Sources, Distribution and Transport of Aerosols over UAE based on Multiple Satellites, Ground measurements and WRF model

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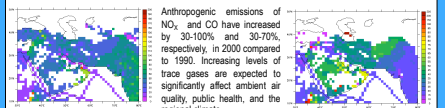
Background and Motivation

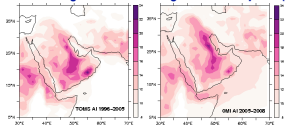
- Lack of understanding of the region in terms of air quality and regional climate change
- Complexity in regional chemistry and meteorology
- Field experiments are limited to specific periods (e.g., UAE[2])
- Increasing trend of energy demand (4-6% per annum)
- Uncertainty in natural emissions such as dust storms
- Lack of high resolution data on aerosols and trace gases. Data is limited to a few UAE monitors

Relative increase of NO_x and CO emissions in 2000 versus 1990

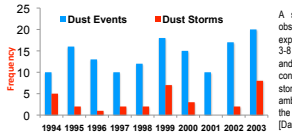


Anthropogenic emissions of NO_x and CO have increased by 30-100% and 30-70%, respectively, in 2000 compared to 1990. Increasing levels of trace gases are expected to significantly affect ambient air quality, public health, and the regional climate.
Data source: EDGAR/GEIA

Changes in aerosol regimes from space (1996-2008)



The long-term mean of the aerosol index over the Arabian Peninsula from TOMS and OMI depicts a widening of dust pollution to the neighboring oceanic region. AI values frequently cross the threshold of 1.2, showing severe dust loadings over the Arabian Peninsula.



A study based on 10 years of observations shows that Abu Dhabi experiences an annual average of 3-8 dust storms, 10-20 dust events and a total of 242 days with haze conditions. Understanding these storms and their implications on ambient concentrations is critical for the UAE air quality.
[Data source: Villiers et al., 2007]

Introduction, Objectives and Data Sources

Ground measurements of aerosols over the United Arab Emirates (UAE) are sparse with respect to space and time. High-resolution satellite data can potentially be used for environmental management, monitoring air quality, permitting quick responses to dust-related epidemics. This study demonstrates the advantages of using observations from multiple satellites and ground measurements along with a regionally-tuned WRF model to track and monitor aerosols over the UAE. Episodic enhancement of aerosol abundances and dust emissions are obtained from a global and a simple dust model. The onset and evolution of triggering dust storms and their impacts on regional aerosols are examined based on observations and model simulations. The main objectives of this study are

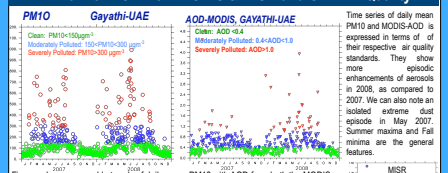
- **Examine the seasonal distribution of aerosols, and air quality over UAE in terms of daily PM10 and aerosol optical parameters (AOD, AI, AOT from AERONET)**
- **Compare and find the correlation between PM10 and AOD from different satellites**
- **Examine the advantages of using multiple satellites to track and monitor dust events over the UAE**
- **Better understand the physical processes associated with episodic dust events and transport, and their impacts on UAE-air quality.**

Data Sources:

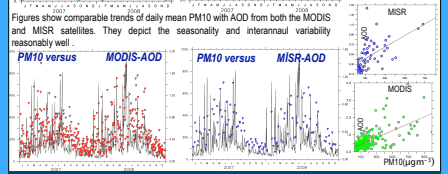
Satellite observations

(i) MODIS: Moderate Resolution Imaging Spectrometer (AOD at 550 nm, Terra and Aqua)
(ii) MISR: Multi-angle Imaging Spectroradiometer (AOD at 558 nm)
(iii) OMI: Ozone Monitoring Experiment (AOT at 500 nm, AI)
Ground Measurements: (i) **PM10**, (ii) **AERONET**, (iii) **Visibility**
Model simulations
(i) WRF: Weather Forecasting and Research Model for UAE*(WRF-IE version, after Xiu and Davis)*
(ii) MATCH + DEAD: Model for Atmospheric Chemistry and Transport-Desert Entrainment and Deposition model *(Mahowald et al., Liu et al., 2003)*
(iii) Simple Dust Model *(Adelman et al., 2009)*

PM10 with AOD from MODIS & MISR and UAE Air Quality



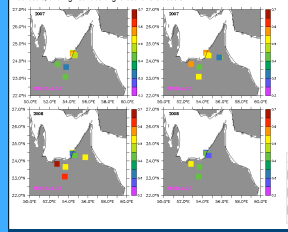
Figures show comparable trends of daily mean PM10 with AOD from both the MODIS and MISR satellites. They depict the seasonality and interannual variability reasonably well .



Time series of daily mean PM10 and MODIS-AOD is expressed in terms of of their respective air quality standards. They show more episodic enhancements of aerosols in 2008, as compared to 2007. We can also note an isolated extreme dust episode in May 2007. Summer maxima and Fall minima are the general features.

