CHAPTER 6

DUST STORMS AND DUST

6.1 INTRODUCTION

Estimates have been made that, worldwide, annually up to about two billion metric tons of dust are carried up into the atmosphere, mainly by dust storms. One dust storm can lift and deposit more than 200 metric tons of dust (Griffin et al 2002). The Arabian Peninsula has been listed as one of five major dust producing regions (Idso 1976), while Goudie (1983) added that dust storms are frequent in the area.

Apart from being a hazard and nuisance to the general public, dust storms and sand storms and their attendant poor visibility and gusty winds are a danger to aircraft landing and taking off. This can lead to diverted flights, delayed departures and attendant airport operational problems. Other effects include the scouring of aircraft surfaces and damage to engines as well as hampering ground operations.

A dust storm, or sand storm, is a collection of particles of dust, or sand, vigorously lifted to a great height by a strong and turbulent wind and the visibility is reduced to below 1000 metres (UKMO 1991). The visibility is most likely to be at its worst during daylight hours when the wind is at its strongest (UKMO 1994).

Criteria for defining a dust storm, or sand storm, in the region vary. At ADIA the definition is that the 10-metre wind must be in excess of 17 knots and the surface horizontal visibility below 1000 metres. Safar (1985) uses the same stipulations, but adds that when the visibility falls below 200 metres, the storm is classified as severe.

6.2 SCOPE OF THE STUDY

To the author’s knowledge no research results as to when dust events and dust storms occur at ADIA have been published. This chapter examines the weather conditions when dust storms occurred at ADIA from 1994 to 2003 by means of a brief statistical analysis as well as case studies and a methodology for forecasting these events is proposed. In addition, all dust events observed at ADIA when the visibility was reduced to 5000 metres, or less, were included in the statistics.

6.3 METHOD

Dust storm events are researched using surface weather observations at ADIA, as well as 1200 UTC and 0000 UTC atmospheric soundings at ADIA and Eta GFS NWP model data.

6.4 DYNAMICS

Although weather observers may make little distinction whether the cause of the poor visibility is dust or sand, there is a significant difference. The diameter of grains of desert sand usually varies from 0.15 mm to 0.3 mm with the lower limit being 0.08 mm. A diameter below 0.08 mm is defined as dust. Dust is more likely to be found in and around inhabited areas where human and vehicular activity tends to break and crush sandy soil to produce finer sand or dust (UKMO 1994).

The conditions that allow dust to be raised in suspension in the atmosphere for prolonged periods are dry soil, strong winds and a deep and well-mixed boundary layer with a nearly dry adiabatic lapse rate (Jauregui 1989, Safar 1985 and Blair 1957). Over the UAE the extremely dry soil conditions, especially during summer, merely require strong turbulent wind to raise dust and sand.

Wind turbulence, forced by the terrain, is normally too weak to raise grains of sand more than about a metre above the ground until the 10-metre wind speed reaches 20 knots. Sand lifted by the wind is then carried across the surface, but tends to fall back to the ground where they bounce back into the air and in the process disturb other grains of sand on the ground, a process known as saltation. The sand quickly settles to the ground when the wind drops and the visibility immediately improves. Dust, on the other hand, can be easily raised to great heights and, long after the surface wind has dropped, be held in suspension in the atmosphere for hours and even days before settling. Dust grains begin to be lifted when the 10-metre wind speed reaches 15 knots. Larger particles, in falling back to the ground, also disturb smaller particles, which are lifted higher into the air by turbulence and remain in suspension longer (UKMO 1994).

Two atmospheric mechanisms that provide a wind strong enough to lift dust and sand are the outflow from thunderstorms downdrafts and the synoptic situation when there is a strong pressure gradient between an anticyclone and a cyclone (Wheaton and Chakravarti 1990, WMO 1983). Below a thunderstorm dust is raised by the ascent of air in convective thermal currents, as well as in the zone of severe turbulence where the strong downdraft induced wind creates the storms gust front. This mesoscale phenomenon is virtually impossible to predict by coarse grid numerical models (Miller et al 2008). In the synoptic scale strong pressure gradient situation, stable thermal stratification at the edge of the anticyclone normally exists. Lifting of the dust is to due turbulence and vertical motion caused by the steep pressure gradient induced wind. Raised dust permeates upwards in small turbulent eddies that move up through one thermal layer of the atmosphere to the next. Dust raised this way is much more extensive than that lifted by thunderstorms and can cover over a million square kilometres (WMO 1983). Dust storms are also known by the Arabic word Haboob (see Appendix A, Glossasry), a name initially used in the Sudan, but its use is now becoming more widespread (Miller et al 2008).

6.5 STATISTICS

Observational records kept at ADIA from 1982 to 2001 show that while haze, due to dust, commercial pollutants, or moisture, is very common and occurs on average on 242 days per year, dust storms are far less frequent, the average being 3 per year with the maximum being 8 in 2003. By way of comparison, inland at Al Ain and using data from 1994 to 2001, haze occurs on an average of 304 days per year while dust storms average 4 days per year with a maximum of 7 in 1994. A total of 173 events (141 dust and 32 dust storms) were identified during the period from 1994 to 2003 (table 6.1).

Table 6.1. Events when dust haze, or dust storms were observed at ADIA and the visibility was ≤ 5000 metres from 1994 to 2003.

YEAR	DUST EVENTS	DUST STORMS	TOTAL
1994	10	5	15
1995	16	2	18
1996	13	1	14
1997	10	2	12
1998	12	2	14
1999	18	7	25
2000	15	3	18
2001	10	0	10
2002	17	2	19
2003	20	8	28
TOTAL	141	32	173

These events were divided into 3 groups according to when the wind direction was from the south-east (SE) to west-south-westerly (WSW), or from the west (W) to north-north-west (NNW), or northerly (N) to east-south-east (ESE) (table 6.2). The logic behind these divisions being that wind from the SE to WSW blows from the desert areas to the south-east to south-west. It also blows when a low pressure cell, or trough approaches from the west. Wind from the W to WNW has a track mainly down the longer length of the Arabian Gulf during post trough, or low pressure situations and high pressure building to the west. While that from the N to E either comes from the mainland of Iran to the north and NE, or had to come across the Gulf of Oman Sea and over the peninsula to the east. N-ESE events were difficult to categorise. These winds are most likely when low pressure/trough systems and the building anticyclone are more to the north-east, or east of the UAE. There were borderline instances that were difficult to categorise, such as when the wind blew from a northerly direction and it was possible that the wind was a north-westerly Shamal that with time veered to the north. The Shamal is defined in chapter 5.1.

The visibility was most often reduced at ADIA when the wind was from the south-east to west-south-west. This wind, referred to as a Kaus wind by the U.A.E. Ministry of communications **(**1996), has a long track off the desert. The visibility is less often reduced when the wind arrives from across the length of Gulf Sea to the north-west, or the Gulf of Oman. to the east. This is also the case at the much narrower sea in the vicinity of the Strait of Hormuz to the north-east (table 6.2), whence the cold and dry Nashi wind comes (section 6.6.3). It is interesting to compare the events when the visibility was less than 5000 metres listed in table 6.2 with the number of dust event observations when the visibility limit is raised to less than 8000 metres, as depicted in figures 6.3 to 6.5. The total 95 SE-WSW events in figure 6.2 constitute 45% of the total 211 observations. Similarly 42 W-WNW events out of 103 observations represent 41% and 36 out of 57 N-ESE events equals 63%. These statistics indicate that dust events from the N-ESE are far more frequent than previously thought. The simple fact is that, in this desert region, if the wind blows strong enough across the land dust haze and dust storms must be expected.

There is a close association between dust in suspension and vertical instability (Chepil and Woodruff 1957). It is therefore not surprising to note that there were many instances when a dust storm was associated with the presence of a thunderstorm Cumulonimbus (CB), or Cumulus Congestus (CU), with a high base (±5000 feet). Consequently, the wind direction and high speed was often of a short duration as was the poor visibility. Of the 32 dust storms, convective cloud was present on 15 occasions, most often during N-ESE winds (table 6.3).

Table 6.2. Direction frequency of dust events and sand storms during the period 1994 to 2003 when visibility was reduced to below 5000 m.

DIRECTION	DUST EVENTS	DUST STORMS	TOTAL
SE-WSW	83	12	95
W-NNW	33	9	42
N-ESE	25	11	36
TOTAL	141	32	173

Table 6.3. Direction frequency of dust storms associated with convective cloud during the period 1994 to 2003 when visibility was reduced to below 1000 m.

	SE-WSW	W-NW	N-ESE
Dust storm with CB	2	2	6
Dust storm with CU	1	3	1

The average duration (to the nearest 5 minutes) of visibility at, or below, 1000 metres at ADIA in a dust storm was found to be 1 hour and 15 minutes with the maximum time being 4 hours 30 minutes. The average time when the visibility is at, or below, 3000 metres is 3 hours 45 minutes with the longest time being 15 hours. Taking all 173 dust events into consideration the average time when the visibility was at, or below, 5000 metres is 3 hours 30 minutes and the most 21 hours. On average thunderstorm gusts reduce the visibility to dust storm levels for 37 minutes with the longest time being nearly 60 minutes. These poor visibility periods due to dust during thunderstorms could be longer, because observations when rain was present with dust during a thunderstorm were excluded and it is impossible to determine form the data which of the two was the prime cause of the poor visibility.

Dust reduction of the visibility to below 5000 m, with SE to WSW winds, was most frequent during the morning and most of the afternoon, as depicted by figure 6.1 and where it should be remembered that UAE local time is 4 hours ahead of UTC. This coincides with the regular morning land breeze that would reinforce any southerly flow due to the synoptic pressure pattern, such as when low pressure systems are present to the west. Conversely, dust reduced visibility associated with a W-NW flow, was most likely during the mid and later afternoon when a north-westerly Shamal would be strengthened by the sea breeze. An explanation for the peak of N-ESE events in the late afternoon and early evening is that at this time the sea breeze begins to veer towards the east. More likely, this increased frequency is due to increased wind speed caused by deepening of the diurnal heat low over the Empty Quarter to the south-west (Rao et al 2003).

There is a marked frequency peak in dust reduced visibility by midday and a decrease soon after sunset (figure 6.1). Night cooling of the ground and the air immediately above it by radiation, results in increased stability that suppresses the vertical movement of wind eddies, uncouples the surface wind from the stronger wind aloft, and allows surface friction to further reduce the near surface wind speed. Dust is therefore given time to settle. During the day increased heating and thermally induced turbulent eddies reduces stability and increases mixing with the air aloft, which increases the wind speed and lifts dust (Kessler 1985).

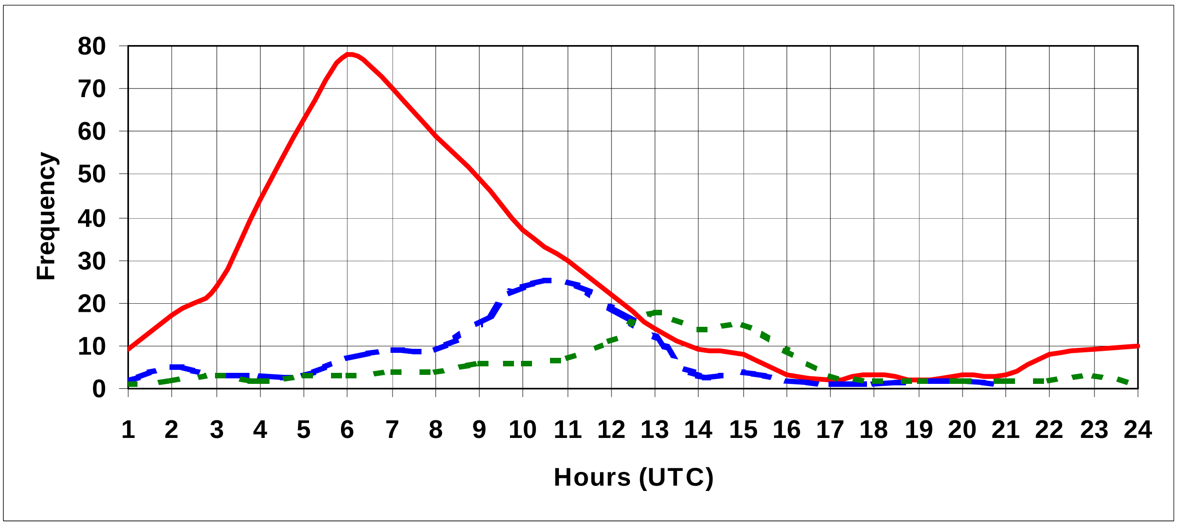

Figure 6.1. Diurnal frequency of dust events (visibility ≤ 5000 metres) from 1994 to 2003, inclusive. SE-WSW wind events – solid red line, W-NNW – blue long dashed line, N-ESE – green short dashed line. Local time is UTC plus 4 hours. Annually the sunrise varies from ±0530 in summer to 0700 in winter (0130 to 0300 UTC) and sunset from 1900 in summer to 1730 in winter (1500 to 1330 UTC).

Correlation between wind speed and visibility was difficult to establish as the scatter graph depicting the relationship for the 32 dust storms events shows (figure 6.2). This is attributed to the visibility remaining poor due to dust remaining in suspension in the atmosphere after the wind has dropped, as well as poor visibility in low sun conditions, particularly at sunrise. Another contributing factor is dust brought aloft from afar by a synoptic system. Such as the trough that caused by a persistent 5-day Shamal from the 16th to 20th May 2003 (section 6.6.2), which carried dust from eastern Saudi Arabia, across the Gulf Sea to Abu Dhabi and reduced the visibility to 3000 metres. Nevertheless, the Pearson product-moment coefficient of correlation (Harper 1977) yields a negative correlation of 0.64.

