THE ENHANCEMENT AND MONITORING OF DUST EVENTS BASED ON VISIBLE AND INFRARED REMOTE SENSING TECHNIQUES

Institute of Geophysics ,University of Tehran,Iran

ftaghavi@ut.ac.ir

In recent years, the frequency of dust pollution events in the Southwest of Iran are increased which caused huge damage and imposed a negative impacts on air quality, airport traffic and people daily life in local areas. In this study, two methods based on the analysis of satellite visible and infrared measurements have developed to enhancement and monitoring of dust events from origin source to local areas. In order to do this work, two dust cases using MODIS observation and METEOSAT data are investigated in two parts A and B.In part A, a method to modify the initial state of model in the numeric analysis using discrepancies between dynamic fields and the Water vapor (WV) satellite imagery are presented. Results from superposition of vorticity fields and satellite WV images shows a close relationship in the circulation systems of extratropical cyclones. but, a mismatch between the vorticity fields and the imagery can indicate a model analysis or forecasting error. In part B,the magnitude of the difference in Brightness Temperature (BTD) in selected bands of MODIS and NDVI, MNDVI indices used to infer the signature of dust. Initial results show that MNDVI index cannot detect dust over water completely. Thus we used the algorithm of combining BTD of dust between the wavelengths 8.5µm (MODIS band-29) and 11µm (MODIS band-31) with negative values of bands -31 and 32 BTDs. In this study for extraction of dust areas, (BT8.5-BT11) – (BT11-BT12) values larger than obtained threshold and (BT11-BT12) smaller than zero are used.The use of thermal infrared spectrum algorithm detects dust well.The aerosol optical depth (AOD), ground-based observations and surface visibility are used to validation of output product .Comparing the results with synoptic maps and output of a Dust Regional Atmospheric Model (DREAM 8b) showed that using enhancement algorithms is a more reliable way than other MODIS products or model outputs to detect dust.Finally, using backward trajectories of NOAA HYSPLIT model showed how the dust transports from the source to other areas.

1-Introduction

The detection of certain important weather events and other environmental phenomena in satellite imagery is often quite challenging. Recently, operational remote sensing of aerosols from long-term satellites provides a means to achieve a global and seasonal characterization of aerosol. In last decade, dust events and repeated droughts have been main hazards in areas of Southwest of Iran. Taghavi and Asadi (2008) showed that several complex dust storms occurred in this region (e.g. March 25 2003, April 17 2003, April 12 2007, May 17 2007) which caused huge damage and imposed a negative impacts on traffic, air quality, and people's daily life in local and downstream areas in recent years. For high temporal and spatial scales, satellite remote sensing may serve an ideal technique for studying the life cycle of dust storms including their generation, development and decay. Some researchers have studied dust storms by means of different satellites images, such as Landsat TM/ETM (Fraser, 1976), METEOSAT data (Wald, 1998; Legnard, 2001) and NOAA-AVHRR (Janugani, 2009). Earlier researchers used visible spectrum to monitor dust outbreaks as well as to estimate dust optical depth over oceanic regions (Carlson, 1979; Norton *et al*., 1980). However, monitoring dust aerosol outbreaks over land using satellite visible and near-infrared data is difficult due to the bright underlying desert surface. The 1996 version of the MODIS-aerosol algorithm (Algorithm Theoretical Basis Document (ATBD-96: Ackerman et al, 2002) introduced the rationale for performing aerosol remote sensing from MODIS on a global scale. On a water vapor image (considering radiances in the 6.2, 6.3, or 6.7-micrometer channels displayed as radiative temperatures in gray shades, the dry areas in the upper troposphere (above 600hpa) appear warmer than the higher moisture areas. WV image matche with various fields to provide operational forecasters and it is a valuable tool for synoptic-scale analysis. It provides an opportunity to make real-time observations of the upper-level circulation of the atmosphere (Santurette and Georrgiev, 2005). Because dust storms mostly occur over desert or arid regions with bright surfaces, such as the Sahara desert, the surface contribution to the satellite signal is quite large and often unknown. As a result, estimates of the properties of dust aerosol are highly uncertain (Zhang *et al.*

2006). Zhao *et al*. (2010) introduced a detection algorithm of dust and smoke for application to satellite multi-channel imagers. The objective of the work described herein is to use satellite data to better understand and monitoring of dust events in southwest of Iran .In order to investigate of these events , enhancement and monitoring of two dust cases in southwest of Iran using METEOSAT data and MODIS observation are presented in two parts A and B.

