Dust radiative forcing and Heat Low dynamics over West Africa

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Rationale

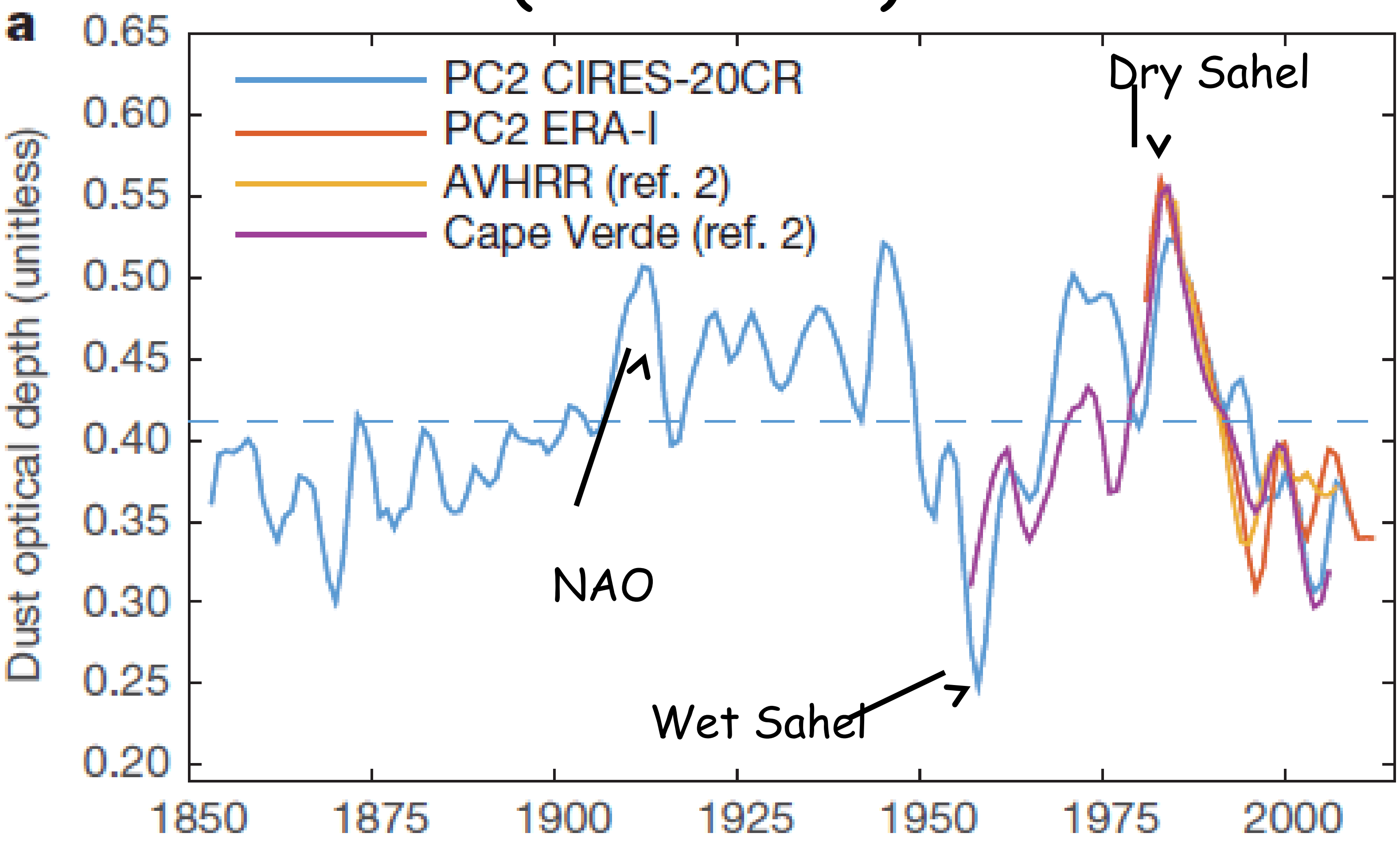
Africa North of the Equator is by far the greatest aerosol source in the world (almost exclusively mineral dust).

African dust is known to influence processes such as:

- Amazon productivity and Ocean fertility,
- Cyclonic activity of the Atlantic
- Atlantic climate modes (through changes in SST)
- Regional scale
  - atmospheric composition
  - radiative balance
  - atmospheric dynamics
- Precipitation in the Sahel

Projections concerning African dust loading are quite uncertain to a lack of understanding of processes related to interactions between **dust & atmospheric dynamics** and their representation in climate models

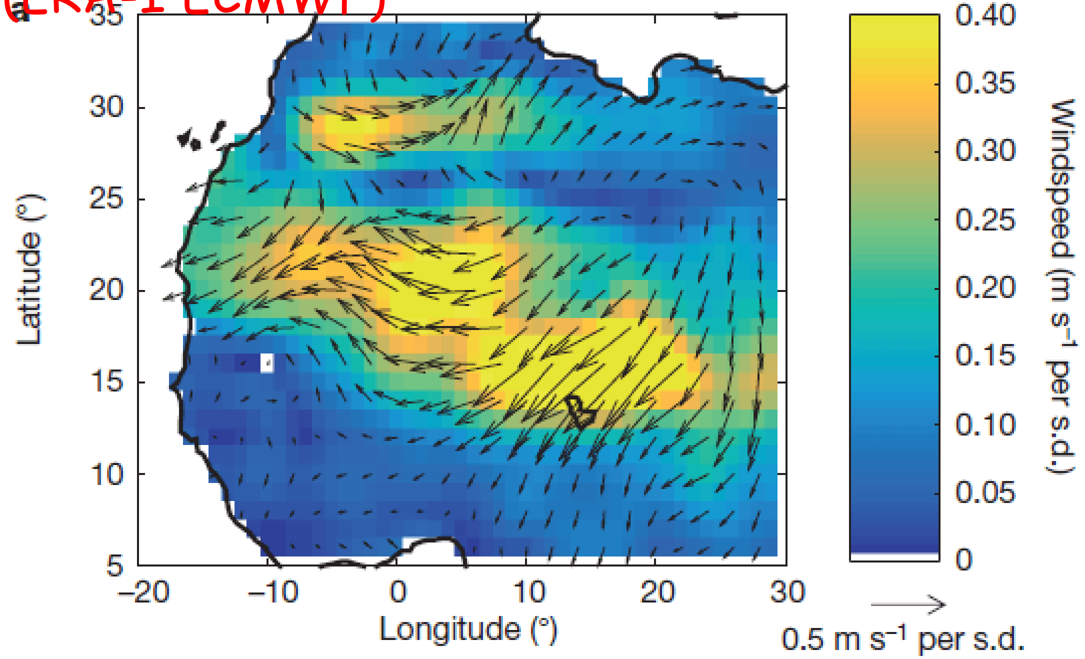
African dust optical depth over the Atlantic (1851-2011)



A variety of processes (NAO, ENSO, ITCZ, …) have been found to influence dust emissions over the Sahara at different time scale.

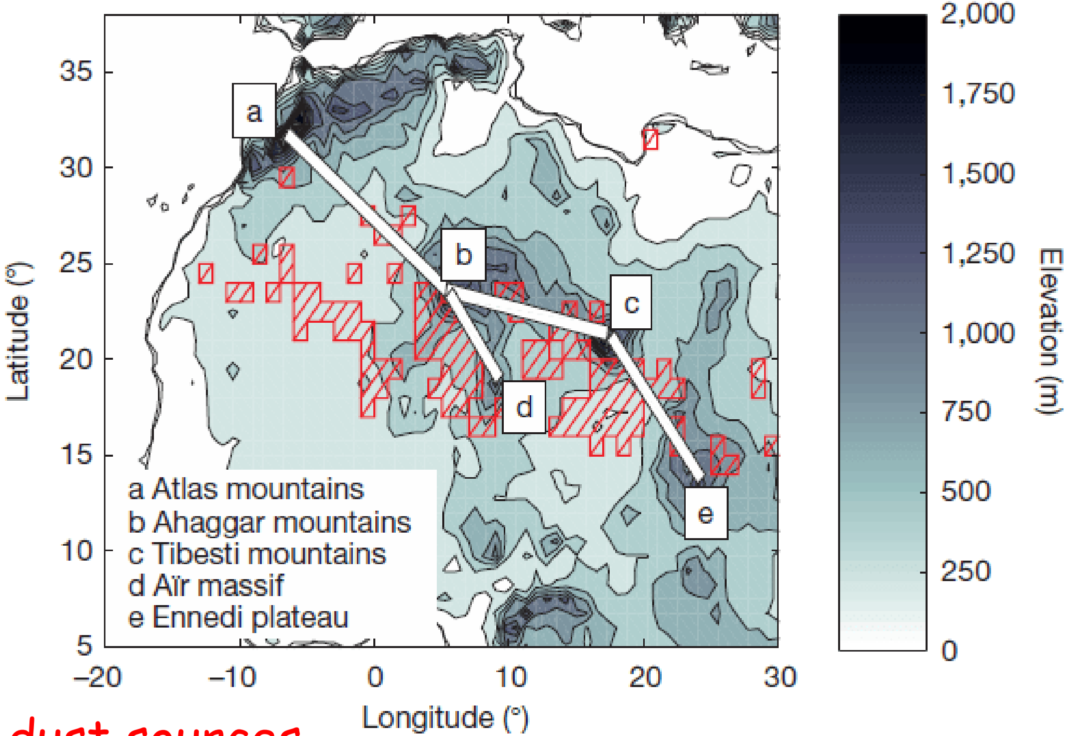
Evan et al., 2016 Nature

10-m winds (ERA-I ECMWF)



Surface wind is the main driver for dust emissions over the Sahara !

