The Infrared Difference Dust Index

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Abstract

The **Infrared Difference Dust Index** (IDDI) derived from Meteosat IR, “First Generation“ (MFG) is a dust indicator over land during the middle of the day. It is defined as a space **radiance contrast** or **brightness temperature contrast** arising from dust presence, especially effective over arid and semi-arid surfaces, including cases at low altitude.The IDDI is then relevant to study **emission** of dust particles from desert sources and **transport** of dust plumes.

An **upgraded IDDI** version is now available. A **24-year IDDI database over Africa** (1982-2006) has been realized with Meteosat at 0°. A secondary **IDDI database over SW Asia** (1998-2007), arising from the presence of Meteosat-5 at 63° E, has been added to the archive.

In this presentation, I will (i) recall the physical bases of IDDI, (ii) describe the new IDDI algorithm and present examples of the resulting products and (iii) show results in relation with various applications and researches, using the data from the new base:

- Desert dust sources climatology;
- Study of dust emission and transport;
- Relations between dust and clouds;
- Long-term heating/cooling evolution;
- Desertification/humidity recovery.

Basics

Remote sensing with terrestrial radiation :

Source = Earth surface

Atmosphere observation by <u>transmission</u>

like

Sun photometry :

Source = Sun surface

Atmosphere observation by <u>transmission</u>

different of

Remote sensing with solar radiation :

Source = Sun surface

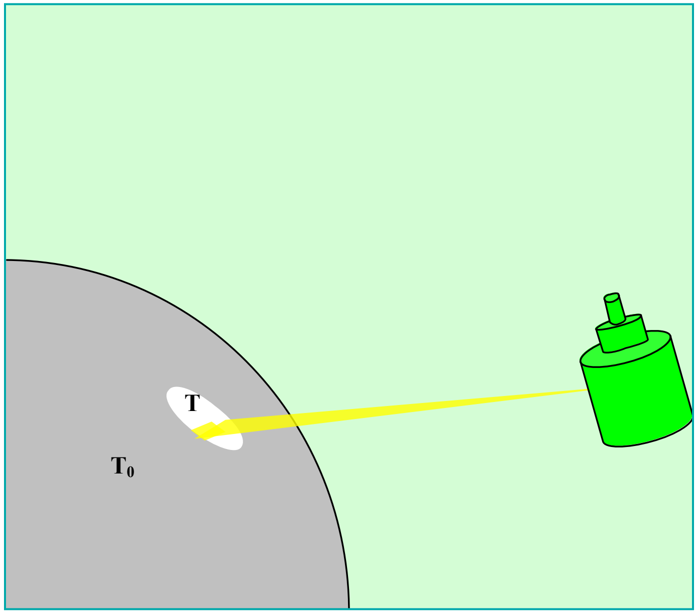
Atmosphere observation by <u>reflection</u>

MFG: IR channel
10.5-12.5 µm (IRT)

Geostationary

What is measured?
Radiance
Brightness temperature

Physical bases
Contrast of an object



A real surface is never perfectly black: instead, it is characterized with an emissivity ε: $0 < \varepsilon < 1$.

- Contrast definition (with the radiances):

$$C = L - L_0$$

Radiance and brightness temperature are related by:

$$L = B(T^*)$$

B is the blackbody function.

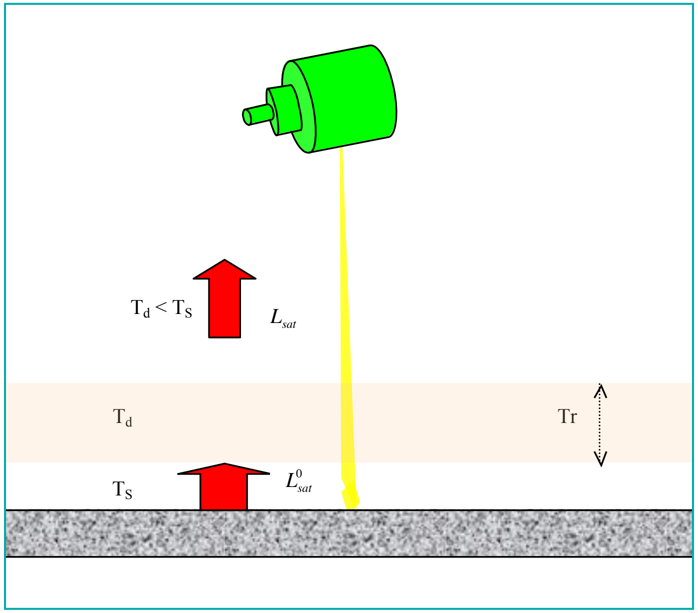
- **H1**: Object and Earth's surface black in the TIR;
- **H2**: No atmosphere:

$$T^* = T$$

A definition of the object contrast can be given with the brightness temperatures (BT) as well:

$$C = B(T) - B(T_0) \qquad C_T = T^* - T_0^* = T - T_0$$

Thermal contrast of a dust layer



Estimating dust impact (i.e.contrast) using the simplifying assumptions needs values for T_S, T_d and Tr (or dust optical depth δ in TIR)

Let us consider this question for mineral dust over an arid area (Sahara, Sahel in the dry season)

- Dust layer: semi-transparent absorbing, scattering and emitting object.
- Simplifying assumptions:
- **H1**: absorbing gases not considered
- **H2**: surface assumed black, at temperature T_s
- **H3**: dust layer assumed non scattering and isothermal at Td, with transmittance Tr
- Radiance outgoing to space:

without dust: $L^0_{sat} = B(T_S)$

with dust: $L_{sat} = Tr.B(T_S) + (1 - Tr).B(T_d)$

- Dust impact (contrast):

