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

jose.prieto@eumetsat.int

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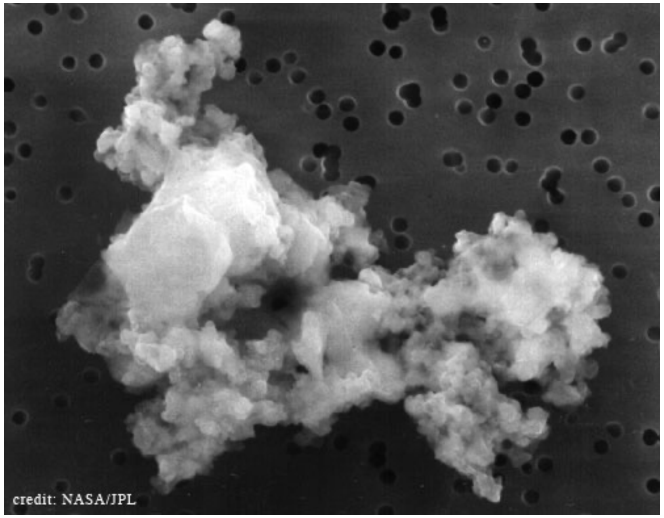
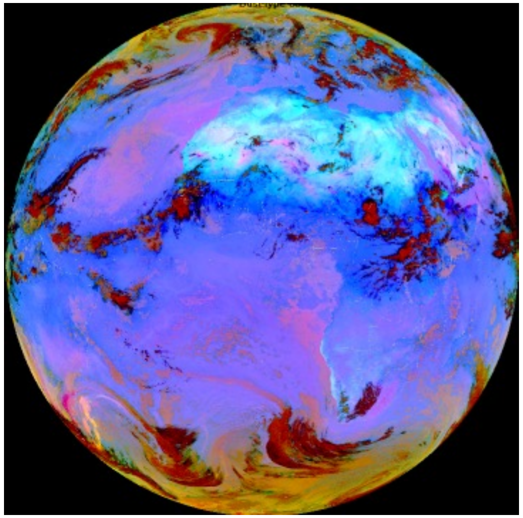
Can a satellite see dust particles ?



← 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)
- Trace for atmospheric circulation (polluting cars)
- Life vector (Saharan protozoa and bacteria to the Caribbean)

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Better dust detection in the infrared?

Best contrast ?	DAY	NIGHT
IR		
VIS		

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

Ocean	DAY	NIGHT
IR	good	good
VIS	good	A/N/A

Desert	DAY	NIGHT
IR	good	bad
VIS	bad	A/N/A

- 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.
- On VIS imagery over **water**, dust is easy to note. Over **land**, however, the dust plume and dry surfaces look similar

Consecutive days in Fuerteventura, January 2010

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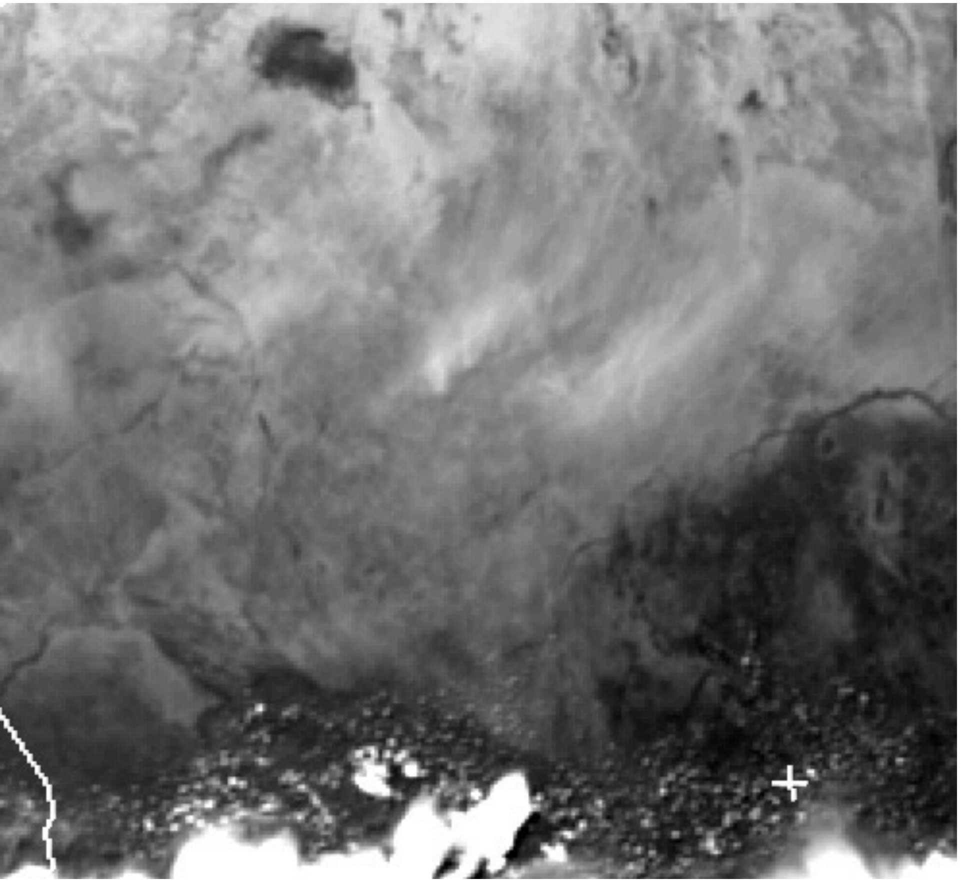
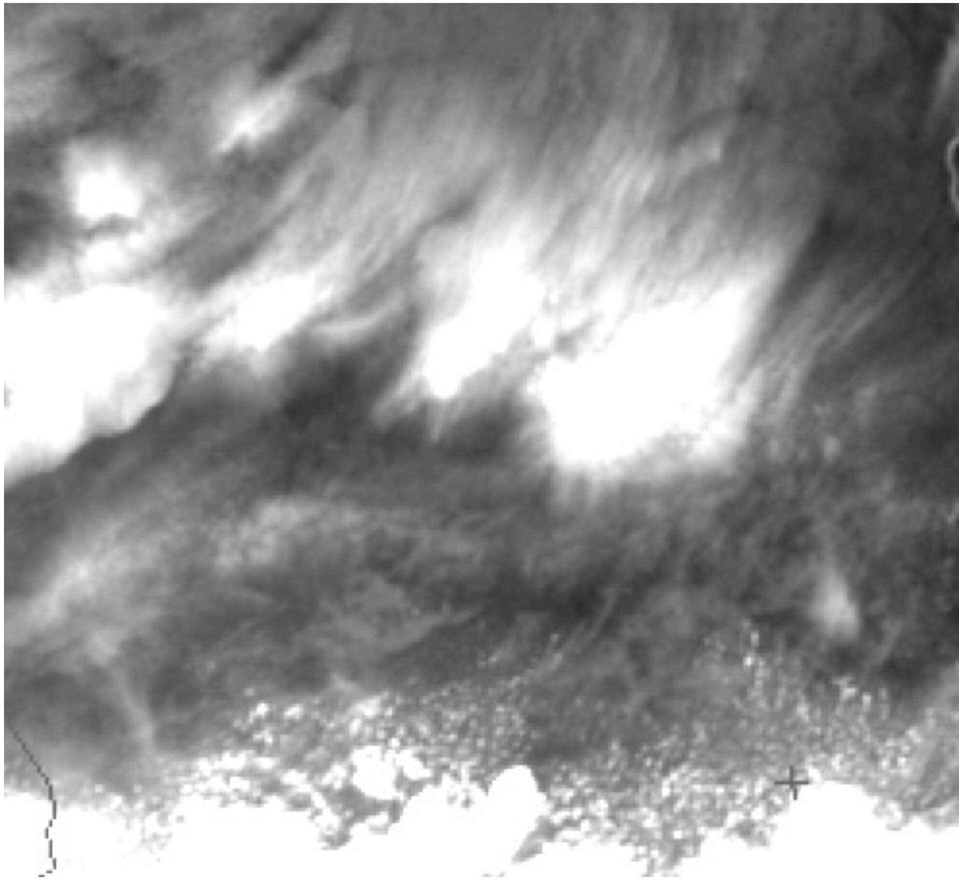
Dust on visible and infrared



2004-05-13 13:00 UTC, 0.8 µm

•Dust **reflects** back solar energy to space



Same date and time, 10.8 µm

•Dusty air rises and **cools** down

Desert scene, Southern Sudan

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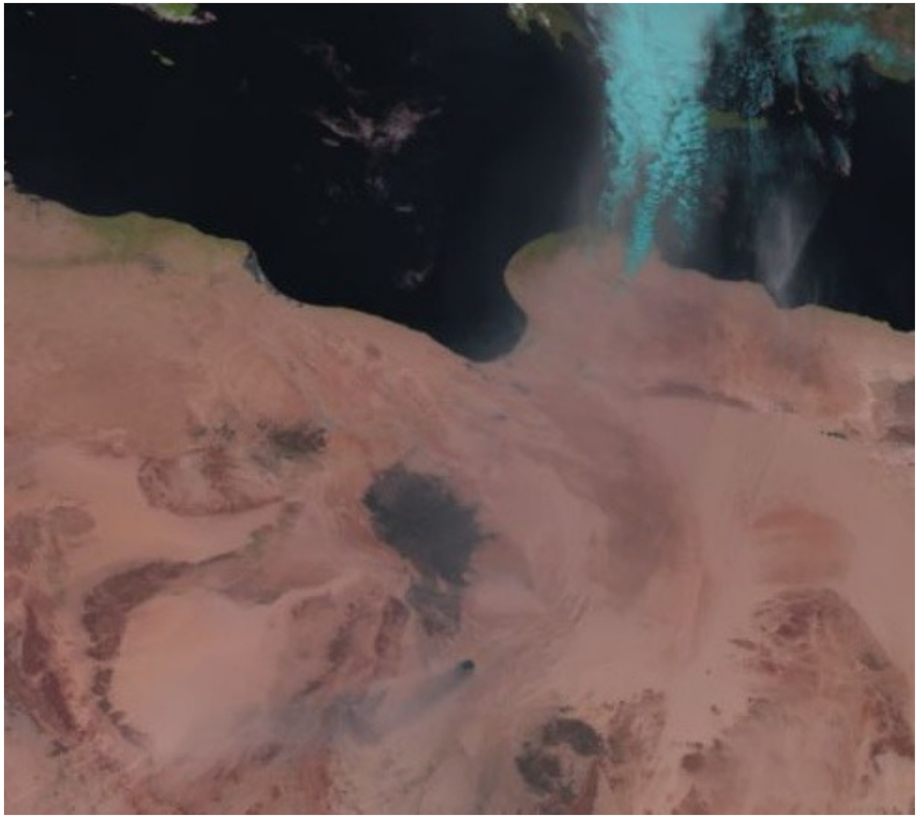
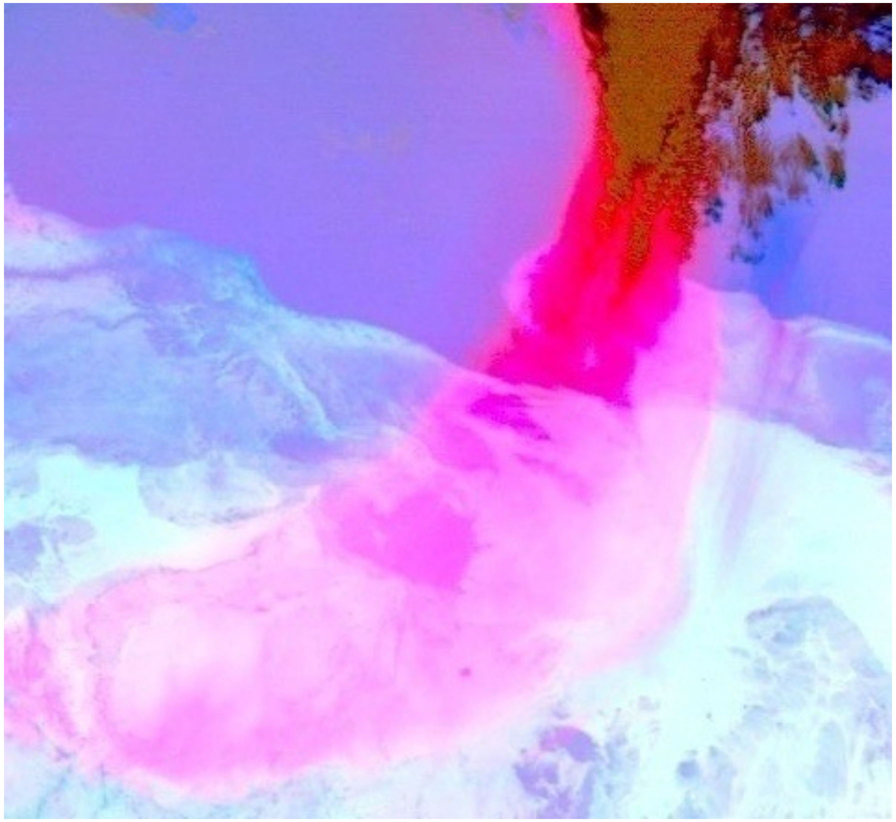
DUST RGB composite:
the strength of infrared for dust detection



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

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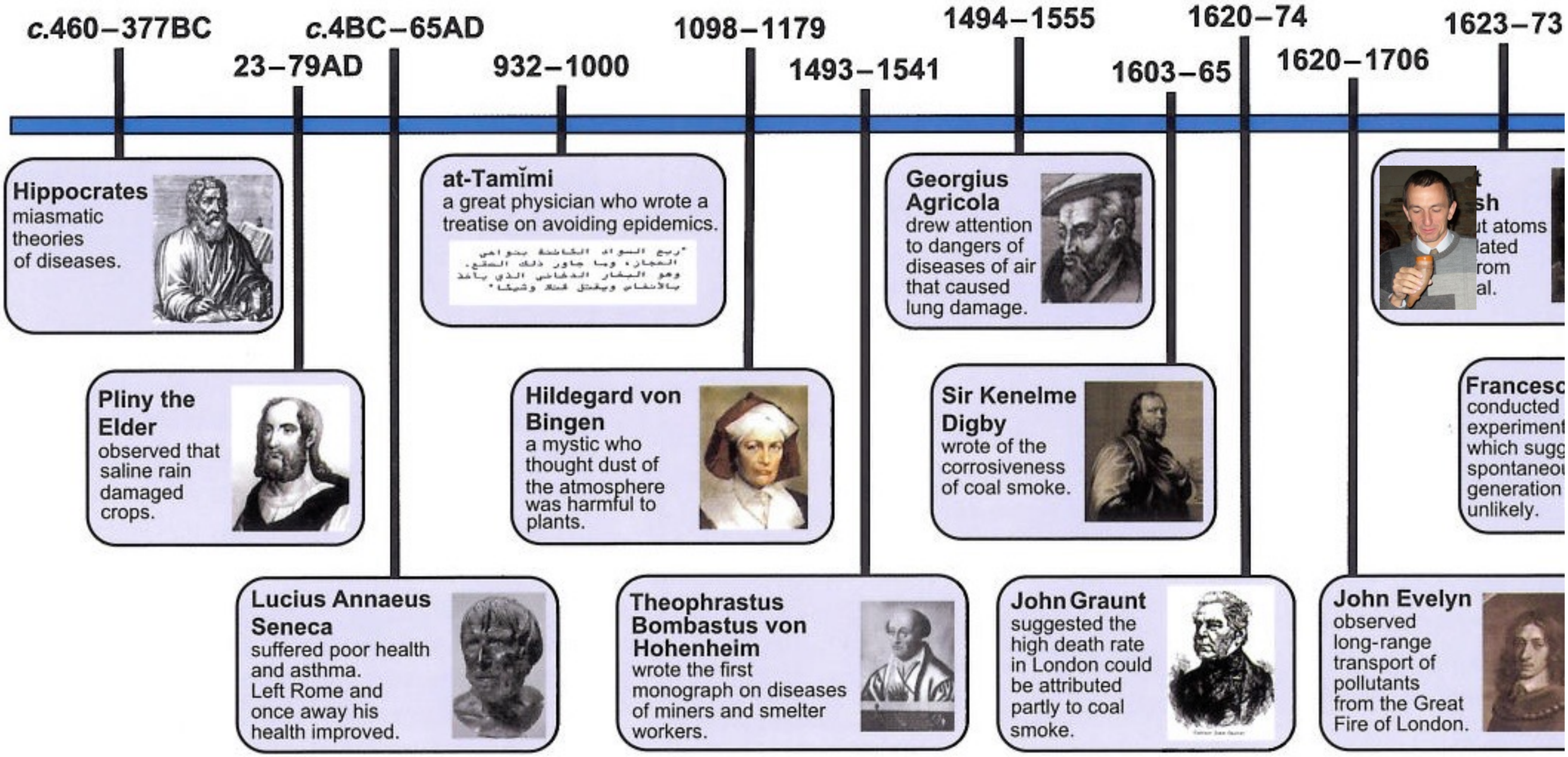
Aerosol and health