2-Study Region

In Southwest Asia, some areas such as west of Iran are much more prone to dust storms than others, due to differing soils and climates .This area is strongly affected by the dust storms blown from the great deserts in Iraq, Saudi Arabia, and Syria every year, especially in the hot season. Here,we are concentrating on the southwest of Iran which include main cities Ahwaz, Abadan and Dezfool that experience severe dust storms during spring season.Fig.1 show frequency of daily dust during 8 times in 24 hours in these stations in the period 1979-2008.

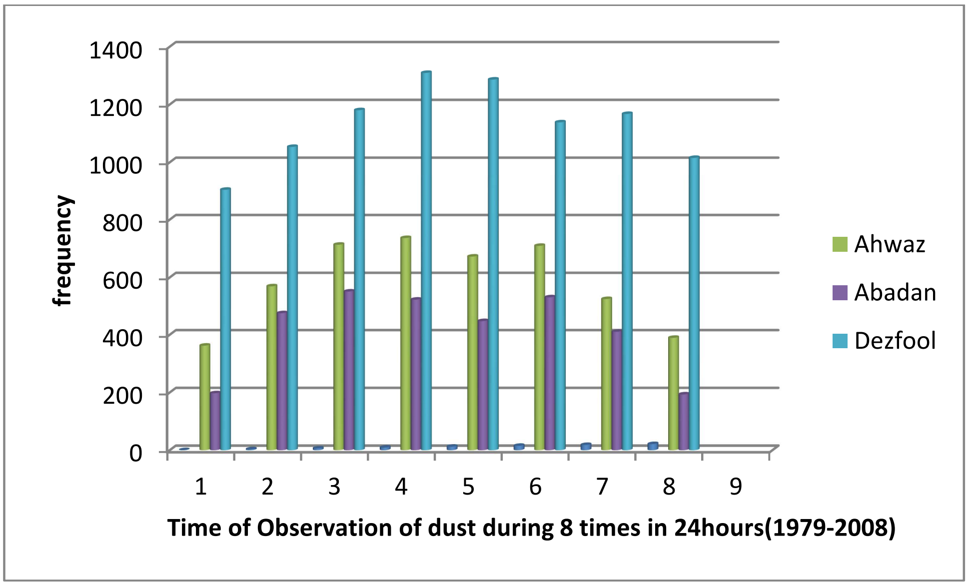

Fig1.Frequency of dust in three important synoptic stations on south west of Iran in the period 1979-2008

Part. A- Monitoring of dust case on 26 march 2003

On 26 March 2003, a rare heavy storm (with respect to the last decade) occurred in southwest of Iran, figure.2 shows this low pressure system that is bringing dust and sand to parts of the southwest of Iran. To investigate dust event in this area, a grid with coordinates 40E-60E longitude and 20N -40N latitude selected. This particular storm selected to illustrate the above, with special focus on the interpretation of water vapor satellite imagery. Figure.3 depicts this intense storm on over the Middle East and the Persian Gulf by a Meteosat5 water vapor image.The image coordinates is 30- 75 longitude (E), 20-45 latitude (N). In this part, a method to modify the initial state of model in the numeric analysis using discrepancies between dynamic fields and the Water vapor (WV) satellite imagery in a grid are presented. In this method, we used a mismatch between dynamic fields and the satellite image as a trigger that the model is in error and so model modification will be required. For selected cases, the EUMETSAT /Meteosat products compared to NWP output in this grid. A MM5V3 model from Thi application with these characteristics are selected: configure user ImPHYS=4 simple ,ICUPA=3 Grell Cumuls with final analysis Data source:Terrain: ftp//ftp.ucar.edu/mesouser/mm5v3/terrain-data/ and Regrid DATA : Ncep final analysis (FNL) (dso83.2) 1*1 degree : http//dss.ucar.edu/dataset/ dso83.2/. In this study, RT6-SST.0.5 from http://polar.ncep.noaa for sea surface temperature is used. Outputs of run of the model for 36 hours with time step 21600s in 23 sigma level used. For this run 3 grids with mother grid center (longtitude 40, latitude 37.5) , grid space 81 km and time step 540s used for iteration. Also meteorological variables such as Uwind, Vwind , height of 500hpa level and mean sea level pressure extracted from the National Center for Environmental Prediction (NCEP).The first step is to superimpose isobars of sea level pressure, contours of 500 hPa height and dynamics fields such as vorticity field on its correct position in the satellite image. The second step is to compare the analyzed and forecast dynamic fields in order to find the discrepancies between the NWP output and the images**.**