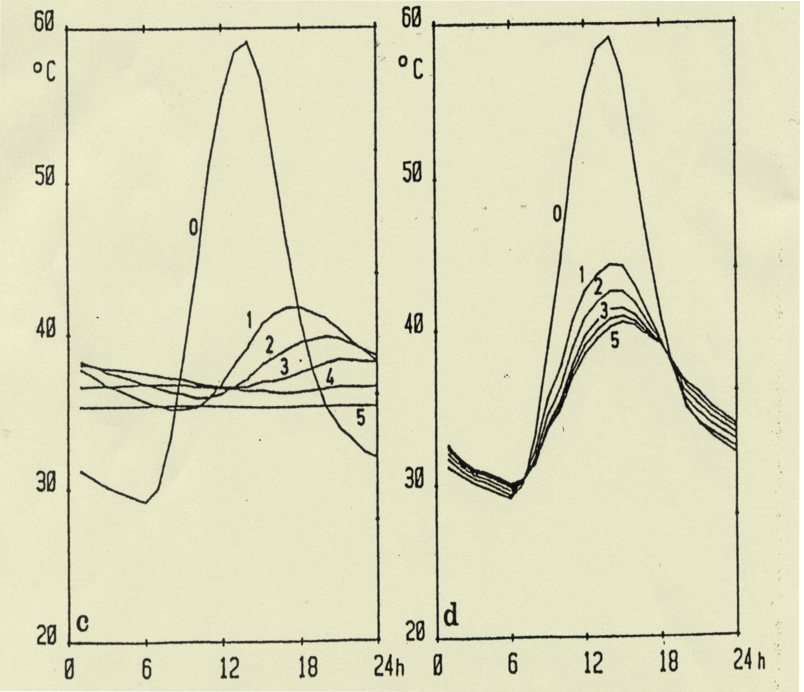
$$\Delta L_{sat} = (1 - Tr).[B(T_d) - B(T_S)]$$

- The radiance contrast (defined as > 0) is **$|\Delta L_{sat}|$.**
- The BT contrast (defined as > 0) is:

$$C_T = |T_d * - T_s|$$

- it is maximum for Tr = 0, at **$|T_d - T_s|$.**

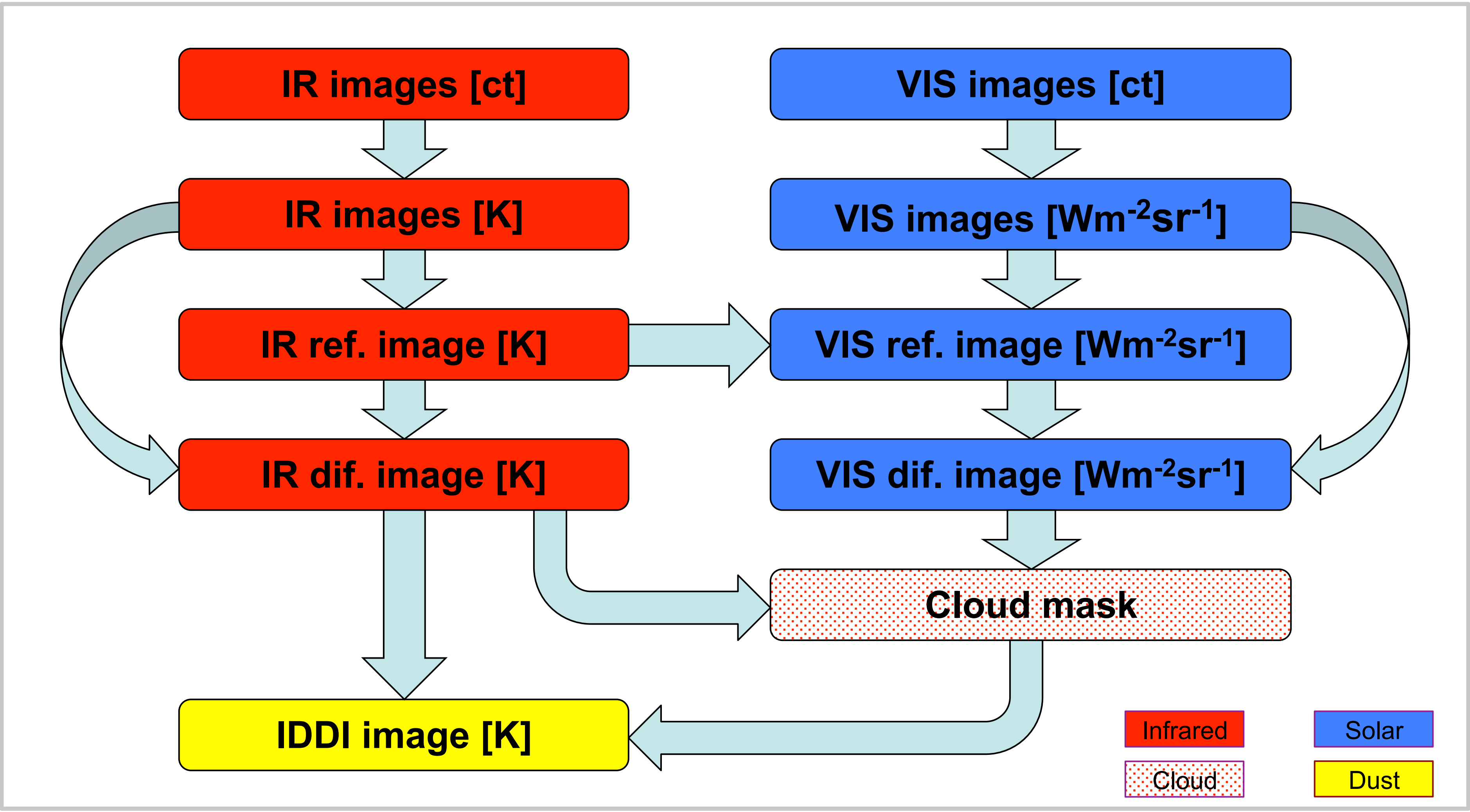
Skin temperature of an arid surface



Standard diurnal temperature variations (c) in the ground and (d) in the air. Level 0 is at surface, levels 5 are at 90 cm (c) and 6 m (d). Yantala campaign North of Niamey, end of dry season (Frangi et al. 1992).

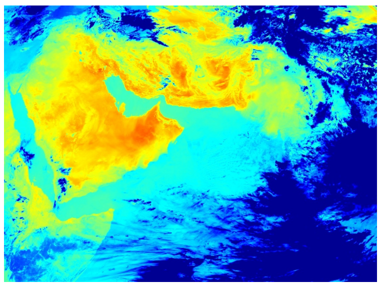
- A large amount of solar energy is absorbed by an arid surface during daylight and mostly confined within a thin soil layer (< 1m) under the surface.
- As a result the surface temperature undergoes a diurnal cycle with a large amplitude alternating strong heatings and coolings (amplitude 30°C, maximum 60°C for T_s).
- A strong daylight superadiabatic lapse rate is observed in the first meters (especially the first centimeters) of atmosphere over the surface (up to 60°C/m).
- The superadiabatic lapse rate is modeled as a large temperature discontinuity between ground surface and atmosphere during daylight (19°C at 12 LST).
- Even in the air at soil contact, dust is 15-20 K colder than the surface, giving rise to a large temperature contrast in midday.

