Dust Variability

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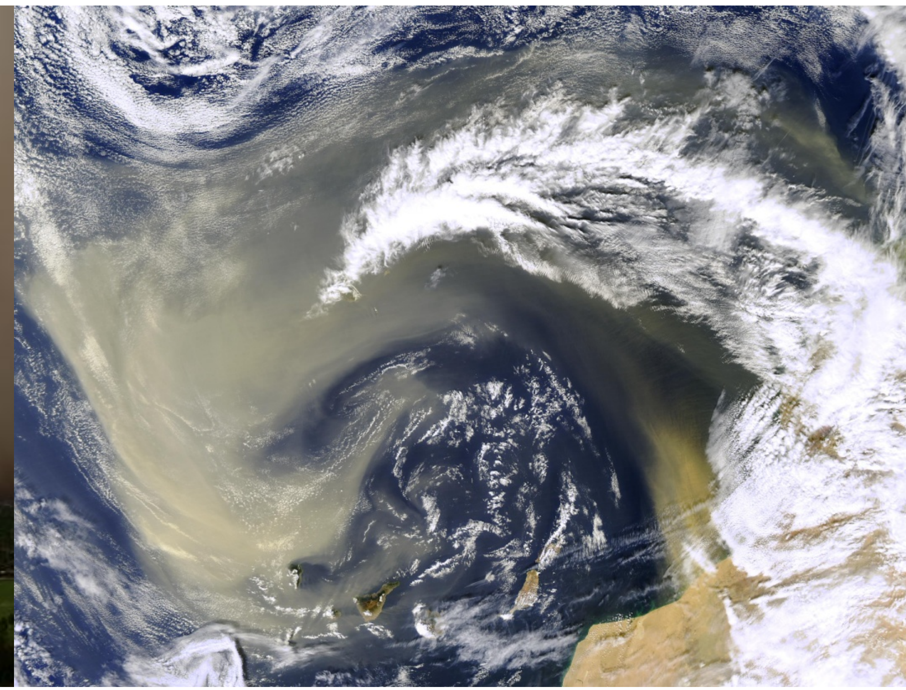

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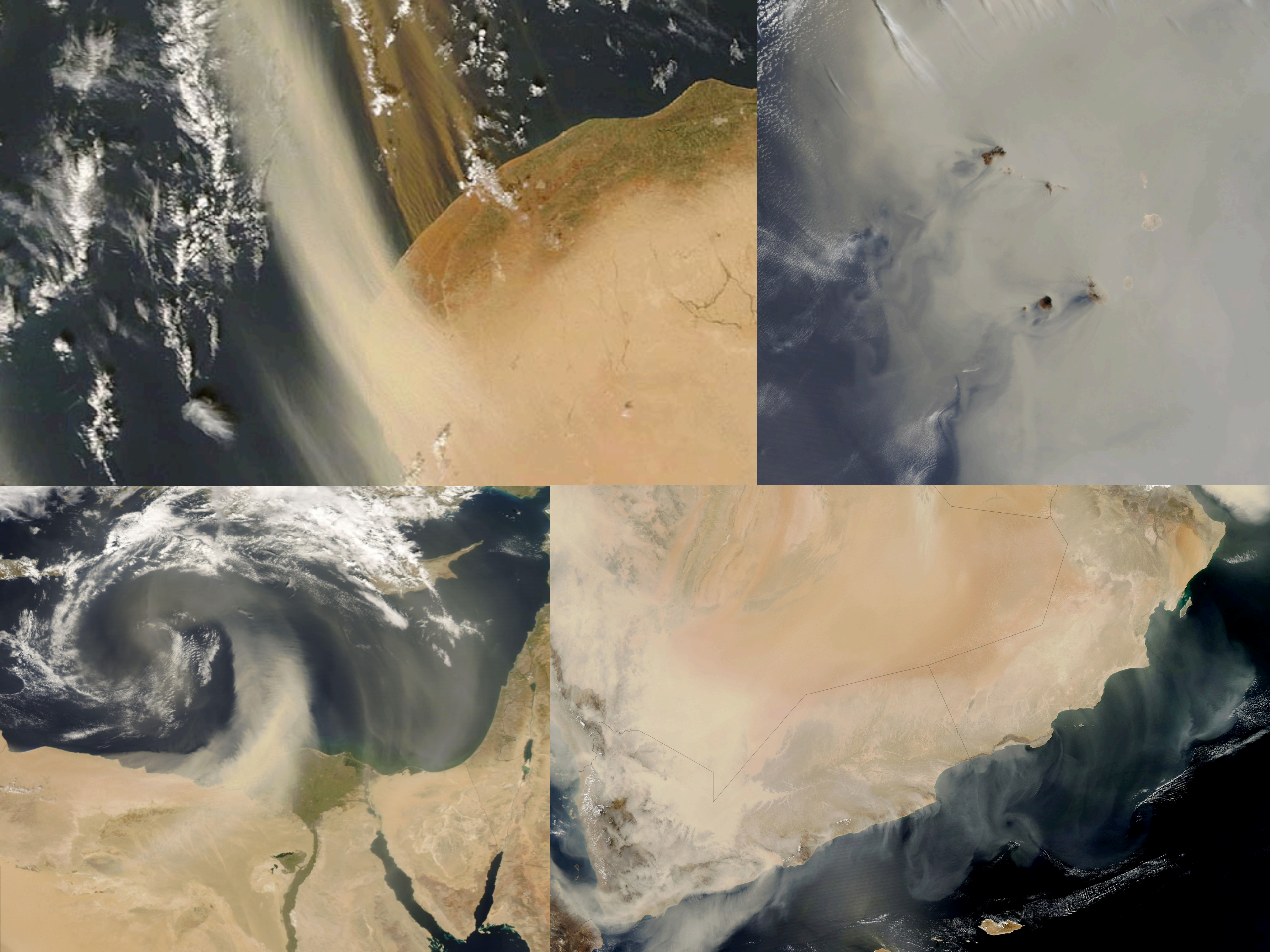
TROPOS
Leibniz Institute for
Tropospheric Research

Australia, 23 Sept 2009

Niger, 2006

Texas, 1935

Phoenix, AZ, 2011



Variability of Dust

- Temporal variability
  - Sub-daily and daily
  - Seasonal
  - Year-to-year
  - (Glacial – interglacial changes)

- Spatial variability
  - Changes in local dust source activity
  - Sediment supply and/or wind regime

Temporal Variability: Scales

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- Daily time scale
  - Controlled by synoptic-scale and meso-scale meteorology
  - Relevant for regional forecast
- Seasonal time scale
  - Controlled by meteorology, i.e. dominant wind regimes (e.g. Shamal)
  - Controlled by surface characteristics like vegetation, agriculture
- Interannual and decadal time scale
  - Controlled by climate regime and surface modifications
- Glacial-Interglacial time scale
  - Controlled by climate and source areas

Temporal Variability: Short-term

- Hourly and daily variability in dust atmospheric concentration
  - sub-daily variability in dust emission fluxes
  - transport of dust
- Important for forecasts
- Observations:
  - SYNOP and METAR: report of horizontal visibility, current weather (WX)
  - AERONET sun-photometer network: Aerosol Optical Thickness (AOT)
  - MSG IR dust product (15-minute)

Sun-Photometer AOT

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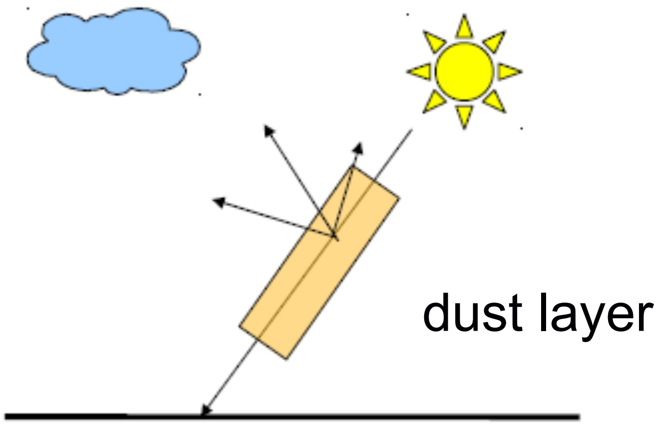
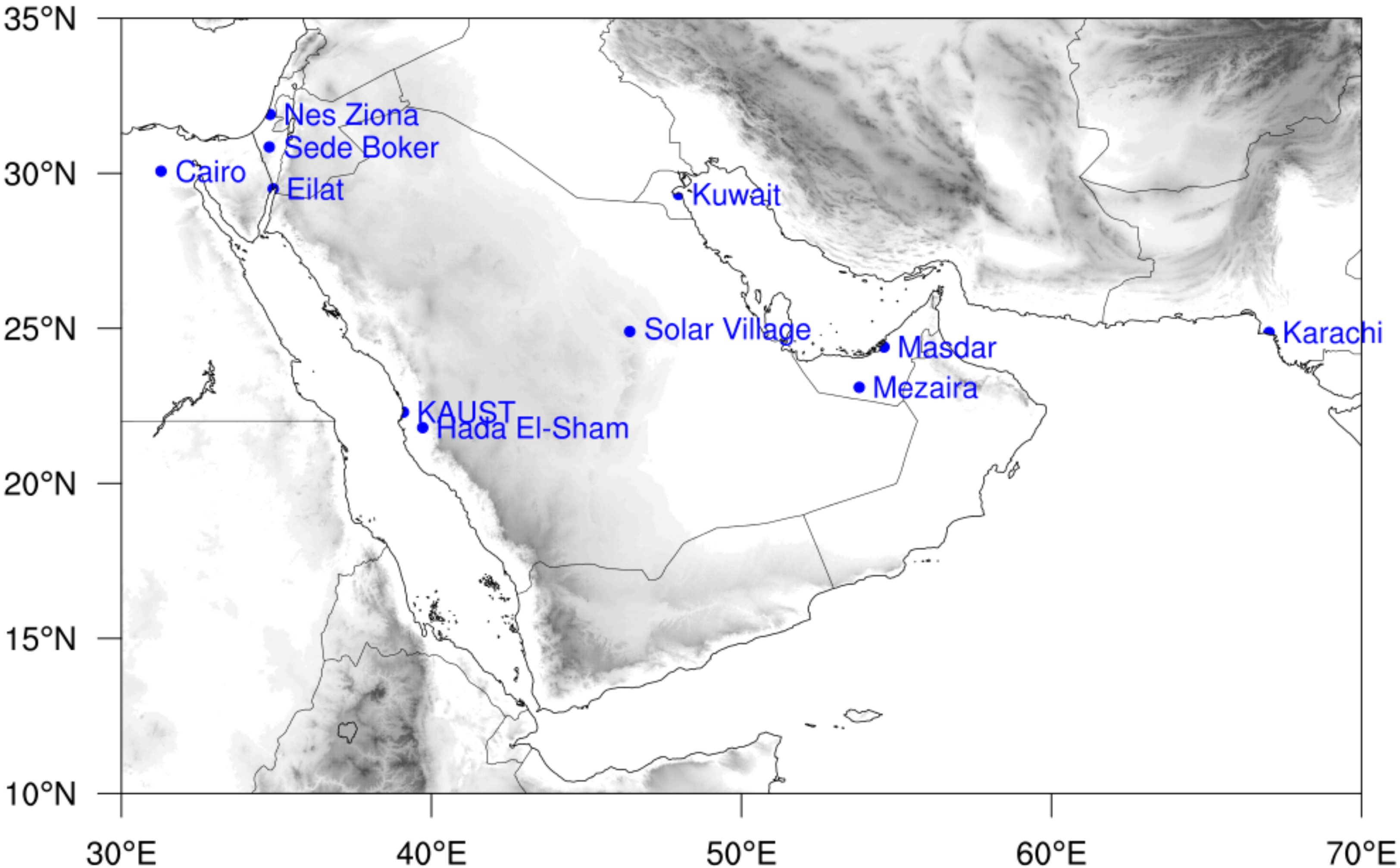
- AOT is a measure for the transmissivity of the atmosphere
- Ratio of radiation measured at surface and radiation at top of atmosphere
- AOT represents the atmospheric aerosol content – large values mean high aerosol loading