World Atlas of Atmospheric Pollution. Editor: R. S. Sokhi

Impact on: agriculture (fertile fields), climate (radiative balance), aviation (ash in routes)

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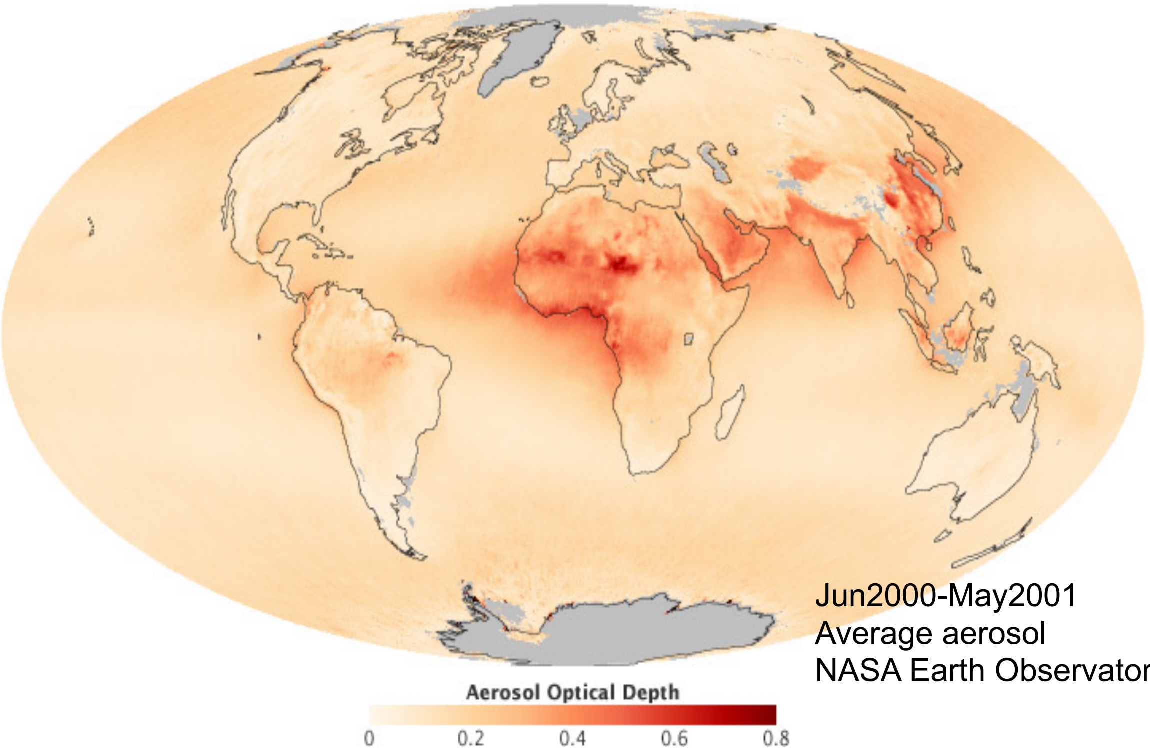
Aerosol is more than dust



Jun2000-May2001
Average aerosol
NASA Earth Observatory

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

?

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Dust characteristics

- Dust storms occasionally reach up to 1km | 5 km | 10 km **height**, and are as thick as 100m | 1km | 5 km

- Dust optical depth is around 0.1 | 0.5 | 1 (average on land) or 3 | 10 | 50 for storms, in the visible range. Optical **thickness** in the IR is about 40% of those values.

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

- Aerosol **density** average in the atmosphere 10^{-7} kg/m3 (equivalent of depth 0.1 | 1 | 3)

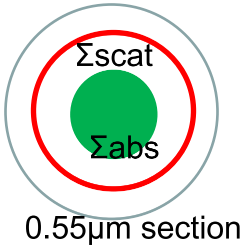
Dust characteristics

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

- Dust optical depth around 0.5 (average on land) or 3 for storms, in the visible range. Optical **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 (equivalent of depth 0.1)



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

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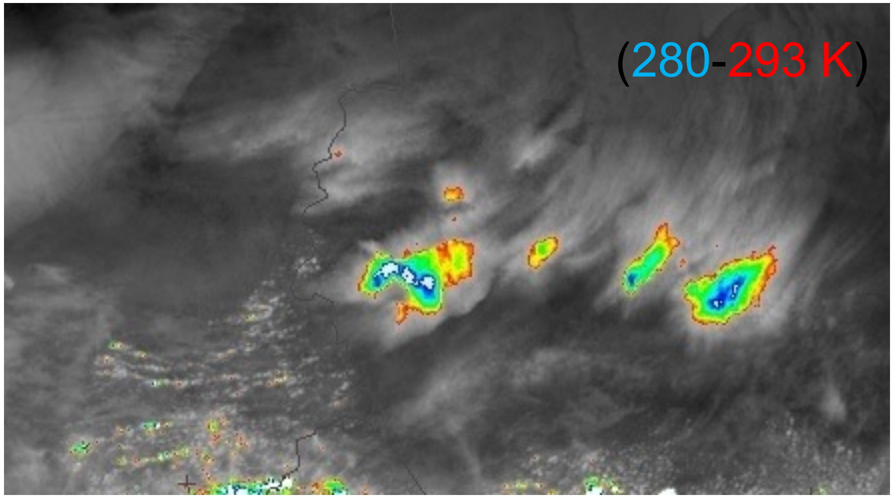
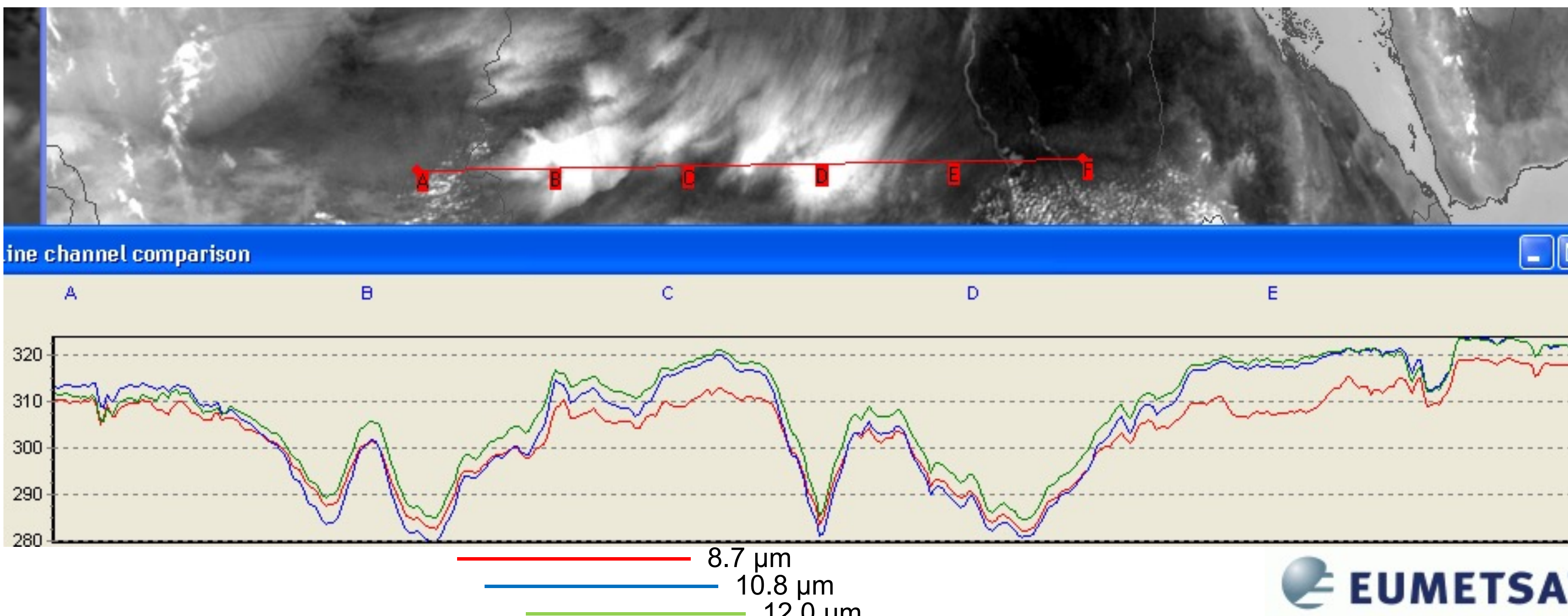
Dust enhancement in a single IR channel (?)



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



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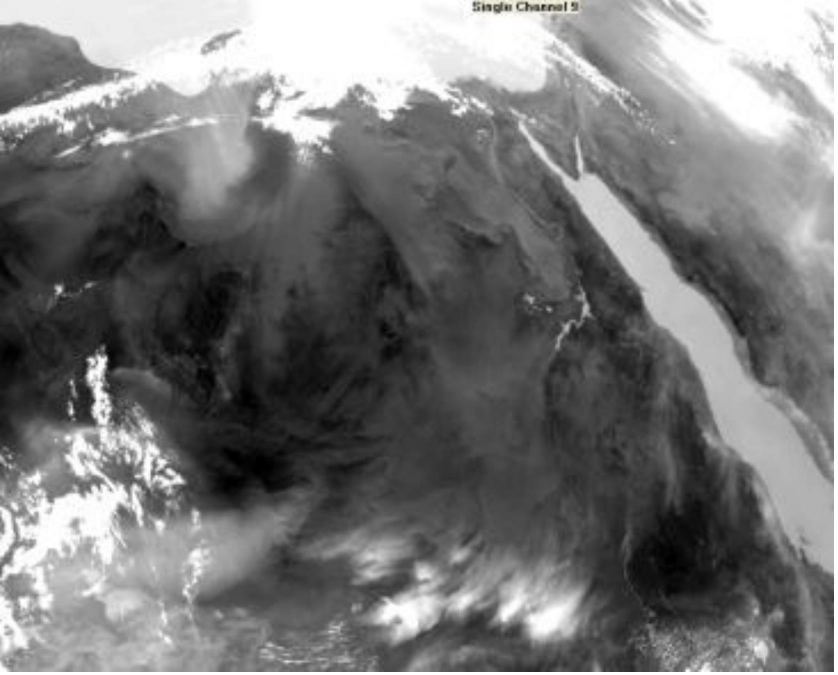
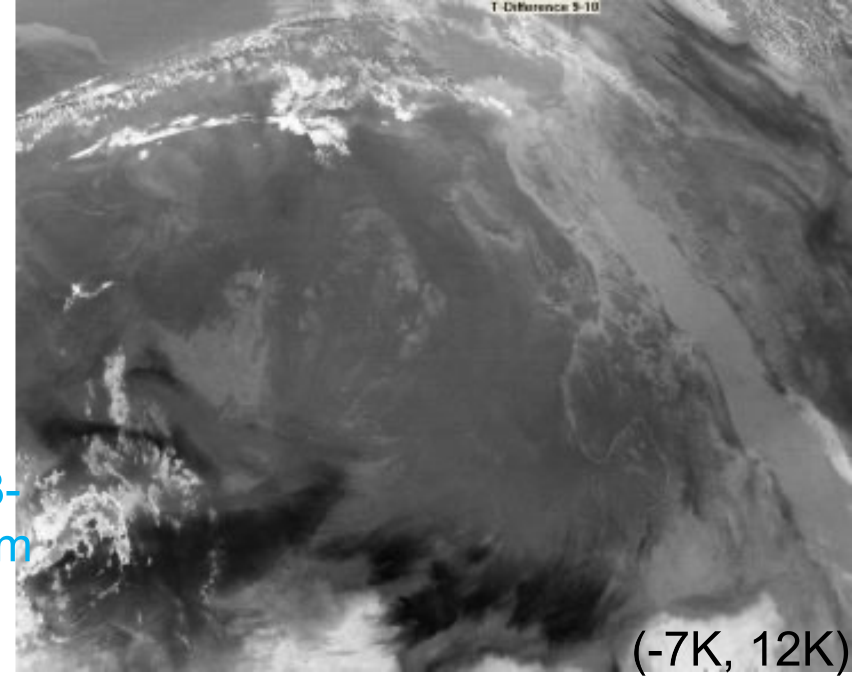
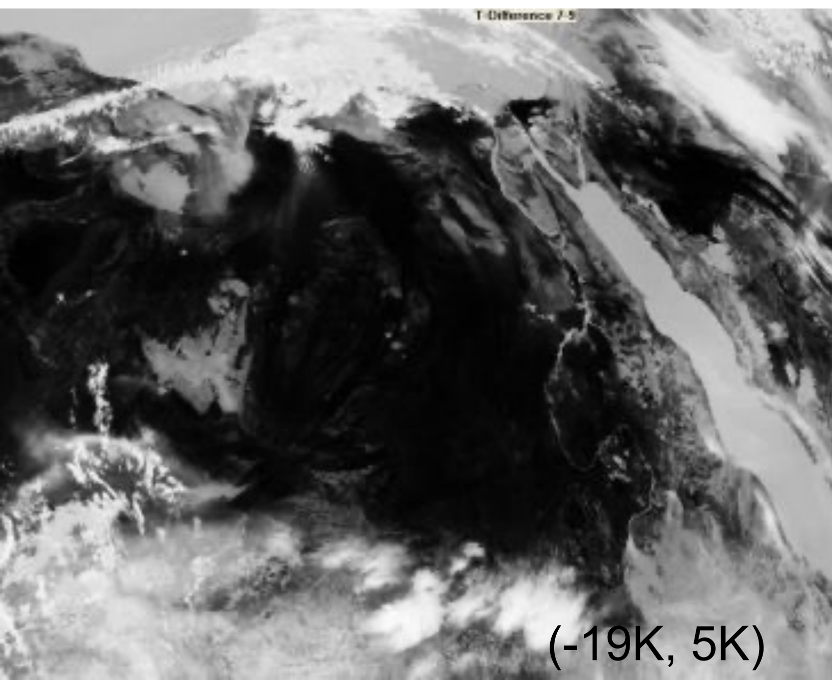