Viewing figure 6.2 it is clear that the greatest concentration of points lie in an area where the wind speed exceeds 15 knots and the visibility is less than 3000 metres. Below 15 knots most of the pixels are in an area where the visibility is greater than 4000 metres. Although a considerable number are present in an area where the visibility is greater than 4000 metres and the wind is between 15 to 20 knots. Bear in mind that wind direction, such as a shorter track off the sea, has not been taken into consideration. However, there are some loose deductions that can be made;-

i Above 15 knots the visibility can be below 8000 metres and is often less than 5000 metres.
ii Above 20 knots the visibility will be less than 5000 metres and is often less than 2000 metres, but most likely below 1000 metres.
iii Above 25 knots the visibility will be less than 2000 metres and is more likely below 1000 metres.
iv Above 30 knots the visibility will be less than 1000 metres.

Scatter graphs were compiled of dust events during 2003 according to the three wind direction groups. Of the 28 identified during the year, 17 were associated with the southerly sector, 8 from the north-west sector and 3 from the north-east sector (figures 6.3, 6.4 and 6.5).

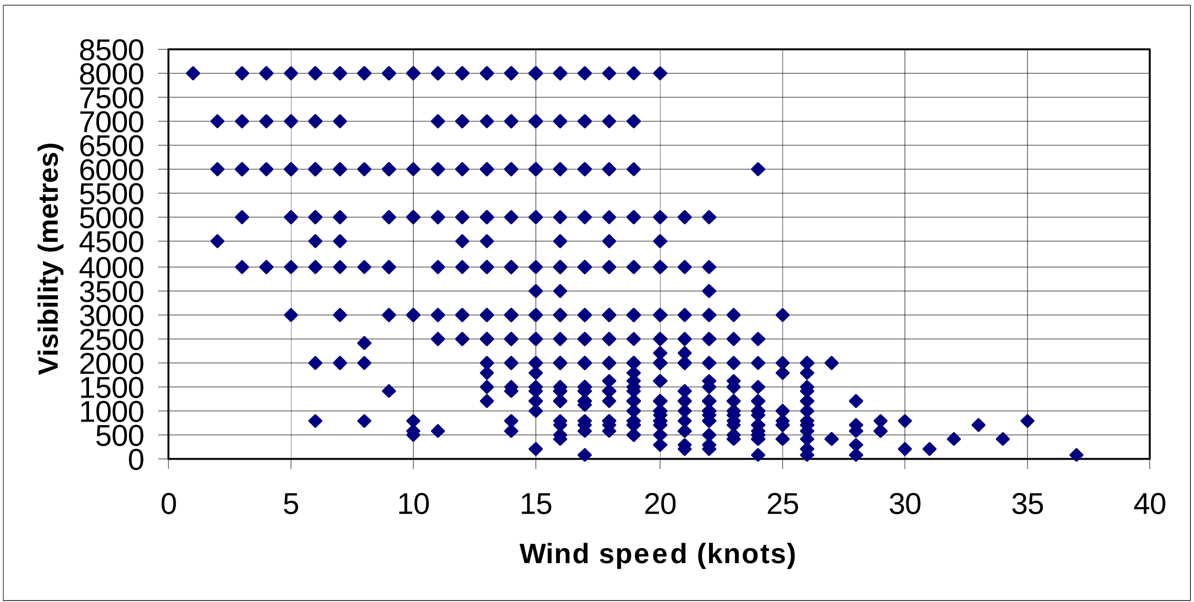

Figure 6.2. Scatter graph of visibility and wind speed recorded (715 observations) during dust storms in ten years from 1994 to 2003 when the visibility was ≤ 8000 metres. Correlation -0.64.

Of the three wind direction groups, the best correlation between the wind and visibility existed when there was a southerly desert wind, the correlation being –0.67 (figure 6.3). For the most part at 5 knots the visibility was never below 6000 metres and at 10 knots the minimum visibility was 3000 metres. A wind speed above 15 knots accounted for most of the observations when the visibility was below 3000 metres. Above 20 knots the visibility was below 1000 metres.

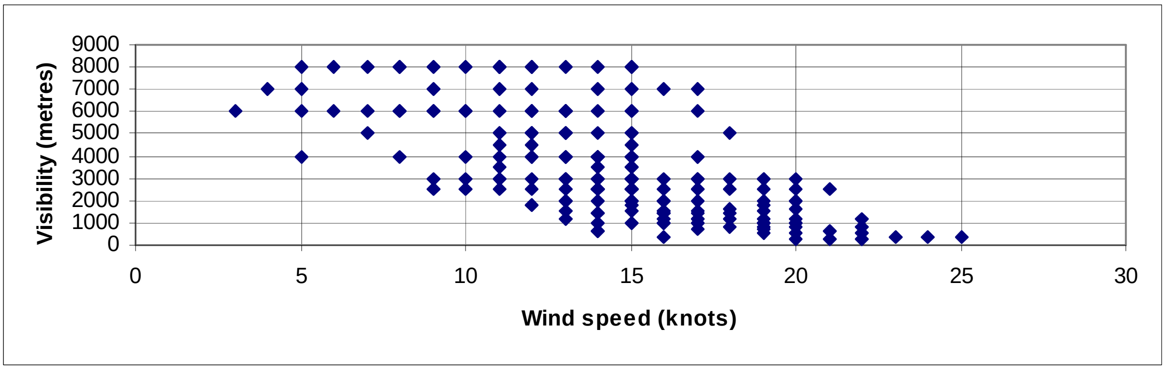

Figure 6.3. Scatter graph of visibility and wind speed recorded (211 observations) during dust events in 2003 when the wind was SE to WSW and the visibility was ≤ 8000 metres. Correlation -0.67.

The correlation between visibility and wind speed for north-westerly winds was poor, namely, -0.4 (figure 6.4). The most probable explanation is that the dust arrived after passing over a broad expanse of water. The visibility was therefore more dependent on how much dust was still in suspension and not the wind speed.

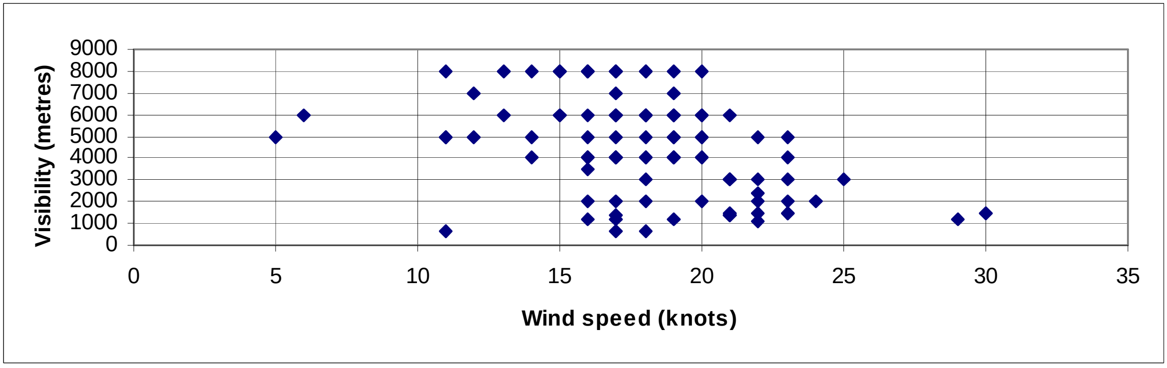

Figure 6.4. Scatter graph of visibility and wind speed recorded (103 observations) during dust events in 2003 when the wind was W to NNW and the visibility was ≤ 8000 metres. Correlation -0.41.

Strictly speaking there were too few events for a reasonable analysis to be made of the north-easterly wind group (figure 6.5). Nevertheless, the scatter graph is interesting. Note, although classified as two calendar day events, two consecutive days were associated with dust that arrived from the north-east after travelling a considerable distance from Iran (13th and 14th December 2003), the so-called Nashi wind. The wind at ADIA was never more than about 13 knots (with one observation of 17 knots). Winds below this speed do not usually cause serious visibility reduction. However, in this instance there were numerous observations when the visibility was below 5000 metres and even less than 1500 metres with the wind below 7 knots. Clearly the dust was not raised locally, but brought from far afield at Iran. This is discussed in section 6.6.3. Another interesting aspect of the graph is that all the winds above 17 knots were observed during brief periods of less than half an hour when there were thunderstorms near to and at the airport. In these instances the dust was clearly locally generated by outflow from the thunderstorms.

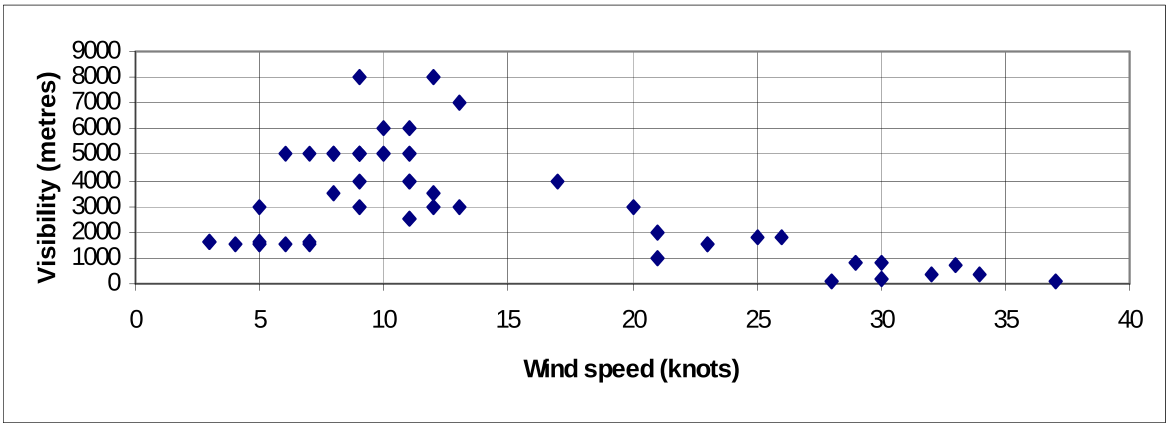

Figure 6.5. Scatter graph of visibility and wind speed recorded (57 observations) during dust events in 2003 when the wind was N to ESE and the visibility was ≤ 8000 metres. Correlation, -0.53.

6.6 STUDY OF DUST STORM EVENTS AT ABU DHABI AIRPORT

Three examples will be presented, one each according to the three wind categories that have been mentioned. An example of a dust storm associated with a thunderstorm will not be discussed, as this will be provided in the section on thunderstorms in chapter 8 and in particular a thunderstorm that occurred on the 18th March 2002.

6.6.1 THE DUST STORM OF THE 12TH AND 13TH MARCH 2003

6.6.1.1 Introduction

A particularly severe dust storm occurred on the 12th and 13th March 2003 when a well developed surface low pressure cell passed close by to the north of the UAE. Apart from the poor visibility experienced, the event was also noteworthy in that the storm lasted for two days. Usually the system moves through fast enough for the storm not to last longer than the daylight hours of one day. More often than not, diurnal land and sea radiation heating differential causes the afternoon sea breeze from the north to overcome the southerly desert wind. It was therefore unusual, during the evening of the first day, to see blurred street and vehicle lights through a haze caused by dust rather than the more usual humidity haze.

Visibility on the 12th at ADIA deteriorated to 1000 metres in a southerly wind that averaged 15 to 20 knots. At Al Ain International Airport the visibility fell to 3500 metres in a gusty wind that reached an average speed of 25 knots.

On the second day at Abu Dhabi the average wind was 20 to 25 knots and the observed visibility intermittently reduced to between 300 and 600 metres for nearly 7 hours during daylight (figure 6.6). At Al Ain the still gusty wind reached 29 knots with the visibility down to 1200 metres.

Figure 6.6. Central Abu Dhabi during the dust storm on the 13th March 2003.

The wind off the hot and dry desert caused the temperature to peak at 42°C and 41°C on the first and second day respectively at Abu Dhabi, with the relative humidity down to 5% and never above 20% during the day. Meanwhile at Al Ain the peak temperature was 39°C and 38°C on the two days, respectively and the daytime relative humidity was between 13% and 20%. The mean maximum temperature in the UAE in March is about 30˚C, so the weather was certainly considerably hotter than normal.

Finally, late on the 13th, the northerly Shamal in the wake of the low brought clear and more humid air from the Gulf Sea and a considerable drop in temperature. The maximum temperature on the 14th being 25°C at Abu Dhabi and 26°C at Al Ain. Of interest is the fact that when the Shamal started at Abu Dhabi, the visibility temporarily deteriorated before steadily improving.

6.6.1.2 NWP model data and the synoptic situation

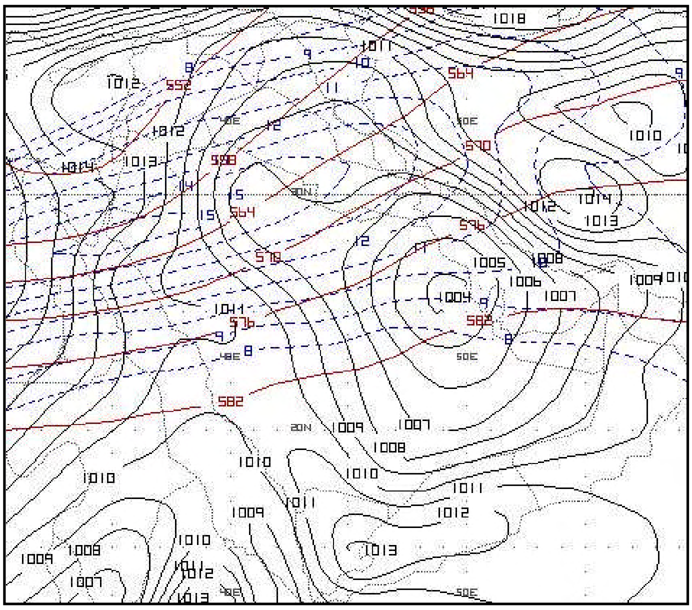

Figure 6.7. Eta GFS analysis at 0000 UTC (T+0) 2003-03-12. Black MSL pressure (hPa), red 500 hPa heights (decametre) and blue 250 hPa wind speed (tens of knots).

