A long time series of Metop/IASI observations of Saharan aerosols distribution

V. Capelle, A.Chédin , N. Scott, C. Crevoisier , R. Armante, L. Crepeau

LMD, Ecole polytechnique/CNRS/IPSL, Palaiseau (France) ***http://ara.lmd.polytechnique.fr***

virginie.capelle@lmd.polytechnique.fr

Aerosols represent one of the dominant uncertainties in radiative forcing, partly because of their very high spatiotemporal variability, a still insufficient knowledge of their microphysical and optical properties, or of their vertical distribution. Observations from space offer a good opportunity to follow, day by day and at high spatial resolution, dust evolution at global scale and over long time series. Infrared observations allow retrieving dust aerosol optical depth (AOD) as well as the mean dust layer altitude, daytime and nighttime, over oceans and over continents, in particular over desert. Therefore, they appear complementary to observations in the visible. By its excellent calibration and stability and the expected long time series of observation, the Infrared Atmospheric Sounder Interferometer (IASI), on board the suite of European Satellite Metop A, B and C, launched respectively in October 2006, September 2012 and November 2018 is particularly suited for accurate monitoring of dust evolution. Here, IASI observations have been processed pixel by pixel to derive a time series of more than 14 years long of 10µm dust AOD and mean altitude. The method used is detailed in Capelle et al., RSE (2018). It is based on a physical approach relying on the use of Look-up-Tables (LUTs) of simulated IASI cloud-free brightness temperatures computed for a large selection of atmospheric situations, for extended ranges of variation of surface properties (spectral emissivity, temperature, and pressure), as well as of dust optical characteristics.

IASI contribution to the observation of dust emission over the Sahara

Objective : separate fresh emitted from aged transported dust

IASI can provides constraint on the altitude of the aerosol layer that can help distinguishing aged transported from fresh emitted dust

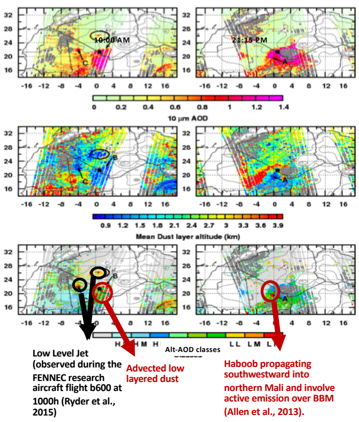
Method :

- Daily IASI AOD and Altitude are gridded at 0.5°
- Only cloud-free spots are processed.
- Dust events are classified according to the altitude: high-medium-low altitude
- A dust emission index (DEI) is derived from the probability of dust emission events

Dust aod/alt classification on daily analysis

- **For identifying dust emission, altitude and AOD are binned in one unique information**
- **9 ALT/AOD classes are defined** :
  - ⇒3 categories of altitudes: Low : alt<1.1km, Medium 1.1km<alt<2.4km, High: 2.1 km < alt < 4km
  - ⇒3 categories of aods : High: aod > 0.8, Medium: 0.5 < aod < 0.8, Low: 0.2<aod<0.5
- **Dust with AOD>0.5 and altitude < 1.1km** (**LM** and **LH** classes) corresponds to probable fresh dust emissions
- **Finally** a **Dust Emission Index (DEI)** is defined as the **frequency of occurrence of the classes LM and LH,** estimated for mean **monthly, seasonal, and annual** values over the IASI period and normalized by the total number of cases observed (clear sky, with or without dust).
- Note that due to the quite poor IASI time coverage (two observations per day) low level transported dust may sometimes be considered as local emission. This should be improved using a much higher temporal sampling such as the one planned for IRS.

Fig.1: Example of IASI results for the 17th June 2011 at 0930 hr (left) and 2130 hr (right): AOD (top), altitude (middle), AOD-altitude classes. Dark gray applies for clouds detected by IASI (Chédin et al., JGR, 2020).



The IASI Dust Emission Index (DEI) climatology

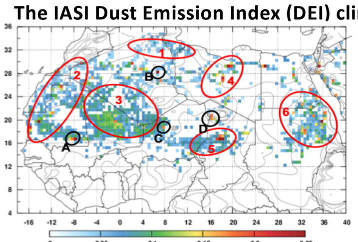


Fig.2: IASI 0.5° resolution DEI for the period July 2007- December 2018, morning + evening (Chédin et al., JGR, 2020). The red contours delineate the main potential broad-scaled source area identified on Figure 1 of Formenti et al., ACP (2011): (1) northern Algeria and Tunisia, (2) southern Atlas and western Sahara-Mauritania, (3) Mali-Algerian border, (4) central Lybia, (5) Chad Bodele paleo lake, and (6) southern Egypt-northern Sudan. The black contours indicate more locally known area of dust emission.

⇒ **DEI allows characterizing the spatial distributions of the main dust source areas**

⇒ **Good correspondence with other previous** studies including ground-based visibility data, analysis of chemical/mineralogical composition of the aerosol and underlying soil, and satellite observations (see refs. in chédin et al., JGR, 2020).