10.8µm

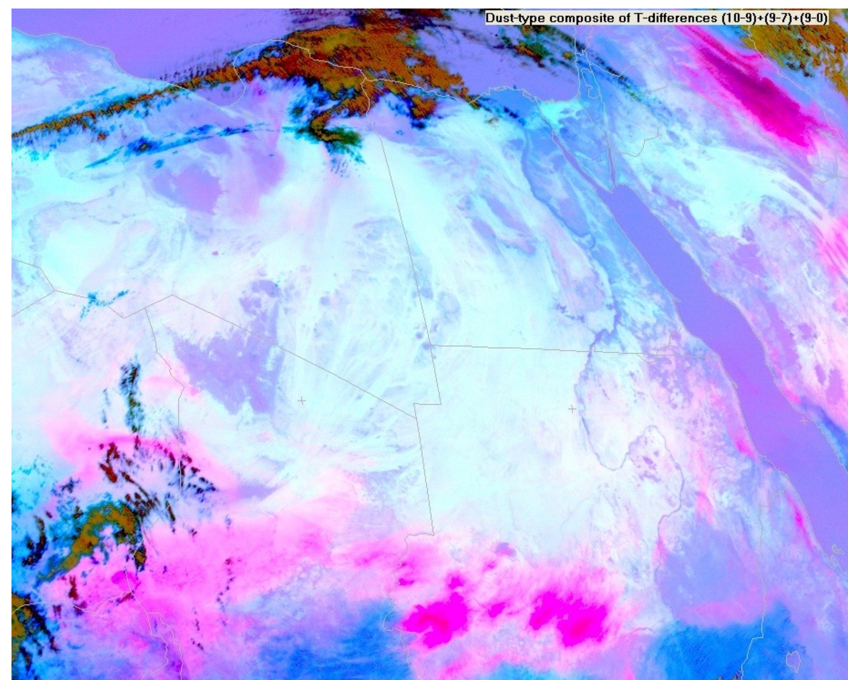


10.8-12µm

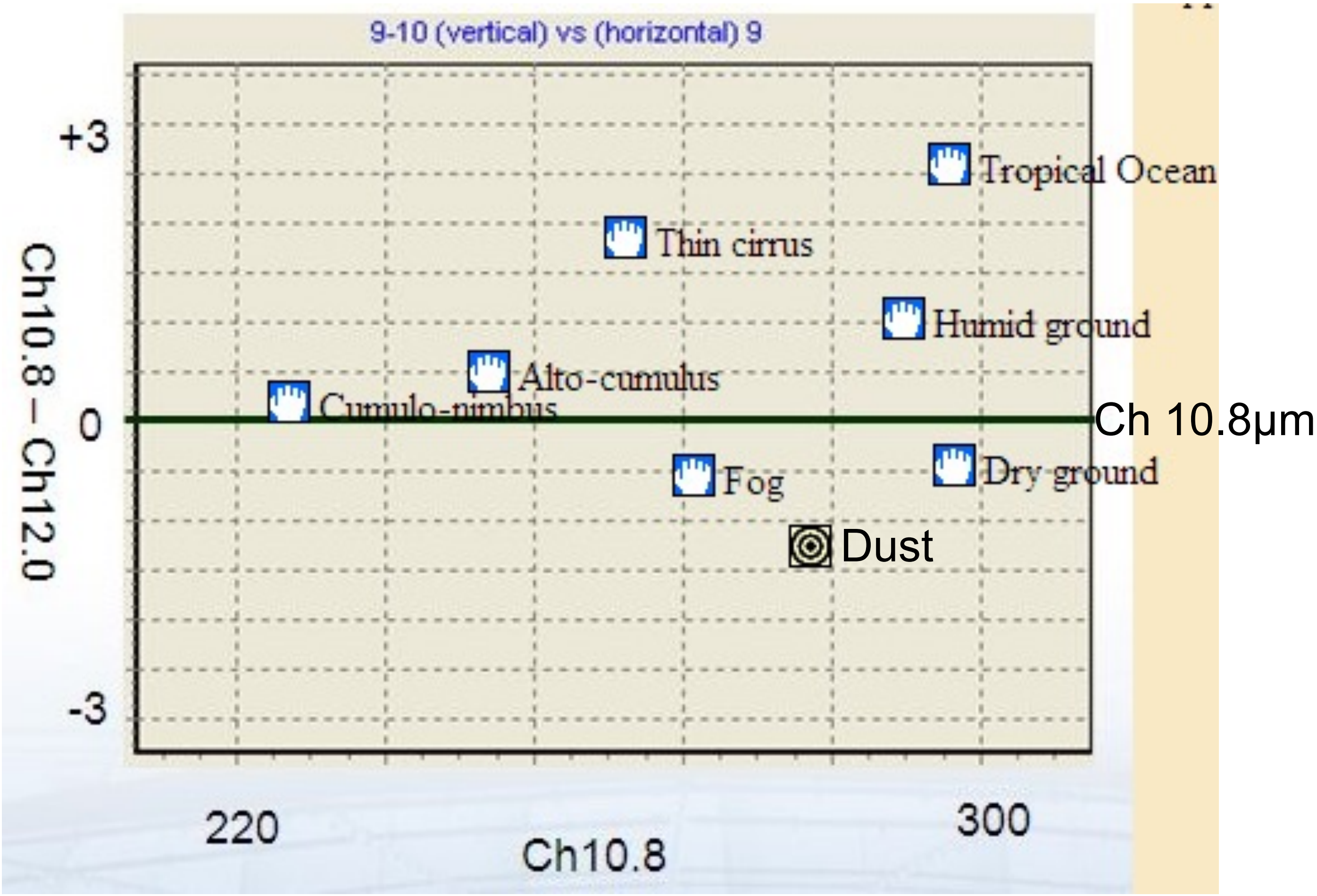
Ch9 (*upper left*) and three independent differences



8.7-10.8µm



The 10.8µm-12µm difference (vertical)



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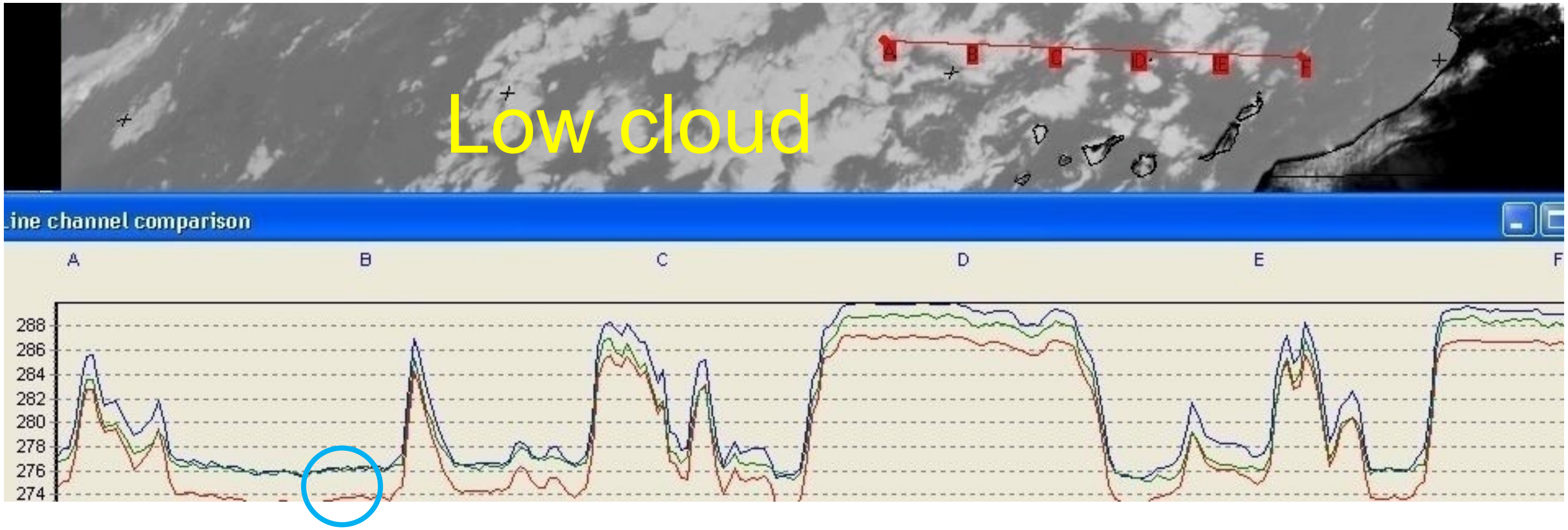
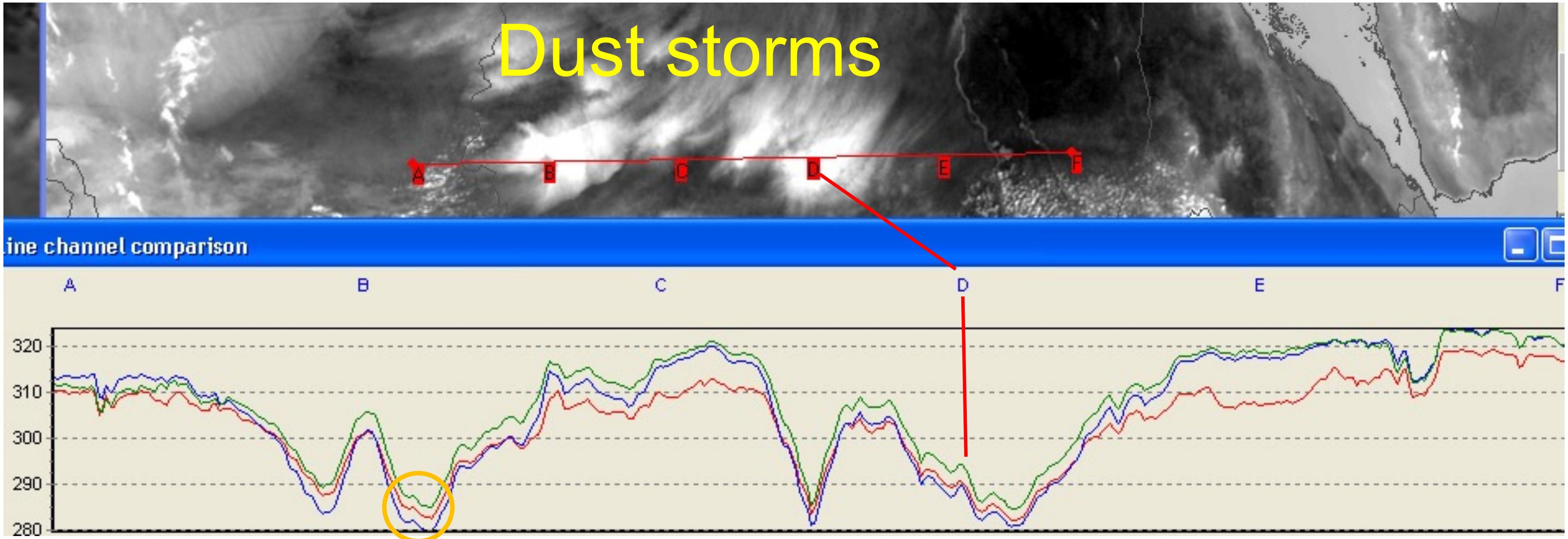
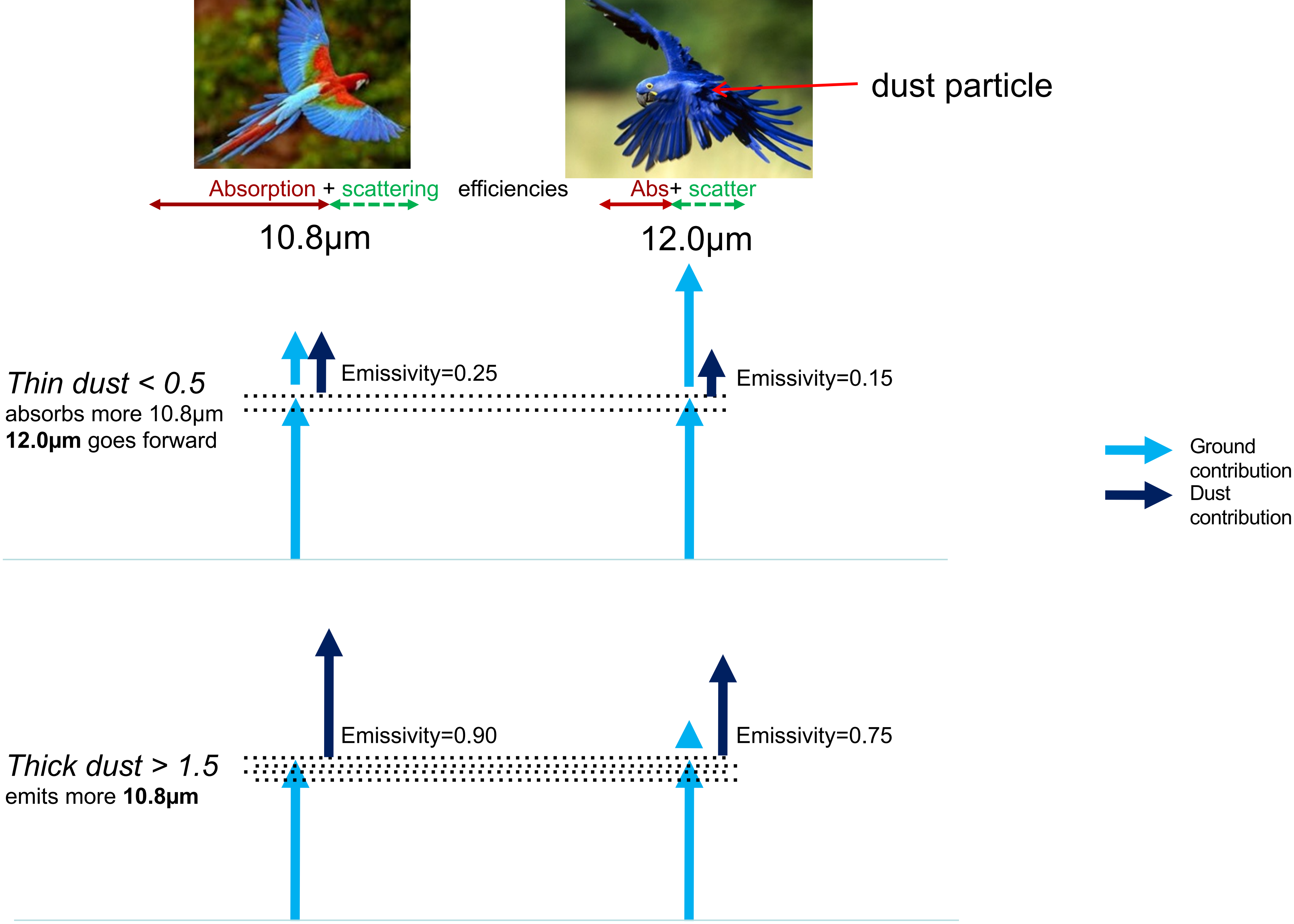
Comparison of water cloud and dust in the IR window





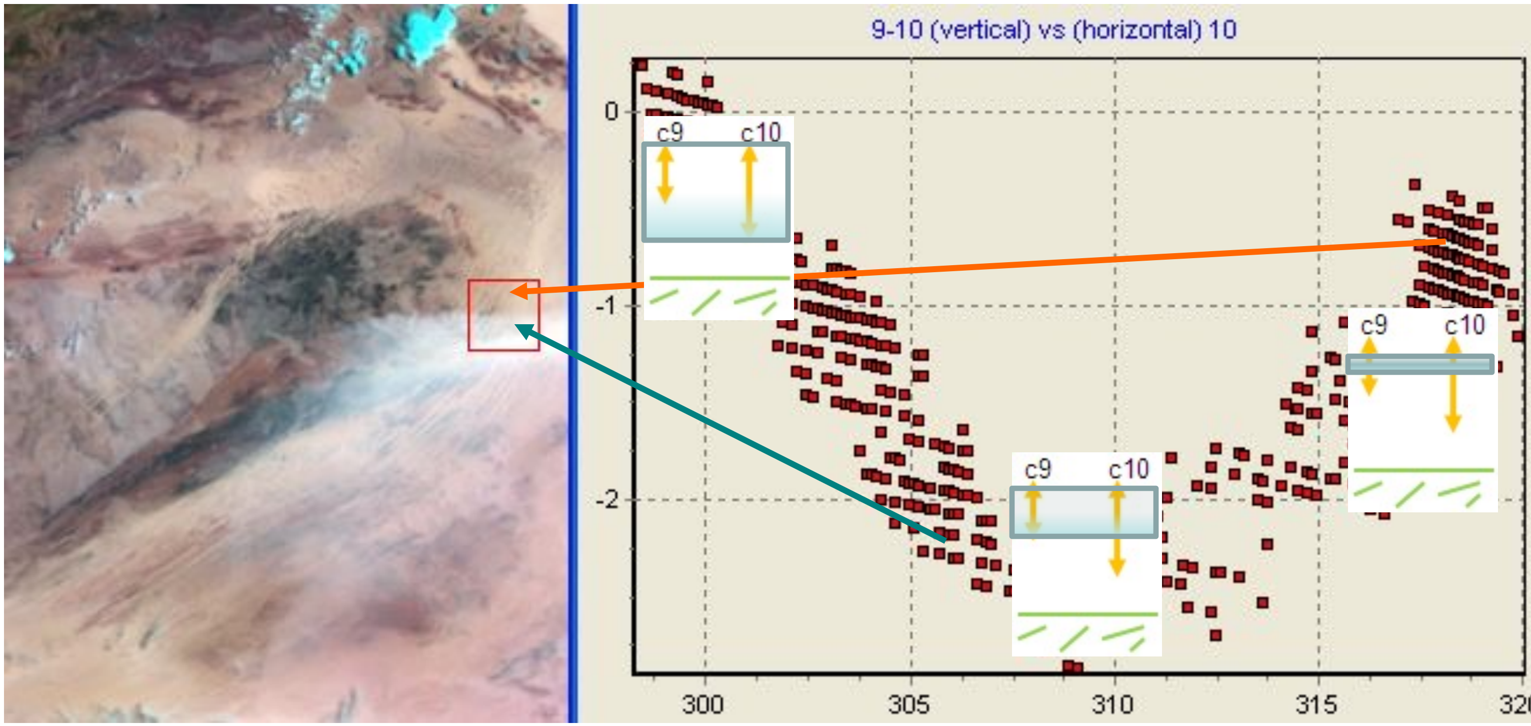
8.7 µm
10.8 µm
12.0 µm

EUMETSAT



dust particle
Absorption + scattering
efficiencies
Abs+ scatter
10.8µm
12.0µm
Emissivity=0.25
Emissivity=0.15
Thin dust < 0.5
absorbs more 10.8µm
12.0µm goes forward
Ground contribution
Dust contribution
Emissivity=0.90
Emissivity=0.75
Thick dust > 1.5
emits more 10.8µm

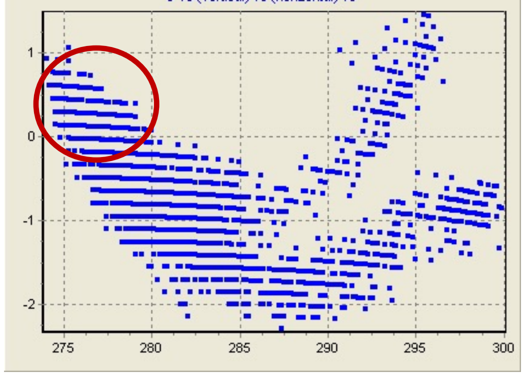
“Reversed arc” for dust scenes: Ch9-Ch10 versus Ch10



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 at 10.8µm
- 10.8µm channel shows higher BT than 12µm for thick dust due to higher emissivity

Exercise: plot 9-10 versus 10



Why is the brightness temperature difference Ch9-Ch10 turning positive for very thick dust layers?

