THE EFFECT OF SURFACE WIND ON SEA SURFACE TEMPERATURES NEAR GIBRALTAR

Lieutenant Commander Durward B. Mommsen, Jr.

U.S. Navy Fleet Weather Central
Rota, Spain
FPO New York 09540

Abstract

Surface wind observations at Gibraltar were compared with sea surface temperature (SST) gradients appearing in Defense Meteorological Satellite Program (DMSP) infrared imagery of the Strait of Gibraltar and Alboran Sea during July and August 1977. Winds in the area were found to be predominantly from the east or west. Westerly winds tended to cause upwelling along the Spanish coast of the Alboran Sea with some of the cold upwelled water entrained into an anticyclonic gyre in the western Alboran. Easterly winds tended to weaken the upwelling adjacent to the Spanish coast. The easterly winds appeared to generate upwelling along the Moroccan coast of the Strait and cold SST in the area immediately to the east of the Gibraltar peninsula. The cause of these effects was not determined although wind induced, Ekman type, upwelling was felt to be a dominant factor. The occurrence of upwelling could be related to the formation of fog in the area.

Editor's Note *- Although this study considers a European site, similar situations are observed along all coastal areas. Transport of differing air masses over varying sea surface temperature fields produce recurring localized cloud patterns. These could become more predictable if water temperature variations were monitored and considered.*

1. INTRODUCTION

Drastic changes in nearshore Sea Surface temperature (SST) can be important in forecasting weather in coastal areas. An example is the incidence of fog at the RAF Gibraltar airfield located on the Gibraltar peninsula. McKay (1977) reports that fluctuations of SST have an important bearing on the incidence of sea fog and low stratus at and near Gibraltar. He has observed day to day changes in SST off Gibraltar as great as 8^{o}F during the summer. He has found that, with a change of wind from west to east, fog is generally first observed in the central and southern Straits but that there may be a considerable lag before the airfield at Gibraltar is affected. In such circumstances he finds that the direction of arrival of fog is from the northeast. Fog is very seldom seen at Gibraltar with a westerly wind.

An examination of DMSP infrared imagery at Fleet Weather Central, Rota, over the past three years has shown a variety of sharp SST gradients in the Strait of Gibraltar and Alboran Sea. Certain features, such as upwelling[1] along the Spanish coast and an anti-cyclonic gyre in the western Alboran, have shown up frequently, but have varied in extent and intensity. Day to day observations have revealed recurrent patterns which appeared to be related to surface wind direction. The effect of wind was ignored by Lanoix (1974) in his classic explanation of currents and upwelling in the Alboran Sea, but Stevenson (1976), Ovchinnikov et al (1976), McKay (1977) and others have stressed the importance of wind on the SST and current patterns in the area. This report is the result of an attempt to correlate wind observations at Gibraltar with SST gradient patterns found in DMSP infrared imagery.

2. WIND OBSERVATIONS

The most readily and consistently available wind observations in the Strait of Gibraltar and Alboran Sea area are from RAF Gibraltar. These observations are from the airfield located at the landward (north) end of the peninsula (see Figure 1). Although these wind observations may not be as representative, under certain wind conditions, as others in the area they do provide adequate indication of the general wind direction through the Strait.

The basic winds in this area are best described in the following quotations from the British Air Ministry, Meteorological Office, publication "Weather in the Mediterranean":

"In the Strait of Gibraltar and the Alboran Channel between Spain and Morocco, owing to the configuration of the land, winds are mainly from east or west. The easterly wind of the Strait and of the Alboran channel is known as levanter ..."

"In summer, levanter generally occurs as a flow of

[1] *Upwelling is defined as the displacement of surface water at an angle of 45^{o} to the right, Northern Hemisphere, of the wind. Cooler subsurface water is brought upwards (upwelled) to replace the transported surface water.*

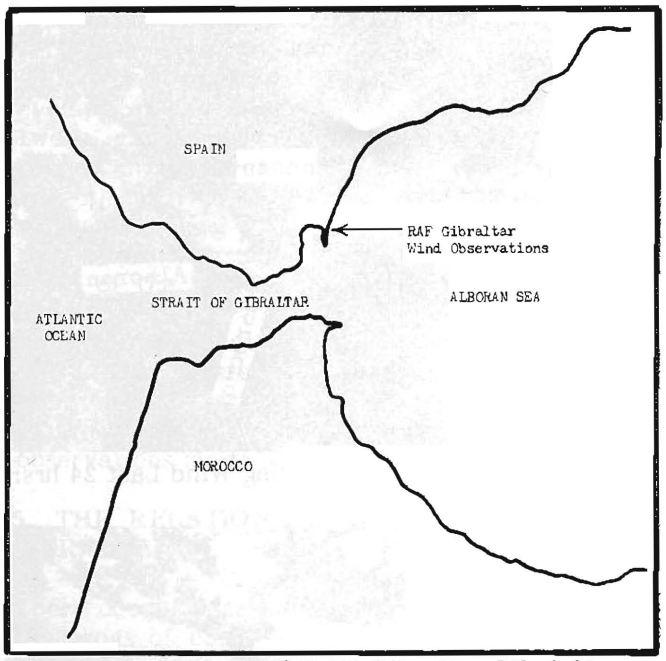

Figure 1. Location of RAF Gibraltar Wind Observations.