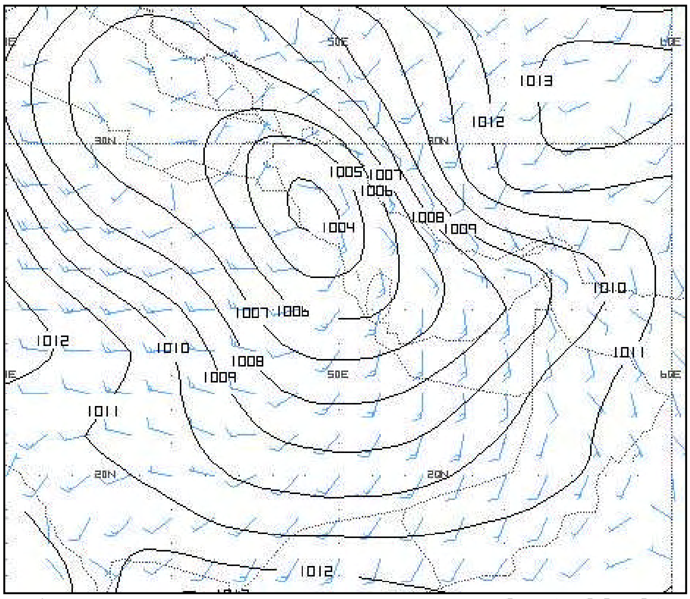

Figure 6.8. Eta GFS MSL pressure (hPa) (black) and 10 metre winds (blue) at 0600 UTC (T+6) 2003-03-12.

The passage of the low pressure cell from west to east was associated with an upper air trough system that was approaching from the west, and to the north, of the Gulf region. The 500 hPa trough was over the eastern Mediterranean Sea and eastern Turkey and at 250 hPa there was a north-westerly jet stream up to 140 knots over the Middle East with the 250 hPa low situated over eastern Turkey (figure 6.7).

The surface low pressure cell began to develop over central Saudi Arabia west of Qatar on the 11th. It had deepened to ±1004 hPa north-west of Qatar by 0600 UTC on the 12th with a 5 hPa pressure gradient across the UAE indicated by the model and a 15 knots southerly wind (figure 6.8). In the event the wind reached 20 knots at ADIA with the visibility down to 1000 metres.

The system moved eastward and by 0600 UTC on the 13th, it was north of ADIA over the Gulf Sea with a 5 hPa pressure gradient straddling the eastern part of the UAE and northern Oman with a wind of up to 25 knots (figure 6.9). It was around this time that the strongest southerly to south-westerly wind and poorest visibility occurred.

At 1800 UTC on the 13th, the cyclone had moved to the Gulf of Oman and a strong Shamal had invaded the UAE with slow visibility improvement (figure 6.10). By the following day it had moved away to the north-east over Iran and was approaching Afghanistan, while Shamal winds continued over the Gulf Sea and the UAE.

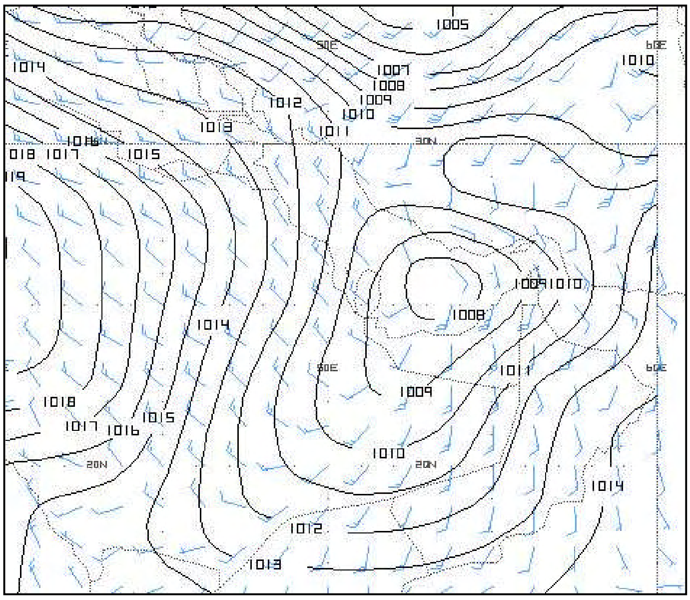

Figure 6.9. As figure 6.8, but at 0600 UTC (T+30) 2003-03-13.

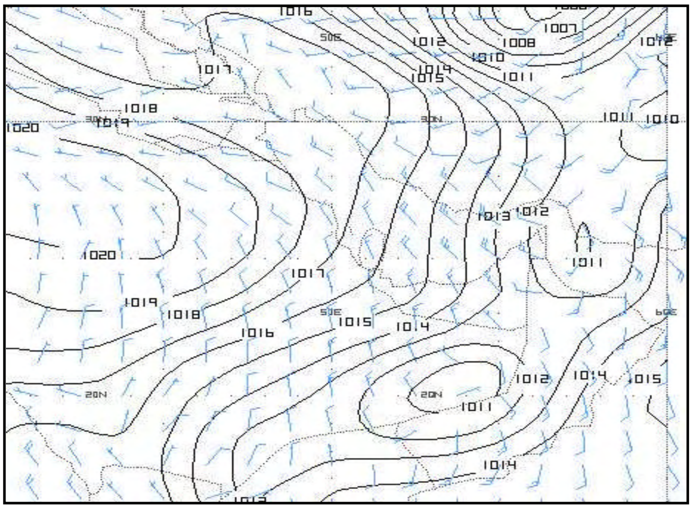

Figure 6.10. As figure 6.8, but at 1800 UTC (T+42) 2003-03-13.

The development of eddies of strong upward currents are necessary to lift dust and fine sand to higher layers of the atmosphere. The upward currents must have vertical speeds that exceed the gravitational falling speed of the particles (WMO Technical Note No.178, 1983). According to the Stokes formula in the WMO Technical Note to lift particles of about 0.1 mm diameter, requires upward currents of 3 to 3.5 ms^{-1}. "The drop in pressure in the centre of the eddy is equal to 1-1.3 hPa, and the rise in wind speed is 10-12 ms^{-1}. The wind speed is almost nil at the height of a few centimetres from the earth, growing quickly in the eddy and reaching l0 m s^{-1} and more at the level of 40-50 metres. The vertical speeds also increase rapidly with height and reach 3-4 ms^{-1}, which allows the eddy to transfer fine sand and dust to a height of up to 1-2 km and even higher".

The Eta GFS time cross section in figure 6.11 clearly shows the correct conditions for dust storm development. Apart from strong winds with little velocity shear up to 850 hPa on both days, indicative of a well mixed boundary layer and the ±5 hPa pressure gradient mentioned earlier, there was also marked upward vertical velocity of up to 3.5 Pa s^{-1} to 700 hPa on the chart ($\omega = dp/dt$ in the x, y, p, t pressure coordinate system, $\omega = -g\rho w$ Holton (1992)). This was associated with the model presenting surface convergence east of the approaching trough system. This indicates that there was sufficient upward motion to carry dust aloft (figure 6.12). Upward motion extended into the middle atmosphere on the 13th when the trough system was closer and there was strong upper air divergence indicated by the model around the 300 hPa level.

The uniform direction and strong winds from the surface to above 5000 feet is depicted by the Eta Grads time cross section on the 12th and the earlier part of the 13th (figure 6.13). Unfortunately, no further model products during this event are available. However, it is worth noting that up to the end of the available data at 0800 UTC on the 13th, the model prognosis was very good and correct in predicting stronger winds for that day.

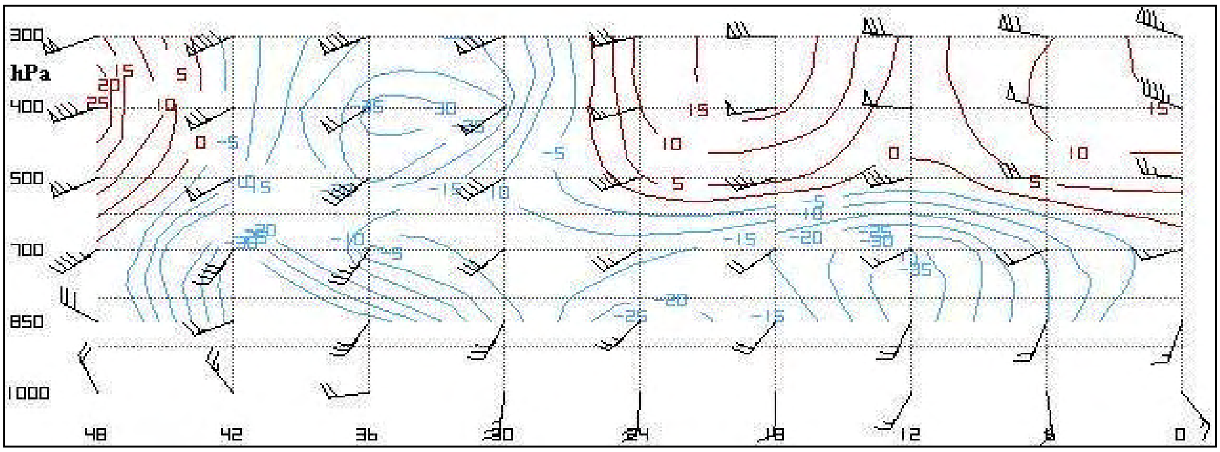

Figure 6.11. Eta GFS vertical time cross-section from 2003-03-12 0000 UTC to 2400 UTC on the 13th. Southerly 15 to 30 knots low level winds are shown up to 850 hPa with upward (blue, negative) vertical velocity of up to 35 micobars s^{-1} (3.5 Pa s^{-1} to 700 hPa).

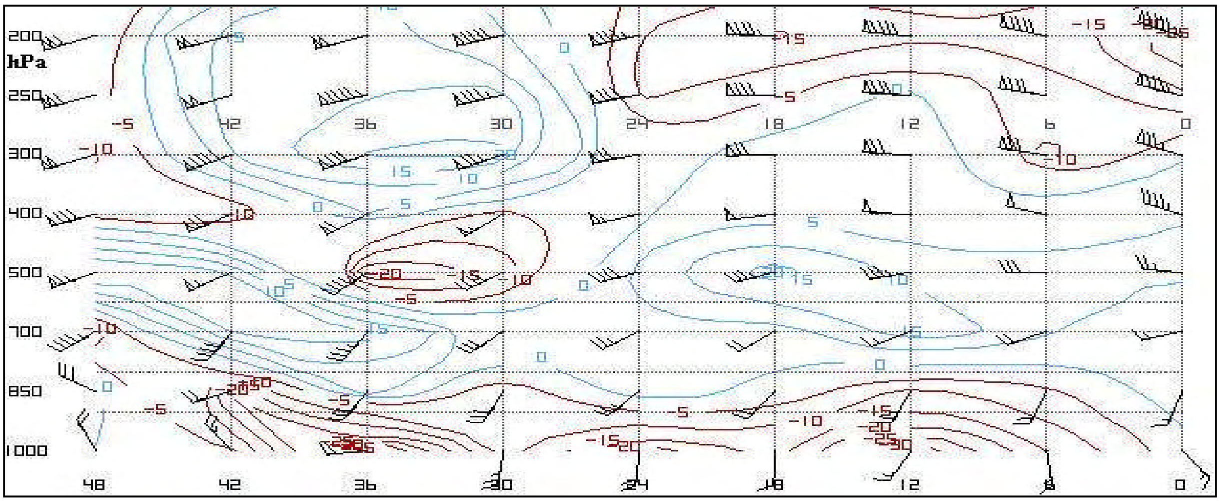

Figure 6.12. Eta GFS divergence time cross-section from 2003-03-12 0000 UTC to 2400 UTC on the 13th. Surface convergence with divergence aloft, coincides with the low level upward vertical velocity in figure 6.11, especially at T+30 to T+36 when the upper air trough was approaching the UAE.

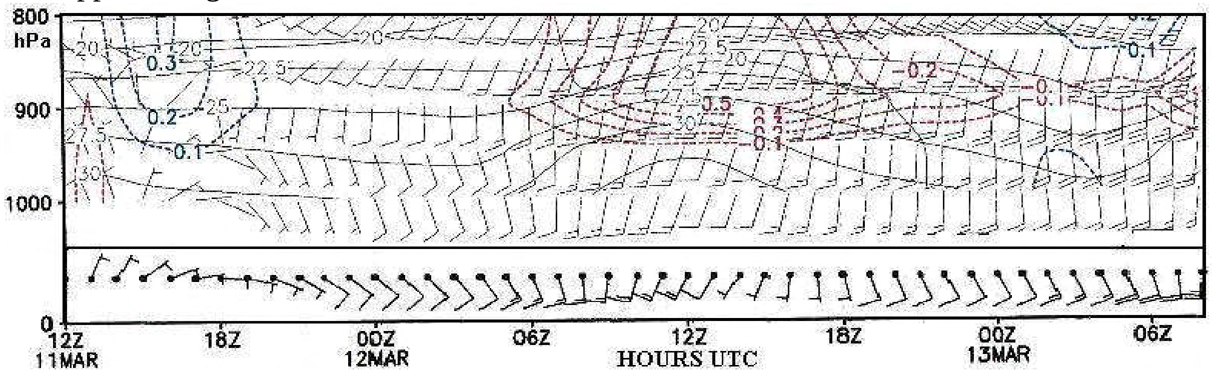

Figure 6.13. Eta GFS prognostic winds at 2003-03-11 1200 UTC. The figure emphasises the steady and strong low level winds, in knots, from the surface up to 800 hPa.

