Jet Propulsion Laboratory
California Institute of Technology

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Identification and characterization of dust source regions across North Africa and the Middle East using MISR satellite observations

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North Africa and the Middle East: dustiest region on Earth

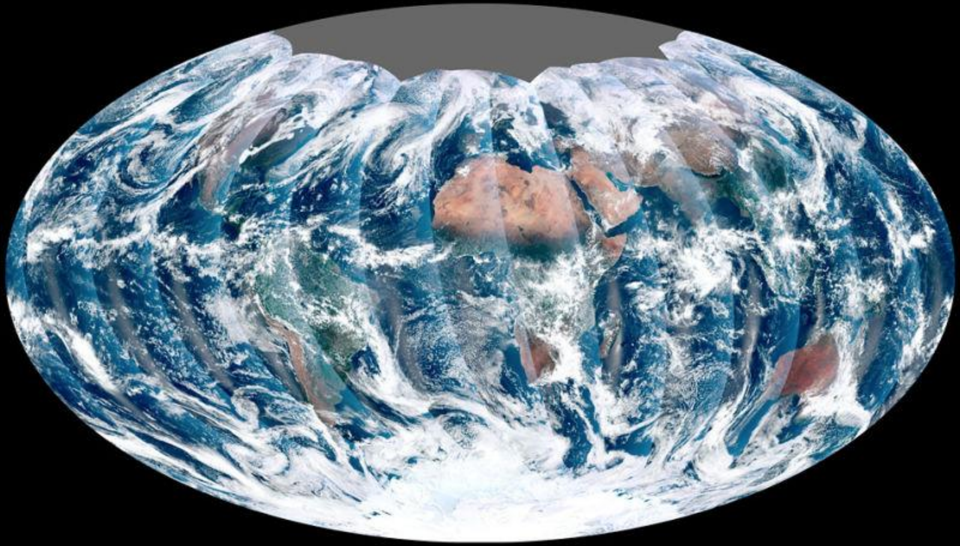


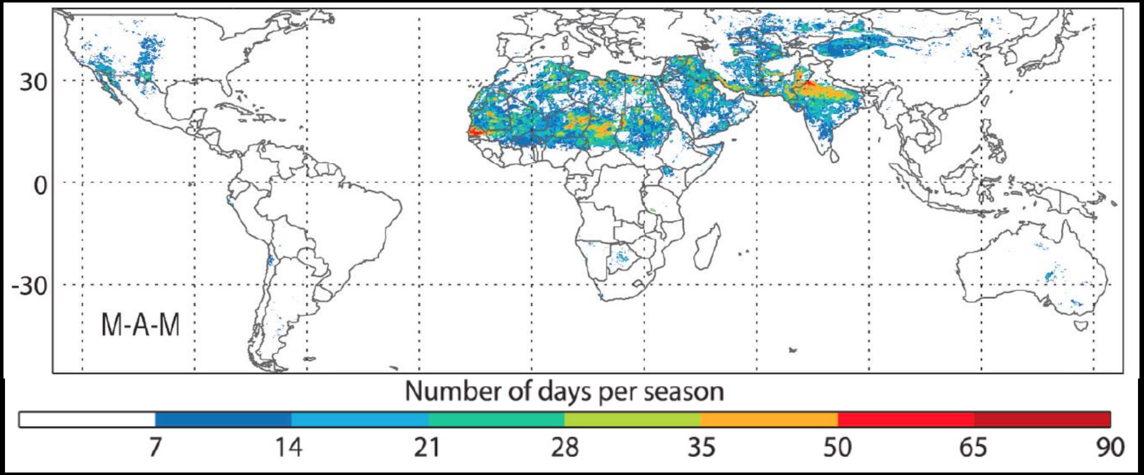
Image from Visible Infrared Imager Radiometer Suite (VIIRS) November 24, 2011

- Global arid and semi-arid regions supply 1100 to 5000 Tg of aeolian dust to the atmosphere each year, primarily from North Africa and secondarily from the Middle East.
- Dust aerosol plays a key role in the Earth's energy and nutrition budget, influencing global and regional environment.
- Dust storms cause reduced visibility and elevated particulate matter concentration.

Past satellite-based dust source identifications

Aerosol loading-based approach identifies regions with high aerosol loadings, detected by satellite aerosol optical depth (AOD) products such as the Deep Blue algorithm applied to Moderate Resolution Imaging Spectroradiometer (MODIS) data from the Terra and Aqua satellites, or absorbing aerosol index (AI) product from the Ozone Monitoring Instrument (OMI) aboard the Aura satellite.

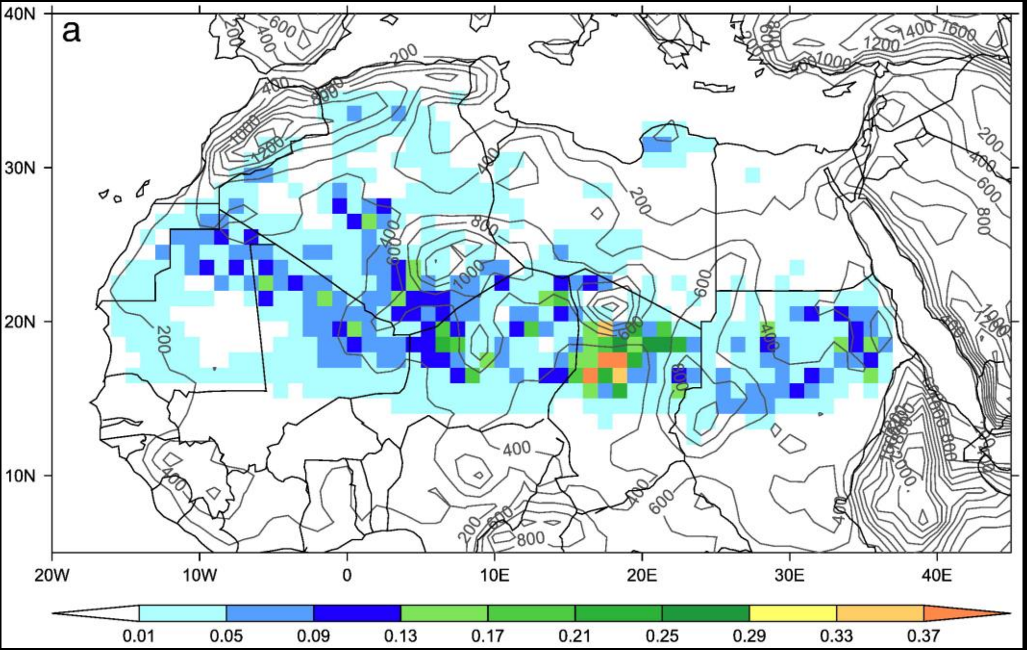
March-May mean (2003-2009) number of days with MODIS-DeepBlue dust optical depth > 0.2 (Ginoux et al. 2012)



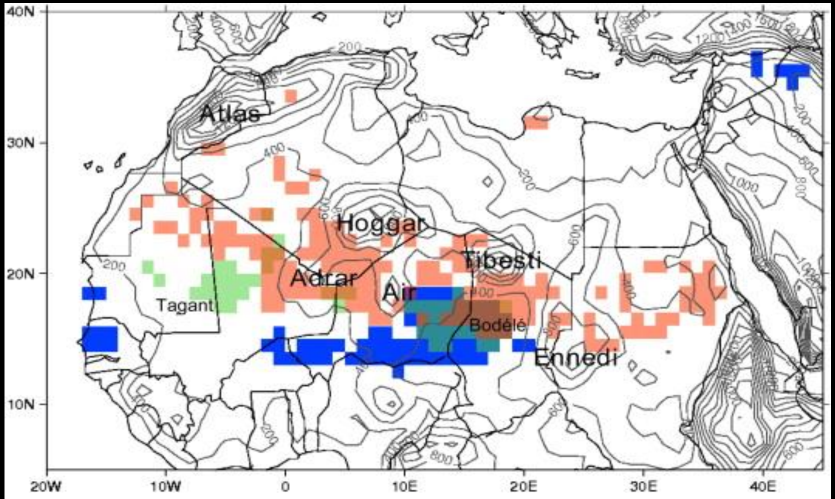
Past satellite-based dust source identifications

<u>Dust-tracking approach</u> back tracks individual dust plumes based on Brightness Temperature (BT) difference, using 15-minute resolution data from the Spinning Enhanced Visible and Infrared Imager (SEVIRI) instrument aboard the geostationary Meteosat Second Generation (MSG) satellite.