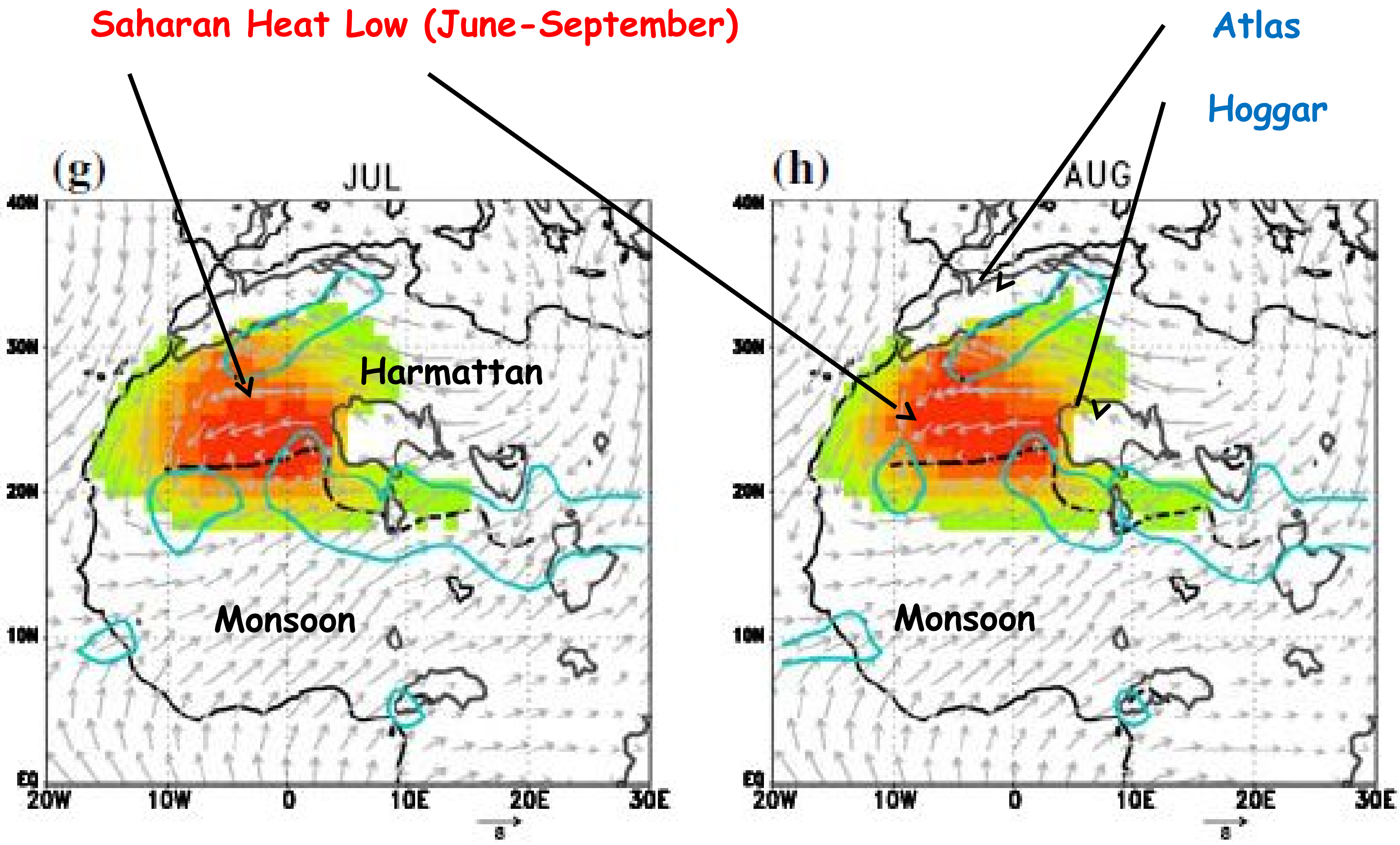
85% of dust emissions over NW Africa is from source regions downstream of main orographic features of the Sahara (*strong winds and source regions are co-located*)



Orography & dust sources

Evan et al., 2016 Nature

Atmospheric Dynamics in Summer (1979-2014)

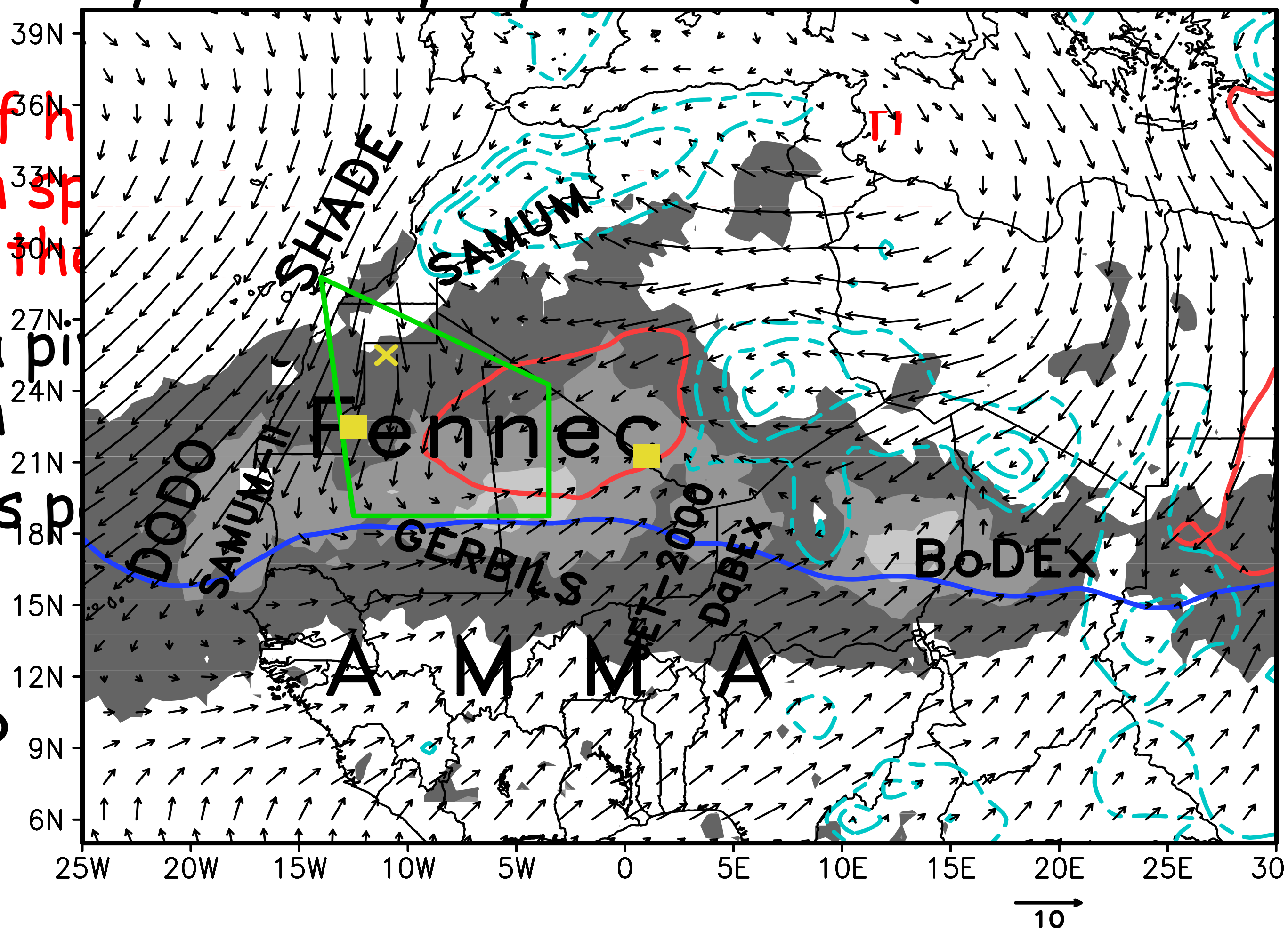


Lavaysse et al., 2009 Clim. Dyn.