⇒ Of particular importance in the IASI DEI are large regions of high dust emission: **southwestern Algeria-northern Mali, Algeria-Mali-Niger triple point** (together they constitute region 3), **Bodele Depression, central Mauritania, northern Sudan.**

Morning versus evening seasonal IASI-DEI variations

Morning versus evening DEI variations can be interpreted as a different response to the varying meteorological conditions, leading to different dominant dust uplift mechanisms:

- **nocturnal low-level jet (NLLJ)**, which **drives dust emissions peaking in the midmorning** when the LLJ momentum is mixed to the surface after sunrise
- **convective cold pools**, occurring when downdraughts in moist convective systems spread out at the surface whose strong winds generate dust fronts (haboobs), occur preferentially **during the afternoon and nighttime** **(**but may also occur during a larger diurnal window).

Example over the Bodele region

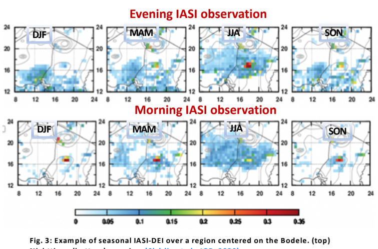


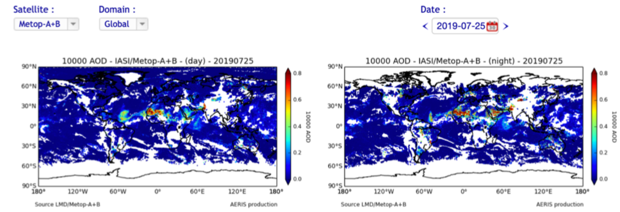
Fig. 3: Example of seasonal IASI-DEI over a region centered on the Bodele. (top) Nighttime, (bottom) morning (Chédin et al., JGR, 2020).

- During most of the year, DEI values on Bodele are higher in the morning than evening, **consistent with extensive previous work highlighting the morning peak in LLJ-driven dust emission**
- In summer, nighttime DEI is larger than morning DEI. **In summer, haboob systems are most prevalent** in the region likely associated with a marked evening peak in convection and rainfall in the region

Visualization/distribution on AERIS

- IASI/**METOP-A**, IASI/**METOP-B** and IASI/**METOP-C** data are processed daily in near-real time (day-1) in terms of 10µm AOD and mean layer altitude.
- Results can be visualized, as well as downloaded from AERIS webpage: https://iasi.aeris-data.fr/dust-aod/

DUST-AOD from IASI (Level 2)



IASI/Metop-A data access

IASI/Metop-B data access

Long-term analysis: Dust AOD trends detection

Rationale:

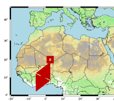
Detecting trends in geophysical variable time series requires taking into account:

- Weak values of geophysical trends
- Non-Gaussian samples
- Presence of « holes », « outliers » or large interannual variations in the data
- Presence of serial correlations

Method (Chédin et al., Atm. Res., 2018) :

1. **0.5 ° gridded monthly mean AOD** are determined (median rather than the mean)
2. **morning** and **evening** time series are calculated **separately**
3. For each pixel, time series are **deseasonalized** and **whitened** (deserialized)
4. **Trends** are determined using **the non-parametric Theil-Sen slope estimator** followed by the Mann-Kendall statistical test
5. Resulting trends are judged to be significantly different from zero if their so-called "confidence level" is above a given percentage, usually 95% (="real" trends)
6. The **number of years** of data required to detect a "real" trend of a specified magnitude with **probability 0.9** ("probability-assigned real" trend) is finally determined following (Tiao et al., 1990)

Example of Bordj_Badji_Mokhtar



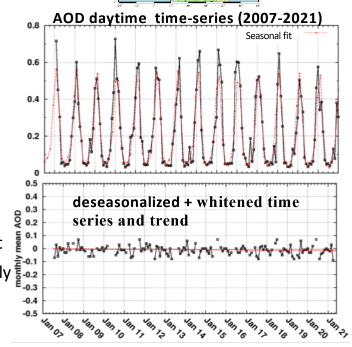


Fig. 3: IASI AOD morning time series for the (2.25E, 21.25 N) 0.5° grid-point located close to the AERONET site of Bordj_Badji_Mokhtar. Top-left: original AOD time series (black) and seasonal fit (dotted red); bottom: whitened time series and linear trend slope (red).

Global morning and evening trends over 2007-2021

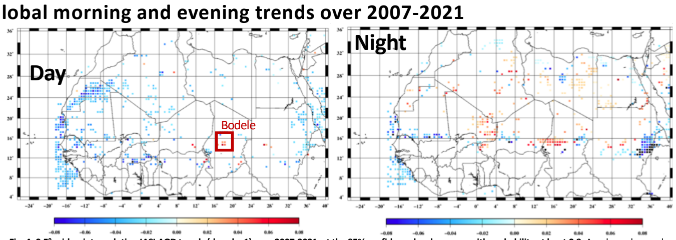


Fig. 4: 0.5° grid-point resolution IASI AOD trends (decade–1) over 2007-2021 at the 95% confidence level or more with probability at least 0.9. Are shown here only the pixels for which the number of years required is not larger than the years available (here 14). Right: from am IASI data; left: from pm IASI data.

- Several 0.5° grid-points present significant trends for which the number of years required to be assigned a probability of 0.9 is not larger than 14
- Significant trend are principally located in the main potential dust source regions (see Fig.1)
- Trends are essentially negative in the morning, in agreement with the literature (AERONET, etc..), except for the Bodele. There are mostly positive in the evening, with however some negative trends within the Sahelian band.
- The difference in the trend sign between morning and evening might be related to the different uplift processes involved throughout the day.