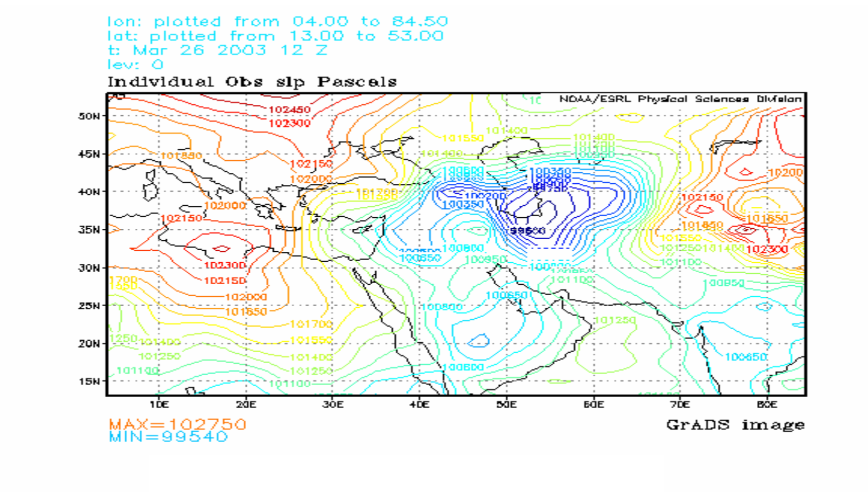

Figure2. Sea level pressure map on 26 March 2003

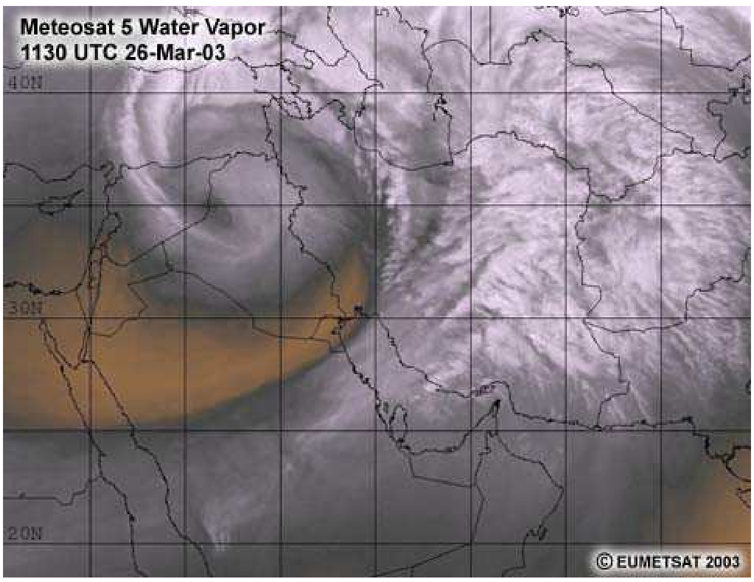

Figure3: Meteosat5 water vapor image on 26 March 2003

3- Data processing and results

As seen in figure 4a, a spiral pattern on the WV image indicates the conditions of the upper air cyclone. But forecasting geopotential height of 500hpa level and mean sea level pressure fields overlaid it show that model have errors and phase lag more than 90° is seen(Fig4a and Fig4b).Also, comparing the forecast temperature fields with cold(-6.14°) and warm(+38.176°) centers as observed in the image show the discrepancies between the NWP output and WV image (Fig5a). Results from superposition of vorticity fields and WV image shows a close relationship in the circulation systems of this Mid-Latitude cyclone but, the mismatch between the vorticity fields and the image indicate forecasting errors(Fig5b).