925 hPa winds (ERA-I ECMWF)

The Saharan Heat Low (SHL)

- Region of extreme climate especially in summertime
    - High temperature (> 45°C),
    - Deepest Planetary Boundary layer on Earth (5-7 km),
    - The region of h
      derived from sp
      located with the
- The SHL plays a pi
  Monsoon system
- Understanding is p
  scarce

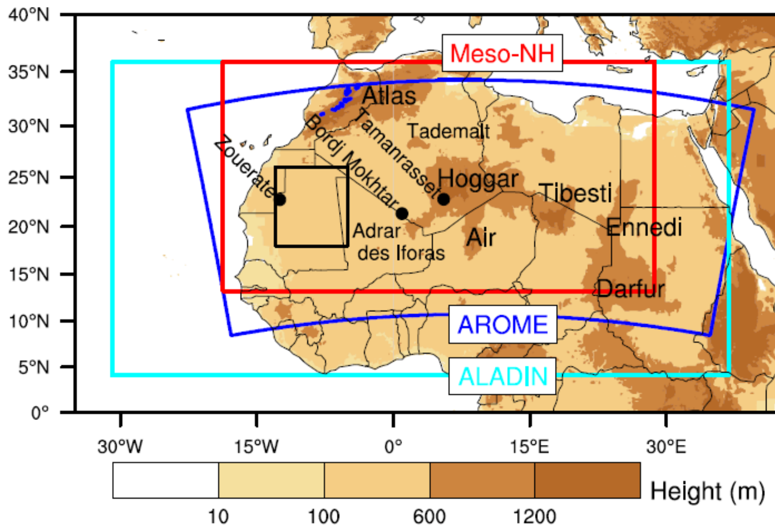


MISR (2000-2012) **AOD**
Contours: 0.4, 0.6, 0.8

Red: SHL (ECMWF)
Arrows: 925 hPa wind

Todd et al., 2013 JGR

Dust emission processes in the SHL region



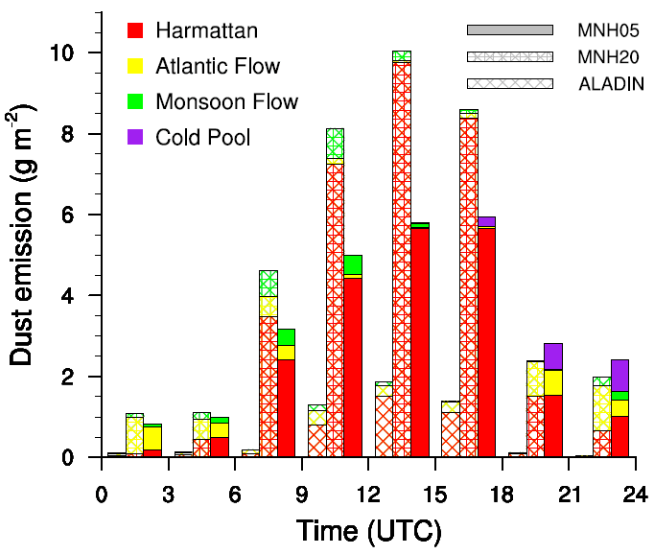
3 mesoscale models (ALADIN, Meso-NH):
24, 20 and 5 km grid
first level: 10-40 m

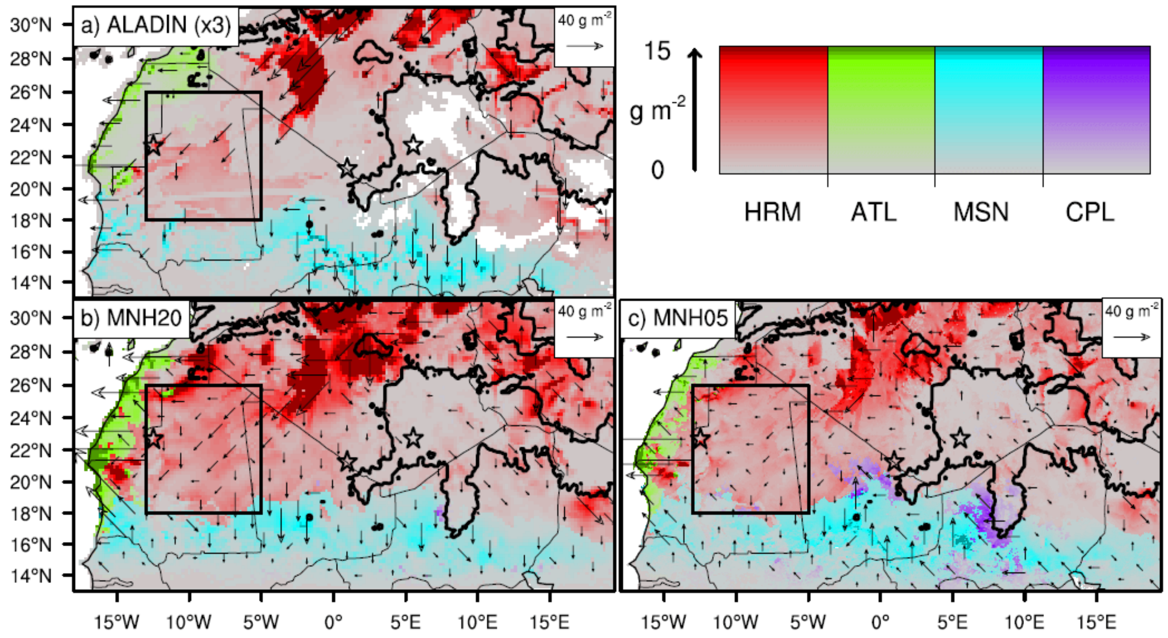
4 processes:

- Early morning: harmattan ➔ 80%
- Night: Atlantic inflow & monsoon ➔ 15-20% (depending on model res)
- Evening: Cold pools related to deep convection ➔ 5% (for high res model)

FENNEC 2011

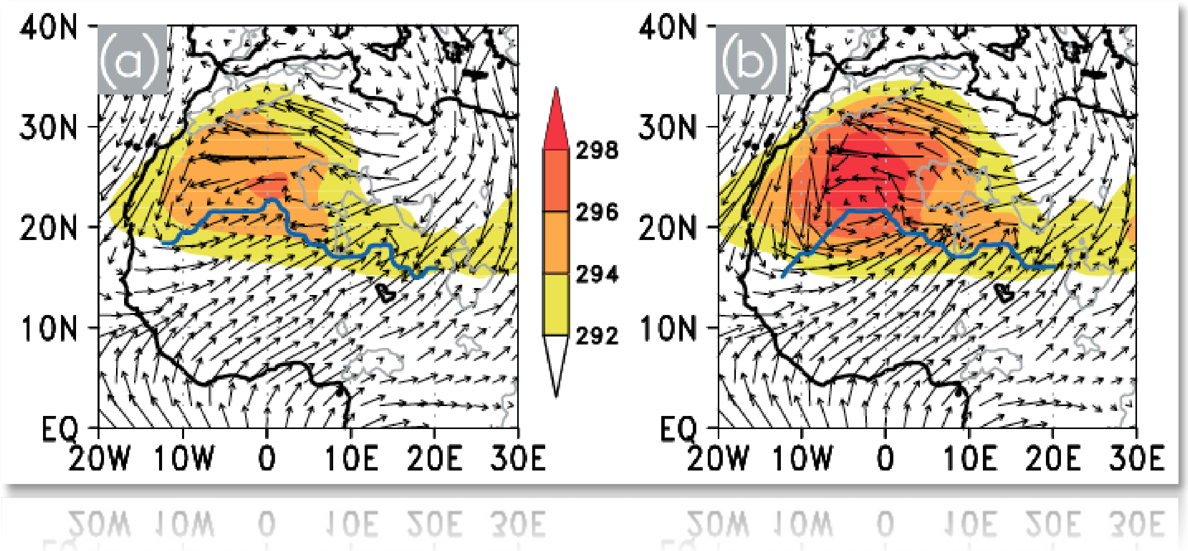
Chaboureau et al., 2016 ACP





SHL variability at interannual scales and impacts

925 hPa winds and SHL Intensity (ERA-I ECMWF)



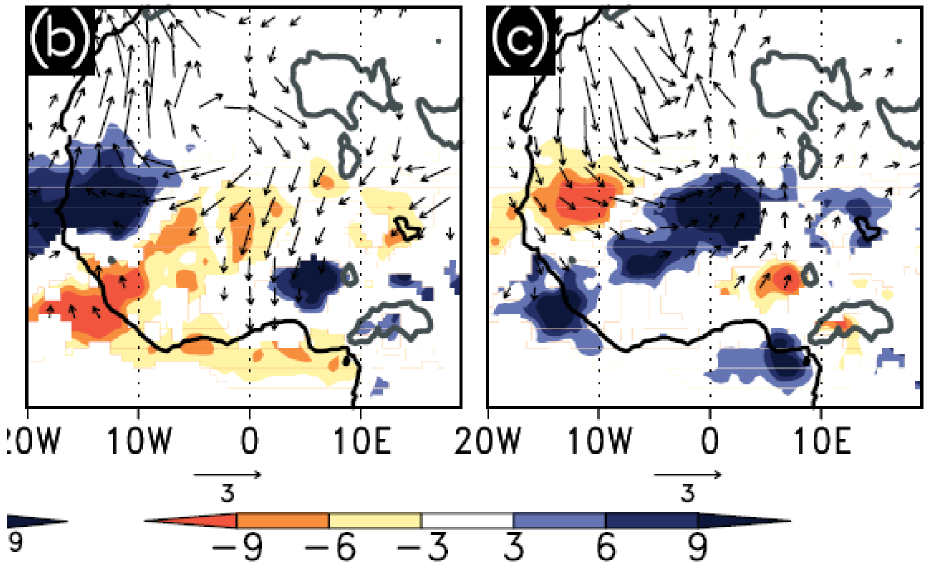
SHL intensity/depth (geopot. difference 925-700 hPa)
∝ Temp over the Sahara

SHL phases (1984-2001)

