3.4 OBSERVATIONS AND MODELING OF THE COASTAL METEOROLOGY OF THE UNITED ARAB EMIRATES DURING THE UNIFIED AEROSOL EXPERIMENT(2004)

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1. INTRODUCTION

The United Arab Emirates Unified Aerosol Experiment (UAE[2]) was proposed to study the complex meteorological and aerosol interactions in the Arabian Gulf region. This field experiment will aid in dust measurements, measuring the effect of aerosols on the radiative balance of the area, validating numerical models in desert regions, and studying the role of land-air-sea interactions on meteorology. During the summer months, the Arabian heat low dominates the Middle East. This in turn drives the southwesterly monsoon. Over the Arabian Gulf, the monsoon winds cause northwesterly surface winds. However, this synoptic forcing is weak and allows for the formation of sea and land breeze circulations on both coasts of the Arabian Gulf. These circulations are found during all seasons of the year.

The formation of a sea breeze and a sea breeze front depend on many factors, including the strength and direction of the synoptic winds. Arritt (1993) and Bechtold et al. (1991) have shown that the strongest sea breezes are the ones that just reach the coastline in the presence of calm to moderate offshore flow. This is due to convergence of the opposing flows. The sea breeze can exist entirely offshore with strong offshore synoptic winds. Offshore synoptic winds that are very strong (above 11 m s^{-1}) will inhibit the formation of the sea breeze (Arritt 1993). Onshore synoptic winds typically cause weaker convergence and a weaker sea breeze front, if one forms at all (Simpson 1987). In addition, onshore synoptic flow will inhibit the formation of a sea breeze if the winds are stronger than 3 m s^{-1} (Arritt 1993).

Using observations, Zhu and Atkinson (2004) found offshore nocturnal and onshore daytime winds throughout the year. Through a modeling study, they found the sea breeze front on the coast of the UAE to extend over 250 km inland and the depth of the sea breeze to vary from 1 km in January to 1-1.5 km in April, July, and October.

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2. OBSERVATIONS

Hourly surface observations from Abu Dhabi, United Arab Emirates (UAE) are available through the National Climatic Data Center (NCDC) for 1995-2002. This was used to determine the long-term frequency of sea breeze and land breeze events at Abu Dhabi. A sea breeze is defined as winds from 235° through north to 45°, and a land breeze is defined as winds from 45° to 235°. Sea breezes occur more than 90% of the days from March through December. In the months of May through December, land breezes occur on more than 90% of the days. February has the fewest days with sea breezes (77%) and land breezes (71%).

In addition to the long-term surface observations at Abu Dhabi, the Department of Water Resources Studies, Office of His Highness the President, UAE has 50 meteorological surface stations located throughout the country and on the islands to the north of the UAE. Meteorological variables measured at these sites include air temperature, wind speed, wind direction, mean sea level pressure, relative humidity, dewpoint temperature, precipitation, solar radiation, and soil temperature and moisture.

Figure 1. Selected automated weather stations in the United Arab Emirates.

Figure 1 shows the locations of the stations used in this paper, including Das Island, Qarnen, Dalma, Sir Bani Yas, Alqlaa, Owtaid, and Mukhariz. These stations are aligned approximately north to south with the first four stations offshore, Alqlaa on the coast, and the final two inland. The distance between Das Island and Mukhariz is about 250 km. Das Island, the furthest offshore station, is about 115 km offshore. Mukhariz is located about 130 km from the coast, near the UAE/Saudi Arabian border.

3. MODELING

3.1 Model Description

The atmospheric portion of the Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS™) (Hodur 1997) is a non-hydrostatic three-dimensional model. COAMPS was developed by the Marine Meteorology Division of the Naval Research Laboratory. Further documentation of COAMPS is available on the model Web site (http://www.nrlmry.navy.mil/coamps-web/web/home). Initial conditions and lateral boundary conditions were provided by the 56 km Navy Operational Global Atmosphere Prediction System (NOGAPS) from Fleet Numerical Meteorology and Oceanography Center (FNMOC) and were updated every 6 hours starting at 0000 UTC 8 September 2004. A single nest with a horizontal grid spacing of 12 km (Fig. 2) and 30 vertical levels is centered over the Southern Arabian Gulf. The three lowest sigma levels are at 20, 40, and 70 m. The simulation was integrated for 24 hours, starting at 0000 UTC 8 September 2004, with results archived every 3 hours.