New IDDI algorithm scheme (BT in K)

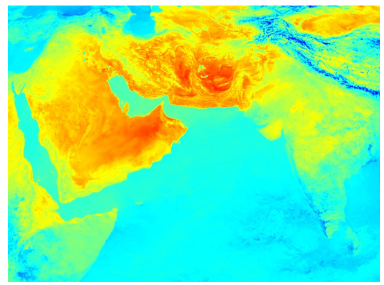


IDDI algorithm images
(MFG 5 - 63°E – 10/06/1999 @ 8:00 UTC)

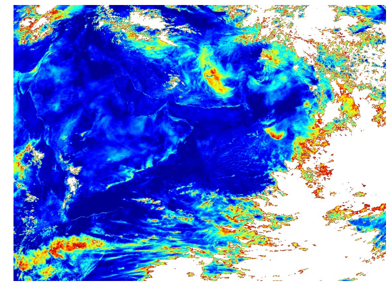
Daily IR



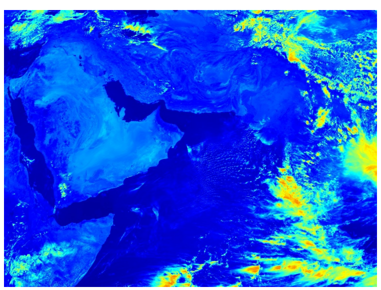
IR reference



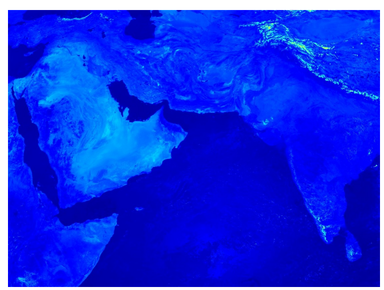
IR difference



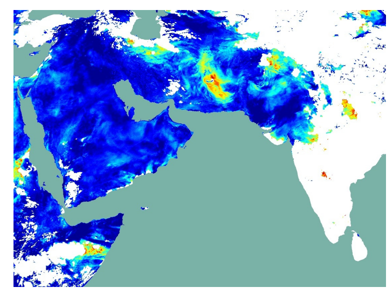
Daily VIS



VIS reference

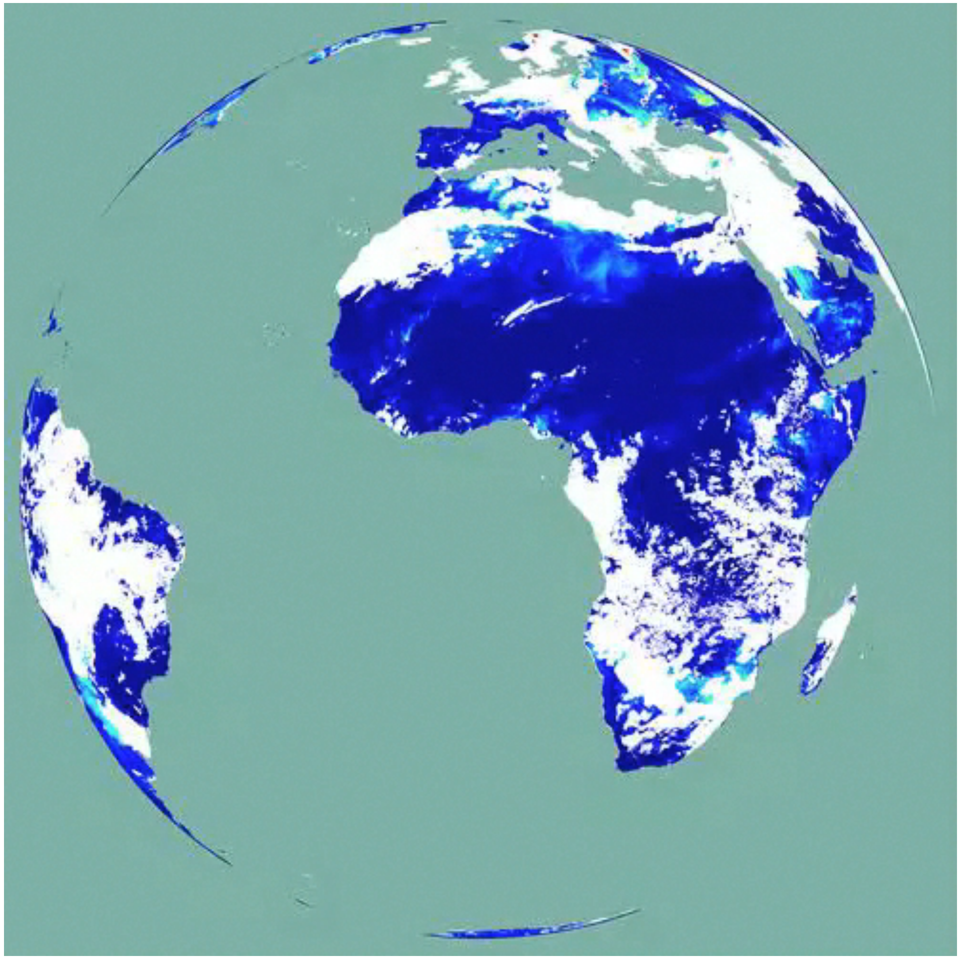


IDDI



Increasing IR and VIS radiances & BT from blue to red (BT scale from 250K to 340K).
Increasing IR BT differences and IDDI from blue to red (IDDI (K) scale from 0 to 25 K).