Cool : 10% coldest yrs
Warm: 10% warmest yrs

Cool

Warm



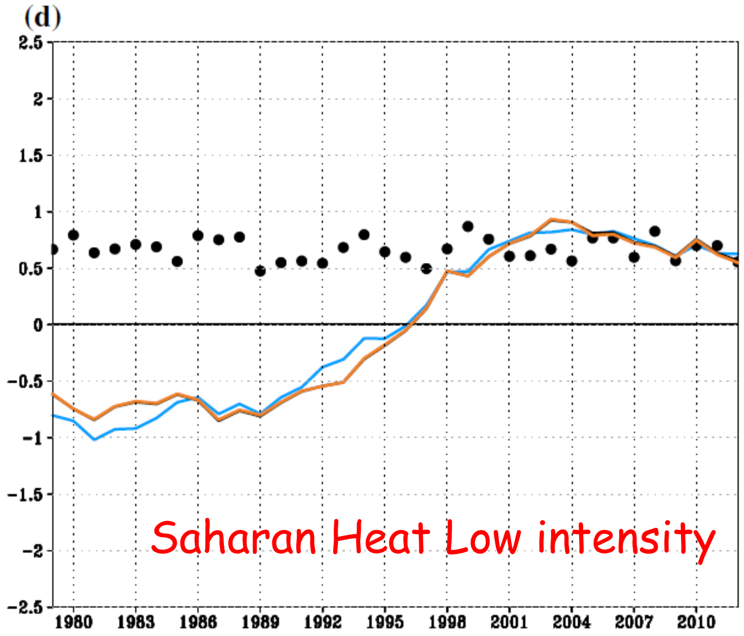
➔ SHL phase affects rainrall across Sahel (east-west gradient)

Convection:
Outgoing Longwave Radiation (CLAUS database)

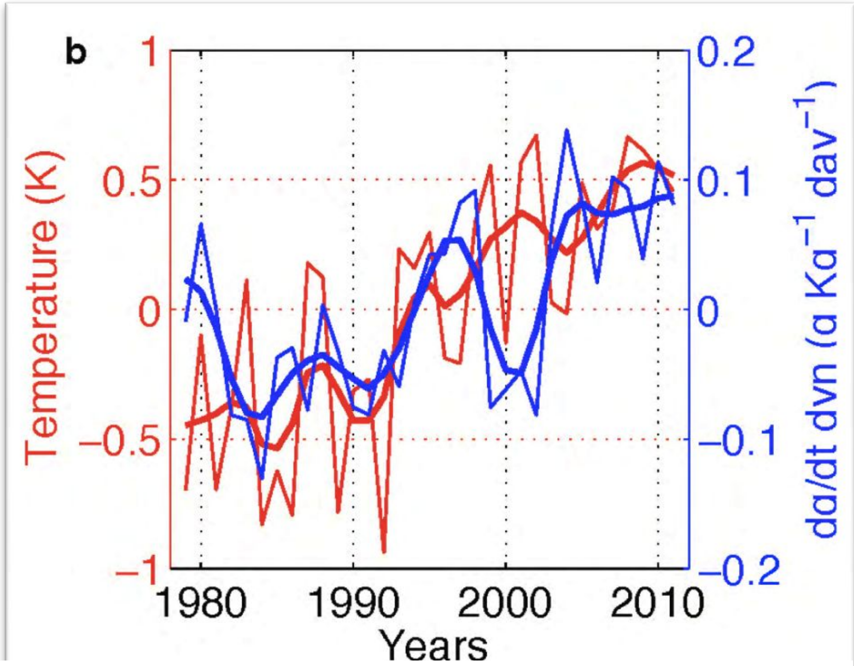
Lavaysse et al. 2010, ASL

What happened in the last 30+ years

The SHL has intensified (transition from a "cooler" phase to a "warmer" phase): the Sahara has warmed up faster that any other region of the world.



Lavaysse et al. 2015, Clim. Dyn.

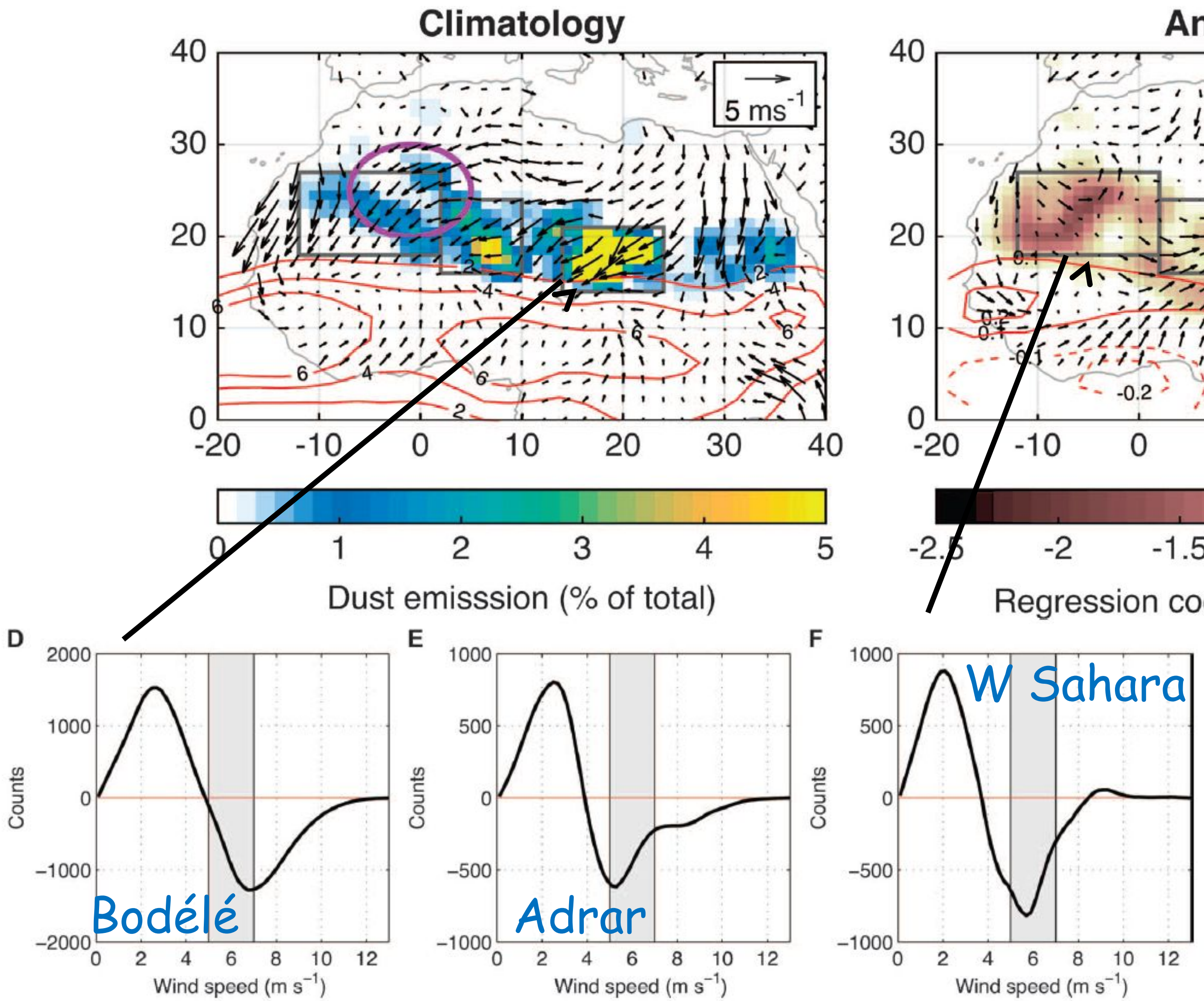


Evan et al. 2015, J. Clim.

The SHL has intensified due to enhanced advection of moisture over the Sahara (enhanced greenhouse effect)

What happened in the last 30+ years

The SHL intensification has accelerated the monsoon flow and slowed down the harmattan flow over dust sources

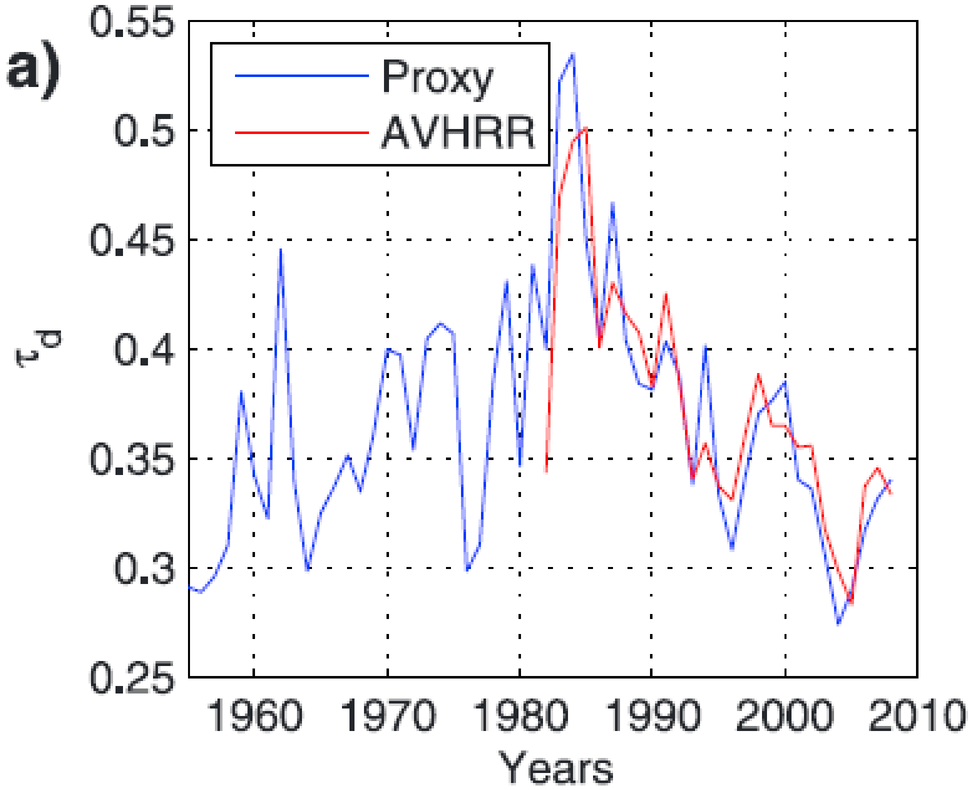


"2000s – 1980s"