Correlation between PM10 and AOD from MODIS and MISR, 2007-08

The correlation between PM10 and AOD over the UAE is inconsistent and shows a wide variation in space and time. Generally, higher correlations (>0.5) at many stations are noted for MISR than for MODIS, and in 2007 than in 2008. The discrepancy in comparison for this region could be due to aerosol plumes above the boundary layer, lack of instrument sensitivity to surface aerosols, and high surface brightness for the desert.



Correlation: PM10 versus MODIS AOD

STATION	r (2007)	r (2008)	r (2007-8)
GAYA	0.42	0.67	0.57
KHAF	0.56	0.31	0.35
HAMD	0.49	0.21	0.30
BANI	0.46	0.43	0.39
LIWA	0.42	0.60	0.56
MUSA	0.52	0.28	0.39
BIDA	0.30	0.53	0.48
ALSC	0.1	0.51	0.44
KADJ	0.48	0.52	0.51

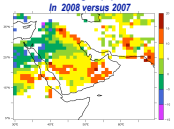
Correlation: PM10 versus MISR-AOD

GAYA	0.56	0.53	0.54
KHAF	0.74	0.40	0.51
HAMD	0.57	0.28	0.32
BANI	0.52	0.28	0.33
LIWA	0.52	0.42	0.45
MUSA	0.51	0.43	0.46
BIDA	0.42	0.40	0.35
ALSC	0.33	0.15	0.27

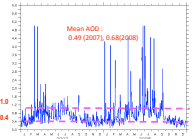
Contrasting years of air quality in terms of Aerosols

The year 2008 is more polluted in terms of aerosols than 2007, because of frequent occurrences of dust events especially in winter 2008 (normally, the season of highest precipitation in UAE). This is because of changes in regional meteorology due to shifts in the locations of convection, shifts in Middle Latitude Jet streams to the south, and sources of emissions.

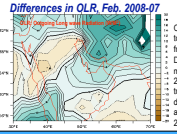
Relative changes (%) in OMI-AI In 2008 versus 2007



Areal mean of daily 1 hour maximum AOD from MODIS for UAE (2007-08)

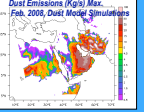


Differences in OLR, Feb. 2008-07



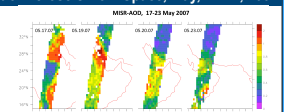
OLR, a proxy of convection, shifts to dust source regions, extending from NW Africa to the Saudi Desert. Unusual dust emission maxima can be seen in winter 2008 over UAE, mainly due to transport and the pronounced divergence over the UAE region as compared to that in winter 2007.

Dust Emissions (Kg/s) Max. Feb. 2008, Dust Model Simulations



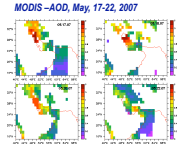
Episodic enhancement of Aerosols from Space, May, 17-24, 2007

Satellite imagery of dust plumes swept over the Arabian Gulf on 17th May 2007, from MODIS-Aqua. A rapid increase in AOD can be seen for the UAE for the period of 19-21st May.

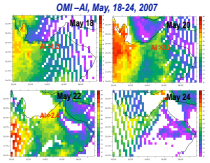


The dust appears to have originated from north Iraq and blows toward the southeast, which covers western Iran, Kuwait and wide area of Saudi Arabia through southeastern Iraq. This can be seen in the plots for 17th-24th May 2007

MODIS –AOD, May, 17-22, 2007

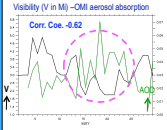


OMI –AI, May, 18-24, 2007

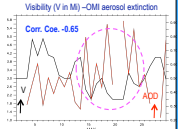


This brings an observed aerosol index of greater than 2.4 during this period over UAE, which is about two times higher than the threshold level (AI=1.3) of an intense dust loading. The AI level reached a peak (>3.0) on 22nd May, covering most of the UAE region, and especially very strong over south and western part of UAE. (OMI-AI scaled to 10)

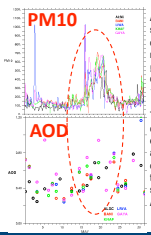
Visibility: an indicator of dense aerosol loading and haze conditions



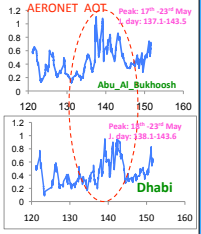
The impact of the dust storm on visibility based on OMI-derived aerosol absorption and extinction-AODs at 500 nm are examined for the episodic periods. A strong negative correlation (> 0.6) is found between AOD and the observed visibility over the UAE stations.