Dust source activation frequency (2006-2010) from MSG SEVIRI (Schepanski et al. 2012)



Past satellite-based dust source identifications

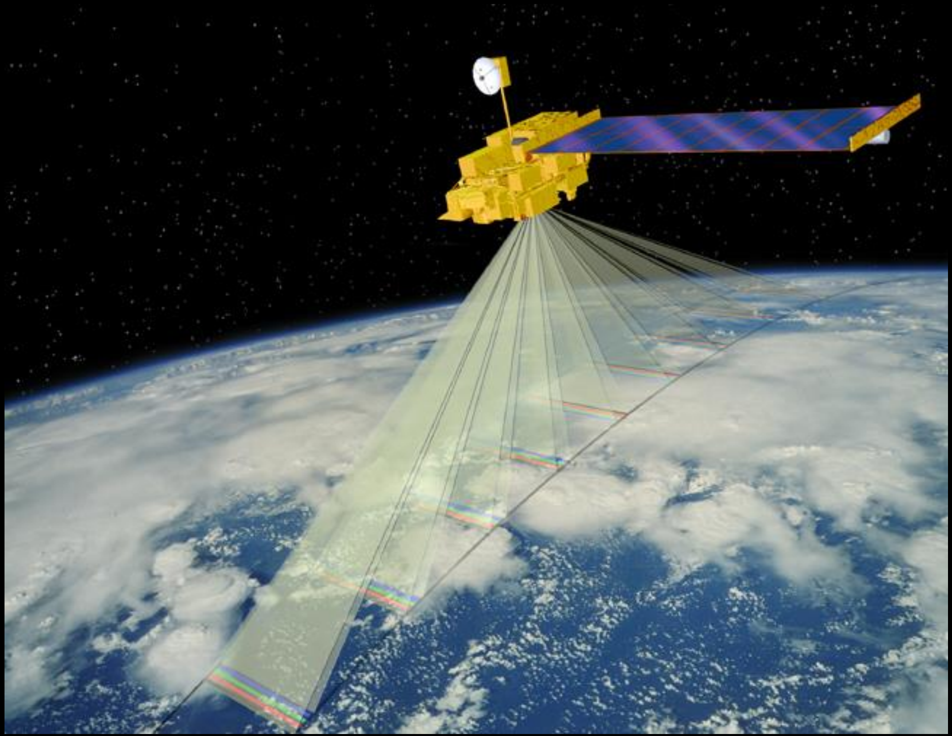


blue—frequency (MODIS DeepBlue AOD > 0.5) > 40%
green – frequency (OMI AI >2) > 40%,
red – frequency (MSG DSA) > 6%,
contour – elevation (m).
(Schepanski et al. 2012)

Inconsistency between the dust-tracking and aerosol loading-based methods due to their different sensitivities:

- AI is sensitive to dust layer height and meteorological variables (Mahowald, 2004).
- Regions with high AOD or AI do not always indicate dust sources due to dust transport (Ginoux et al. 2012).
- AOD-based techniques saturate for extremely high aerosol loadings (Witek et al. 2018).

Multi-angle Imaging SpectroRadiometer (MISR)



9 view angles at Earth surface: 70.5º forward to 70.5º backward

7 minutes to observe each scene at all 9 angles

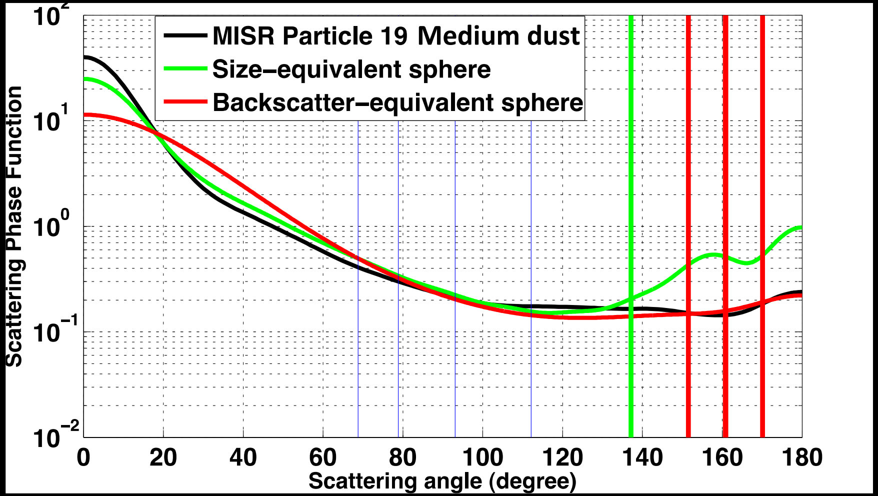
Terra satellite crosses Equator at 10:30 local time: important for North African and other dust sources active in the morning

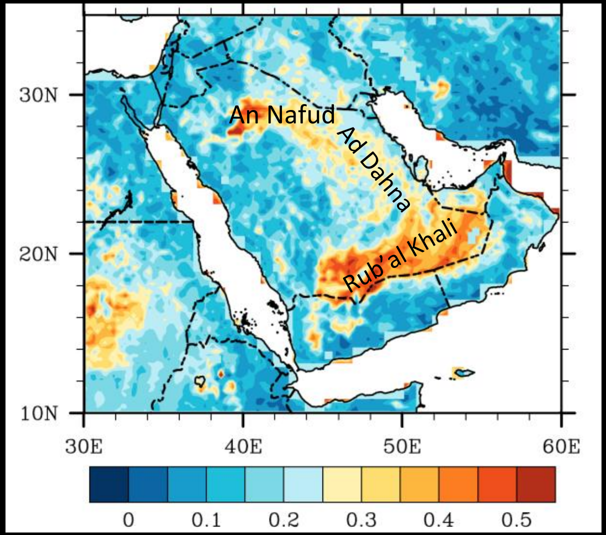
400-km swath: views the study region of North Africa and the Middle East every 6-7 days

MISR dust AOD (DAOD)

MISR detects particle shape classes through their effect on scattering phase function (Kalashnikova et al. 2013).

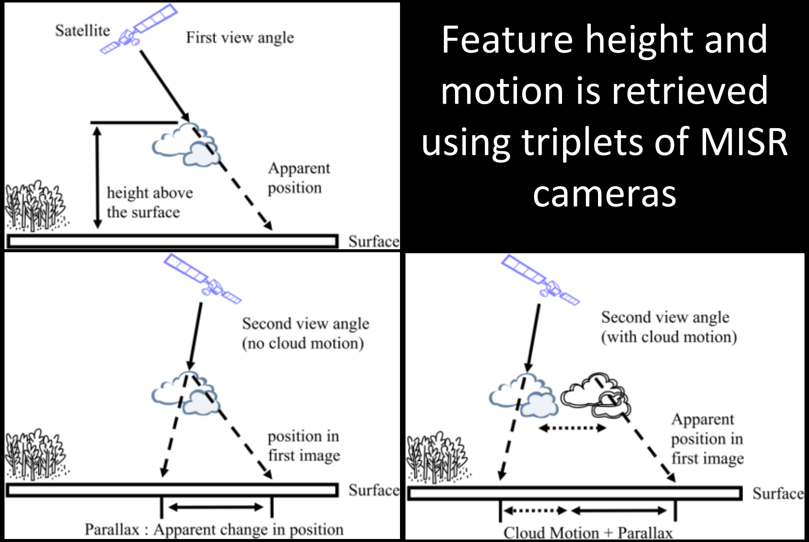
The MISR nonspherical AOD fraction is often referred to as "fraction of total AOD due to dust", as dust is the primary nonspherical aerosol particle in the atmosphere, especially over deserts (below).





Yu, Y., M. Notaro, Z. Liu, O. Kalashnikova, F. Alkolibi, E. Fadda, F. Bakhrjy (2013), Assessing temporal and spatial variations in atmospheric dust over Saudi Arabia through satellite, radiometric, and station data, ***Journal of Geophysical Research-Atmospheres***, 118 (23), 13253.

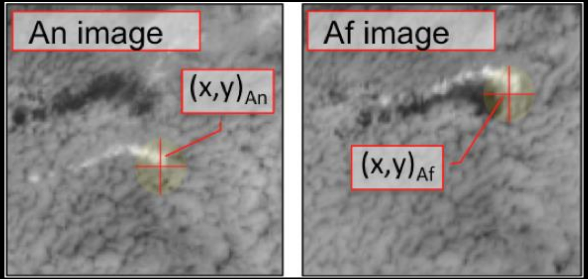
MISR cloud motion vector product (CMVP)



Feature height and motion is retrieved using triplets of MISR cameras

Gobi desert
March 30, 2007

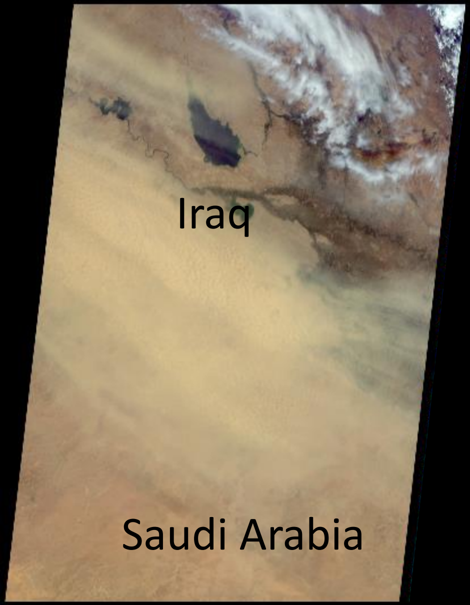
Dust plumes move fast near source.



