoum, under flow having a more northerly component instead of a southwest to west component so that continued advection of dust into the central and southern portion of the Red Sea at low levels would not occur.

The surface streamline analysis at 1200 GMT (1E-16b) reveals an intensified low-pressure area near the southern portion of the Red Sea, and widely scattered thunderstorms, with little evidence of any strong westerly component to bring additional dust over the Red Sea. Verification of the decrease in dust over the Red Sea is revealed in MFTOSAT visible (1E-16a) and infrared (1E-17a) pictures. These pictures show a thin veil of suspended dust, as terrain features again are revealed in greater clarity over the Khartoum region and along the Nile River. By 1200 GMT on the following day (15 June), the MFTOSAT visible picture (1E-17b) shows only a faint veil of dust in suspension over the southern portion of the Red Sea, with no evidence of renewed dust-generating thunderstorm complexes over the Sudan region.

Important Conclusions

1. Heavy convective activity, such as that associated with tropical disturbances over the Sudan, can generate Haboobs which lift large quantities of dust over extensive areas and to high altitudes.

2. Earliest detection of duststorms over land can be obtained by comparing visible imagery with previously cloud-free dust-free imagery over the same region.

3. Infrared imagery clearly reveals dust plumes as soon as the dust is raised to an altitude where it radiates at a temperature colder than the surrounding land surface.

4. During the summer monsoon, the southwesterly flow ahead of mobile polar troughs advancing across the eastern Mediterranean can pick up the dust from duststorms originating over the Sudan. The raised dust forms a huge cloud of dust which may be advected over the Red Sea, resulting in widespread reduced visibilities.
Dust Storm over the Red Sea

ARABIAN PENINSULA

IF-15a F-1 DMSP P1S Low Enhancement 0559 GMT 14 June 1979
Dust Storm over the Red Sea

Case 2

METEOSAT Enlarged View Infrared Picture 1155 GMT 14 June 1979

METEOSAT Enlarged View Visible Picture 1155 GMT 15 June 1979
Case 3  Red Sea/Persian Gulf—Summer

Persian Gulf Duststorms

During the summer monsoon, the surface thermal low over Iran, Iraq, Afghanistan brings persistent northerly or northwesterly flow over the Arabian Peninsula/Persian Gulf region. Moderate to strong (15–25 kt) northwesterly winds develop over the Persian Gulf and are so persistent that the phenomenon has been identified as the "Forty-Day Shamal," which lasts from early June to mid July. Short duration (2-3 days) Shamal conditions, with attendant high winds, severe duststorms, and unusually high sea state on the Persian Gulf, occur when strong northerly, upper-level winds are superimposed on the lower-level northwesterly winds over the Persian Gulf area. The short-duration Shamals are laden with dust from the desert which reduces visibility, but they are rarely accompanied by thunderstorms or squalls.
Large-scale Duststorm During the Summer Shamal
Persian Gulf
June 1979

21 June

By late June, the Shamal (persistent northerly flow over the Persian Gulf) is well established. The surface streamline analysis (IE-20b) confirms the presence of the Shamal—20-kt northwest winds are reported over the Persian Gulf at Bahrain (O1) and northwesternes (speed illegible) at Basra, Iraq (O2), which also reports suspended dust. The low-level northerly flow over the northern Persian Gulf has developed from a merger of easterly flow around the northern periphery of the thermal low centered over the southeastern Arabian Peninsula and westerly flow around the anticyclonic cell over the north-central Arabian Peninsula.

At 500 mb (IE-20a), general high pressure, typical of upper-level summer conditions over the Red Sea/Persian Gulf region, extends from Africa, across the Arabian Peninsula, to Iran. Over northern Europe, the large-scale circulation shows a well-developed "Omega" type blocking high with a cutoff low L1 to the south. The presence of an omega block over northern Europe is a precursor condition for the development of intense, short-duration (2–3 day) duststorms over the Persian Gulf region. In the omega blocking pattern, the polar jet upstream of the block shows two branches—one branch moving northward over the block and the other branch advancing under the block across the Mediterranean. At 500 mb, the 60-kt westerly winds at Nicosia, Cyprus, just south of the cutoff low L1, identifies the southerly branch of the split flow, and general westerly flow is observed to the east across the eastern Mediterranean coastline.

