Satellite observation of dust

Dust estimation via the Meteosat triple window IR (8.7µm, 10.8µm, 12.0µm)

jose.prieto@eumetsat.int

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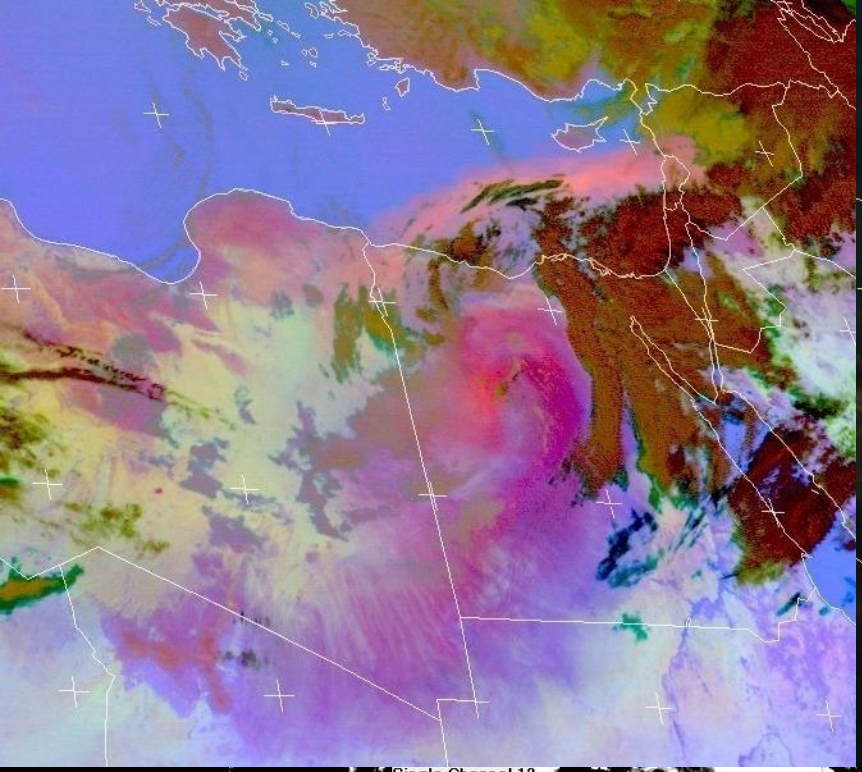
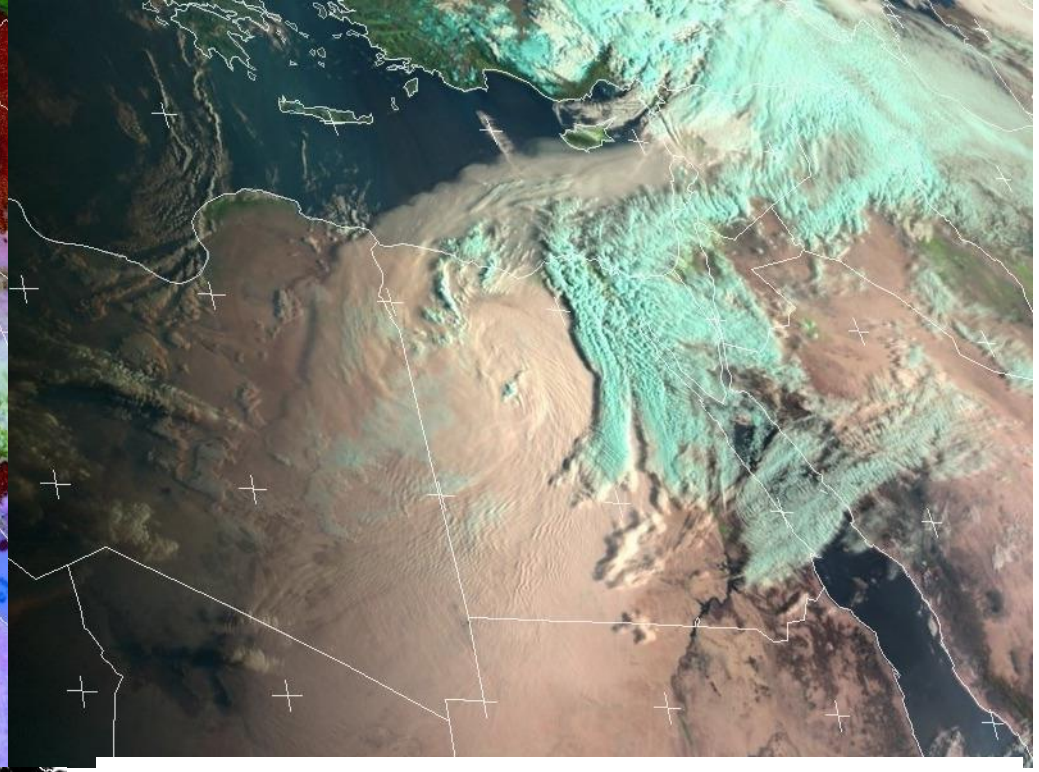
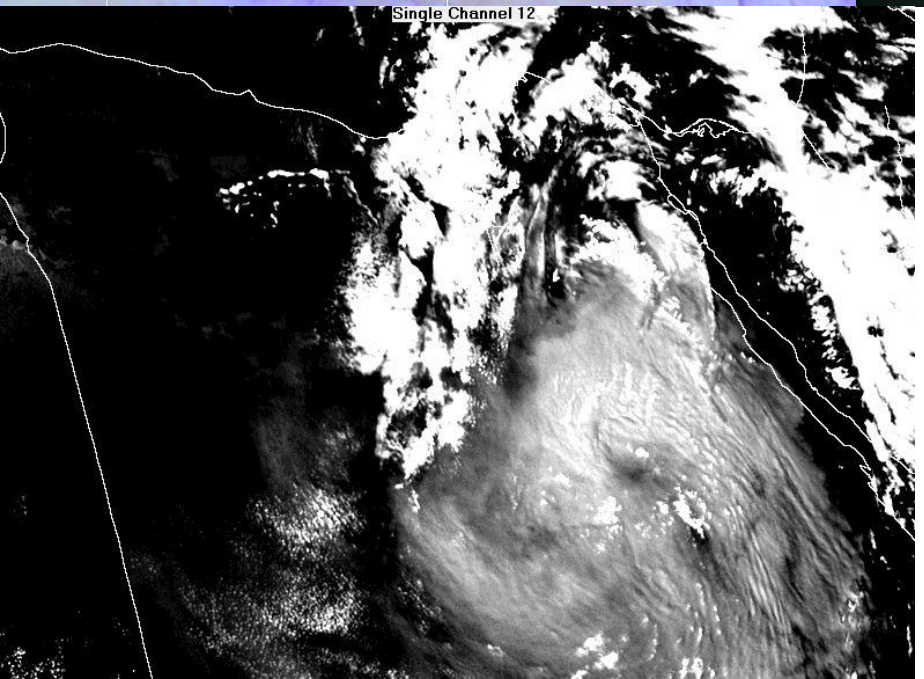
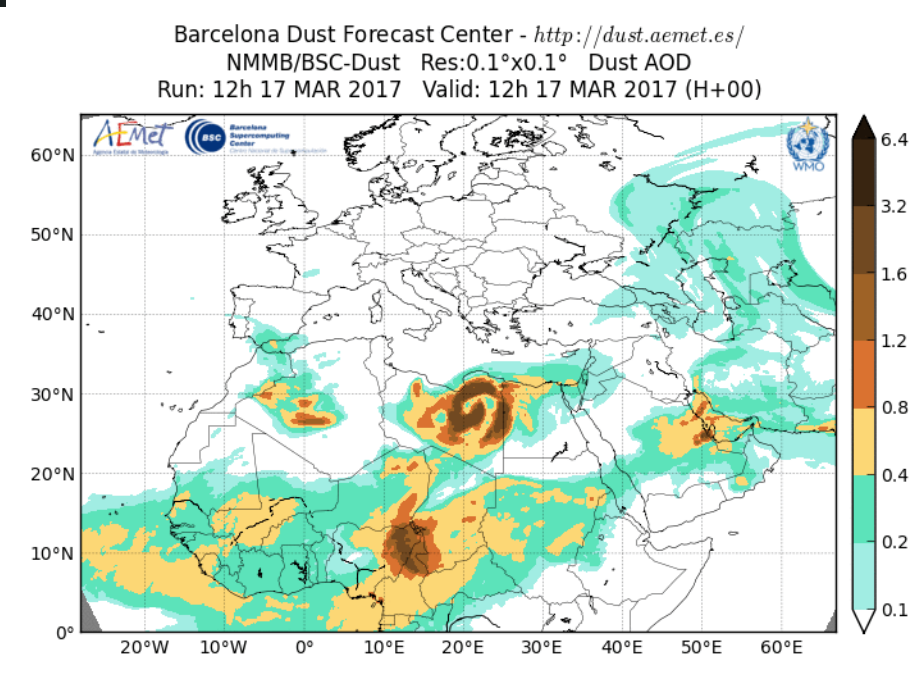
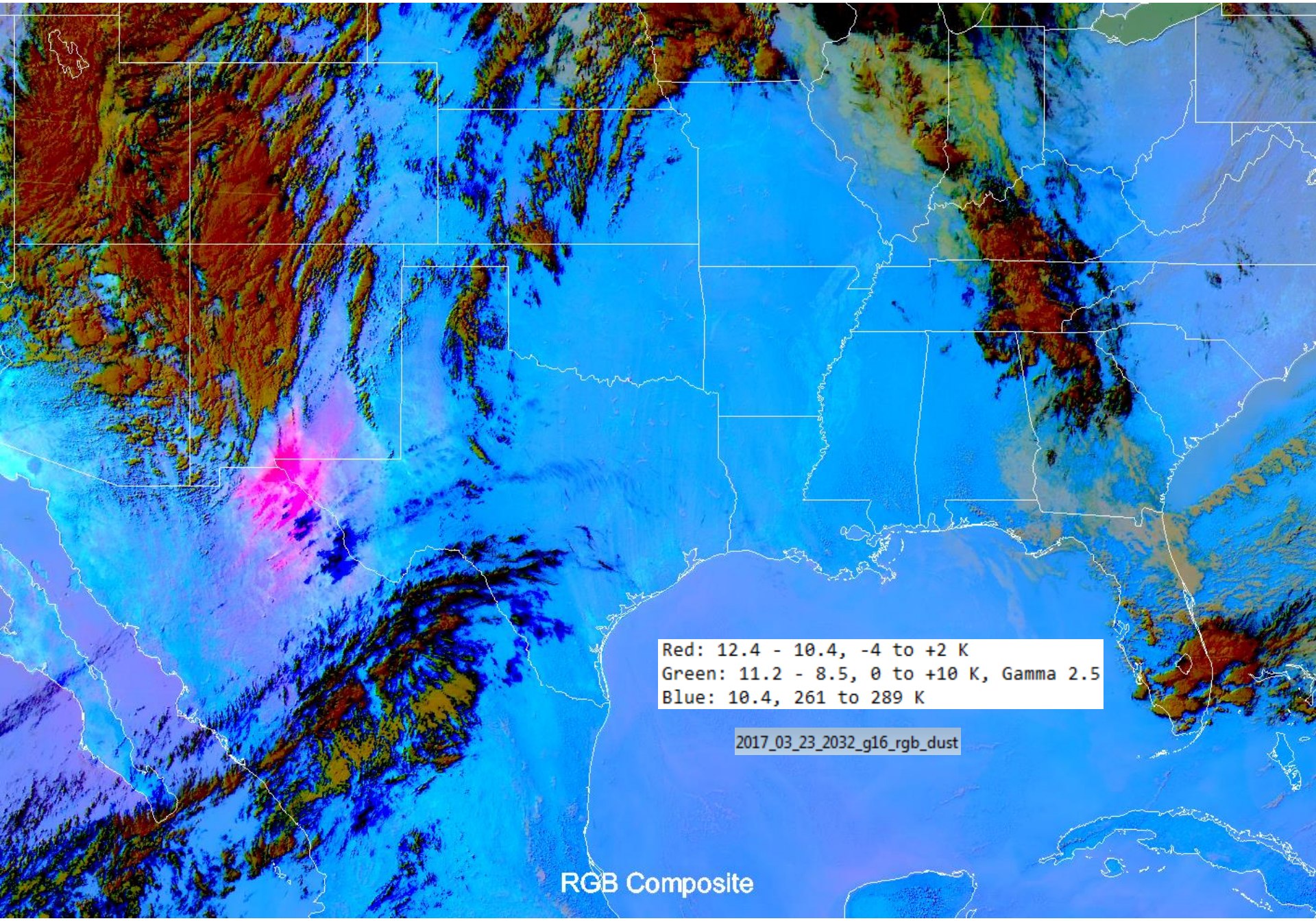





Single Channel 12


Barcelona Dust Forecast Center - http://dust.aemet.es/
NMMB/BSC-Dust Res:0.1°x0.1° Dust AOD
Run: 12h 17 MAR 2017 Valid: 12h 17 MAR 2017 (H+00)
60°N
50°N
40°N
30°N
20°N
10°N
0°
20°W
10°W
0°
10°E
20°E
30°E
40°E
50°E
60°E
6.4
3.2
1.6
1.2
0.8
0.4
0.2
0.1



GOES-16

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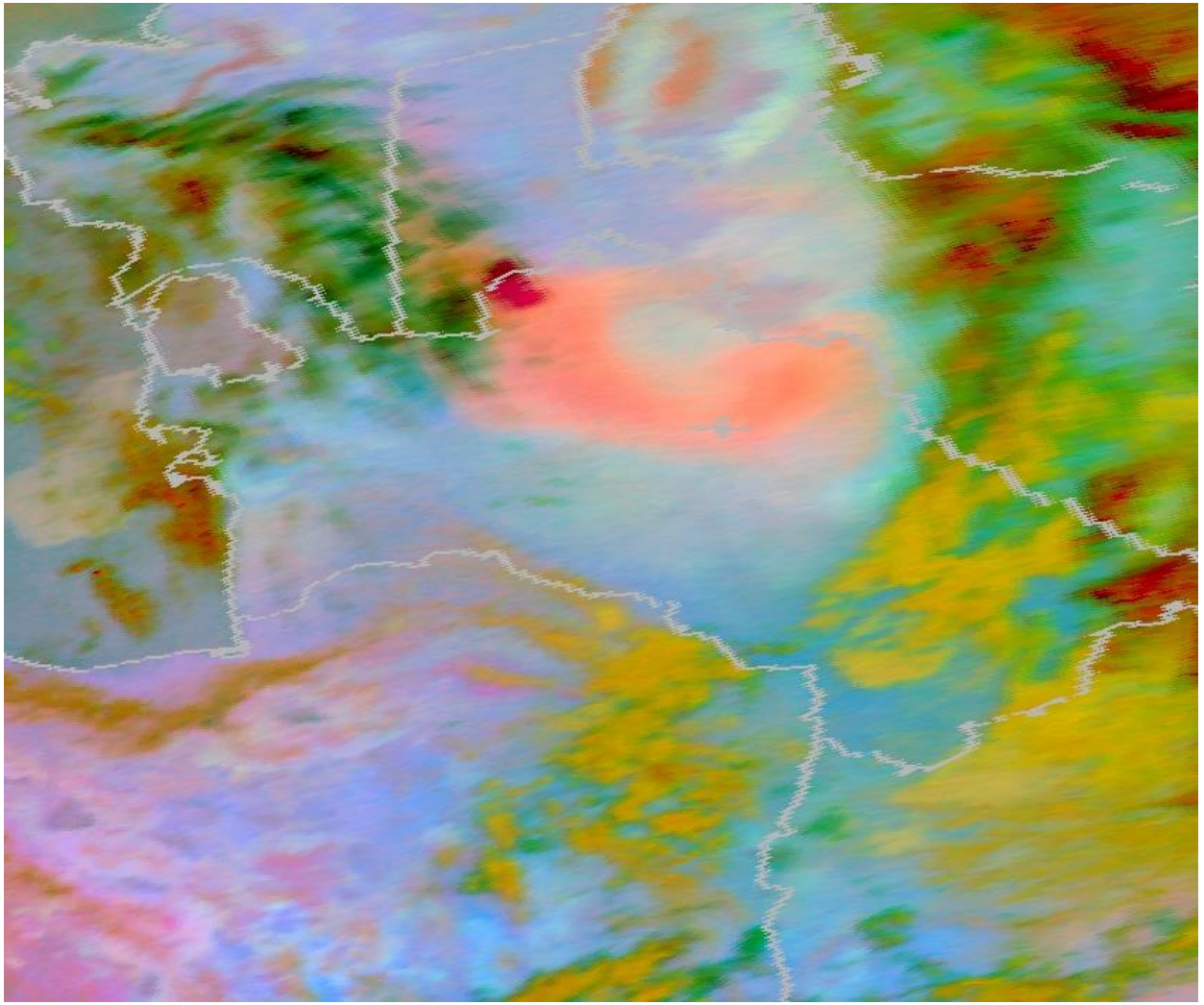
“Peach” for big particle dust