T Ex ❑ Dust shows a higher emissivity at Ch9 than at Ch10

F NEx ❑ Water vapour condenses on dust and favours Ch9 emissivity over Ch10 emissivity

T NEx ❑ Dust has a scattering component, higher at Ch9 than at Ch10

T NEx ❑ Dust Ch10 signal comes from a thicker (and therefore warmer) top layer

Ex: explains NEx: does not explain

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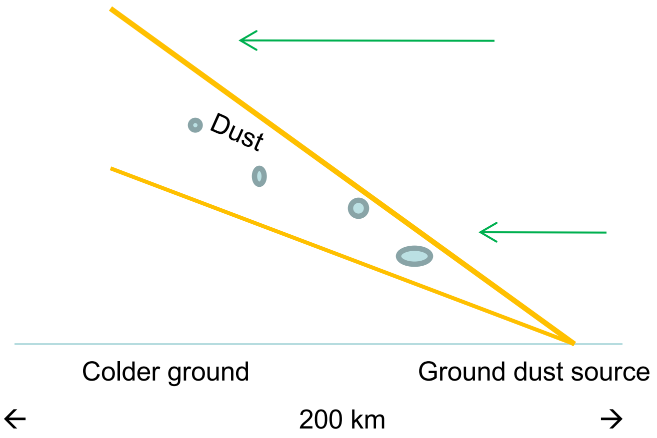
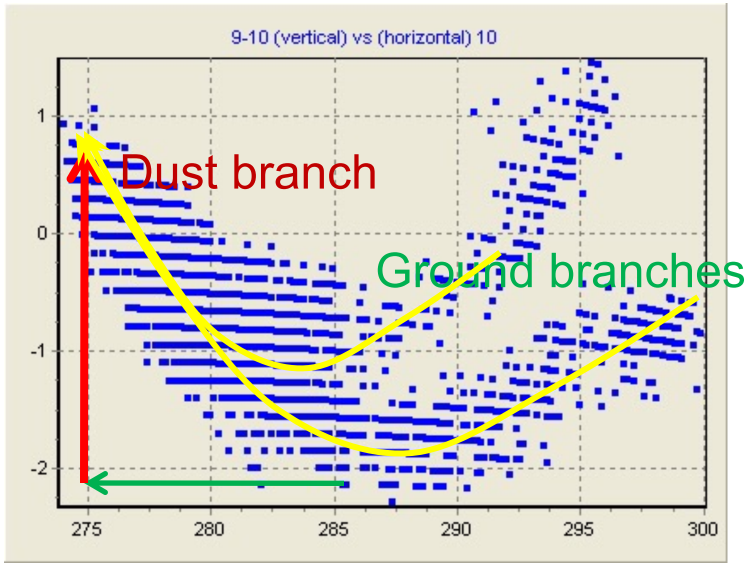
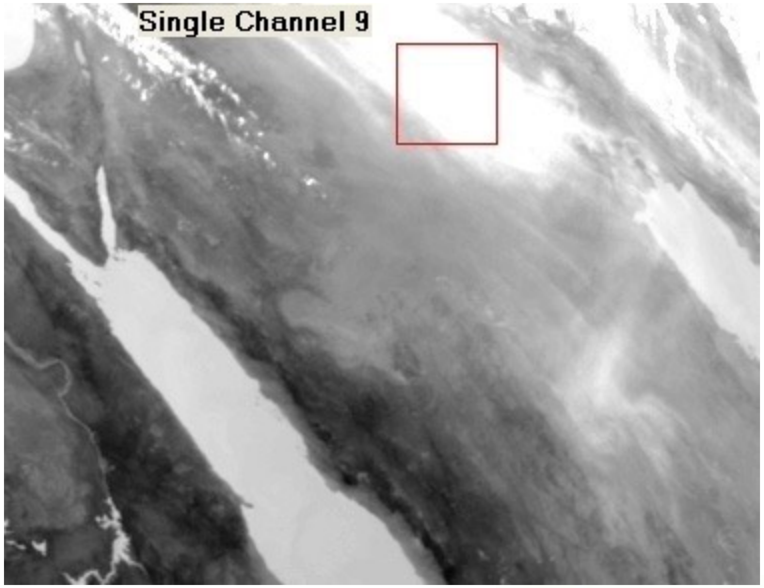
Dust model



- 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...)





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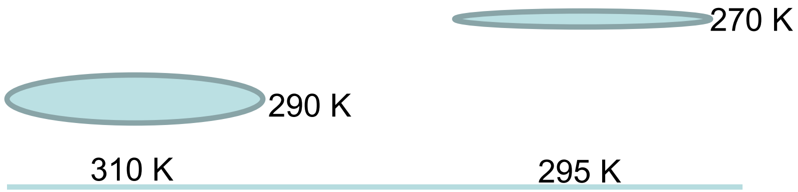
Model assumptions (limitations)

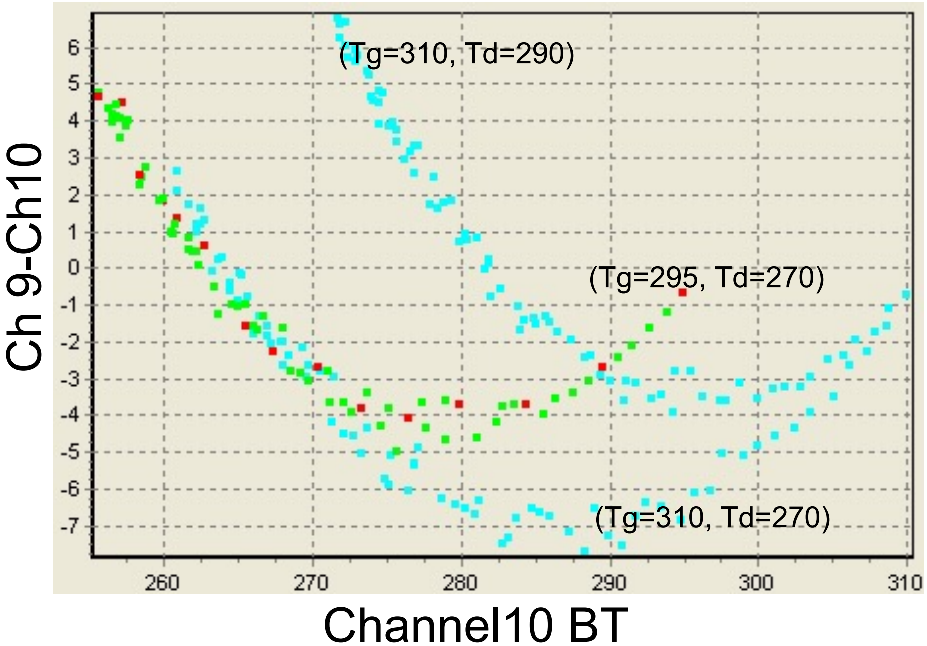
- (32x32 surroundings): min T10.8-T12.0 < *-1.3K*
- Empirical AOT estimates for channel saturation:
  0.14----1.3----3.5----4.8
- Uniform dust type
- Dust in the pixel at a single height
- Size not dependent on height
- Ground temperature affected by thick dust above
- Good results in areas 200 km across

- Four result categories:
  - Dust-free (or low-level only, or night-time, or dry ground)
  - Only dust traces
  - Dust
  - Mixed with cloud

Graphical analysis



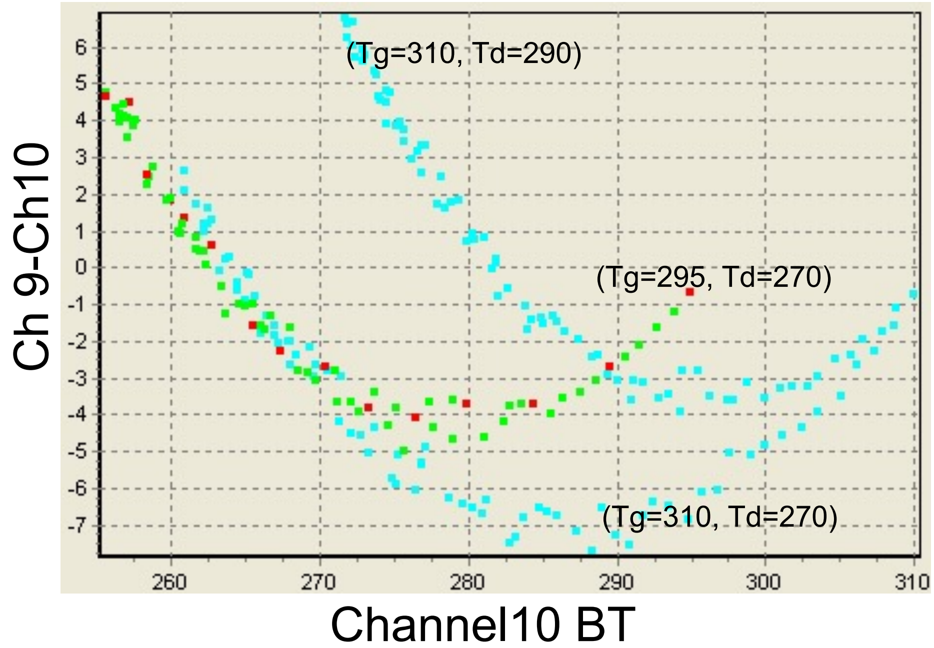
- **Thick** dust cloud at **low** level can be confused with a **thin** layer **high** above
- Reduction of the ground temperature by dust screening the sun (‘thermal **deficit**’)
- Use channel difference **8.7µm – 10.8µm** (negative for thin, positive for thick)



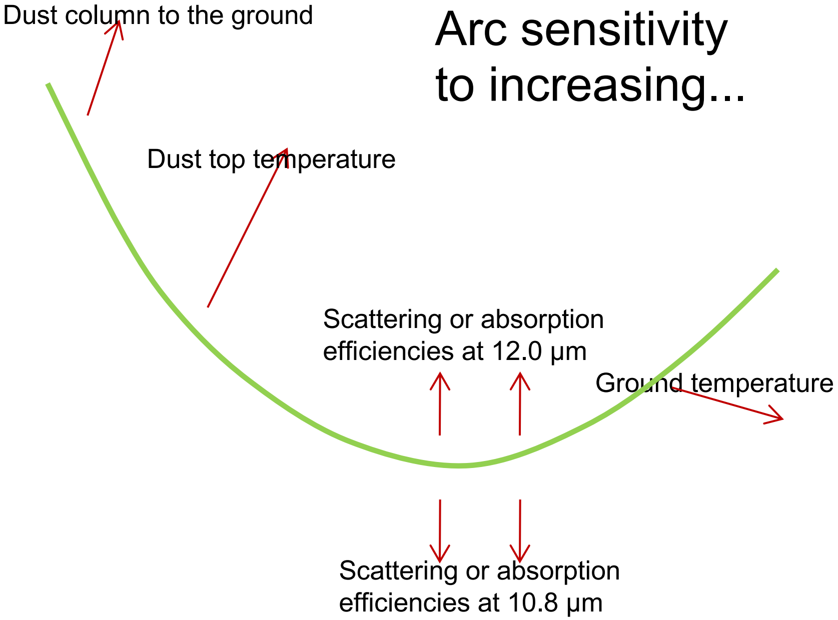
Green-red dotted curve for (Tground=295, Tdust=270)
Cyan curves for Tg=310, and two values of Td=270 and 290

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



Arc sensitivity
to increasing...



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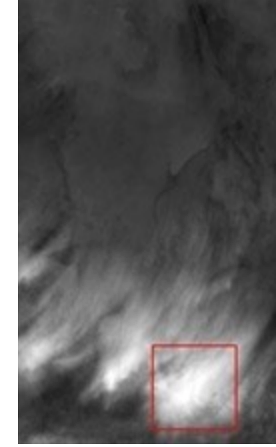
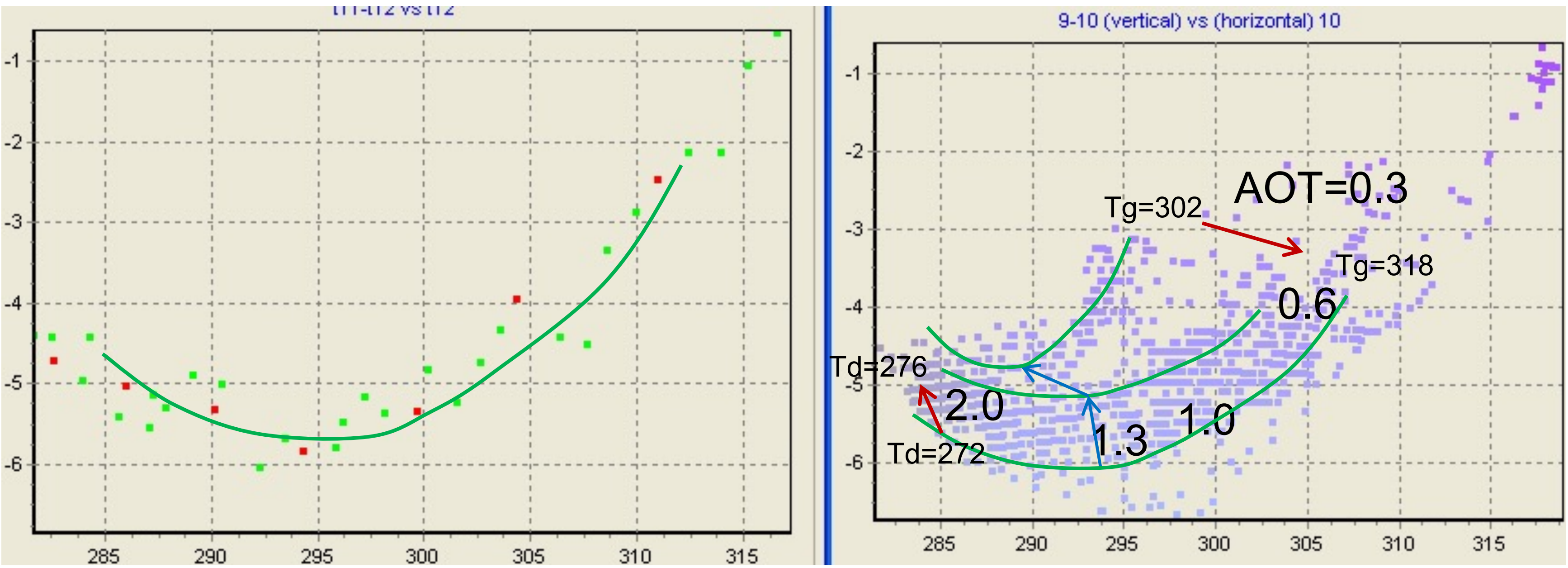
Dust (Td) and ground (Tg) temperatures estimates