The METEOSAT visible picture at 1155 GMT (IE-21a) shows a cloud-free view of the Arabian Peninsula and the adjacent Red Sea and Persian Gulf region. The corresponding infrared picture (IE-21b) shows no distinct light gray shade areas (colder temperatures) over the Arabian Peninsula that can be identified as active duststorms in the visible picture. In the visible picture, however, a well-defined narrow dust plume is observed across the northern Persian Gulf coastline—a confirmation of the Shamal. The light gray shades over the southern Persian Gulf indicate an accumulation of suspended dust over the area. On the surface streamline analysis (IE-20b), suspended dust is reported at O2, which is in the general location of the dust plume on the satellite picture. Although suspended dust is reported at Amman Jordan (O3), it cannot be identified in the visible imagery, but it appears as a slightly cooler temperature response in the infrared imagery (IE-21b). Note how clearly the Dead Sea, just to the south of Amman, stands out on the visible satellite picture.

22 June

The METEOSAT visible picture at 1155 GMT (IE-23e) reveals a faint, light gray shade plume P1 in the Syrian Desert, just to the east of Lebanon, which suggests the presence of raised dust. The simultaneous infrared picture (IE-23d) shows two distinct, light gray shade plumes P1 and P2, and a number of minor plumes, in the same geographical area. The light gray shade plumes P1 and P2 have the characteristic features (cold temperatures) associated with suspended dust, as observed on infrared imagery, which confirms the presence of dust on the satellite picture. The dust plumes indicate that low-level winds have increased over the region.

On the surface streamline analysis (IE-23b), 03 shows a wind of 20 kt and suspended dust. Suspended dust and a surface wind of 15 kt is reported over the central Syrian Desert at Rutbah, Iraq (O4). Further east, suspended dust is also reported at O2, on the Persian Gulf. On the visible satellite picture (IE-23c), a dust plume (Shamal) is observed across the northern Persian Gulf coastline, just south of Basra, as on the previous day (IE-21a). Suspended dust is also reported at Hail (O5) and Riyadh (O6), Saudi Arabia, where winds have increased in speed about 10 kt from the previous day (IE-20b).

At upper levels, the southern branch of the split polar westerlies, associated with the omega block over northern Europe, dominates the flow pattern over the eastern Mediterranean. At 200 mb (IE-22a), the subtropical jet has merged with the polar westerlies along the base of the cutoff low L1, resulting in the 90-kt isospeed maximum over the eastern Mediterranean coastline. At 500 mb (IE-22b), there are 40 50-kt westerly winds crossing the eastern Mediterranean coastline ahead of the cutoff low L1, and at 850 mb (IE-23a), westerly winds of 25–35 kt are also observed in the same region. The juxtaposition of westerlies from 200 to 850 mb across the eastern Mediterranean coastline produces strong, turbulent winds at low levels, which are generating the dust plumes P1 and P2 observed on the visible and infrared satellite pictures (IE-23c and 23d).

The westerlies crossing the eastern Mediterranean coastline at 500 mb (IE-22b) and 850 mb (IE-23a) are also influenced by the anticyclone centered over the northern Red Sea. The westerlies are turned anticyclonically around the high cell and are funnelled to the south over the southern Arabian Peninsula (300 mb) and to the east into the Persian Gulf region (300 mb and 850 mb). At 850 mb, the northerly winds approaching the Persian Gulf are enhanced by their location between the anticyclone over the northern Red Sea and the split trough T1 to the north of the Persian Gulf. The alignment of northerly upper-level winds approaching the Persian Gulf region signals the potential for the development of an intense Shamal over the Persian Gulf.