Wang et al. 2015, Science Advances

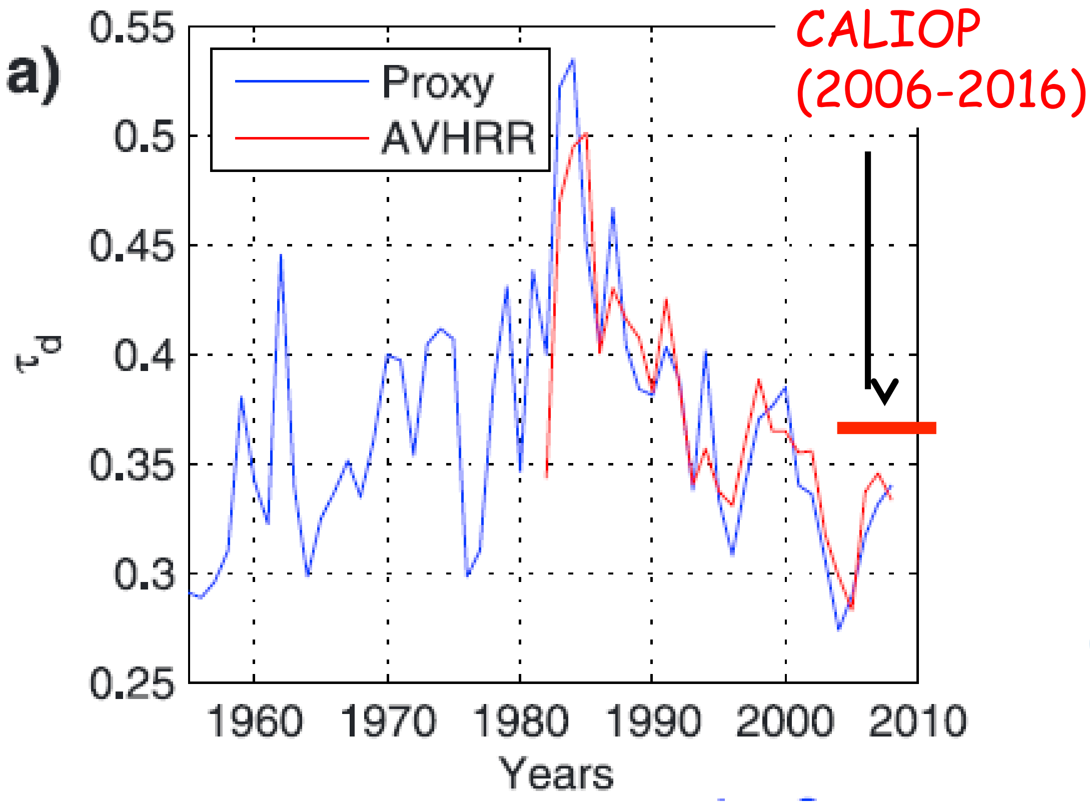
What happened in the last 30+ years

The slow-down of harmattan led to a reduction of dust emissions over land and transport over the Atlantic



AOD in the SHL region is linked to near-surface winds over source regions
and hence to SHL intensity (i.e. SHL depth)
and *possibly* to SABL depth in the SHL region

Where do we stand with CALIOP/CALIPSO?



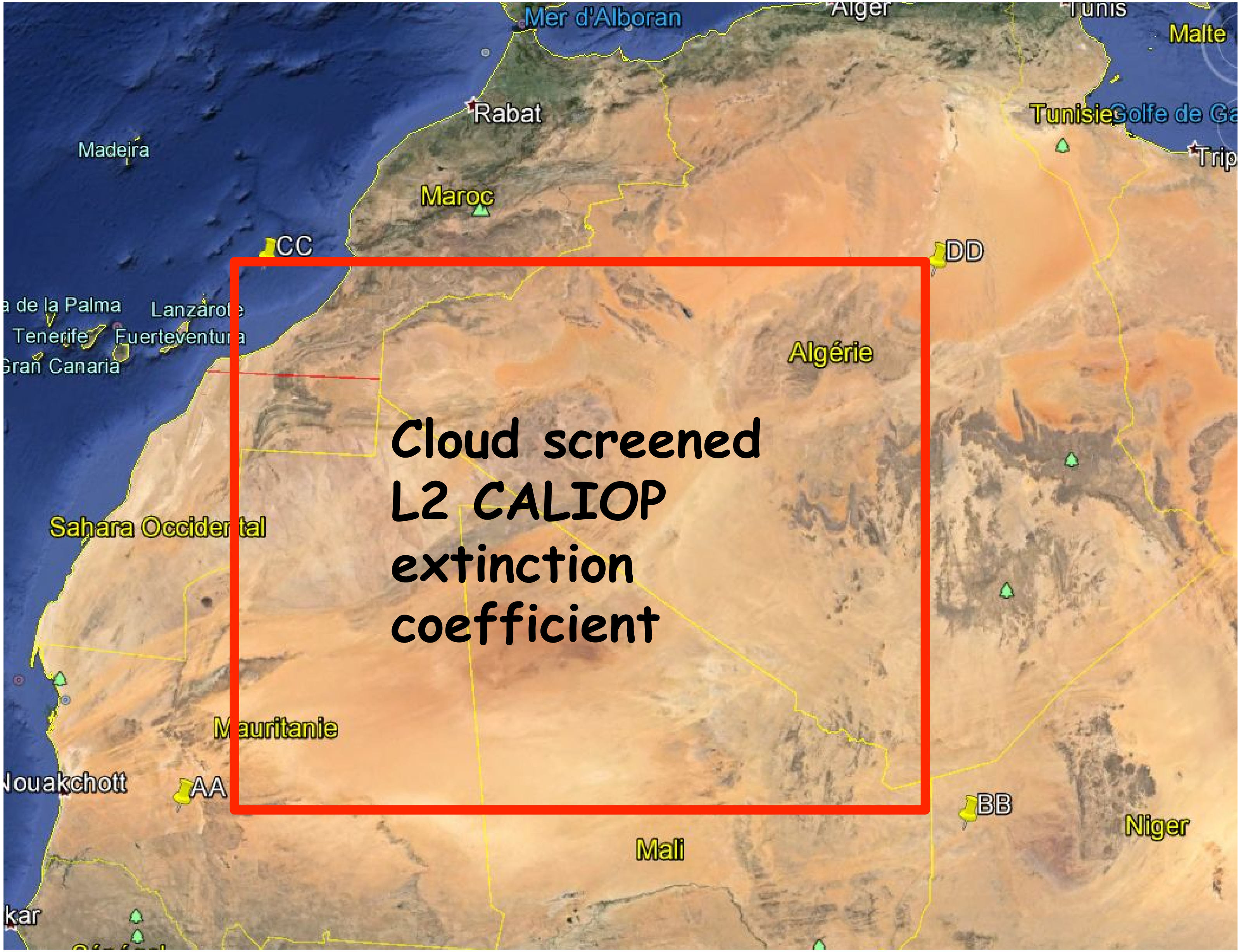
Can we identify the signature of SHL-related metrics in the CALIOP observations?

How does SHL dynamics drive dust emissions and impacts the direct aerosol radiative forcing (DARF)?