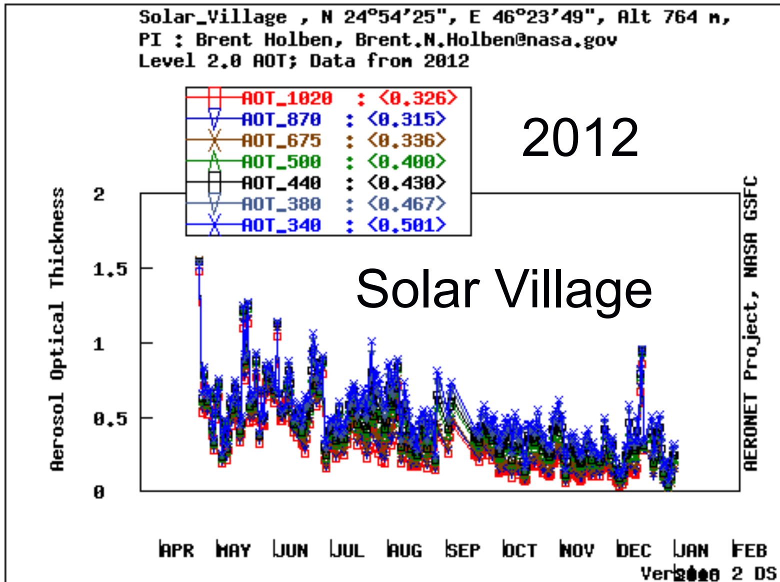
Cimel at Zouerat, 2011

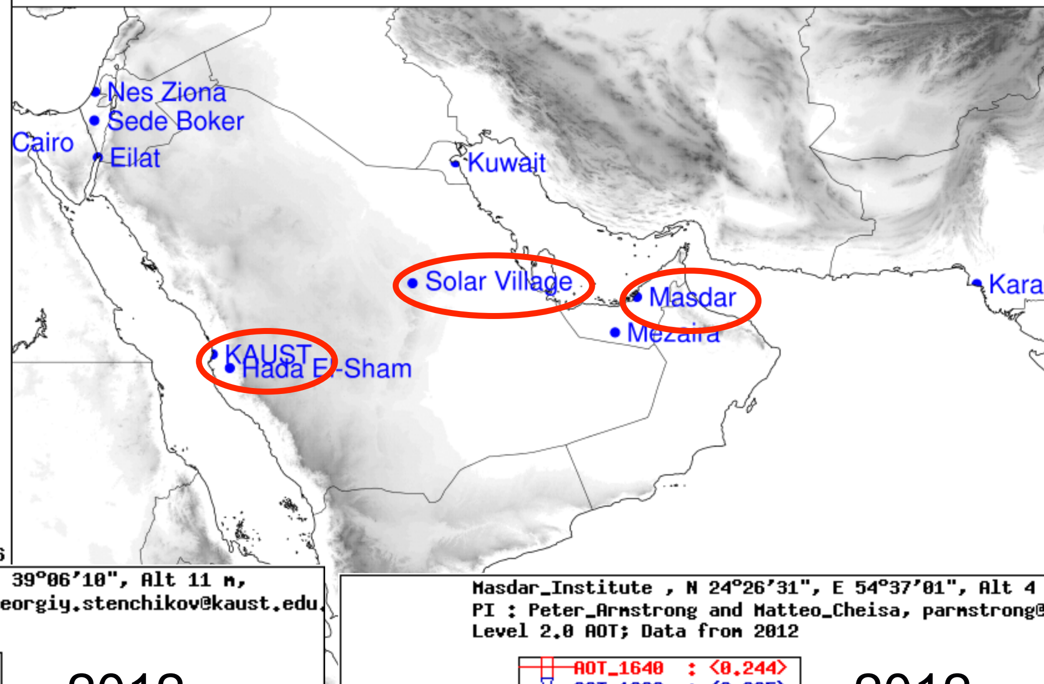
Sun-Photometer Measurements

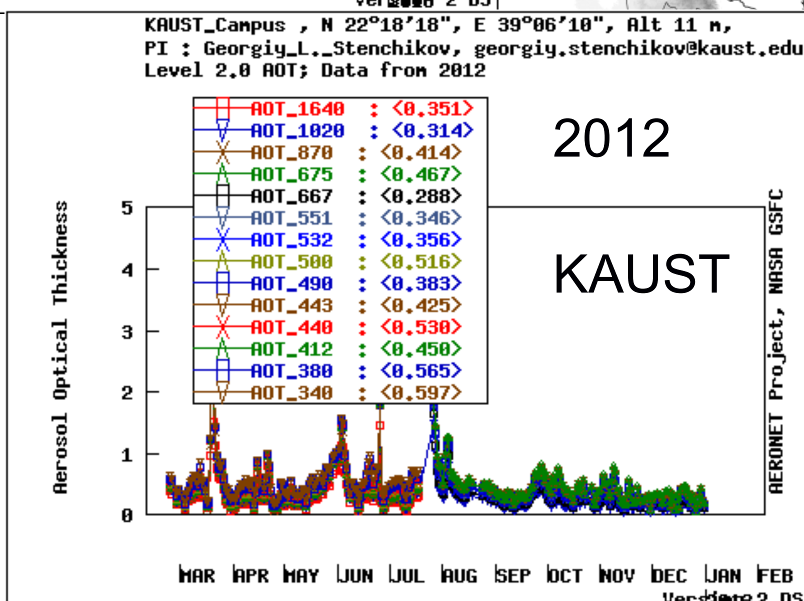


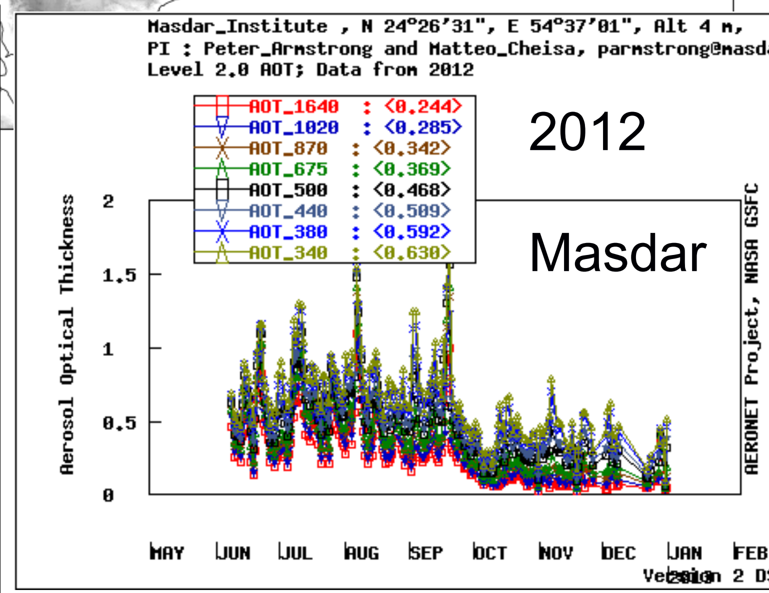
selected AERONET stations that have been reporting in 2012, http://aeronet.gsfc.nasa.gov