Geometric retrieval of feature height based on automatic pattern matching in MISR imagery

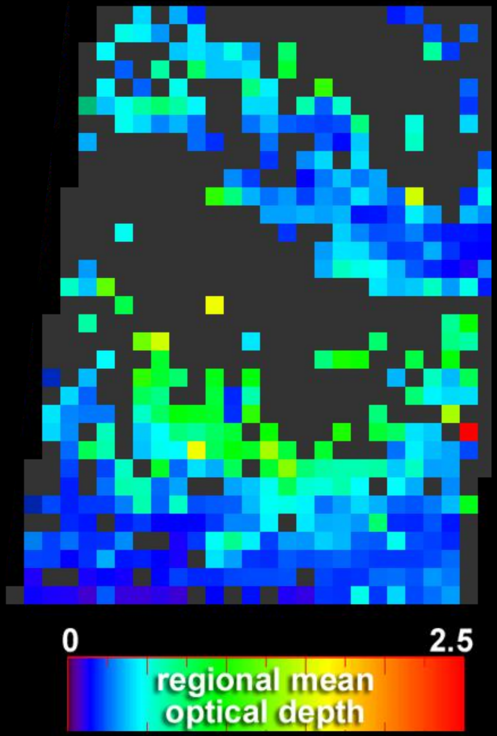
From MISR
May 13, 2004

Natural-color image



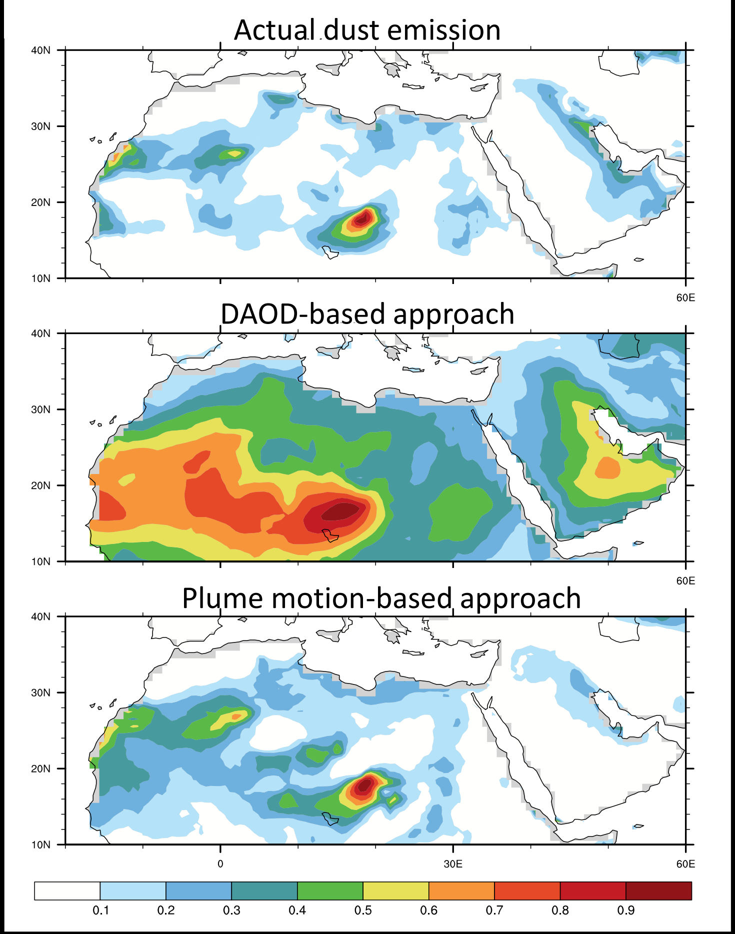
70° forward

AOD



Using MISR CMVP, a "dust activation event" is identified over the study region when the dust plume moves faster than 10 m s^{-1} and the plume top height is within 2 km of the ground.

A conceptual test of dust source identification approaches



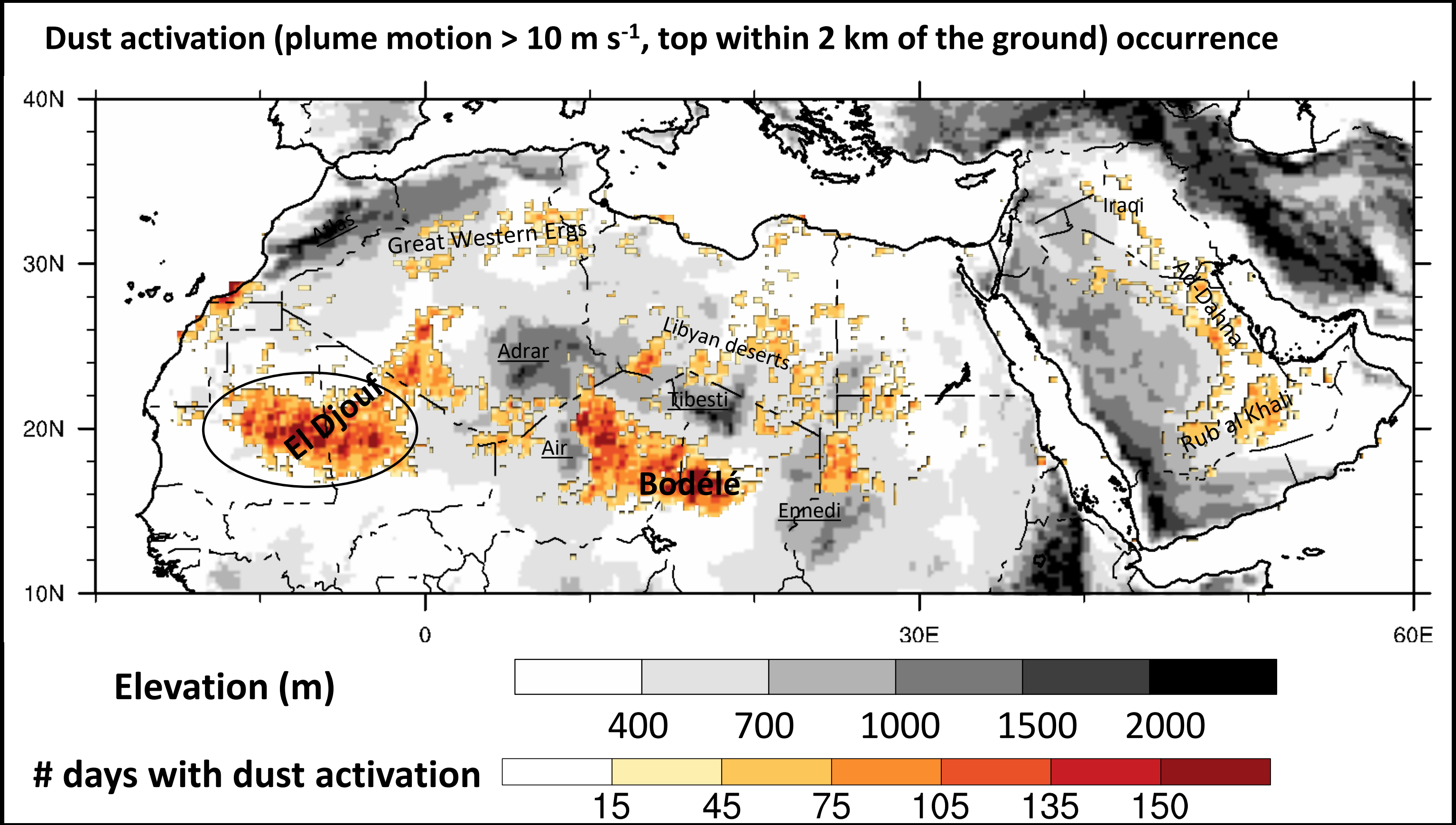
Frequency of high DAOD

Occurrence of fast moving, near surface dust plumes

Scientific questions

- Where does dust activation occur most frequently across North Africa and the Middle East, according to the novel motion-based dust source identification?
- What climatic features are responsible for the seasonal distribution of dust activation and dust concentration?

