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# VARIABILITY OF WIND SYSTEM AND ITS EXPECTED EFFECTS ON OIL SLICK MOVEMENT IN THE ARABIAN GULF

By

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# تغيرات نظم الرياح وتأثيراتها المتوقعة على حركة البقع النفطية في منطقـــة الخليـــج العـــربي

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في هذا البحث اشير إلى بعض النماذج الرياضية المستخدمة في التنبؤ بحركة البقعة النفطية في مناطق مختلفة بما فيها منطقة الخليج العربي كما نوقشت البيانات الأساسية المطلوبة لتطبيق هذه النماذج والتي تتعلق بنظم التيارات البحرية والرياح .

وقد تبين من ذلك أن معظم بيانات التيارات البحرية المتواجدة بمنطقة الخليج العربي لم يتم معايرتها بقياسات مباشرة وبالتالي فإنه لا يمكن تقييم مدى دقتها . اما بالنسبة لنظم الرياح بالمنطقة فقد تم تحليل البيانات الساعية لسرعة الرياح عند مطار الدوحة وذلك في الفترة من يناير ١٩٨٤ حتى ديسمبر ١٩٨٨ باستخدام طريقة المتجهات وقد دلت النتائج على أنه مع افتراض أن نظام الرياح في مجال المياه القطرية يشبه النظام عند مطار الدوحة ، فإن البقعة النفطية تزاح تحت تأثير الرياح كما يلي :

خلال معظم شهور العام يتوقع حركة البقعة النفطية في أتجاه الجنوب والجنوب الشرقي ( أي في اتجاه موازٍ تقريباً للسواحل القطرية ) ما عدا في شهري اغسطس وسبتمبر حيث يتجه التيار المتولد الناشىء عن الرياح في احيان كثيرة نحو الغرب والجنوب الغربي تجاه السواحل القطرية الشرقية .

وقد تم اقتراح بعض الوسائل للحصول على قاعدة للبيانات البحرية اللازمة للحصول على تنبؤات أدق لحركة البقعة النفطية .

*Key Words:* Wind, Oil slick, Arabian Gulf.

## ABSTRACT

The marine data required for the models of the oil spill movement prediction (current and wind data) are discussed. The available water current data in the Arabian Gulf can not be used with confidence because of lack of the direct current measurements. The hourly wind velocity data at Doha Airport in the period (1984-1988), are analysed to determine the daily and monthly mean vectors. These results are compared with wind roses at the same station in different years. Assuming that wind pattern is similar in Qatari waters, the wind is expected to generate currents, carrying the oil spill, towards the S-SE direction, except in August and September where the wind driven current could flow towards W to SW. Suggestions are proposed to obtain accurate input wind data to get more reliable forecasting of oil spill movement.

## INTRODUCTION

The Arabian Gulf is an area with an average length of 1000 km, width 55 to 340 km and total area of about 240000 km$^2$. This area is relatively small compared with other offshore oil producing areas. The Gulf is very shallow with an average depth between 31 and 37 meters, (Lehr, 1984), (Fig. 1). Excluding disastrous spills in the Gulf, the estimate of the oil which will be spilled over the coming decade, with a 5% annual increase in oil production, is 3. 10$^6$ tons, (Hays & Gundlach, 1977). This estimate is only related to tanker transport. Therefore, the Arabian Gulf is one of the most polluted areas by oil and it is of great interest to predict the movement of oil spills for the future planning as well as for combating the environmental effects in

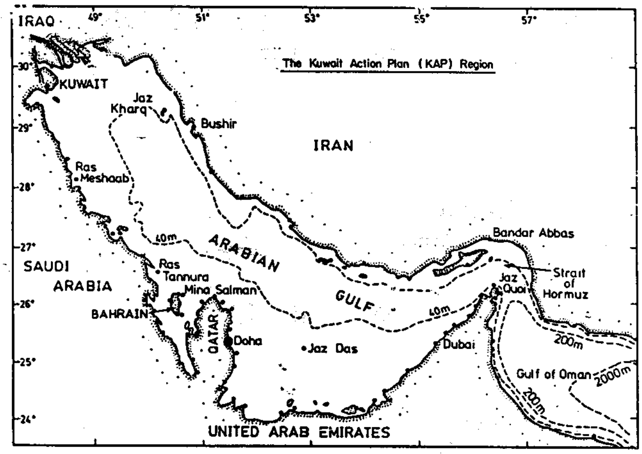


Fig. 1: A map of the Arabian Gulf; contours and meteorological station position.