Met-10 2009-04-02 06Z Infrared window composite

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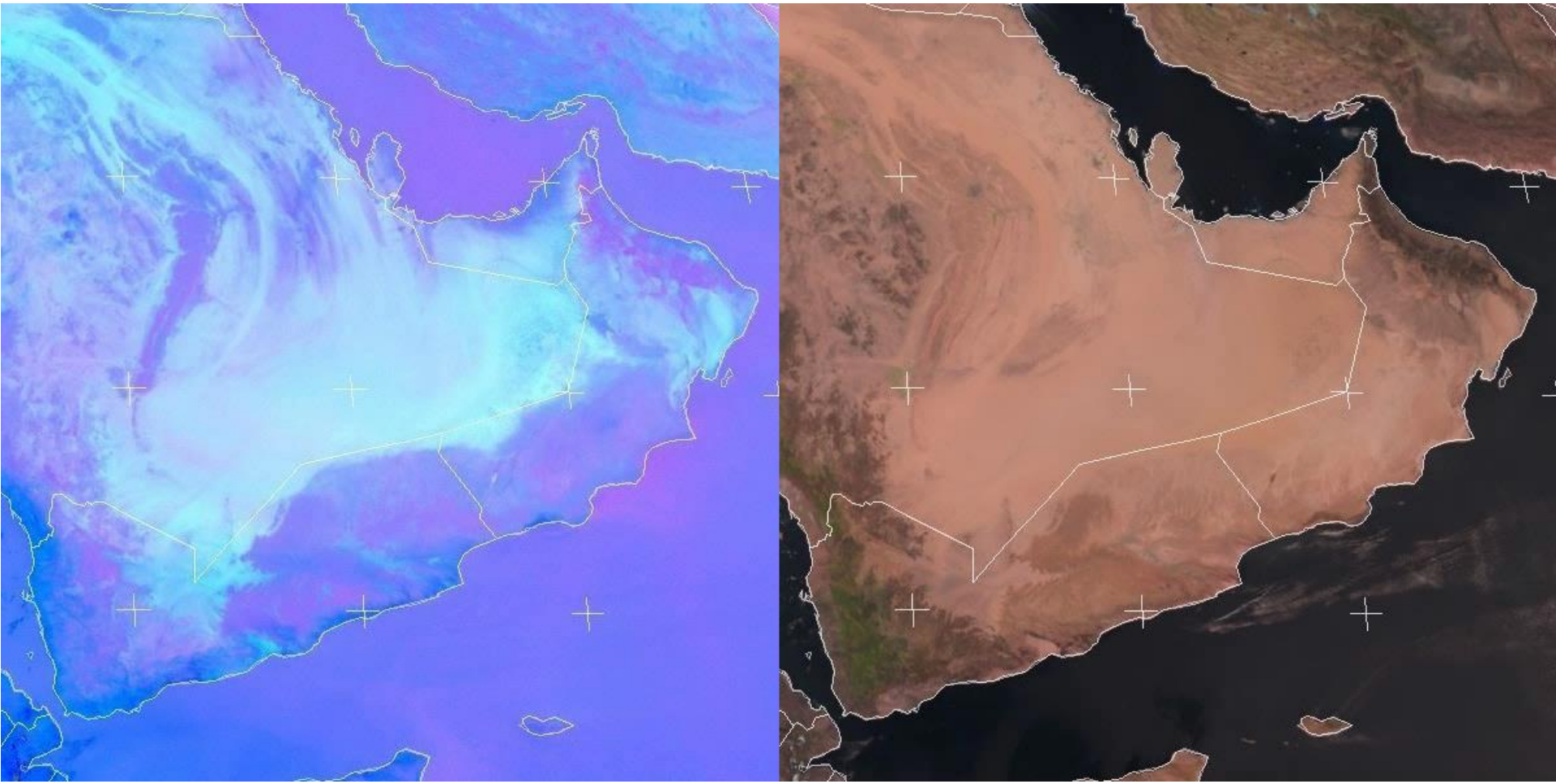
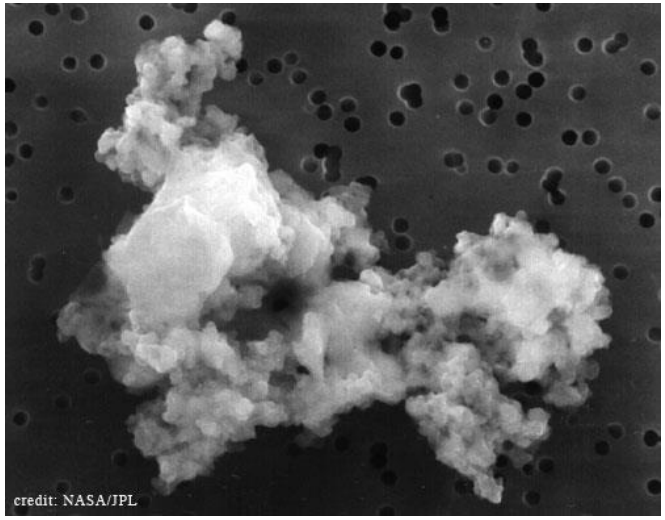
Animation

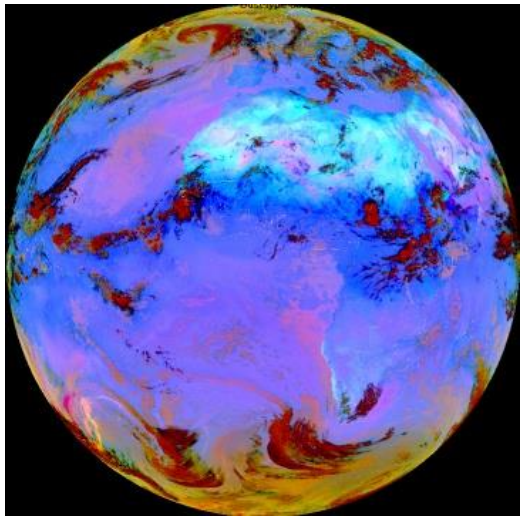


2017_05310600-06011100_m08

Can a satellite see dust particles ?



← Dust particle 10 µm →



← Earth globe 10 Mm →

- From micro to mega, twelve orders of magnitude difference in size
- 10^{12} kg in the atmosphere (10^{-7} of atmospheric mass) = fill all lorries!
- Disputed human contribution to global cooling (S.K. Satheesh, 2006)
- Inert tracer for atmospheric circulation
- Life vector (Saharan protozoa and bacteria to the Caribbean)

Better dust detection in the infrared?

Best contrast ?	DAY	NIGHT
IR		
VIS		

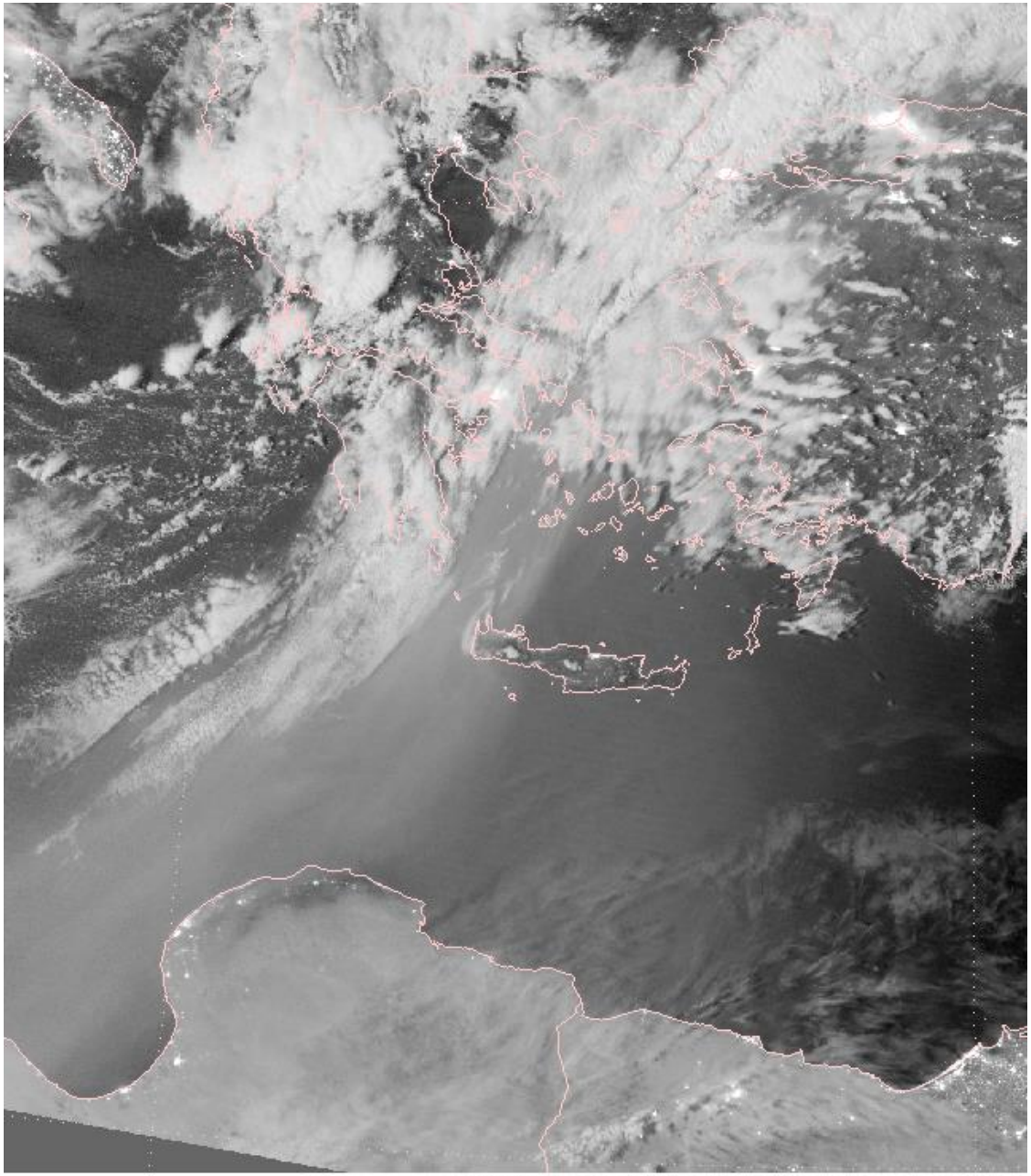
Choose one of the four fields, the one with best contrast between free-surfaces and dust areas

Ocean	DAY	NIGHT
IR	strong	strong
VIS	very strong	A/N/A

Desert	DAY	NIGHT
IR	very strong	weak
VIS	weak	A/N/A

Consecutive days in Fuerteventura, January 2010

- On IR imagery, dusty air appears cool in contrast to the hot **daytime** land surface. At **night**, the thermal difference between the background and the dust lessens. Dust is not raised by thermals, too.
- On VIS imagery over **water**, dust is easy to note. Over **land**, however, the dust plume and dry surfaces look similar



snpp DNB - 2015-02-01 23:45UTC

Dust at the moonlight

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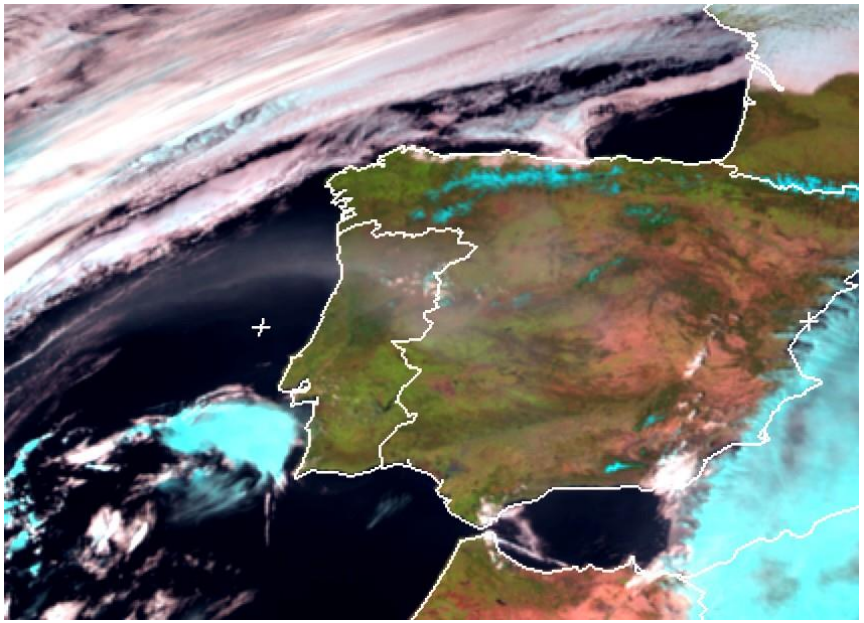
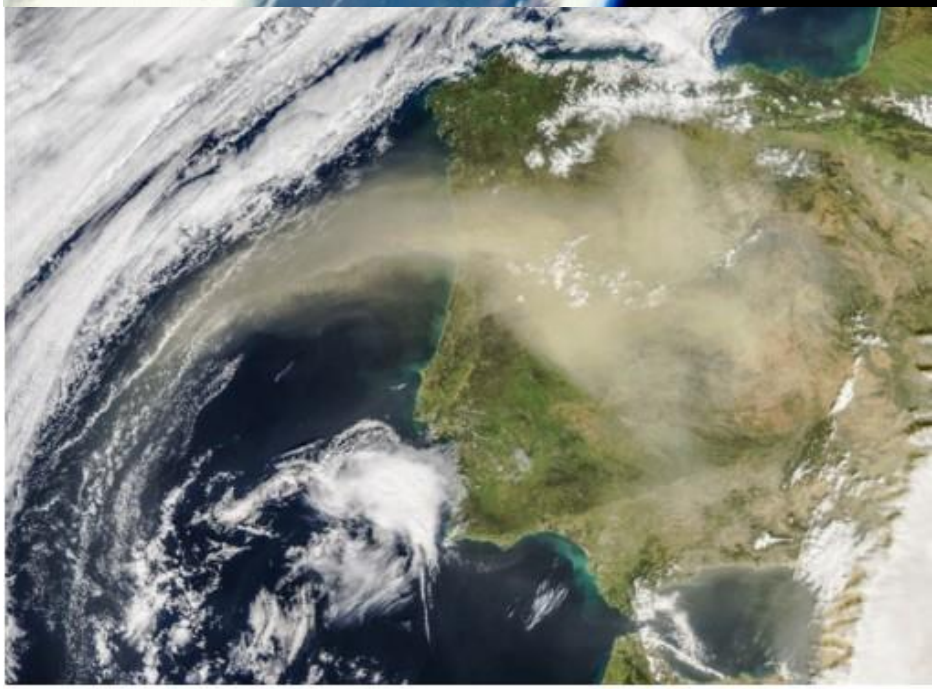




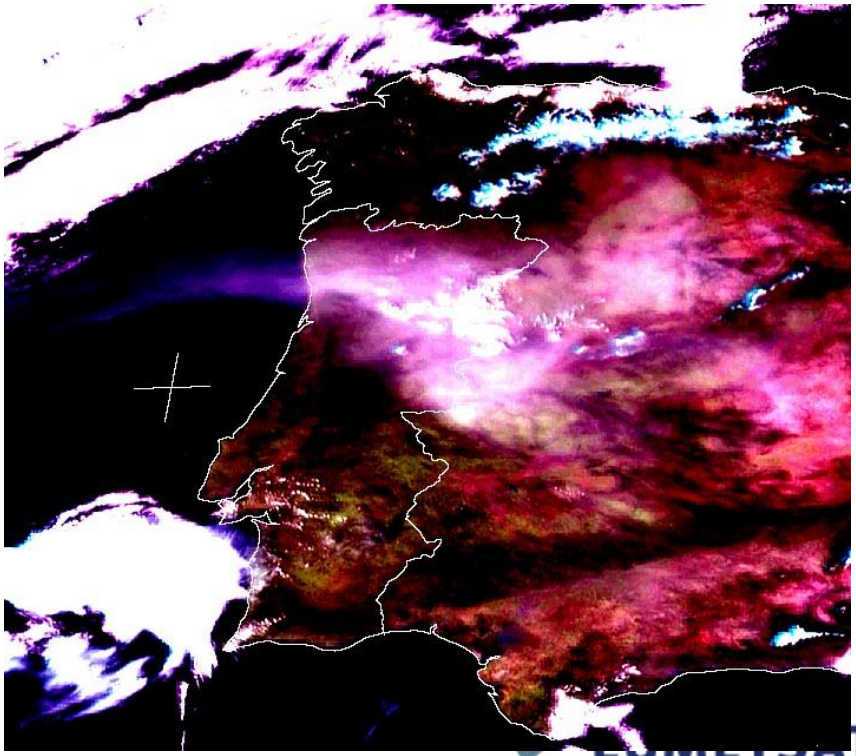
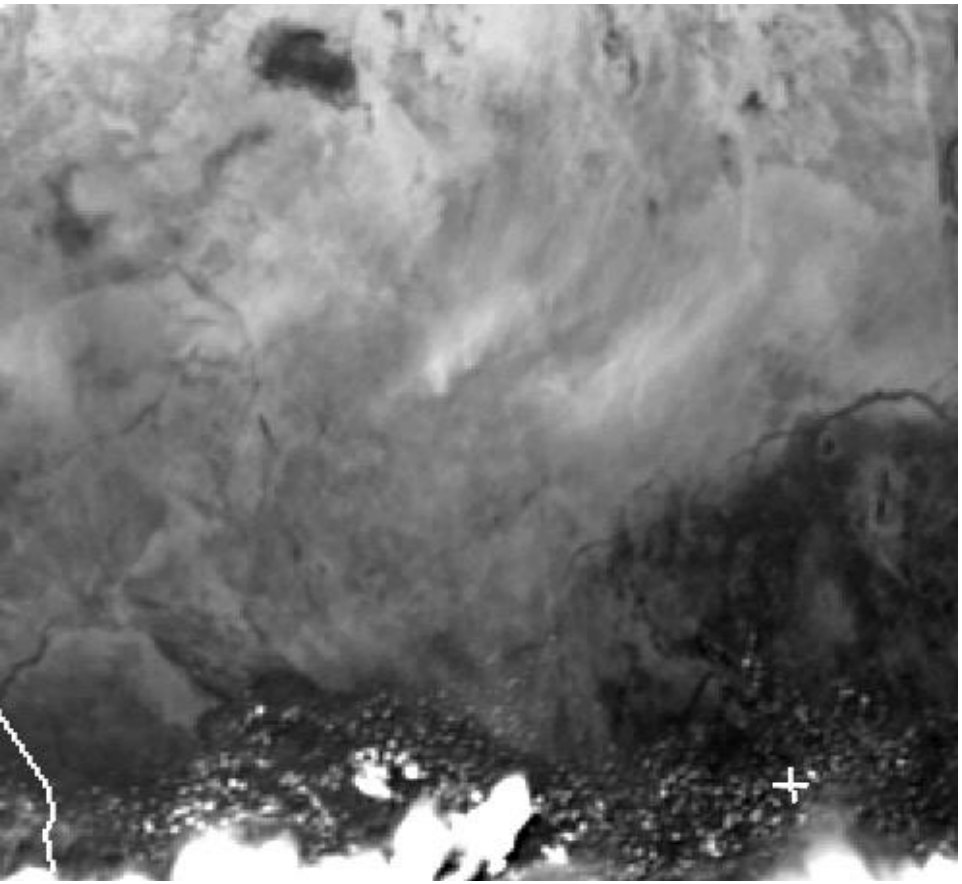


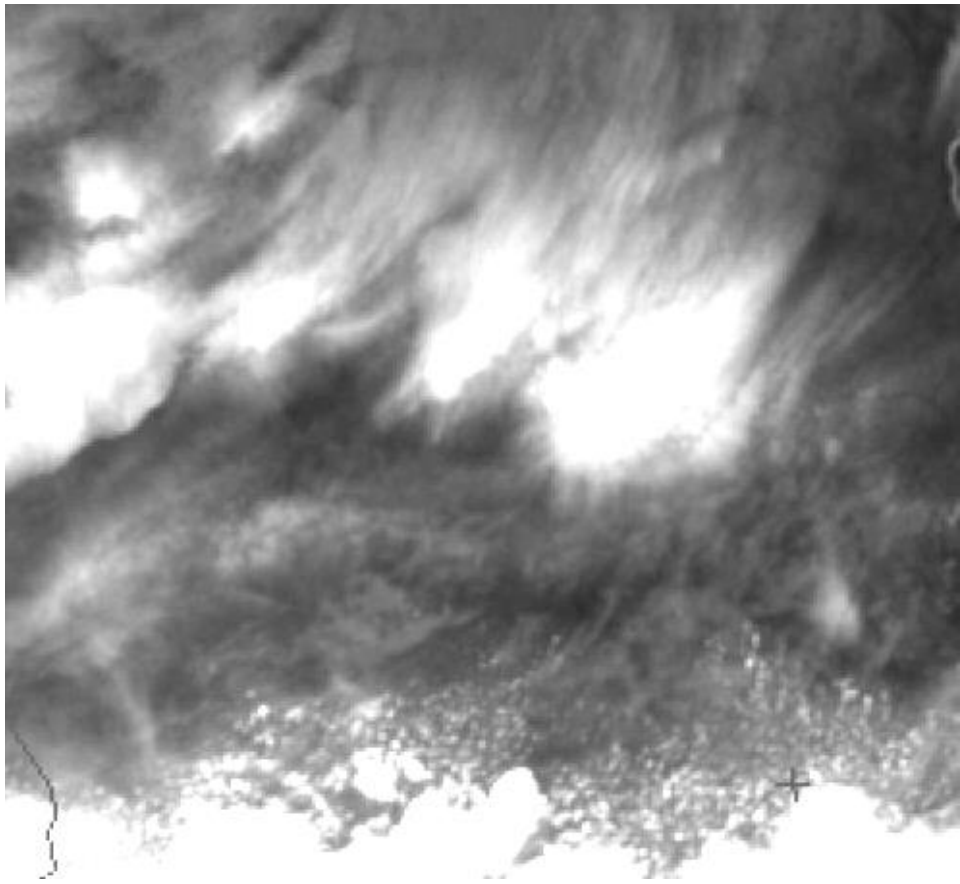
Fig. 1: immagine satellitare MODIS del 21.02.2016 alle 14:00 UTC (NASA'a Aqua- Earth)