Dust source regions identified from MISR CMVP

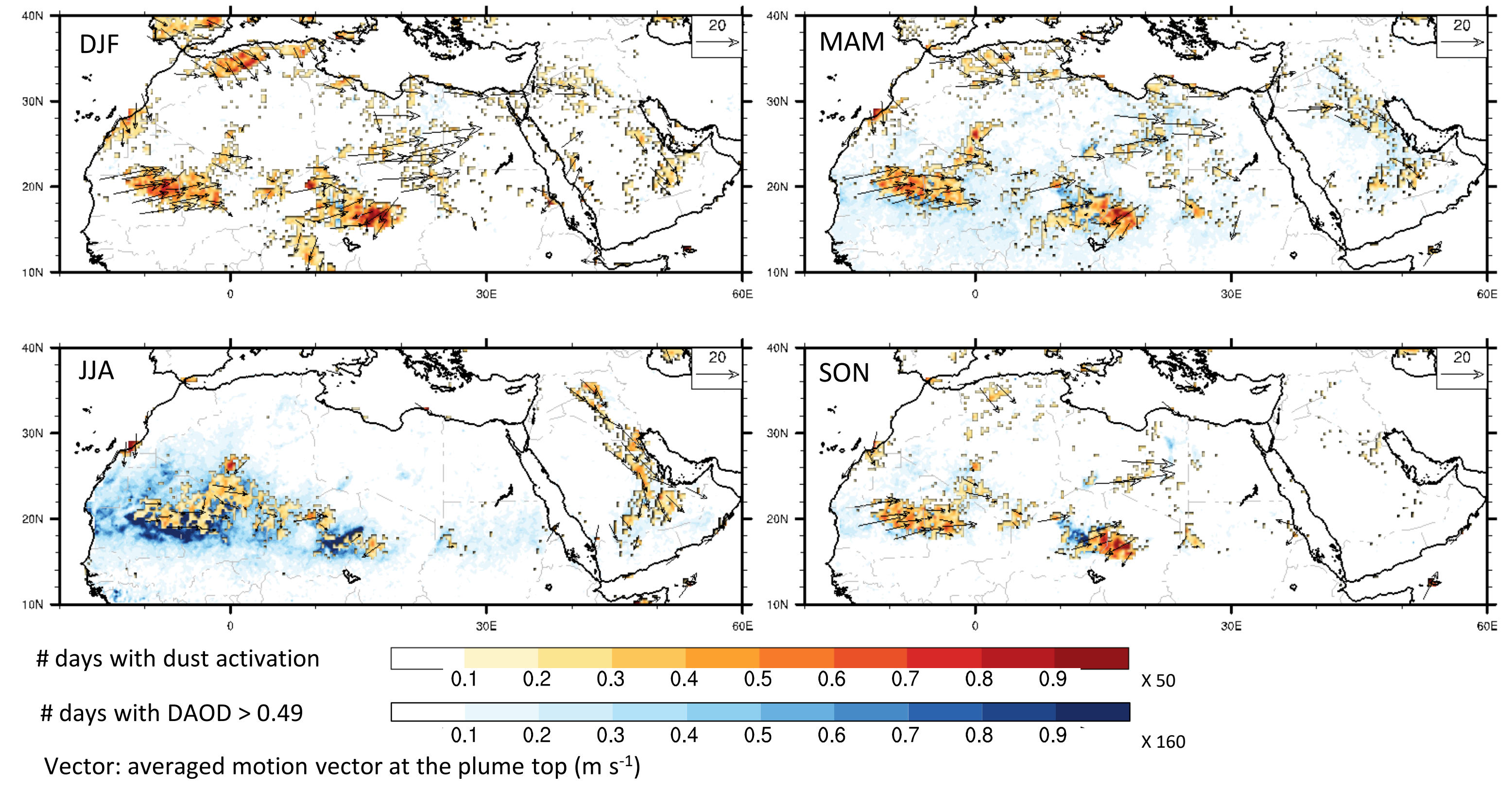


Inconsistency: West African deserts

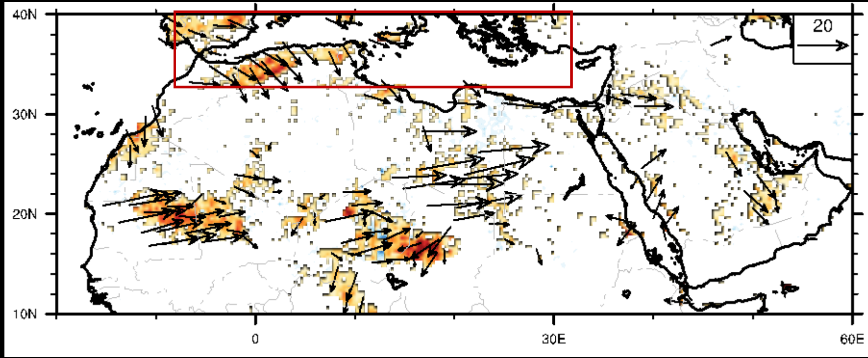
- The West African deserts are active dust sources according to MISR CMVP but not according to AOD-based approach.
- West African dust storms are often caused by deep convection and characterized by optically thick dust walls known as haboobs, which cannot be retrieved using typical aerosol-loading approaches.

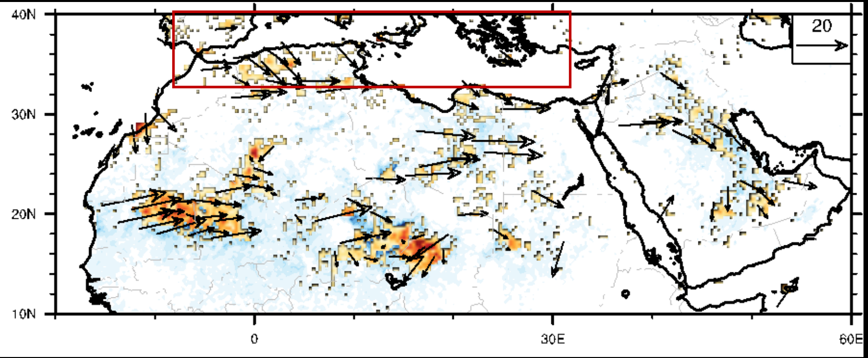
Photo of “haboob”