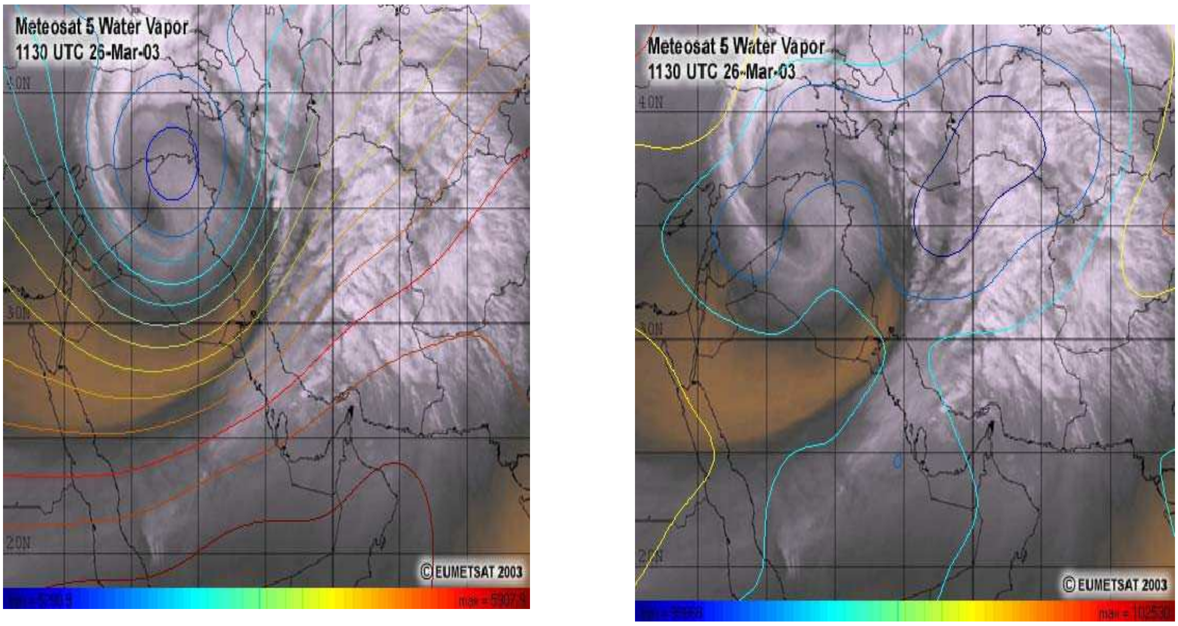

Figure4. (a)Water vapor imagery overlaid by corresponding geopotential height of 500hpa level field (b) mean sea level pressure field on26 march 2003