An environmental lapse rate that approaches the dry adiabatic temperature lapse rate facilitates upward motion of sand and dust particles (Safar 1985 and Blair 1943). Prevailing synoptic weather conditions apart, this is most likely in the early afternoon when surface heating is at its maximum and there is unlikely to be a surface temperature inversion. Clear indication of this happening was provided by the two prognostic vertical profiles at 0300 UTC and 0900 UTC on the 13th (figure 6.14) and verified by the atmospheric soundings carried out at 0000 UTC and 1200 UTC (figure 6.20). The visibility deteriorated from 6000 metres when a surface temperature inversion was still indicated at 0300 UTC, to 300 metres at 1025 UTC when the lapse rate became close to the DALR. These factors being conducive to vertical motion (turbulent mixing) of the surface air at a time when the surface wind increased from 12 knots to over 20 knots, resulting in more dust in suspension.

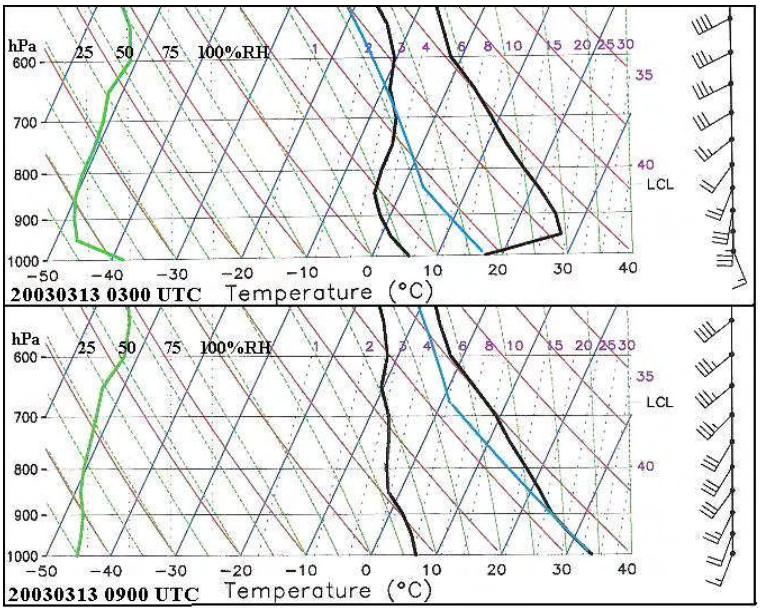

Figure 6.14. Eta GFS prognostic atmosphere profiles at ADIA at 2003-03-12 1200 UTC and 0300 UTC (T+15) on the 13th and 0900 UTC (T+18). DALR, pink lines and mixing ratio, dashed green lines.

6.6.1.3 Surface observations

The 68 observations of wind speed and visibility, from the start to the end of the dust storm, yield a less than encouraging correlation of –0.57. However, if one looks at the scatter graph in figure 6.15, it can be seen that there is a clear negative relationship between wind speed and the visibility. If a visually estimated best fit line is applied to the graph it can be seen that the visibility is about 10 000 metres when the wind is below 10 knots, below 5000 metres at 15 knots and below 1000 metres when the wind exceeds 20 knots. These values are similar to those arrived at in the statistics section (6.5).

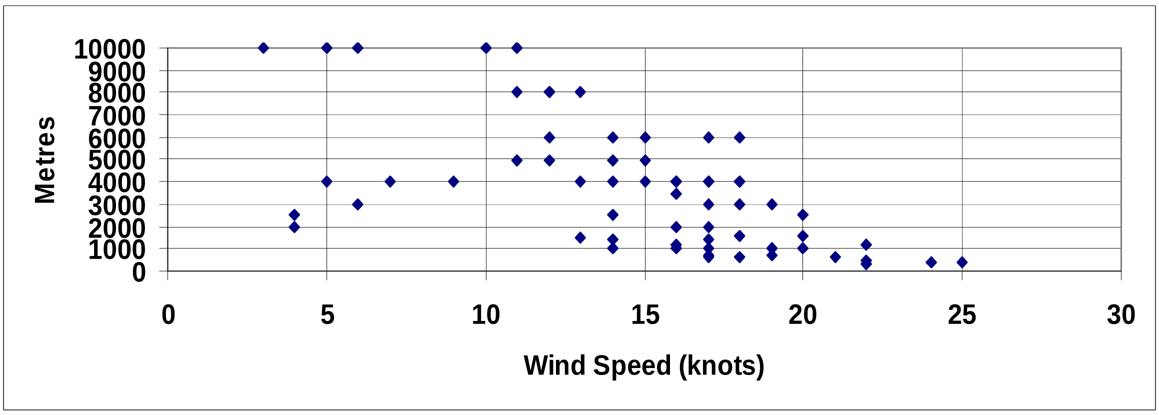

Figure 6.15. Scatter graph of wind speed verses visibility for the 30 hours from 0000 UTC on the 12th March 2003 to 0600 UTC on the 13th.

On the 12th the visibility steadily deteriorated to 1000 metres as the wind, aided by the land breeze, increased to about 20 knots from the south-south-east during the morning and later from the south-south-west during the afternoon (3 to 9 hours UTC in figure 6.16). In the late afternoon, after 4 pm (1200 UTC), the wind moderated as it rapidly changed to a north-westerly sea breeze and the visibility improved to 5000 metres (figure 6.16). During the night it veered to south-easterly again (and temporarily westerly), became light at times and the visibility improved to 10 000 m, or greater (15 to 24 hours).

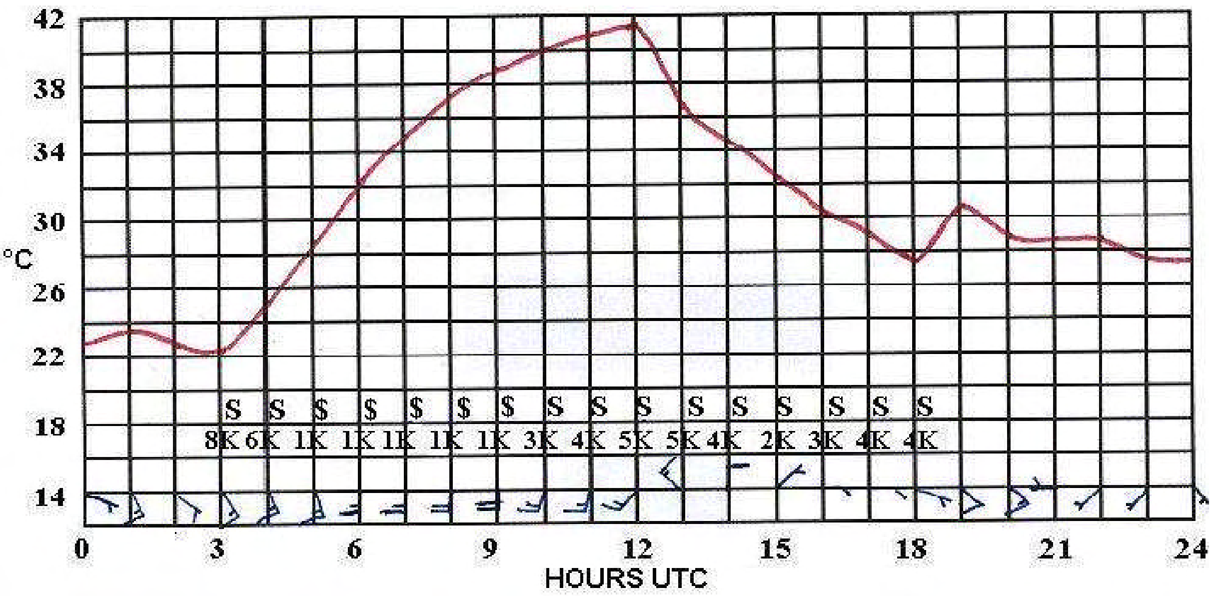

Figure 6.16. Surface observations at ADIA 2003-03-12. The air temperature (°C) is indicated in red, while the dew point temperature is off the bottom of the chart. The wind feathers are in knots (x 10), visibility is indicated in kilometres with dust (S) and blowing dust/sand ($) symbols.

About two hours after sunrise on the 13th (02 to 06 hours in figure 6.18), strengthened by the land breeze, the wind was already up to 20 knots and the visibility down to 500 metres. In the early afternoon it reached 25 knots with the visibility down to 300 metres between 1100 and 1200 hours (figure 6.17). This time it was nearer to 5 pm (1300 UTC) before the wind moderated and swung around to a 15 to 20 knots north-westerly Shamal. Although the sea air caused the visibility to gradually improve, apart from a brief period when the visibility suddenly deteriorated from 3500 metres to 600 metres, it was not until after sunrise on the 14th before the air was again clear enough for the visibility to exceed 5000 metres (figure 6.18). In total the visibility deteriorated to 1000 metres, or less, for about 5 hours on the 12th and 6 hours on the 13th.

The air temperature and dew point temperature graphs reveal very dry and hot desert air with the southerly wind on both days and temporary moister conditions during the intervening night when the wind changed to a north-westerly sea breeze in the evening (figure 6.19). Rapid cooling took place around 4 pm local time on the second day when the Shamal arrived at 36 hours on the chart.

An ambiguity, as mentioned in the introduction (6.6.1), is that on both days the maximum wind was stronger inland at Al Ain than at Abu Dhabi and yet on both days the visibility was

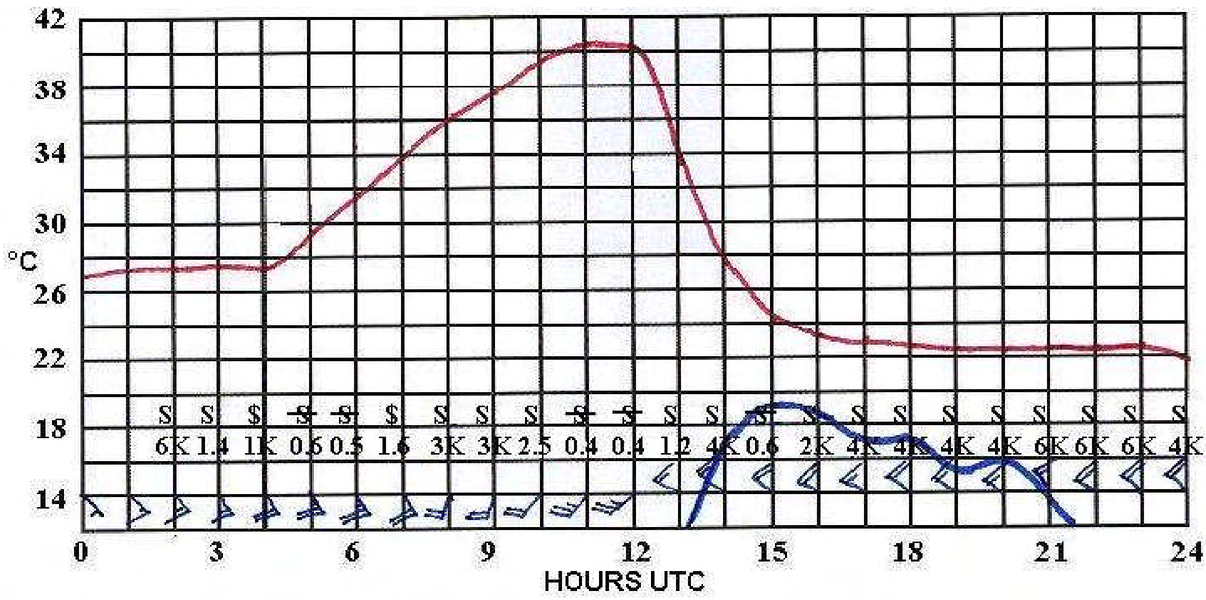

Figure 6.17. As figure 6.16, but for 2003-03-13. S with – strike through = sand storm.