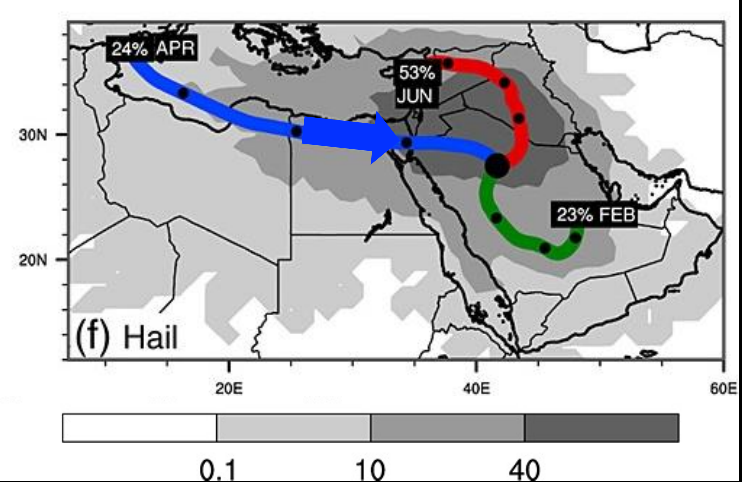
Seasonal dust source and transport



Winter and spring: Sharav Cyclone

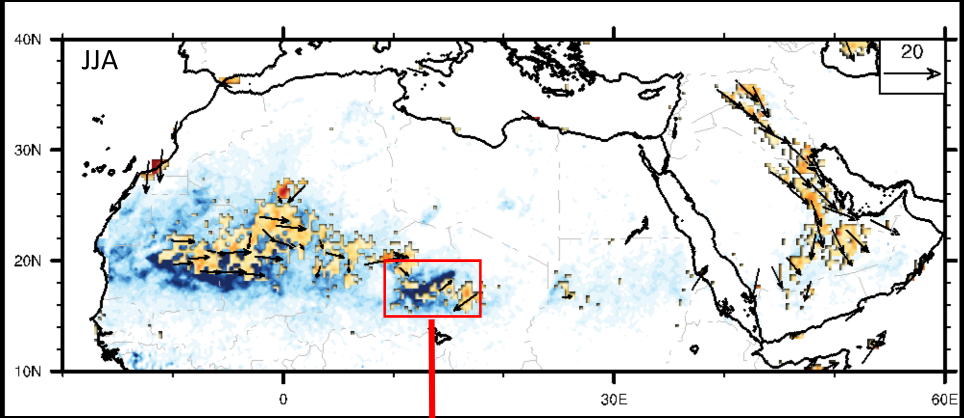


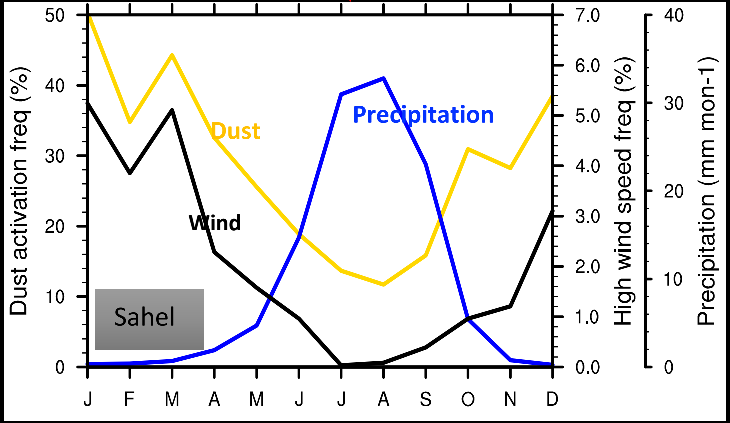




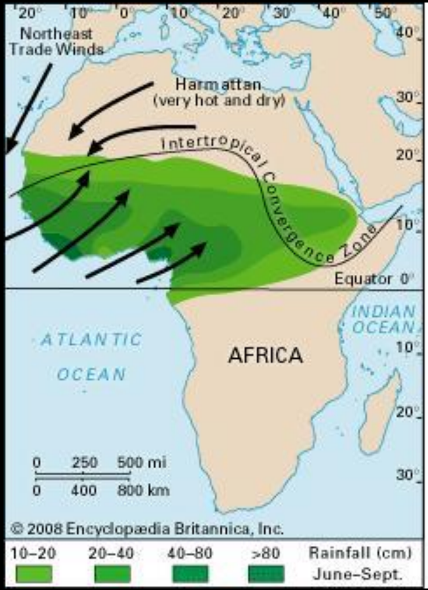
Sharav Cyclones contribute ~20% of dust activity in the Middle East, according to trajectory analysis (Notaro et al. 2013).

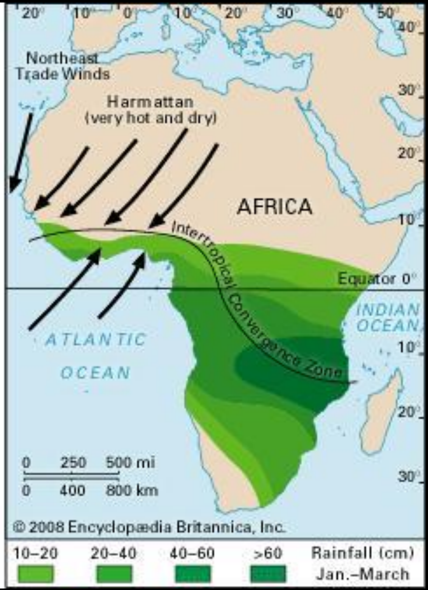
Summer: Inhibited dust activation in West Africa and Sahel



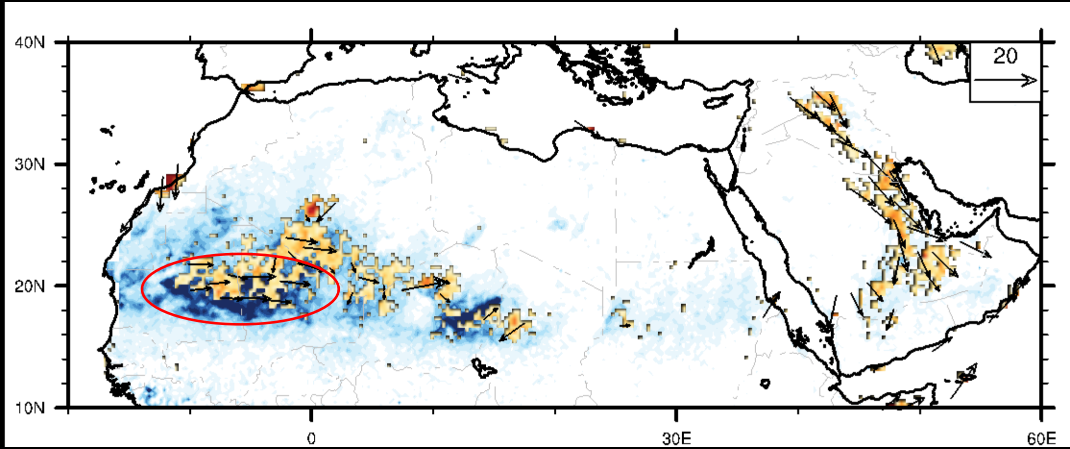


ITCZ controls seasonal precipitation

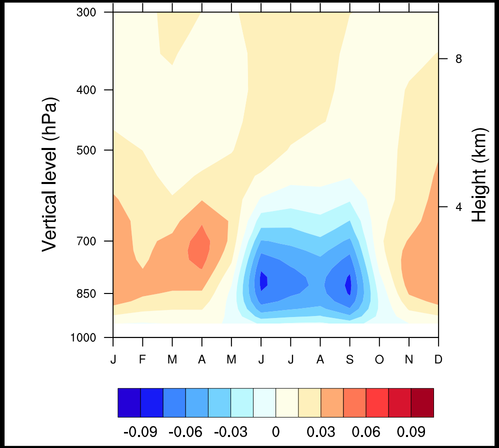




Summer: Low dust activation but high DAOD in West Africa

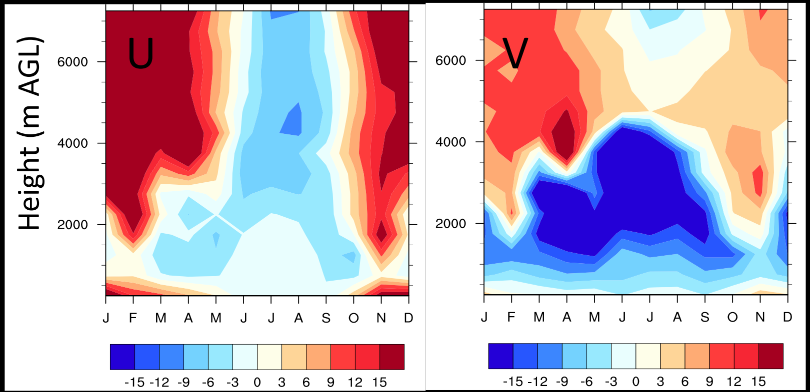


Climatology in vertical motion (Pa s^{-1}) averaged over West Africa (16˚N-22˚N, 12˚W-4˚E) during 2000-2016 from reanalysis shows enhanced ascending motion in summer.