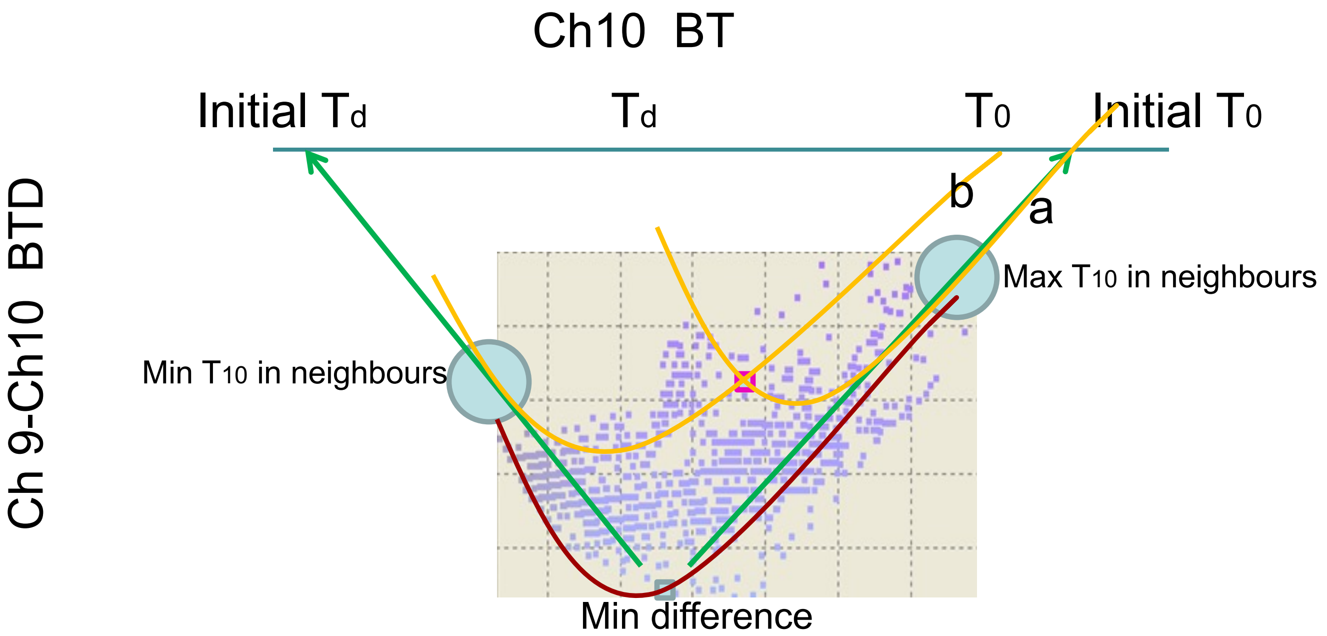


Real (blue dots, right h.s.) compared with simulated (green-red dots left h.s. and lines) scatterograms based on Tg=318 Td=272 Σ11=0.6, 0.3 Σ12=0.2, 0.25

Dust column down to 50% of that temperature difference

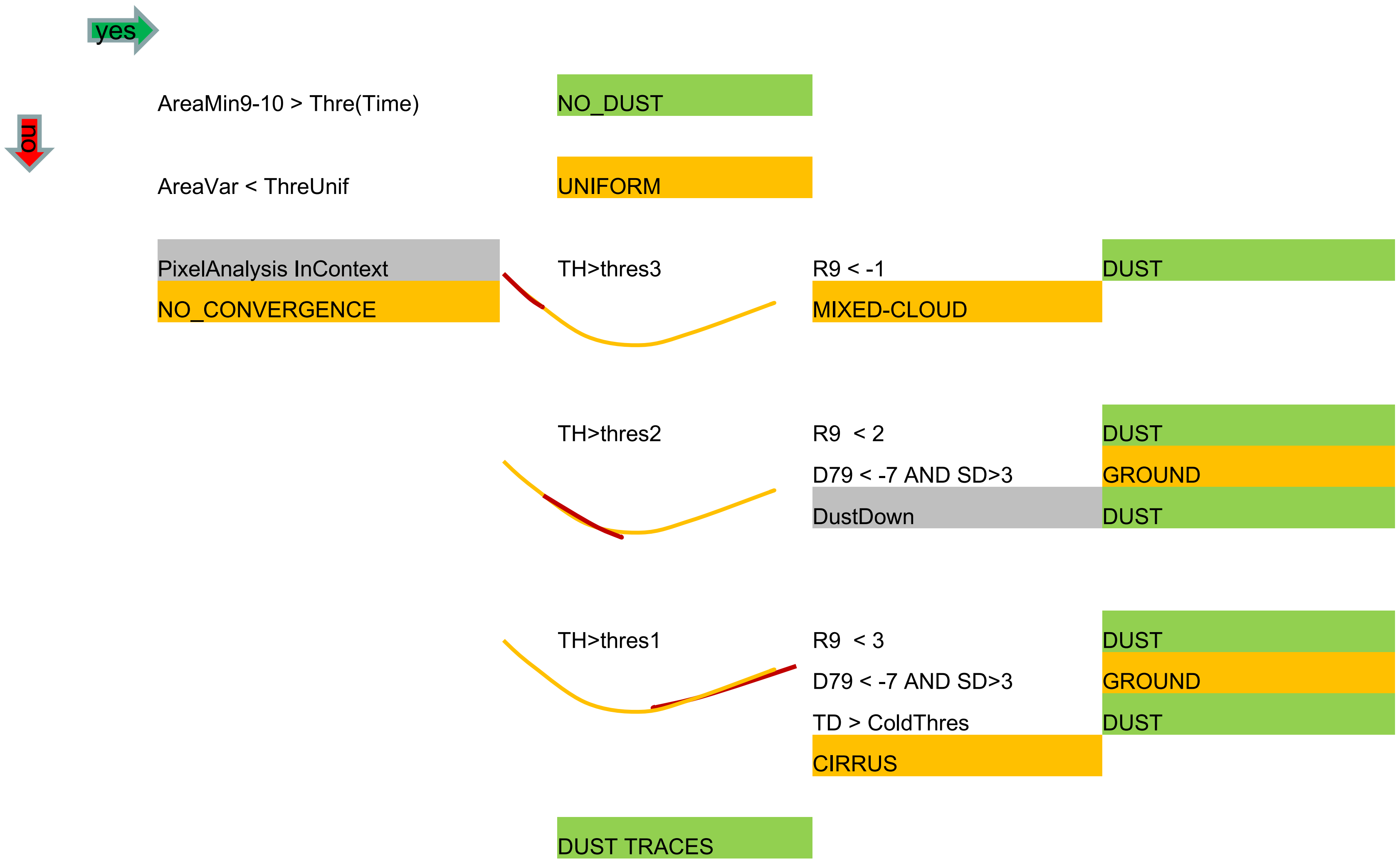
Smaller arcs, higher in the scatterogram, indicate less temperature contrast (Tg – Td)

IR model operation



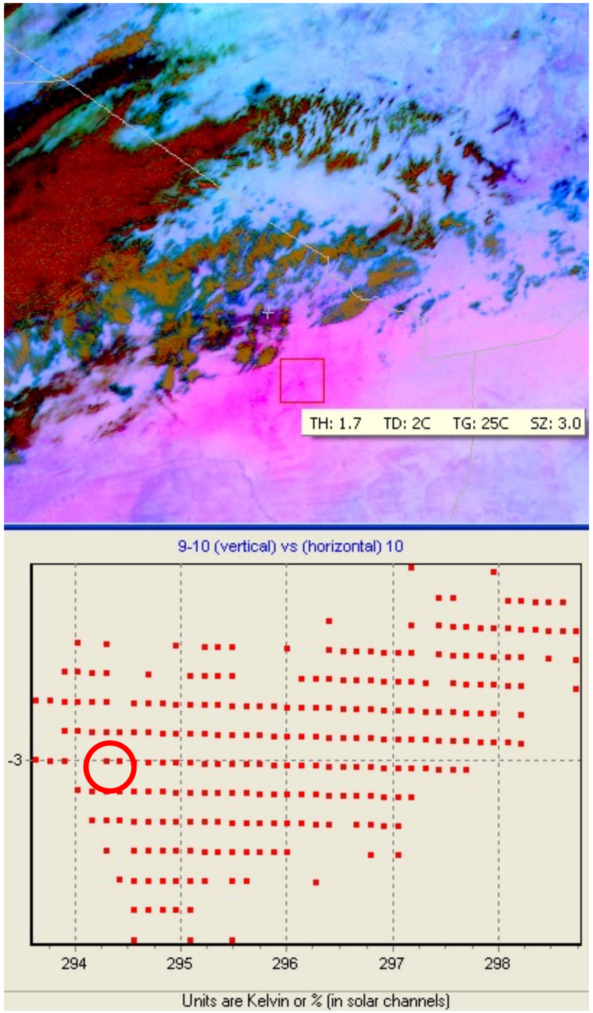
If slope=b, refresh T_0
If slope=a, refresh T_d

Decision tree

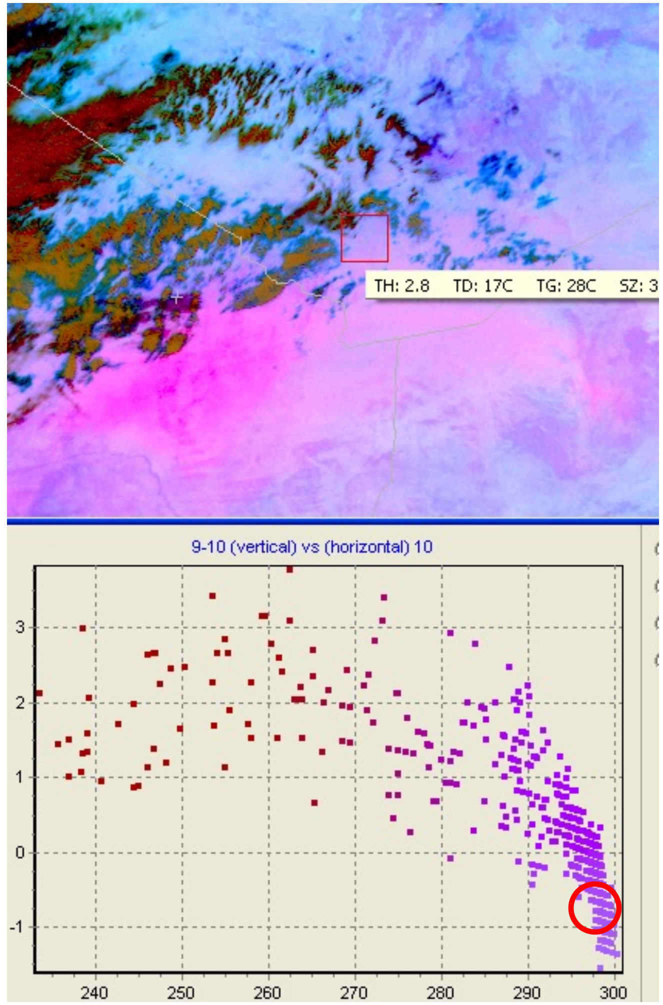


1. Subjective **verification** against masks, images and news media: Done
2. **Verification** from other sources (AERONET, LIDAR): In progress
3. **Inter-comparison** with other methods (Solar): Not started

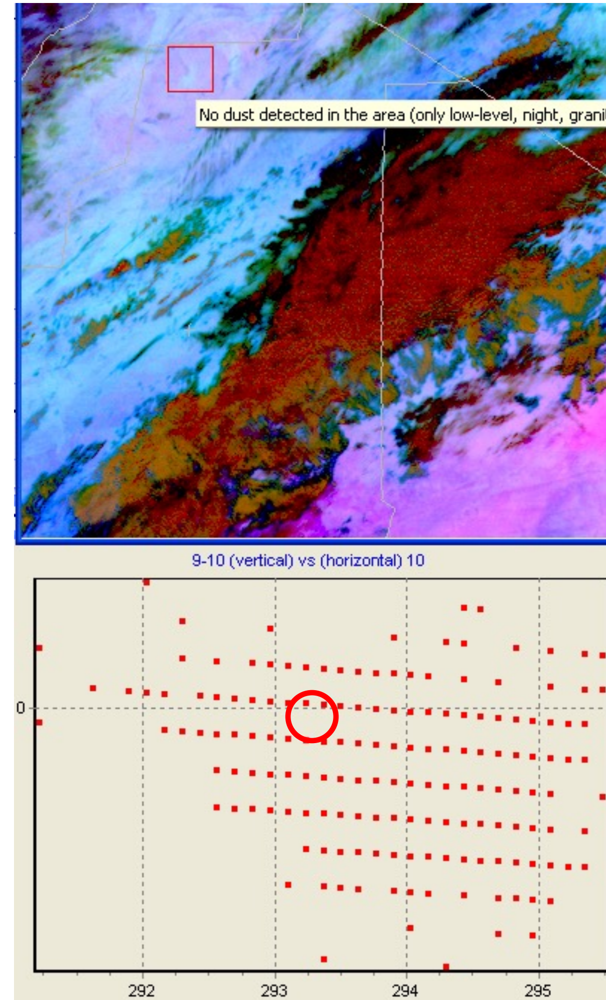
Graphical validation



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

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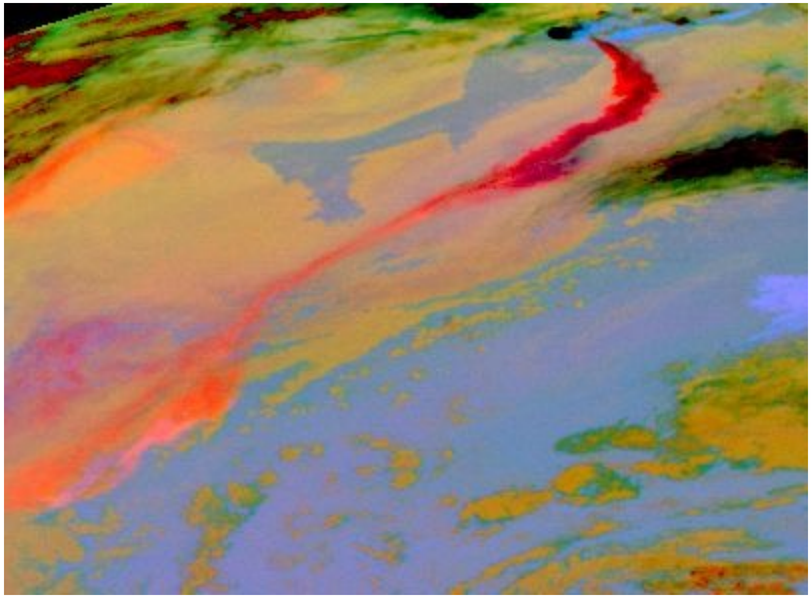
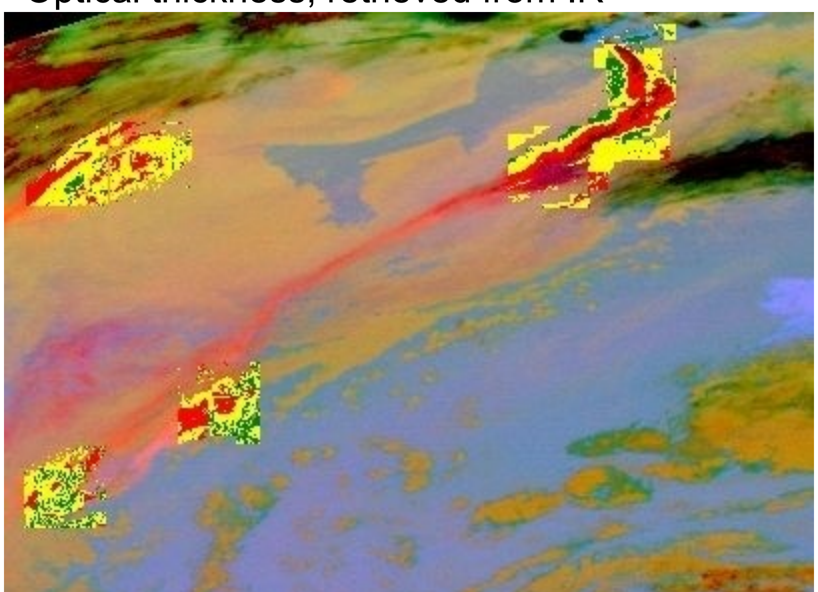
Applicable to volcano ash



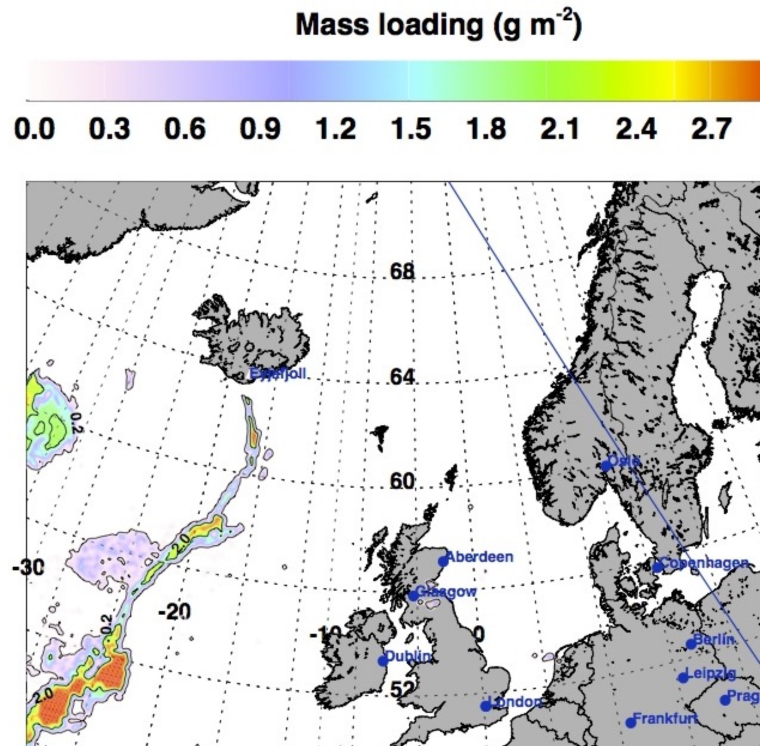
Dust RGB 2010-05-08 12UTC Icelandic ash

Optical thickness, retrieved from IR



•Model results are quite different from the RGB visual impressions, and add information in RGB non-pink areas with small dust depth