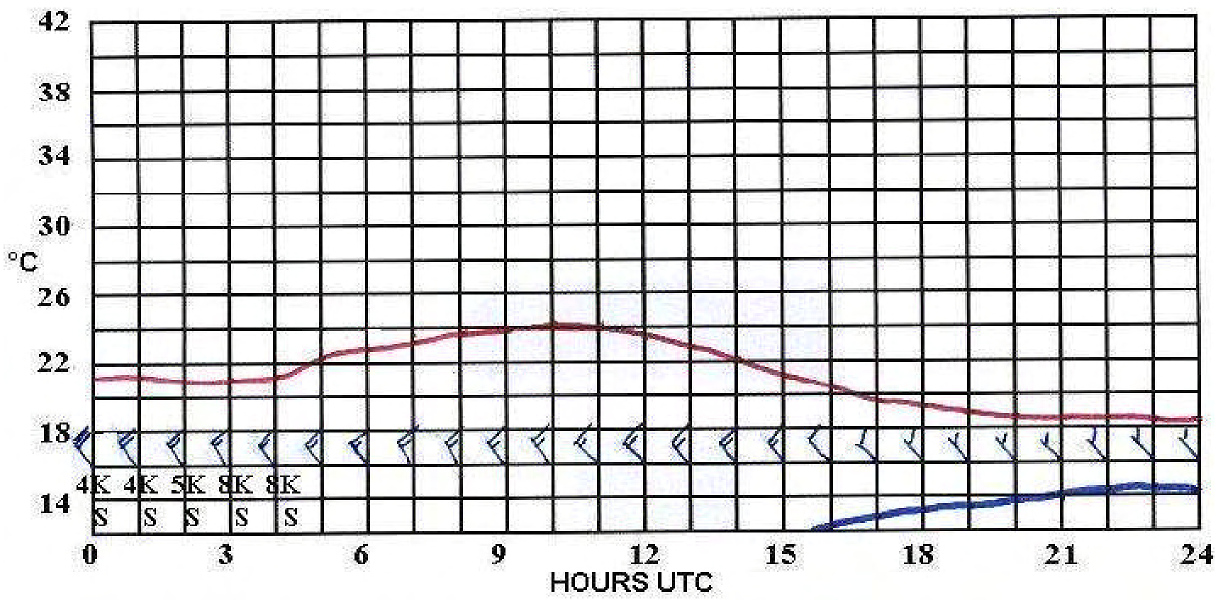

Figure 6.18. As figure 6.16, but for 2003-03-14.

not as poor at Al Ain as at Abu Dhabi. The reason for this is not clear. It could be that the nearby western slope of the Hajar Mountains induced a downward component to the wind, which suppressed the lifting of dust. Another, more likely, explanation is that the sand is different. On trips inland to Al Ain it was noted that the sand is a fine, white and salty dust deposit along a wide coastal strip that becomes a distinct red/brown coloured and much coarser desert sand as one approaches Al Ain. It is, therefore, probable that it is more difficult for the wind to lift the sand at Al Ain than the dust at ADIA. Furthermore, smaller particles, more effectively reduce visibility than larger particles (Robinson 1968), thereby accounting for the poorer visibility at ADIA.

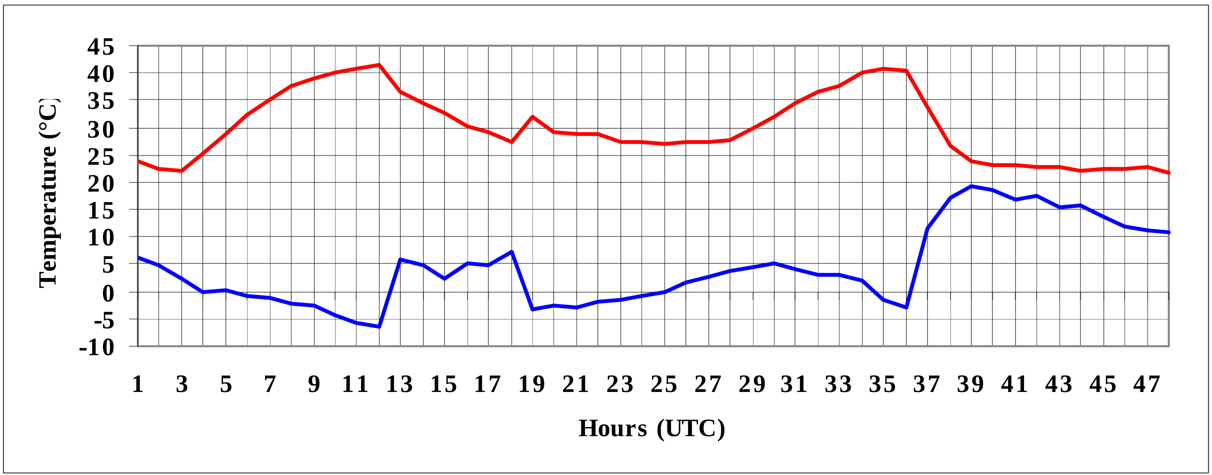

Figure 6.19. Air temperature (red) and dew point temperature (blue) for the 48 hours starting at 0100 UTC on 12-03-2003. The graph shows the extremely dry conditions during the desert wind and much cooler and moister conditions when the Shamal started.

6.6.1.4 Upper air

Table 6.4 gives a clear indication of the change from north-westerly sea breeze conditions on the afternoon of the 11th to a strengthening southerly desert wind during the 12th. The stronger winds, when the low pressure cell in the Gulf Sea was close to ADIA, are also evident on the 13th. Uncoupling of the 10 metre wind at 0000 UTC from the wind higher up is also present due to an overnight radiation cooling surface temperature inversion which developed overnight below 150 metres (500 ft) MSL.

Another noteworthy aspect is the low level nocturnal jet (Blackadder 1957) and wind shear between 150 metres to 610 metres (2000 ft) on the morning of the 13th (table 6.4). Of particular interest is the wind speed shear from 42 knots at 300 metres (1000 ft) to 3 knots at the surface. Weaker wind shear conditions existed on the other mornings.

Table 6.4. Low level winds at ADIA 11th to 14th March 2003.

	11/1200	**12/0000**	**12/1200**	**13/0000**	**13/1200**	**14/0000**
Surface	33009	11007	19015	20003	22024	32018
150 m	34509	12016	19522	18030	22031	32028
300 m	36009	13510	19523	18542	22034	32029
410 m	03509	16019	20522	19037	22037	32530
900 m	09505	18018	20524	20032	21537	32031
1200 m	11508	18019	20525	20530	21539	31522
1500 m	19502	20012	21019	21029	22039	30524

Low level wind shear is a significant hazard to aircraft during landing and take-off. A definite hazard exists if the wind change is sudden enough and big enough to exceed the aircraft's acceleration, or deceleration capacity and large enough to match its airspeed safety margin over the minimum approach, or climb speed (UKMO 1994, ICAO 1987). On the morning of the 13th, a landing aircraft approaching to land into the wind on runway 13 at ADIA, would experience a rapid loss of airspeed below 150 metres due to the headwind dropping from 30 knots to 3 knots. This translates to loss of lift and rapid sink. If not rapidly counteracted, at the best it results in a hard landing, at the worst a crash landing short of the runway. Taking off on runway 31 with an acceptable 3 knots tailwind results in a tail wind of 30 knots at 150 metres with similar loss of lift effects.

A similar problem exists when there is a large temperature shear such as associated with a surface temperature inversion. On the morning of the 13th the temperature increased by 5°C at 300 metres, but on the morning of the 12th it increased by 8° at 180 metres. An increase in temperature means a decrease in air density, less energy available to the aircraft engines, a loss of lift and aircraft sink (Kermode 1972). Therefore a heavily laden aircraft taking of on runway 31 within ground take-off limits, potentially could have found itself in serious difficulties, if the crew were not aware of the tailwind and higher temperatures aloft.

A similar propensity for danger exists in any situation where strong wind shear and/or strong surface temperature inversions exits, such associated with thunderstorms, land and sea breezes (ICAO 1987) and by implication Shamal conditions in the previous chapter.

The atmospheric soundings at 0000 UTC and 1200 UTC on the 13th are representative of the conditions that prevailed on both days (figure 6.20). The only difference being that the surface temperature inversion was more pronounced on the morning of the 12th. The soundings confirm the Eta model prognostic vertical profiles in figure 6.15.

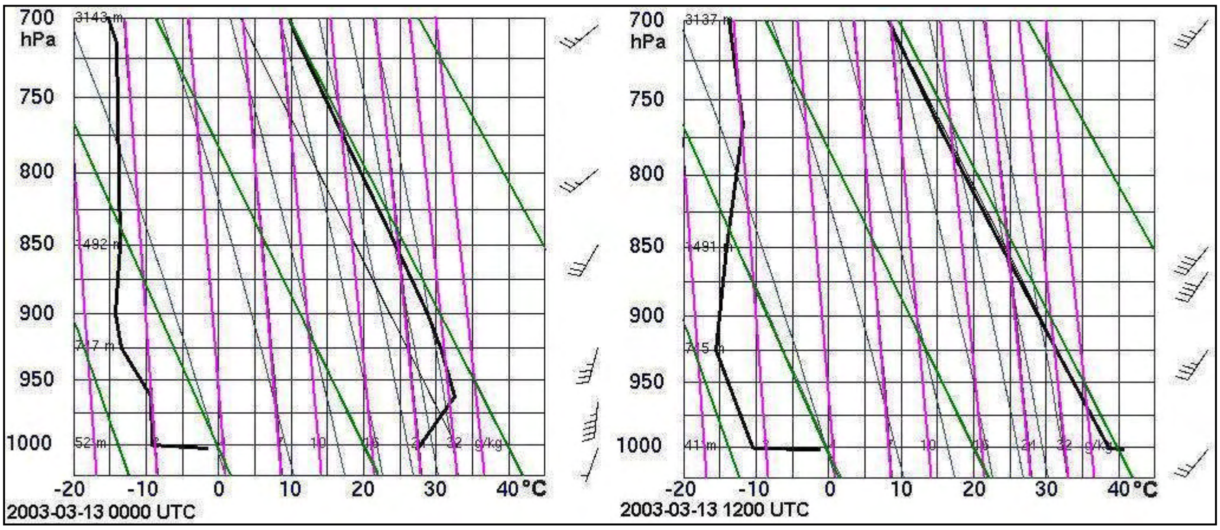

Figure 6.20. Atmospheric soundings at ADIA 2003-03-13 at 0000 UTC and 1200 UTC. The dry adiabatic lapse rate lines are in green and the mixing ratio lines in pink (courtesy of the University of Wyoming).

6.6.1.5 Summary

The dust storm occurred when a southerly wind, which lasted for two days, blew at 20 to 25 knots, reducing the visibility to 300 metres at times. The wind developed due to a strong pressure gradient between an anticyclone retreating to the east and a low pressure cell that approached from the west. The strongest winds and worst visibility occurred on the second day when the low pressure cell passed close by to the north on its passage to the east. Hot and very dry weather accompanied the wind.

The Eta NWP model gave an accurate indication of the wind velocity to be expected and its duration. The event culminating in the beginning of a cooler Shamal wind and change of air mass that is reminiscent of a cold front.

Conditions were ideal for upward transport of dust and poor visibility.

i A well mixed boundary layer with strong winds and little shear existed up to 850 hPa on both days.

ii An environmental lapse rate that approached the dry adiabatic temperature lapse rate resulted in unstable conditions. In this respect, the visibility was worst later in the morning and the early afternoon when the surface heating was at its maximum and destroyed the surface temperature inversion.

iii There was also marked upward motion ($\omega = -3.5$ Pa s^{-1}) up to 700 hPa associated with surface convergence.

In spite of a poor wind speed and visibility correlation factor of -0.57 for the duration of the dust storm, visual inspection of the scatter graphs show that one can generally conclude that below 10 knots the visibility is about 10 000 metres, or better. Above 15 knots the visibility falls below 5000 metres and falls below 1000 metres when the wind exceeds 20 knots. However, when the wind switches from a southerly desert wind to a north-westerly wind off the sea, the visibility slowly improves, even if it continues to blow at 15 to 20 knots.

6.6.2 FIVE DAYS OF DUST: 16TH TO 20TH MAY 2003

6.6.2.1 Introduction

Sometimes widespread dust from the north-west occurs over the area. It is lifted to the north of the UAE and carried southward on a persistent Shamal wind that can last for days. Such an event happened on the 16th to the 20th of May 2003. Strictly speaking this was not a dust storm event, but it is remarkable for its long duration.

6.6.2.2 NWP model data and the synoptic situation

The dust was raised over northern Saudi Arabia on the 15th where the visibility was reduced to 2000 to 5000 metres during the day, but it became as low as 300 to 800 metres at Bahrain at 1500 UTC.

Early on the 16th, at 0000 UTC, the dust in suspension reached the western part of the UAE at Jebel Dhana, where the visibility fell to 3000 metres. Surface winds were generally 5 to 10 knots from the north-west over the entire region, although the wind was up to 10 to 20 knots over the deep-sea part of the Gulf. During the course of the day the wind blown dust spread to the rest of the Emirates, with the visibility as low as 2500 metres. However, at Doha (in

Qatar) the visibility was 800 metres, while at Bahrain it was 600 metres and down to 200 metres at times. The wind over the Gulf region was north-westerly 5 to 10 knots, but up to 20 knots at the Doha offshore oilrigs. Overnight the wind was lighter, with 2500 to 4000 metres visibility. Figure 6.21 shows the pressure pattern and surface wind at 1200 UTC on the 16th (T+12).

There was little change in the weather on the 17th and the 18th when the wind was 5 to 15 knots from the north-west, but up to 20 knots offshore on the 18th. However, further offshore to the west it reached 25 knots at the Doha oilrigs. The surface pressure and wind analysis at 1200 UTC on the 18th (T+00) is shown in figure 6.22.

At ADIA the wind was generally 10 to 15 knots from the north-west and briefly, for two hours, reached 19 knots on the 16th. The minimum visibility on each day, shortly after sunrise, was 4000 metres on the 16th, 3000 metres on the 17th, 1800 metres on the 18th, 6000 metres on the 19th and 5000 metres on the 20th.

On all days the Shamal penetrated to Al Ain and blew stronger than at the coast on all days and the visibility was worse on most days. This peculiarity of the Shamal and sea breeze wind blowing stronger inland at Al Ain was discussed in the previous chapter in section 5.7. On the 16th it reached 20 to 25 knots with gusts approaching 40 knots and 2500 metres visibility. On the 17th it blew at 15 knots with gusts of 25 knots with 3000 metres visibility. The wind averaged up to 18 knots on the 18th and up to 17 knots on the 19 with 2500 metres visibility on both days. On the 20th it blew up to an average of 19 knots with gusts to around 30 knots and the visibility down to 3000 metres.

After the 20th the visibility continued to improve. The wind remained predominantly north-westerly until the 25th, but by now it had moderated to the point that it was more of a sea breeze than a true Shamal.