Dust on solar and infrared images



2004-05-13 13:00 UTC, 0.8 µm

- Dust **reflects** back solar energy to space
- Midday, unfavourable reflection conditions



Same date and time, 10.8 µm

- Dusty air rises (**cools** down)

Desert scene, Sudan

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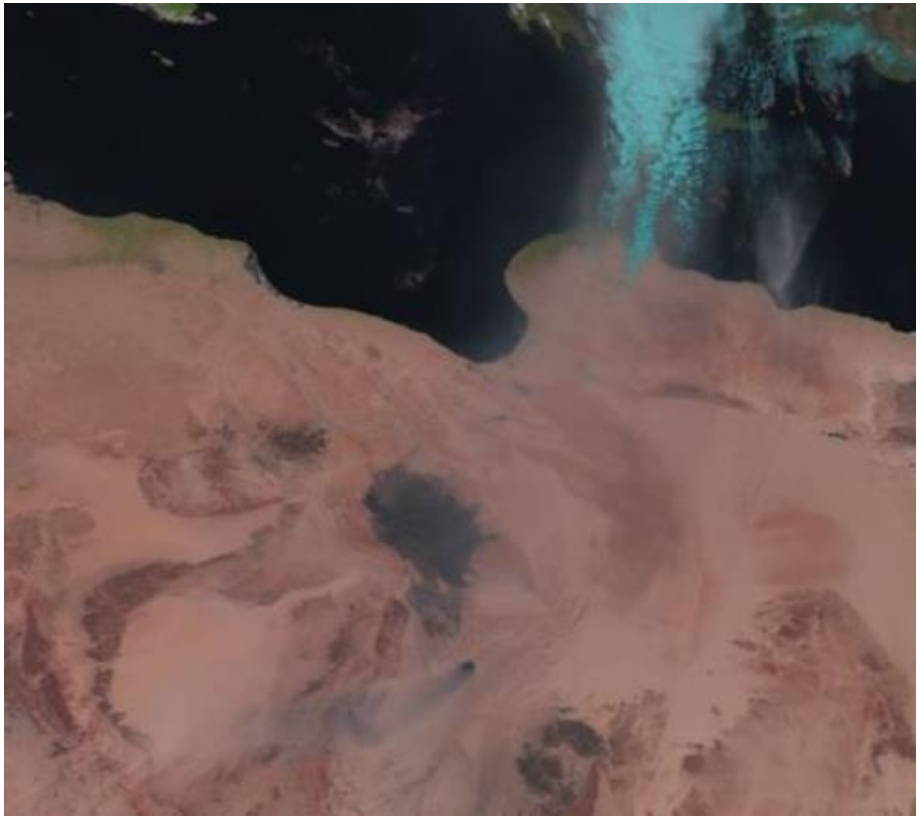
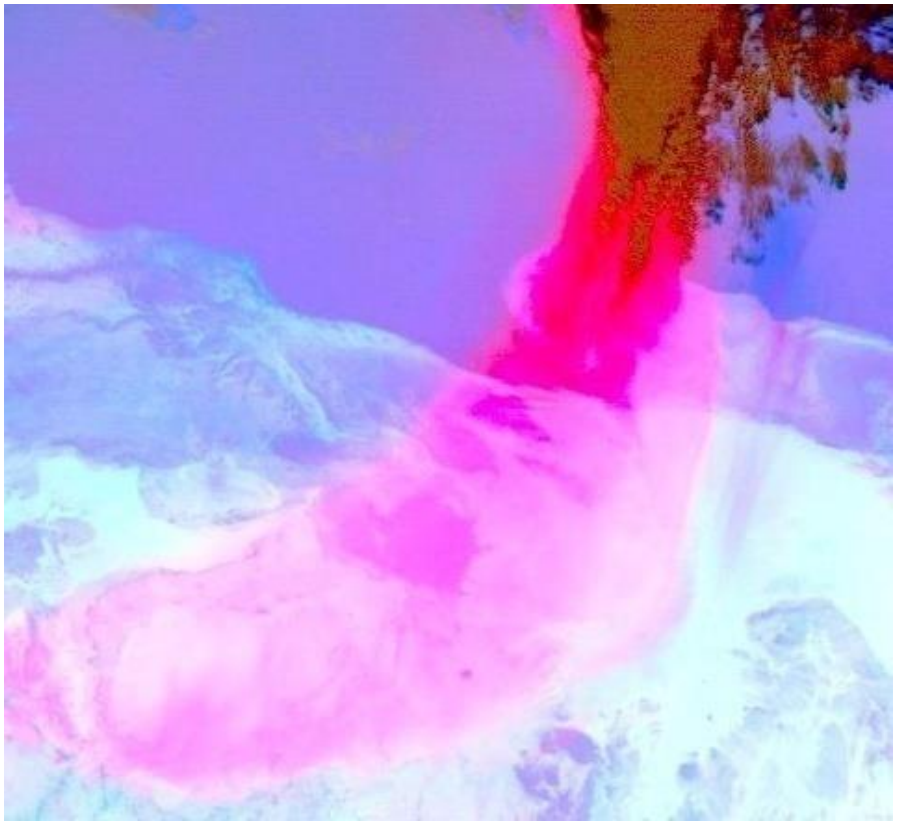
DUST RGB composite:
the strength of infrared for dust detection

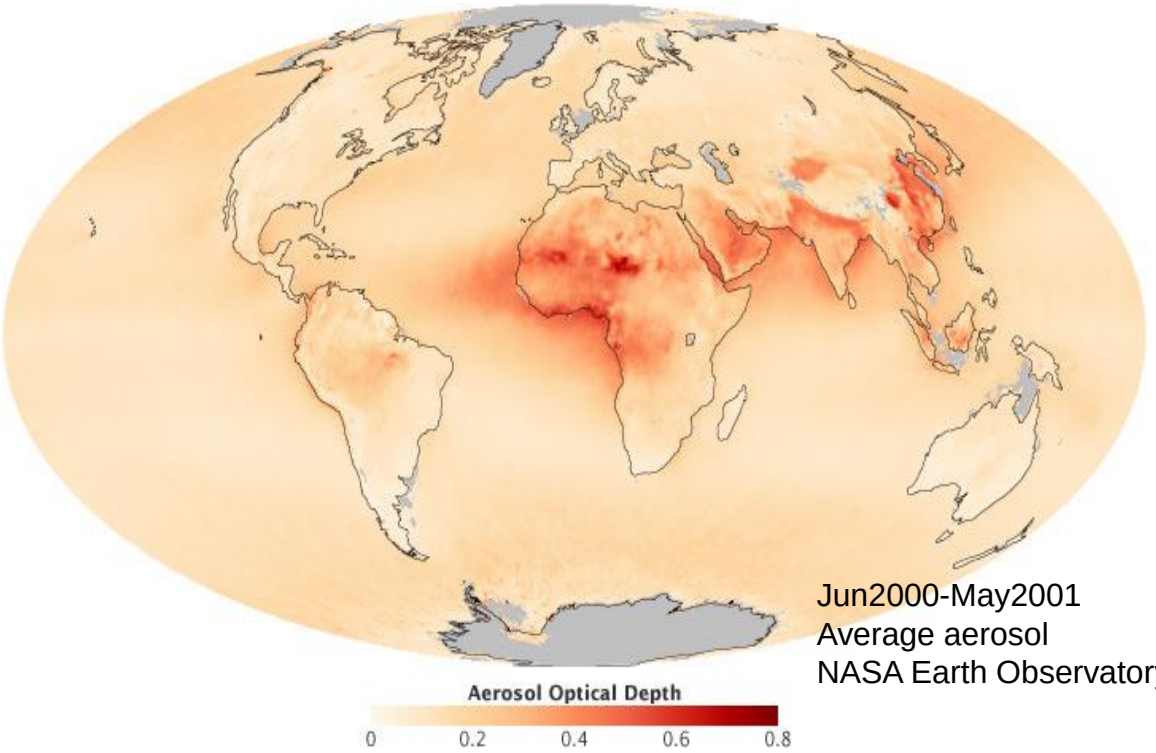


Solar RGB composite based on channels at 1.6, 0.8 and 0.6 µm



IR RGB composite based on channels at 8.7, 10.8 and 12.0 µm

Aerosol is more than dust



Jun2000-May2001
Average aerosol
NASA Earth Observatory

Dust
Marine salt
Smoke
(biomass burn, HUMAN
industrial carbon)
Ash
Pollen
Ice crystals
?

Forward fraction=exp(-AOD)

Contents

- Infrared dust properties
  - Where you learn how cool dust really is
- A model of atmospheric dust
  - Where you learn to distinguish high thin from low fat
- Validation via AERONET
  - Where you learn that models can help your eyes
- Mixed scenes: cloud and dust
  - Where you learn that dust associates with water
- Conclusions
  - Where you learn that there is more dust on books than books on dust

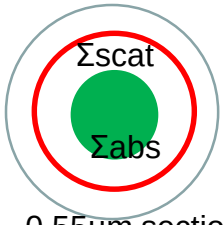
Dust characteristics

- Dust storms occasionally reach 5 km **height**, frequently thicker than 1km

- Over land, dust optical depth is typically around 0.5 or 2 for storms, in the visible range. Efficient **thickness** in the IR is about 40% of those values.

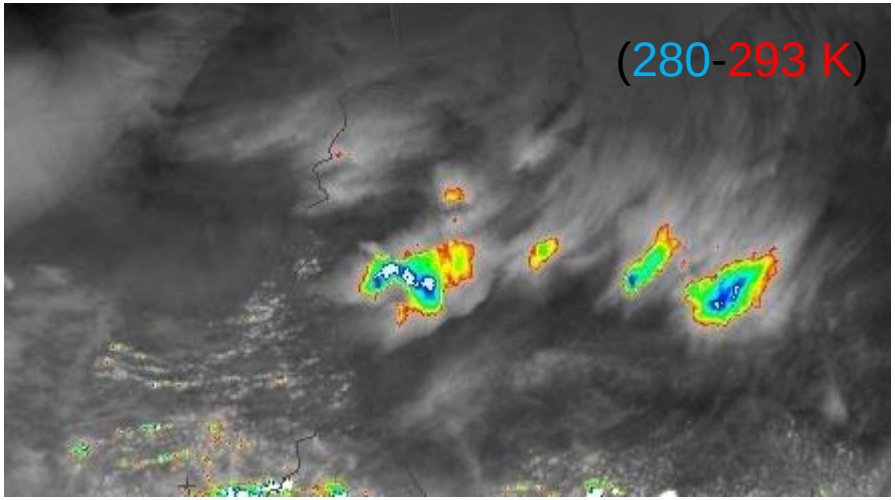
- Dust absorbs and scatters **infrared** radiation in the **Mie** region

- Aerosol **density** average in the atmosphere 10^{-7} kg/m3 (optical depth 0.1)



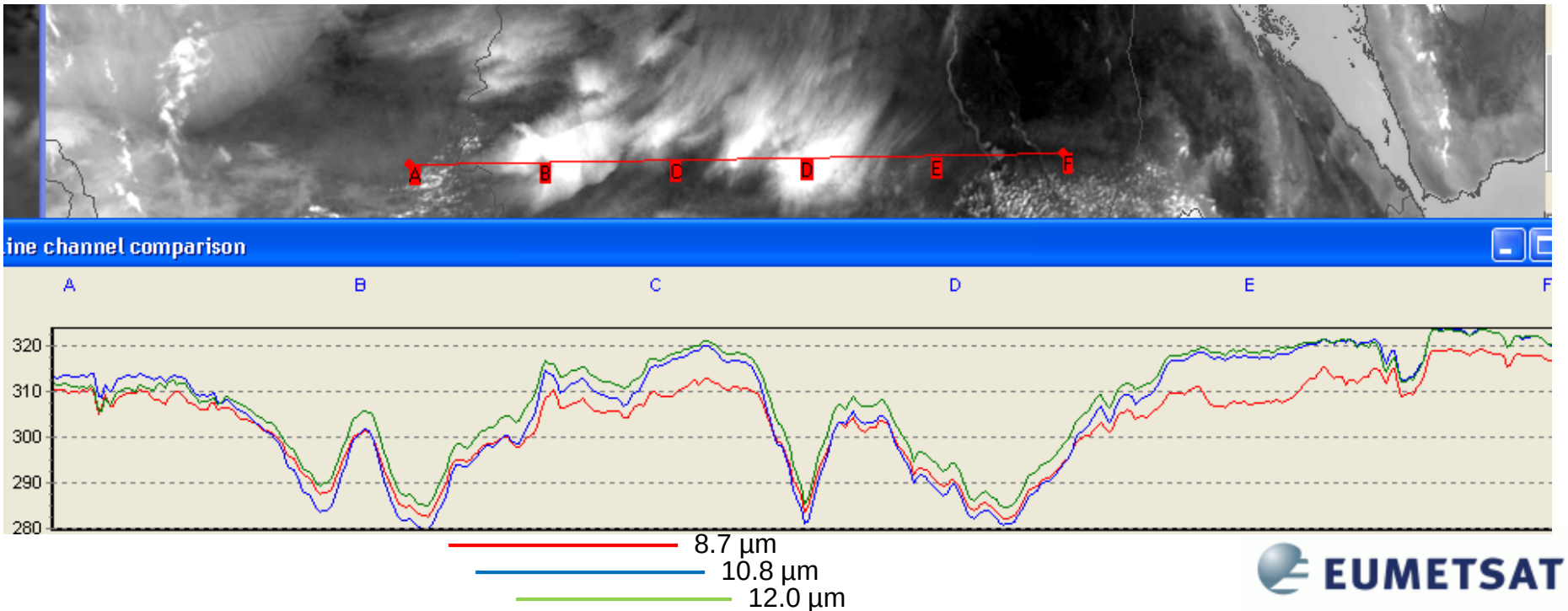
- Dusty air ~ AOD=1 ~ 1 mg/m^3 ~ 1 g/m^2

Dust seen at a single IR channel



-Variable limits for colour enhancement
-Uncertain nature of the cold area (cloud?)
-Possible mixture of cloud and dust

2004 May 13th 13:00 Meteosat **10.8µm**
colour-enhanced (left) and gray-enhanced (below)



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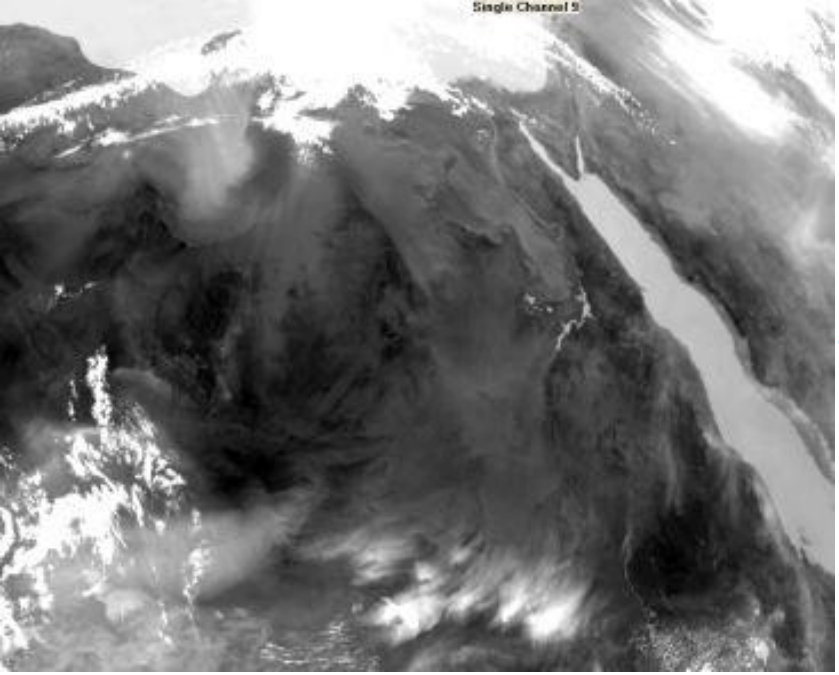
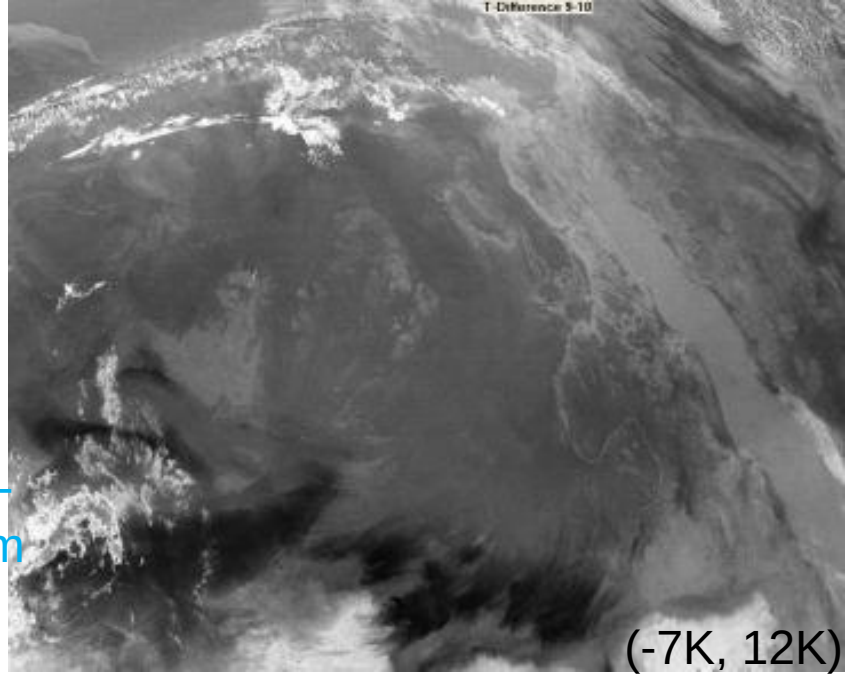


