Monitoring aerosols using satellite remote sensing data concurrently with ground observations in Iraq

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Abstract:
Dust particles from storms are one of the main atmospheric constituents that affect the air quality and the Earth's climate system. Monitoring of these atmospheric constituents is only possible through satellite measurements because ground based measurements are very limited in space and time and these constituents get transported over long distance from their source region. Absorbing Aerosol index is a qualitative parameter however it does excellent job in classifying UV absorbing and non absorbing aerosols. In most areas, we can classify dust storms by the broad meteorological conditions that cause them. The AI is a measure of the change of spectral contrast in the near ultraviolet (with respect to a purely molecular atmosphere) brought about by the radiative transfer effects of UV-absorbing aerosols such as smoke , volcanic ash and desert dust in a Rayleigh scattering atmosphere. The AI is a very useful qualitative indicator to identify aerosol sources and transport patterns. In this paper we will examine the most common events that occur in Iraq concurrently with satellite observation. These events are dust storms caused by prefrontal and postfrontal winds that primarily occur in the winter, and summer dust storms caused by persistent northerlies. In this paper will conduct complete and thorough case studies of the meteorological conditions that led to the dust storm.

Keywords: dust; aerosols; remote sensing; soils.

مراقبة العوالق باستخدام بيانات اقمار التحسس النائي بالتزامن مع المشاهدات الارضية بالعراق

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الخلاصة:
تعتبر جسيمات الغبار من العواصف كواحدة من مكونات الغلاف الجوي الرئيسية التي تؤثر على نوعية الهواء وعلى نظام مناخ الارض. ان مراقبة مكونات الغلاف الجوي تكون ممكنة فقط من خلال قياسات الاقمار الاصطناعية لان القياسات من سطح الارض تكون محدودة جدا" بالمكان والزمان والمنطقة . يعتبر معامل العوالق الممتصة عامل نوعي ولكن يؤدي وظيفة ممتازة في تصنيف العوالق الممتصة والغير ممتصة للاشعة الفوق البنفسجبة . في معظم المناطق ، فاننا نستطيع ان نصنف العواصف الغبارية بواسطة الشروط الانوائية العامة المسببة لها . ان العامل (AI) هو مقياس للتغير في تباين الطيف القريب من الاشعة فوق البنسجية (نسبة الى الغلاف الجوي الجزئي الصافي) والناتج بفعل نقل الاشعاع للعوالق الممتصة للاشعة الفوق البنفسجية مثل الدخان ، الرماد البركاني ، غبار الصحراء في الغلاف الجو ي لاستطارة رالى . ان AI يعتبر مؤشر نوعي مفيد جدا لتحديد مصادر العوالق وانماط الانتقال في هذا البحث سوف نختبر الحوادث الاكثر شيوعا التي تحدث بالعراق وبالتزامن مع مشاهدات الاقمار الصناعية هذة الحوادث هي العواصف الغبارية المتسببة بفعل الرياح قبل الجبهة وبعد الجبهة والتي تحدث بشكل رئيسي بالشتاء والصيف للعواصف الغبارية الناشئة بفعل الرياح الشمالية. في هذا البحث سوف نعرض بشكل كامل ومن خلال دراسة حالات للظروف الانوائية التي تؤدي الى العواصف الغبارية .

كلمات مفتاحية : غبار ، عوالق ، تحسس نائي ، ترب .

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Introduction:

Smoke from biomass burning, and dust particles from desert storms are among the main atmospheric constituents that affect the air quality and the Earth's climate system. Monitoring of these atmospheric constituents is only possible through satellite measurements because ground based measurements are very limited in space and time and these constituents get transported over long distance from their source region. For more than two decades, Total Ozone Mapping Spectrometer (TOMS) instruments [1], [2]. Have been providing useful global data on the long range transport of smoke and dust plumes, TOMS measures back scattered radiances in the near Ultra Violet (UV) region of the spectrum and from these measurements, the TOMS ozone retrieval algorithm computes an absorbing Aerosol Index (AI), which is a qualitative measure of the presence of UV absorbing aerosols such as mineral dust and smoke. At the present time, the long term data record of the aerosol information from the TOMS instrument is continued by the Ozone Monitoring Instrument (OMI) flown on the EOS Aura spacecraft (launched July 2004). The key objectives of the OMI measurements include monitoring of aerosols and smokes from biomass burning, SO2 from volcanic eruptions, and key tropospheric pollutants and surface UV radiation that are threat to the human health. Because of better measurement accuracy and better spatial resolution (13x24 km) OMI provides better estimates of atmospheric pollutants and their transport through the Earth's atmosphere. In spite of the fact that the Aerosol Index is a qualitative indicator of the presence of the absorbing aerosols, many scientists have used it in variety of applications with the encouraging results. For example, AI has been used in identifying the sources of air pollution over the globe, understanding the transport of air pollution across the oceans and continents, air quality forecast models, and radiation energy balance, and climate forcing studies[3],[4].

Absorbing Aerosol Index:

The absorbing aerosol index (AI) from the current Earth Probe TOMS is defined as the difference between the measured (includes aerosols effects) spectral contrast of the 360 and 331 nm wavelength radiances and the contrast calculated from the radiative transfer theory for a pure molecular (Rayleigh particles) atmosphere. In the current version8 Nimbus7 TOMS (1979-1993) and Earth Probe TOMS (1996-present) and version2 Aura OMI (2004-present) algorithms, it is mathematically defined as:

AI= 100 { log10[(I360/I331)meas] log10[(I360/I331)calc] }

Since I360 calc calculation uses reflectivity derived from the 331 nm measurements, the Aerosol Index definition essentially simplifies to:

AI= 100 log10 (I360_meas /I360_calc)

The Aerosol Index detects dust, smoke and volcanic ash over all terrestrial surfaces including deserts and snow ice covered surfaces. These aerosol types are also detected intermingled with clouds and above cloud decks. The AI can differentiate very well between absorbing and non absorbing aerosols, because it provides a measure of absorption of UV radiation by smoke and desert dust. AI positive values are associated with UV absorbing aerosols, mainly mineral dust, smoke and volcanic aerosols [5], [6].

However, negative values are associated with non absorbing aerosols (for example, sulfate and sea salt particles) from both natural and anthropogenic sources [7]. Near zero values indicate cloud presence. In interpreting the results care has to be taken that some surface effects, such as sea glint and ocean color, can also enhance the AI.

Dust Storms:

The Fertile Crescent is a source region comprised of alluvial fans and dry flood plains containing a mixture of clay particles, which have a typical size of less than 2 micrometers, and silt particles, which range in size between 2-50 micrometers, as shown in Figure 1. The other source regions are generally comprised of fine to medium sand, ranging in particle sizes from 50-1000 micrometers, with only a few small areas of silt [8].