warm subsided air between the Azores anti-cyclone and the low pressure over North Africa. This air gives frequent fog and low stratus in the Strait. At the east end it always gives heavy dew, frequently mist and sometimes drizzle."

"Vendaval is the name given to the strong west to south-west wind ... of the Gibraltar-Alboran Channel."

"Vendaval tends to blow stronger in the Strait than in the Alboran Channel owing to funnelling, but if the wind is basically south-westerly it may be reduced near the shelter of the North African coast."

Table 1 gives selected wind observations from Gibraltar for the period 11-21 July 1977. Table 2 gives the same information for the period 8-21 August 1977.

3. DMSP SST INTERPRETATION

DMSP infrared imagery has proven to be a reliable method of determining SST gradients in cloud-free areas. Actual SST determination is not feasible at this time because of several factors the most important of which is variations in atmospheric water vapor. At Fleet Weather Central, Rota, coverage of the Gibraltar area is available four times a day with satellite passes at about sunrise, noon, sunset and midnight. High resolution (1/3 nautical mile) infrared imagery is available during the sunrise, sunset and midnight passes. Only low resolution (2 nautical miles) infrared imagery is available during the noon passes and this has been found to be of little value in detailed SST gradient analysis.

Date	Zulu Time	Wind
11 Jul 77	1930	230/12
12 Jul 77	1200	220/11
	1400	210/12
	1900	210/13
13 Jul 77	1400	210/13
	1700	260/20
14 Jul 77	1930	230/9
15 Jul 77	1600	270/17
	2030	280/18
16 Jul 77	0600	220/5
	0900	005/5
	1000	060/7
	1730	090/10
17 Jul 77	1400	100/14
	1530	090/13
19 Jul 77	1300	100/11
	1800	090/11
20 Jul 77	0600	070/9
	1230	090/9
21 Jul 77	1500	090/13
	1630	090/12

Table 1. Wind Observations at RAF Gibraltar, 11-21 July 1977. (wind direction in degrees True/ wind speed in knots)

The enhancement procedure used at Fleet Weather Central, Rota, is to display the clouds in about 45 gray shades, with lighter shades indicative of colder temperatures, and the sea surface area of interest in six gray shades ranging from white to black with each gray shade representing a range of 1.56°C. As in the clouds, lighter gray shades indicate colder temperatures. All temperatures warmer than the sea surface area of interest are shown in black.

Figures 2 through 5 are DMSP infrared imagery of the Gibraltar/Alboran Sea area. In Figure 2 cold water can be seen along the Spanish coast and along the northern and eastern edge of a gyre in the western Alboran Sea (herein referred to as the Gibraltar anticyclonic gyre). Clouds can be seen along the Atlantic coast of Morocco and over the mountains of Morocco and Spain. (Most of the land area appears in black because it is warmer than the water.) Similar interpretations may be made of the imagery in Figures 3 through 5.

4. ANALYSIS OF DMSP AND WIND DATA

Two periods were chosen for analysis: 11-21 July 1977 and 8-21 August 1977. Each period was composed of winds from one direction for the first half of the period followed by winds from the other direction for the second half. Another factor, besides wind direction, which had a bearing on the periods chosen, was the availability of good quality, relatively cloud-free, DMSP image-

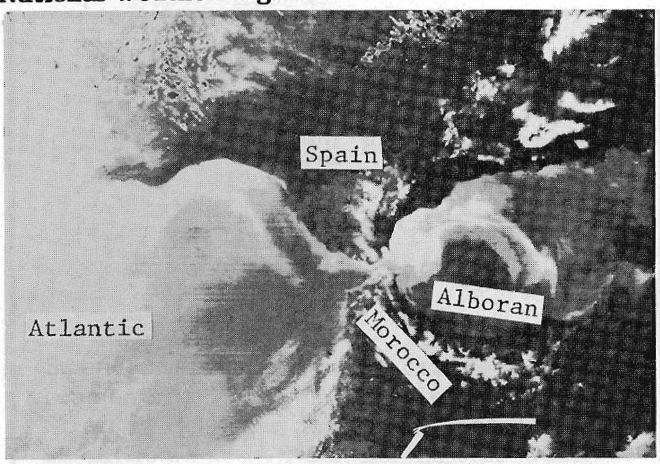

Figure 2. July 14, 1977, Evening Wind Last 24 hrs: Westerly, 9-15 Knots.