Sun-Photometer Measurements



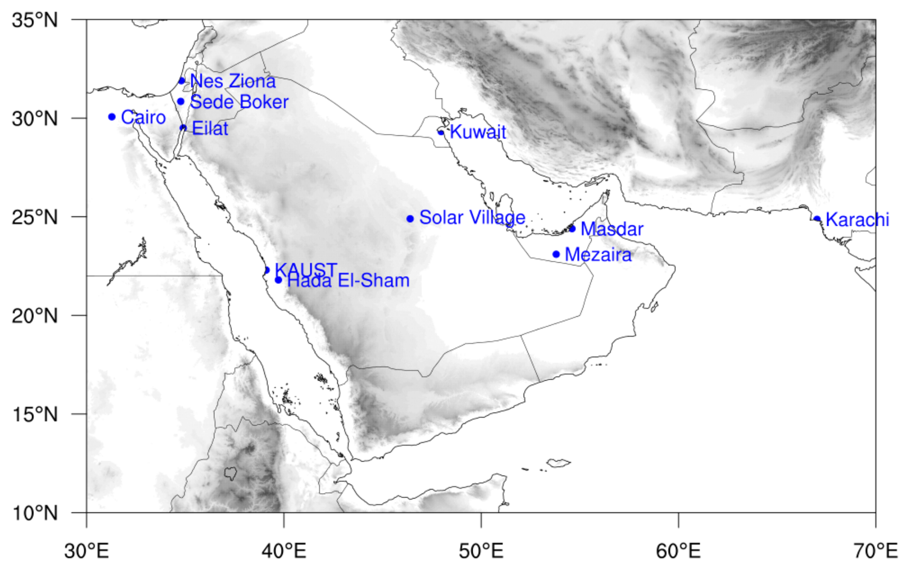






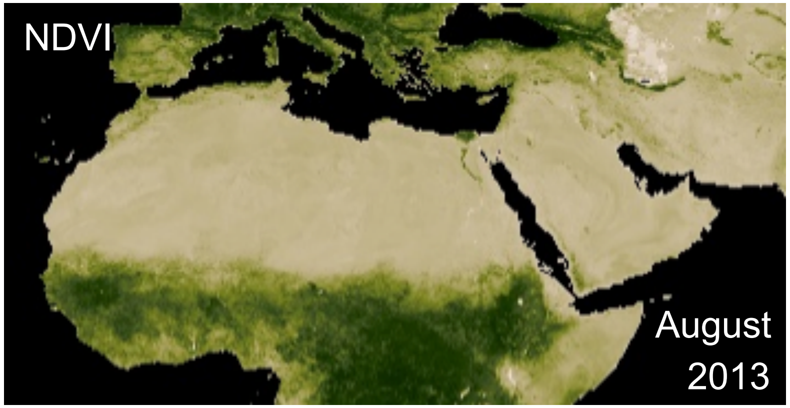
Sun-Photometer Measurements

- AERONET provides quantitative information on atmospheric dust load
- Sub-daily temporal resolution revealing temporal changes in atmospheric dust loading, e.g. approaching dust front
- Transported dust
- Due to wind transport, information on dust source variability is limited



Precondition for Dust Emission

1. Suitable surface conditions
   - Sparse vegetation cover
   - Low soil moisture
   - Smooth surfaces
   - Fine, loose soil particles (e.g. dry river beds, lake sediments, fields)



2. Strong surface winds
   - Frontal systems
   - Down-drafts from meso-scale convective systems (MCS), Haboobs
   - Boundary layer turbulence

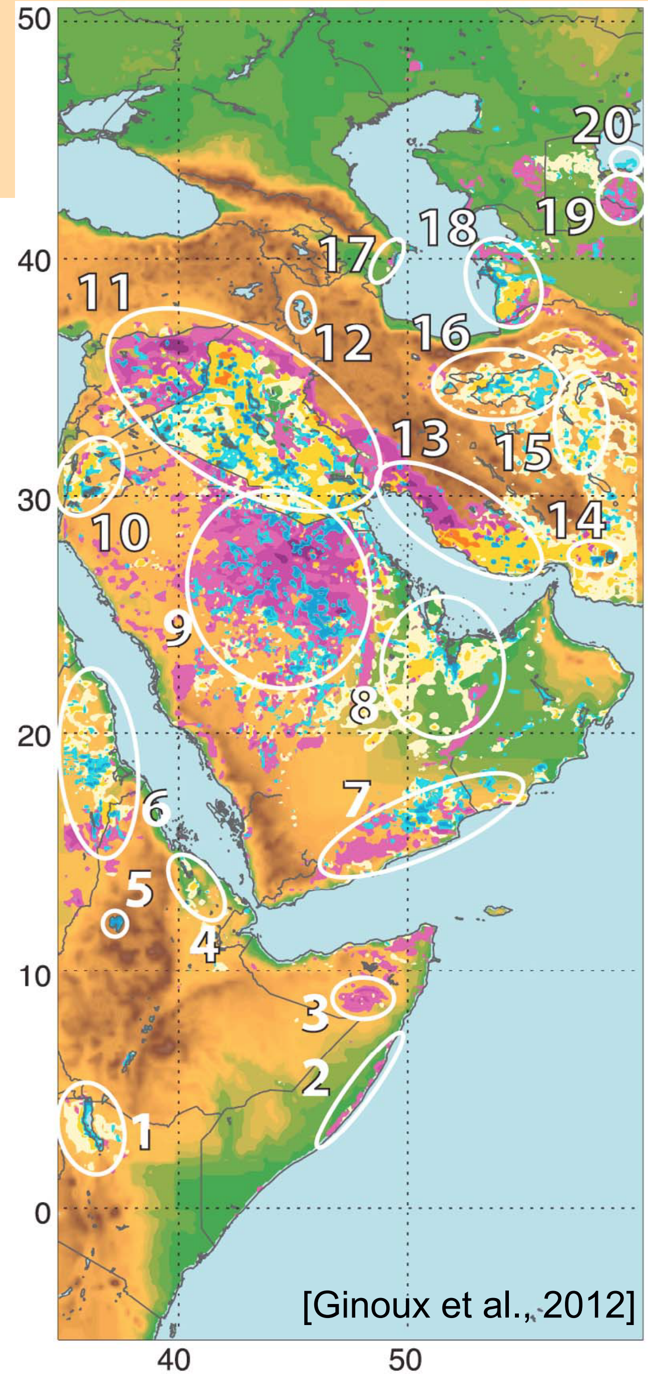
Dust Storm Triggering Winds

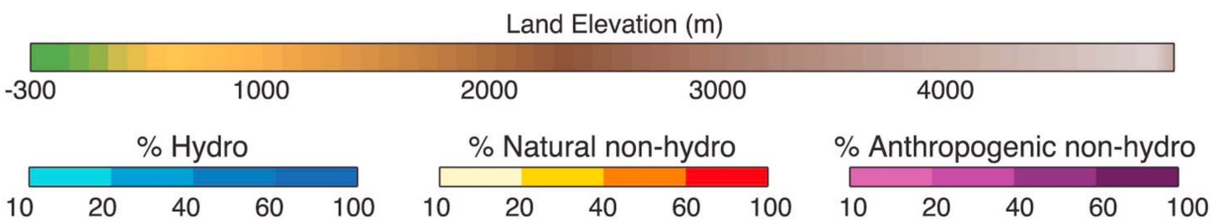
TROPOS

- Cool season: dynamical uplifting through cold fronts and associated mid-latitude troughs
- Frontal passage is most frequent trigger for dust fronts due to strong winds associated with intense baroclinicity
- Warm season: diurnal vertical mixing related to solar heating
- Monsoon region: uplift along convergence zone and embedded convective systems
- Areas of complex terrain: katabatic winds, LLJs forming along mountain ridges
- Shamal winds, i.e. omnipresent summer Shamal

Dust Variability: Dust Source Types

- Dust sources can be distinguished into different source types
  - Natural, non-hydro: e.g. sand sheets
  - Hydro: e.g. alluvial deposits
  - Anthropogenic, non-hydro: agriculture
- Each source type shows characteristic soil types and variability in erosivity, e.g. vegetation cover changing with land use





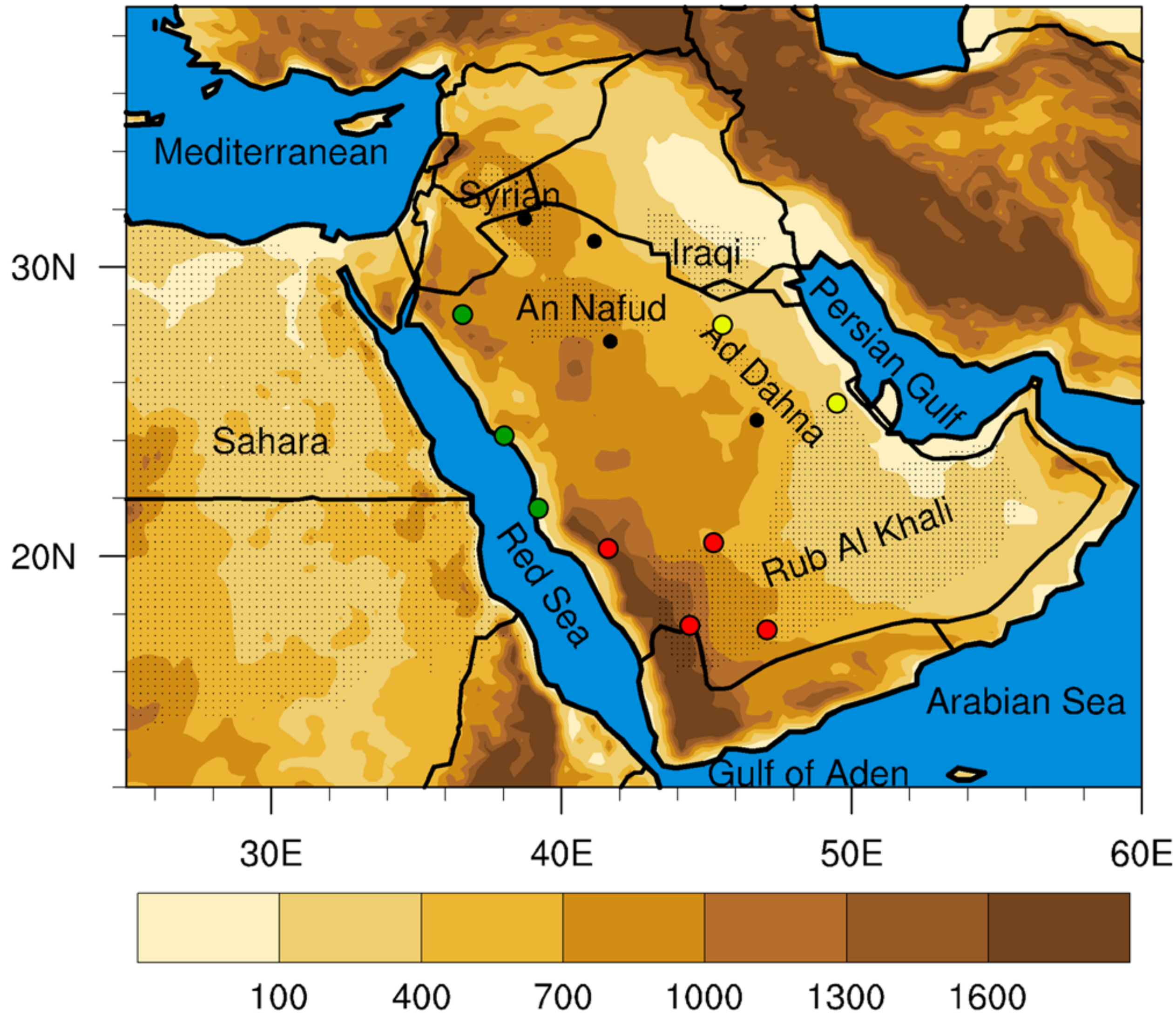
Arabian Deserts

- 3 primary desert regions
- Depending on location, dust from different sources is arriving:

🔴 Rub Al Khali

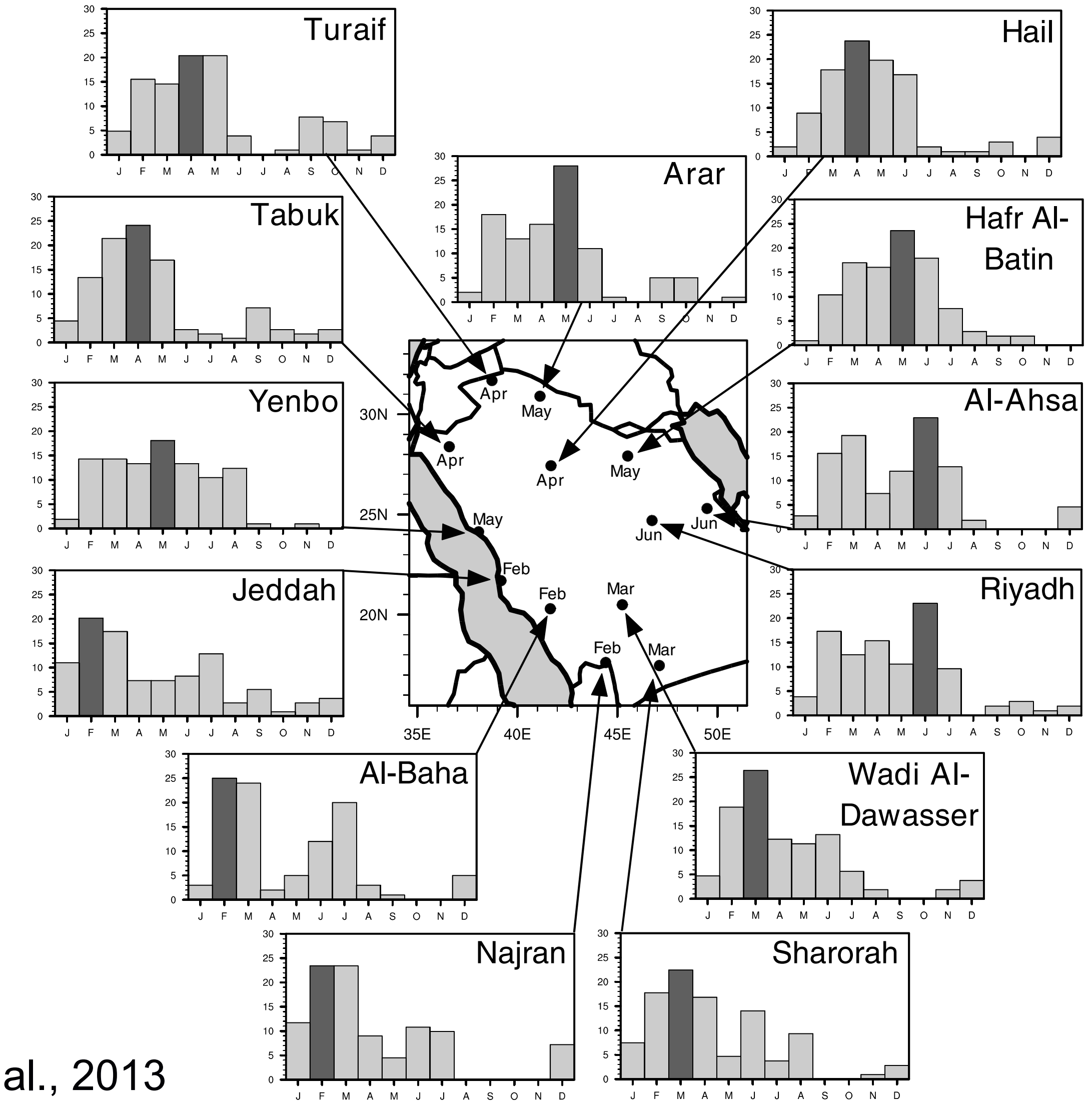
🟢 Sahara

🟡 Iraqi Desert



Seasonal Variability

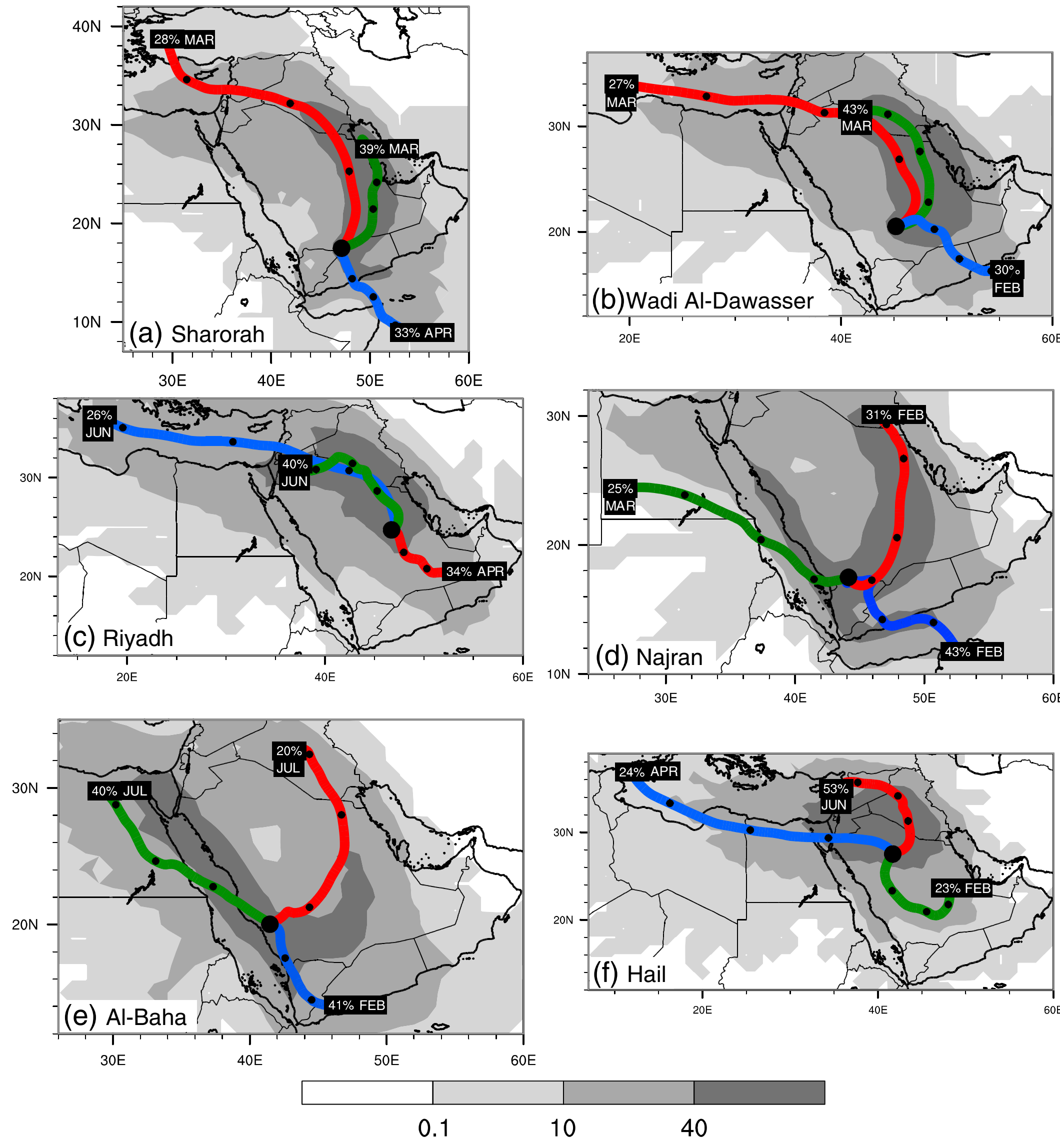
- Clear seasonal cycle in dust storm frequency
- Bi-modal distribution due to changing transport regime
- Seasonal changes due to:
  - Source areas
  - Uplifting wind systems
  - Transporting wind regime