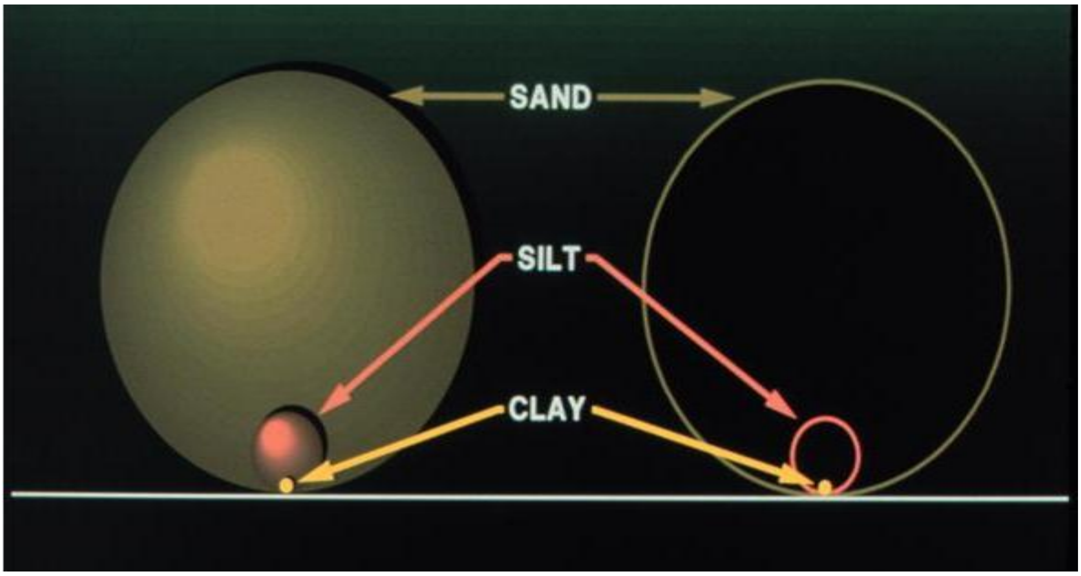

Figure.1- Particle Size Distribution.

Once the composition of the source regions is known, it is possible to look at the physical processes by which the dust is transported through the atmosphere. The dust storm is studied as a global phenomenon taking place frequently in semiarid and arid areas over the globe [9].

Physical Processes of Dust Transport:

The transport of dust can be described in three processes depending on particle size and wind strength. These processes are creep, saltation, and suspension, as shown in Figure 2. Creep refers to a process by which particles slide or roll over the surface, generally without breaking contact with the surface. This process is favored by large
particles or lower wind speeds and will not usually result in large-scale dust storms [8]. Saltation is a process by which the particles may get airborne for short distances before falling back to earth. Although the particles do not travel far from their source regions in this process, they can contribute to much larger scale dust transport by disrupting the surface at each impact, thus kicking up much finer particles which are then more susceptible to the third process, suspension. Suspension occurs when the particles are held aloft by the air currents and can result in the dust plume being carried far away from the source region if the lofted particles are small enough for the air currents to keep them airborne [8].

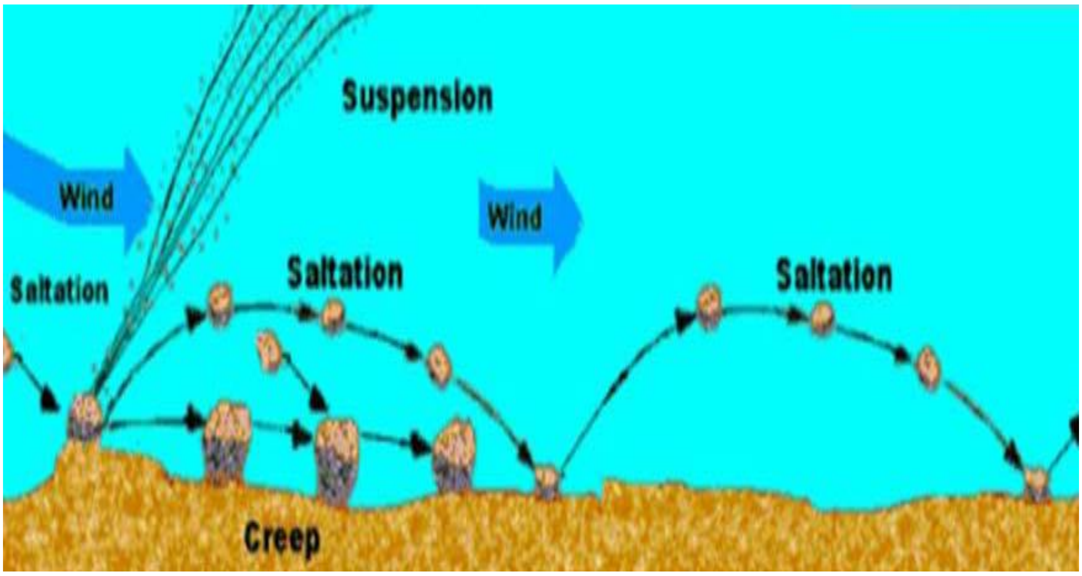

Figure.2- Dust Transport Processes.

Generally the wind speeds required to activate particle movement, and thus initiate the three processes summarized above will depend on the size of the particles [10]. In general, the critical threshold wind speeds for mobilization of particles are summarized in Table 1.

Table.1- Critical wind speeds for dust mobilization.

Soil Type	Wind Threshold
Fine to Medium Sand Dunes	10-15 mph (8.7- 13 kts)
Sandy Areas, Poorly developed desert pavement	20 mph (17.4 kts)
Fine Materials, Desert Flats	20-25 mph (17.4-21.7 kts)
Alluvial Fans, Crusted Salt Flats	30-35 mph (26.1-30.4 kts)
Well-Developed Desert Pavement	40 mph (36.8 kts)

Parcel Theory:

In addition to achieving a critical wind speed, the lofting of dust also requires turbulence in the boundary layer. Nearly all the procedures routinely used to evaluate and analyze the stability of the atmosphere involve applications of the "parcel" method. The theory assumes a simplified model of the behavior of the atmosphere. Following is a brief discussion of the "parcel" method. The temperature of a small parcel of air is assumed to change adiabatically as the parcel is displaced vertically from its original position. If the parcel is unsaturated, its temperature is assumed to change at the dry-adiabatic lapse rate, 9.8 °C/km. If the parcel is saturated, the change will occur at the saturation—adiabatic lapse rate, which is approximately 6 °C/km in the lower levels. In addition, it is assumed there is no transfer of heat or mass across the boundaries of the moving parcel; i.e., the parcel does not "mix" with nor does it disturb the surrounding air. If after the vertical displacement, the parcel temperature is warmer than the surrounding air, it is less dense than the surrounding air and is subject to a positive buoyancy force and will be accelerated upward. Conversely, if its temperature is colder than the surrounding air, the parcel will be denser than its environment and is subject to a negative buoyancy force. In this case it will be pushed downward until it returns to its initial or equilibrium position. The atmosphere surrounding the parcel is said to be stable if the displaced parcel tends to return to its original position; unstable if the parcel tends to move farther away from its original position; and in neutral equilibrium when the displaced parcel has the same density as its surroundings. According to the theory, the behavior of a parcel which becomes saturated is as follows. At saturation and freezing, the rising parcel cools at a slower rate because of its release of the latent heat of condensation and fusion. If the parcel is warmer than the surrounding air (its environment) it ascends under acceleration from the positive buoyancy force as shown in Figure-3.