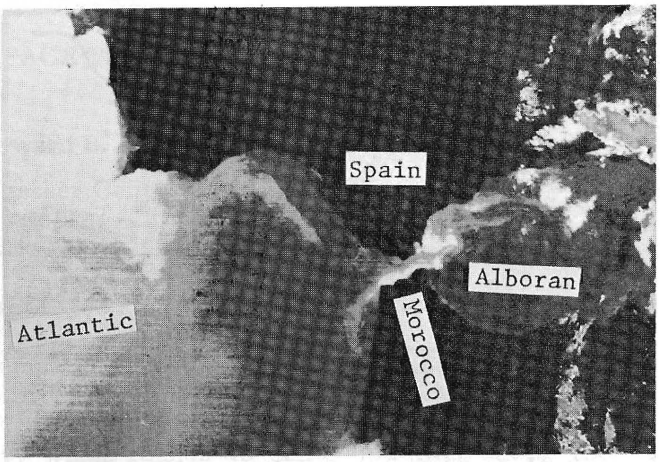

Figure 3. July 20, 1977, Evening Wind Last 24 hrs: Easterly, 9-11 Knots.

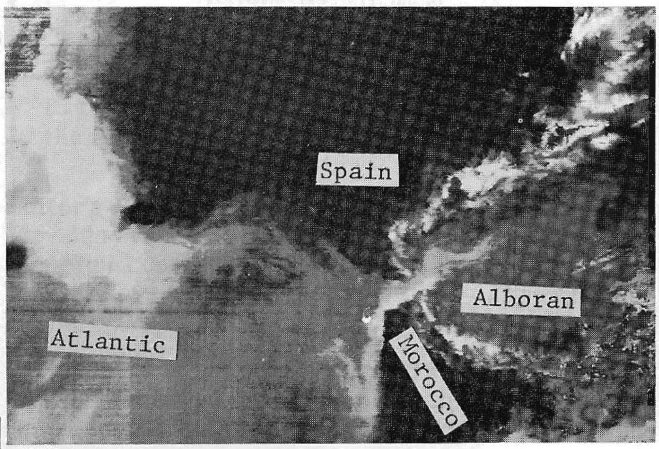

Figure 4. August 10, 1977, Evening Wind Last 24 hrs: Easterly, 13-19 Knots.

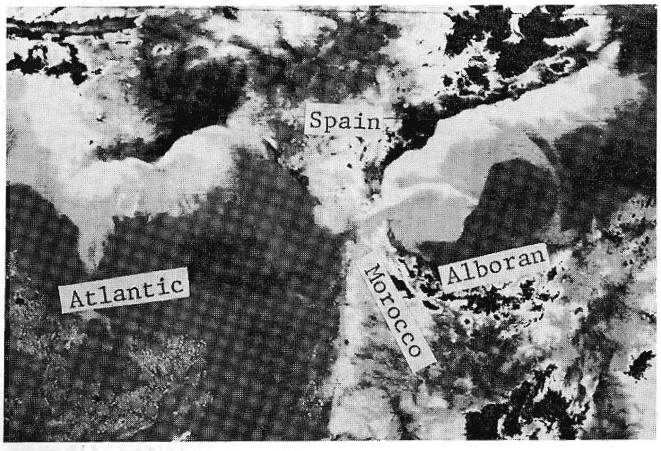

Figure 5. August 10, 1977, Evening Wind Last 24 hrs: Westerly, 15-18 Knots.

ry. Because of the frequent occurrence of atmospheric contamination, including clouds, it is usually necessary to work with one or two good pictures and several mediocre ones. Although all pictures during the period were used in this analysis, only selected ones are shown here.

11-21 July 1977. In Table 1 it can be seen that the winds were basically westerly from 11-15 July. On the morning of the 16th the wind shifted to the east and remained easterly through 21 July. Figure 2 shows the SST gradients on 14 July during the period of westerly winds. Cold water upwelling can be seen along the Spanish coast of the Alboran Sea and sharp SST gradients are evident between the outer and inner portions of the Gibraltar anticyclonic gyre. In the Strait of Gibraltar, cooler water can be seen along the Spanish and Moroccan coasts (although colder on the Spanish side) with warmer water through the middle of the Strait. Close observation of high resolution visual imagery (not shown) during periods of westerly winds shows no evidence of clouds or fog forming in this area. It is therefore concluded that what one is seeing is some type of upwelling process that is producing the cold SST. Movement of this surface water with the current produces the gyre. The water gradually warms away from the coast where the upwelling subsides.