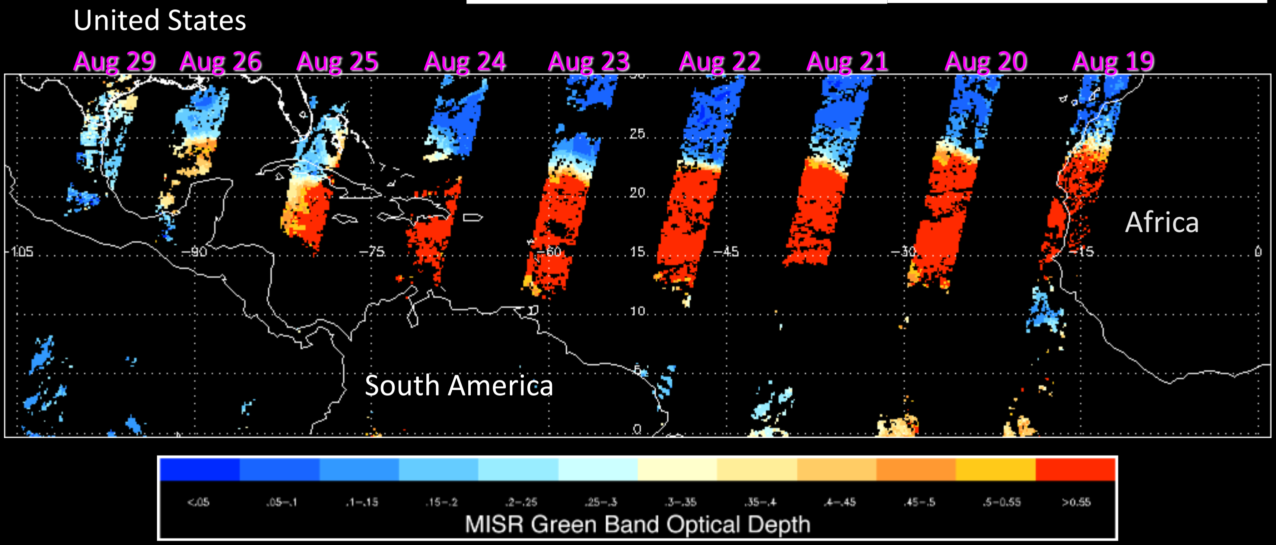


Summer: enhanced cross-Atlantic transport of African dust

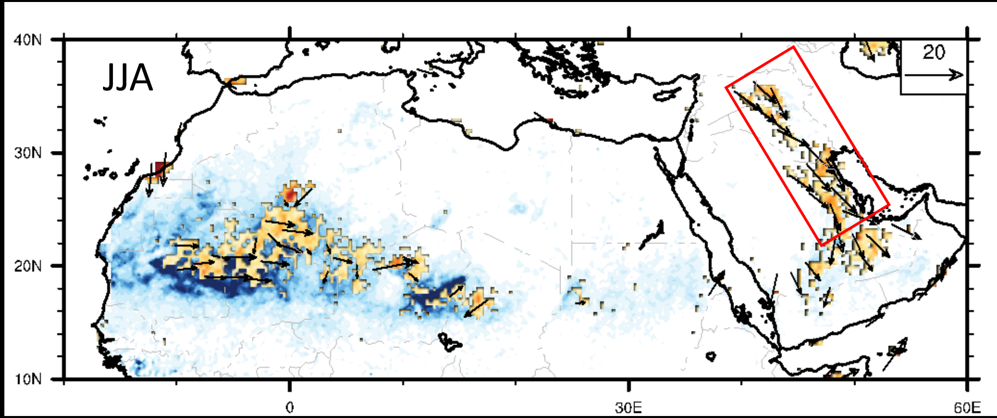
Climatology in U and V (m s^{-1}) over West Africa during 2000-2016 from MISR CMVP suggest higher potential for southwestward dust transport in summer.



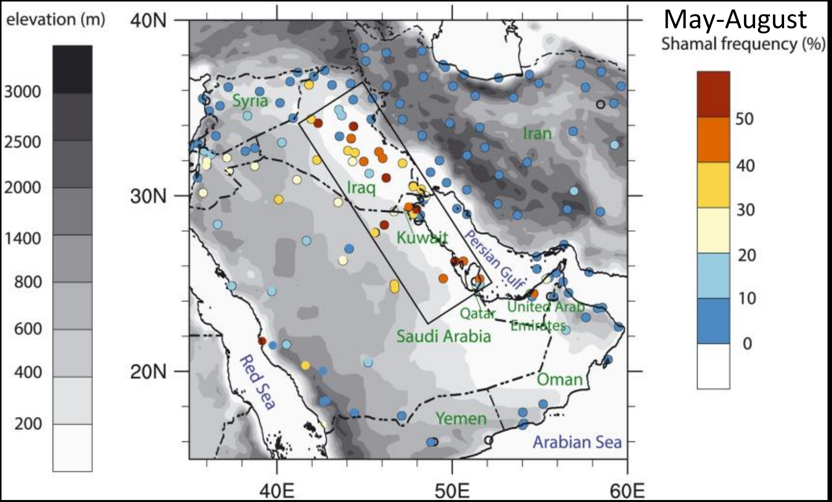
Dust from the Sahara Desert reaches Houston, TX summer 2006



Summer: Middle Eastern Shamal wind

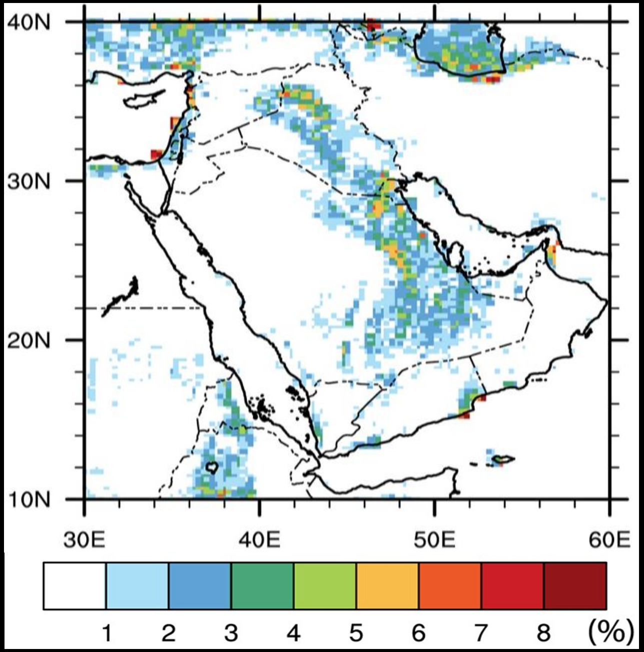


Shamal: strong, northwesterly wind near surface, persistent in summer (Yu et al. 2016).

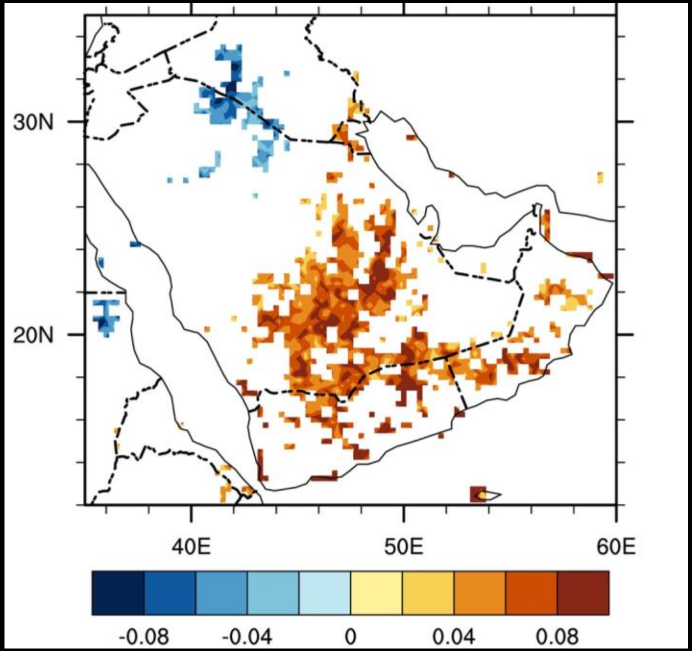


Summer: Middle Eastern Shamal wind

Frequency of near-surface, fast-moving dust plumes from MISR CMVP shows dust sources during Shamal



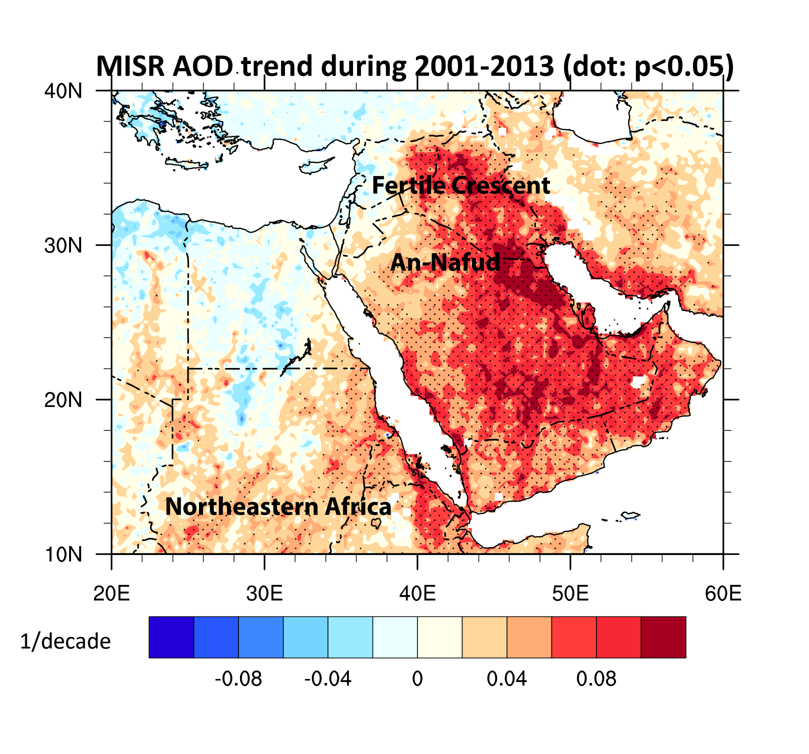
High MISR DAOD downwind



Yu, Y., M. Notaro, O. Kalashnikova, M. Garay (2016), Climatology of summer Shamal wind in the Middle East, ***Journal of Geophysical Research-Atmospheres***, 121(1), 289-305.

Using MISR aerosol and plume motion data together provides a unique opportunity for joint examination of the interannual variability in dust emission and concentration over the broader Middle East and North Africa.