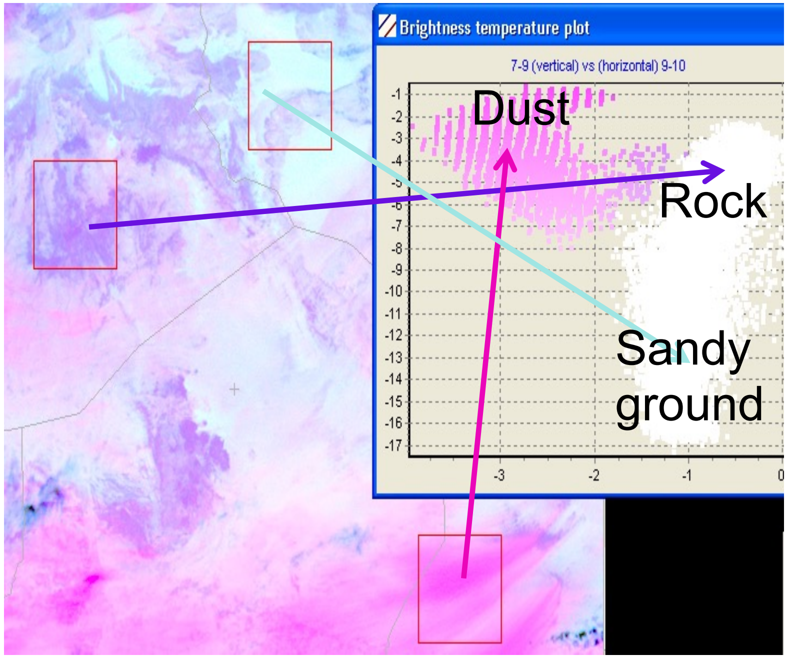
•No direct comparison with mass loading without ash density estimate



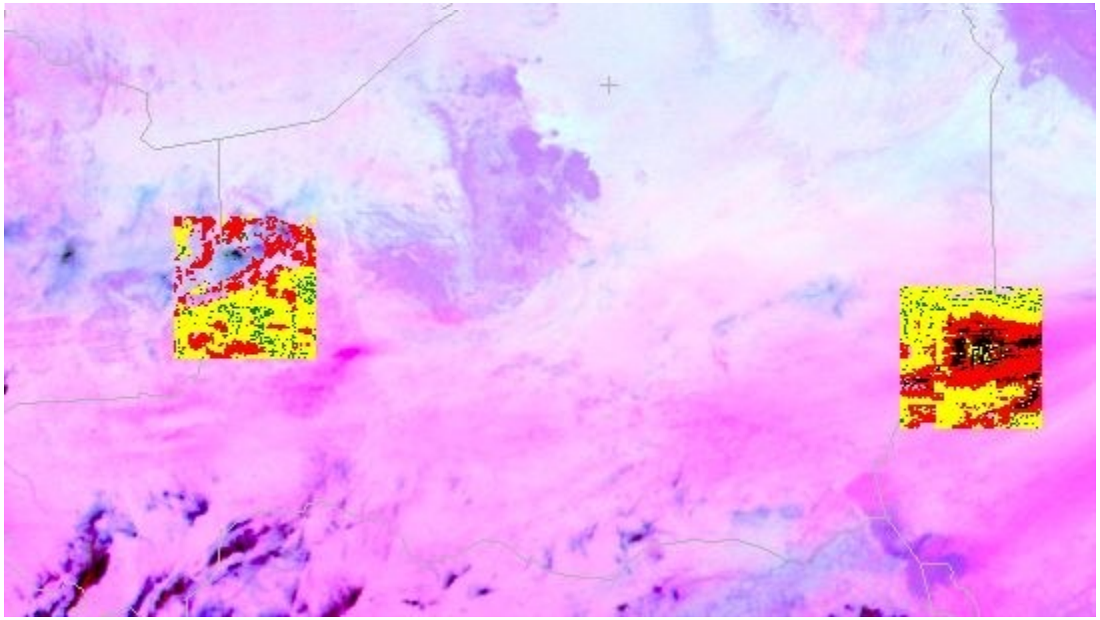
courtesy of F Prata

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

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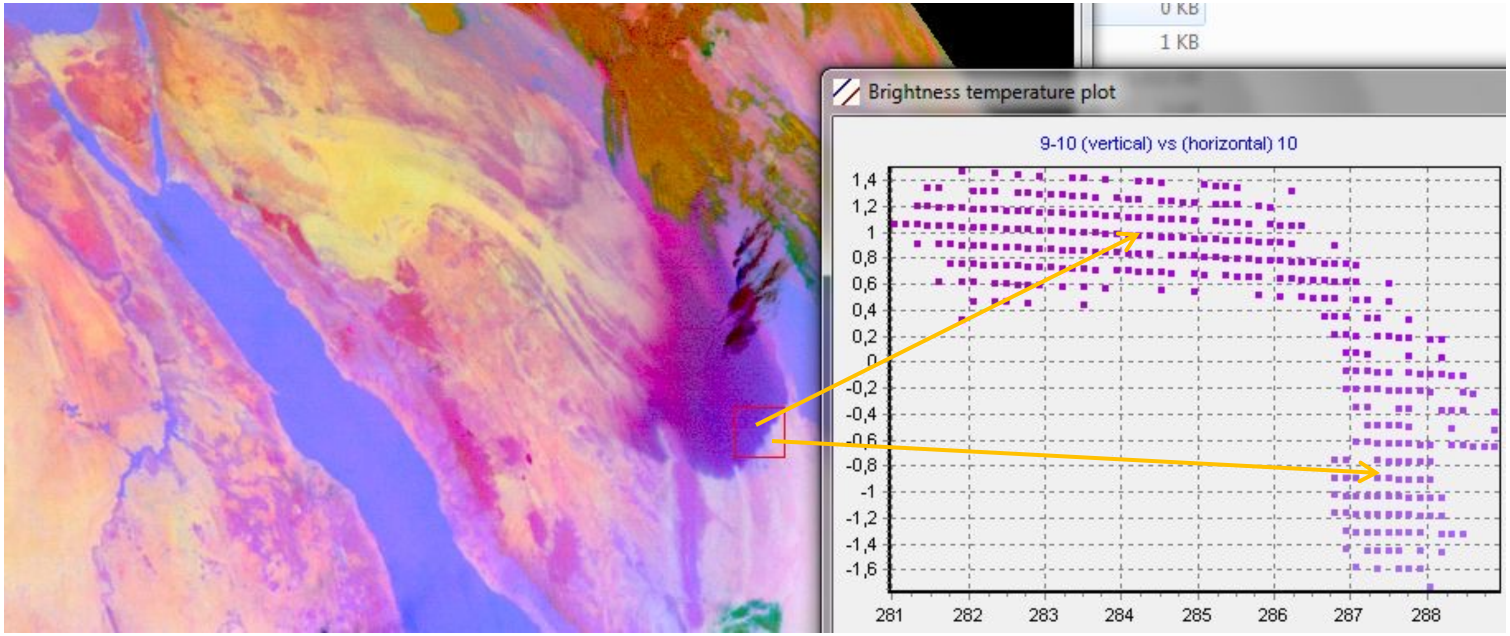
Model fails for atmospheric inversions

- 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



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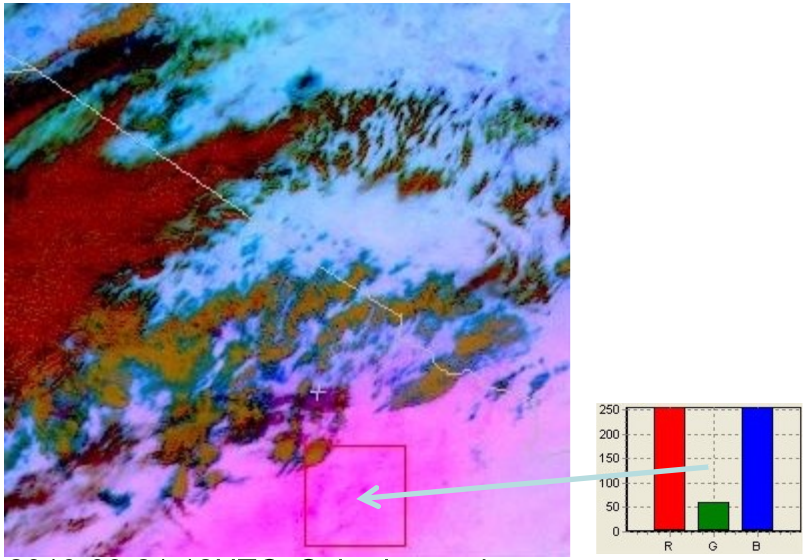
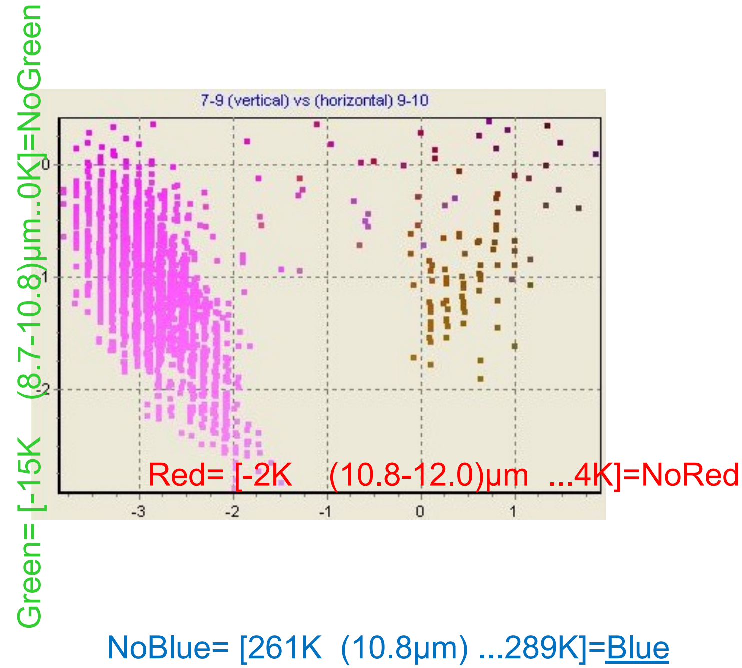
Dust RGB

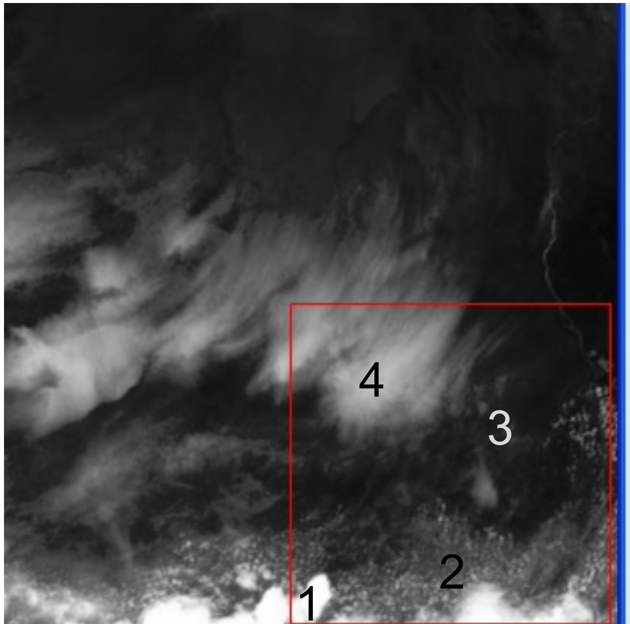


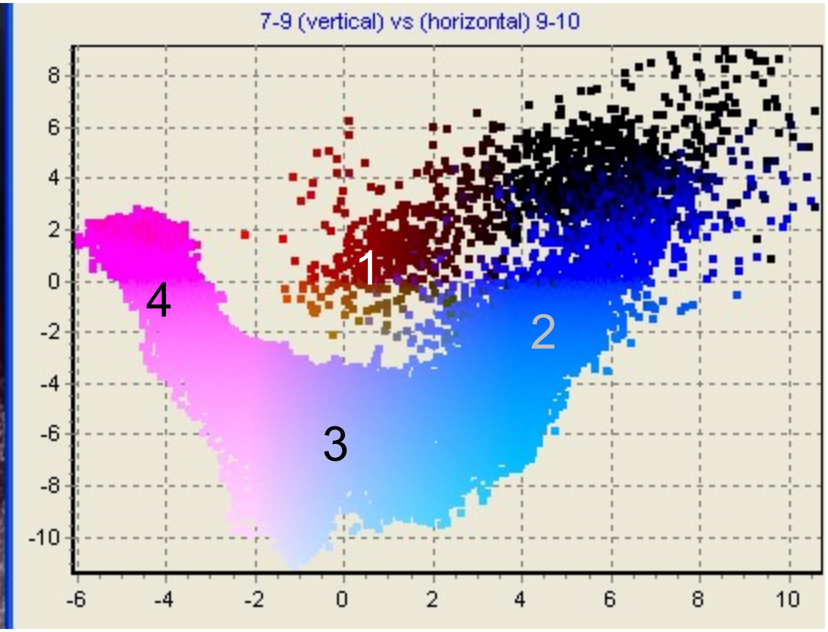
2010-03-21 12UTC, Saharian region



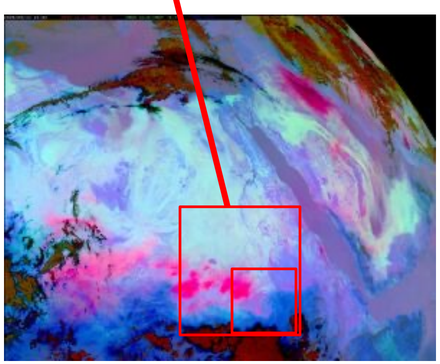
- Magenta areas are typically dusty: neither necessary nor sufficient condition
- Inside **magenta** areas, **darker** (less green) pixels show a smaller difference c7-c9 which means **higher AOD**
- The threshold in the red component (-2K) is exceeded in large areas of the dust storms.
- Blue component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

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

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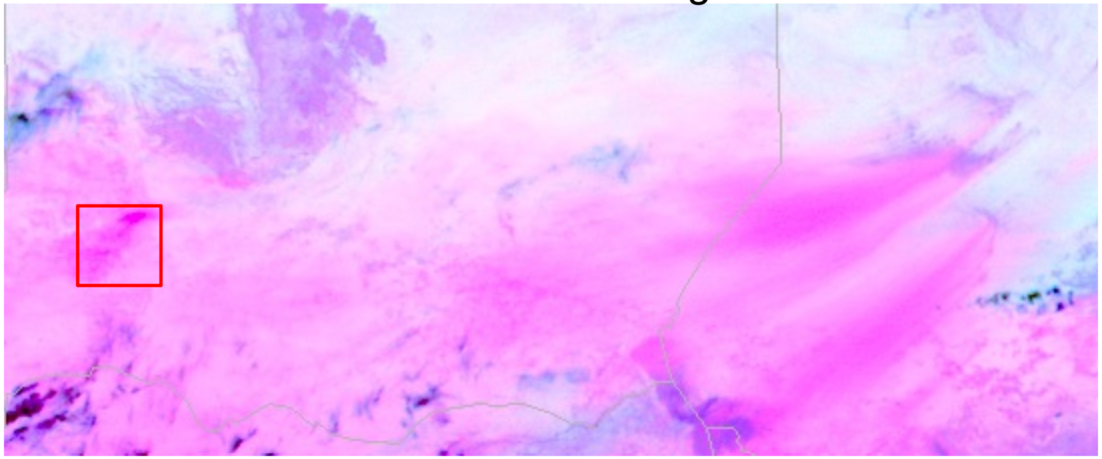
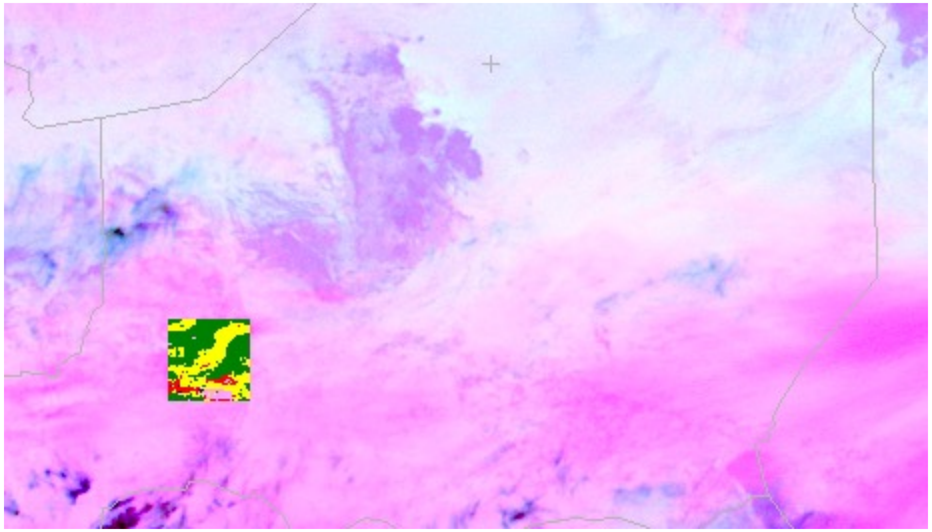
RGB compared with the IR-MODEL