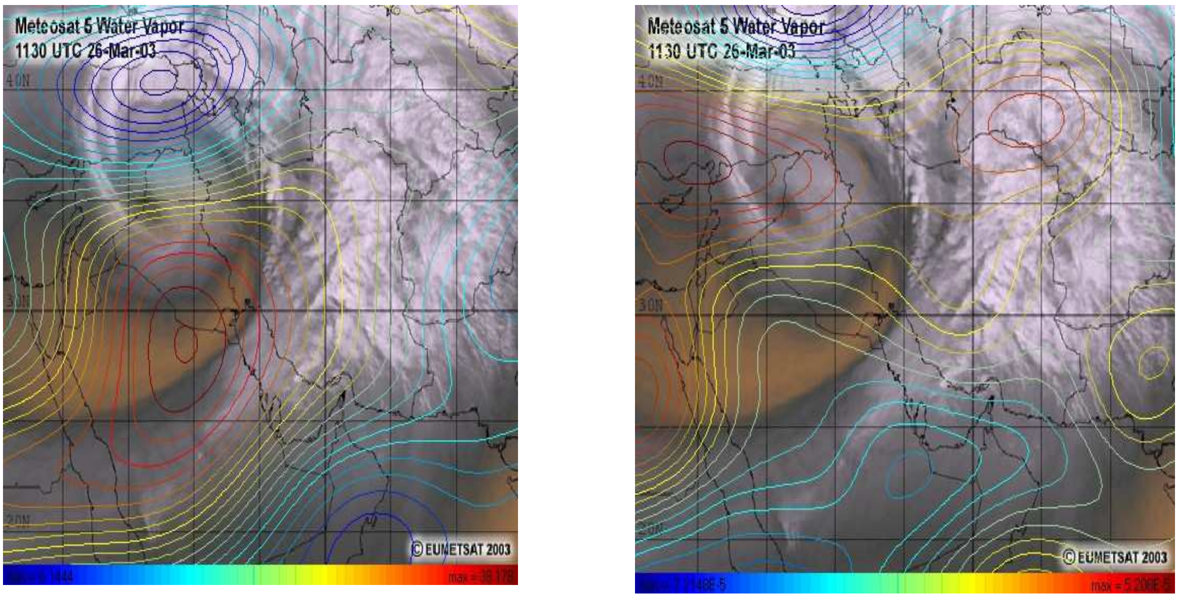

Figure. 5(a) Water vapor imagery overlaid by corresponding temperature surface field (b) by corresponding vorticity field on 26 March 2003.

Part. A -Enhancement of dust case on April 13th 2011

Dust enhancement based on the brightness temperature differences (BTD) in two or three channels and Modified Normalized Difference Vegetation Index (MNDVI) using two different algorithms namely MNDVI algorithm and Thermal Infrared (TIR) algorithm. The algorithms using ENVI (Environment for Visualizing Images) software and HDF data prepared and output products are in HDF format. The MODIS observations of the dust that occurred in the west of Iran on April 13th 2011 are selected as case for development of the enhancement algorithms . Seven MODIS bands, i.e., band 1, 2, 3, 4, 29, 31 and 32 and a MODIS image with 33-65 longitude (E) and 27-50 latitude (N) from Aqua at crossing time 9:45 UTC on 2011/04/13 used for identifying of dust case.The spectral ranges of these bands are listed in Table. 1. The HDF calibrated data, which has the spatial resolution of 1km for dust enhancement used.

Table2: Characteristics of bands used in this study (MODIS website, 2009)

Primary Use	Band	Bandwidth	Spectral Radiance	Required SNR (Signal to Noise Radiation)
Land/Cloud/Aerosols Boundaries	1	620 – 670	21.8	128
	2	841 – 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 – 479	35.3	243
	4	545 – 565	29.0	228
Cloud Properties	29	8.400 - 8.700	9.58(300K)	0.05
Surface/Cloud Temperature	31	10.780 - 11.280	9.55(300K)	0.05
	32	11.770 - 12.270	8.94(300K)	0.05

To understand the dynamics of this dust storm, we can consider a number of meteorological variables collected at Ahwaz station. Ahwaz is at 31º 20'' latitude(N),48º 40'' longitude(E). Table1 show the weather report from Iran Meteorology Organization(IRIMO) on this case for Ahwaz synoptic station . These are the visibility records at the most intense of dust situation in this station. The visual visibility is reported every 30 minute. Four levels of SDS, i.e. floating dust, blowing dust, sand/dust storm (SDS), and severe SDS, are classified, which correspond to a visibility of >10 km, 1 km–10 km, 500 m–1 km and <500 m, respectively .As we see in this table none existing of enough humidity, (big differences between temperature and dew point) could cause more intense dust case with lower visibilities. Sea level pressure of this case show that a low pressure was the main cause of this dust storm (Figure.6) .

Table 1. Weather report from IRIMO on 13th April for Ahwaz synoptic station.