Included in the simulated domain is the al-Hajar mountain range, located along the eastern coast of Oman with peaks reaching 3075 m. The southern Zagros Mountains in Iran are in the northern part of the domain. Most of the UAE has an elevation under 200m, with the terrain slowly increasing from the north to the south.

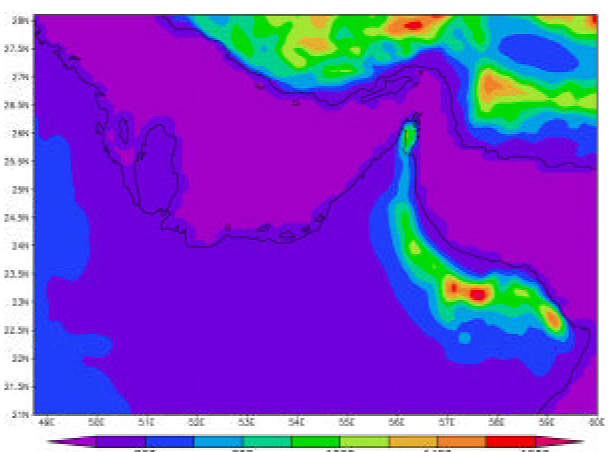

Figure 2. 12km domain over the Southern Arabian Gulf, United Arab Emirates, northern Oman, and southern Iran.

3.2 Model Results

Six-hourly wind speed and direction valid 1000 local time (LT) (0600 UTC) 8 September through 0400 LT (0000 UTC) 9 September are shown in Figure 3. Wind speeds are shaded in $m\ s^{-1}$.

1000 mb winds valid 1000 LT (0600 UTC) are from the southeast over the UAE (Figure 3a). This offshore flow is the land breeze that forms overnight. At 0700 LT, there is a wind speed maximum of 10 $m\ s^{-1}$ located near the UAE coast that moves to the northwest across the Arabian Gulf and diminishes in strength to 7 $m\ s^{-1}$ by 1100 LT (0900 UTC) (not shown).

1000 mb winds valid 1600 LT (1200 UTC) are shown in Figure 3b. Winds near the UAE coast have veered and become northerly, indicative of the sea breeze. The wind is easterly on the Oman coast as a sea breeze has developed there. The extent of the sea breeze can be seen from the location of low wind speeds just inland and just offshore of the coasts. The sea breeze front is parallel to the coast, clearly simulated along the Oman coast. The sea breeze in the UAE extends from 50 km offshore to 25 km onshore. The sea breeze over Oman extends further inland than the one over the UAE. Wind speeds are maximum near the coastline (4 $m\ s^{-1}$) due to frictional convergence.

At 1900 LT (1500 UTC), the sea breeze extends from 100 km offshore to 50 km onshore (not shown). The wind speed increases to 5 $m\ s^{-1}$ at the coast. The sea breeze is weakening over Oman with winds becoming parallel to the coast. By 2200 LT (1800 UTC), the sea breeze extends from 100 km offshore to 50-75 km onshore (Figure 3c). Wind speeds at the coastline remain 5 $m\ s^{-1}$. Slower wind speeds are located south of the coast as the sea breeze front penetrates further inland. The sea breeze also extends further offshore in the late evening. The remnants of the sea breeze front in Oman have retreated to the east as the down slope winds in the Jebel Mountains increase.