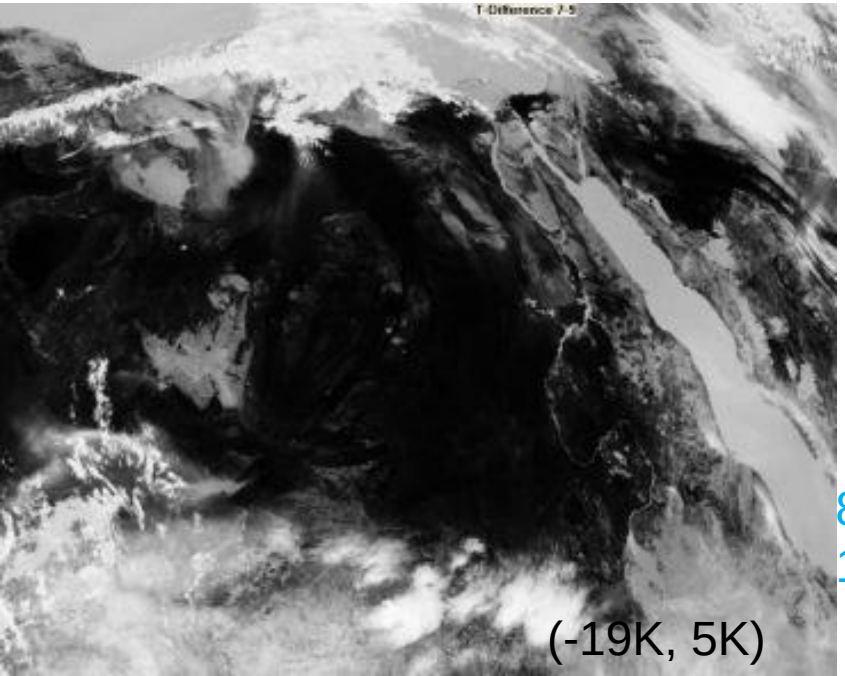
10.8µm

10.8-
12µm



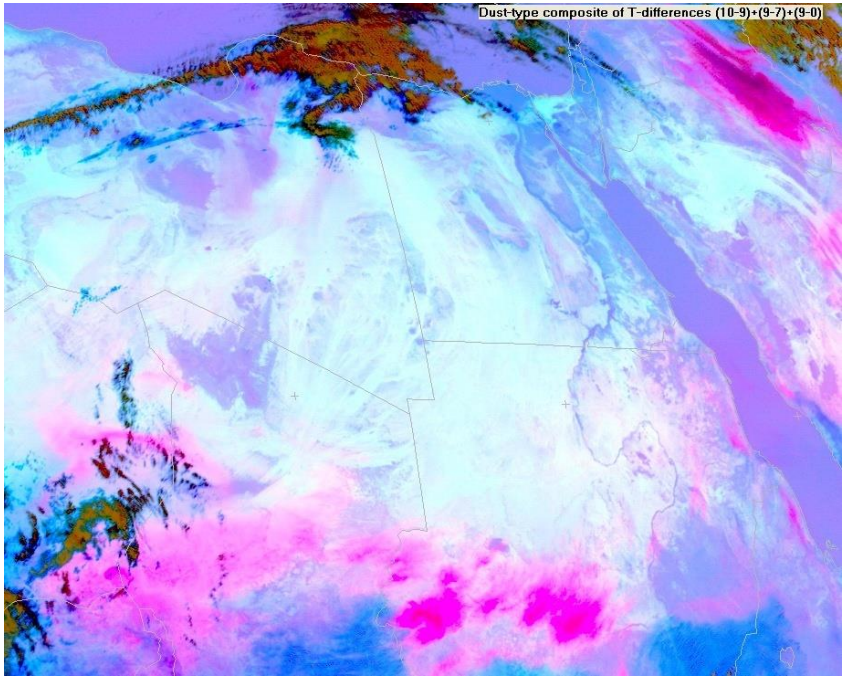
(-7K, 12K)

Ch9 (*upper left*), two independent differences, and all together as colour

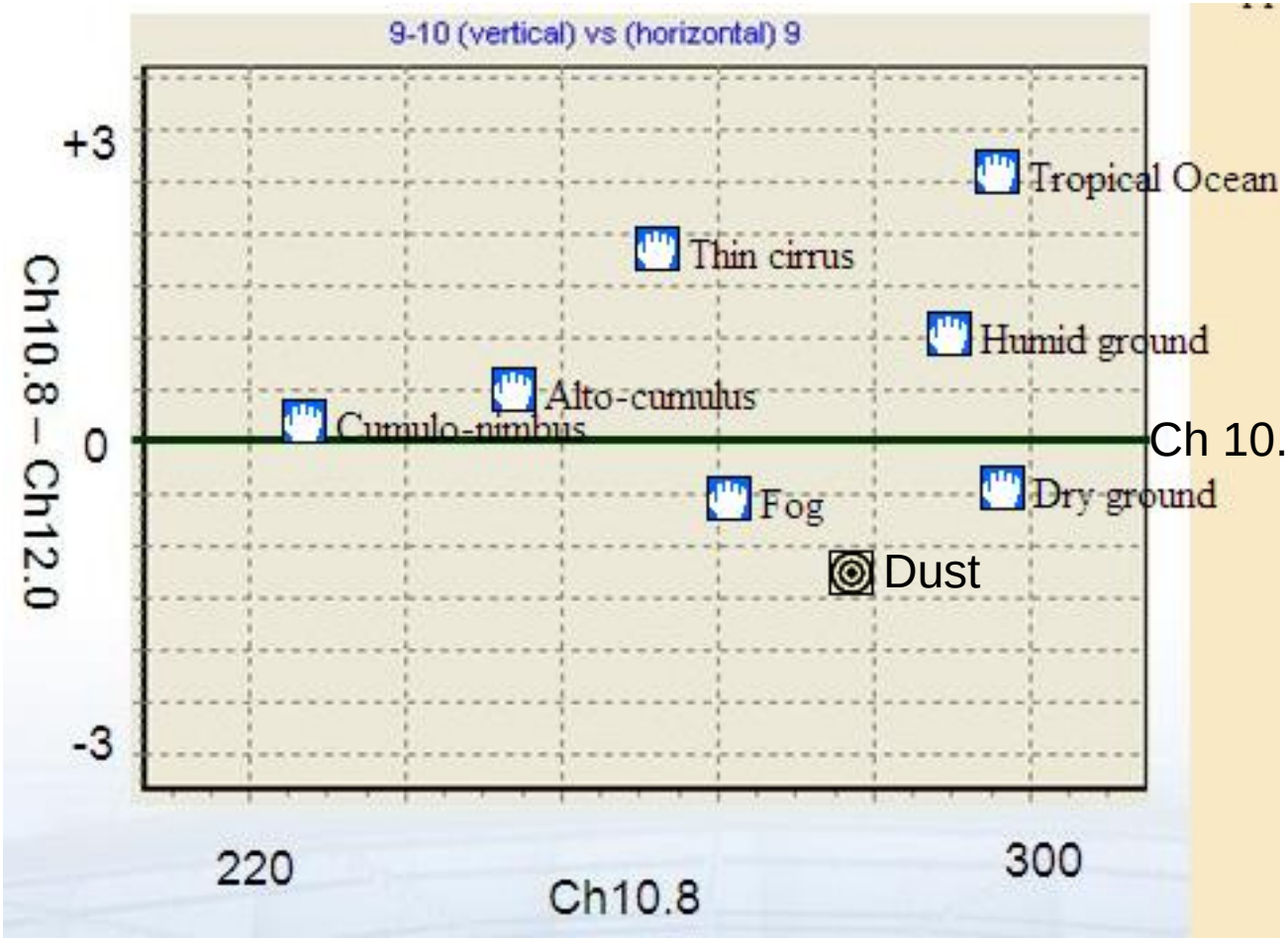


(-19K, 5K)

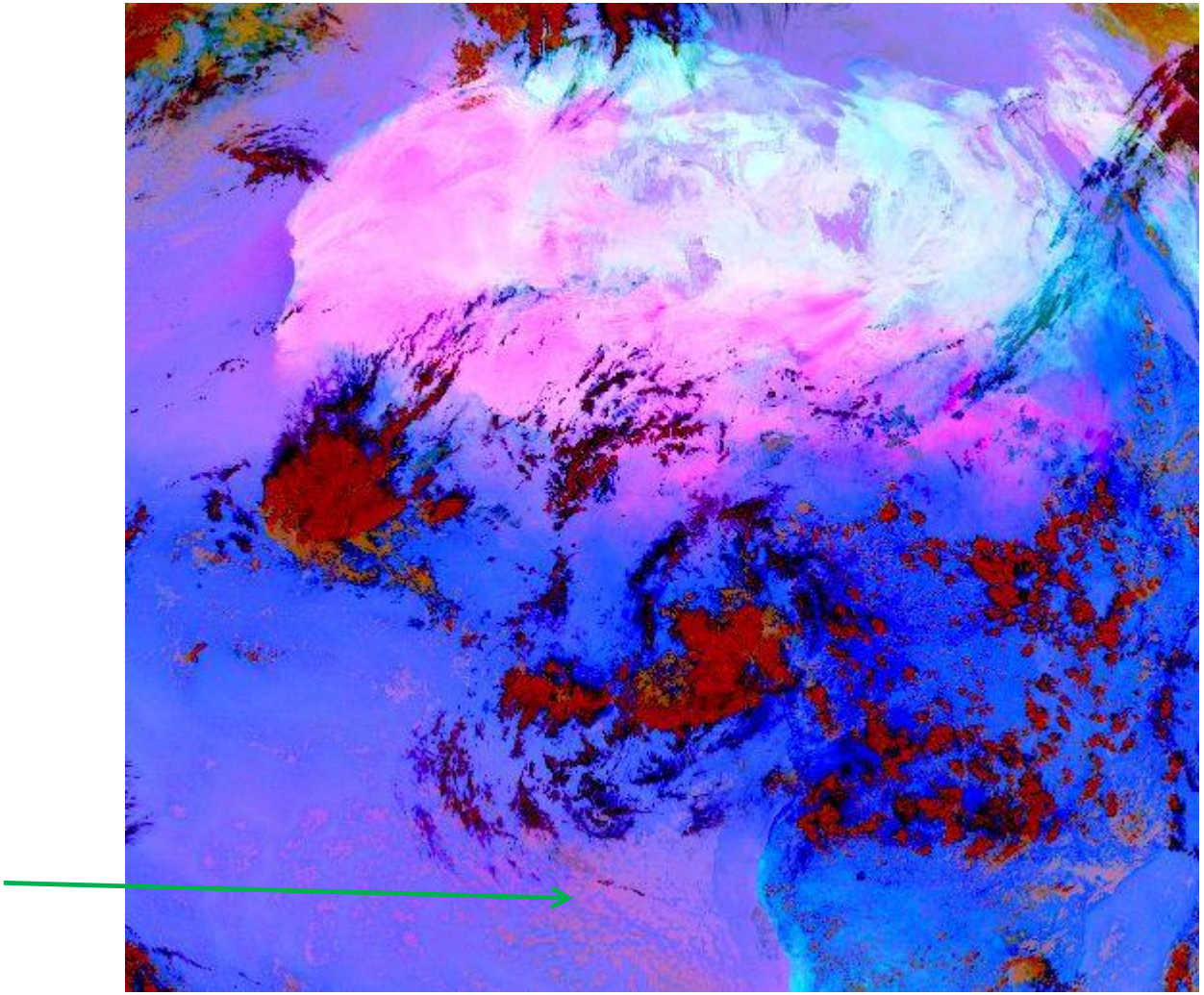
8.7-
10.8µm



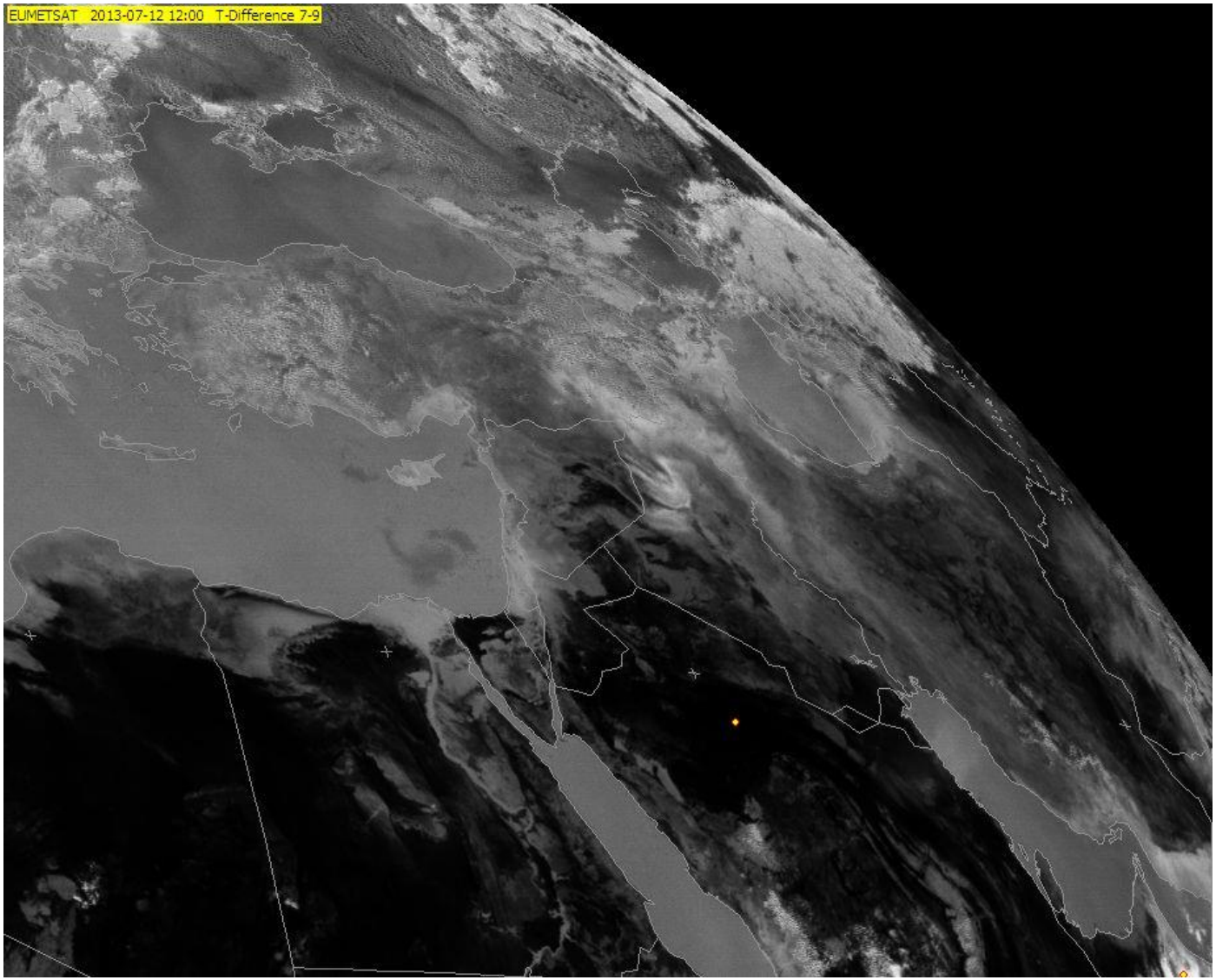
The 10.8µm-12µm difference (vertical)



Dust RGB 21 March 2010 12UTC



pink is not always dust



Met-8, 2013 July 12 12UTC, ch9-ch10, ch7-ch9 (-17K to 5K) differences and Dust RGB

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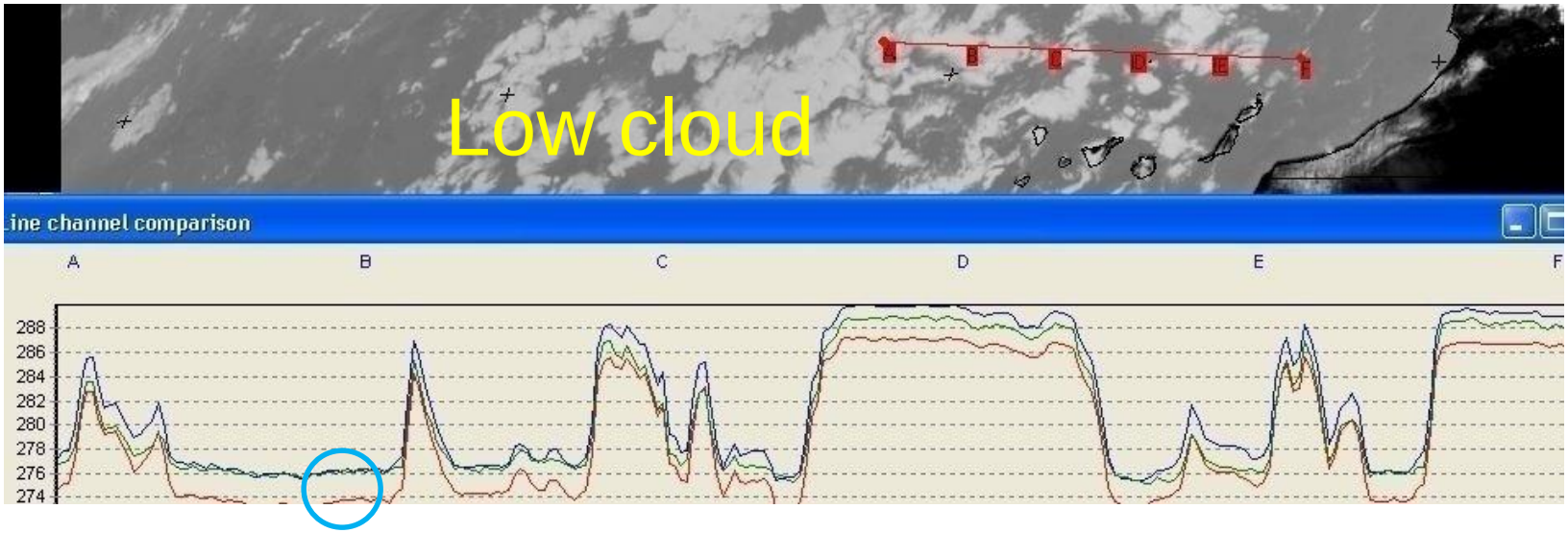
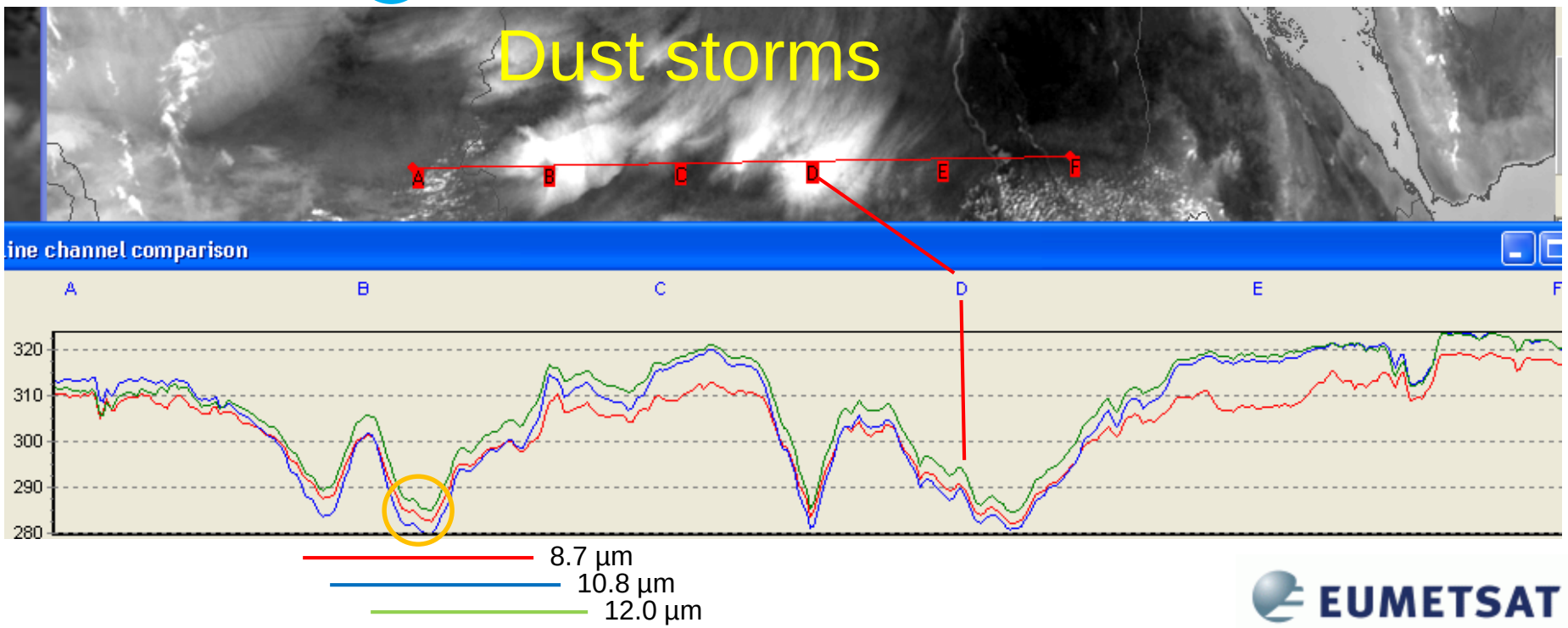
Comparison of water cloud and dust in the IR window