23 June

A most important development on this day is the increase in northwesterly wind speeds at 850 mb (IE-24b) from the eastern Mediterranean, across the Syrian Desert, to the Persian Gulf region (note the 50-kt wind at Basra, Iraq). This is primarily due to the increased height-contour gradient between the anticyclone over the northern Red Sea and the split trough T1 to the north of the Persian Gulf. The

23 June continued on page 1E-24
Duststorm over the Persian Gulf

Red Sea/Persian Gulf
Summer
Case 3


Duststorm over the Persian Gulf

Red Sea/Persian Gulf
Summer Case

850 mb

surface

1E-23a. NMC 850-mb Analysis 1200 GMT 22 June 1979

1E-23b. NMC Tropcal Surface Streamline Analysis 1200 GMT 22 June 1979
Duststorm over the Persian Gulf

Red Sea/Persian Gulf

Summer Case 3
The FNOC 500-mb analysis for 0000 GMT (1E-26a), which is comparable to the NMC 500-mb analysis, shows the blocking high over northern Europe, the cutoff low L1, and the trough T2 over northeast Africa. Note how clearly this analysis depicts the anticyclonic turning of the winds over the northern Red Sea which is producing northwesterly flow across the Persian Gulf region.

The FNOC 36-hr 500-mb prognosis (1E-27a), based on the initial 500-mb analysis (1E-26a), indicates that the blocking high will be maintained over northern Europe, the southern branch of the westerlies will persist across the eastern Mediterranean, and the anticyclone over the northern Red Sea will dominate the circulation over the Arabian Peninsula. With the persistence of the northwesterly flow over the Syrian Desert, increased amounts of raised dust can be expected to be transported to the south over the Arabian Peninsula and to the east over the Persian Gulf (duststorm already in progress at 07; see 1E-24c).

23 June continued on page 1E-28

1E-26a. FNOC PE Initial 500-mb Analysis. 0000 GMT 23 June 1979.
Duststorm over the Persian Gulf

Red Sea/Persian Gulf
Summer Case 3

500 mb

At 200 mb (1E-28a), the wind speeds in the merged polar westerlies and subtropical jet over the eastern Mediterranean have increased to over 100 kt. A similar increase in wind speeds (85 kt) is observed at Beirut, Lebanon, at 500 mb (1E-28b). At 850 mb (1E-29a), strong (30-35 kt) winds extend from the eastern Mediterranean coastline to the central Persian Gulf. On the surface streamline analysis (1E-29b), reports of duststorms and suspended dust extend from the eastern Mediterranean to the central Persian Gulf — confirming that the dust suspended in strong upper-level winds has reached to the surface. Where skies were mostly clear in this region on the previous day (1E-24c), they are now obscured by dust.

At Toraybeel, Iraq (09), in the Syrian Desert, a duststorm is in progress, wind is northwest at 35 kt. Further to the east, 02 is showing a northwest wind and a duststorm in progress. Suspended dust is reported over the Persian Gulf at 01 and at Dubai, United Arab Emirates (010). The duststorm at 02 is reflecting the downward transport of the strong winds aloft and suggests that an intense Shamal is occurring over the Persian Gulf at this time. These intense Shamals are of short duration and can be expected to last for only about 3 days. Over the central Arabian Peninsula, a duststorm is reported at 06, and suspended dust is reported as far south as Salalah, Oman (011).

The dust plumes over the Syrian Desert, first observed on the previous day (1E-23c) are very distinct on the METEOSAT visible imagery on this date (1E-29c). A careful comparison of the two views shows gray shade changes that suggest dust, first generated over the Syrian Desert, has now reached over the northern Persian Gulf and entered into the south-central Arabian Peninsula. Infrared imagery (1E-29d) fully confirms this situation. Note that temperatures are very cold over the Syrian Desert source region, and temperatures and dust amounts suggest no additional major source regions until the east-central Arabian Peninsula, where temperatures again appear colder and larger amounts of dust appear to be generated.

The DMSP visible picture at 0211 GMT (1E-30a) shows almost total obscuration of the Persian Gulf region by dust. A DMSP visible picture several hours later (1E-31a) shows that the dust covers the entire southern Arabian Peninsula and extends across the Red Sea into the Sudan.