PM10 and AERONET-AOT 17-24 May 2007

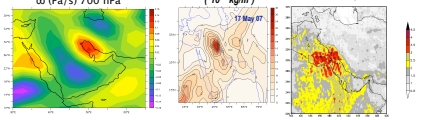


All the stations show peak values of PM10 (>300 μg/m^3, reaching 700 μg/m^3 or more) during the period of 17th-23rd May.



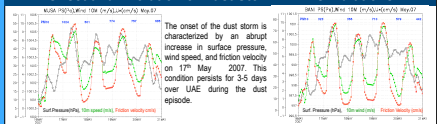
These findings are consistent with the enhanced aerosol abundance as observed during this period by the satellites and AERONET stations.

Aerosol abundance from the global model and OMI

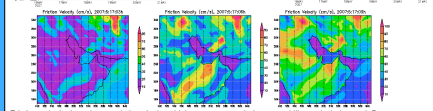


The global model is able to reproduce the dust mass column density and is comparable to the spatial and temporal pattern of OMI-AI as observed over the Arabian Peninsula on 17th May 2007. Enhanced aerosol can be seen over the north west of Arabian Gulf, Iraq, southern Iran and Saudi Desert in both the plots. Pressure velocity at 700 hPa shows the pronounced maxima of upwelling motion over the source locations.

Onset and Evolution of Dust Storm-WRF simulations

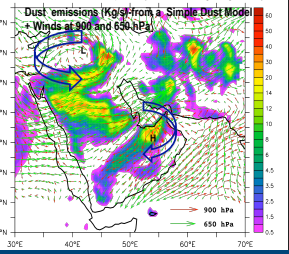


The onset of the dust storm is characterized by an abrupt increase in surface pressure, wind speed, and friction velocity on 17th May 2007. This condition persists for 3-5 days over UAE during the dust episode.

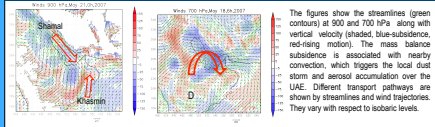


Friction velocity is a characteristic velocity which represents turbulence, stability and wind speed. Dust mobilization is proportional to the fluxes of momentum in to ground. Frictional velocities of more than 40-55 cmps are typically required to suspend dust under unstable conditions, with a wind speed of more than 5-8 mps. The rapid increase in friction velocities can be seen on subsequent days over UAE, beginning17th May.

The regional meteorology and its seasonal variability is highly heterogeneous and complex with respect to the influences of prevailing shamal winds associated with the passage of frontal systems. UAE is often influenced by both migratory and local meso-scale wind systems. The figure shows the cyclonic vortex at the northwest in the surface layer (900 hPa) and anticyclonic circulation over the UAE at 650 hPa. The shaded area represents the dust emissions, following the synoptic flow. This provides a favorable mechanism for subsidence and accumulation of pollutants over the UAE.

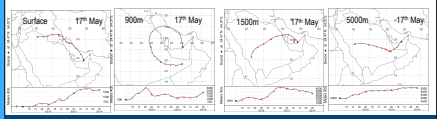


Synoptic Conditions and Transport Pathways



The figures show the streamlines (green contours) at 900 and 700 hPa along with vertical velocity (shaded, blue-subsidence, red-rising motion). The mass balance subsidence is associated with nearby convection, which triggers the local dust storm and aerosol accumulation over the UAE. Different transport pathways are shown by streamlines and wind trajectories. They vary with respect to isobaric levels.

Hysplit 72-hours backward Trajectory analysis based on WRF model simulations



Conclusions

- This study has shown the potential to use observations from multiple satellites to track and monitor aerosols and air quality over the United Arab Emirates.
- The trend and air quality analysis of daily PM10 and AOD from MODIS and MISR indicates that the region is mainly polluted in spring and summer, however episodic events in winter are not negligible (e.g., winter 2008).
- The correlation between PM10 and AOD over UAE is inconsistent and shows a wide variation in space and time. Generally, higher correlations (>0.5) are noted for MISR than for MODIS, and in 2007 than in 2008. OMI-AI provides a better tool to track and monitor the dust plumes. OMI-derived AOD for absorption and extinction shows a strong negative correlation (>0.6) with the observed visibility during the episodic periods.
- The WRF model is able to reproduce the onset and evolution of the dust storms reasonably well.
- Our analysis suggests that aerosols over the UAE in the spring is sensitive to transport from Saudi Arabia, Iran, Iraq and local sources. However meso-scale features associated with shamal conditions make this region more sensitive to local emissions.

Acknowledgement: Thanks are due to Zac Adelman and Uma Shankar, UNC Institute for the Environment, for providing dust emission data based on a simple dust model, and Natalie Mahowald, Cornell University for providing the dust column density and emission data from a global model (MATCH-DEAD). We also express our thanks to Sarav Arunachalam and Zuber Farooqui for useful discussions. The project support by Jacqueline MacDonald is appreciated. Finally, satellite data support from NASA GFC, GIOVANI, and Langley ASDC are gratefully acknowledged.