the cases of accidents. Different computer hydrodynamic models are applied by different institutions and review articles were published on this aspect, e.g. (Galt, 1983). The SLIKFORCAST model which was developed by the Continental Shelf Institute and Det Norske Veritas, (Lehr, 1984), and the model described by (Simons *et al*, 1975), are examples of these models. The first model for the Arabian Gulf (GULFSLIK) was developed by (Lehr & Cekirge, 1979). However, the various models for forecasting of oil slick movement have the same basic ideas simply presented by (Fig. 2).

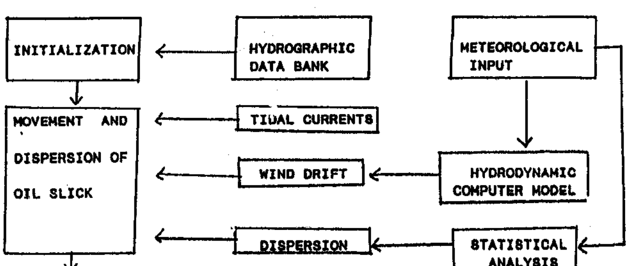


Fig. 2: Program functions of an oil spill model, after T.J. Simons, G.S. Beal, K. Beal, El-Shaarawi and T.S. Murty, 1975.

The dynamics of surface waters in relation to oil slick in the Arabian Gulf are influenced by:

1. The tidal current and the quasi-stationary water movement due to density distribution in the Gulf and the river discharge at its northern part,
2. The wind driven current, and
3. The effects of quasi-random disturbances of wind and current patterns, leading to non-uniform spreading of the oil slick.

The studies of the water movement in the Gulf were reviewed by different authors. According to (Provost, 1984), diurnal, semi-diurnal and mixed oscillations of tides were found in the region. The tidal ranges are large and increasing from the middle of the Gulf. They exceed one meter everywhere and reach 3 meters at Shatt Al Arab, north of the Gulf. These large amplitudes cause strong tidal currents, commonly exceed 50 cm/sec at maximum ebb and flood (Defense Mapping Agency, 1975). The flood is towards the west and NW and the ebb is in the opposite direction (Lehr, 1984). Hunter, (1984), used the ship drift observations, the salinity distributions and hydrodynamic models to present the circulation pattern in the region. These data are only partially consistent, but the general pattern of the stationary currents manifested the inflow of low salinity water, of Arabian Sea origin, along the Iranian side and an outflow of high salinity water along the Arabian side. Some cyclonic eddies were also shown. The discussion indicates that most of the available water current data are concluded from indirect methods and hydrodynamic models and no current meter observations are found to test the validity of these data and to determine the relative importance of tidal, wind driven and stationary currents on the spatial scale in the Arabian Gulf.

The wind driven current can be determined using meteorological observations or predictions of wind velocity, considering both time and space variations. The simplest approach is based on the classical Ekman theory in which a steady state wind driven current is assumed over the area for a given month or a season. In such case, the current speed value is nearly 0.03 times the wind speed. In shallow waters, the wind and currents have nearly the same direction (Simons *et al*, 1975). The wind data required for simulation of wind driven current depend on the objectives of the study; for planning purposes, the mean wind velocities in a given month or a season are used, while in disastrous cases the actual observations and predictions are utilised. The wind system in the Arabian Gulf is influenced by extratropical weather systems, while the Gulf of Oman is affected by the tropical system and the strait of Hormuz is considered as a boundary region between the west to east moving depressions in the north of the strait and the east to west moving depressions south of the strait. The predominant wind directions in the Arabian Gulf are NW-N and the strong Winter winds are called 'Shamal', (Peronne, 1981). In order to get reliable predictions for the oil spill movement, the temporal (monthly and annual) as well as the spatial variations of wind velocity might be studied by means of wind roses and the vectorial monthly means. An attempt to show the temporal variations is presented in this paper.