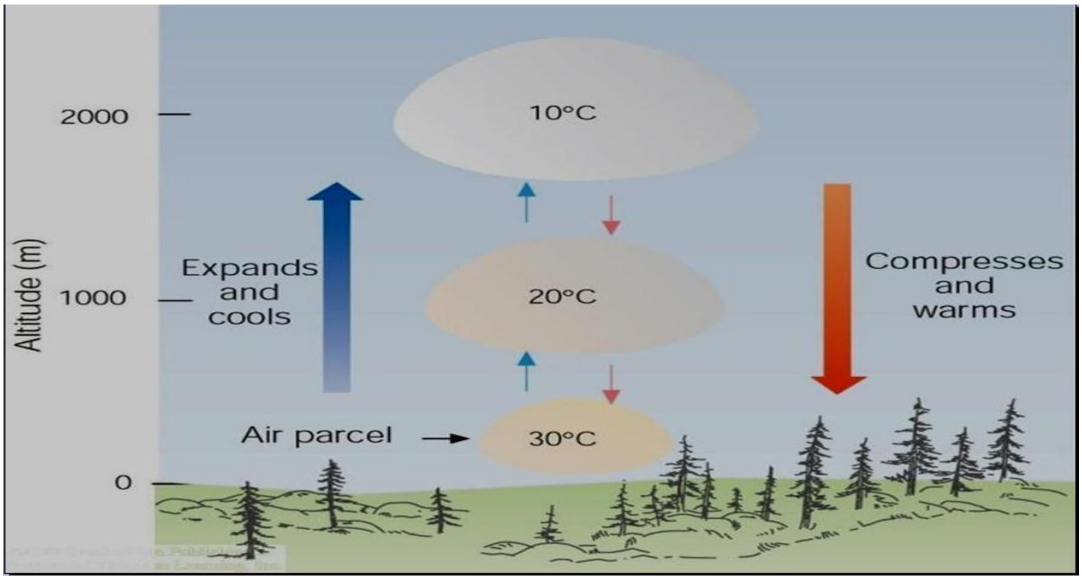

Figure.3- The Parcel Theory.

As long as the parcel remains warmer than the surrounding environment, the rate of ascent will increase. The acceleration persists until the height is reached where the saturation-adiabatic path of the parcel crosses the temperature curve; i.e., where the parcel temperature becomes equal to the ambient temperature of its environment. This point has been defined as the equilibrium level (EL). At this point, the rising parcel has its maximum momentum. Above the EL, the parcel becomes colder than the environment (negative buoyancy) and is decelerated in the upper negative area until it stops rising at the maximum parcel level (MPL). There it will begin to descend, since it is in a zone of negative buoyancy. The overall stability or instability of a sounding is sometimes conveniently expressed in the form of a single numerical value called a stability index. Such indices have been introduced mainly as aids in connection with particular forecasting techniques or studies. Most take the form of a difference in one or more parameters between two arbitrarily chosen surfaces, such as 850 mb and 500 mb 1000 mb and 700 mb, etc. Indices of this type have the advantage of ease of computation, flexible choice of the layer most pertinent to the particular problem or area, and a numerical form convenient for ready use in objective studies and operational forecasting [11],[12].

Soil Texture:

It is the fineness or coarseness of a soil. It describes the proportion of three sizes of soil particles. These are:

1. Sand --large particle
2. Silt-- medium sized particle
3. Clay-- small particle

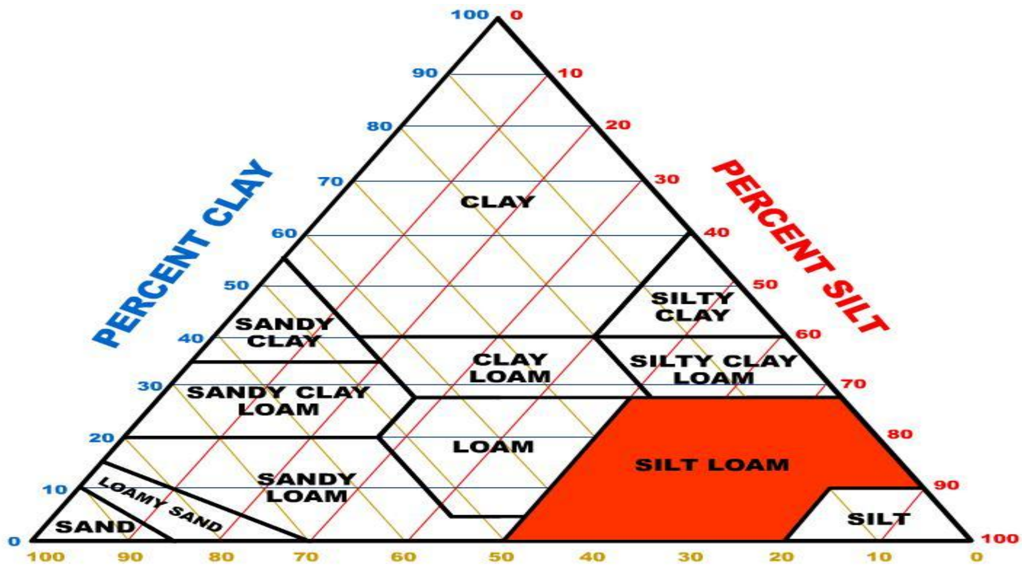

Figure.4-: Soil Texture Triangle.

Texture is important because it affects :

1. Water-holding capacity the ability of a soil to retain water for use by plants.
2. Permeability the ease with which air and water may pass through the soil.

Soil texture may be determined by the percentages of sand, silt, and clay may be tested in the lab. You may determine the textural class of the soil by referring to the texture triangle[13],[14].

Results and Discussion:

The objectives for this paper are conducting a complete and thorough case study at two dates of the meteorological conditions that led to the dust storm. The analyses will be compared to satellite imagery.

Case(1): The following case is discussed using weather charts for the distribution of sea level pressure, surface temperature, surface visibility, surface and 850 mb. wind speed,as shown in Figures 5 to 13. From the synoptic charts on April 4,2011. Iraq was under the influence of low pressure area concentrated in the south of Iraq moving north west of Iraq presses against High pressure area centered on Saudi Arabia , another high pressure area (subtropical) concentrated on north of Africa, a warm front passing south and middle area of Iraq with low pressure which causing prefrontal dust storm which call sharki. At 15Z a cold front passing Baghdad with postfrontal dust storm under the effect of advection of high pressure, associated with south east to southly wind with direction (110 – 180) degree in the time of dust storm with wind speed of (4 – 9) m/s, Basrah observation station (Hai Al Hussain) has register with gusty wind speed of 30 m/s at 15Z .Wind direction change to north west (300 – 330) at 15Z. Horizontal visibility was 6000 meter at 03Z with gradual decreases reaching 400 m. at 17Z followed by an increasing to 4000m after the change of wind direction to north west under the effect of advection of high pressure area moving from north of Africa starting at 18Z with visibility of 600m . At 12Z, 850 mb. wind direction chart, wind was south eastly direction. From synoptic analysis of air temperature for Middle East area for two fixed points first one on Baghdad and the second on the coastal of Lebanon to determining temp. gradient which reveal a gradient of (8 – 16) °C difference between these two point enhance dust storm to occurred.weget dust forecast and total dry drops of dust (mg/m) on our area. On 12Z there was precipitation of 2363 (mg/m2) of dry drop as indicated in Figures 14,15 shows the values of OMI Aerosol Index on April 04,2011. Baghdad air port observation station report meteorological element and its value as below in Table 2.