Notaro et al., 2013

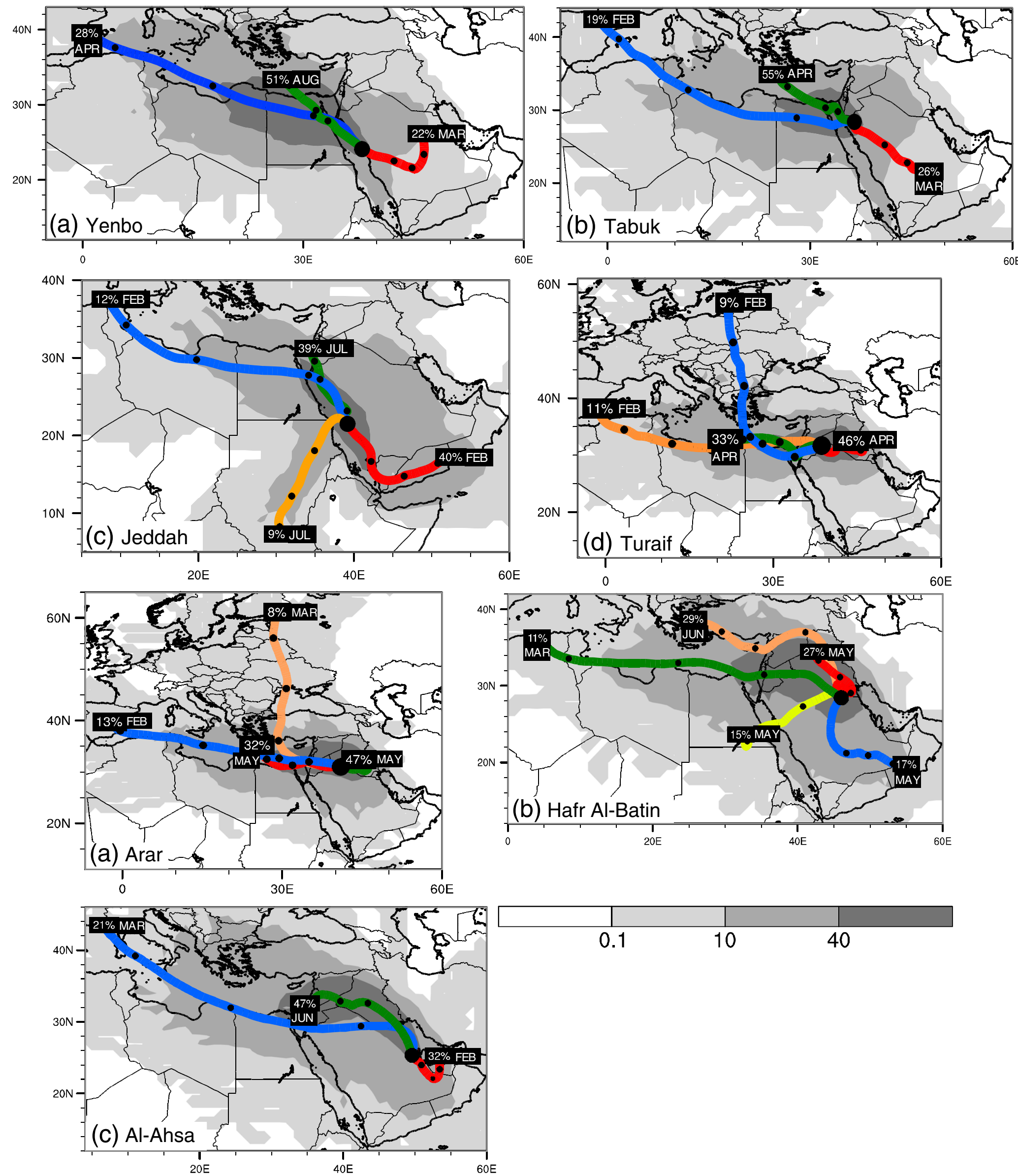
Dust Transport from local Sources

- Main trajectory clusters highlighted by different colours
- Local sources within Saudi Arabia
- Northwestern trajectories associated with summer Shamal



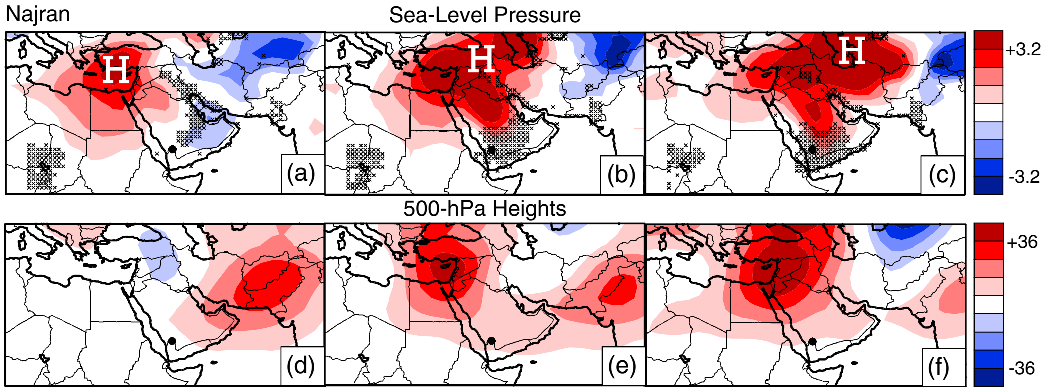
Dust Transport from remote Sources

- Stations primary receiving dust from sources outside Saudi Arabia
- Mainly from Saharan Desert (top) and Syrian/Iraqi Desert (bottom)
- Saharan Desert contributes most to dust arriving at stations in W to NW Saudi Arabia



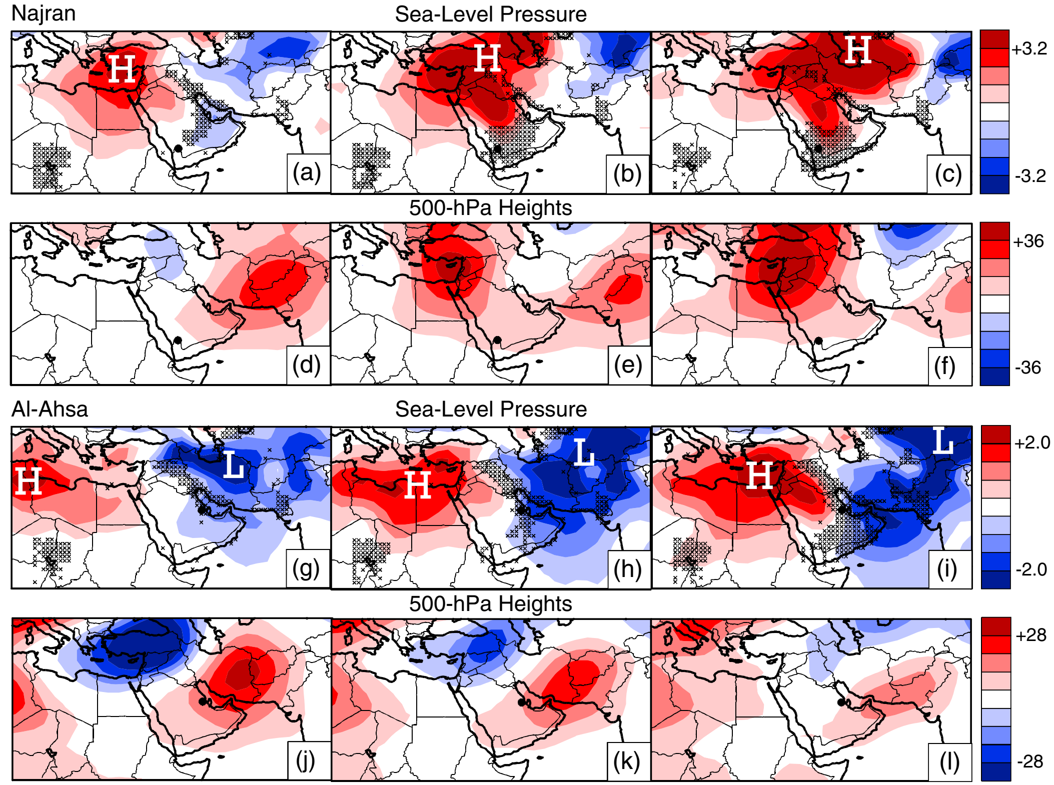
Dust Transport Regimes

- Winds resulting into dust uplift associated with eastward propagating ridge over Mediterranean Sea



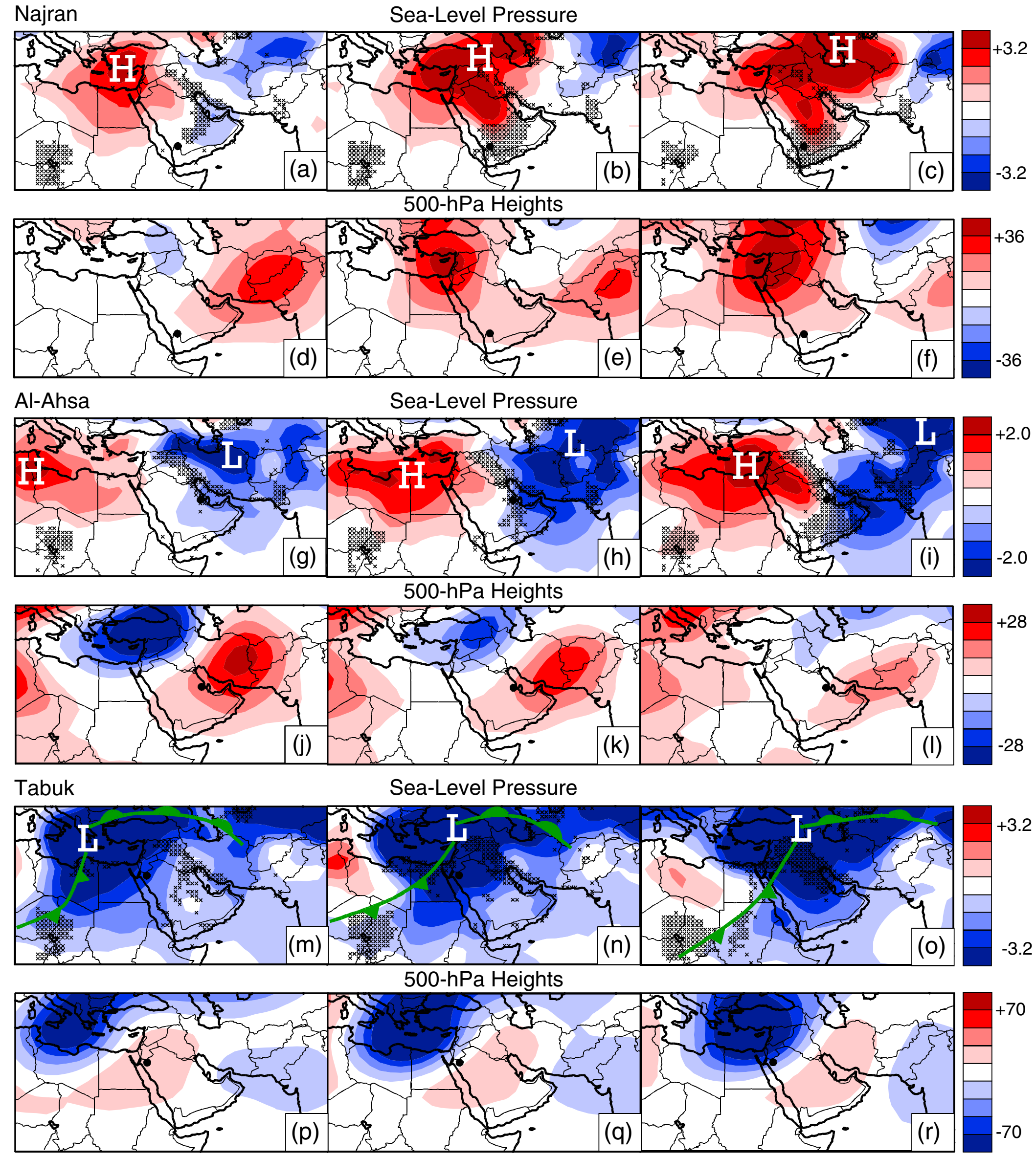
Dust Transport Regimes

- Winds resulting into dust uplift associated with eastward propagating H over Mediterranean Sea
- Wind system associated with pressure gradient between North African H and Caspian L