Trends & interannual variability in Middle Eastern dust activities



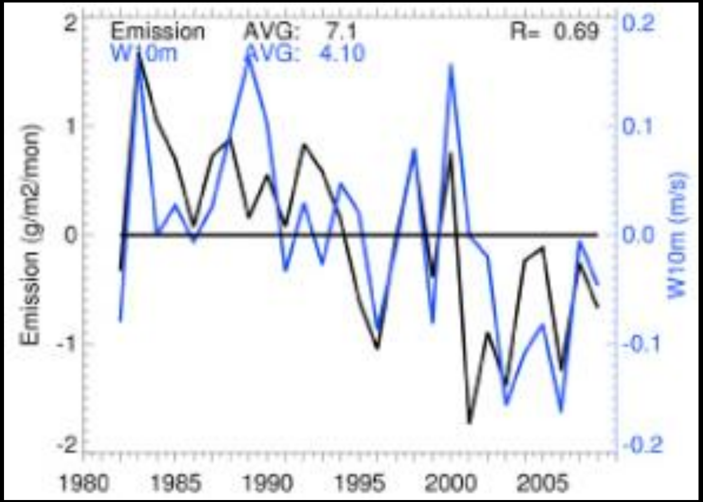
A substantial increase in AOD over the Middle East since the onset of the 21st century has been revealed from various observations (e.g. Yu et al. 2015) and reproduced by global aerosol models (Chin et al. 2014).

- **What is the source of the AOD increase over the Middle East?**
- **Is it really a trend or a segment of long-term variability?**

Yu, Y., M. Notaro, Z. Liu, F. Wang, F. Alkolibi, E. Fadda, F. Bakhrjy (2015), Climatic controls of the interannual to decadal variability in Saudi Arabian dust activity: Towards the development of a seasonal prediction model, ***Journal of Geophysical Research-Atmospheres,***120(5), 1739-1758.

Trends & interannual variability in Sahel dust activities

Kim et al (2017) found dust emission decreased across Sahel from 1982-2008, regulated by wind speed and modified by vegetation change.



Other studies revealed Sahel greening since 1980s (Dong & Sutton 2015; Evan et al. 2015), suggesting long-term trend of inhibited Sahel dust emission.

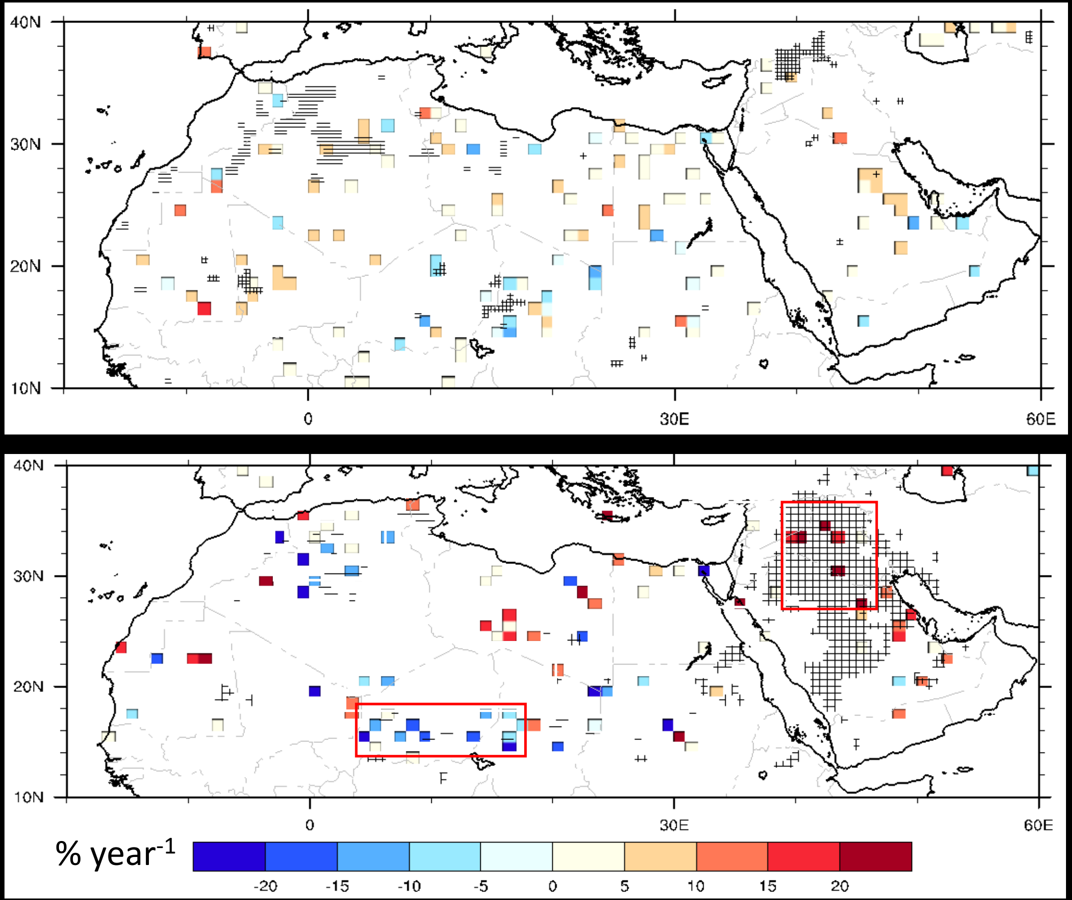
- **What is the observed trend, interannual variability, and environmental drivers of dust emission and concentration over Sahel?**

Dust activity: trend or interannual variability?

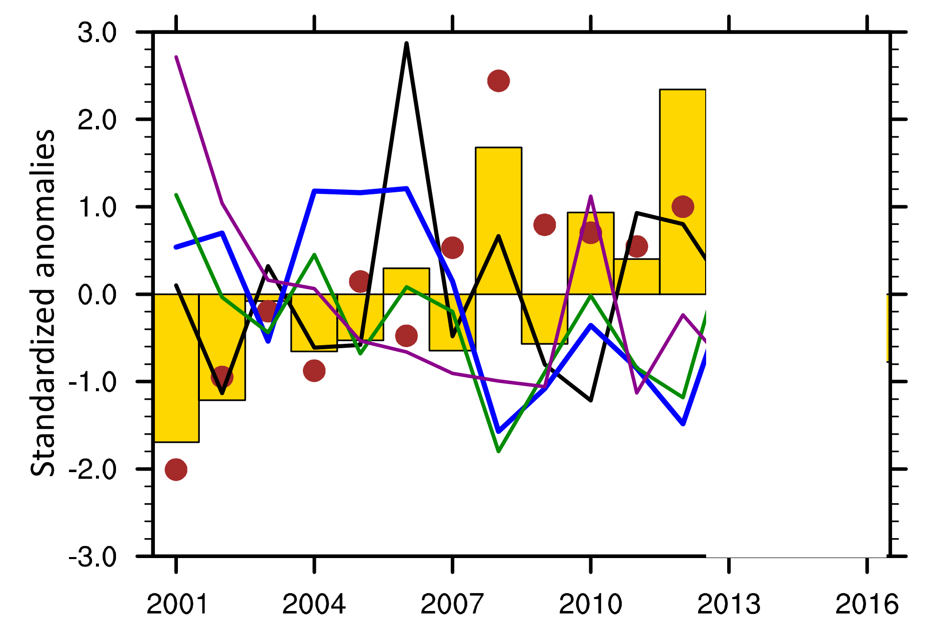
Overall trend in dust activation (color) + DAOD (+ : positive, - : negative) during 2001-2016

Maximum trend during 10-year sub-periods: 2001-2010, 2002-2011, etc

Only statistically significant trends are shown.