Finally, the dispersion of the oil spill can be simulated by the random disturbances of wind and current fields, (Simons *et al*, 1975). Since no current measurements are available, the dispersion can only be obtained by the wind velocity distributions. The resultant motion and shape of the spill is determined by the all factors previously discussed.

## DATA AND METHODS OF ANALYSIS

The hourly wind data at Doha Airport in the period from January, 1984 to December, 1988 (State of Qatar) were used to estimate the vectorial daily and monthly means. The calculations were done by analysis of the wind velocity into two components; one in the east direction and the other in the north direction which are nearly normal and parallel to eastern Qatari coasts respectively. The daily means for each of the two components were averaged over 24 hours, i.e. the land-sea breeze effect was eliminated. The monthly means of the components were obtained from the daily means and finally the resultants of the mean components were calculated. The vector diagrams of daily mean wind velocities were plotted for each of the 60 considered months to show the effective paths of the wind and their annual variations in the same month. Wind roses published by State of Qatar for the years 1980, 81, 82, 83, 86 and 87 were also grouped on a monthly basis to present the annual variations of the predominant directions. The wind roses and vector diagrams of winds are compared with each other and their implications on a supposed oil spill in Qatari waters are discussed.

## RESULTS

### *Winds at Doha Airport*

1. JANUARY: Wind roses, (Fig. 3a), show that the predominant directions were between NW and NNW with frequent SE winds in some years, e.g. 1980 and 1981. The dominant directions agree with those of wind vectors, (Fig. 3b), where the monthly mean wind speeds were (3.6-4.7) knots and directions were (307-345°), (Table 1).

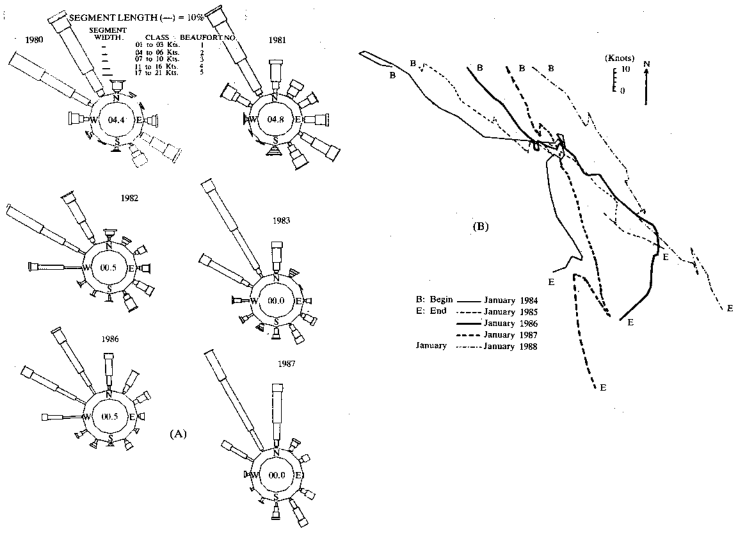


Fig. 3A: Wind roses at Doha Airport, and

Fig. 3B: Vector diagrams of daily mean winds in January.

**Table 1**

Speeds (Knots) and directions (o) of mean wind vector velocity at Doha airport from 1984 to 1988.