Time	Weather situation	Temperature	Dew point	visibility	Wind speed & direction
07:30		22	3 ºC	50 m	NW,10.8 km/h
08:00		22	1 ºC	50 m	NW,10.8 km/h
08:30		22	1 ºC	50 m	N,18 km/h
09:00		23	0 ºC	50 m	NW,18 km/h
09:30		22	-2 ºC	50 m	NW,18 km/h

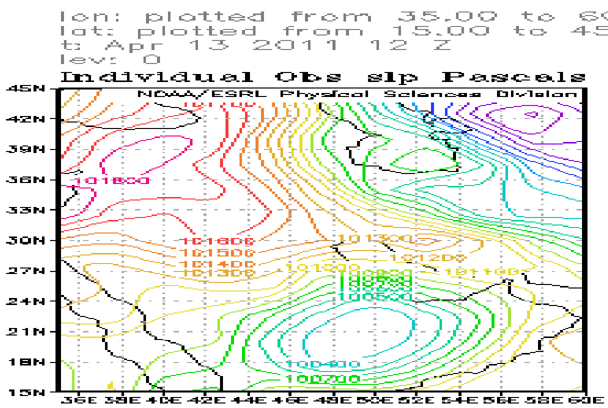

Figure 6. Sea level Pressure of Case on April 13th, 2011.

In the first algorithm, the MNDVI and BTD [11,12] parameter to separate the semi-arid areas with low vegetation covers and the threshold temperature of 290K in MODIS band-31 is used to distinguish cloud from dust event. Clouds are spectrally neutral and appear white to our eyes. For this reason, the reflectances at 0.86 µm, 0.64 µm and 0.47µm have been used to identify dust (Zhao et al., 2010). To get better results, we use MNDVI, smaller than a threshold that is obtained by trial and error in different dust cases:

The definition of MNDVI and NDVI are:

$$MNDVI = \frac{(NDVI)^2}{(R_1)^2} \qquad (1)$$

$$NDVI = \frac{R_2 - R_1}{R_2 - R_1} \qquad (2)$$

where R_1 and R_2 are the reflectances of MODIS band-1 and band-2, respectively.

The second algorithm, called Thermal Infrared (TIR) algorithm which is based on the optical and radiative properties of dust in mid-infrared and thermal infrared spectral regions, which include BTD in split window channels. For second algorithm, we used (BT29-BT31) – (BT31-BT32) > -1, (BT31-BT32) values lower than zero and a threshold temperature of 290K in MODIS band-31 to distinguish the clouds from dust. Thus, with increasing the amount of dust, the difference (BT29-BT31) increases and that of (BT31-BT32) decrease. To enhance the dusty areas with true color images, we use a reflectance combination of bands 1, 3 and 4 of MODIS. So the dusty regions are shown in pink color as we see in Fig. 7a and Fig. 7b. As we see in Fig. 7a, the first algorithm misses many dusty areas, especially over water and so the MNDVI algorithm cannot clearly detect the dust. Therefore, we used the TIR algorithm of combining brightness temperature difference of dust between the wavelengths of 8.5μm and 11μm with negative values of BTD [11, 12]. To define dust areas we used (BT29-BT31) – (BT31-BT32) values larger than the obtained threshold and (BT11-BT12) values smaller than zero. Results show that dust area is much better enhanced in second algorithm (Fig. 7b).