Middle Eastern dust activity and environmental drivers

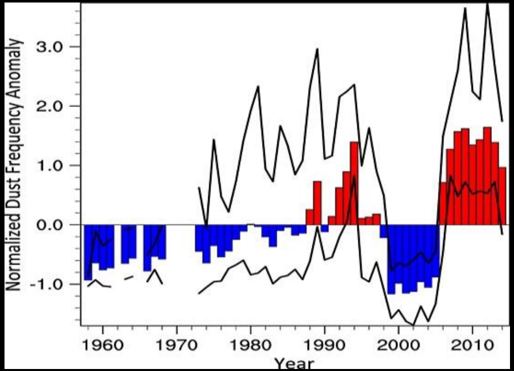


- No persistent trend
- Local source
- Moisture driven

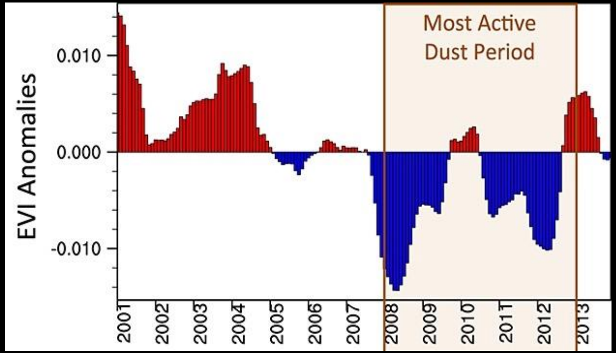
Rank Correlation (*:significant)		Frequency of High Wind Speed —	15-month Precipitation —	Amount of vegetation —
Dust activation	■	0.45	-0.60*	-0.52*
DAOD	●	0.26	-0.71*	-0.82*

Regime shift in Arabian dust activity

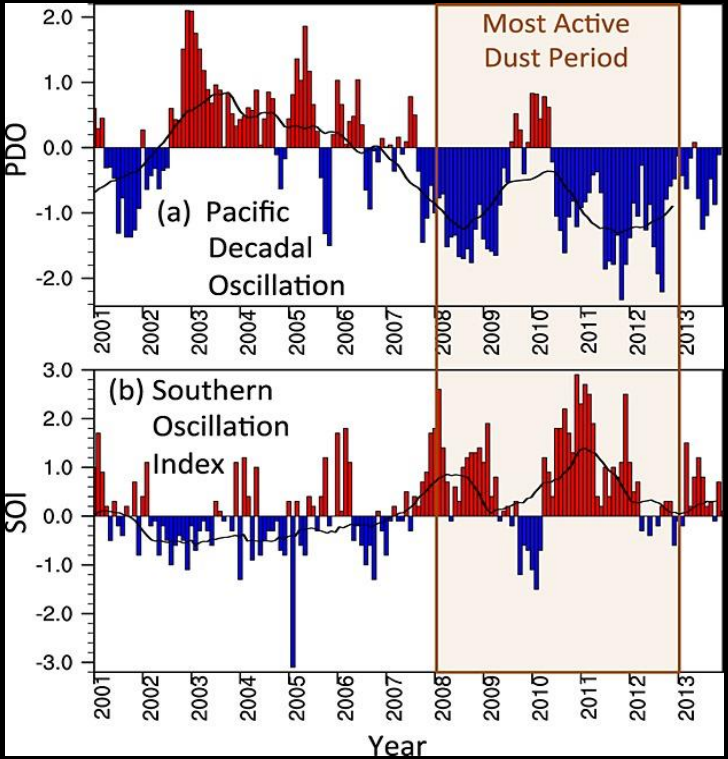
Dust frequency averaged across 31 stations in Arabian Peninsula



Amount of vegetation is mostly responsible for active dust during 2008-2013

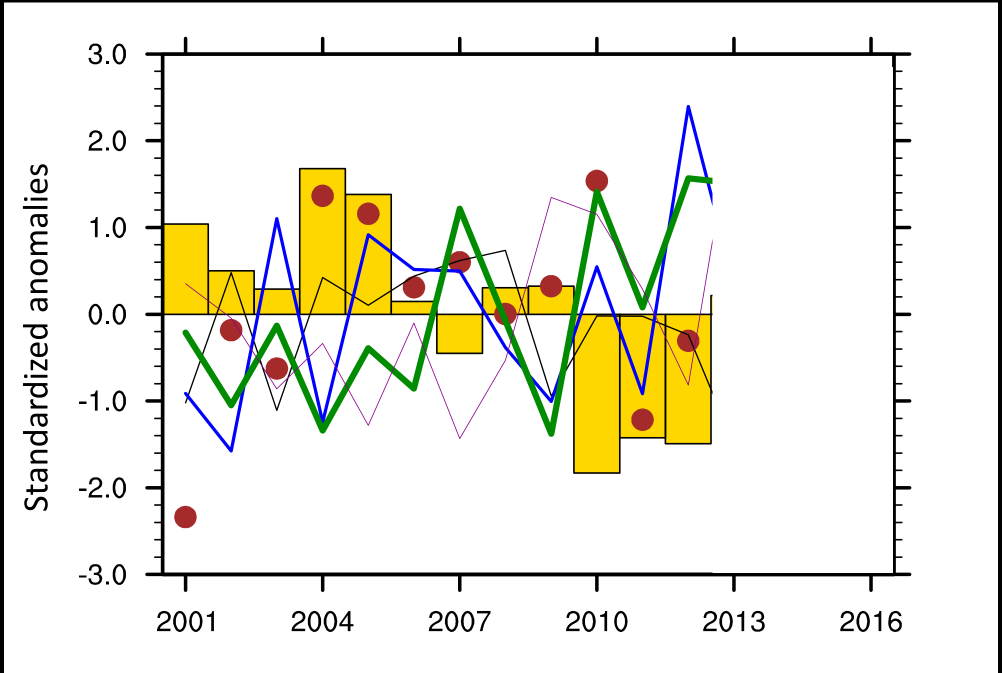


Influence from Pacific Ocean



Notaro, M., Y. Yu, O. Kalashnikova (2015), Regime shift in Arabian dust activity, triggered by persistent Fertile Crescent drought, ***Journal of Geophysical Research-Atmospheres,***120(19),10229-10249.

Sahel dust activity and environmental drivers

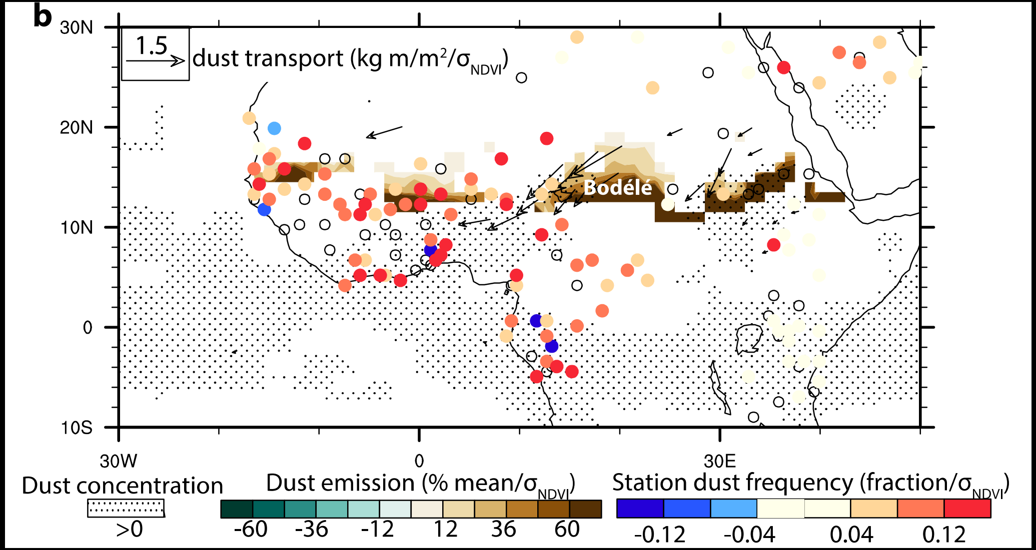


- No persistent trend
- Moisture driven

Rank Correlation (*:significant)	Frequency of High Wind Speed —	15-month Precipitation —	Amount of vegetation —
Dust activation	0.18	-0.48*	-0.75*
DAOD	0.54	0.15	-0.32

Observed vegetation feedback on dust aerosols

Observed responses in dust emission, concentration, transport, and station dust frequency to reduced Sahel greenness in September-November during 1982-2011



- Diminished vegetation and accompanying dry soils lead to enhanced dust emissions and dust concentrations across Sahel during the mid- to post-monsoon season.
- Enhanced dust transport to tropical Atlantic Ocean may inhibit hurricane development.

Yu, Y., M. Notaro, F. Wang, J. Mao, X. Shi, and Y. Wei (2017), Observed positive vegetation-rainfall feedbacks in the Sahel dominated by a moisture recycling mechanism. ***Nature Communications***, 8 (1), 1873.

Summary

- MISR CMVP identifies dust source regions in topographical depressions in North Africa and the Middle East. The West African deserts generate substantial dust activities, but are underestimated by the AOD-based identifications.
- Seasonal distribution of dust activation is primarily driven by the climatology in wind and precipitation.
- According to the joint analysis of MISR CMVP and MISR DAOD, dust emissions and concentrations substantially increased over the Middle East and decreased over Central Sahel during 2001-2012 but partly recovered toward their climatological means afterwards.

Yu, Y., O.V. Kalashnikova, M.J. Garay, H. Lee, and M. Notaro (2018), Identification and characterization of dust source regions across North Africa and the Middle East using MISR satellite observations, in revision (Geophysical Research Letters).