| | 1984 | | 1985 | | 1986 | | 1987 | | 1988 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | dir. | speed | dir. | speed | dir. | speed | dir. | speed | dir. | speed |
| January | 332 | 3.64 | 307 | 4.26 | 330 | 4.15 | 345 | 4.70 | 322 | 4.36 |
| February | 346 | 3.67 | 296 | 5.93 | 355 | 3.57 | 030 | 2.34 | 004 | 3.68 |
| March | 350 | 4.94 | 356 | 6.27 | 002 | 3.72 | 032 | 2.94 | 334 | 5.51 |
| April | 349 | 5.04 | 008 | 3.60 | 015 | 4.20 | 001 | 4.73 | 002 | 4.21 |
| May | 352 | 6.33 | 358 | 5.65 | 015 | 4.04 | 010 | 3.10 | 339 | 9.46 |
| June | 319 | 9.00 | 339 | 8.23 | 345 | 10.8 | 348 | 7.64 | 348 | 7.71 |
| July | 351 | 5.42 | 355 | 7.28 | 030 | 3.13 | 015 | 2.15 | 013 | 3.45 |
| August | 305 | 7.46 | 053 | 4.13 | 012 | 3.16 | 010 | 4.77 | 018 | 3.52 |
| September | 041 | 2.81 | 039 | 3.33 | 095 | 3.05 | 040 | 2.80 | 030 | 3.80 |
| October | 346 | 2.95 | 350 | 5.60 | 042 | 1.55 | 065 | 2.55 | 035 | 2.10 |
| November | 040 | 2.03 | 352 | 4.59 | 017 | 2.19 | 345 | 5.31 | 330 | 3.44 |
| December | 303 | 4.66 | 324 | 3.38 | 334 | 4.12 | 345 | 2.71 | 328 | 3.11 |

2. FEBRUARY: During this month, the wind roses were more variable from year to another; although the NW wind was dominant in 1982, 83 and 86, the directions were more scattered in 1980, 81 and 87, when it was difficult to identify a dominant direction, (Fig. 4a). The directions of the monthly mean wind vectors were (214-004°), i.e. from N to NW, except in 1987 where the mean direction was 30°, with speeds (2.3-5.9) knots, (Fig. 4b) and (Table 1).

3. MARCH: (Fig. 5a) shows significant scattering of directions in this month, and the predominant direction can not be determined in most cases. On the other hand, the wind vectors in 1984, 85, 86 and 88 were mostly from NW-N, with monthly mean wind speeds and directions of (3.7-6.3) knots and (334-002°) respectively, but in 1987 the mean vector was from NE with a speed 2.9 knots and 32°. Therefore, the wind velocity vectors have more decisive trend than wind roses, (Fig. 5b).

4. APRIL: The wind roses had scattered directions, (Fig. 6a), while the vector diagrmas for the different years, (Fig. 6b), exhibit definite trend of winds blowing from NE to NW. The monthly means of wind velocity had speeds of (3.6-5.0) knots and directions (349-015°), (Table 1).

5. MAY: The predominant directions for the sampled data, (Fig. 7a), ranged between NW and N, except 1987 when no prevailing

direction was identified. The vector diagrams, (Fig. 7b), had the same dominant directions with mean speeds (3.1-6.3) knots and directions (339-015°).

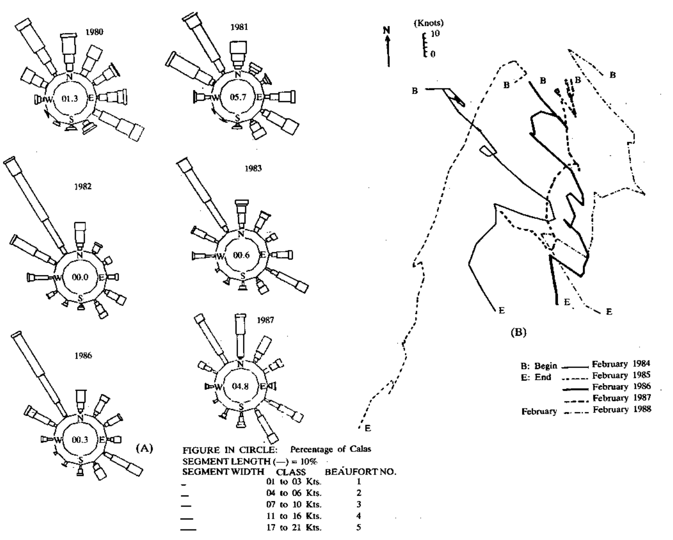


Fig. 4A: Wind roses at Doha Airport, and

Fig. 4B: Vector diagrams of daily mean winds in February.