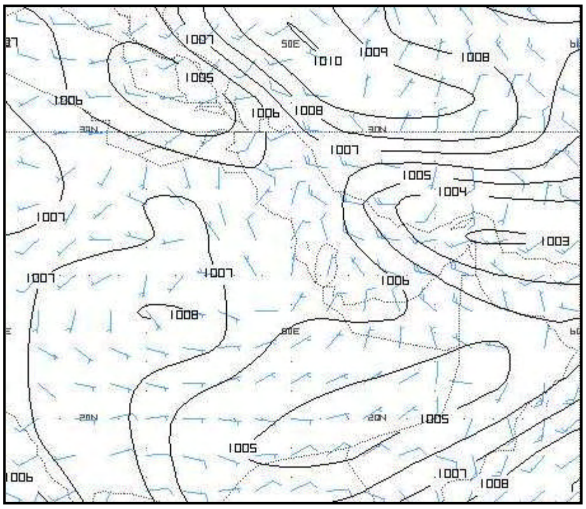

Figure 6.21. As figure 6.8, but at 1200 UTC (T+12) 2003-05-16.

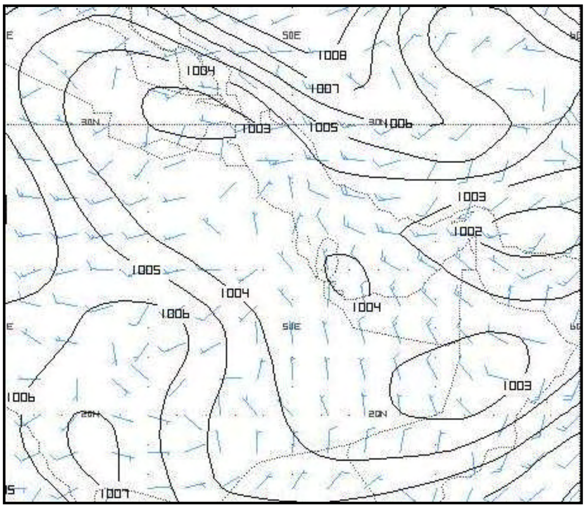

Figure 6.22. As figure 6.8, but at 1200 UTC (T+0) 2003-05-18.

In the previous event (6.6.1) the Eta NWP model indicated that there was low level convergence and upward motion east of the trough. This is to be expected in this region and it would facilitate the raising of dust. In this event, as is normal in a post-trough circulation, subsiding air (figures 6.23 and 6.24) and low level divergence (figures 6.25 and 6.26) was present (Hess 1959). This is not conducive to the raising of dust.

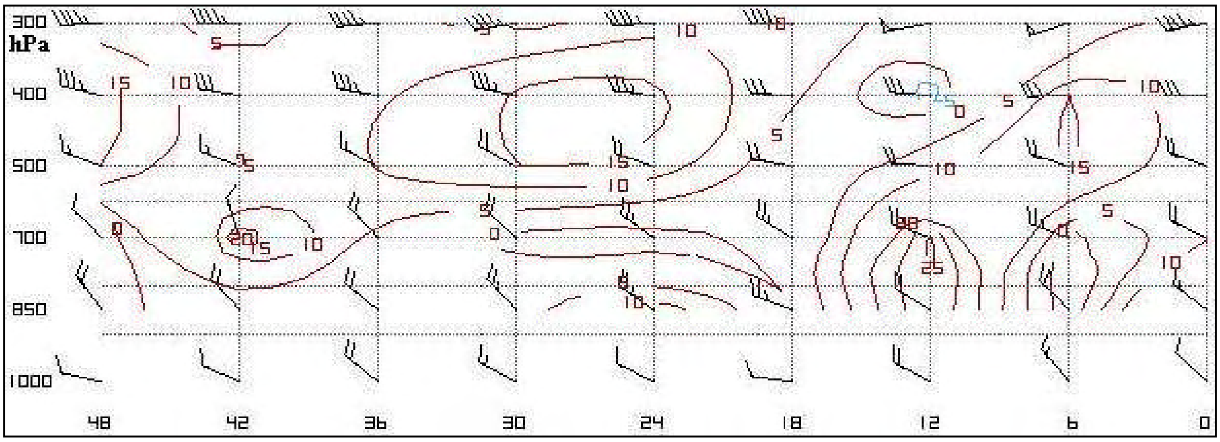

Figure 6.23. Eta GFS vertical velocity (ω) time cross-section 2003-05-16 0000 UTC to T+48 at 0000 UTC on the 18th. Post-trough subsiding air is indicated by the downward motion (ω>0, red) in microbars per second. The wind feathers are in tens of knots.

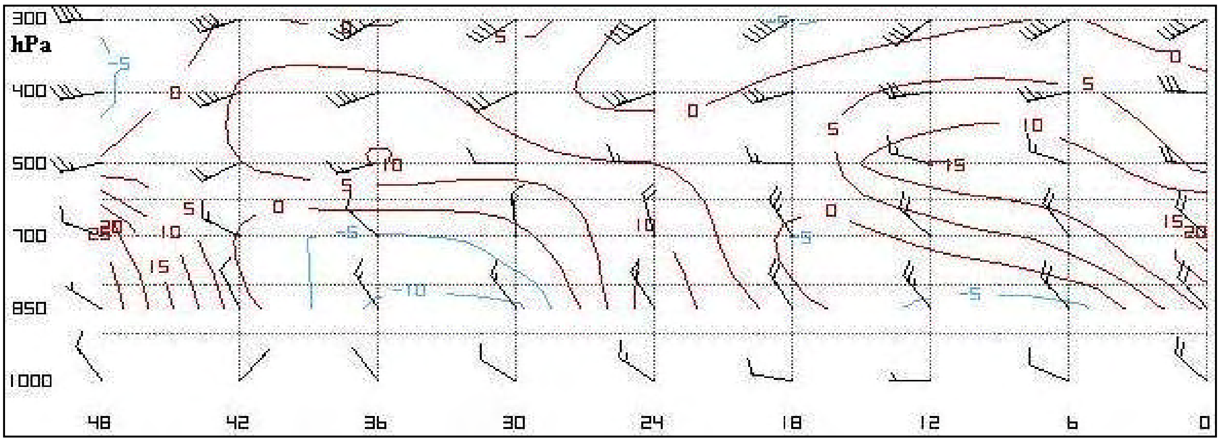

Figure 6.24. As figure 6.23, but for 2003-05-18 1200 UTC to T+48 at 1200 UTC on the 20th. Upward motion shown by blue, negative lines.

The Eta model average wind fields for the 850 hPa to 700 hPa layer at 1200 UTC (T+12) on the 16th (figure 6.27) and 1200 UTC (T+60) on the 18th (figure 6.28), clearly indicate that the dust would be carried from northern Saudi Arabia, across Qatar and the Gulf and then into the UAE.

6.6.2.3 Surface and upper air wind observations

Wind observations at ADIA, in table 6.5 below, show the persistent north-westerly to westerly winds that brought the dust to the region, the exception being a shallow temporary backing change, below ±300 metres, resulting in a southerly to south-westerly wind at 0000 UTC. This is a typical swing and moderation of the Shamal later in the night. Overnight cooling results in the development of a surface temperature inversion. This, combined with

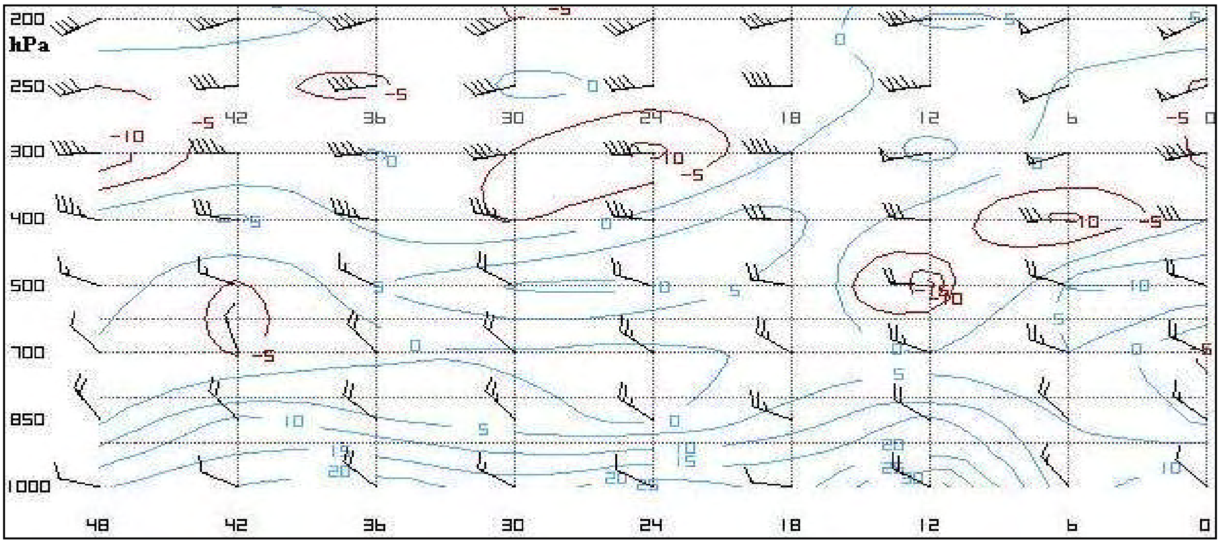

Figure 6.25. Eta GFS divergence time cross-section 2003-05-16 0000 UTC 2400 UTC on the 17th. Surface divergence (positive, blue lines) coincides with subsiding air in figure 6.24.

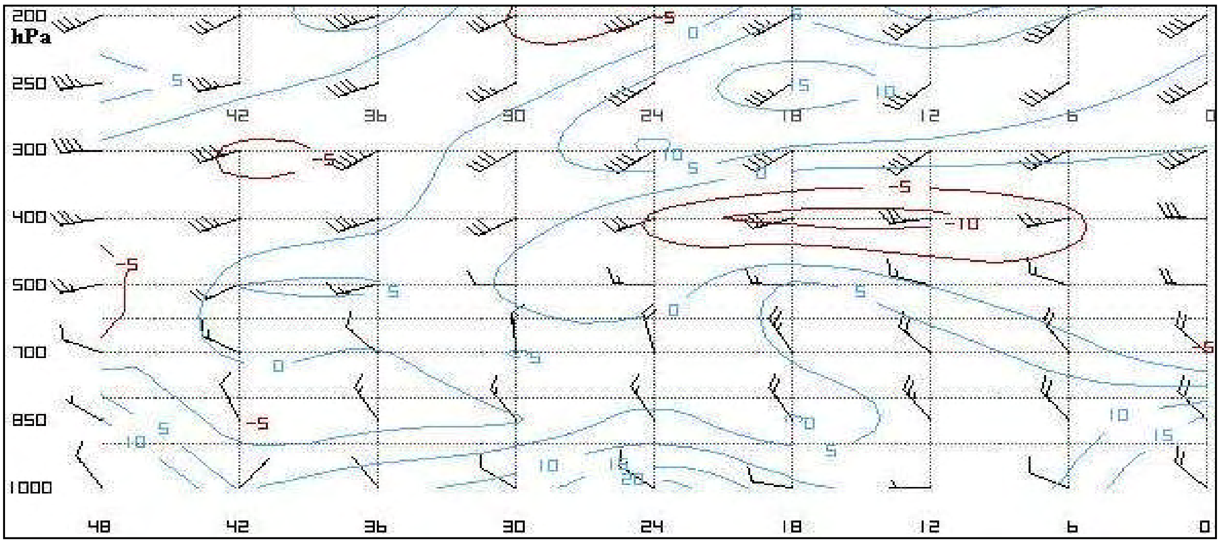

Figure 6.26. As figure 6.25, but for 2003-05-18 1200 to 1200 UTC on the 20th. Surface divergence (positive, blue lines) persists.

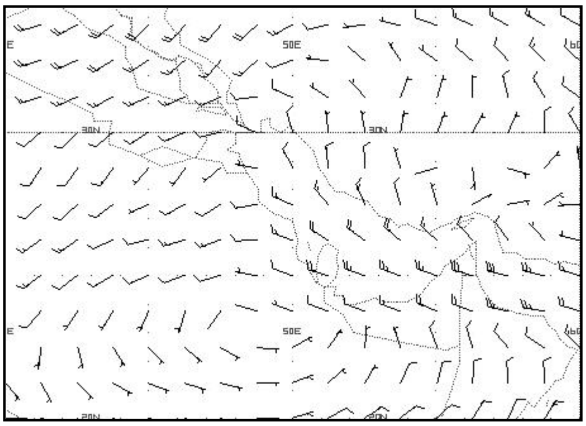

Figure 6.27. Average wind for the 850 hPa to 700 hPa layer on 2003-05-16 1200 UTC (T+12).

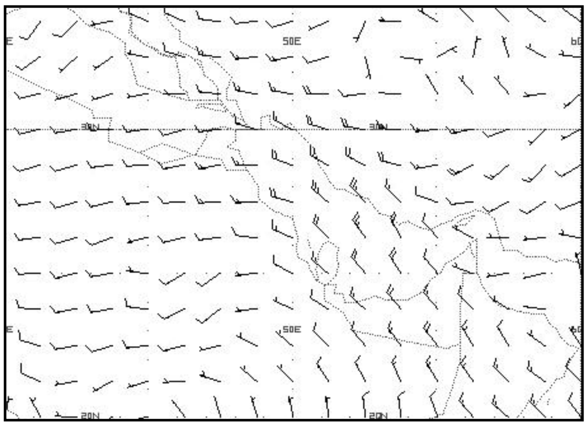

Figure 6.28. As figure 6.27, but for 2003-05-18 1200 UTC (T+60).

the effect of friction, reduces the wind velocity, while the early morning southerly land breeze effect deflects the wind direction (Membery 1983, Riehl 1979 and Hsu 1988).