IR-MODEL discriminates significantly several (>4) levels of AOD
RGB discriminates <4 levels
Pinkness is not a direct measurement of AOD for high AOD



Reduced **ground temperature** under the thicker layer of dust



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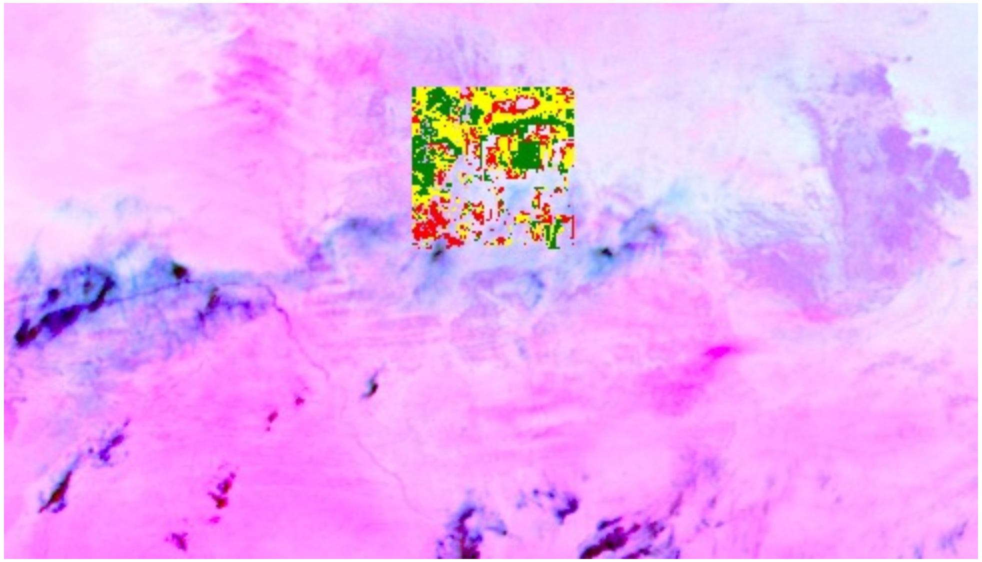
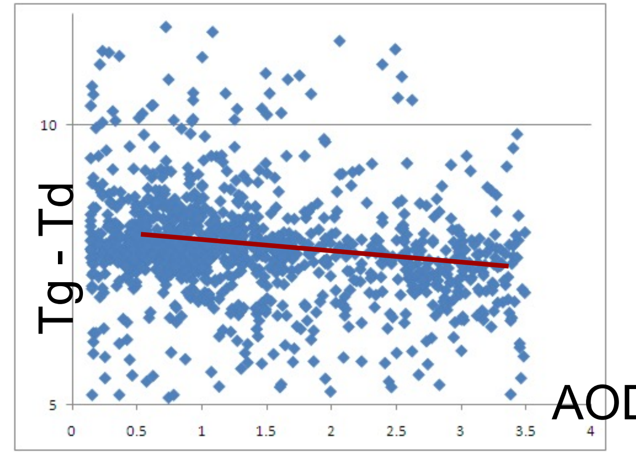
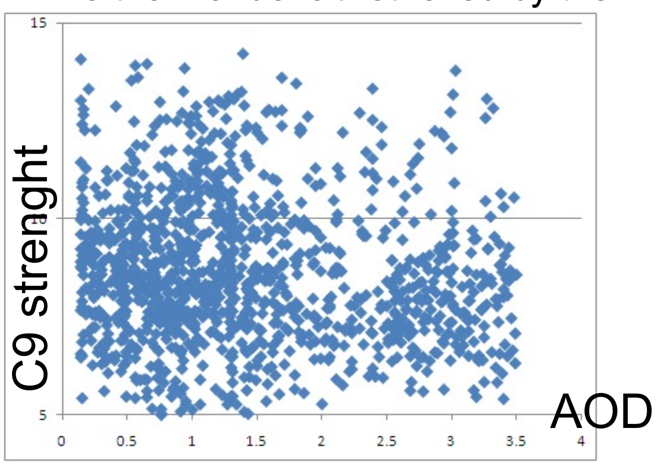
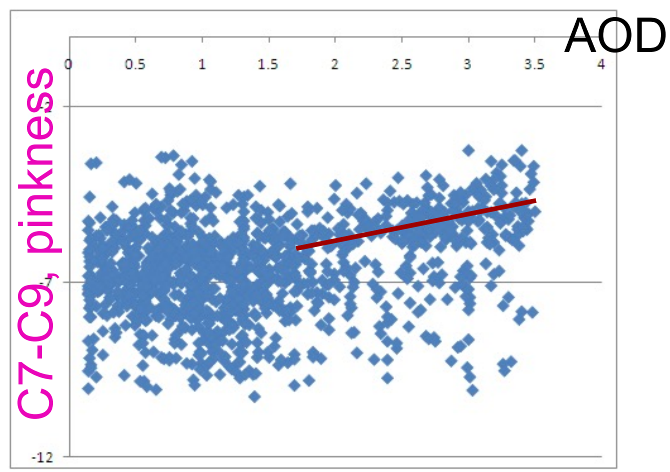
Channel versus model parameter: correlations





Correlations are stronger for AOD > 2
Ch9 strength (compared with the other channels) is not a good indication of AOD
Ch7 – Ch9 is a better indication of AOD, still poor
The thermal deficit retrieved by the **model** is reverse-correlated to AOD





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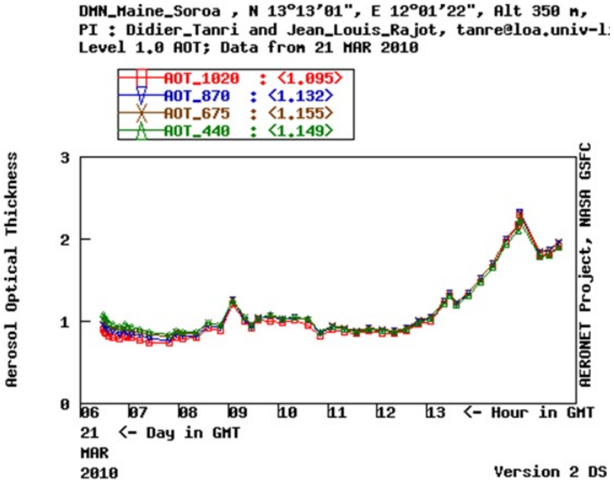
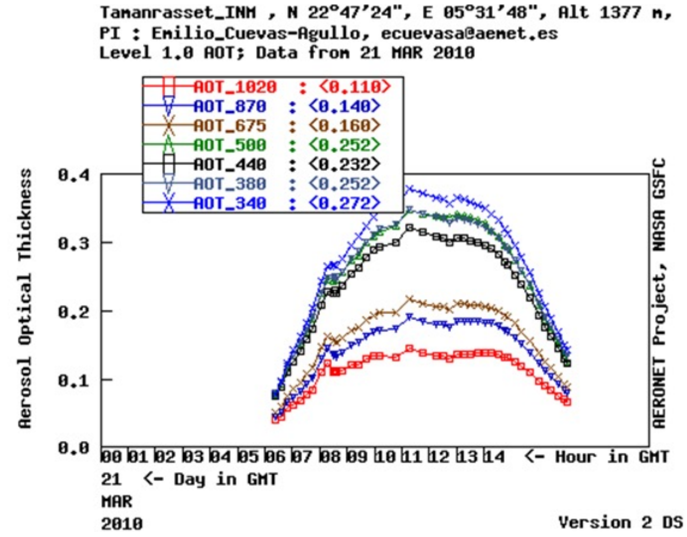
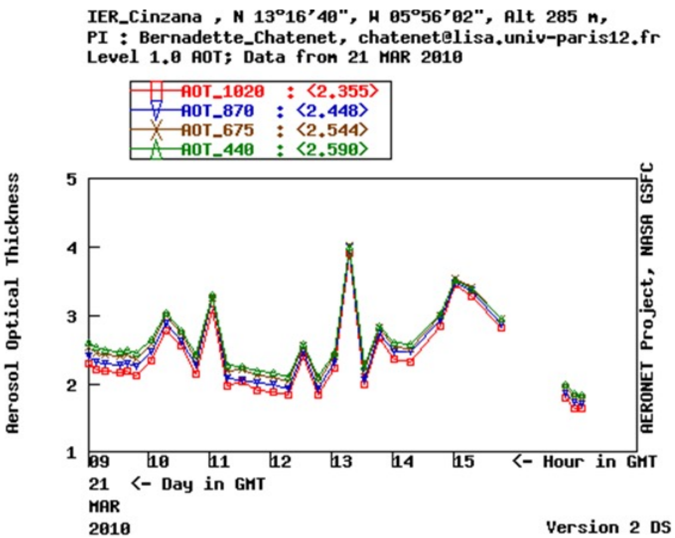


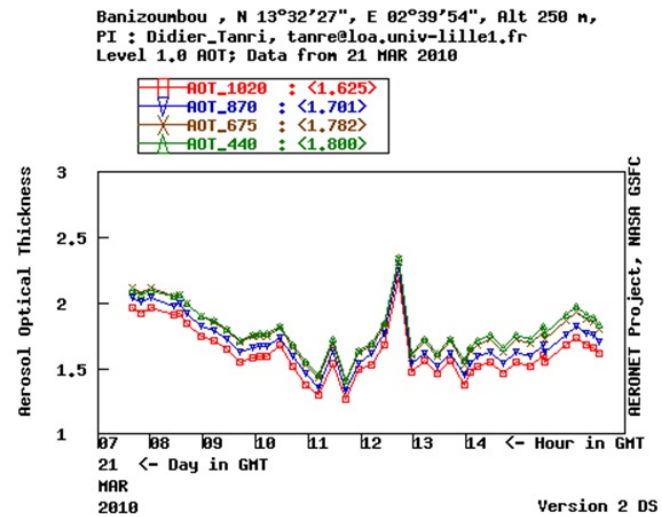
12.02E 13.22N, model on image **at 12UTC**: theta=0.6 31C-39C size=29



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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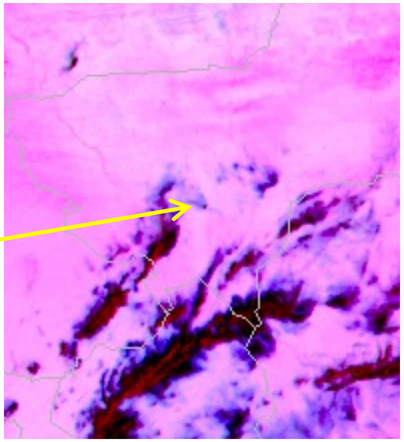
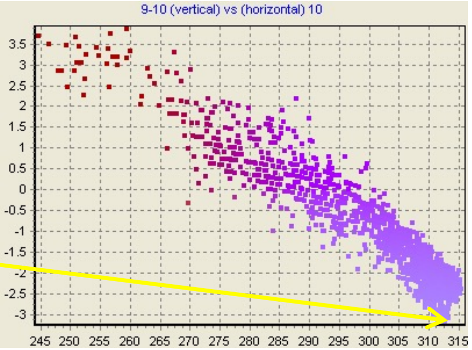
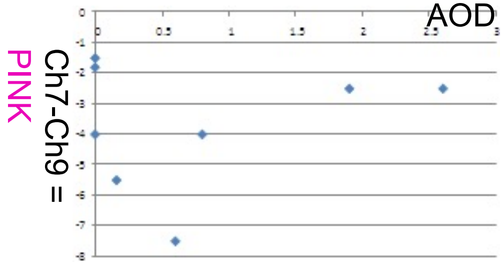
Validation based on ground measurements (AOD units)

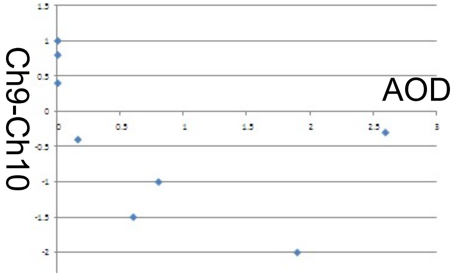
	AEROMET	IR-MODEL		
✓	0.9	0.6	31-39 C	29 µm
✓	0.35	0.2	40-47 C	31 µm
✓	2.1	1.9	31-42 C	
❖	1.6	0.8	33-42 C	14 µm
❖	0.4	NO DUST (too uniform)		
✓	0.1	NO DUST		
✓	1.7	2.6	30-38 C	
✓	0.03	NO DUST		