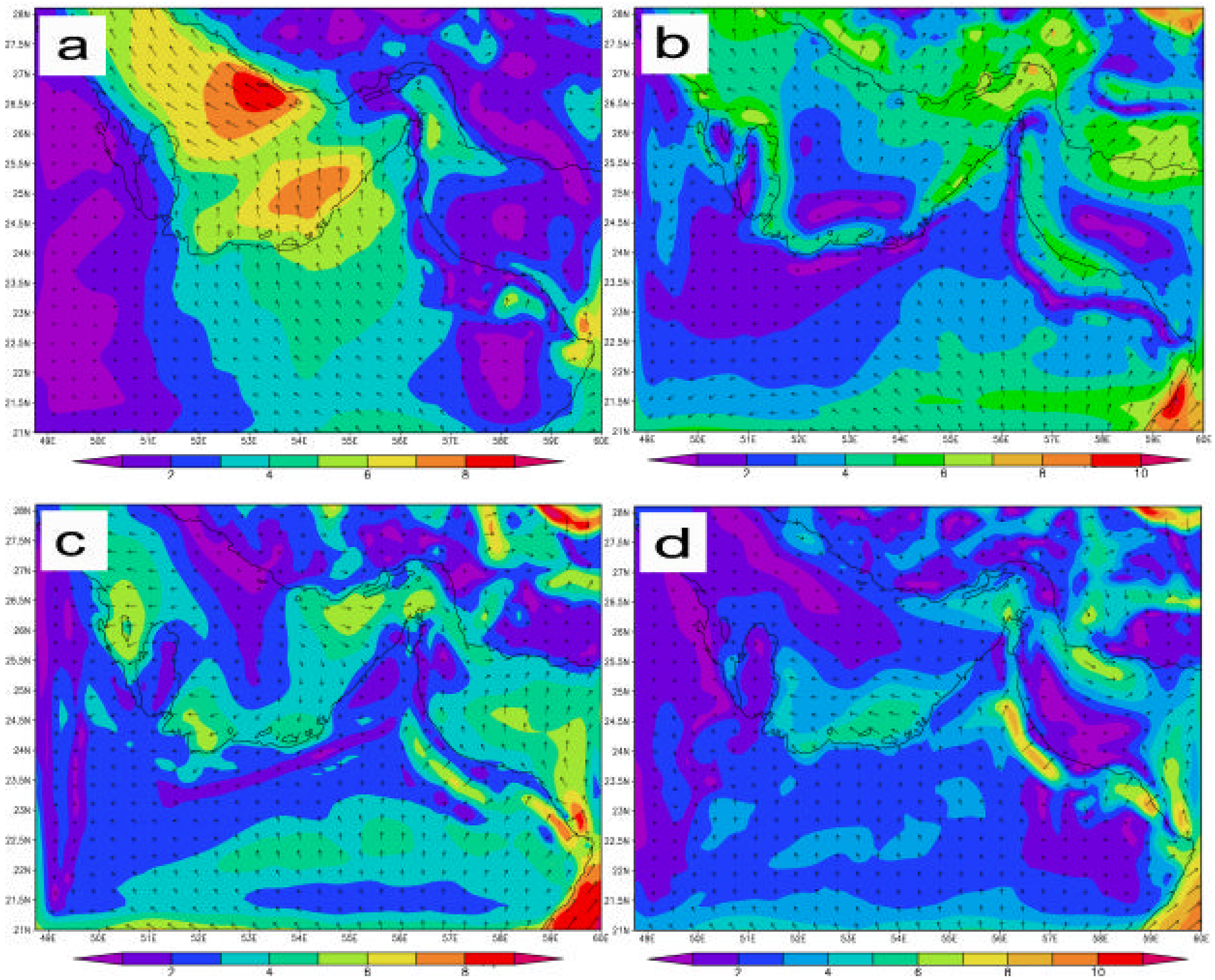

Figure 3. 1000mb wind speeds (shaded, in m s-1) and wind direction (vectors) on 8-9 September 2004. 1000 LT (0600 UTC) in upper left (a), 1600 LT (1200 UTC) in upper right (b), 2200 LT (1800 UTC) in lower left (c), 0400 LT (0000 UTC) in lower right (d).

At 0100 LT (2100 UTC), the winds are northeasterly, parallel to the northern UAE coastline (not shown). Figure 3d shows the winds at 0400 LT (2400 UTC), becoming southerly over the UAE and southeasterly over the southern Arabian Gulf, indicating that the land breeze has developed. Wind speeds are strongest at the coast, with speeds of 5 m s^{-1}. The strongest winds are associated with the down slope flow off the Jebel Mountains with speeds of 8 m s^{-1}.

The location of the sea breeze front can also be determined from the location of maximum convergence. The sea breeze front is located at the leading edge of the sea breeze. Figure 4a shows the convergence (s^{-1}) at 1000 mb valid 1600 LT (1200 UTC) while Figure 4b shows convergence at 0400 LT (0000 UTC). Positive values indicate convergence while negative values indicate divergence. The value of convergence is representative of the strength of the sea breeze. At 1600 LT, the maximum convergence (0.002 s^{-1}) is located parallel to the Oman coast, in the same area as the wind speed minimum (Figure 2b). There is also convergence along the UAE coast. At 0400 LT (Figure 4b), there is divergence along the Oman coast associated with the down slope winds from the Jebel Mountains. There is very little convergence or divergence over the rest of the domain.