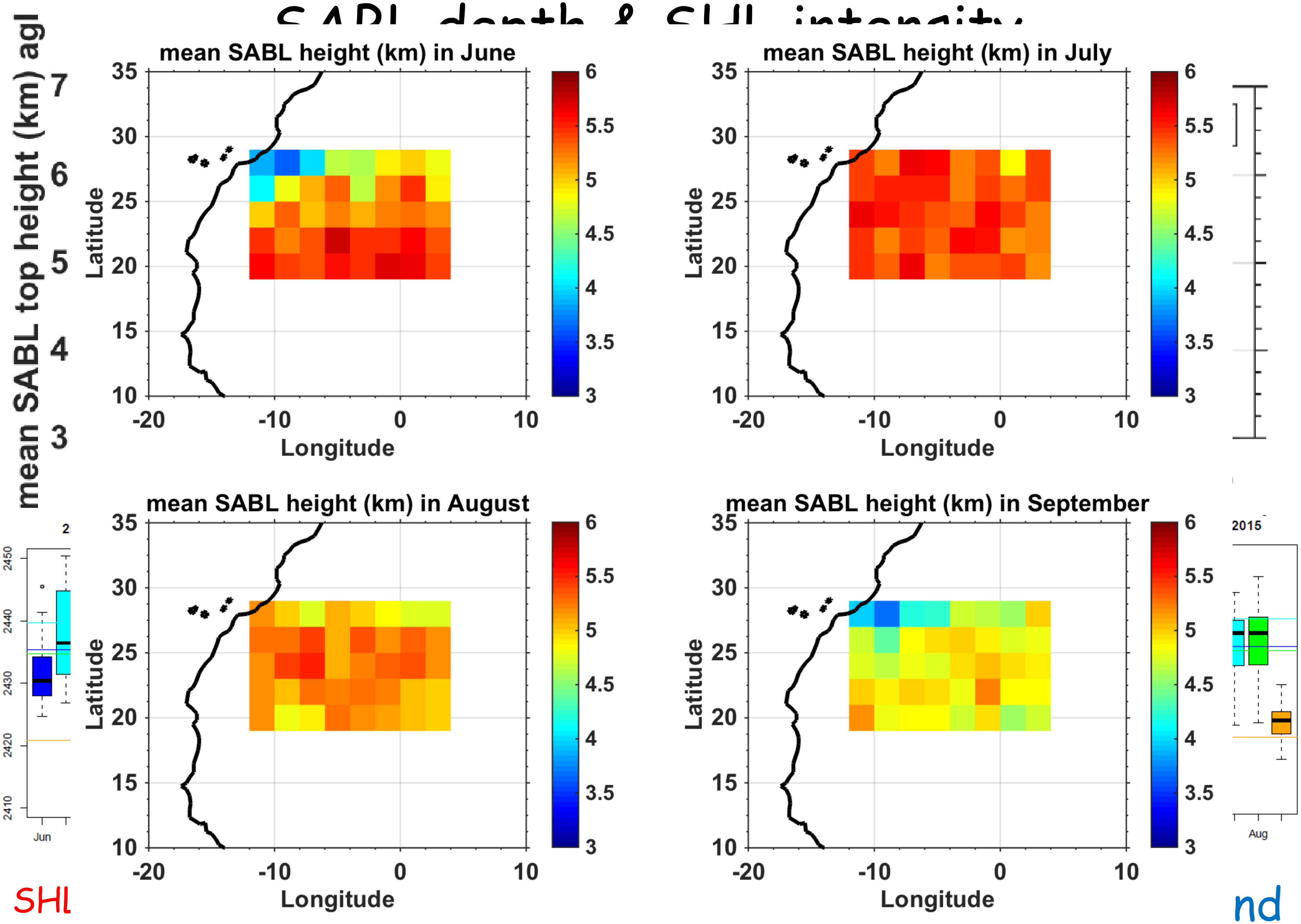
We want to take advantage of the vertical resolution provided by CALIOP:

- Understanding dust-atmospheric dynamics interactions (emissions in SHL region Vs Long-range transport from the remote eastern sources)
- Assessing DARF