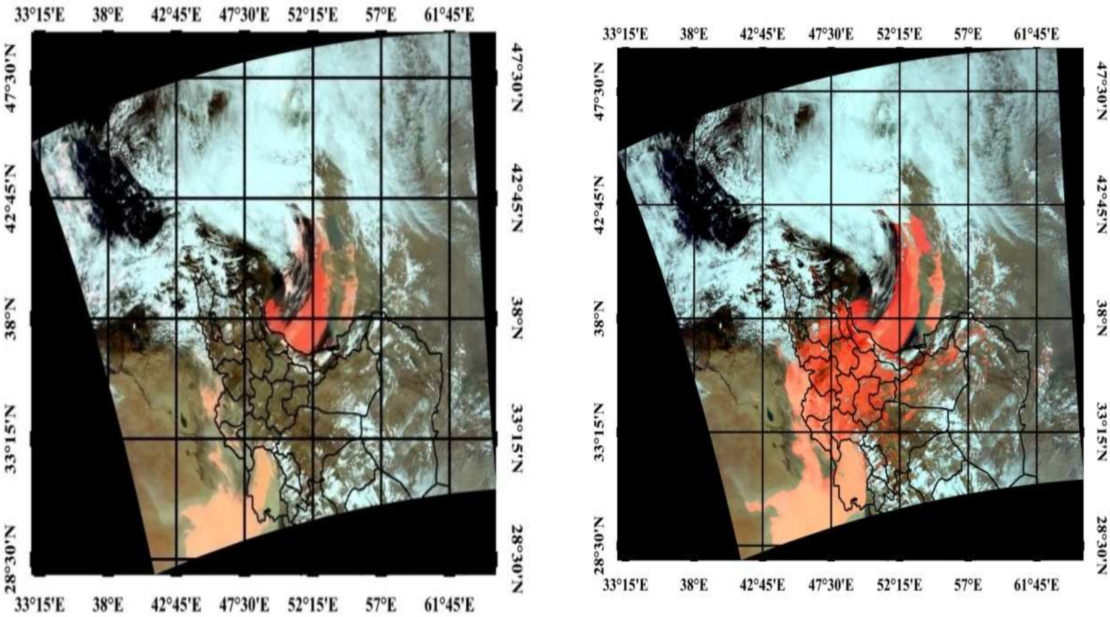

Figure 7: (a) Enhancement of dust on April 13th, 2011 using MNDVI (b)TIR method

After the enhancement of these dust cases, the results are compared with MODIS AOT retrievals at 550nm from Terra and Aqua satellites (Fig.8). The wavelength of 550nm is widely used for getting the AOTs, because at this wavelength we can eliminate the surface radiances, so what we gain at the sensors is the influence of pollutants and dust particles on atmosphere. As we see in MODIS AOT retrievals at dust case 13th April the AOTs are high at almost west half of Iran and even on Caspian Sea. We also used the DREAM 8b outputs for this case (Fig .9a). This dust cycle module simulates dust production, dust advection and turbulent diffusion, and dry and wet deposition (Nickovic et al., 2001). The updated BSC-DREAM8b v2.0 (Basart et al. 2012)and the new NMMB/BSC-Dust are the models developed in the Earth Sciences Dept. to simulate and/or predict the atmospheric cycle of mineral dust at BSC-CNS. In the DREAM system, a dust cycle simulation module is coupled with the National Centers for Environmental Prediction (NCEP) operational Eta Model (Janjic, 1994). For this study, we use the AOT outputs of DREAM-8b model in 550nanometers to see how it works comparing with other results. The AOTs of DREAM-8b model show high values in this case, but it seems that they overestimate the AOTs .Backward trajectories of NOAA HYSPLIT model show how the dust transports from the source to other areas. The trajectories in figure.9b show the direction and the movement of this dust event.

-Conclusion

Two case study was performed to investigate dust events using water vapor imaginary and MODIS observations. It found out that in both cases, there is a low pressure that is bringing dust or sand storms to parts of the southwest of Iran. Results from superposition of dynamics fields on WV image shows a close relationship in the circulation systems of this Mid-Latitude cyclone but, the mismatch between dynamic fields and the image indicate forecasting model errors and so comparison between WV Imagery and dynamic fields it offers a means to control the behavior of the numeric models.Also, two enhancement algorithms proposed for dust detection, using MODIS observations. Results show that TIR algorithm detects dust well, especially over water. Comparing the enhanced images using IR technique with synoptic maps, MODIS AOT values, DREAM 8bmodel outputs and synoptic stations data, we found out that the applied enhancement algorithms provide a more reliable approach to monitor dust storms compared to MODIS AOT retrievals or model outputs.