Table 6.5. Wind observations in metres above sea level at ADIA from 1200 UTC on the 15th May 2003 to the 20th. Wind speed in knots. No observations are available for 0000 UTC on the 16th and the 19th.

DAY	**15th**	**16th**	**17th**	**17th**	**18th**	**18th**	**19th**	**20th**	**20th**
UTC	**1200**	**1200**	**0000**	**1200**	**0000**	**1200**	**1200**	**0000**	**1200**
MSL	330°12	330°15	170°05	350°11	210°06	300°15	300°12	170°03	340°13
300	335°17	325°21	225°10	350°08	280°13	310°18	310°17	280°14	325°17
600	325°10	325°23	265°14	340°08	300°14	315°27	315°19	300°16	325°15
900	005°09	320°21	305°19	325°13	305°16	310°23	315°20	305°18	330°15
1200	340°12	315°20	300°18	325°19	295°19	315°26	320°22	305°18	330°12
1500	335°05	310°25	295°18	320°18	295°23	320°25	325°22	295°16	355°15
2100	280°09	310°34	295°15	300°30	315°23	295°13	345°21	300°18	360°15
3000	290°25	275°26	305°19	305°21	335°17	325°16	340°17	300°20	320°38

6.6.2.4 Summary

The poor visibility was caused by dust in suspension that was transported across the Gulf Sea to the UAE from a considerable distance away to the north-west by a Shamal wind. The wind at Abu Dhabi was generally 10 to 15 knots from the north-west and the visibility was never less than 1800 metres. Inland at Al Ain the wind was stronger, up to 29 knots, but the visibility was never less than 2500 metres. Consequently, this could not be classified as a dust storm event, but it is remarkable for its long duration.

The Eta NWP average wind in the 1000 hPa to 850 hPa layer indicated that the track of the dust would be from northern Saudi Arabia to the UAE, while the prevailing north-westerly to westerly winds aloft at ADIA gave credence to this. The model output was different from the previous event in that post-trough subsidence conditions were present that would not assist the lifting of dust, as opposed to pre-trough upward vertical movement that would have facilitated upward motion.

6.6.3 THE NASHI DUST STORM OF THE 12TH AND 13TH DECEMBER 2003

6.6.3.1 Introduction

The exceptional winter dust storm over the eastern part of the United Arab Emirates (UAE) on the 12th and 13th December 2003 was caused by a cold and dry north-easterly wind known locally as a Nashi wind (UAE Climate 1996). This dust storm caused very low horizontal visibility over the eastern UAE. At Fujairah the visibility remained below 200 metres most of the afternoon of the 12th dropping temporarily to zero metres. On the west coast of the UAE visibility decreased to 1000 metres at Ras Al Khaimah and 500 metres at Dubai and late in the evening, inland at Al Ain, the visibility fell to 2000 metres. This dust reached Abu Dhabi early the following morning where it reduced the visibility to 1500 metres.

In a study of 173 dust events (table 6.2, paragraph 6.5) over the UAE from 1994 to 2003, where the visibility dropped to 5000 metres or less and including dust storms where the visibility drops to below 1000 metres (UKMO 1991), it was found that in 36 (21%) of the events the dust was brought by north-east to easterly winds. Under the same conditions a south-easterly to west-south-westerly wind off the desert accounted for 55% of the events. However, a much higher proportion (31%) of dust storms (visibility less than 1000 metres) came from the north-east. Southerly winds, transporting dust off the desert, accounted for only 13% of the dust storms.

This 'Nashi' dust storm is of considerable interest because of the source region of the dust and the anomalous direction (easterly) from whence it came as well as the very low visibility resulting in extremely hazardous environmental conditions. Furthermore, no other reference or document describing a Nashi dust storm event could be found.

6.6.3.2 NWP model data

The model gave prior warning of a strong anticyclone induced pressure gradient developing over southern Iran on the 12th with 20 to 30 knot easterly to north-easterly winds blowing across the Gulf of Oman and the eastern Gulf Sea into a low pressure cell south of the UAE (figure 6.30). Further to the west, Abu Dhabi was still under the influence of a northerly wind due to a ridge of high pressure extending southward over Saudi Arabia. The wind was the weakened remains of the previous day's Shamal that reached 15 knots when the ridge was more intense.

The wind would still be from the north-east to the east over the UAE on the 13th, but the wind speed much lower due to the retreat of the anticyclone to the east resulting in the collapse of the pressure gradient over the region (figure 6.29). The wind, although still from the east, became even weaker on the 14th.

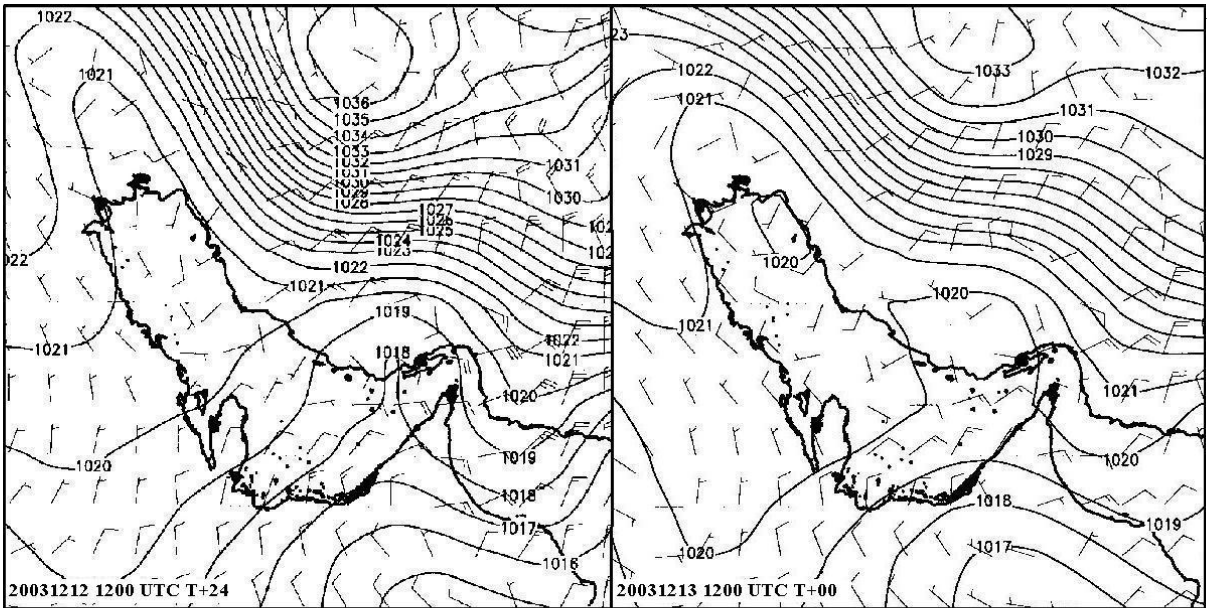

Figure 6.29. Eta GFS Surface pressure (hPa) and wind (knots) fields on the 12th and 13th December 2003. The T+24 field prognoses valid at 1200 UTC indicated that there would be a strong flow from the north-east. The analysis on the 13th shows the weakened flow.

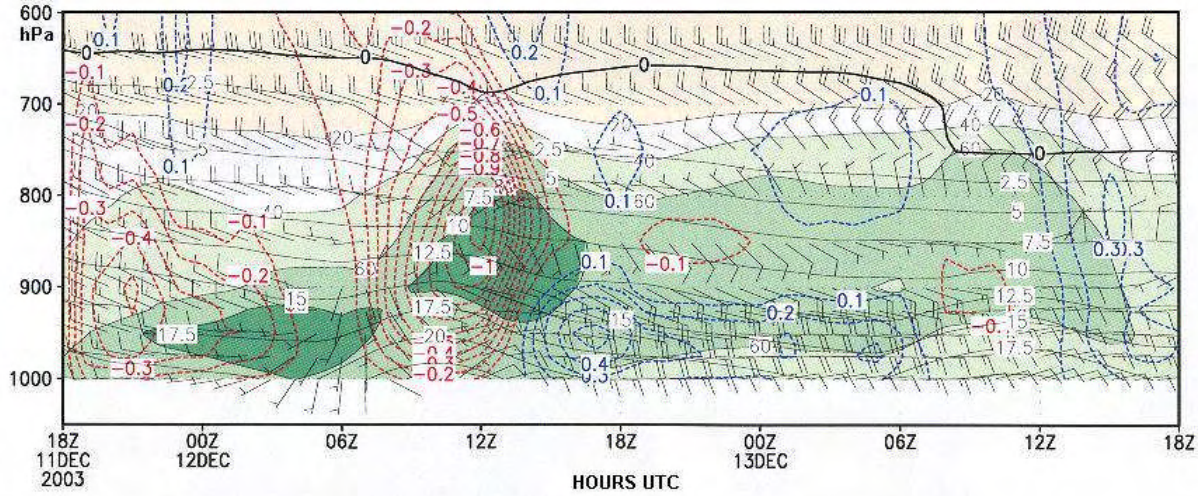

Figure 6.30. Eta GFS time cross-section at Dubai at 2003-12-11 1800 UTC. It shows the distinct atmospheric changes that occurred around 1200 UTC. Warmer air is ascending (red) above colder subsiding air (blue). Note the decrease of the 0°C isotherm height.

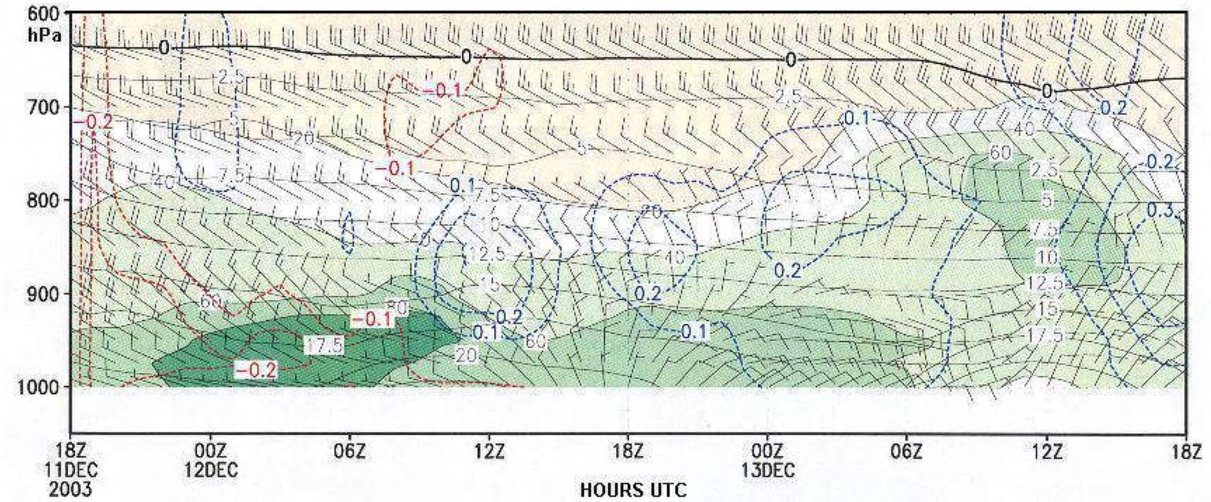

Figure 6.31. As figure 6.30, but at ADIA. The change to a low level easterly winds is indicated nearly 12 hours later than at Dubai with much variation in the vertical of both wind and vertical motion.

6.6.3.3 Surface observations

A strong surface winter anticyclone over Asia, central pressure 1036 hPa, dominated the circulation and maintained a deep, strong, north-easterly to easterly winds from Asia across Iran towards Oman and the UAE. This cold strong turbulent wind picked up dust from the deserts in southern Iran and transported it to the UAE. The wind speed reached 30 knots at Bandar Abbass carrying enough dust to reduce visibility on the Iranian coast to 100 to 300 metres by 0600 UTC on the 12th. The dust crossed the strait to Khasab on the northern tip of the Musandam Peninsula and continued east to the island of Sir Abu Nu’ayr in the Gulf Sea. The dust also crossed the Gulf of Oman to Muscat on the eastern side of the Hajar Mountains where zero visibility was reported.

In figure 6.32 the dashed brown line marks the boundary, at 0600 UTC, of this dust cloud. One hour later the dust cloud reached Fujairah on the Gulf of Oman where visibility fell to 0 metres at the onset and remained below 300 metres for most of the afternoon. During the course of the afternoon the dust reached Dubai reducing visibility to 500 metres. Surprisingly the general wind over the land remained moderate at 9 to 16 knots, direction east. By 1500 UTC (19:00 local time) all the UAE Weather Offices reported their visibility as having increased to 1000 metres, or better.

The Nashi air came from cold regions near Siberia. Figure 6.32 shows that the air moving across Iran was cold and dry as can be seen from the observation in the top right of the figure where the air temperature was –2°C and the dew-point temperature –8°C. This air, descending to the coast, experienced adiabatic as well as diabatic heating and probably maritime modification by the time it reached the coast in the vicinity of the Strait of Hormuz at Bandar Abbass. Here, at 0600, air temperature was a mild 17˚C but the dew-point temperature -4°C meant dry conditions.