An interesting phenomenon, that of gravity waves on the top of the dust layer, appears on the 0211 GMT picture (1E-32a), with a focal point near 30°N, 47.5°E. Basra, Iraq, located just to the northeast of the source of the gravity waves, reported 1/2 mi visibility, with a duststorm in progress, at 0600 GMT (not shown), about 4 hours prior to the DMSP picture. The fact that the gravity waves have a focal point is very interesting since the terrain in the area is very flat and well removed from the mountains, so it is unlikely that the gravity waves are terrain induced.

The gravity wave generation point, however, is very near the center of a major oil field. The DMSP nighttime visible picture (1E-33a), obtained at a much later date, shows city lights and oil fires over the Persian Gulf region. A careful comparison with the previous picture and the DMSP visible picture (1E-32a) shows that the Az Zubair oil fields are precisely at the focal point of the gravity waves. The implication is that the buoyant effect of hot air rising from the burning natural gas over the oil field has induced gravity waves on the dust sweeping over the area. Gravity wave production implies that the heaviest concentration of dust is capped by an inversion. Such a concentration would likely occur at a lower, rather than higher, level. Unfortunately, probably due to the duststorm conditions, RAOB data were not available in the immediate area of the gravity waves. They were available further to the north, however, with Damascus, Syria, showing a very strong low-level inversion, with a top at about 2,500 ft MSL (station elevation 2,000 ft). Smaller dust particles undoubtedly extended well above this altitude.

The gravity waves in the DMSP picture (1E-32a) spread outward toward the southwest quadrant and in no other direction. This suggests a low-level wind from the northeast. A streamline superimposed on the 850-mb analysis (1E-32b) reveals northwesterly winds changing to northeasterly near the oil field area, which verifies the above hypothesis. The anticyclonic turning of the flow over the northern Arabian Peninsula additionally supports the concept of a stable layer (subsidence inversion) above the duststorm.

continued on page 1E-34
Duststorm over the Persian Gulf

850 mb


surface

IE-29b. NMC Tropical Surface Streamline Analysis. 1200 GMT 23 June 1979
Dust storm over the Persian Gulf

Red Sea/Persian Gulf
Summer Case 3

ARABIAN PENINSULA
1E-32a  F-3, DMSIP LF Low Enhancement 0211 GMT 24 June 1979. (Note this picture is a sector of 1E-30a.)

1E-32b  NMC 850-mb Analysis 0000 GMT 24 June 1979
24 June

The METEOSAT visible picture at 1155 GMT (IE-35a) shows gray shades over the Persian Gulf and Red Sea regions associated with the duststorms. A comparison of the land area with the previous dust-free view (IE-21a) shows a degradation of contrast implying dust over portions of the land areas of Iraq, Iran, and the Arabian Peninsula. The METEOSAT infrared picture (IE-35d) is most useful at this time to delineate the areas of dust contamination. The picture reveals that the Persian Gulf is entirely obscured by dust. That dust is very heavy over the central and southern Arabian Peninsula, and that dust appears as far west as the Sudan. Perhaps more important for the area further east, dust continues to persist over the source region just southeast of the Caspian Sea, over northern Iraq and Iran. It is also apparent that the Syrian Desert east of Lebanon has ceased being a dust source, as no evidence of dust-associated cold temperatures appears evident. This suggests that the wind speed maximum has passed the area and that lighter winds now prevail over Lebanon and the Syrian Desert.

The surface streamline analysis at 1200 GMT (IE-35b) reveals widespread reports of dust in suspension over the Arabian Peninsula. Note that a duststorm is reported in progress at 06, where sustained northwest winds of 25 kt are reported. The 850-mb analysis (IE-35a) verifies that winds have diminished in speed over Lebanon and the Syrian Desert, and that they have increased somewhat over the Persian Gulf and the central Arabian Peninsula, where dust is reported being generated. The 500-mb analysis (IE-34b) shows the blocking high at mid-latitudes persisting along longitudes 20° E. A comparison of this analysis with the INOC 36-hour prognosis, valid at 1200 GMT (IE-34b), shows excellent correspondence. The trough over northern Africa and the anticyclone over the northern Arabian Peninsula, following the trough over Iran, also appear precisely as forecast.