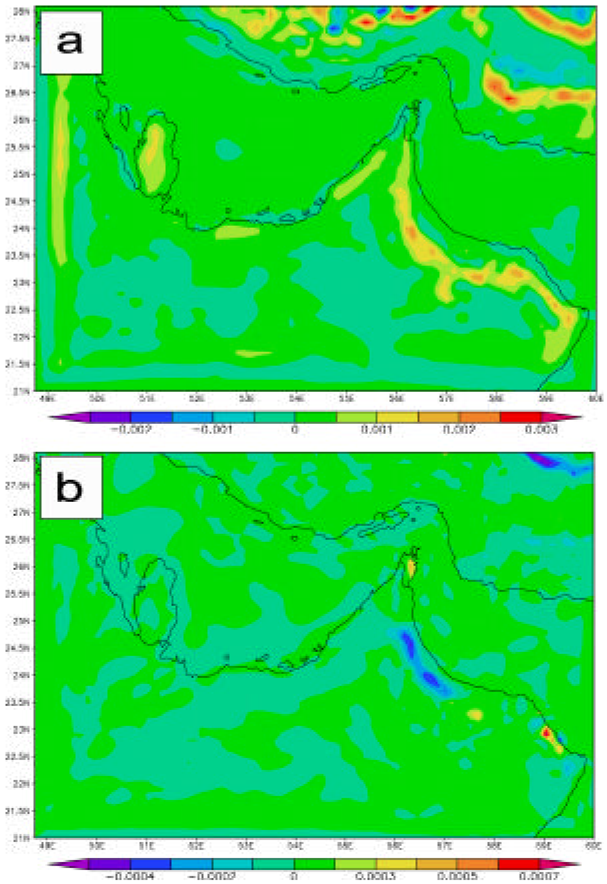

Figure 4. Simulated convergence at 1000 mb for 8 September 2004. 1600 LT (1200 UTC) shown in top plot (a), and 0400 LT (0000 UTC) shown in bottom (b).

4. VERIFICATION

The wind speed and direction of the simulated sea breeze are compared with observations from the seven stations listed in Section 1. The coastline at Alqlaa is aligned approximately east to west. A sea breeze at this location was defined as winds from 270° through north to 90°. A land breeze was defined as wind directions from 90° to 270°.

Observed wind directions for 0000LT 8 September to 0400LT 9 September are shown in Figure 5. Observations are missing on 8 September from 0100 LT to 1000 LT. At 1100 LT, the winds at all seven stations are between 120° and 180°, showing the presence of a land breeze. At 1300 LT, the winds at Alqlaa turn to become northerly as the sea breeze reaches this location. By 1400 LT, the sea breeze extends from Sir Bani Yas to Owtaid. At 1700 LT, the sea breeze extends inland to Mukhariz, located on the UAE/Saudi Arabian border. The sea breeze reaches Qarnen by 2000 LT, however, the winds at Das Island do not become northerly until 0000 LT. The sea breeze likely never reached as far north as Das Island. It appears the sea breeze on 8 September 2004 existed from about 90 km offshore to 130 km onshore. By 0200 LT on 9 September 2004, the winds at all the stations except Das Island have become southeasterly and southerly as the land breeze formed overnight.

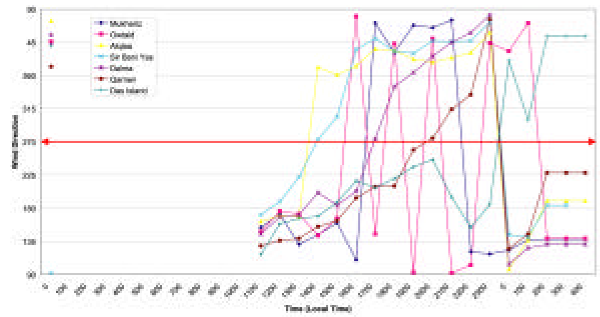

Figure 5. Observed wind directions for 8 September 2004 for seven stations oriented north-south in western UAE. The arrow at 270° separates land breeze winds (below arrow) from sea breeze winds (above arrow).