Table.2- Meteorological Elements At Baghdad Airport Station.

Time Z	Visibility (m)	Wind speed(m/s)	Direction (degree)	Dry temp. (degrees C)	Present weather
03	4000	04	160	22.8	06
06	3000	08	140	25.3	07
09	2000	08	180	29.3	07
10	2000	08	170	31.6	07
11	600	08	140	31.6	32
12	600	08	150	32.2	31
13	600	05	170	31.6	32
14	700	05	210	31.2	30
15	600	09	310	26.4	32
16	1000	07	300	25.6	9
17	400	09	320	24.2	32
18	600	04	330	23.8	09
19	800	02	310	22.0	06
20	1200	02	320	21.4	06
21	3000	02	320	21.0	06

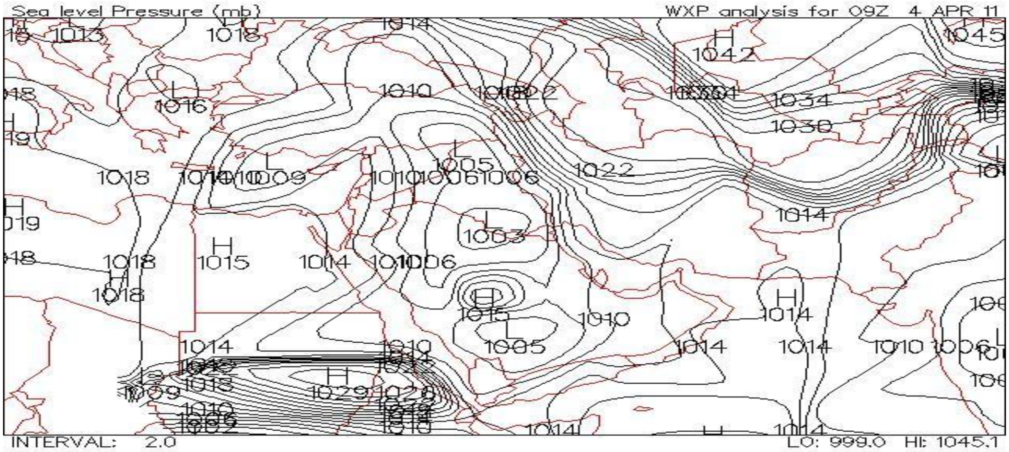

Figure.5- Sea Level Pressure (mb) At 09Z

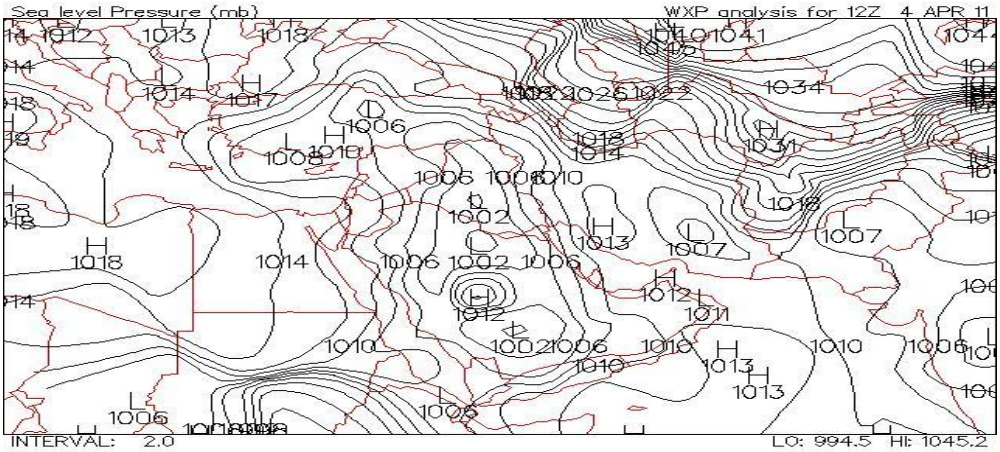

Figure.6- Sea Level Pressure (mb) At 12Z

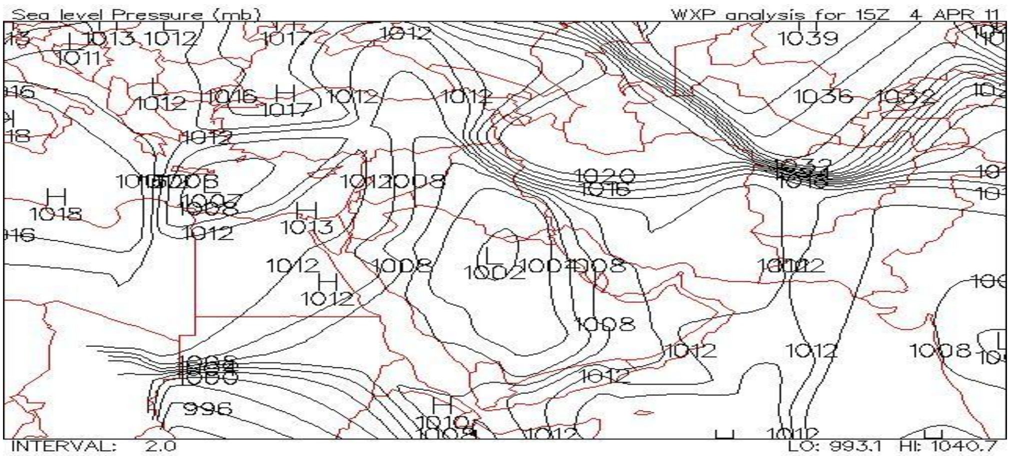

Figure.7- Sea Level Pressure (mb) At 15Z.