On the 12th the western part of the UAE remained free of this dust. At the Liwa Oasis and Bu Hasah and Al Ain the visibility was more than 6000 metres. This was because it was west of a surface trough axis that maintained a north-westerly Shamal wind that traversed the length of the western Gulf Sea. In summer the Shamal is a hot, dry north-westerly wind that blows over Iraq and the Gulf (UKMO 1991, Rao et al (2001)). On this mid winter day the boundary of the cool air, brought by the Shamal, is marked by the dashed green line in figure 6.32. On the 13th the conditions could no longer be classified as a dust storm. However, the dust did spread further west and the visibility was down to 1500 metres at Abu Dhabi in a 5

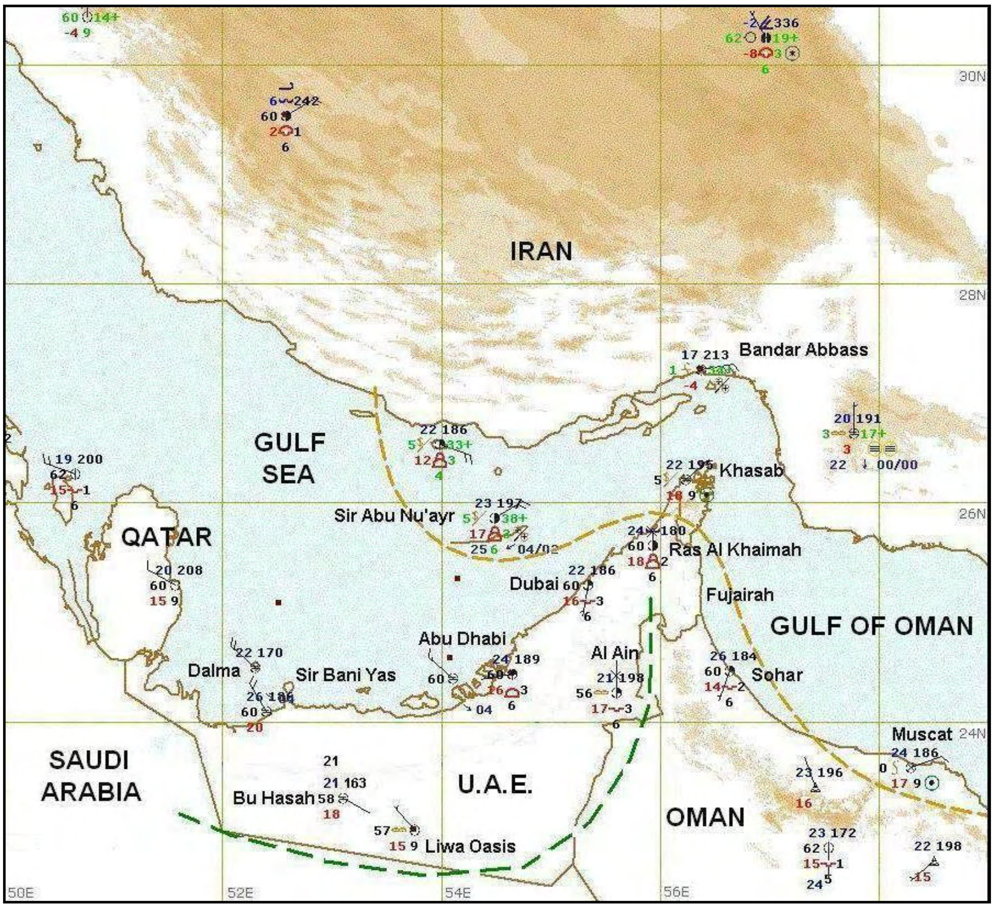

Figure 6.32. Marine surface observation chart at 2003-12-12 0600 UTC. The brown dashed line indicates the dry and colder dust borne Nashi air boundary. The green dashed line indicates the moister Shamal air boundary and the moisture invasion inland.

knots easterly wind by 0400 UTC. By 0600 UTC the dust, in a diluted state, had spread to the western part of the Emirates where the visibility remained greater than 4000 metres at the island of Dalma and at Bu Hasah west of the Liwa Oasis.

6.6.3.4 Satellite image

The invasion of the dust and the contrasting circulation patterns are clearly evident on the remarkable colour enhanced infrared image sensed by the NOAA polar orbiting satellite 17 at 0722 UTC on the 12th (figure 6.33). The image shows how, nearly an hour and a half after the weather observations in figure 6.32, the dust has blown into the eastern part of the Gulf Sea and, having crossed the Gulf of Oman, is now inland of the Fujairah and Oman coasts, but it appears that here its progress inland was hindered by the higher ground of the Musandam Peninsula and the Hajar Mountains.

Figure 6.33 also shows a stream of cloud southward past Qatar over the Gulf Sea. These clouds were formed by the Shamal, which brought cooler air southward over the warm waters of the Gulf Sea. Convection combined with turbulent mixing produced the cloud that penetrated inland as far south as the Liwa Oasis.

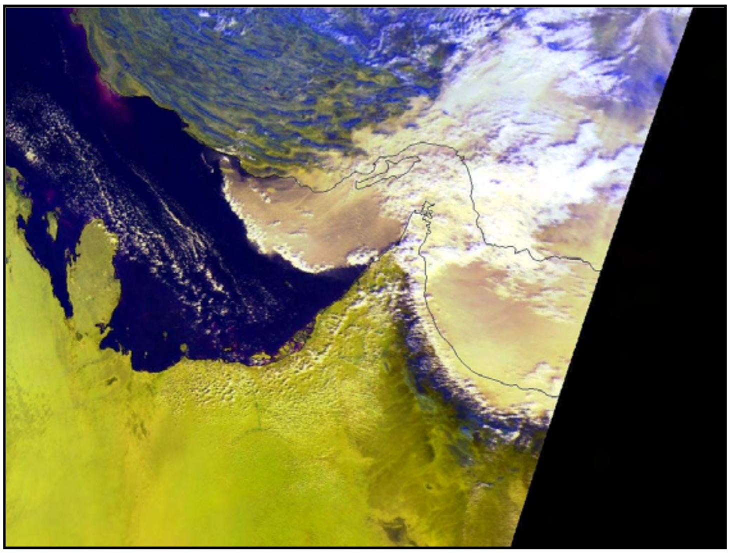

Figure 6.33. NOAA polar orbiting satellite 17 colour enhanced image at 0722 UTC on the 12th.

On the other hand the air brought from the Asian continent by the Nashi wind was cool and very dry. As it moved over the eastern Gulf Sea and the Gulf of Oman it undercut and lifted warmer and moist maritime air ahead of it much as the advance of a cold front would. This resulted in a line of cloud that developed and moved just ahead of the advancing dust front. This is particularly evident over the Gulf Sea and where the anvil head (Cirrus Calvus) remains of short lived thunderstorms can be seen in the strait that developed near and over the northern head of the Musandam Peninsula where the weather station at Khasab reported thunderstorms that had dissipated by 0300 UTC. The storms were probably forced by enhanced convergence of the Nashi and Shamal winds as well as by topographic lifting caused by the Hajar Mountains at the tip of the Musandam Peninsula.

6.6.3.5 Atmospheric soundings

The differences in the air masses invading the eastern UAE is clearly evident in the upper air temperature and dew-point profiles of figure 6.34 obtained from the atmospheric soundings taken at 1200 UTC on the 12th at Bandar Abbass and Abu Dhabi, respectively. At Bandar Abbass the dew-point remains near -10°C from the surface to the 850 hPa level and the dew-point depression well below 20°C for this layer. This extremely dry air was brought from Iran by a strong east-north-easterly wind prevailing in this layer. In this layer the ambient temperature lapse rate follows the dry adiabatic lapse rate (DALR) while the dew-point follows the constant humidity mixing ratio line. Both these factors indicate air well mixed by turbulence (UKMO 1997). The profile for Abu Dhabi also indicates a well mixed layer up to 925 hPa. But at Abu Dhabi the dew-point depression remained between 8 and 10°C up to this level showing that the north-westerly Shamal air arriving at Abu Dhabi is considerably more humid.

The 850 hPa wet bulb potential temperature is often used to differentiate between air masses (Petterssen 1956, Haurwitz 1941). The air arriving at Bandar Abbass and Abu Dhabi have 850 hPa wet bulb potential temperatures of 280°K and 281°K, respectively. They therefore appear to be parts of the same air mass. However, the profiles in figure 6.34 clearly show the near surface layers had clearly been modified differently. At Bandar Abbass cool and dry continental air is present while at Abu Dhabi the near surface air is modified warmer and moist maritime air.

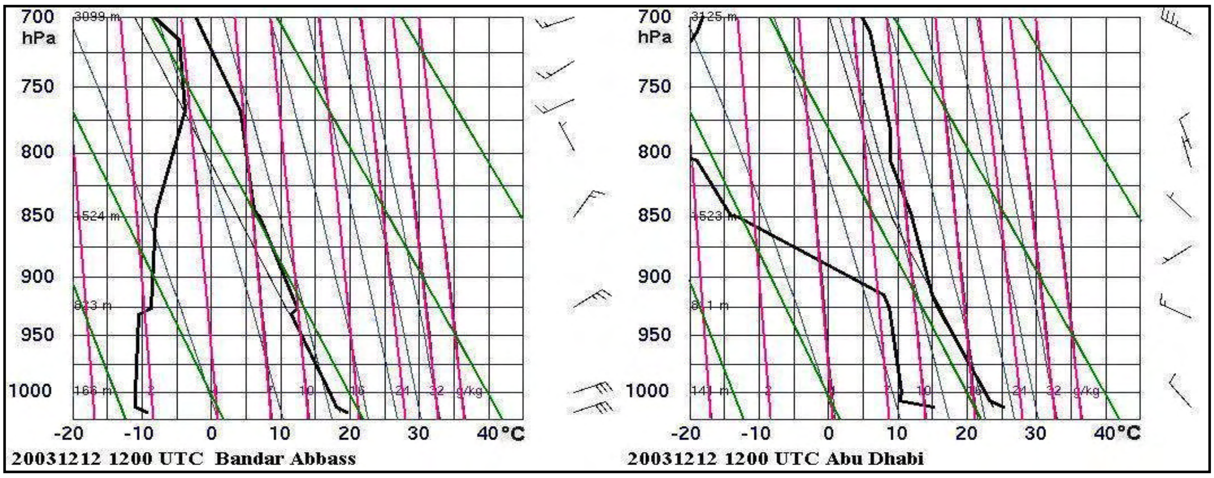

Figure 6.34. Atmospheric soundings at Bandar Abbass, on the Iranian coast, and ADIA at 1200 UTC on the 12th December 2003. Dry adiabatic lapse rate lines in green and mixing ratio lines in pink (courtesy of the University of Wyoming).

6.6.3.6 Summary

The north-easterly to easterly Nashi wind transported dense dust from the deserts of southern Iran to the UAE. Dust brought by the Nashi wind from Asia is less frequent than dust storms over the UAE caused by a southerly wind off the Arabian Desert. Nashi wind dust storms over the UAE tend to be more intense, producing lower visibilities for longer periods. The dust descending over the UAE, resulting in very low visibility, was not accompanied by strong wind. Over Iran, however, wind speed in the lower 1000 metres was 30 to 25 knots very turbulent and kept vast amounts of dust in suspension long enough to reach the UAE.

This Nashi dust storm is also noteworthy because of the contrasting surface weather essentially separated by the Musandam Peninsula on the morning of the 12th. The 850 hPa wet bulb potential temperature indicates that both originated from a single air mass, situated over Asia with fairly uniform characteristics. The route taken to the UAE meant that the

Nashi air had undergone modification as continental air while the Shamal air arrived over the UAE as maritime air. This modification could be clearly identified on the surface synoptic map (figure 6.32) as well as on the satellite image (figure 6.33). Notable also was the cold front like interaction between the cool and dry, but dust laden Nashi air from the north-east with the warmer and moister north-westerly Shamal air over the Gulf Sea and, in the process, producing a marked gust front and thunderstorms.

Model data clearly indicated that the wind was going to be strong in the east with the inference that there would be dust raised and deterioration in the visibility.

6.7 FORECAST CHECKLIST

Use of the Eta NWP model post processing products and satellite imagery gives ample warning of dust and dust storm conditions. Of particular use to initially identify dust storm conditions are the surface wind and pressure fields and the surface wind time cross sections.

Important considerations are;-

- Little or no wind shear.
- An environmental lapse rate that tends to the dry adiabatic lapse rate (instability).
- Dust in suspension is more likely and likely to be more persistent with upward vertical velocity below 700 hPa.
- The dryness of the surface dust/sand.
- Dust and sand storms are most likely with the wind from the south-east to west-south-west. That is, a surface low pressure approaching from the west with a marked southerly pressure gradient.
- The visibility improves when a southerly generating wind veers to north-westerly after the passage of a surface low, or trough, or an afternoon sea breeze develops.
- The visibility improves at night when the wind becomes lighter.
- A low level jet of about 30 knots or more can occur at 150 metres to 600 metres (500 feet to 2000 feet) MSL with attendant wind shear.
- Awareness of dust conditions further afield and dust transport to the UAE.
- Dust from further afield is carried on north-westerly Shamal winds and north-easterly Nashi winds.
- Dust storms with the visibility < 1000 metres last < 2 hours, at the most < 5 hours.
- Dust with the visibility < 3000 metres last < 4 hours, at the most 15 hours.
- Dust and dust storms in southerly winds are most likely between 0300 UTC to 1200 UTC and most prevalent at 0600 UTC.
- Dust and dust storms in a Shamal are most likely between 0800 UTC to 1300 UTC.
- Dust storms are most likely to last about 30 minutes when associated with a thunderstorm and not more than 60 minutes.
- In general, wind speed and visibility relationship in table 6.6 below can be applied.

Table 6.6. Wind speed and visibility relationship at Abu Dhabi

Wind speed	**Visibility**		
> 15 knots	< 8000 metres	often < 5000 metres	
> 20 knots	< 5000 metres	often < 2000 metres	most likely < 1000 metres
> 25 knots	< 2000 metres		most likely < 1000 metres
> 30 knots	< 1000 metres		