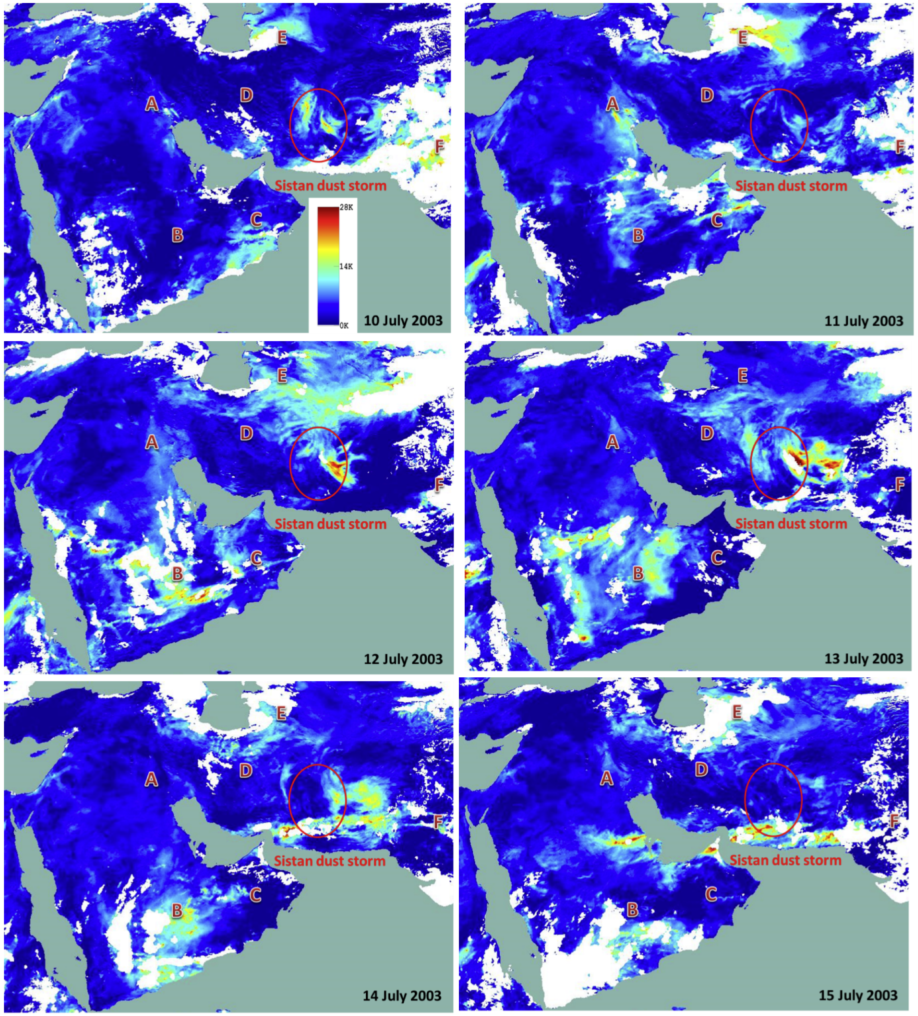
Sources activity in Africa (February 1992)



Video QuickTime:
“sources_1992-02-22.mov“
(external to the diaporama).

Note the presence of stationary dust plumes anchored to sources of the “Sahelian belt“. The sources are activated by the surface wind associated to the proximity of a pressure low.

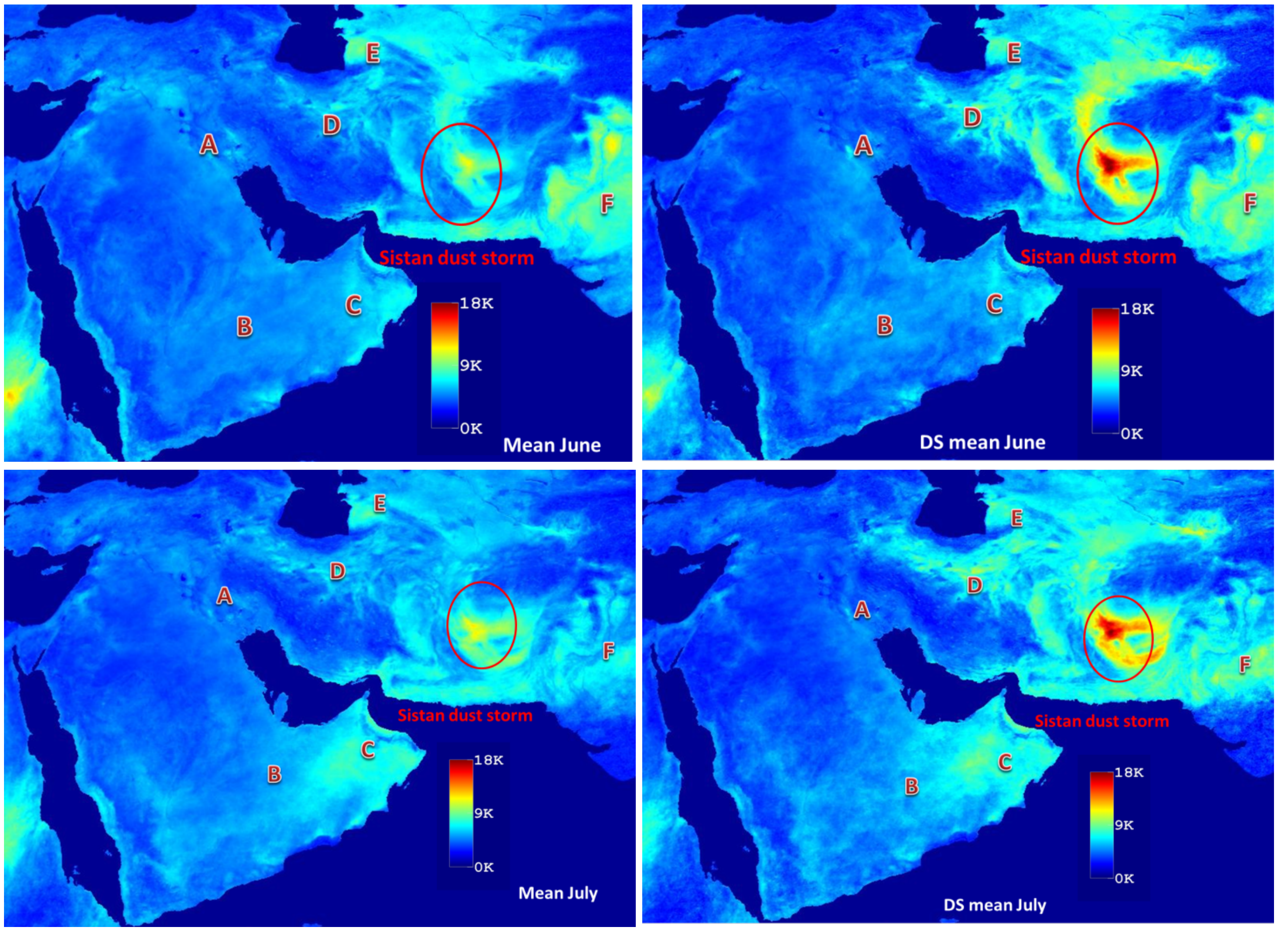
Generation of dust storms from the Sistan source, Iran – 10-15 July, 2003



The Sistan source is located around the Hamoun lakes, near the borders of Iran with Pakistan and Afghanistan. Occurrence of completely dried lakebed during summers of dry periods, leads to strong dust storms (visibility range ≤ 1 km in the June-September season, making this source a prominent hotspot in the region. The figure shows successive dust outbreaks arising from this source, with IDDI values exceeding 30 K.