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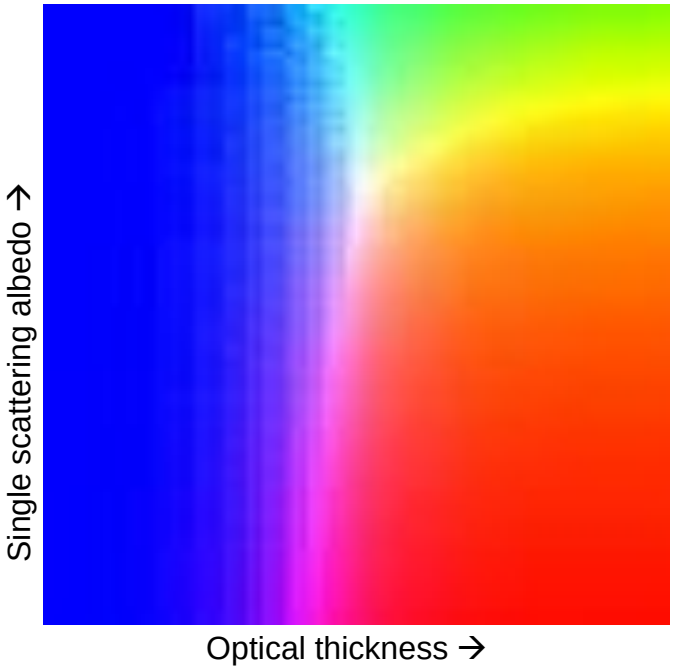
Find the colour for each interaction regime



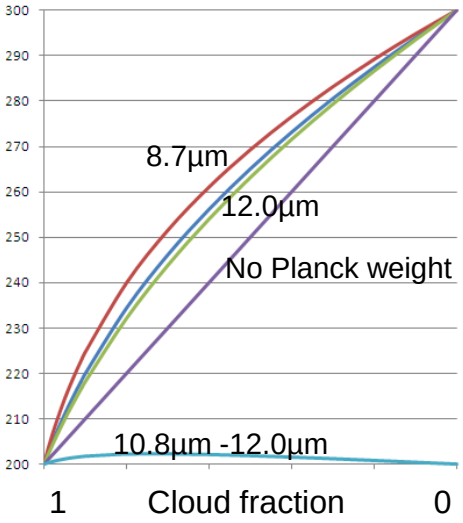
Absorbed

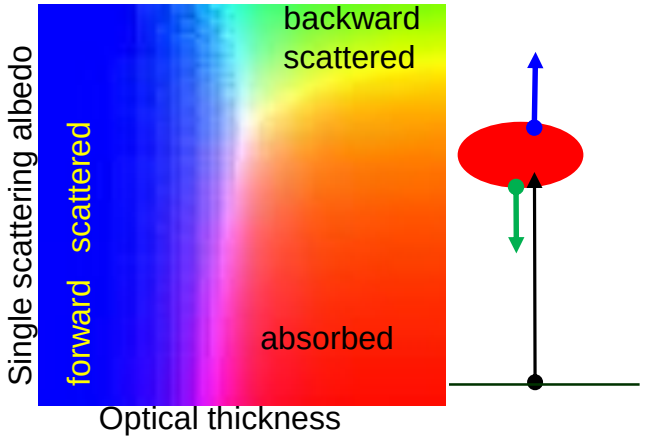
Back scattered

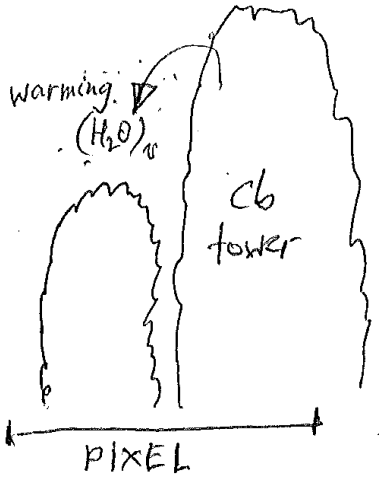
Forward scattered

Channel differences: How do they generate?

- Emissivity: reduced by *scattering*, increased by **absorption**
- Sub-pixel effect: scene mixture or semi-transparency
- Contribution layer: emission from different depths and temperatures
- Water vapour absorption (thermal inversion above shield cloud, adiabatic cooling inside the Cb tower)







And how is it with DUST?

Absorption + scattering efficiencies Abs+ scatter

10.8µm 12.0µm

Thin dust < 0.5
absorbs more 10.8µm
12.0µm goes forward

Emissivity=0.25 Emissivity=0.15

TRANSPARENCY EFFECT
10.8µm < **12.0µm**

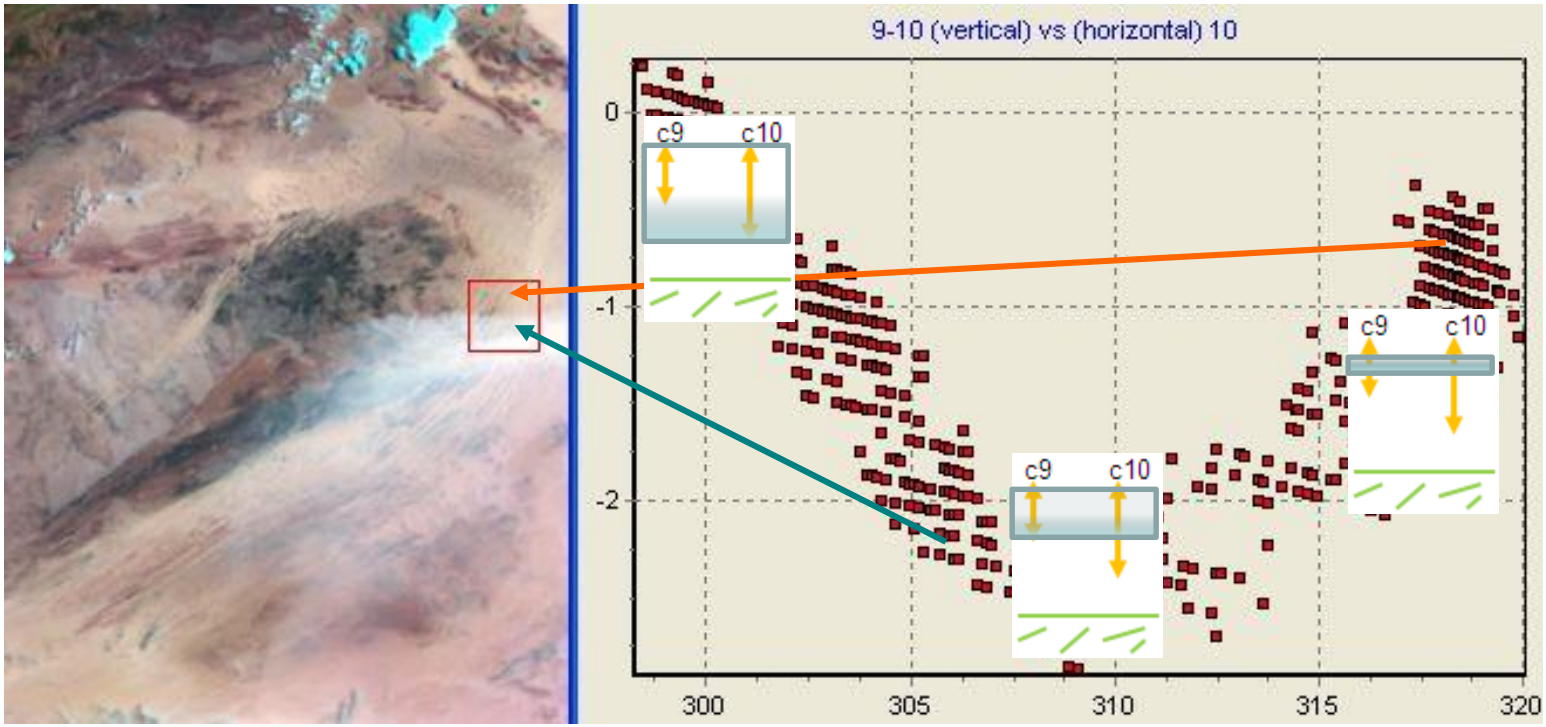
Ground contribution
Dust contribution

Thick dust > 1.5
emits more **10.8µm**

Emissivity=0.90 Emissivity=0.75

EMISSION EFFECT
10.8µm > 12.0µm

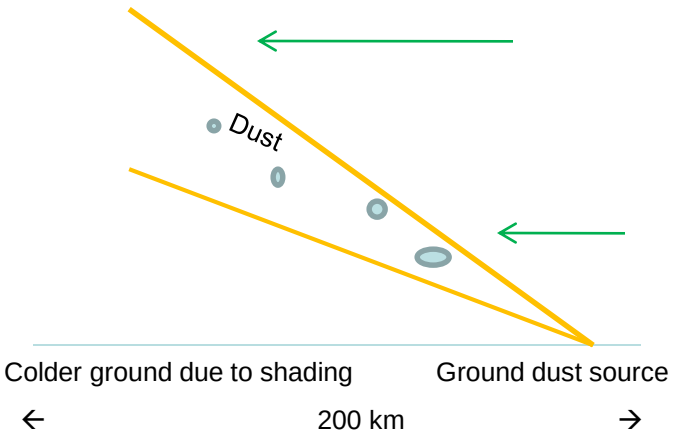
Reversed transparency arc for dust: Ch9-Ch10 versus Ch10



MSG Natural (solar) RGB composite 4-July-2003 10:00 UTC

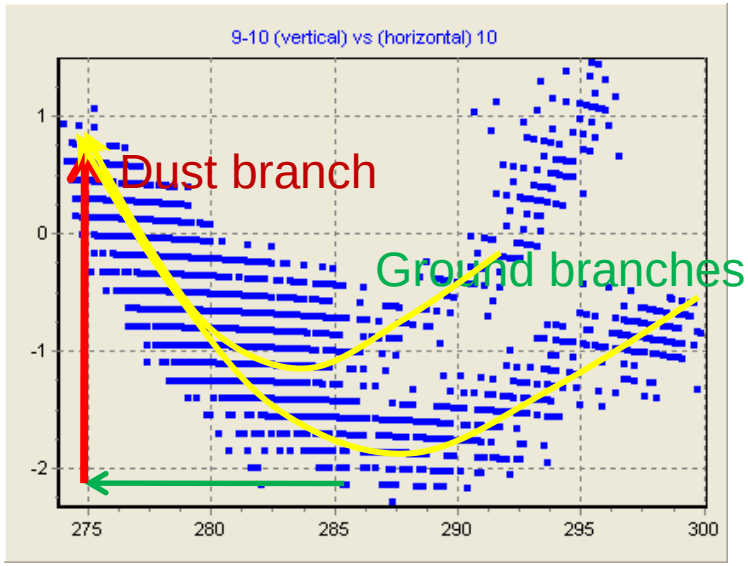
- 10.8µm radiation is more absorbed and more backscattered by dust than 12.0µm
- For dust or ash, arc is inverted due to the thinner contribution layer (**CL**) at 10.8µm
- 10.8µm channel shows higher BT than 12µm for thick dust due to higher emissivity

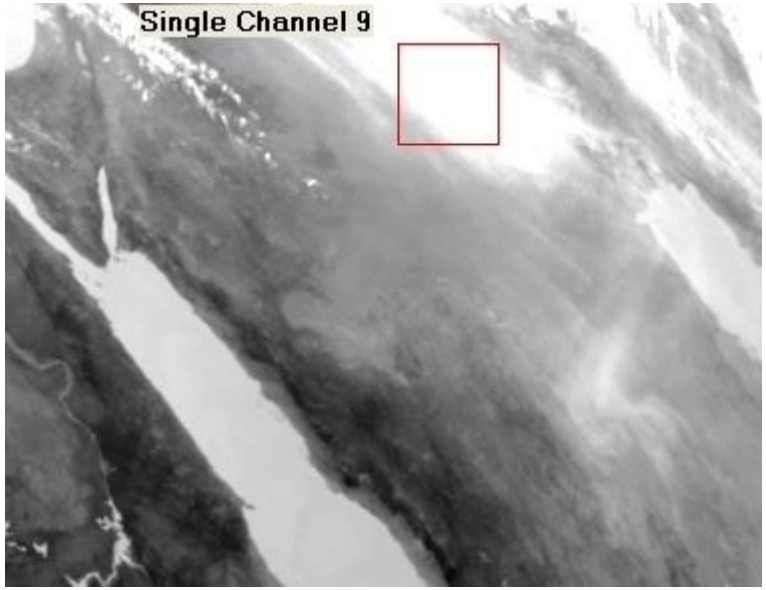
Dust model



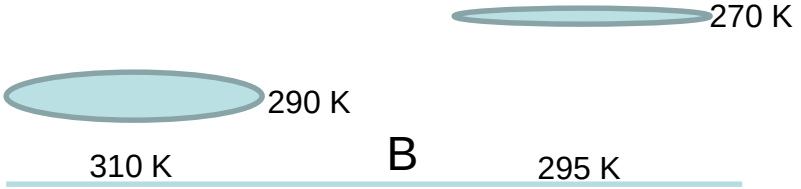
- Dust tends to higher levels far from the source, decreasing in **particle size**

- Decrease in 12.0µm BT due to height and dust thickness (and size and...)

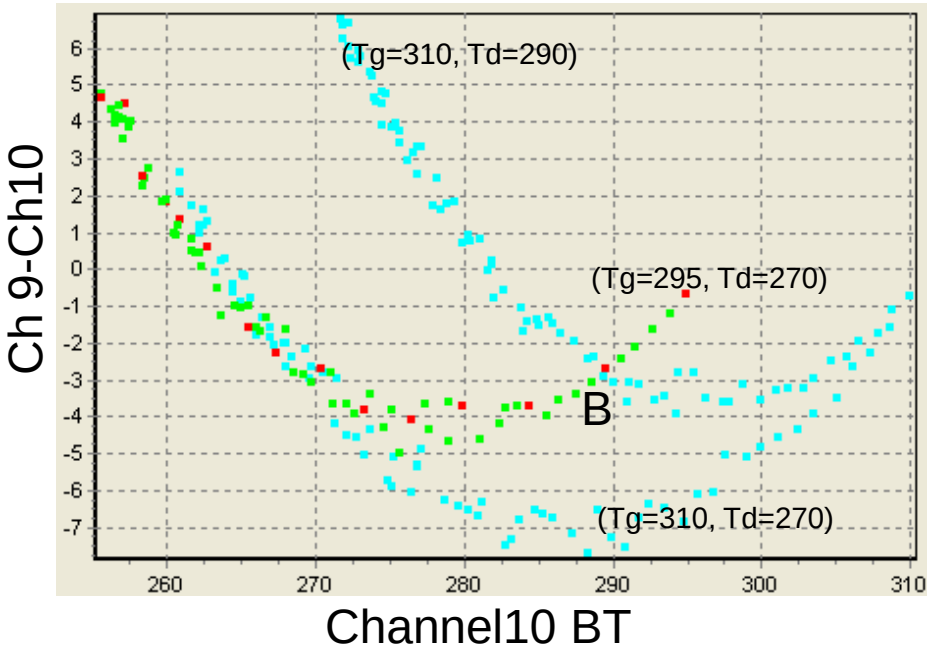




Graphical analysis



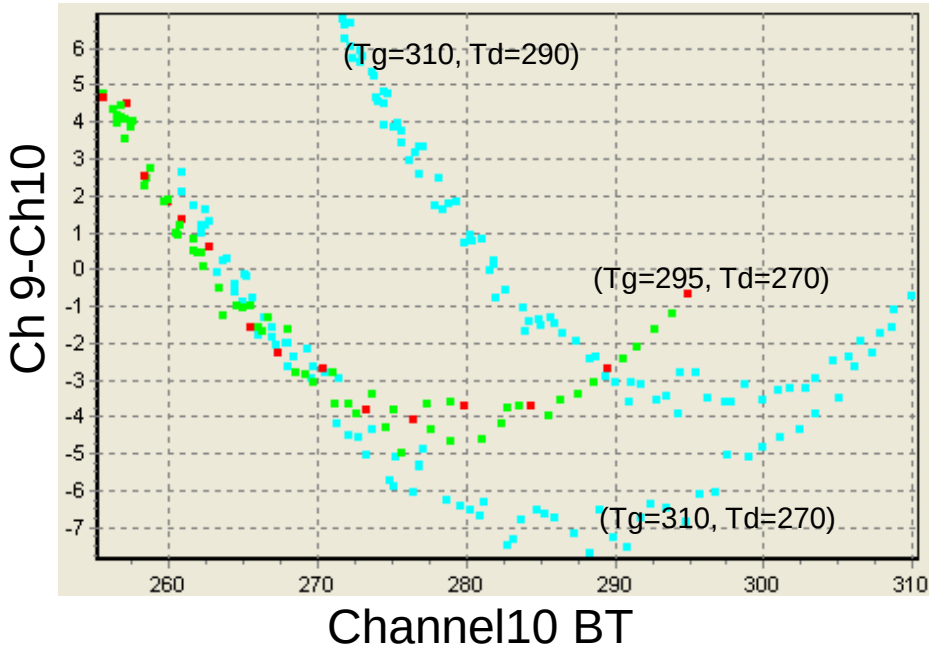
- **Thick** dust cloud at **low** level can be confused with a **thin** layer **high** above
- Reduction of the ground temperature by dust screening the sun ('thermal **deficit**')
- Use channel difference **8.7µm – 10.8µm** (negative for thin, positive for thick)

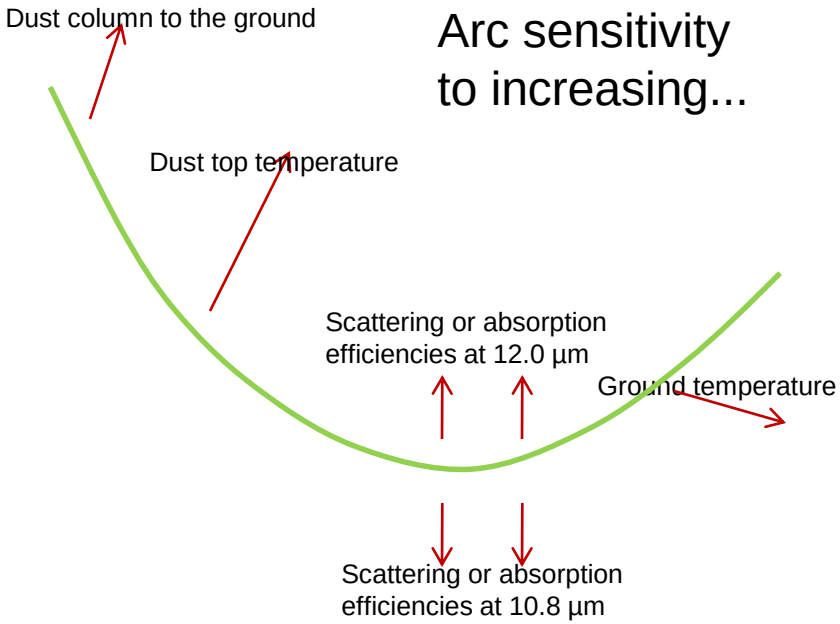


Green-red dotted curve for (Tground=295, Tdust=270)
Cyan curves for Tg=310, and two values of Td=270 and 290 (which is which?)