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





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SAMPLE VALIDATION

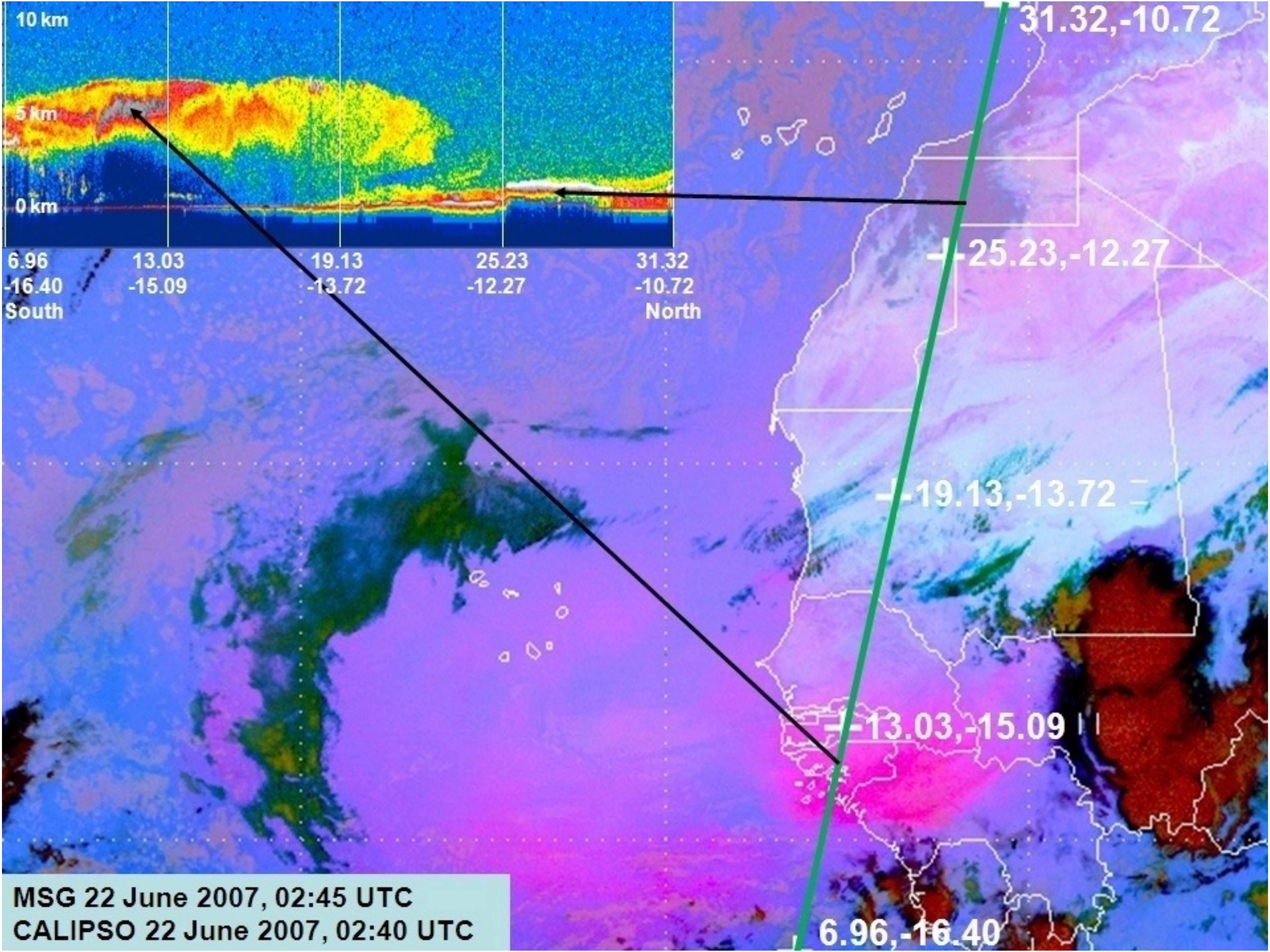
based on AERONET ground measurements

- ❑ 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

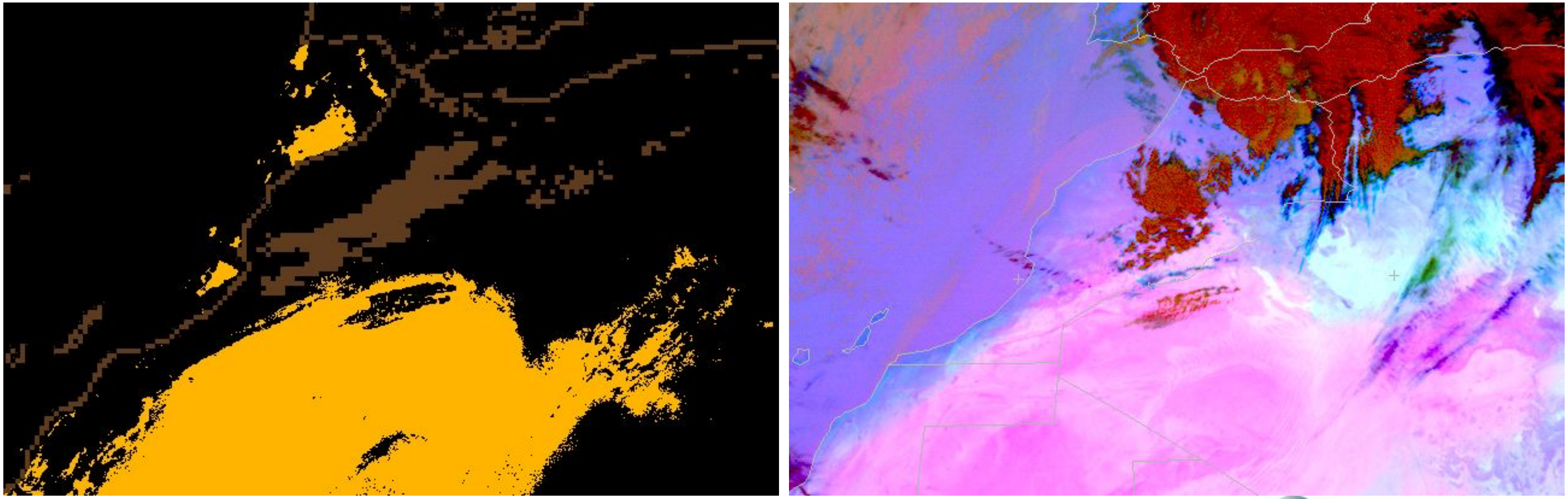
- ❑ No sample validation done so far for dust temperatures (heights), using ground temperature. This is essential for evaluation of the thermal deficit



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

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Low level dust forming a dust wall in Niamey (courtesy of E. Kploguede)

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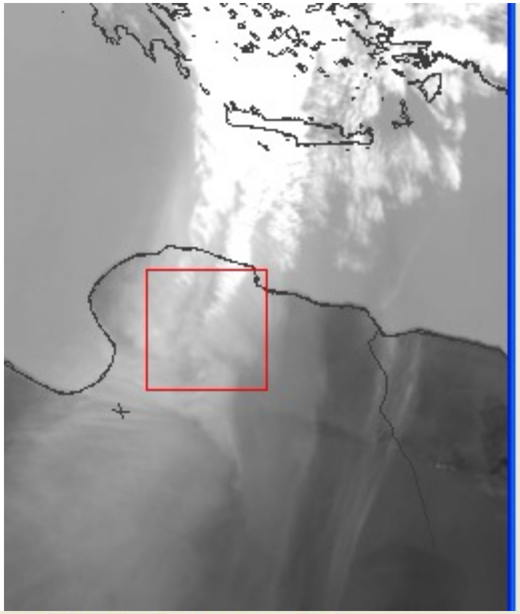
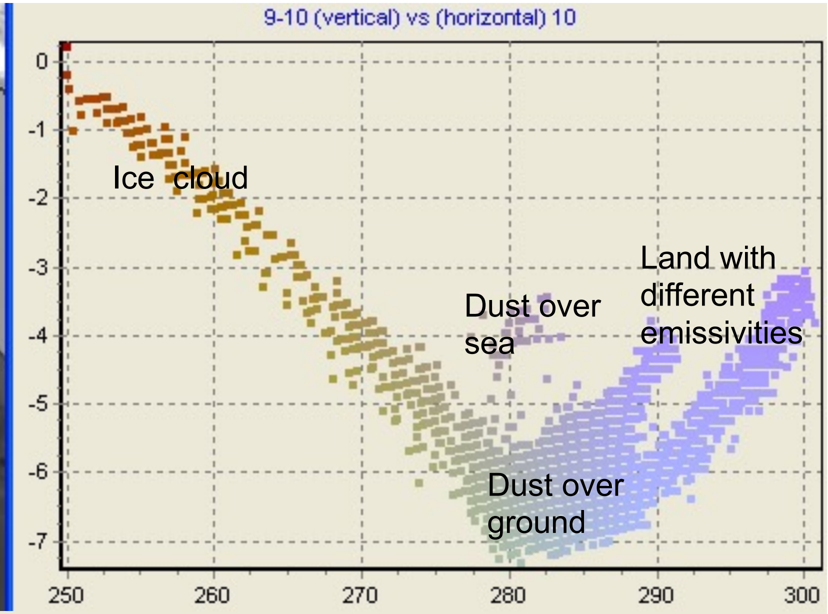
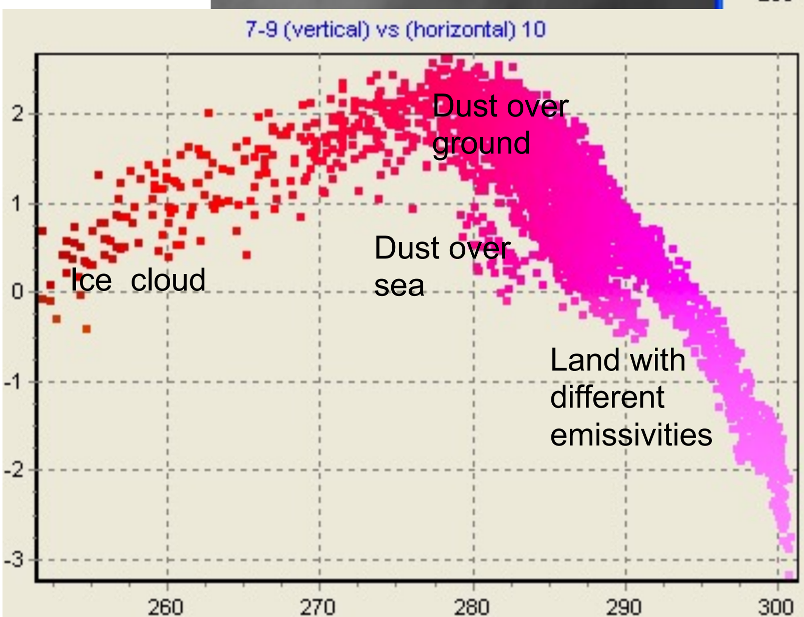
Dust-cloud interaction

2008-03-23 11:30 UTC Meteosat Ch9



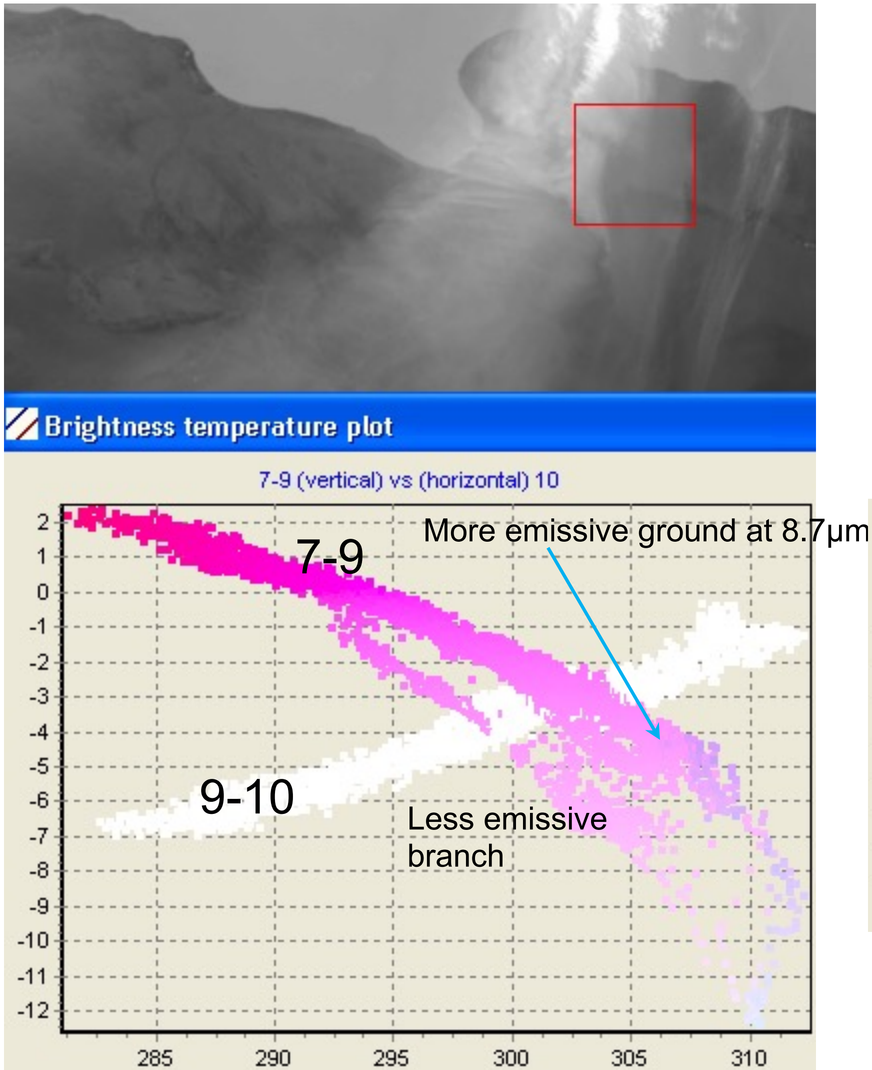




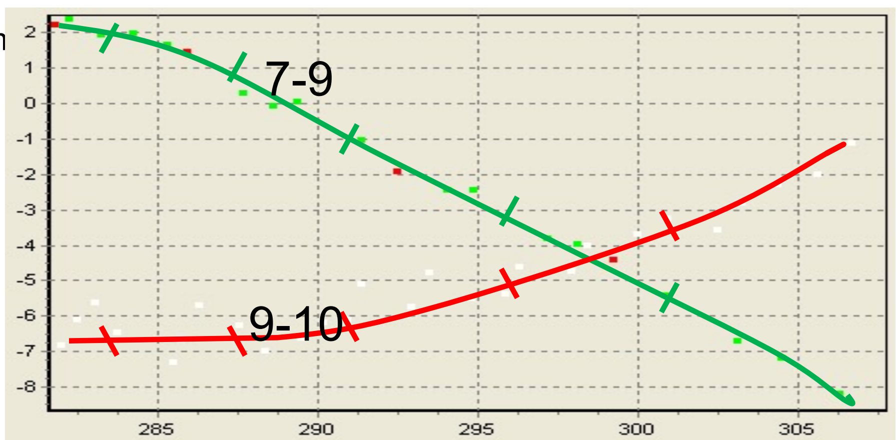
What is the ice temperature at the cloud boundaries?

265 K
275 K
285 K

Value added by the channel 8.7µm



Real (left h.s.) compared with simulated (right h.s.) scatterograms based on Tg=308 Td=266
$\Sigma_{8.7}$=.35, .2 Σ_{11}=.6, .3 Σ_{12}=.2, .25
and ground emissivity 85% at 8.7µm
Marks at optical-thickness third-units from the right ends



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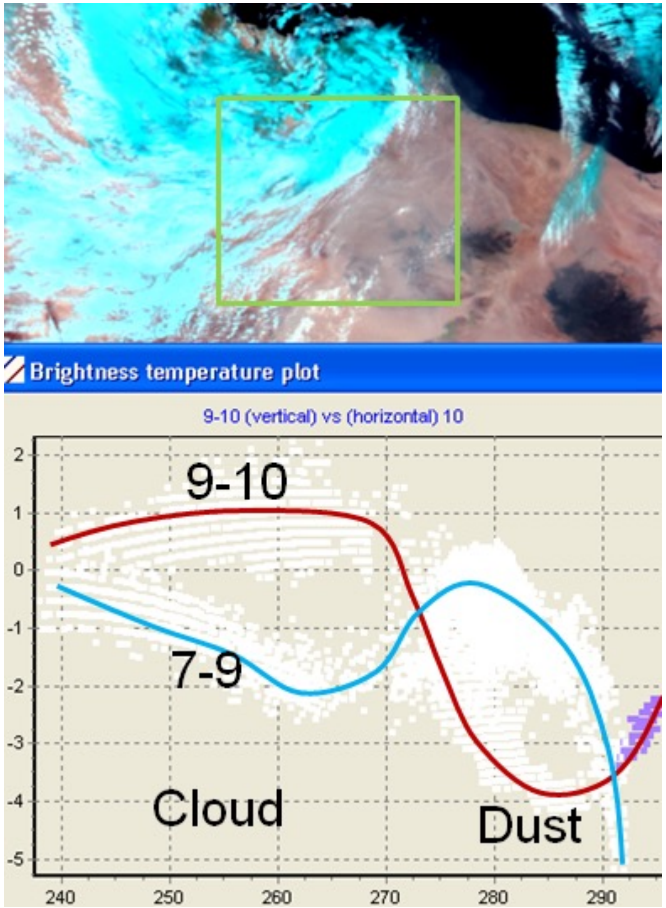
Dust-cloud interaction



Cloud-dust index: 2*ch9 – ch7 – ch10

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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 tools (NWCSAF, LIDAR) are needed

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Outlook

•A pattern for **surface cooling by dust** and **particle size profiles** will improve the simulation of the observed radiances

•**Particle size** affects channel **emissivity** in a way to be learnt, usable to reduce the gap between expected and real radiances (residuals)

•Looking into the BT's for **dust mixed with water or ice** will clarify the role of aerosols in cooling the atmosphere and inhibiting rain (or hurricanes!).

•Coupling IR technique with existing methods for **solar** channels will allow the simultaneous retrieval of surface **albedo** and **aerosol optical depth**

•A **calibration** against the **solar** technique will provide skill for the IR estimate, even during the night

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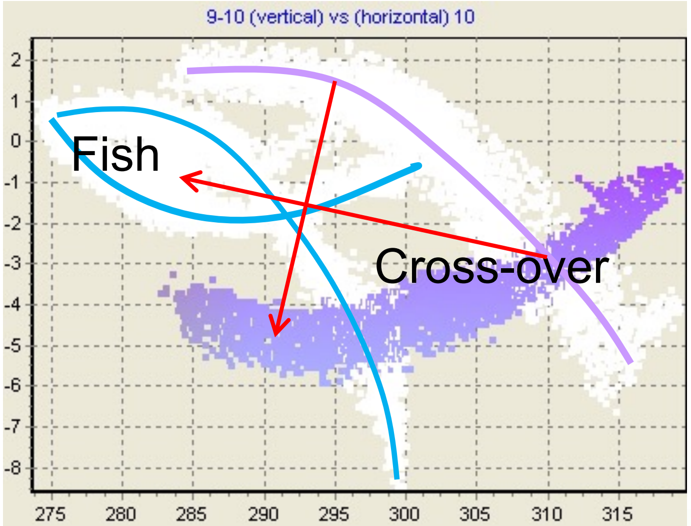
THANKS FOR YOUR ATTENTION !

- List of referred 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



Can you not think of a question?

Just choose one from the following:

1. Why do you see “pink” areas in southern Africa frequently? Is there a diurnal temperature cycle?

2. What can we do in case of thermal inversions? Do channel diagrams help identify those situations?

3. How can we produce the scatterograms by ourselves?

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