

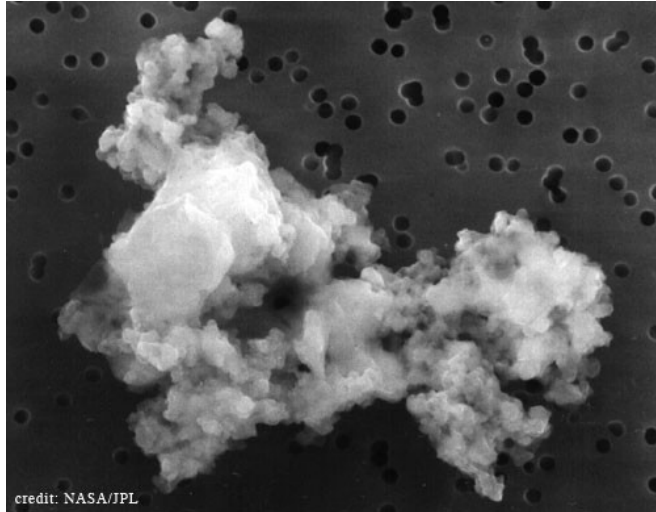


Dust estimation via the triple window IR
($8.7\mu\text{m}$, $10.8\mu\text{m}$, $12.0\mu\text{m}$)

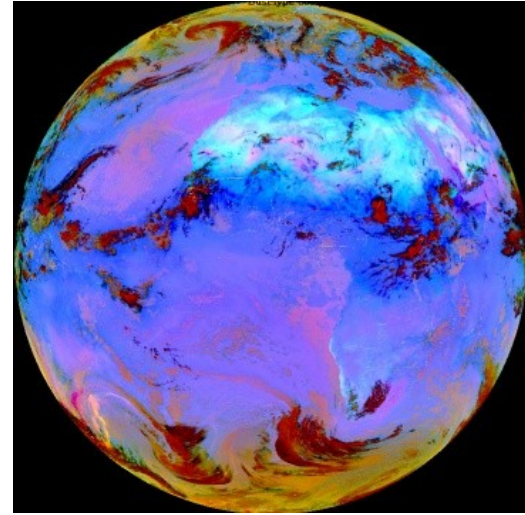


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Can a satellite see dust particles ?



← 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)
- 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