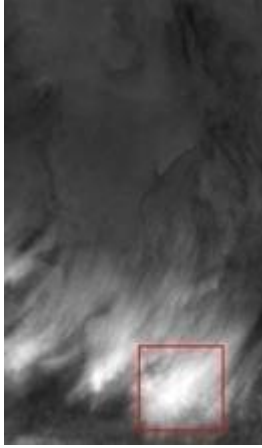
Graphical analysis

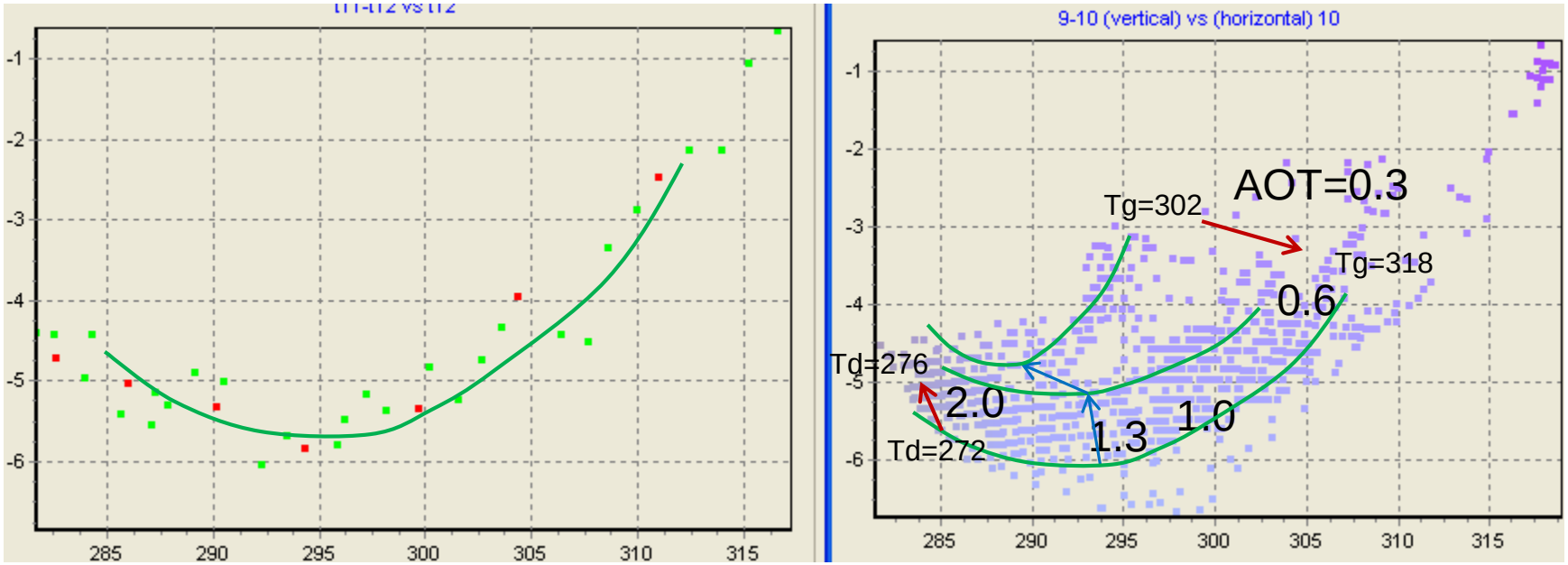
The arc shape depends on temperatures (dust top, ground, dust vertical extension) and
The arc shape depends on efficiencies (dust composition, size, shape)
The dip in the curve depends on relative weights of efficiencies at 10.8 and 12.0 µm





Dust (Td) and ground (Tg) temperatures estimates



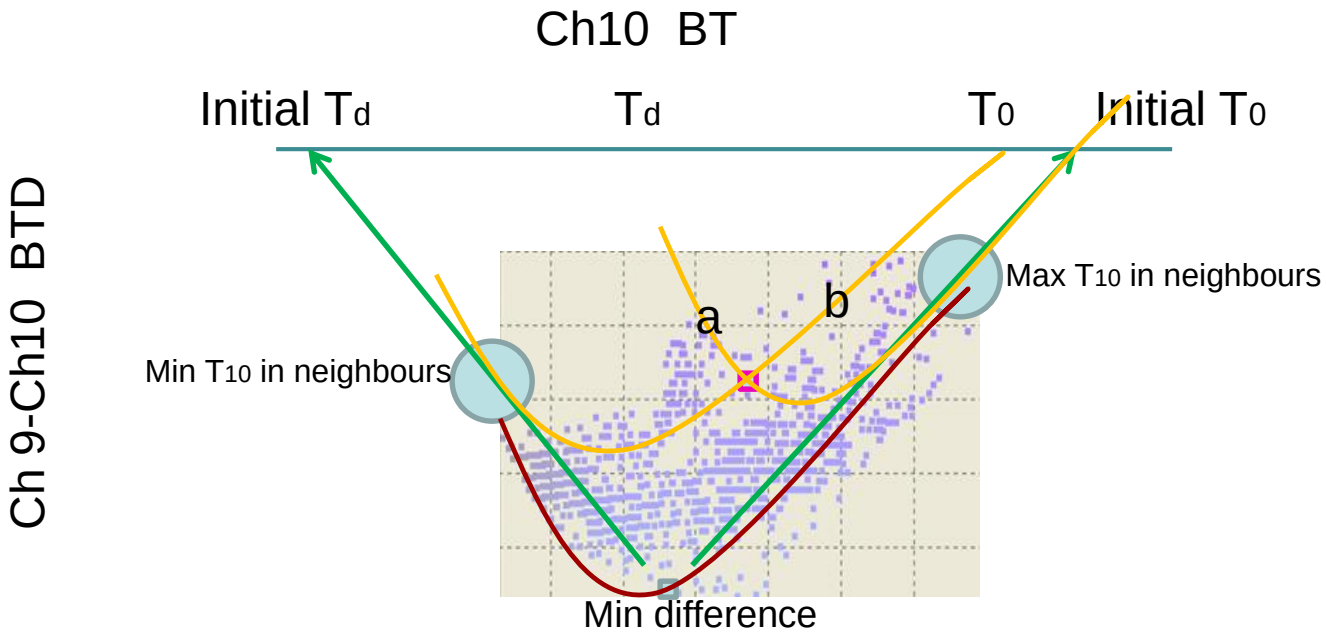


Real (blue dots, right h.s.) compared with simulated (green-red dots left h.s. and lines) scatterograms based on Tg=318 Td=272 Σ11=0.6, 0.3 Σ12=0.2, 0.25

Dust column down to 50% of that temperature difference

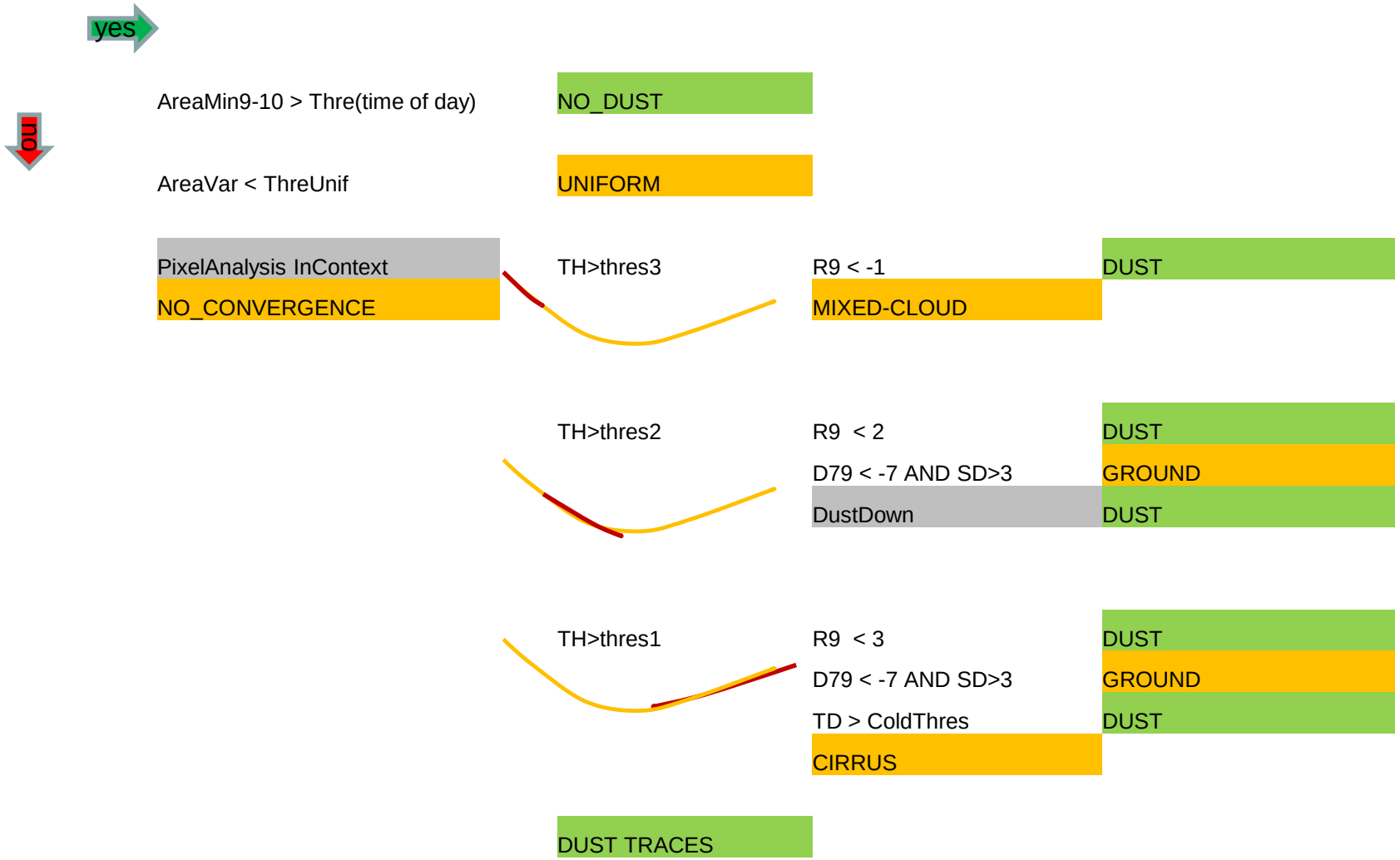
Smaller arcs, higher in the scatterogram, indicate less temperature contrast (Tg – Td)

IR model operation



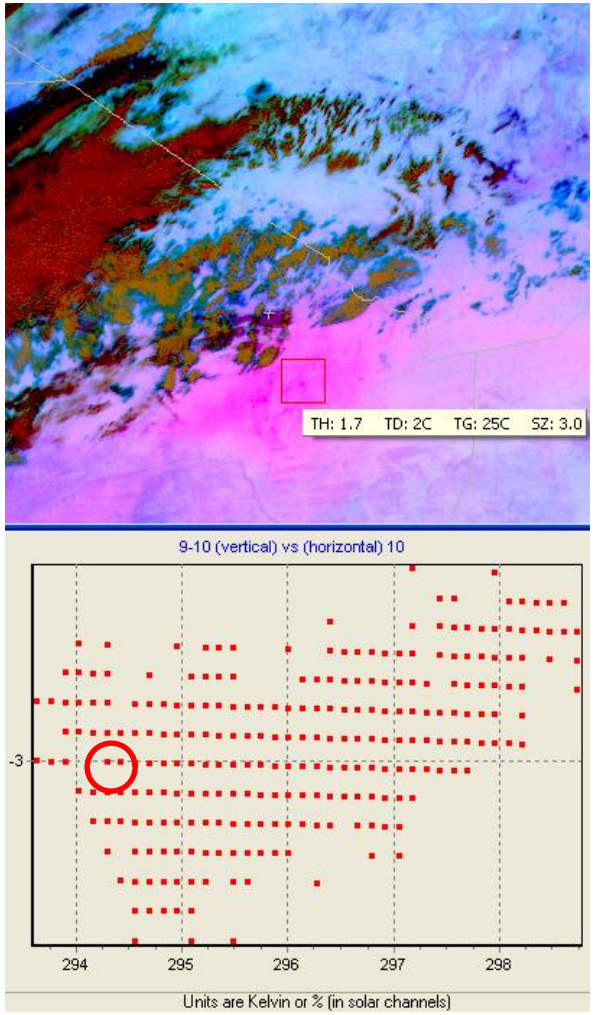
If slope=b, refresh T_0
If slope=a, refresh T_d

Decision tree

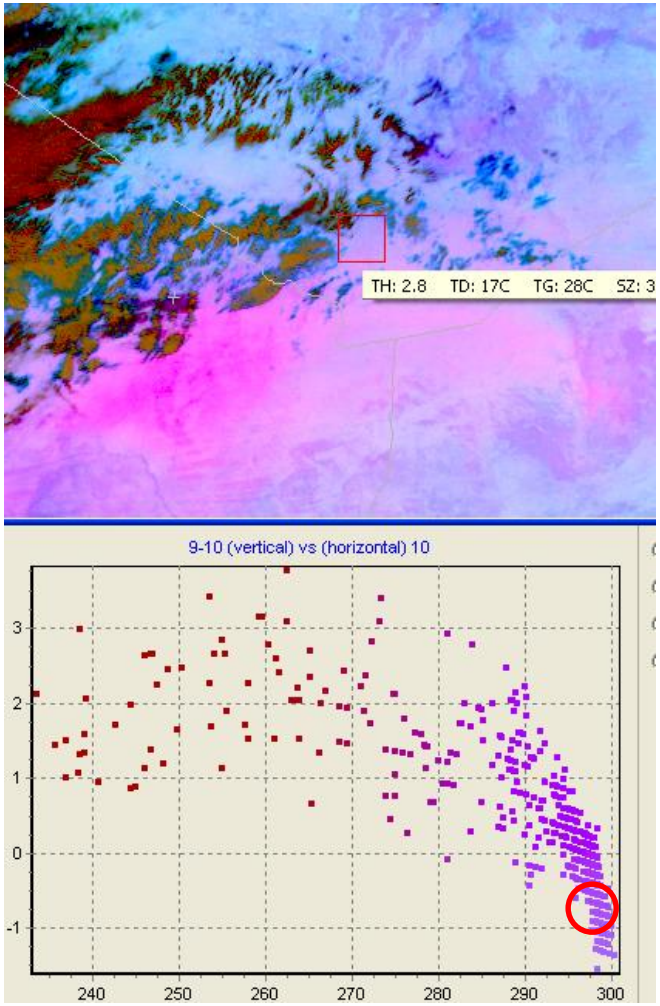


1. Subjective **verification** against masks, images and news media: Done
2. **Verification** from other sources (AERONET, LIDAR): In progress
3. **Inter-comparison** with other methods (Solar): Starting