CALIOP observations in the SHL region



SABL depth & SHL intensity

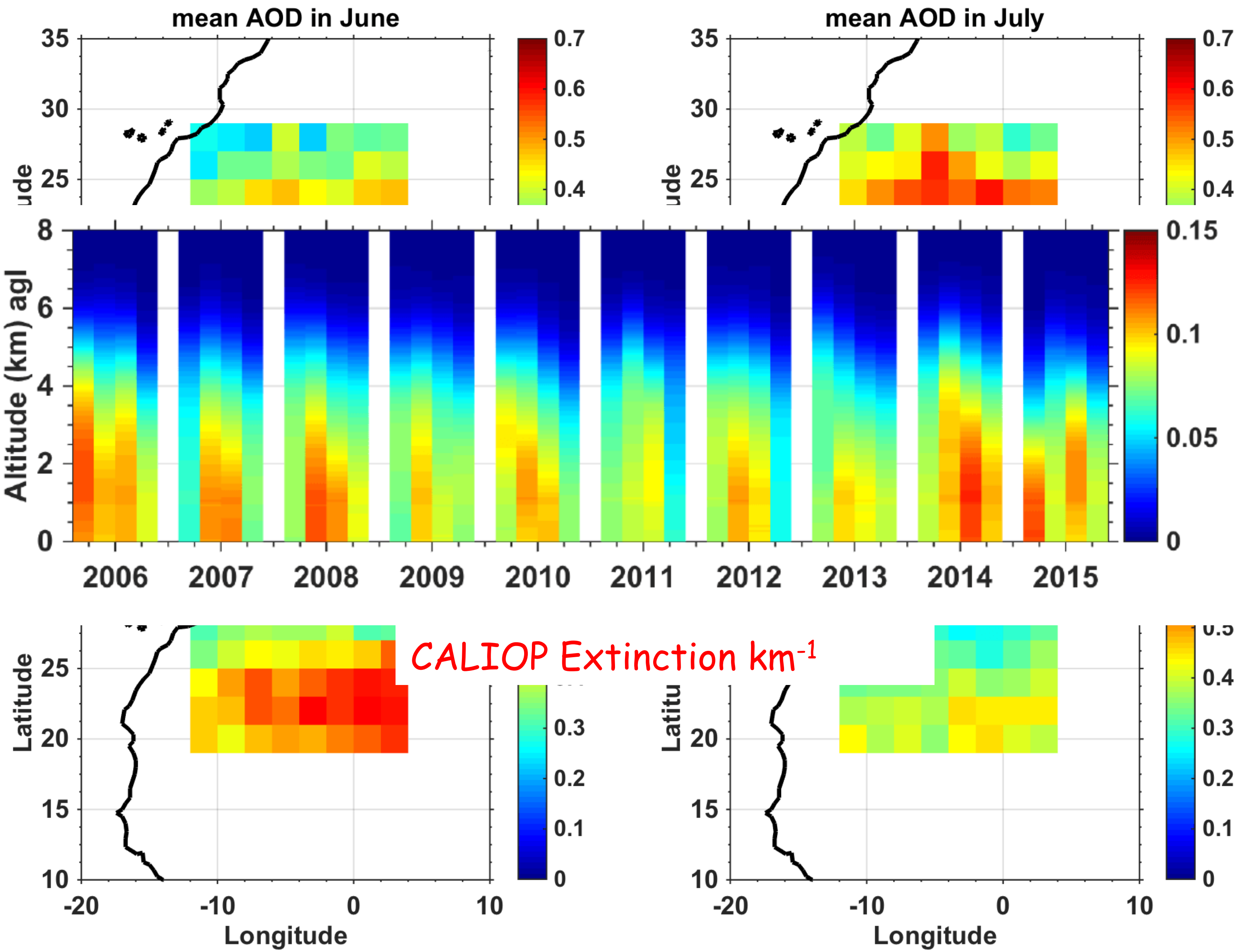


SHL
ERA-I ECMWF

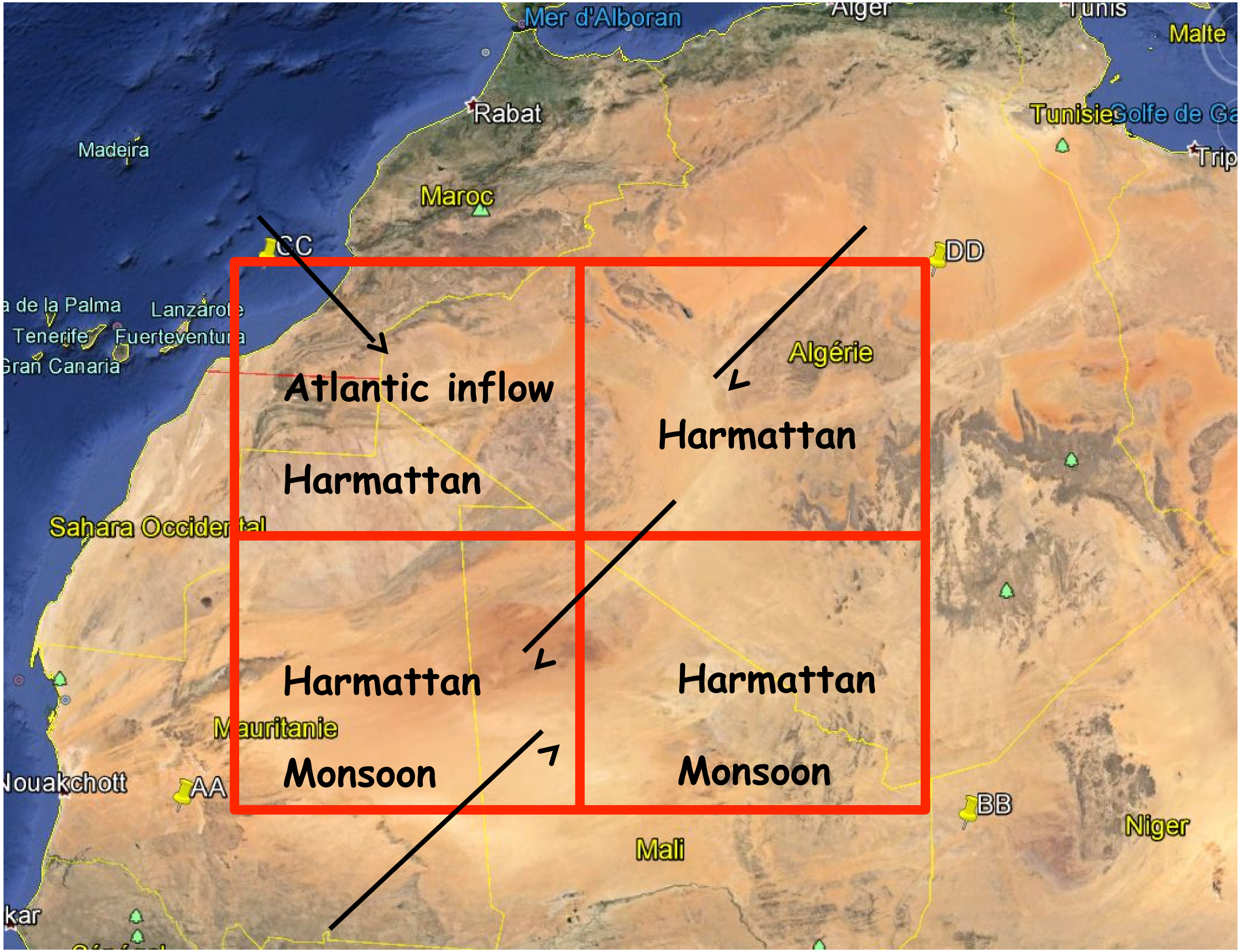
SHL intensity in JJAS ~ 0.6

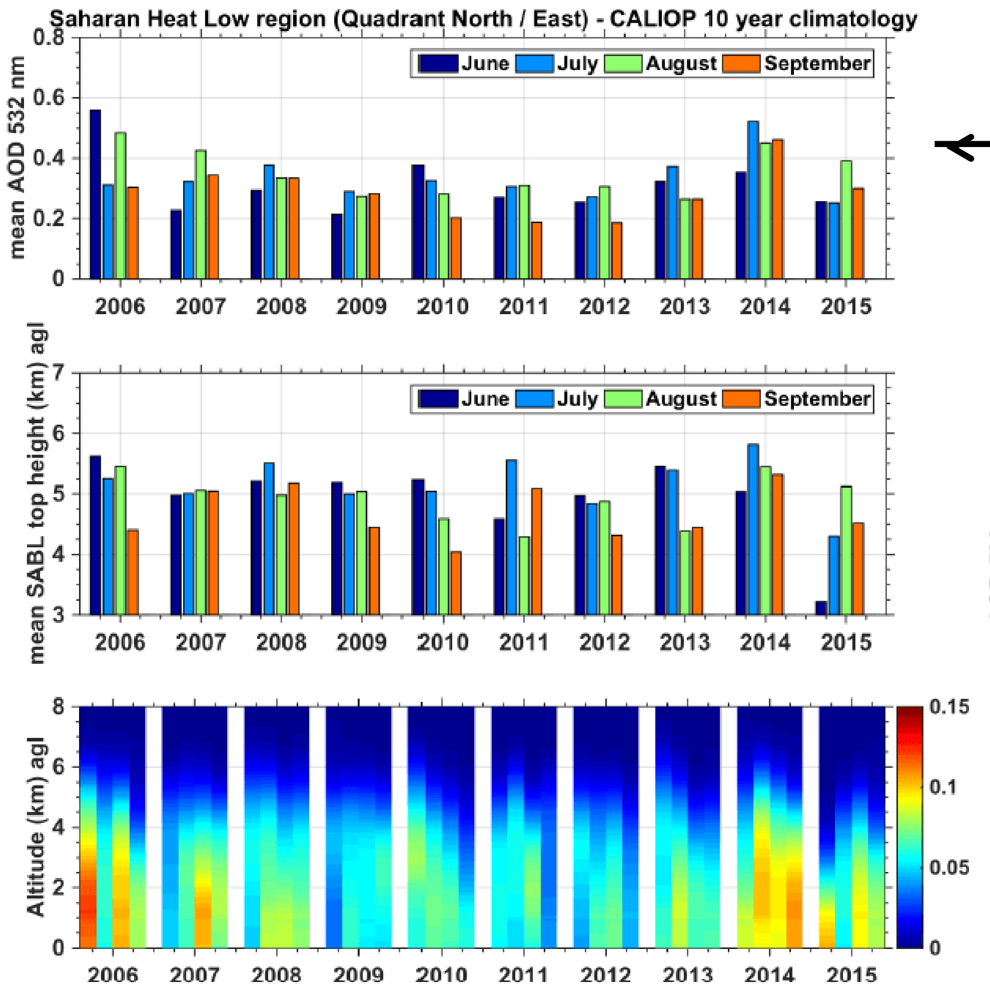
nd

Dust AOD & extinction coeffient

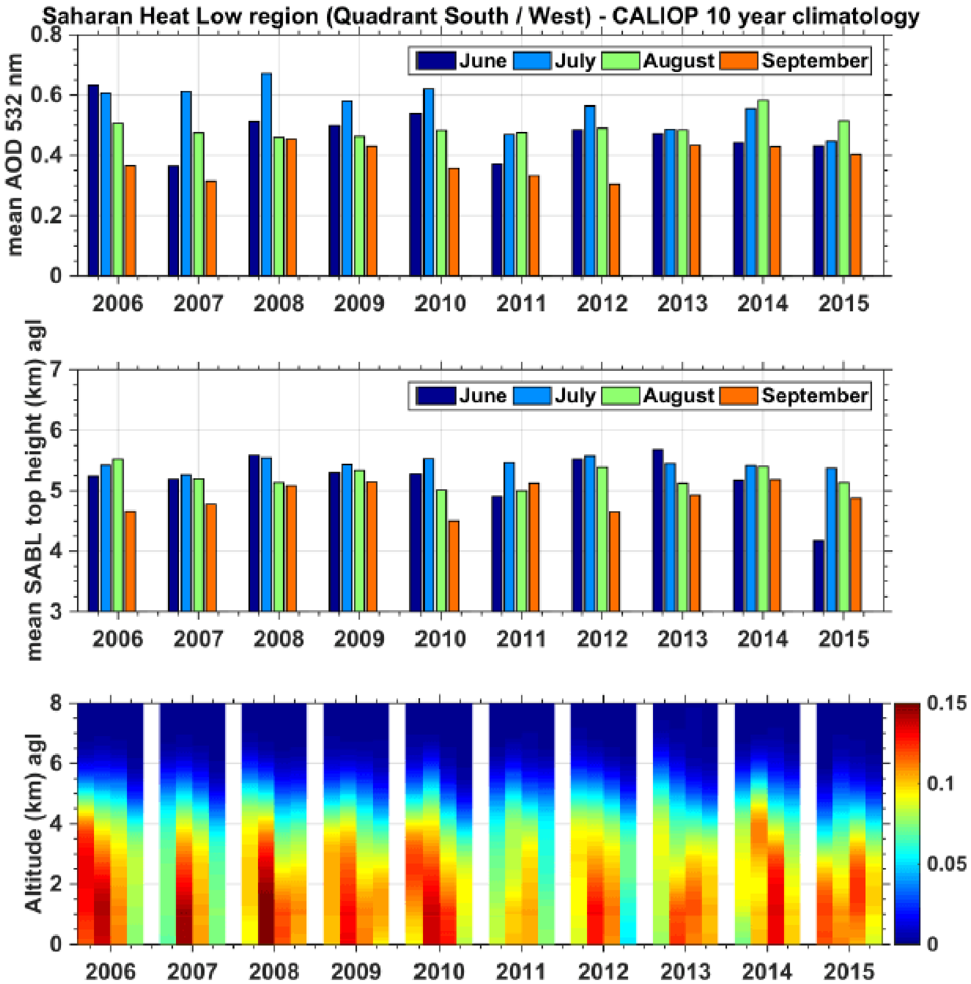


Where do we stand with CALIOP/CALIPSO?



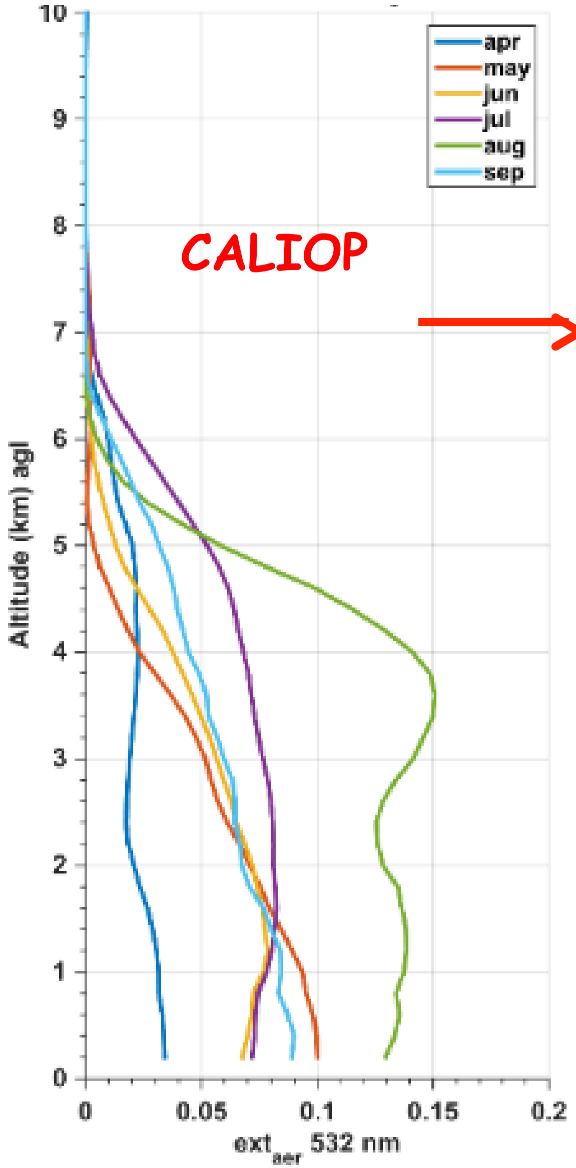


The SABL depth, AOD and extinction coefficient are greater in the SE corner ➔ *Ventilation from the Atlantic*