Dust Transport Regimes

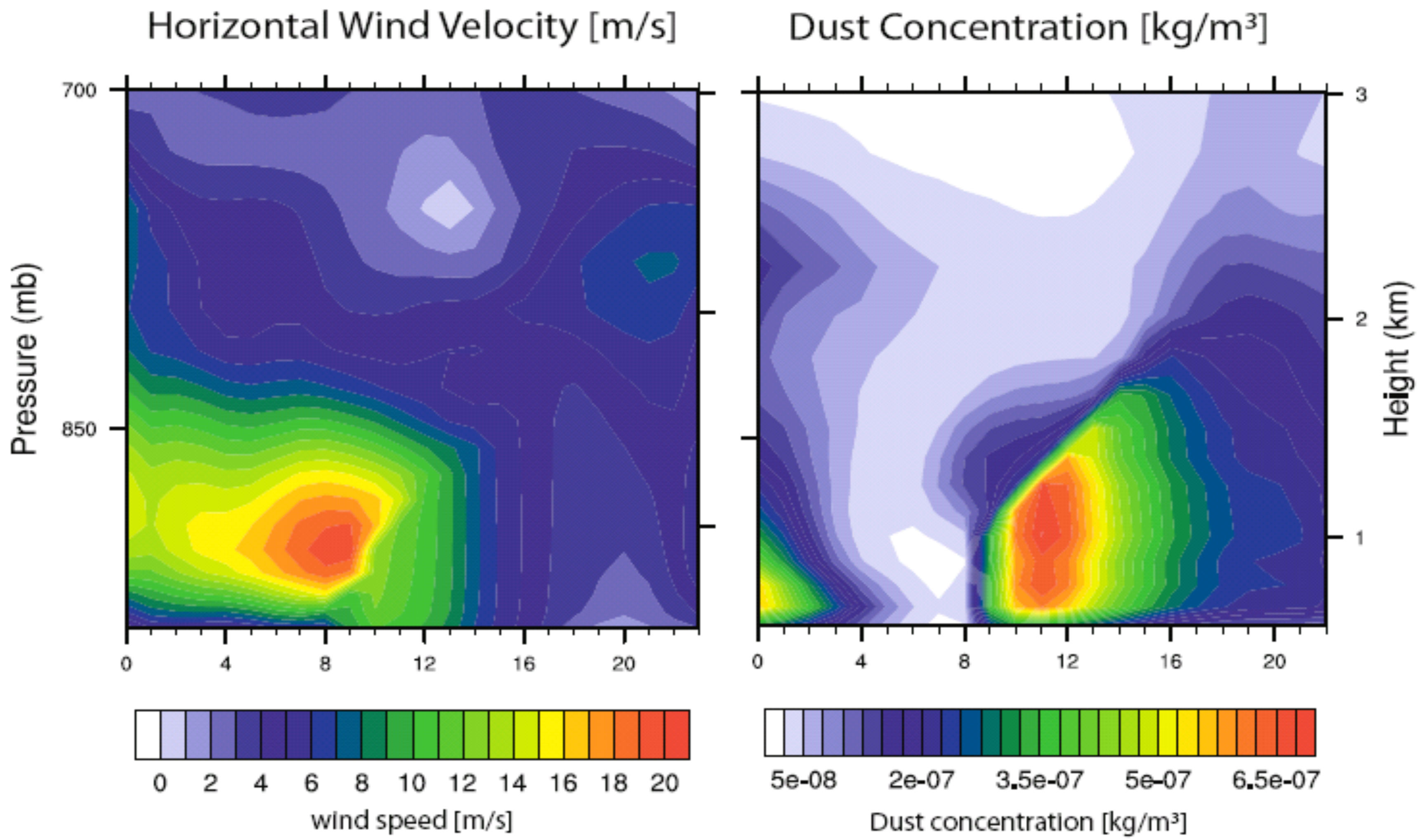
- Winds resulting into dust uplift associated with eastward propagating H over Mediterranean Sea
- Wind system associated with pressure gradient between North African H and Caspian L
- Dust uplift along cold front associated with mid-winter Mediterranean cyclone



Low-level jet as dust-uplifting mechanism

TROPOS

22.25N, 3.5E March 10, 2006



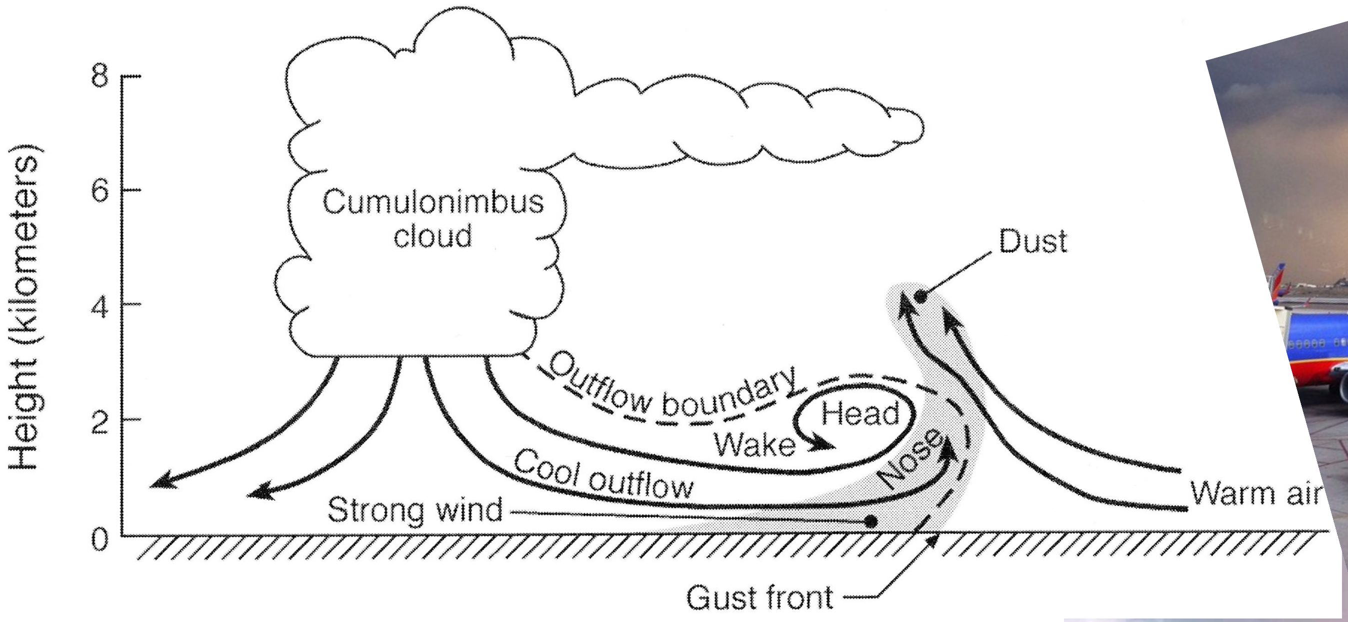
[Schepanski et al., 2009]

Low-level jet as dust-uplifting mechanism

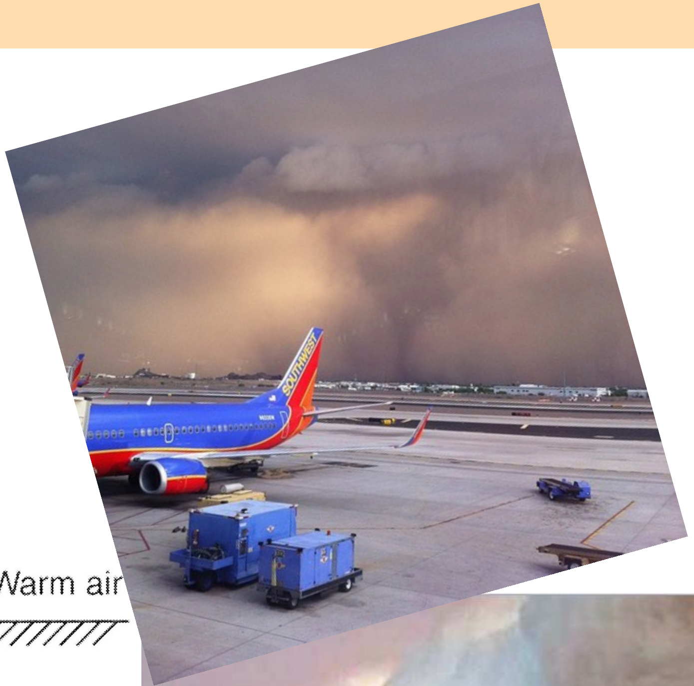
TROPOS

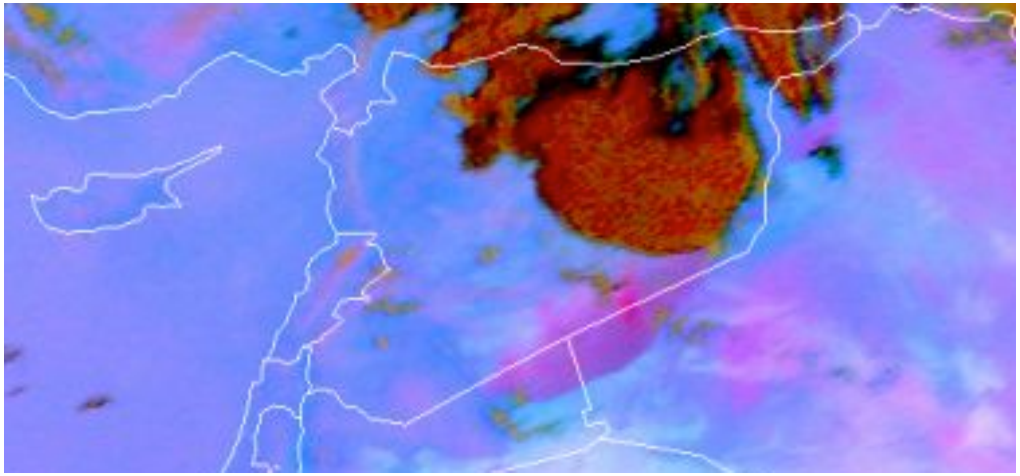
- Embedded in Shamal winds
- Form in parallel to mountain ridges due to daily heating and cooling
- Heating effect may be more important than inertial oscillation for formation of LLJs
- Mountain channelling and land-sea breeze may enhance LLJ