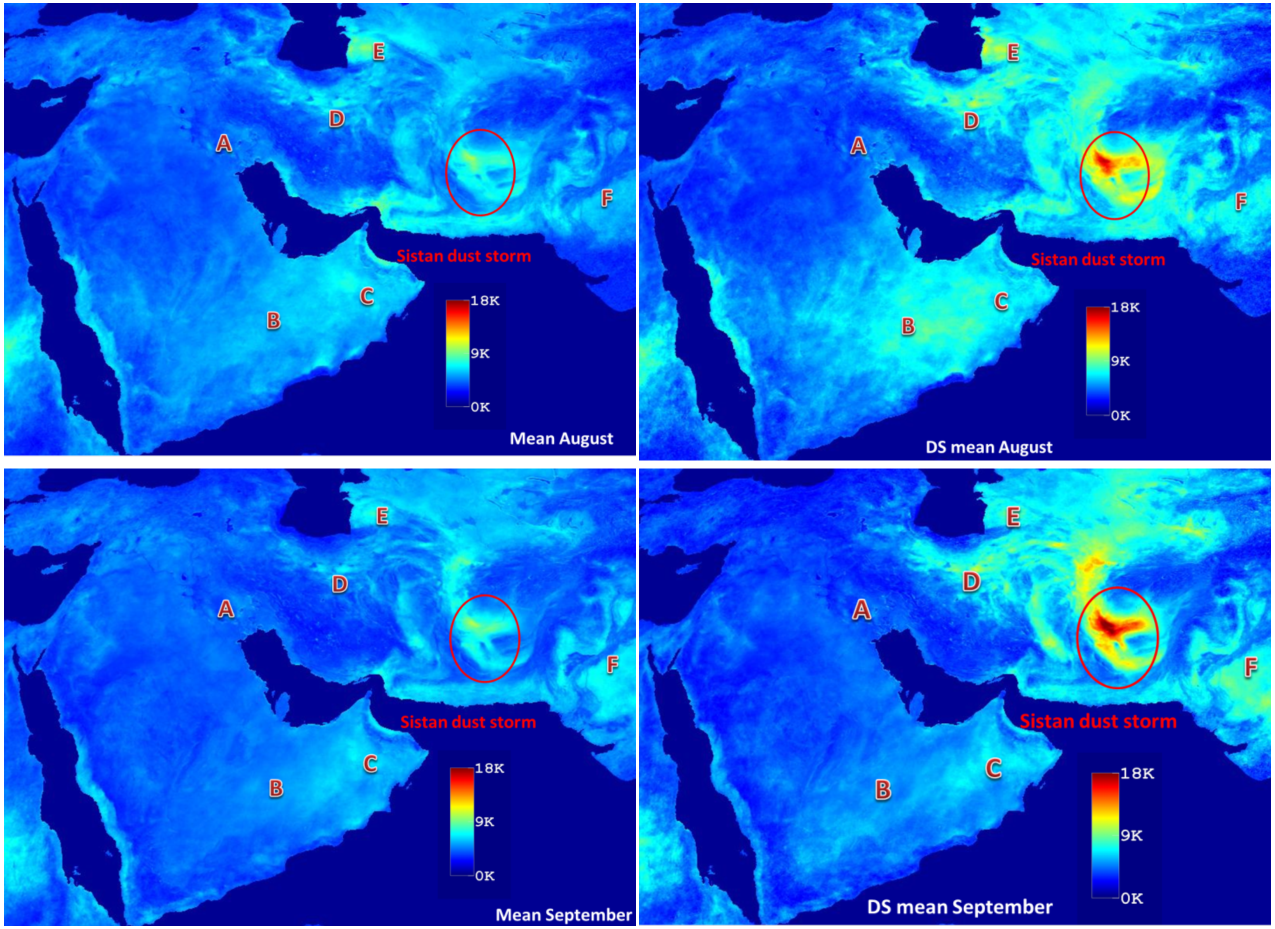
from Rashki et al., submitted

Mean monthly IDDI: all days – dust storm days 2001-2006 (June-July, Sistan)



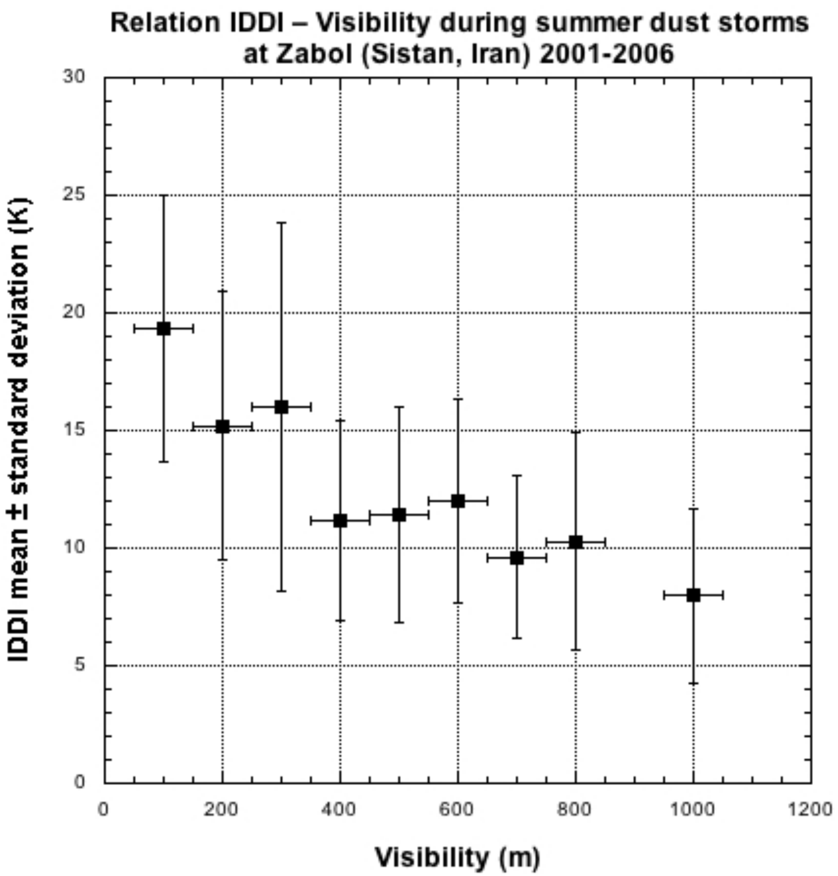
from Kaskaouti et al., submitted

Mean monthly IDDI: all days – dust storm days 2001-2006 (August-September, Sistan)