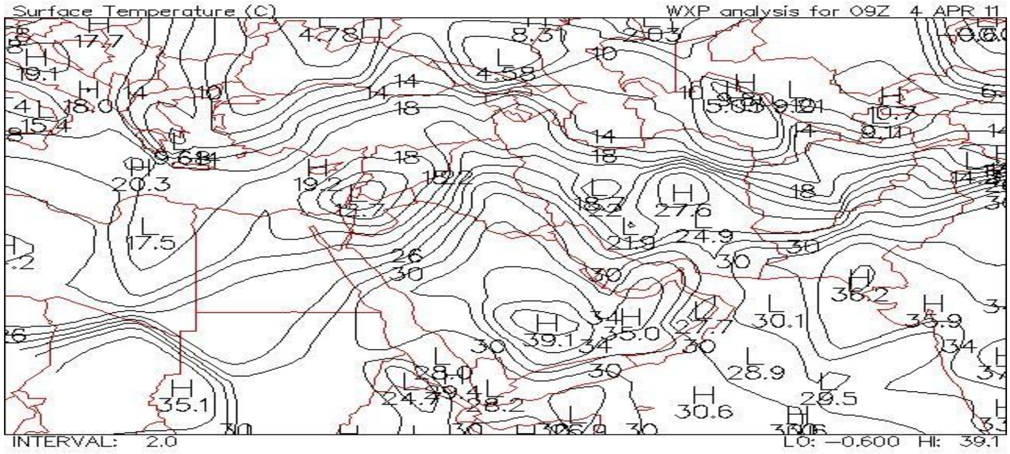

Figure.8- Surface Temperature (degrees C) At 09Z

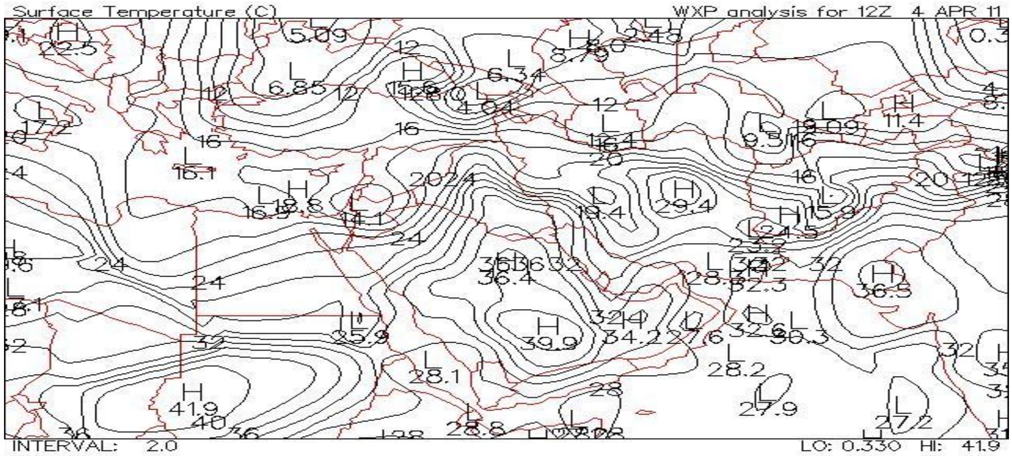

Figure.9- Surface Temperature (degrees C) At 12Z

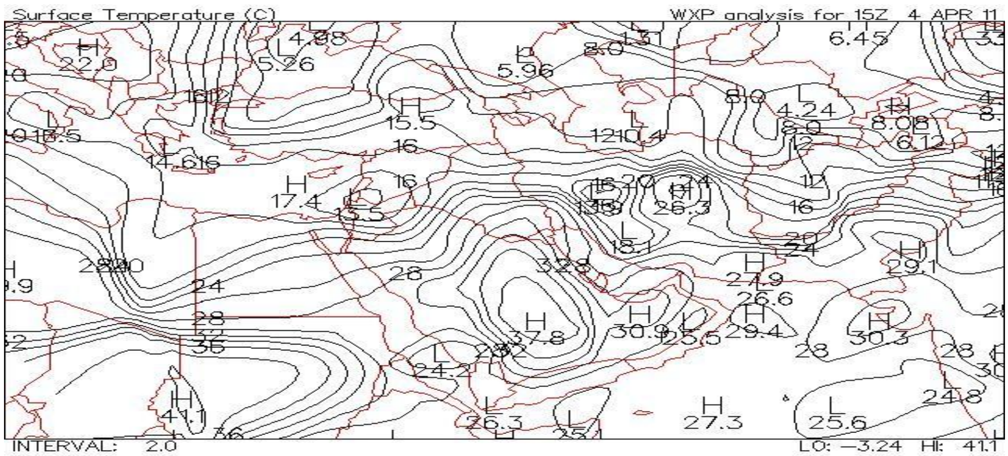

Figure.10- Surface Temperature (degrees C) At 15Z

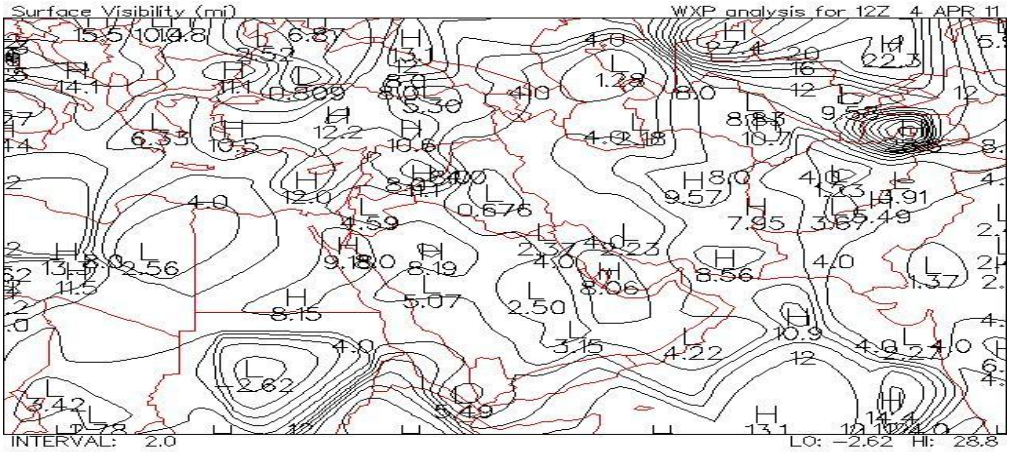

Figure.11- Surface Visibility At 12Z

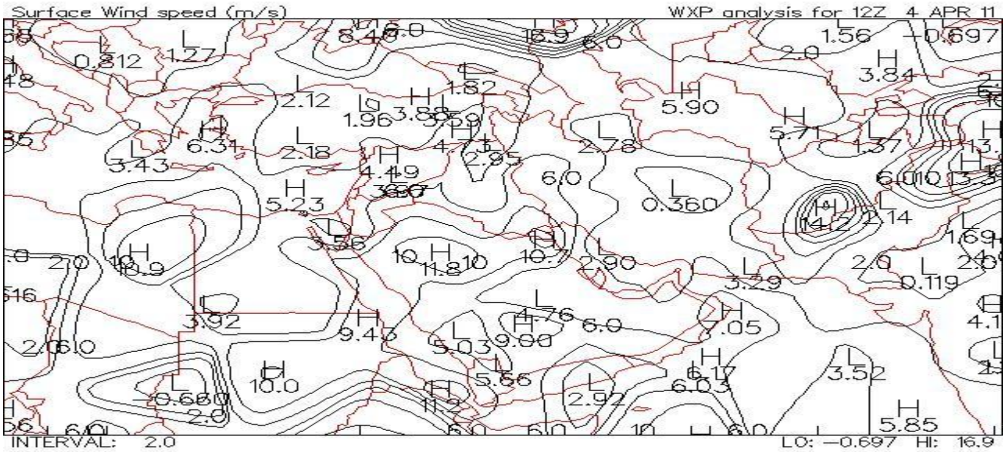

Figure.12- Surface Wind Speed At 12Z

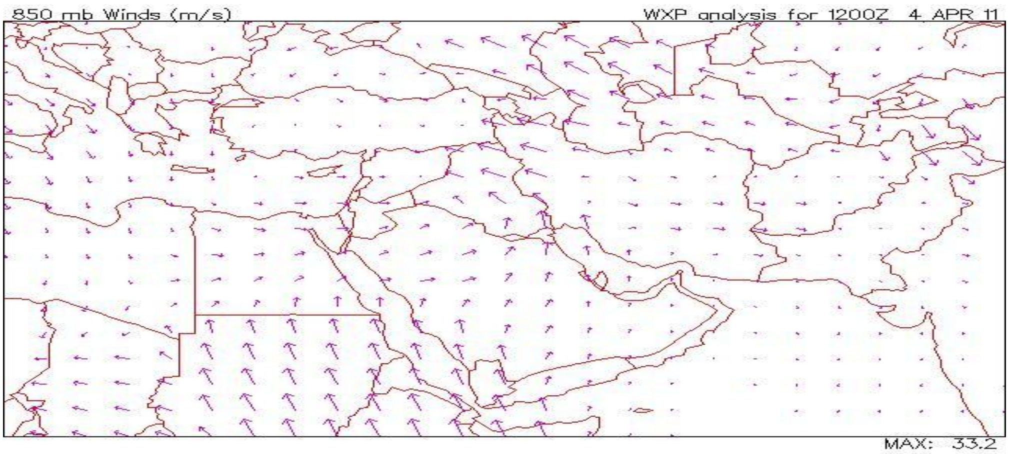

Figure.13- Wind Speed For 850 mb Level At12Z

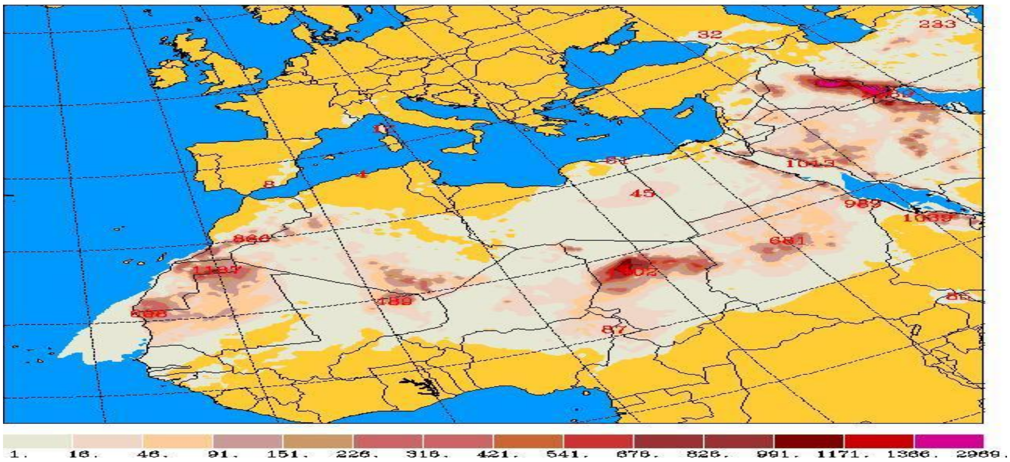

Figure.14- Total Dry Drops Of Dust (mgr/m2)

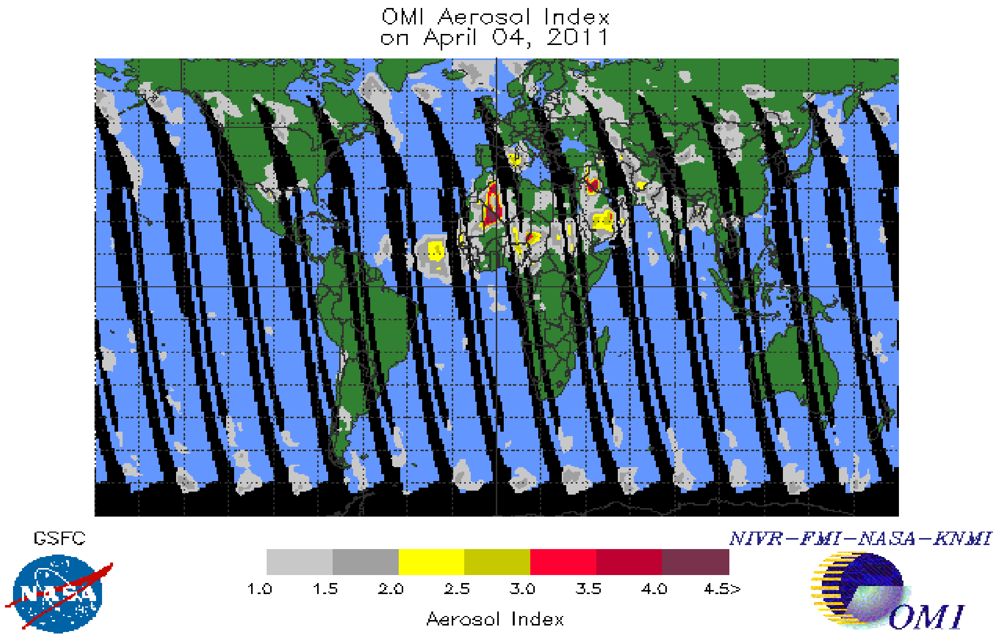

Figure.15- OMI Aerosol Index

Case(2): From the synoptic weather charts on July 27,2011, shown in Figures 16 to 21. Iraq was under the influnce of a trough of monsoon system its axis extended from north west to south east, moving eastward under the influnce of a ridge of high pressure centered at the southern area of the Mediterranean, formed a cold front causing post frontal dust storm, associated with north west wind directions (310- 340) degree in the time of dust storm occurrence with speed of (4 – 9) m/s, 9 m/s considered as approprite to cause dust storm in Iraq area, lowest horizontal visibility was 300 m. , dust storm led to deterioration of horizontal visibility from 07Z where it was 700m. till 17Z with visibility 500 m., after that , there was agradual improvement in visibility. From 850 mb., 12Z wind direction analysis chart, a frontal surface extended from north to south, wind veer from south east to north west cross the surfuce . From synoptic analysis of surface temperature for middle east area and for two fixed points , first on Baghdad ,second on the coastel of Lebnon, determining temperature gradient which reveal that there is a temperature gradient of (10 -16) ^{0}C enhance dust storm to occurrence. We get dust forecast and total dry drops of dust (mgr/m²), on 12Z there was precipitation of 676 mgr/m² indicated in Figures 22, 23 shows the values of OMI Aerosol Index on July 27 ,2011. Baghdad airport observation station of some meteorological element and its value are shown in Table 3 below

Table.3- Meteorological Elements At Baghdad Airport Station.