Haboobs



Height (kilometers)
8
6
4
2
0
Cumulonimbus cloud
Dust
Outflow boundary
Head
Wake
Nose
Cool outflow
Strong wind
Warm air
Gust front



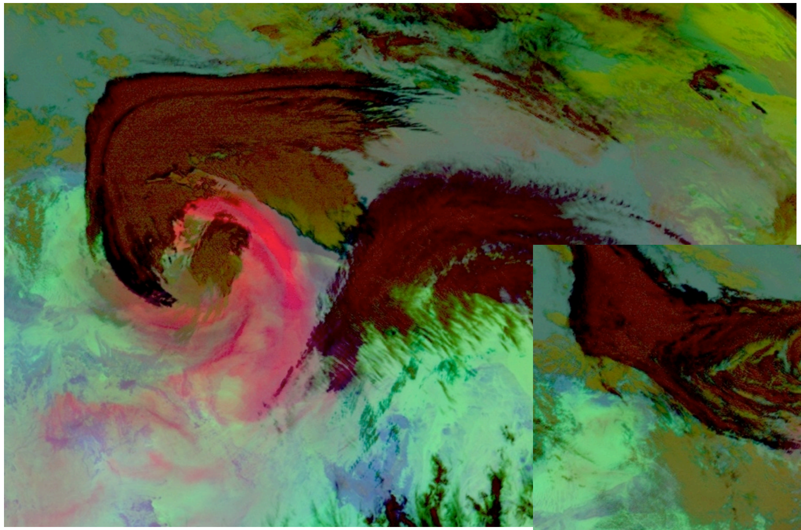


Dust-uplift linked to Cyclones

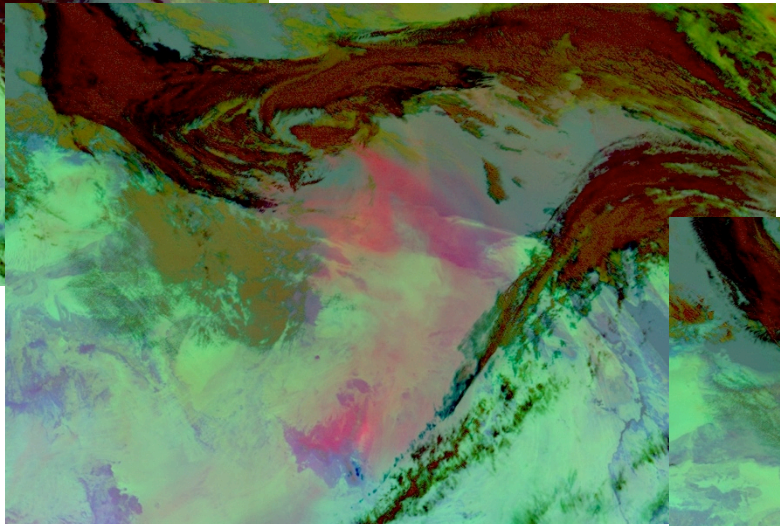
- Wind/gusts associated with front passage
  - Dust uplift by strong winds ahead of cold front

- Sharav cyclones: lee-cyclones enhanced by baroclinity
  - Fast eastward moving (> 10m/s)
  - Active warm front with high temperatures
  - Shallow cold front
  - Heavy dust fronts, low visibilities
  - Frequently observed along Mediterranean coast

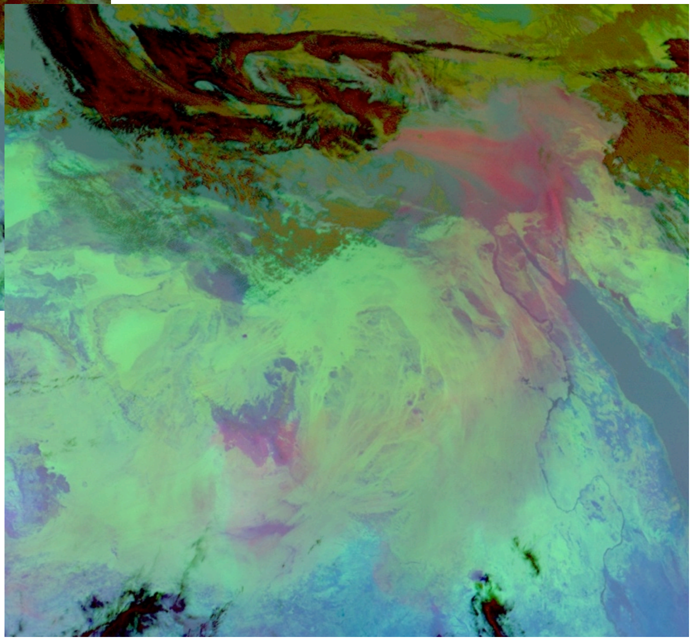
Dust-uplift linked to Cyclones



21 Feb 2007 15UTC



22 Feb 2007 15UTC



23 Feb 2007 15UTC

Dust Variability: Summary

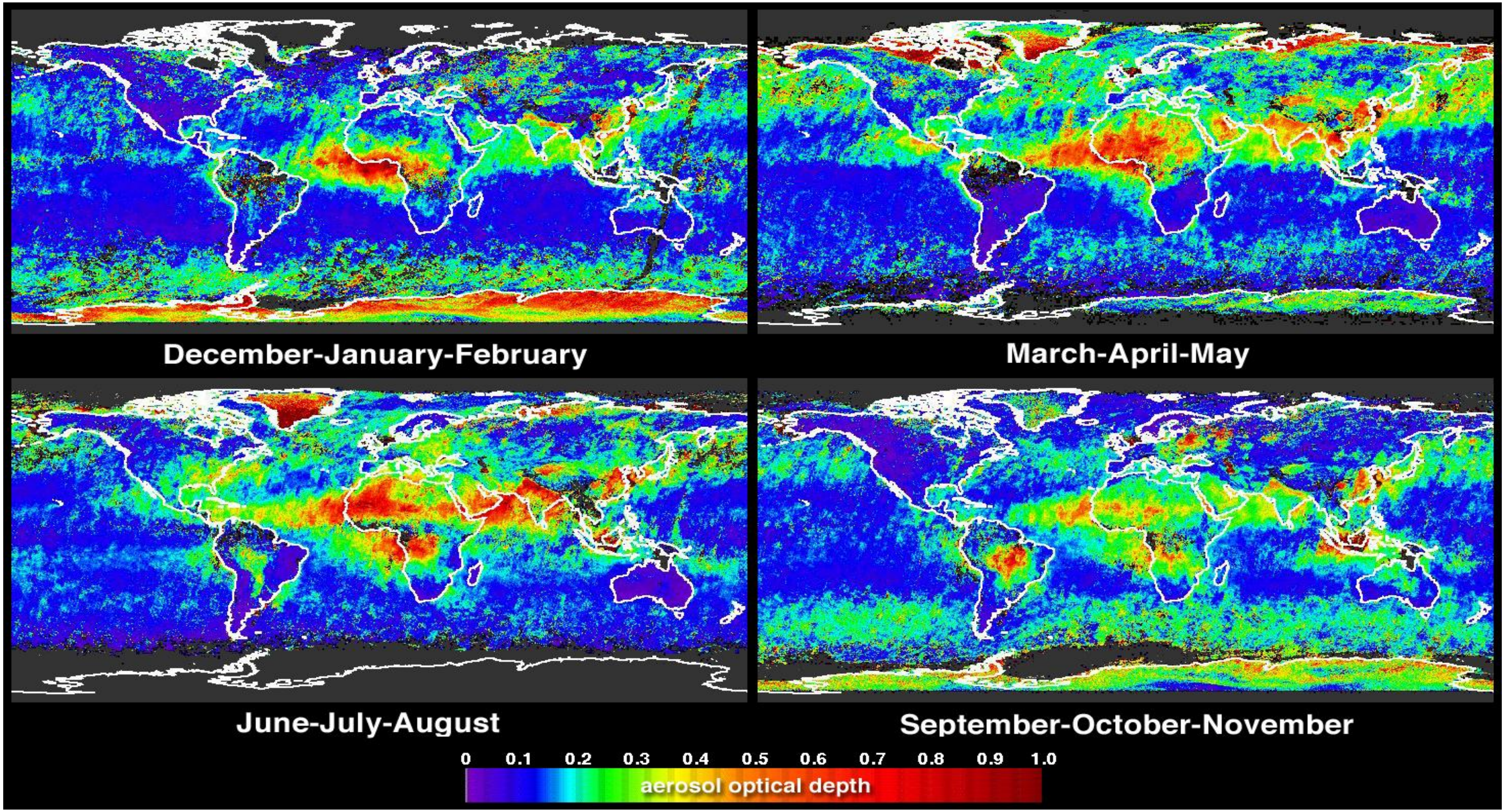
TROPOS

- Dust emissions are mostly caused by short-term meteorological processes.
- Variations in dust transport at the daily and sub-daily time scale is relevant for dust forecasting.
- Skills of models to correctly simulate (sub-) daily dust events depends on the model's ability to reproduce the different meteorological events forcing dust emission.
- Dust transport can usually be captured well by forecast models.