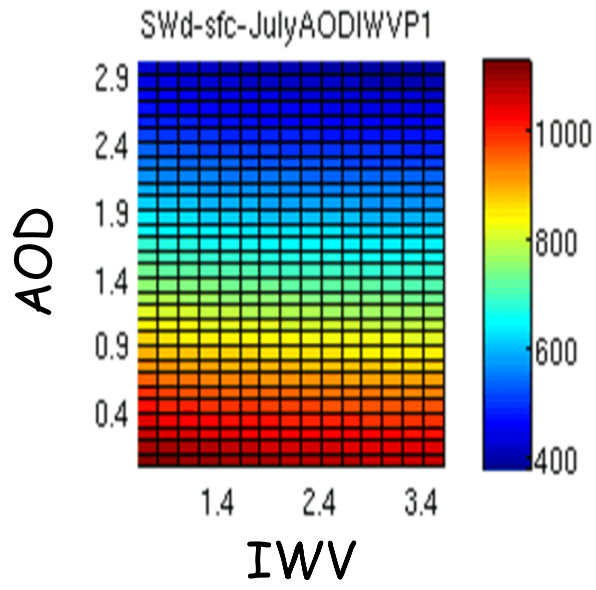
The SABL depth, AOD and extinction coefficients are greater in the SE corner ➔ *low-level convergence between monsoon and harmattan*

Dust DARF

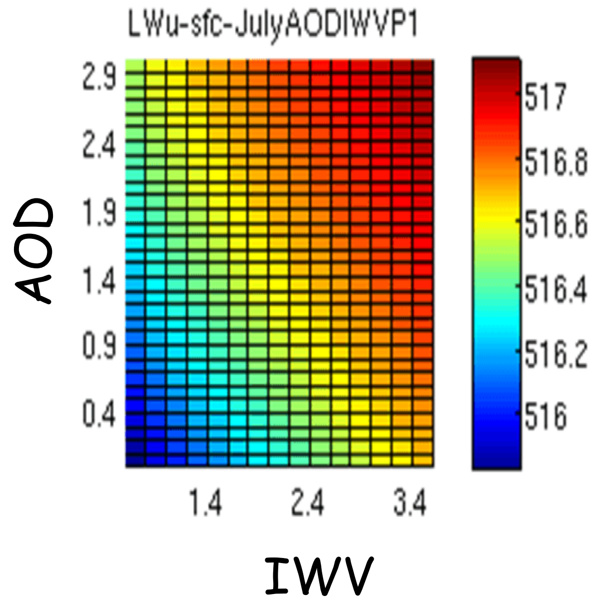


CALIOP

STREAMER radiative transfert model

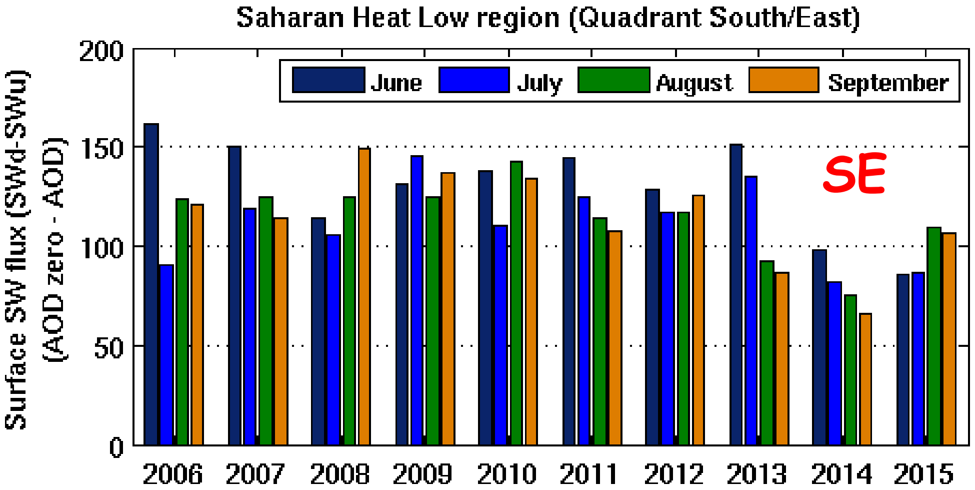


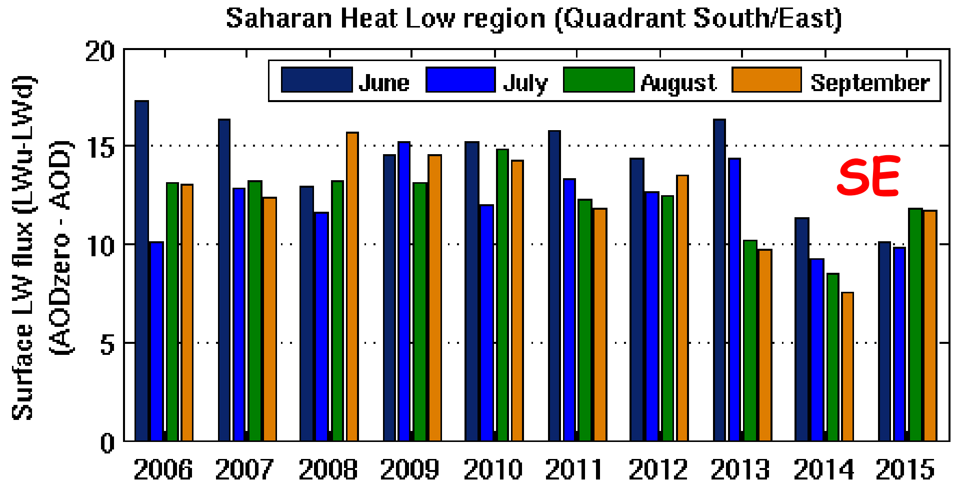
Look up Tables

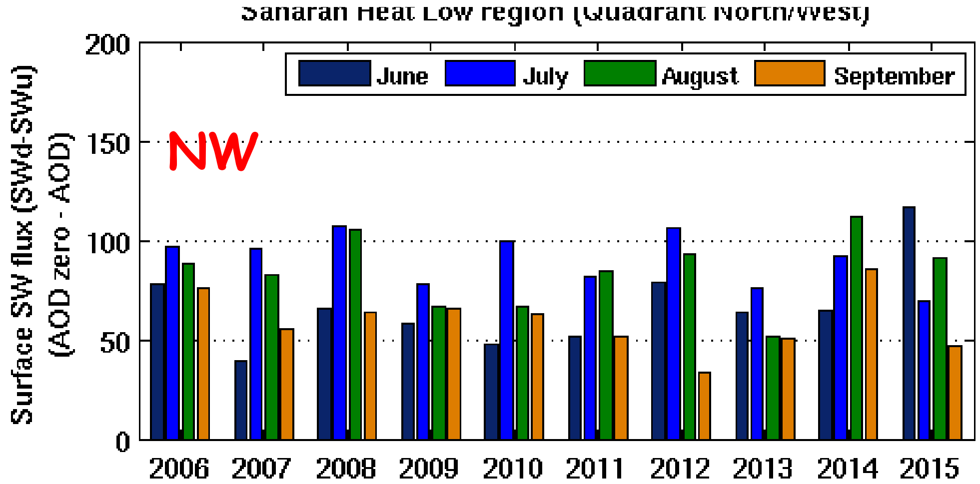


Dust DARF

Net SW & LW flux anomaly at the surface in the presence of dust







LW warming due to dust:

- between 10 and 15 W m^{-2}
- more pronounced in the SE corner

SW+LW ➔ cooling due to dust

Net cooling is more pronounced in the SE
Yet, the SABL depth is greater in SE
➔ Dynamics only?
➔ Elevated heating source (dust)?

SW cooling due to dust:

- between 100 and 150 W m^{-2}
- more pronounced in the SE corner

Summary & Conclusion

AOD in the SHL region is linked to near-surface winds over source regions and in turn to SHL intensity (i.e. SHL depth) at decadal scales

There is a need to monitor SHL intensity/depth to track the inter-annual variability of the West African Monsoon system

AOD is not a proxy for monitoring the SHL, unlike the SABL depth

We have identify the signature of SHL-related metrics in the CALIOP observations

CALIOP observations (extinction, SABL depth, DARF) in the SHL region will likely enhance knowledge of dust-dynamics interactions

There is a need for long time series of vertically resolved "aerosol" observations (lidar) > 10 yrs to extract trends in emissions (link near-surface extinction with SABL depth)