Time Z	Visibility (m)	Wind speed(m/s)	Direction (degree)	Dry temp. (degree C)	Present weather
00	10000	05	320	34.3	06
03	7000	04	320	33.7	06
06	3000	05	320	39.6	06
07	700	05	350	42.0	06
08	500	09	300	43.5	32
09	700	09	310	44.3	35
10	500	08	320	45	33
11	300	10	300	44.6	33
12	300	09	280	44.8	33
13	400	08	300	44.2	33
14	500	08	300	43.8	33
15	400	05	280	42.8	09
16	500	06	300	41.4	06
17	1500	05	280	40.2	06
18	6000	04	280	38	06

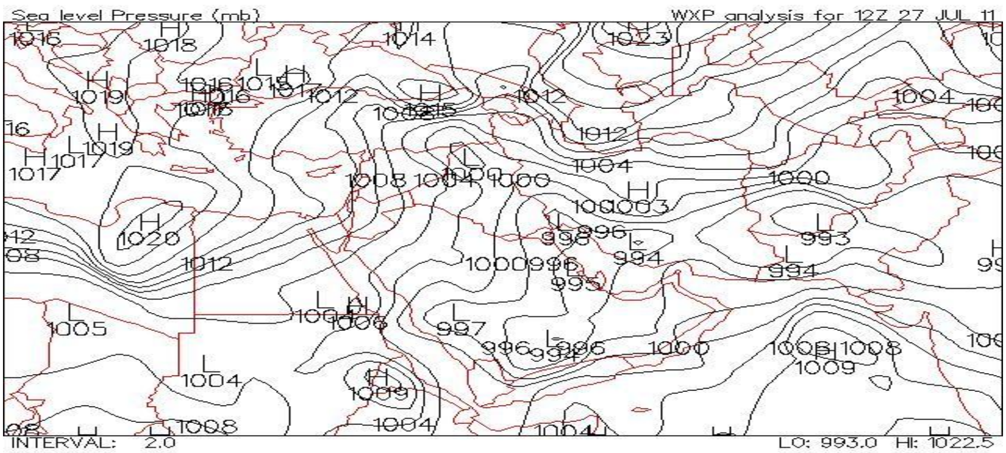

Figure.16- Sea Level Pressure (mb) At 12Z.

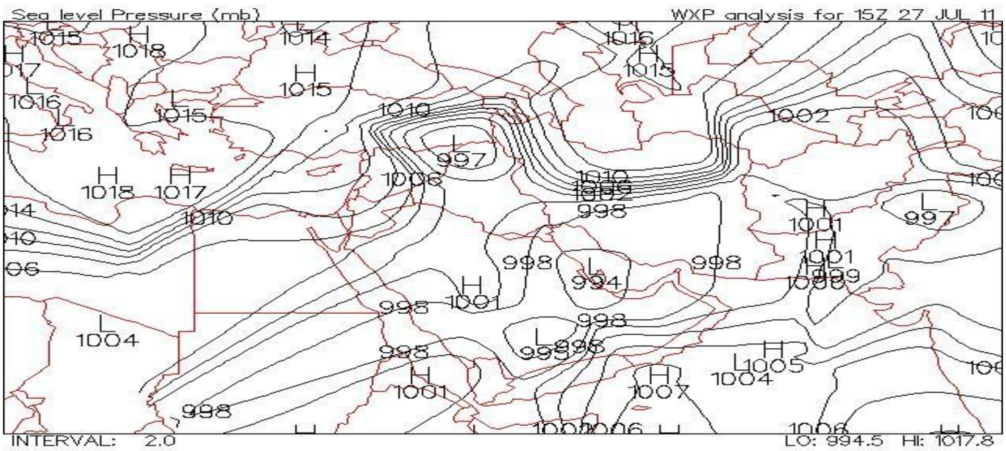

Figure.17- Sea Level Pressure (mb) At 15Z.

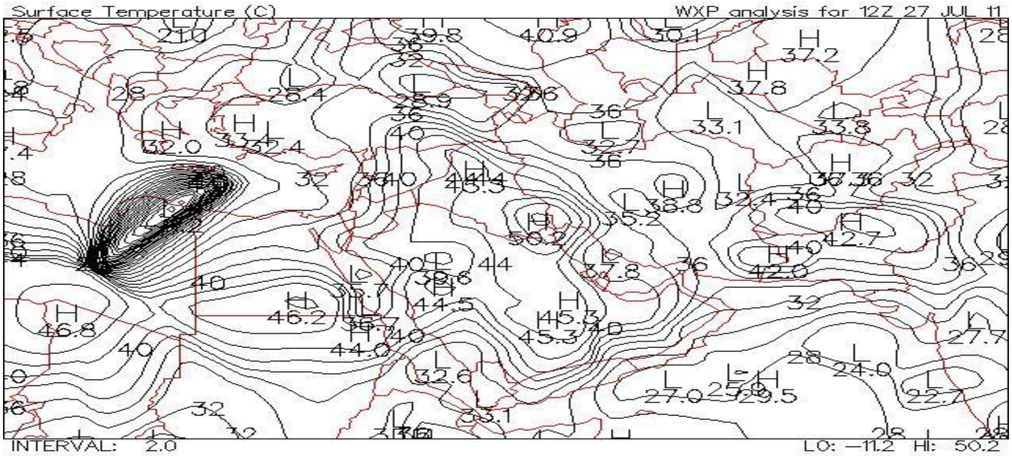

Figure.18- Surface Temperature (degrees C) At 12Z.

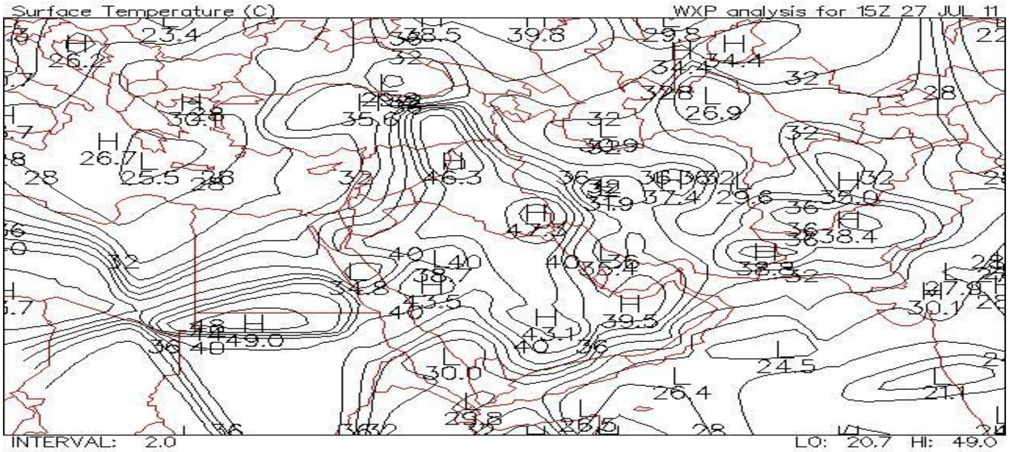

Figure.19- Surface Temperature (degrees C) At 15Z.