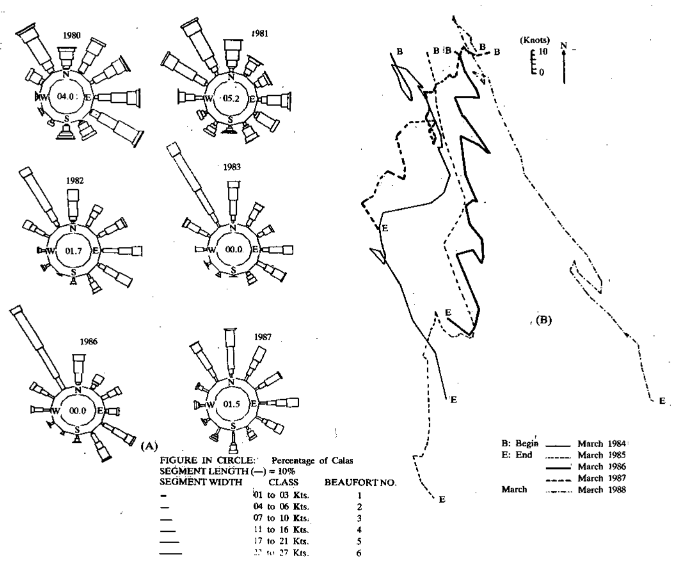


Fig. 5A: Wind roses at Doha Airport, and

Fig. 5B: Vector diagrams of daily mean winds in March.

6. JUNE: The data used in this month, (Figs. 8a & b), show an obvious dominant direction between NW and N. The monthly mean wind vectors had speeds (7.6-10.8) knots and directions (319-348°).

7. JULY: The wind roses, (Fig. 9a), exhibits scattered directions, but the daily mean vectors, (Fig. 9b), had dominant directions from NW to NE. The monthly mean vectors had speeds (2.1-7.3) knots and directions (351-030°), (Table 1).

8. AUGUST: In the years 1980, 81, 82, 83 and 87 the directions were scattered, but in 1986, the dominant direction was NE to

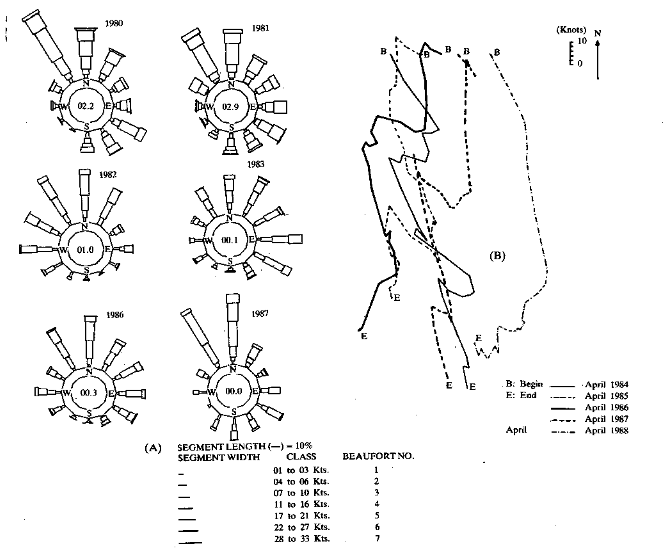


Fig. 6A: Wind roses at Doha Airport, and

Fig. 6B: Vector diagrams of daily mean winds in April.

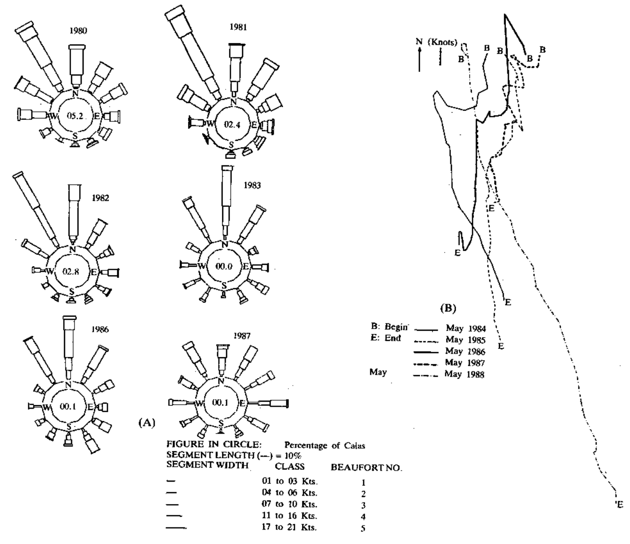


Fig. 7A: Wind roses at Doha Airport, and

Fig. 7B: Vector diagrams of daily mean winds in May.