The 200-mb analysis (IE-34a) continues to show the split flow of the block and the strong jet force winds crossing the eastern Mediterranean coastline. The high-pressure cell over the Arabian Peninsula, however, has moved eastward, diverting these strong winds aloft and out of the Persian Gulf region. The block over northern Europe has also progressed eastward from near 10°E on 22 June at 1200 GMT to near 17°N, 48°E on 25 June, while this area appears much sharper in contrast on 30 June, under clear conditions.

The 500-mb analysis at 1200 GMT (IE-39b) shows a significant change in pattern associated with the cutoff of Shamal conditions in the Persian Gulf and the associated dust phenomenon. The block, originally established near 20°E, has moved eastward as has the anticyclone over the northern Arabian Peninsula. As a result, strong anticyclonically-turning flow no longer extends from Lebanon into the Persian Gulf, which is now “capped” by a high-pressure cell containing very weak winds (see also surface streamline analysis IE-39c). Should the combination of the mid-latitude block and the high-pressure cell over the northern Arabian Peninsula retrogress westward, the potential for a renewed, intense Shamal with dust would again exist.

Important Conclusions
1. The presence of a block over northern Europe, near longitudes 20°30°E, characterized by split flow producing a zonal branch under the block is a pattern favorable for producing the strong persistent winds associated with intense Shamal conditions.

2. The triggering effect for the storms involves an optimum position of strong zonal flow over the eastern Mediterranean, turning anticyclonically around a high-pressure cell over the northern Arabian Peninsula.

3. A cutoff of Shamal conditions and associated duststorm phenomena can be anticipated on breakdown of the block and or movement of the high-pressure cell over the northern Arabian Peninsula in a position to shield the area from strong northerly flow.

4. Satellite infrared data, during mid-afternoon hours, are a primary tool in evaluating the presence and extent of dust, and in determining the most probable source region.

25-30 June

The METEOSAT infrared pictures for 25 June (IE-36b), 26 June (IE-37b), and 27 June (IE-37d) show heavy dust over the central Arabian Peninsula for the first two days, but none or little over that area on 27 June as the intense 3-day Shamal ended. The DMSP visible picture (IE-38a) of the central Arabian Peninsula under duststorm conditions on 25 June, as opposed to the relatively dust-free conditions on 30 June (IE-39a) demonstrate the masking effect of dust in obscuring underlying terrain features. Note in particular that the original dust source region of the Syrian Desert and northern Iraq and Iran is relatively clear of dust in both figures. In the central northern Arabian Peninsula, however, dust obscures terrain features (see especially the dark terrain feature near 17°N, 48°E on 25 June, while this area appears much sharper in contrast on 30 June, under clear conditions).

The METEOSAT visible picture at 1155 GMT (IE-39b) shows a significant change in pattern associated with the cutoff of Shamal conditions in the Persian Gulf and the associated dust phenomenon. The block, originally established near 20°E, has moved eastward as has the anticyclone over the northern Arabian Peninsula. As a result, strong anticyclonically-turning flow no longer extends from Lebanon into the Persian Gulf, which is now “capped” by a high-pressure cell containing very weak winds (see also surface streamline analysis IE-39c). Should the combination of the mid-latitude block and the high-pressure cell over the northern Arabian Peninsula retrogress westward, the potential for a renewed, intense Shamal with dust would again exist.

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Duststorm over the Persian Gulf

IE-35a. NMC 850-mb Analysis. 1200 GMT 24 June 1979

IE-35b. NMC Tropical Surface Streamline Analysis 1200 GMT 24 June 1979

Duststorm over the Persian Gulf

Red Sea/Persian Gulf
Summer
Case 3

METEOSAT. Enlarged View Visible Picture 1155 GMT 26 June 1979.

METEOSAT. Enlarged View Infrared Picture 1155 GMT 26 June 1979.
ARABIAN PENINSULA

45E  50E  55E

Duststorm over the Persian Gulf

Red Sea/Persian Gulf
Summer
Case 3

1E-39a. F-1. DMSP LS Low Enhancement 0750 GMT 30 June 1979

E-39c NMC Tropical Surface Streamline Analysis. 0000 GMT 30 June 1979