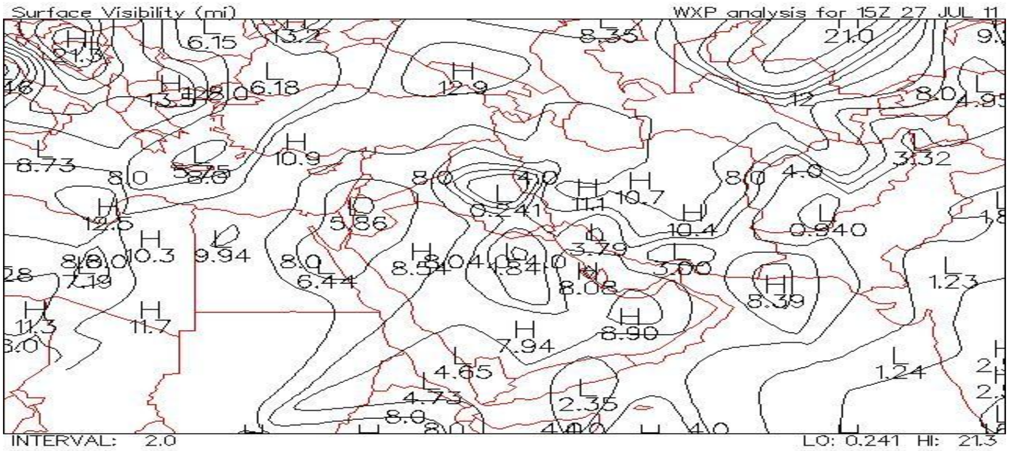

Figure.20- Surface Visibility At 15Z

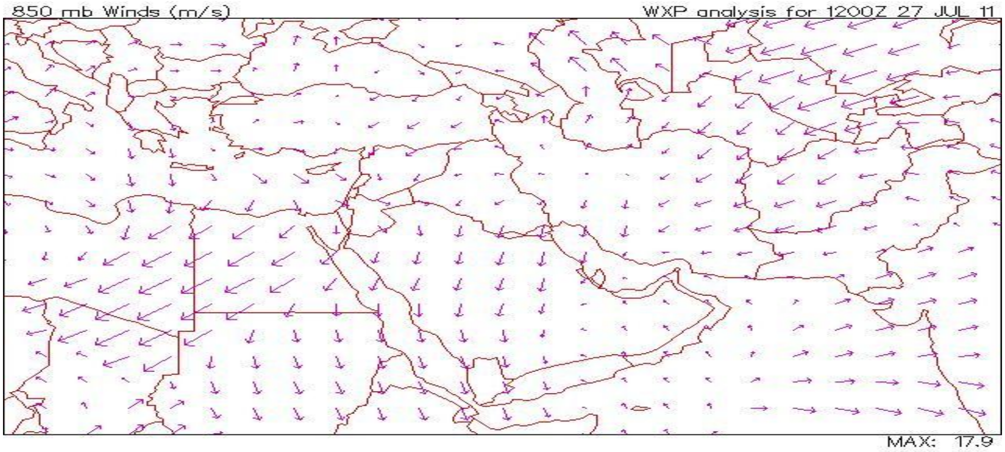

Figure.21- Wind Speed For 850 mb Level At 12Z.

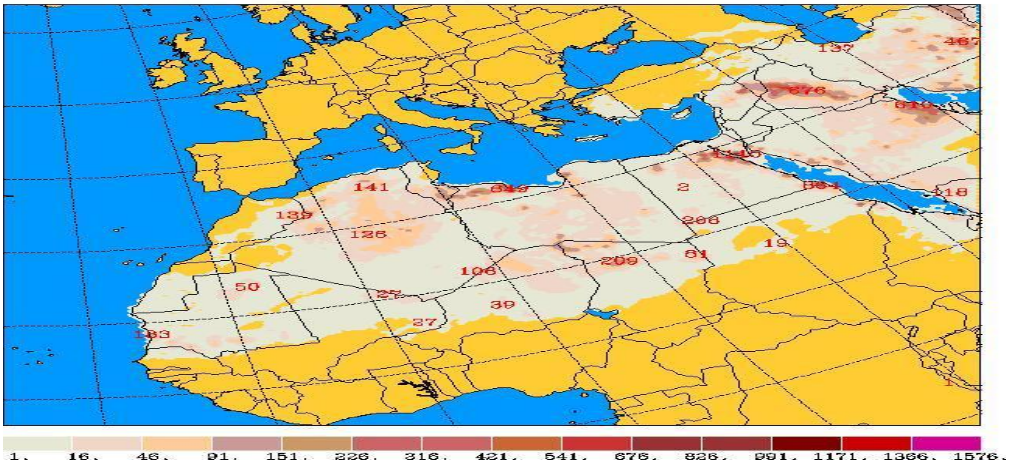

Figure.22- Total Dry Drops Of Dust (mgr/m2).

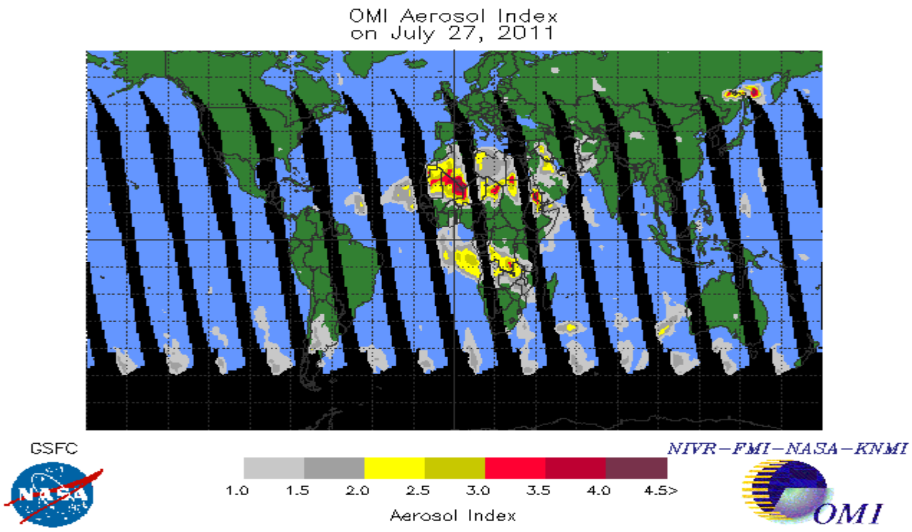

Figure.23- OMI Aerosol Index.

In summary, we have been describing larger-scale events. For these big systems it's critical to forecast where the wind will be sufficiently strong to mobilize dust, combined with a sufficiently unstable boundary layer and an appropriate source region, to excite a dust storm. In conclusion, remote sensing technique can play an important role in monitoring and analyzing dust storm. The dust storm formation mechanisms are very complex. They are related to the local weather system, short-term precipitation, soil moisture, and extent of deforestation, long-term increased drought, land use/land coverage changes, as well as other human activities. Dust storms are a symptom and cause of desertification. They are often an early warning that the depravation of environment. Once they progress from slight to serious and severe categories they contribute to the spread of desertification through the transport and deposition of sediments that can destroy crops, habitation and infrastructure and render areas uninhabitable.

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