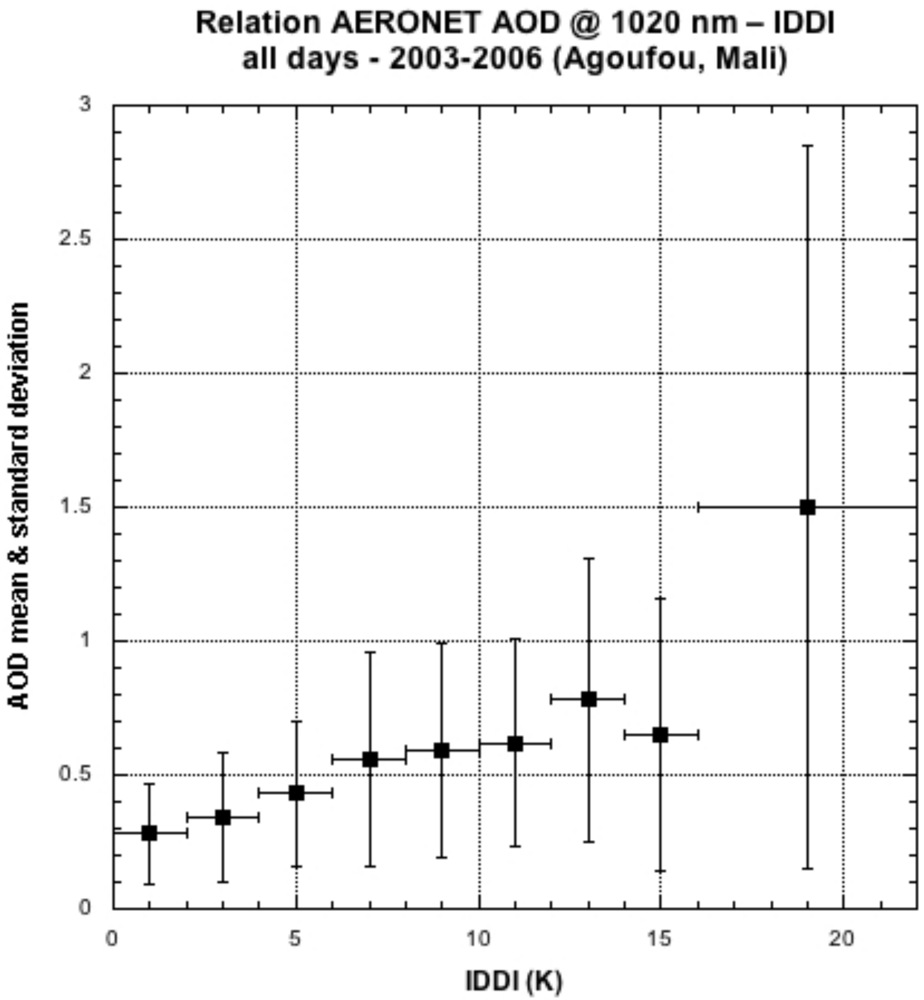
from Kaskaouti et al., submitted (cont'd)

IDDI against visibility range: dust storm days Jun-Sep 2001-2006 at Zabol (Sistan, Iran)

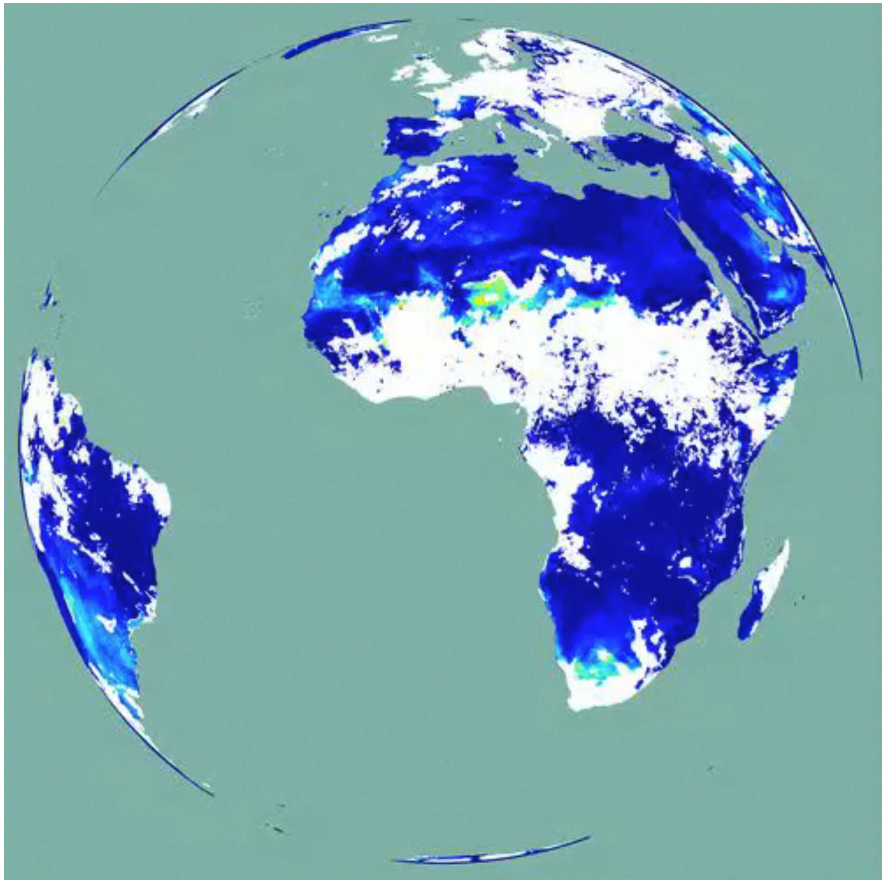


Horizontal visibility range is a reliable index of dust haze concentration (N'tchayi et al., 1994). So, a visibility range not exceeding 1 km, defines a dust storm (WMO).
In the figure are plotted the mean IDDI values for visibility bins 100 m wide covering the range from 0 to 1 km (no bin at 900 m).
The vertical bars are for ± σ (s.d.); the horizontal bars are for ± 50 m (Zabol, Sistan, Jun.-Sep., 2001-2006).

AERONET AOD @ 1020 nm against IDDI: all days 12-13 UTC – 2003-2006, Agoufou (Mali)



Dust transport over Africa toward Atlantic Ocean (July-August 1985)

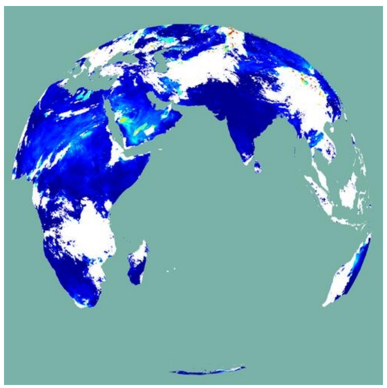


Video QuickTime:
“transport_1985-07-11.mov“
(external to the diaporama).