SE, (Fig. 10a). In 1985 and 86, (Fig. 10b), the vectors were directed from N, E and S at different times of the month, and in 1987 and 88 the E and N winds were observed. Therefore, the annual variations are significant in August, with monthly mean speeds (3.1-7.5) knots and directions (305-053°).

9. SEPTEMBER: The wind roses, (Fig. 11a), show variable wind directions, except in 1986. The wind velocity vectors, (Fig. 11b), had different trends; in 1984, 85, 87 and 88 the N, NE and E directions were manifested, while in 1986 the winds were persistent from E. Monthly mean directions were (030-095°) and the speeds were (2.8-3.8) knots.

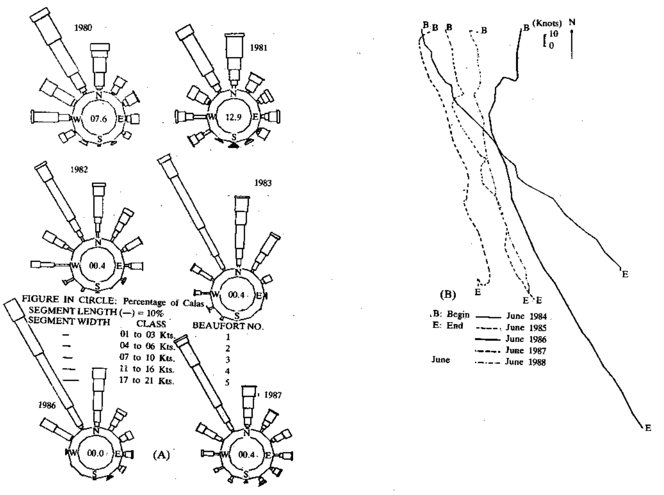

Fig. 8A: Wind roses at Doha Airport, and

Fig. 8B: Vector diagrams of daily mean winds in June.

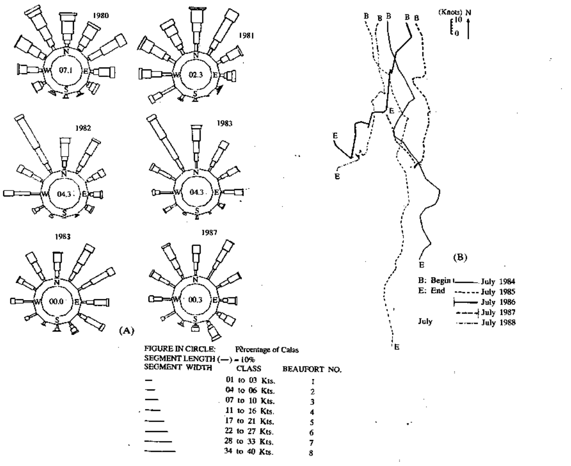

Fig. 9A: Wind roses at Doha Airport, and

Fig. 9B: Vector diagrams of daily mean winds in July.

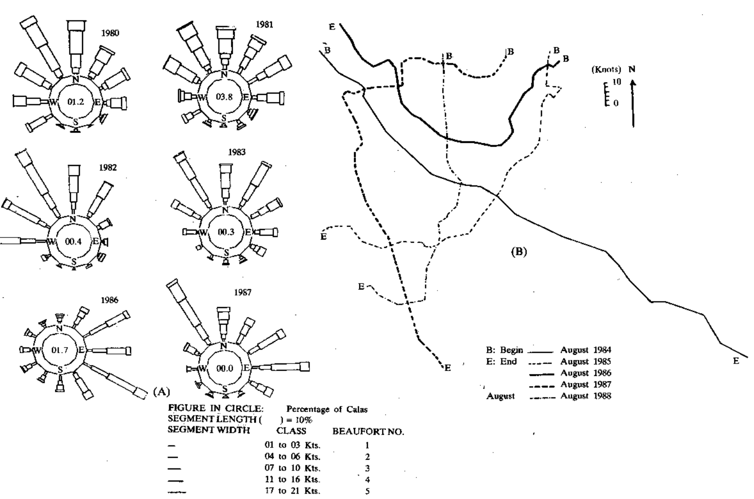

Fig. 10A: Wind roses at Doha Airport, and

Fig. 10B: Vector diagrams of daily mean winds in August.