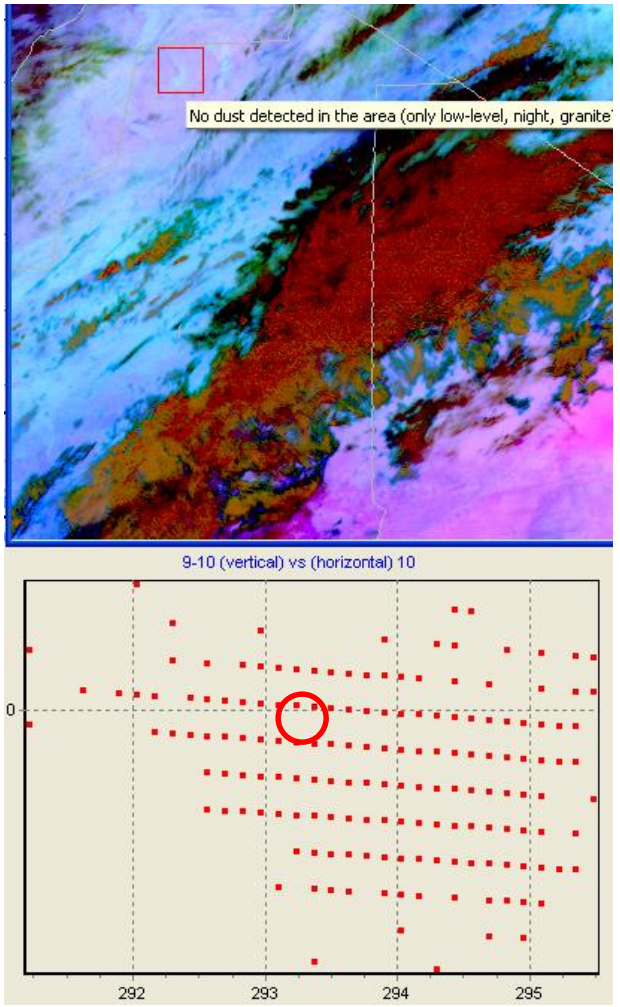
Graphical validation



threshold ch9-ch10 < -1.3K
AOT =1.7, strong depth



threshold ch9-ch10 < -1.3K
AOT =2.8, too strong depth
Due to location of minimum

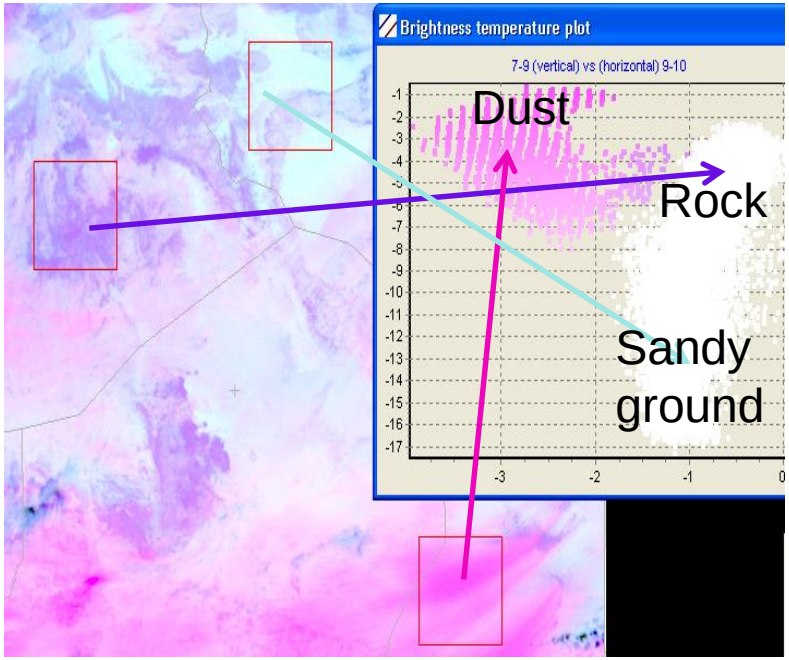


threshold NOT < -1.3K
AOT not calculated

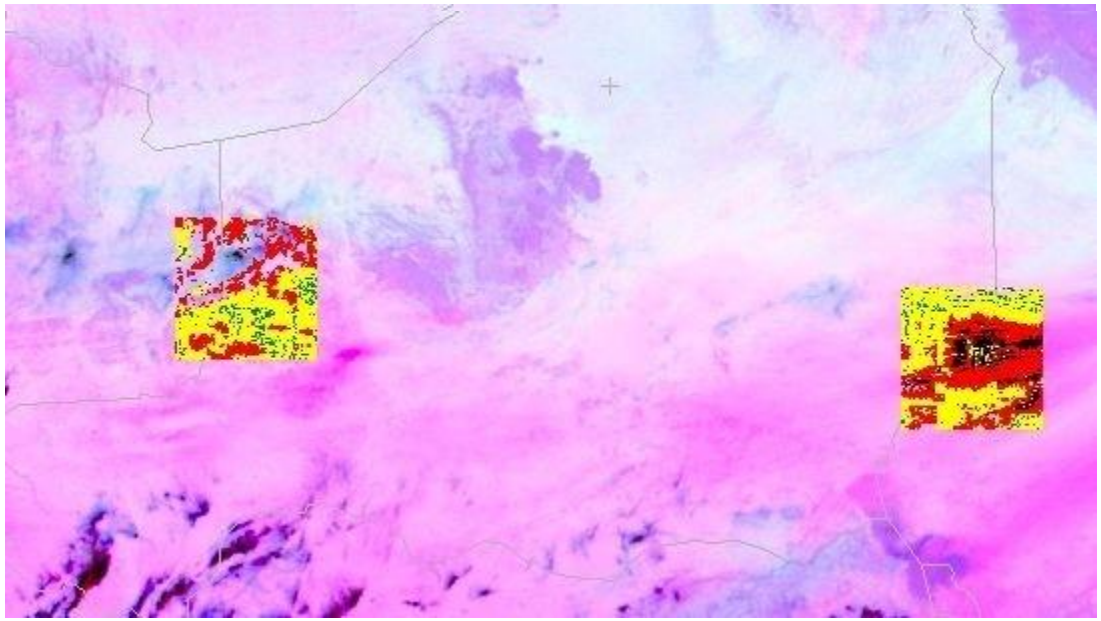
EUMETSAT

Ground versus dust skill

IR model does not usually pick on rock or sand areas



21Mar2010 12UTC Meteosat-9

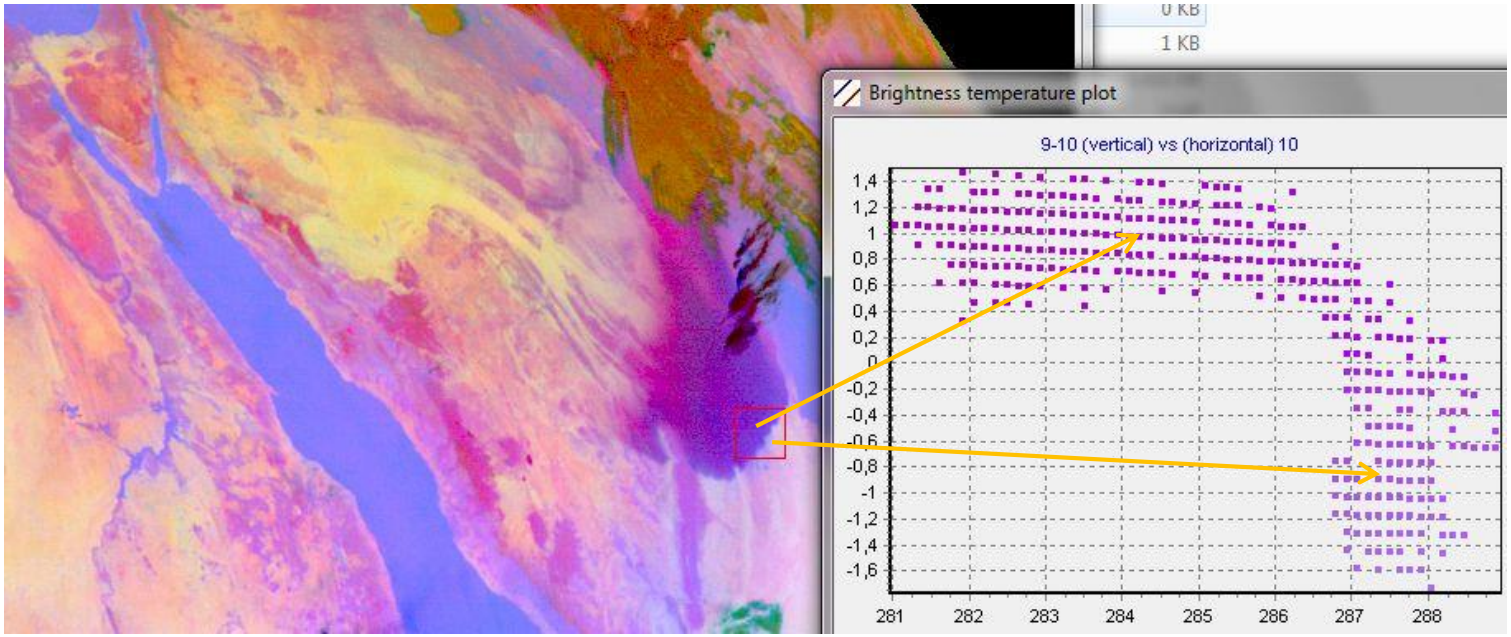


The IR model separates the **dust** areas from the **ground** dry areas

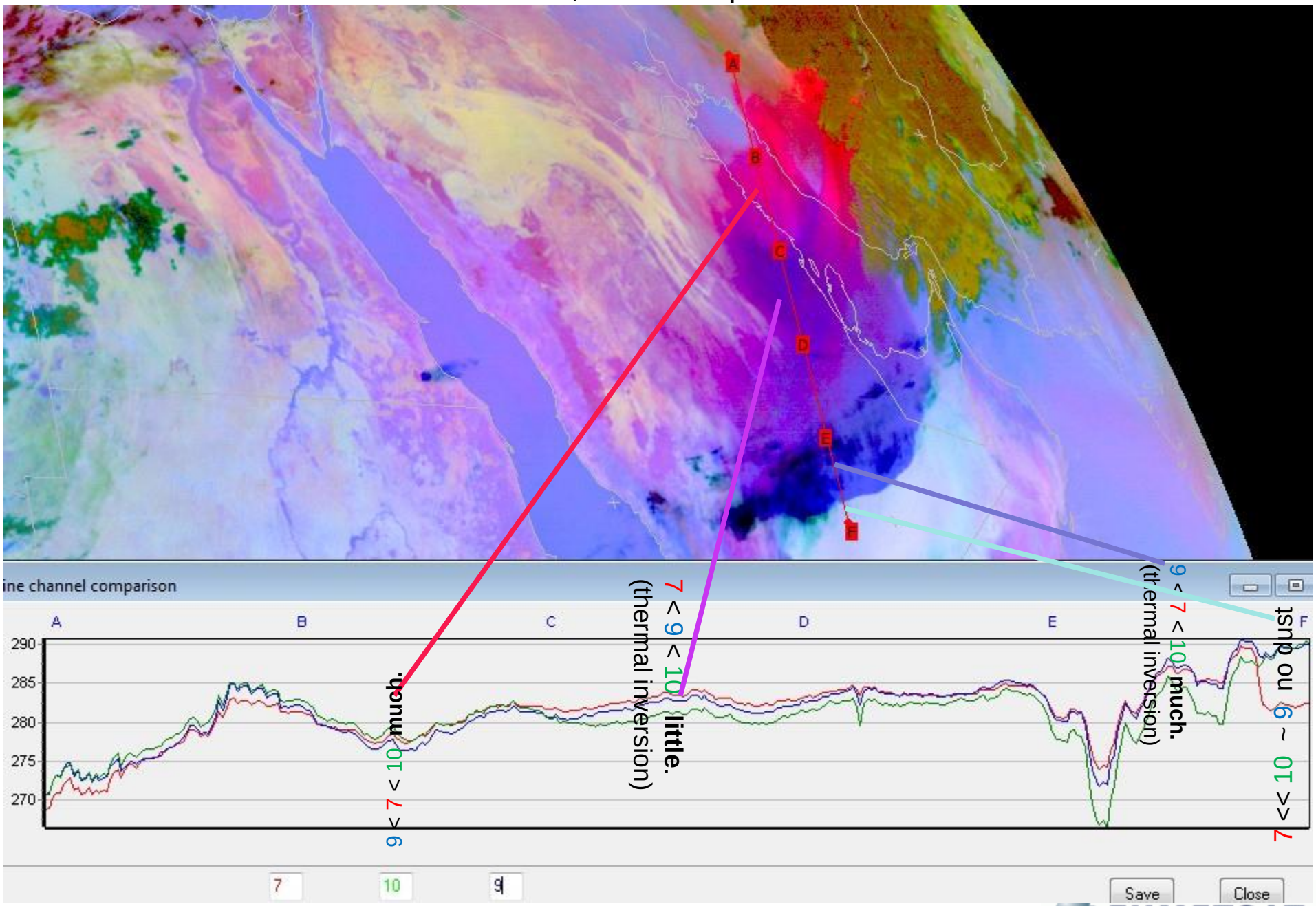
EUMETSAT

Model fails for atmospheric inversions

- Occasionally, during night, thermal inversions duct dust at high speed
- Due to the thickness, no negative 10.8µm – 12 µm difference appears above the dust
- However, negative differences appear over clear ground

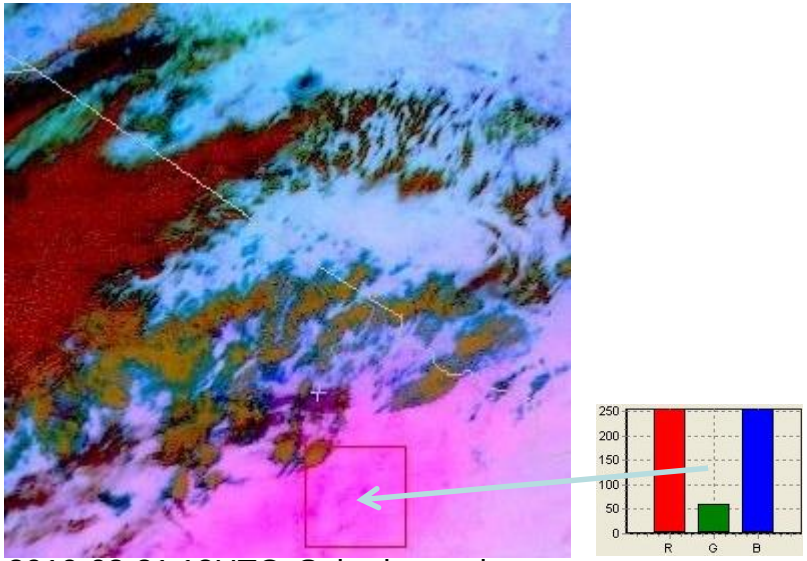


Met-10 2015-04-01 23UTC, Dust composite

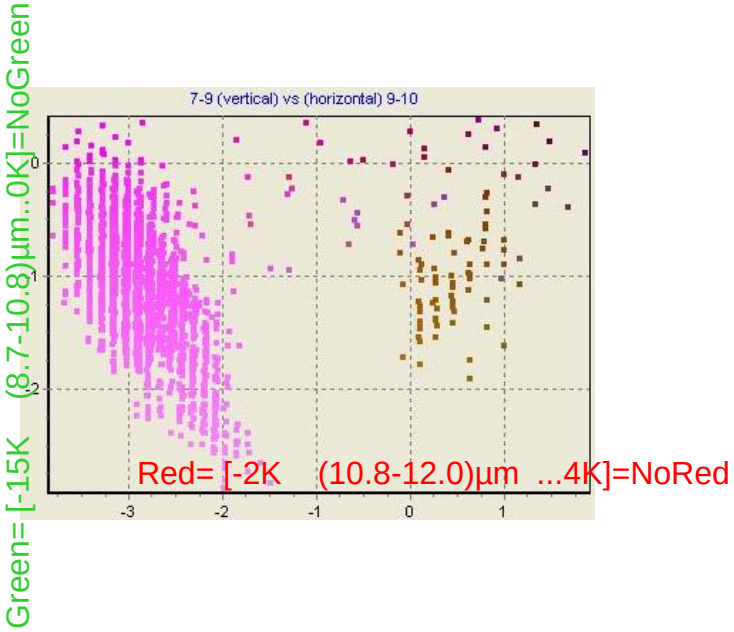


EUMETSAT

Dust RGB



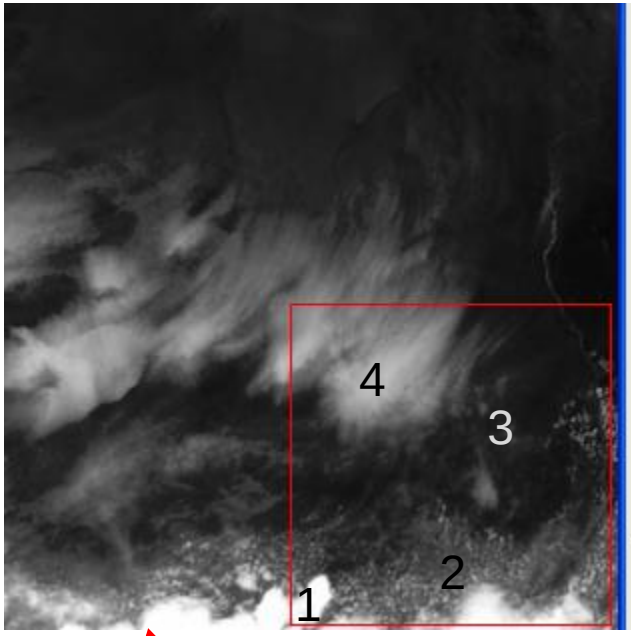
2010-03-21 12UTC, Saharian region

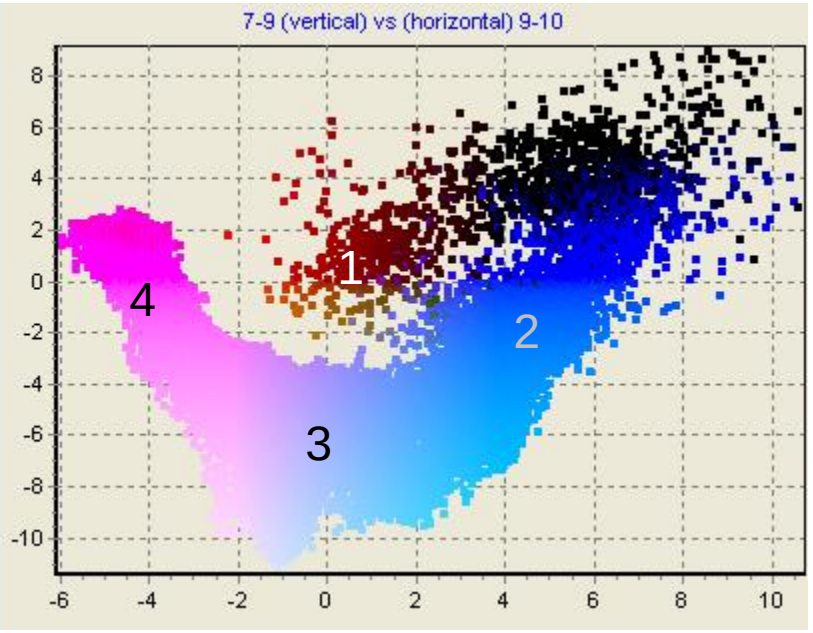


- Magenta areas are typically dusty: neither necessary nor sufficient condition
- Inside **magenta** areas, **darker** (less green) pixels show a smaller difference c7-c9 which means **higher AOD**
- The threshold in the red component (-2K) is exceeded in most pixels of the dust storms.
- Blue component is most of the time saturated (>16°C) over desert areas during day. During night it generates a yellow hue for desert.