- 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



Consecutive days in Fuerteventura, January 2010

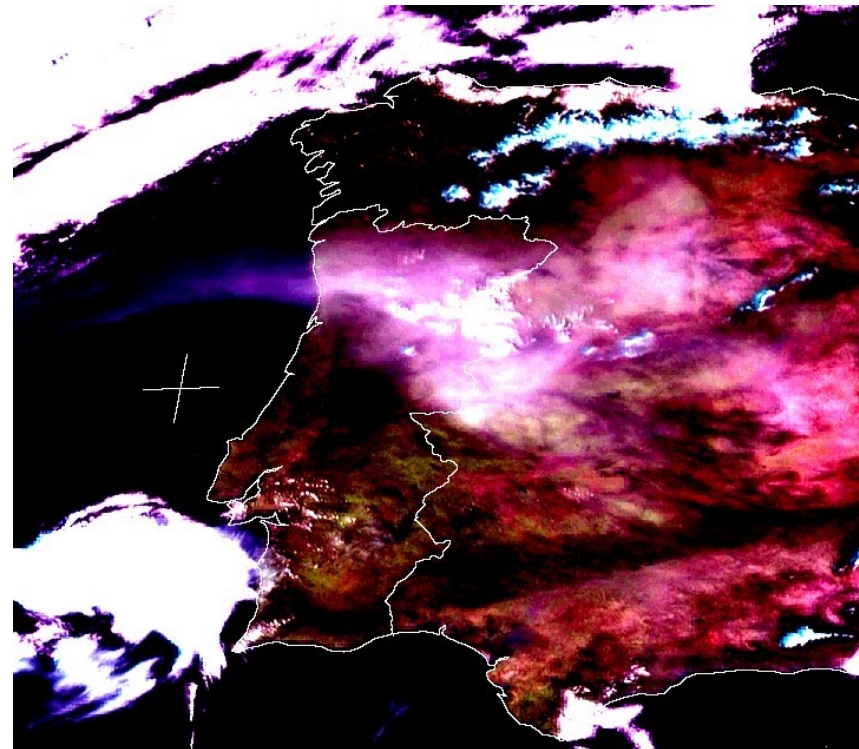
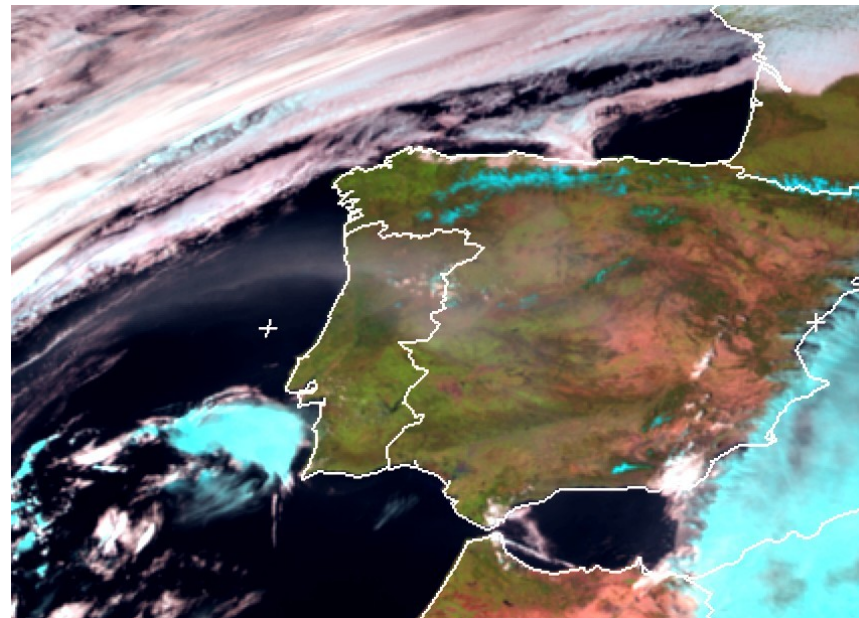
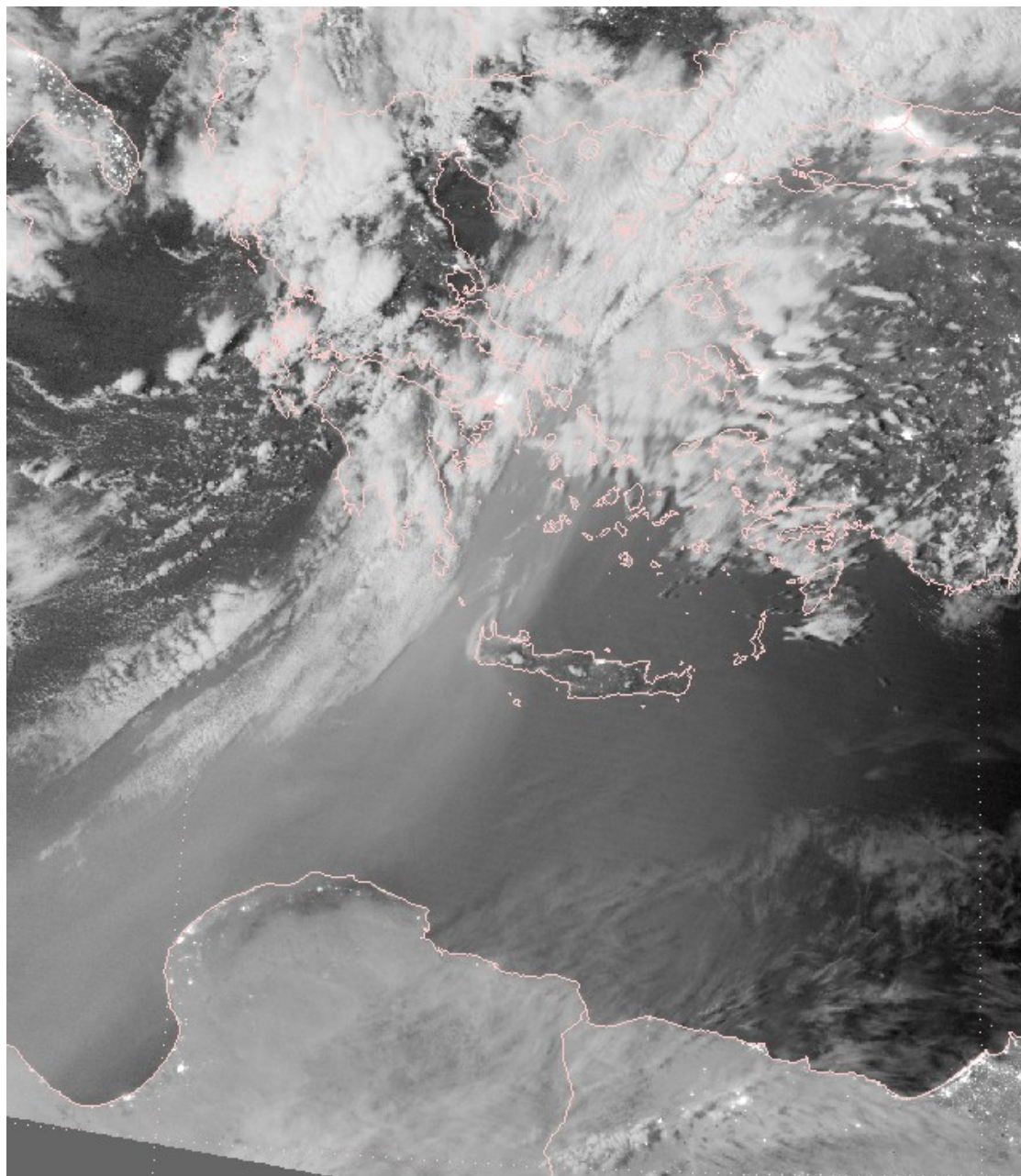