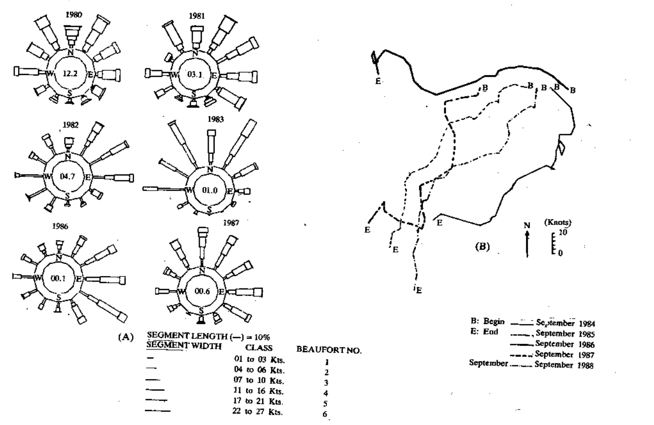

Fig. 11A: Wind roses at Doha Airport, and

Fig. 11B: Vector diagrams of daily mean winds in September.

10. OCTOBER: Most of the cases considered, (Fig. 12a), did not show predominant direction, and wind vector diagrams, (Fig. 12b), presented significant annual changes. In 1984 and 85, N and NW winds persisted with directions (346-350°) and speeds (3.0-5.6) knots, while in 1986 and 88, the wind vectors directions had remarkable changes during the month, with monthly mean direction (035-065°) and speeds (1.6-2.6) knots.

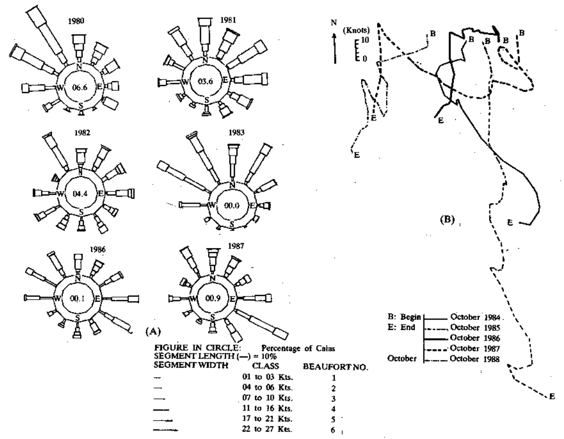

Fig. 12A: Wind roses at Doha Airport, and

Fig. 12B: Vector diagrams of daily mean winds in October.

11. NOVEMBER: (Fig. 13a) show that the wind had often a predominant direction from N to NW. These directions are also persistent in the vector diagrams, (Fig. 13b), except in 1984 when the main direction was NE. The monthly mean wind vectors had directions (330-353°), in 1985, 87 and 88, and directions (17-40°) in 1984 and 1986. The N-NW winds had higher speeds, (3.4-4.6) knots, than for NE winds, (2.0-2.2) knots.

12. DECEMBER: The winds were persistent from NW-N, (Fig. 14a). This evidence is well confirmed by the vector diagrams, (Fig. 14b). The monthly mean velocities had directions (303-345°) and speeds (2.7-4.7) knots, (Table 1).

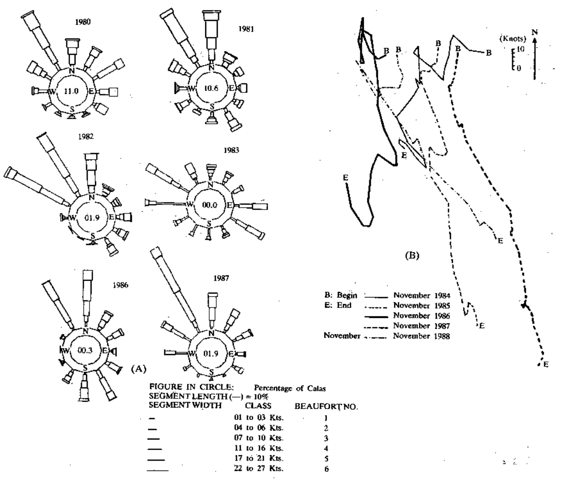

Fig. 13A: Wind roses at Doha Airport, and

Fig. 13B: Vector diagrams of daily mean winds in November.