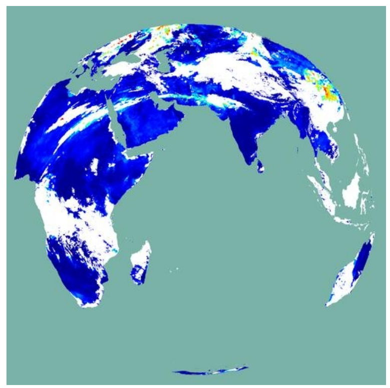
Dust plumes are emitted from the sources of the “Sahelian belt“ and are transported westward and expelled over the tropical Atlantic. The phenomenon is repeated with an approximate periodicity of a few days, giving rise to a real “dust-train“

Dust and Clouds:
An outstanding case of apparent interaction

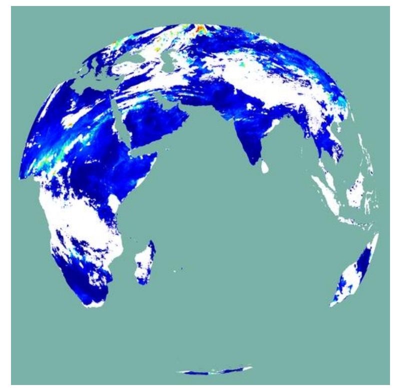
2000-01-30



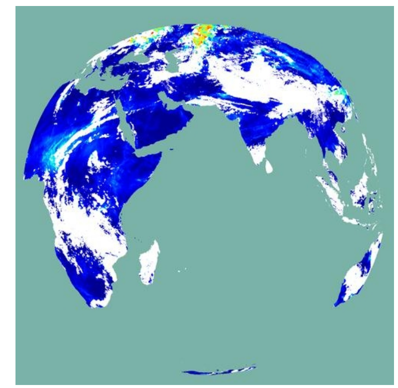
2000-01-31

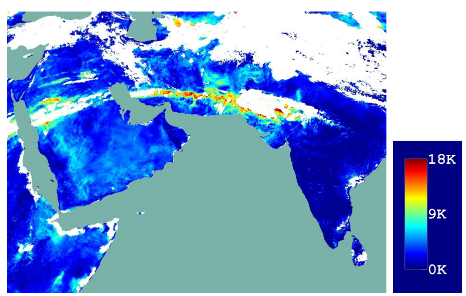


2000-02-01

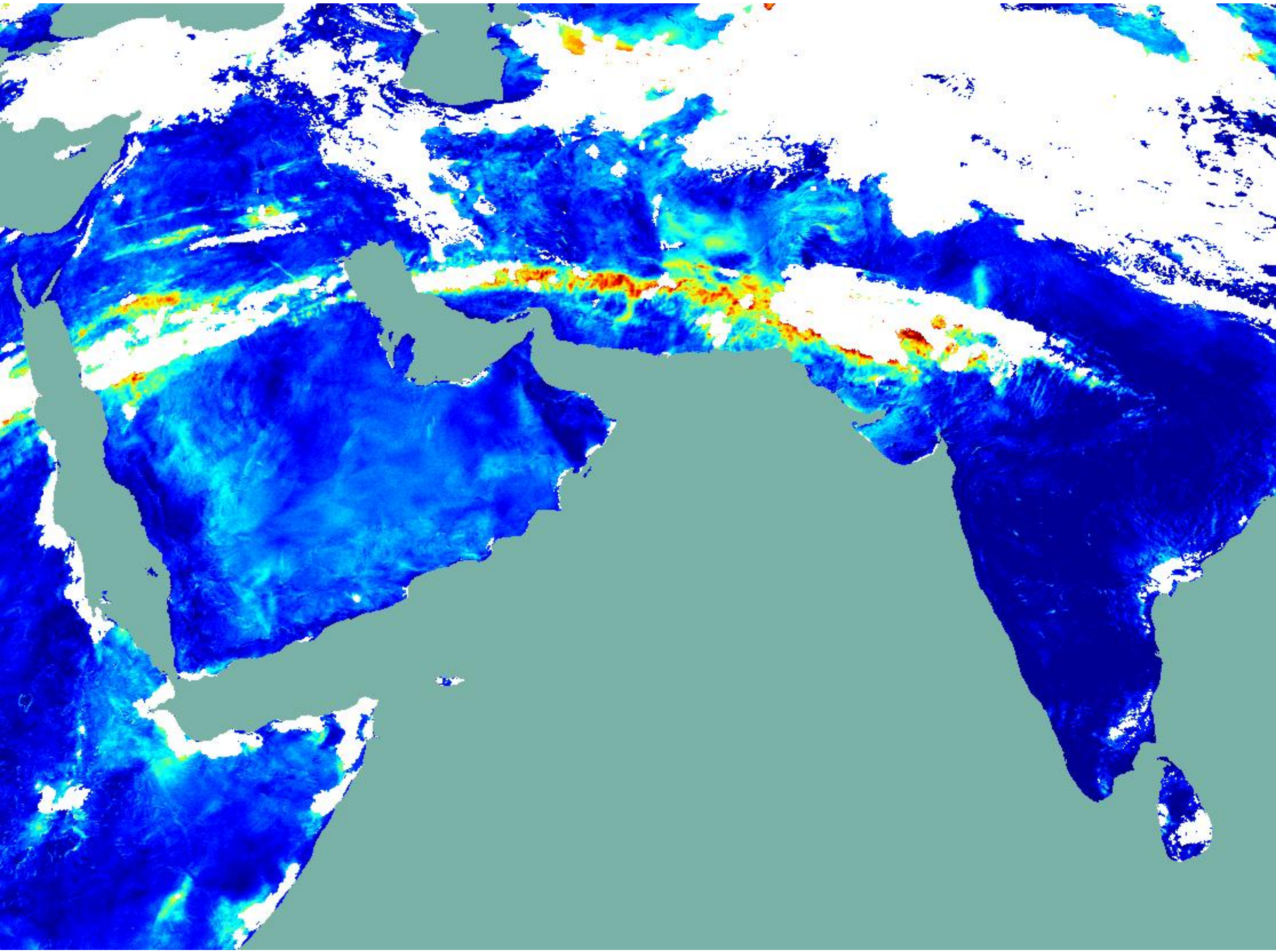


2000-02-02





The long-range structure is apparently an atmospheric jet, associated to the presence of both clouds and dust.
Is this structure an example of cloud-dust interaction?
Further study would be welcome.