Seasonal Variability: AOT

TROPOS

MISR AOT Dec 2001 – Nov 2002



http://eosweb.larc.nasa.gov

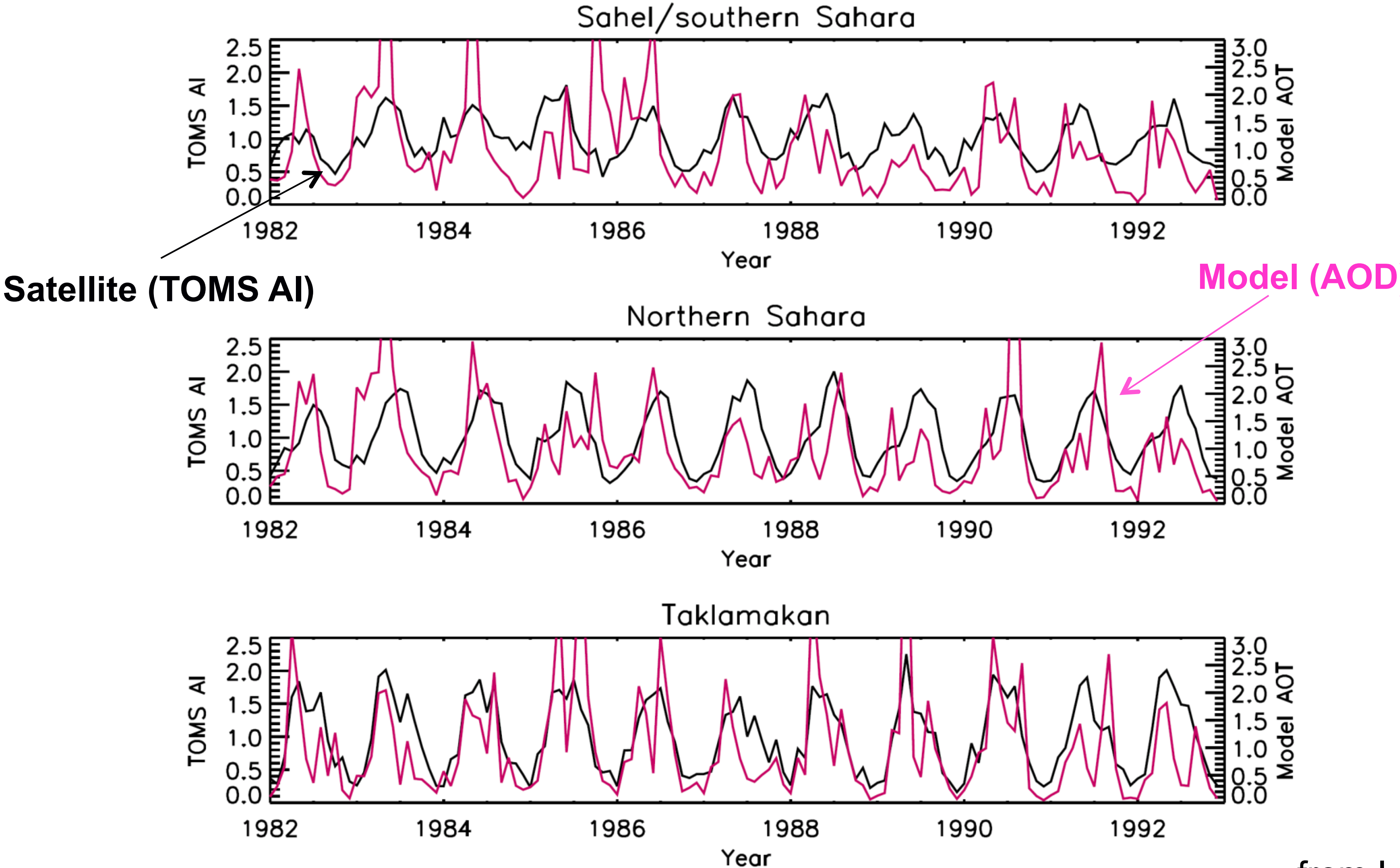
Seasonal Variability: Summary

- Seasonal changes in dust are controlled by
  - Atmospheric circulation pattern, e.g. Shamal, Mediterranean cyclones
  - Vegetation phenology
- Seasonal variability in dust is well characterised
  - Long-term measurements: ground-based and space borne
- Most often, dust maxima over the Arabian Peninsula are observed in spring/early summer

Year-to-Year Variability

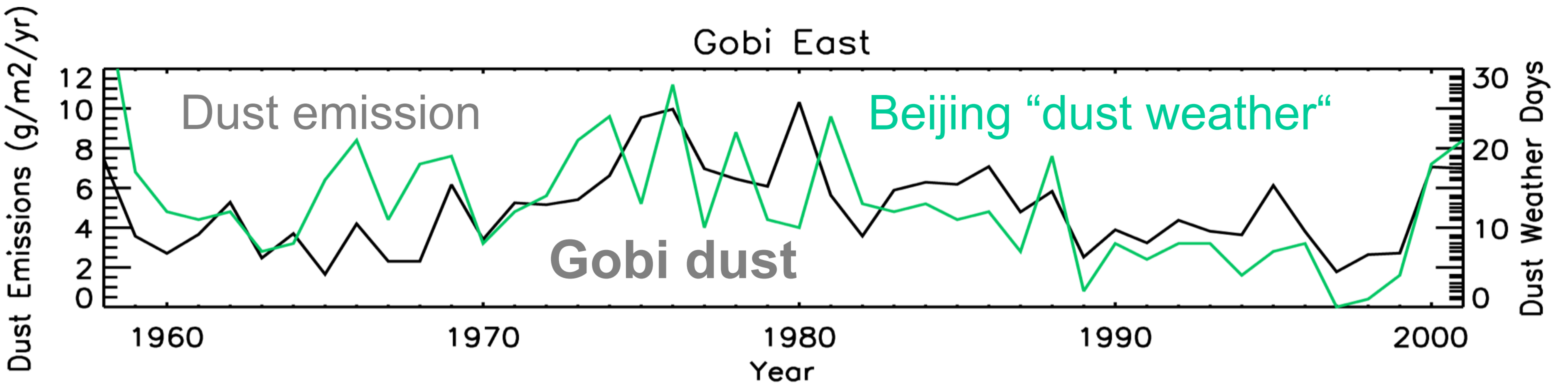
TROPOS

Model results from TM3/ERA-15



from I. Tegen

Decadal Dust Variability



from I. Tegen

- Interannual/decadal change in dust concentration controlled by changes in dust sources
- Changes in meteorology and surface conditions possible causes

Dust Variability: Human Impact

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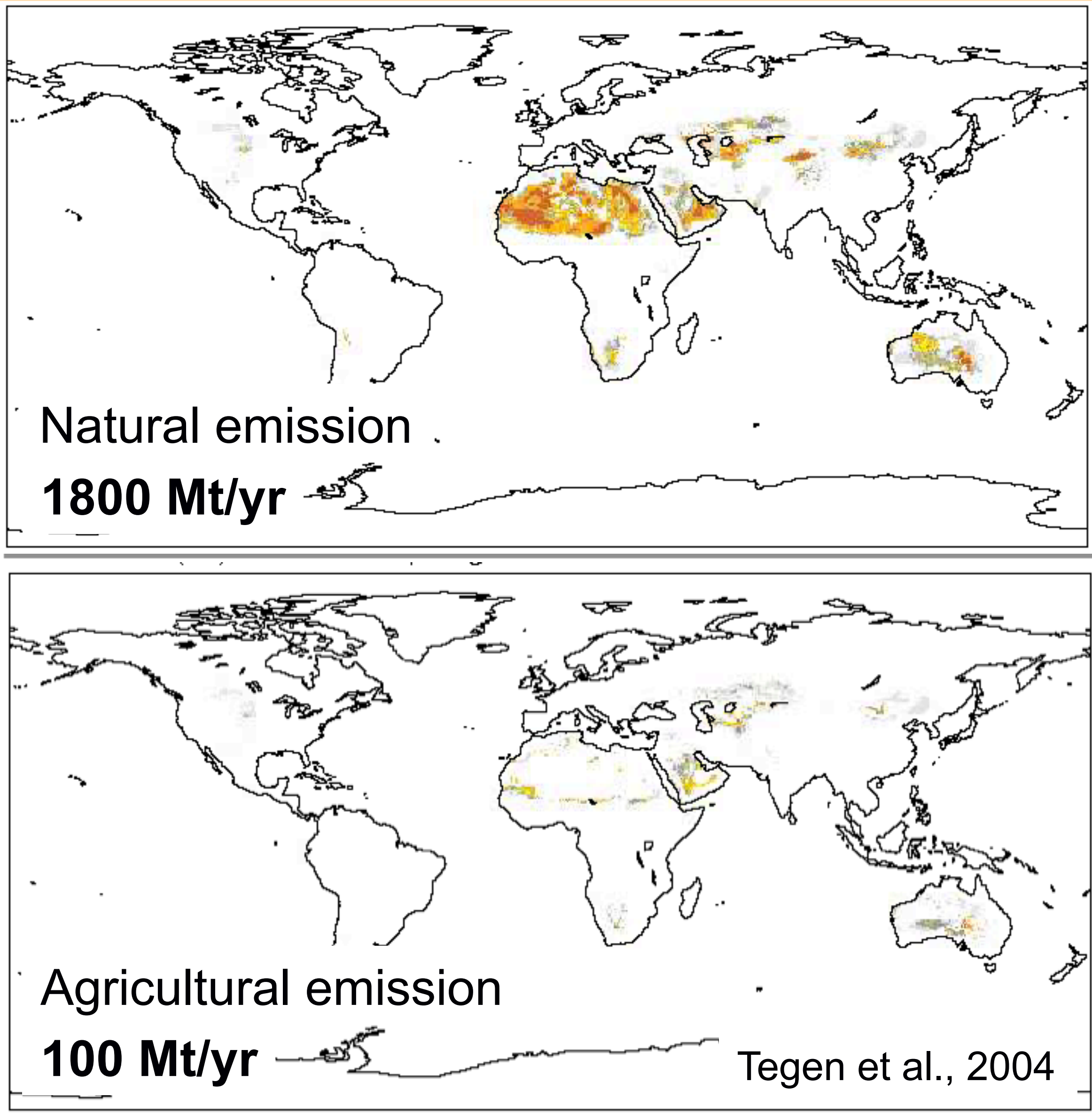
- Impact on soil surfaces
  - Cultivation in arid and semi-arid regions
  - Overgrazing
  - Deforestation
  - Degradation of vegetation variety
  - Soil erosion
  - Road tracks
- Impact on climate
  - Changes in natural vegetation
  - Changes in local meteorology (precipitation, wind)

Dust Variability: Agriculture

- Satellite z_0
- ECMWF ERA15
- Year 1987
- Contribution of agricultural emission: ~6%

- Global estimates of dust fluxes from anthropogenic disturbed soil varies from 0-50%



Year-to-Year Variability: Summary

TROPOS

- Interannual changes in dust are less well understood than seasonal changes.
  - Variability in atmospheric circulation, sediment supply within dust sources, vegetation, …
- Changes in Asian dust loads can be related to changes in large-scale circulation patterns.
- Human activities leading to disturbance of soil surfaces may lead to enhanced dust emissions – the magnitude of this effect is not yet known.

Summary

TROPOS

- Dust varies not only spatially but also temporally at many scales.
- Dust over Arabian Peninsula originates from local sources, but also advected from remote areas such as the Sahara or Syria
- Daily time scale is relevant for regional forecasts, controlled by meteorology.
- Seasonal changes in dust are well characterised, controlled by meteorology and vegetation phenology.
- Interannual and decadal changes are controlled by climate and surface modification, e.g. land use