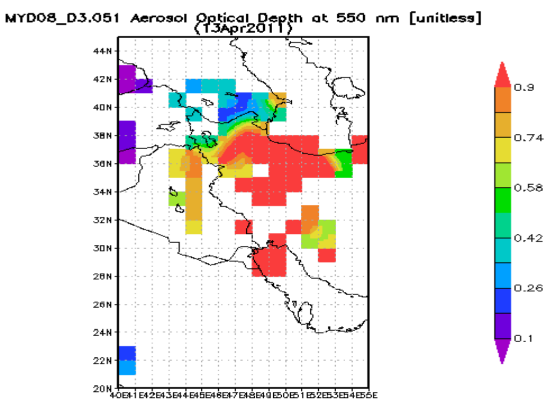

Figure 8 : MODIS AOT Retrieval on April 13th, 2011

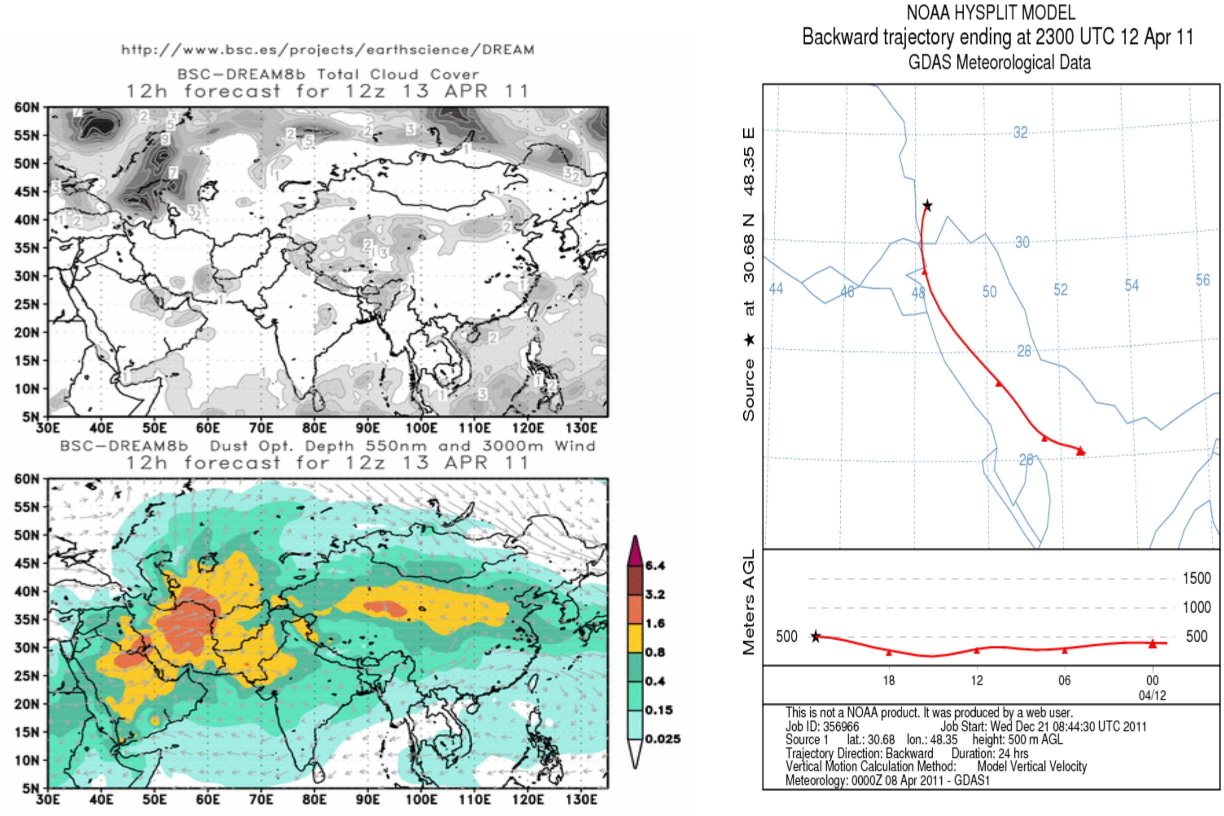

Figure 9: (a)BSC-DREAM8b Model outputs (b) Backward trajectories of NOAA HYSPLIT model 0n Case of April 13th, 2011

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