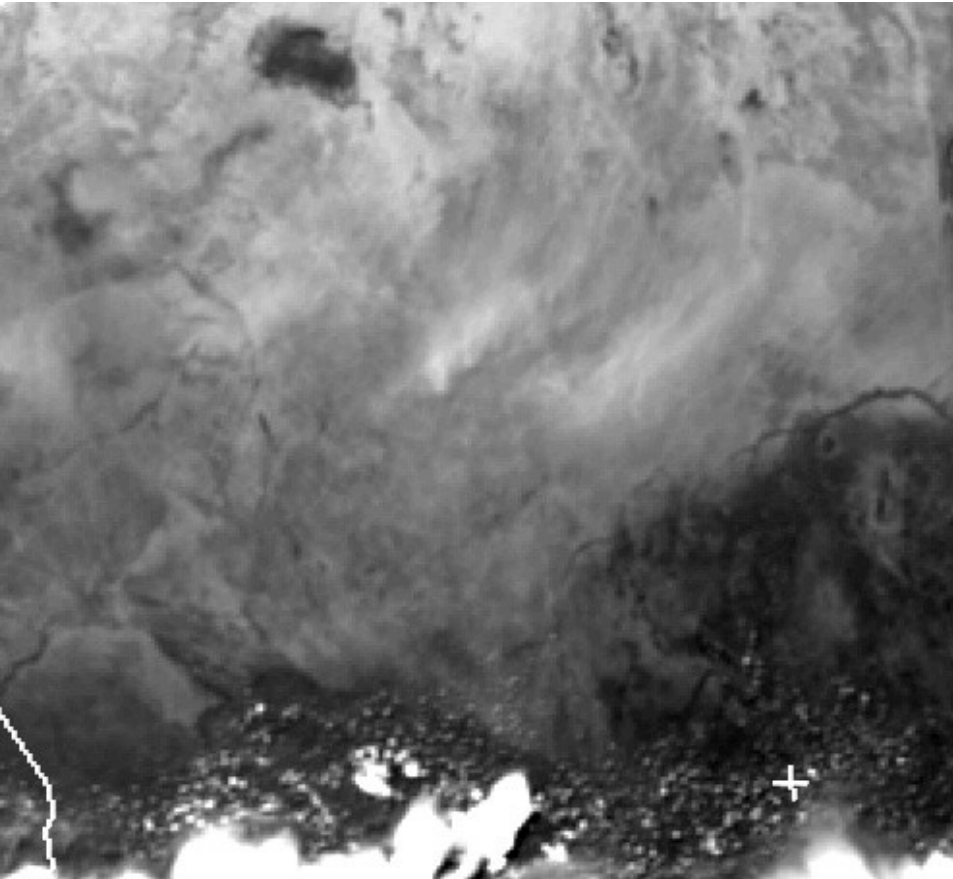
Fig. 1: immagine satellitare MODIS del 21.02.2016 alle 14:00 UTC (NASA's Aqua- Earth)