On 16 July the wind shifted to the east, the upwelling along the Spanish coast decreased, and the SST gradients in the gyre began to weaken until, as can be seen in Figure 3, the gradients on the eastern edge of the gyre had all but disappeared. Surface ship SST measurements in this area confirmed the weakening of these SST gradients. During these levanter conditions, a general increase in cloudiness is usually noted in the Alboran Sea.

Perhaps the most striking characteristic of the easterly wind was the pattern of apparent upwelling along the Moroccan coast of the Strait of Gibraltar and the apparent cold SST to the east of Gibraltar (which may be the residue of the Spanish coast upwelled water). This area is also usually associated with fog and low stratus during easterly wind conditions. Its extent is limited, as deduced it does not show up from the visual imagery. Thus the colder temperatures in the infrared are concluded to actually be an area of cold SST.

8-21 August 1977. Table 2 shows the winds at Gibraltar during the period 8-21 August. Basically, the winds were from the east until the evening of the 11th, shifted back and forth between east and west during the period 12-15 August and then remained from the west from the 16th through the 21st. Figure 4 shows the SST gradients during the initial easterly wind situation. Upwelling may be seen along the Moroccan coast of the Strait with some cold water to the east of Gibraltar. On the other hand, Figure 5, which is representative of the subsequent period of sustained westerly winds, clearly shows upwelling along the entire Spanish coast and sharp SST gradients offshore. These findings agree with the observations made during the July period.

5. THE RELATIONSHIP OF SST TO FOG AT GIBRALTAR

There does appear to be some correlation between the areas of cold SST in the DMSP imagery and the occurrence of fog noted by McKay (1977). The apparent upwelling along the Moroccan coast of the Strait during easterly winds could be the cause of fog forming in the southern Straits. The fog that eventually reaches Gibraltar from the northeast could have formed over the previously upwelled water off the Spanish coast. The lack of fog at Gibraltar during westerly winds could be due to the lack of sufficient upwelled (cold) water to the west.

A detailed investigation of this relationship was beyond the scope of the present study, but hopefully it will be the subject of future investigation.

6. CONCLUSIONS

It is concluded that, during the summer, surface wind direction is an important factor in the generation of SST gradient patterns in the Strait of Gibraltar and Alboran Sea. A westerly wind appears to cause upwelling along the Spanish coast of the Alboran Sea and sharp SST gradients in the Gibraltar anticyclonic gyre. An easterly wind appears to cause a reduction in upwelling along the Spanish coast of the Alboran Sea, a weakening of SST gradients in the Gibraltar anticyclonic gyre, and a pattern of apparent cold SST in the Strait along the Moroccan coast and to the east of Gibraltar.

The degree to which these SST gradient patterns appear in the DMSP imagery seems to depend on the speed of the wind and/or the time since wind shift from east to west or vice versa. The presence of cold water along the Spanish Alboran coast during easterly winds conforms to the usual Ekman type of upwelling.

Date	Zulu Time	Wind
8 Aug 77	0630	250/2
	1200	090/9
	2030	060/6
9 Aug 77	0800	060/2
	0930	070/5
	1330	090/6
	1930	080/6
10 Aug 77	0800	090/14
	1200	090/13
	1830	110/19
11 Aug 77	0330	100/11
	1330	110/9
	1430	110/9
	2100	220/9
12 Aug 77	0500	280/13
	0930	280/11
	1330	270/14
	2000	280/14
13 Aug 77	0200	270/14
	0830	250/3
	1030	070/8
	1330	080/9
	1900	070/5
	2030	040/5
14 Aug 77	0600	090/10
	1000	090/9
	1500	100/11
	2000	090/7
15 Aug 77	0200	110/12
	0800	060/6
	1400	100/10
16 Aug 77	0100	190/2
	0600	240/2
	1230	190/8
	1800	190/16
	1900	230/11
17 Aug 77	0300	280/15
	1100	250/14
18 Aug 77	0200	270/11
	0800	280/16
	2000	280/14
19 Aug 77	0600	230/9
	1330	210/16
	2000	240/13
20 Aug 77	0730	220/18
	1430	260/23
	1900	250/18
21 Aug 77	1600	250/15

Table 2. Wind Observations at RAF Gibraltar, 8-21 August 1977. (wind direction in degrees True/ wind speed in knots)

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