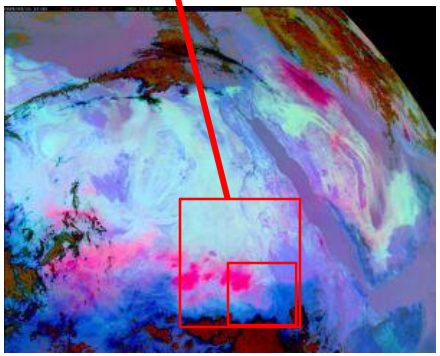
EUMETSAT

The cloud-to-dust spiral in the differences diagram

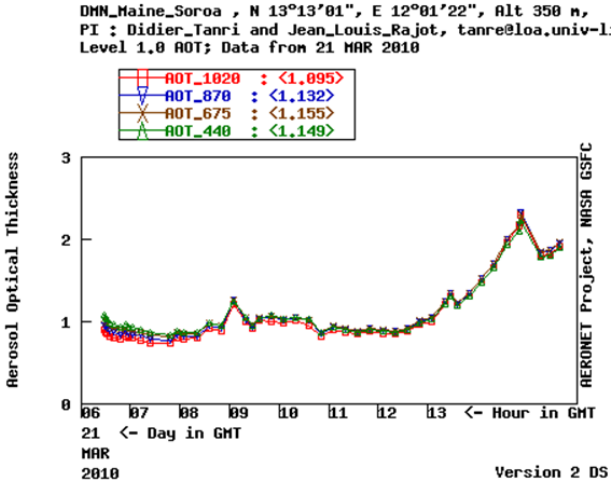




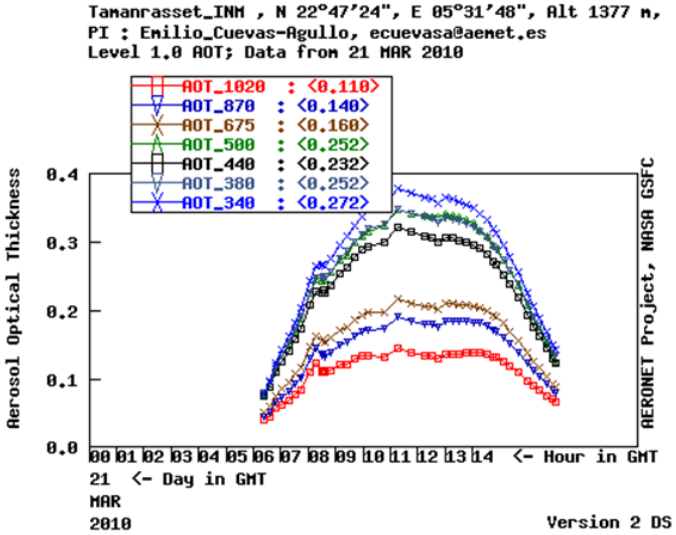
2004-05-13 13:00 UTC, 10.8 µm



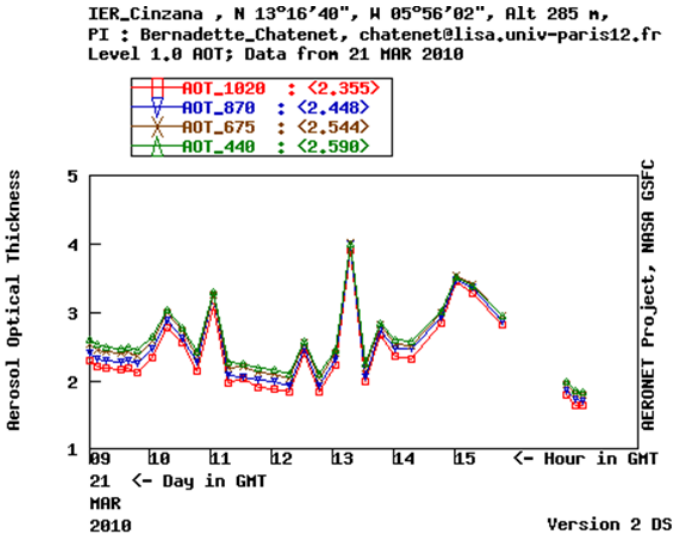
1: Thick high cloud
2: Broken low cloud
3: Ground, drier air towards 4
4: Dust cloud



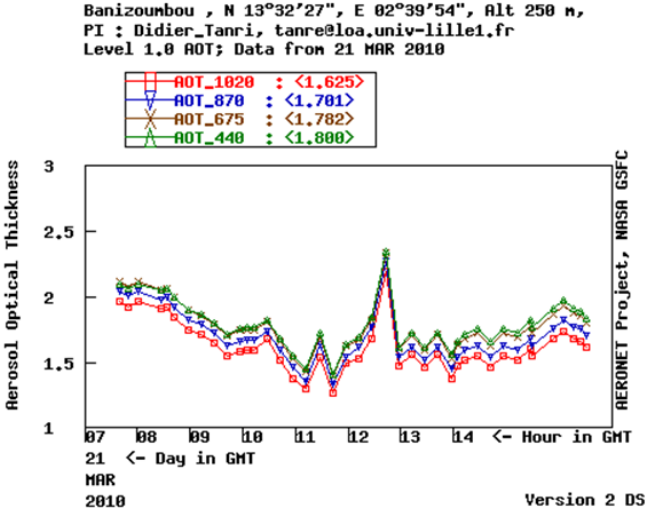
12.02E 13.22N, model on image **at 12UTC**: theta=0.6 31C-39C size=29



5.52E 22.77N, model on image: theta=0.16 40C-47C size=31



-5.94E 13.28N, model on image: theta=1.9, 31C-42C



2.66E 13.53 N, model on image: theta=0.8 33C-42C size=14

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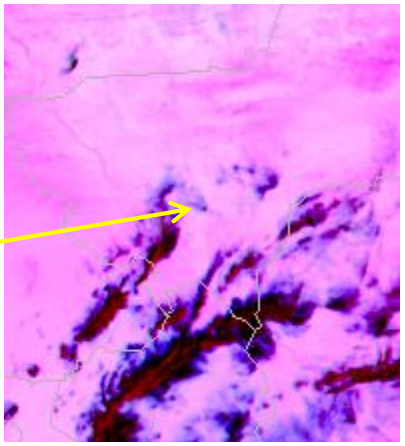
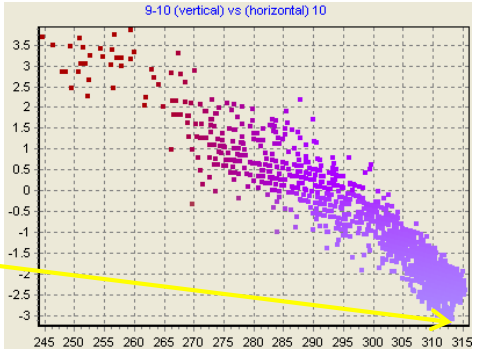
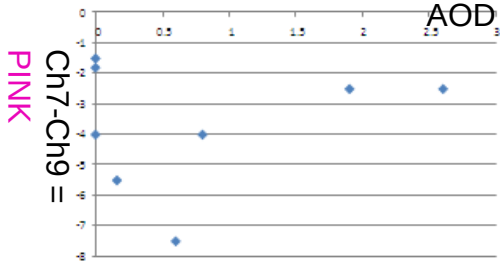
Validation based on ground measurements (AOD units)

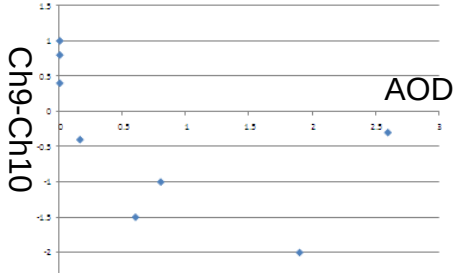
AERONET	IR-MODEL		
✓ 0.9	0.6	31-39 C	29 µm
✓ 0.35	0.2	40-47 C	31 µm
✓ 2.1	1.9	31-42 C	
❖ 1.6	0.8	33-42 C	14 µm
❖ 0.4	NO DUST (too uniform)		
✓ 0.1	NO DUST		
✓ 1.7	2.6	30-38 C	
✓ 0.03	NO DUST		





IR-MODEL is too sensitive to temperature at the arc minimum





EUMETSAT

SAMPLE VALIDATION

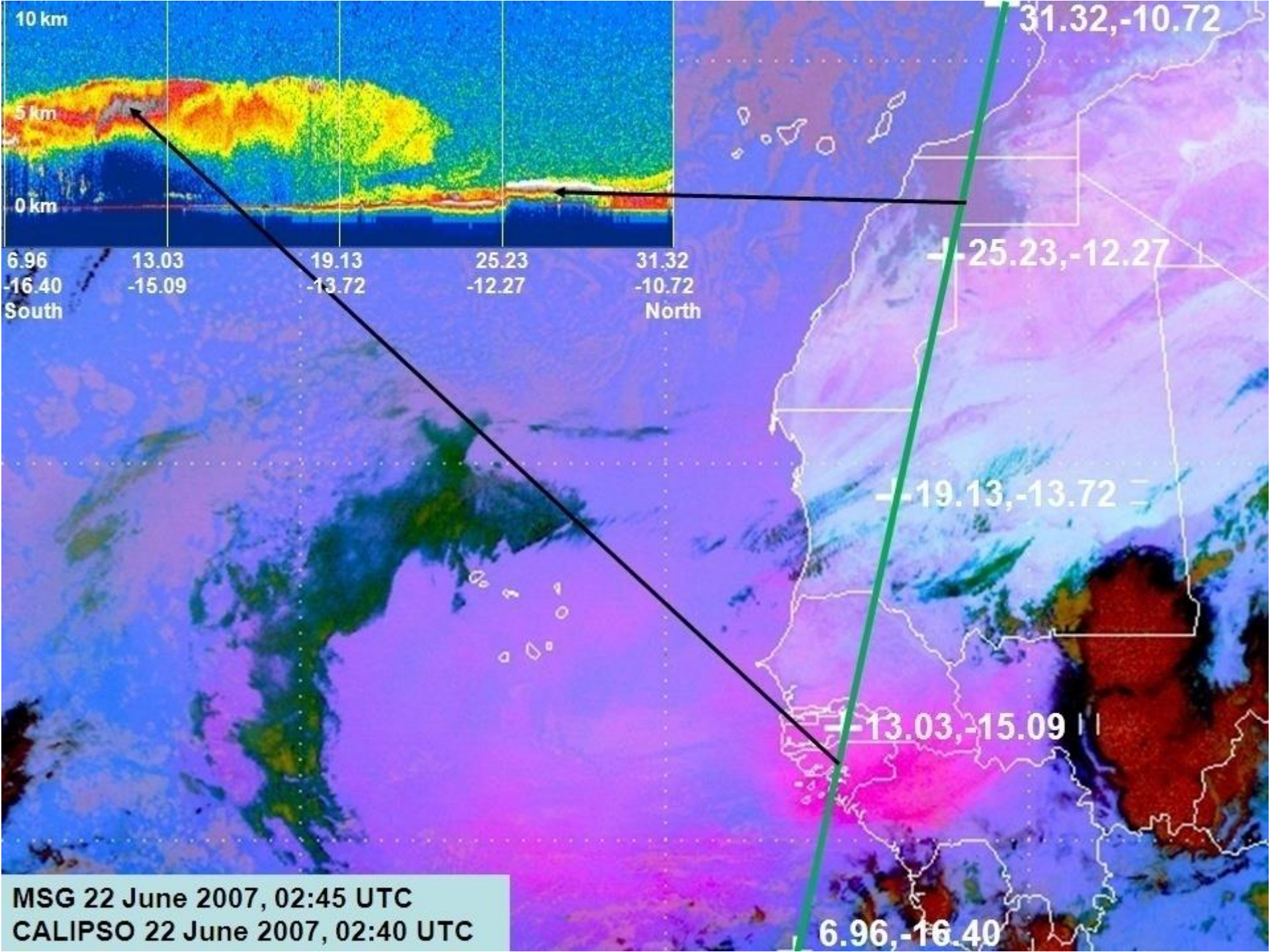
based on AERONET ground measurements

- Good agreement (+/- 30%) over **desert** grounds

- Over the ocean or islands, lack of model sensitivity due to insufficient temperature contrast, dust thinness or **uniform** background for neighbour calculation

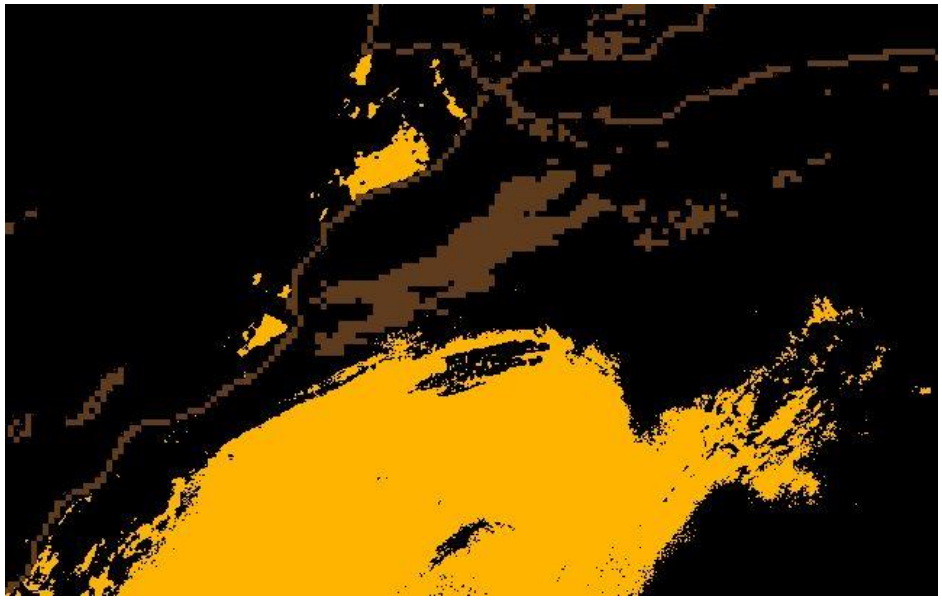
- Better match for **coarse** than for fine aerosol

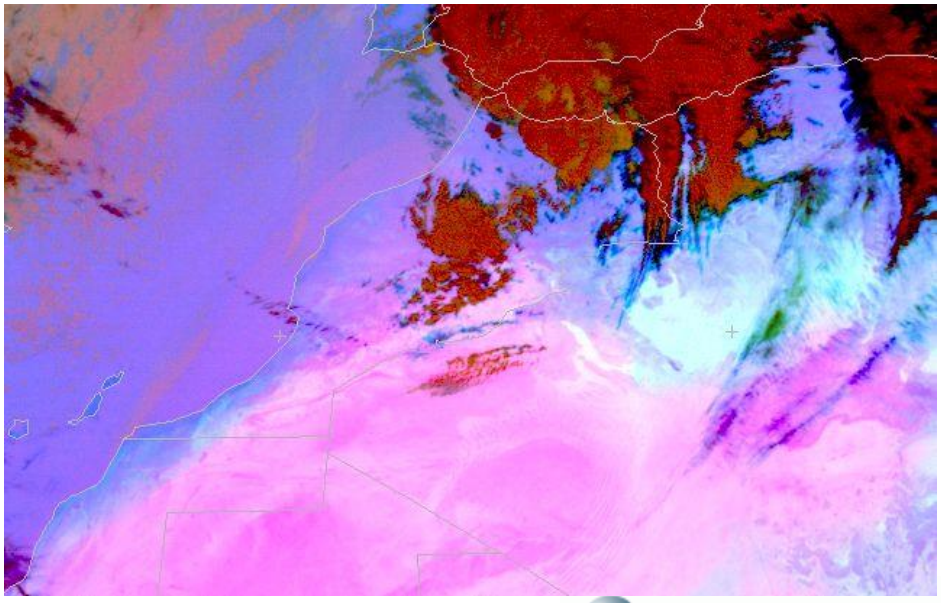
- No sample validation done so far for dust temperatures (heights), using ground temperature. This is essential for evaluation of the thermal deficit


10 km
5 km
0 km
6.96
-16.40
South
13.03
-15.09
19.13
-13.72
25.23
-12.27
31.32
-10.72
North
31.32,-10.72
25.23,-12.27
19.13,-13.72
13.03,-15.09
6.96,-16.40
MSG 22 June 2007, 02:45 UTC
CALIPSO 22 June 2007, 02:40 UTC

Other validation source: Nowcasting SAF dust flag

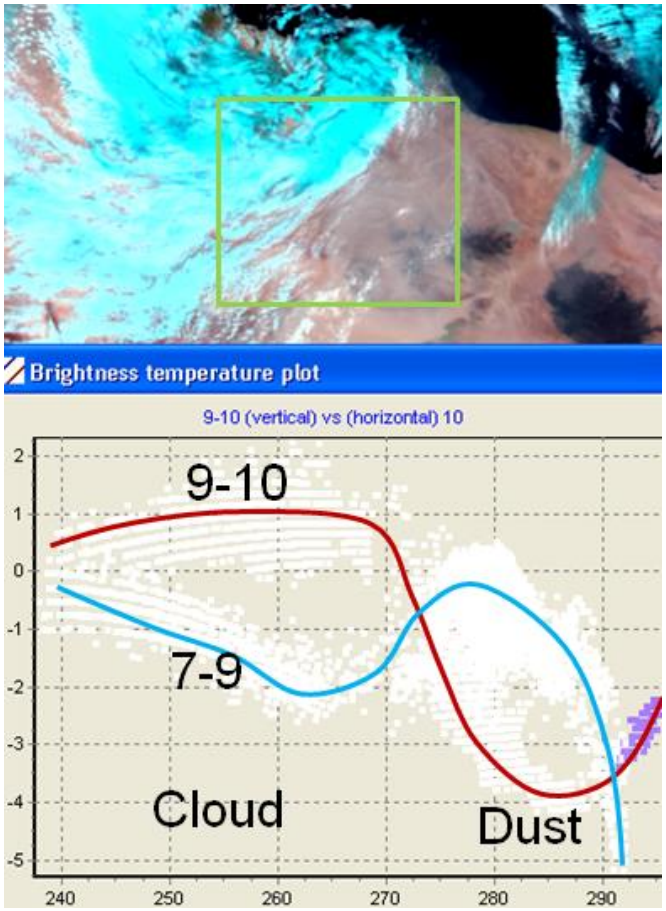
- *For the ocean, day time:* R1.6/R0.6 high, T12.0-T10.8 high, SD(T10.8-T3.9) smooth
- *For the ocean, night time:* same IR, T8.7-T10.8 high
- *For continental surfaces, day time:* not cold T10.8, smooth T10.8, filters for cloud





Nowcasting SAF dust flag and Dust RGB 21-Mar-2010 12 UTC

Dust-cloud interaction



Cloud-dust index: 2*ch9 – ch7 – ch10

Contents

- Infrared dust properties
  - Where you learn how cool dust really is
- A model of atmospheric dust
  - Where you learn to distinguish high thin from low fat
- Validation via AERONET
  - Where you learn that models can help your eyes
- Mixed scenes: cloud and dust
  - Where you learn that life is impossible without water
- Conclusions
  - Where you learn that there is more dust on books than books on dust

Conclusions

•A model based on three **infrared** window channels provides a set of parameters for dust storm severity

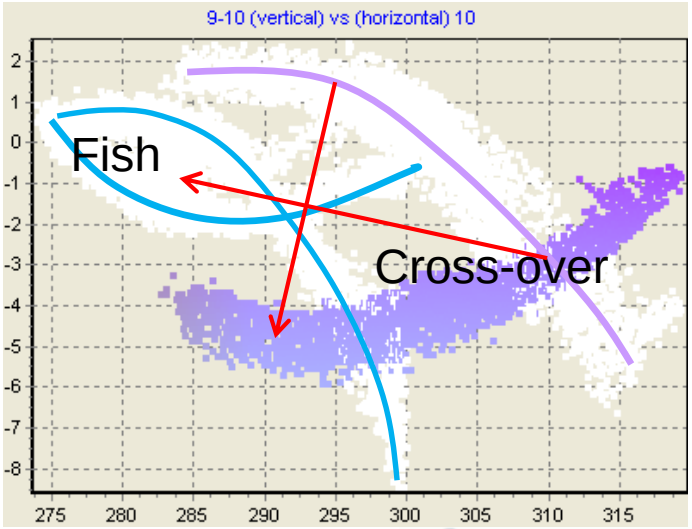
•*Tdust, Tground* and *Depth* values are essentially derived from **10.8µm** and **12µm**

•Channel at **8.7µm** provides **refinement** at the dust end of the curves. Not at the ground branch, due to uncertain ground emissivity

•The model validation against AERONET is satisfactory, but other validation measurements (NWCSAF, LIDAR) are recommended

THANKS FOR YOUR ATTENTION !

- List of used events:
  - 2004-05-13 12:00, Sudan and Saudi Arabia
  - 2008-02-02 06:00, Saudi Arabia
  - 2008-03-23 12:00, Libya
  - 2009-03-28 18:00, Argentina



EUMETSAT

Dust all over the world? (or not so much?)