The wind speed observations at the seven stations are shown in Figure 6. Wind speeds peak between 1200-1300 LT at magnitudes of 5-8.5 m s^{-1} and decrease through the rest of the afternoon and evening. Wind speed observations at Dalma, Alqlaa, and Owtaid are compared with the COAMPS simulated wind speeds at the model gridpoint nearest to each station. Figure 7 shows observed (solid line) and simulated wind speeds (points).

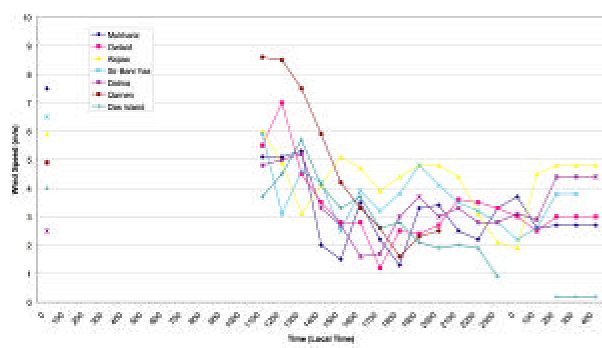

Figure 6. Observed wind speed for 8 September 2004 for same seven stations as Fig. 4. Wind speeds are in m s^{-1}.

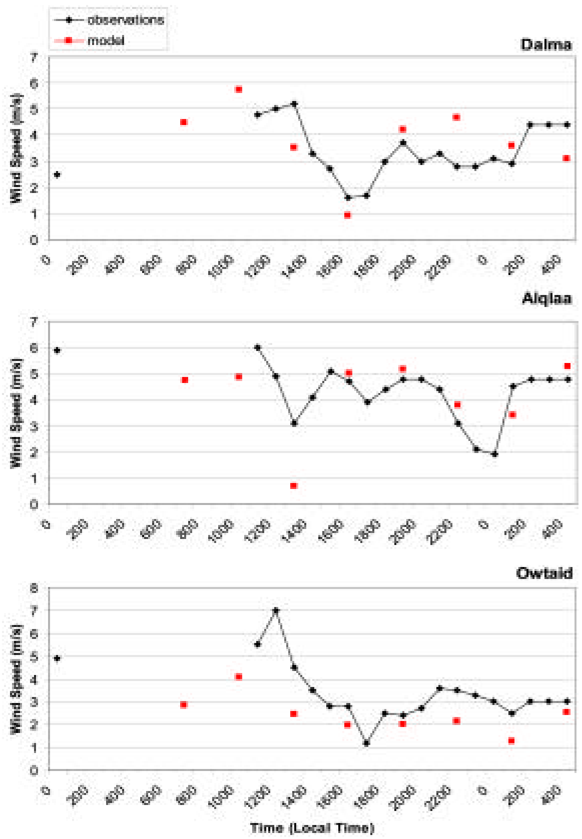

Figure 3. Comparison between observations and simulation for 8 September 2004 at Dalma, Alqlaa, and Owtaid. The observations are the solid line, and the model values are the points.

COAMPS underpredicted wind speeds at Dalma at 1300 and 1600 LT by 0.7-1.7 m s^{-1}, and overpredicted wind speeds up to 1.9 m s^{-1} in the evening. At Alqlaa, COAMPS underpredicted the wind speed by 2.4 m s^{-1} at 1300 LT. The model overpredicted the wind speed between 1600 and 2200 LT by 0.3-0.4 m s^{-1}. At Owtaid, the model underpredicted the wind speed throughout the day by 0.4-2.0 m s^{-1}.

5. SUMMARY

Sea and land breezes are the main mesoscale circulations in the Arabian Gulf that affect the meteorology of the region. They develop due to strong heating of the land and weak large scale winds. In the UAE, a sea breeze is indicated by northerly flow, while a land breeze by southerly flow. The extent of the sea breeze varies based on the ambient winds. The size of the Arabian Gulf allows for the possibility of interactions between the sea and land breeze circulations on opposite coastlines. A modeling study using COAMPS has also indicated the presence of these circulations.

6. ACKNOWLEDGEMENTS

This research was supported by the Naval Research Laboratory, Monterey, California and the State Climate Office of North Carolina. The authors would like to thank Major Abdulla Al Mondoos of the Department of Water Resources Studies, Office of His Highness The President, Abu Dhabi, United Arab Emirates for observation dataset.

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