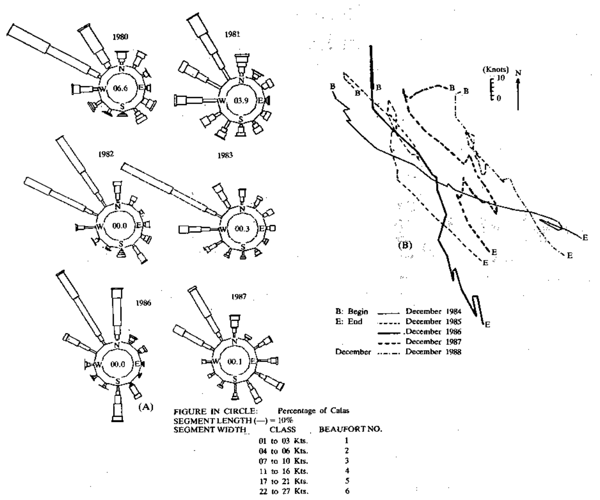

Fig. 14A: Wind roses at Doha Airport, and

Fig. 14B: Vector diagrams of daily mean winds in December.

## DISCUSSION

The objectives of the previous presentation is to discuss two main points; the first is concerned with the reliability of the forecasted oil spill movement using the presently available data on the Arabian Gulf and the second is concerned the data base required to be collected to improve the models results.

The accuracy of the forecasted oil spill displacement depends on the accuracy of current and wind data. The available current data are mostly obtained by indirect methods and they are not calibrated by current measurements. Therefore, the reliability of these data is not known. To improve the forecasts of the oil spill models in this region, it is necessary to do current meter measurements, from which both temporal and spatial variations can be understood. The positions of the current meters should be planned with the consideration of the tidal modes in the Gulf and the environmental sensitivity of the different areas. These current records should be analysed to separate the tidal currents by harmonic method, in order to know its importance relative to total current at the different places of deployment. In addition, these measurements will be a good tool to calibrate the numerical current models.

The wind data required for the model depend on the objectives of the forecasting. In the case of accidents, it is necessary to use wind recent data, usually last week records, and the forecasted winds from synoptic charts. Hence the uncertainty of the predicted oil spill movement is affected by these latter data. On the other hand, if the forecasting is required for planning purpose, the data are taken from previous historical records. The wind data recorded at Doha Airport (1984-88) showed that the monthly mean wind vectors in the different years had often narrow ranges in the period from December to next June when the wind was NW-N, while significant annual changes were observed from July to November. The east wind was more frequent in August and September. The highest mean wind speeds were observed in June. The directions of the mean vectors agreed with the predominant wind direction when the directions in the wind roses are not so scattered. In the months with remarkable annual variations, the right wind data input to the model could be improved after the investigation of the synoptic situations associated with the different wind systems recorded in previous years. For the oil spill movement in the Arabian Gulf, the authors suggest the analysis of wind data (hourly or 3 hourly) at different meteorological stations surrounding the area to understand the spatial distribution of winds.

The wind analysis results presented in this article indicate that, assuming the wind system in the Qatari waters is similar to that at Doha Airport, the wind action will lead to the movement of the oil spill, in most cases, from N or NW directions, which are nearly parallel to eastern Qatari coasts, except in August and September when the E and NE winds are often blowing and expected to drive the oil spill to the west and SW towards the eastern Oatari coasts.

## CONCLUSIONS

The present water current data available in the Arabian Gulf are not adequate to give reliable oil spill movement predictions. The wind velocity data at Doha Airport show that the monthly mean motion is directed from NW-N, except in August and September when E and NE winds are frequent. Due to the annual variations of winds, it is necessary to study the synoptic situations associated with different systems, and consequently the right input wind data can be chosen for the simulation.

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