Background for record-breaking statistics (from Anderson & Kostinski, 2010)

Considering the case of long time series, for example the annually averaged temperatures measured at a meteorological station over the 20th century, we know they show a statistical character with year-to-year fluctuations, meaning that a succession of hot years and cold years are occurring in a random sequence.
To estimate in the previous example whether the local temperature is increasing, decreasing or stationary, a usual statistical method is based on the regression technique. This classical method apart, it is also possible to apply the record-breaking statistics. It consists in considering successively every term of the series, starting with the first term, determining if it is a record-breaking event (the highest value met). It is easily shown that the expected number of records in a random time series of n terms (counting the first term of the series as a record) is:

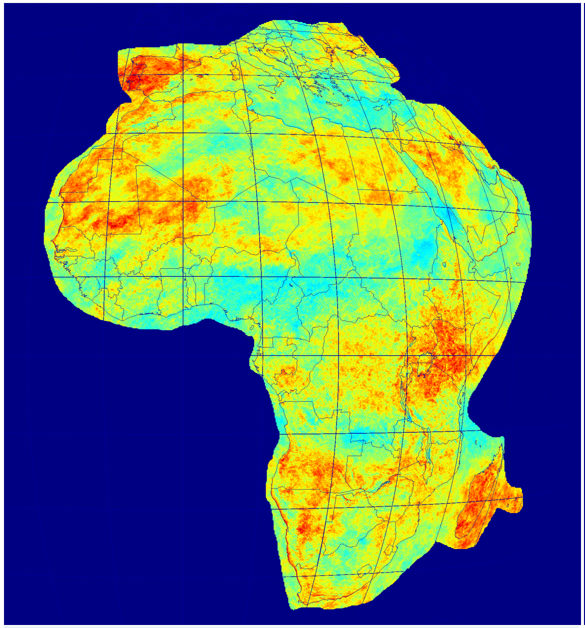
$$E(R) = 1 + 1/2 + 1/3 + ... + 1/n$$

Now, if a positive (resp. negative) bias of temperature is added to the random terms values of a stationary time series, the number of records will be higher (resp. lower) than *E(R)* in the formula above.
We apply this method to the BT imagery over the period 1985-2005, in order to determine if the BT has changed over this period. The application is performed at a given moment of the year in order to avoid the seasonal heating/cooling. The BT time series are 21 terms long, leading to E(R) = 3.6. Higher values, i.e. heating, are in red and lower values, i.e. cooling, are in blue in the following maps.

Long-term evidence of regional heating or cooling using the daily IR images over 1985-2005

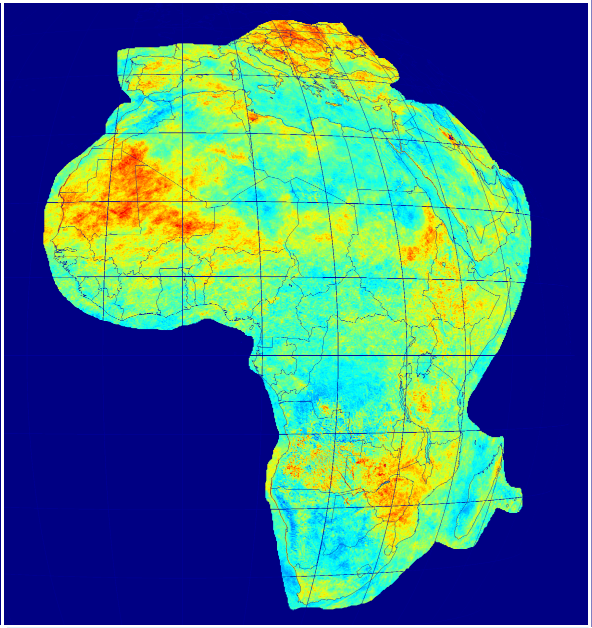
The record-breaking statistics show the existence of regional and seasonal BT increase and decrease.

April, 20-30



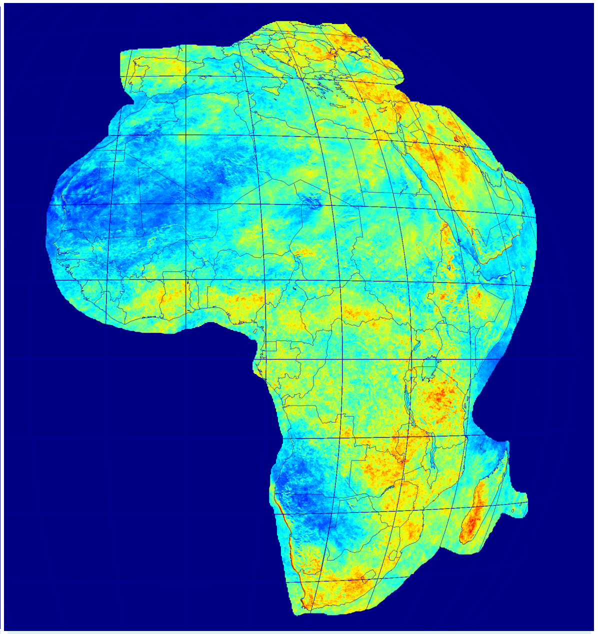
Quasi general heating or equilibrium over Africa and Arabia. Green regions are near equilibrium.

June, 20-30



Heating in western Sahel and Sahara, cooling in South Africa and Arabia.

November, 01-10



Heating in Arabia, cooling in western Sahel and Sahara, and in South Africa.

Summary on the current state of development and projects with IDDI

- MFG 2-7 at 0° – 1982 to 2006: ≈ **24-year archive of IDDI products** including not only IDDI images (binary and jpeg), but also calibrated IR and VIS images, reference and difference (IR & VIS) images, cloud masks and files for quality control.
- The first objectives of these data is to study the long-term (decadal) evolutions of (i) sources activity and dust emission and (ii) desertification/water recovery trends.
- The current database is planned to be extended beyond 2006 through adapted MSG data (which needs spectral channels and spatial resolution adaptations).
- MFG 5 at 63°E (Meteosat-INDOEX) – 1998-2007: a secondary 8-year archive developed in a collaboration with a team of scientists (located in India) on the study of very active dry-bed lakes sources in Sistan, at the borders of Iran, Afghanistan and Pakistan.
- More generally, **the IDDI images are intended to be used by our scientific community** for every subject to which it would be of interest. For this, a website is being created to access archived imageries.