Dust at the
moonlight

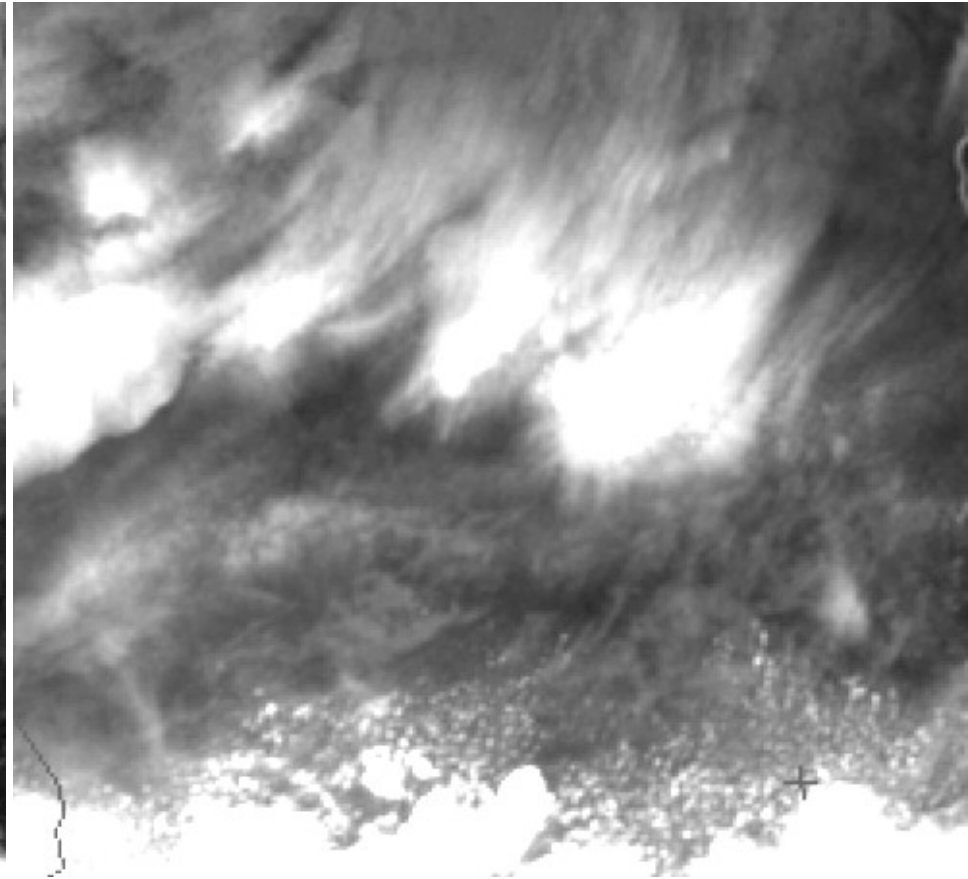
snpp DNB - 2015-02-01 23:45UTC

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

DUST RGB composite: the strength of infrared for dust detection

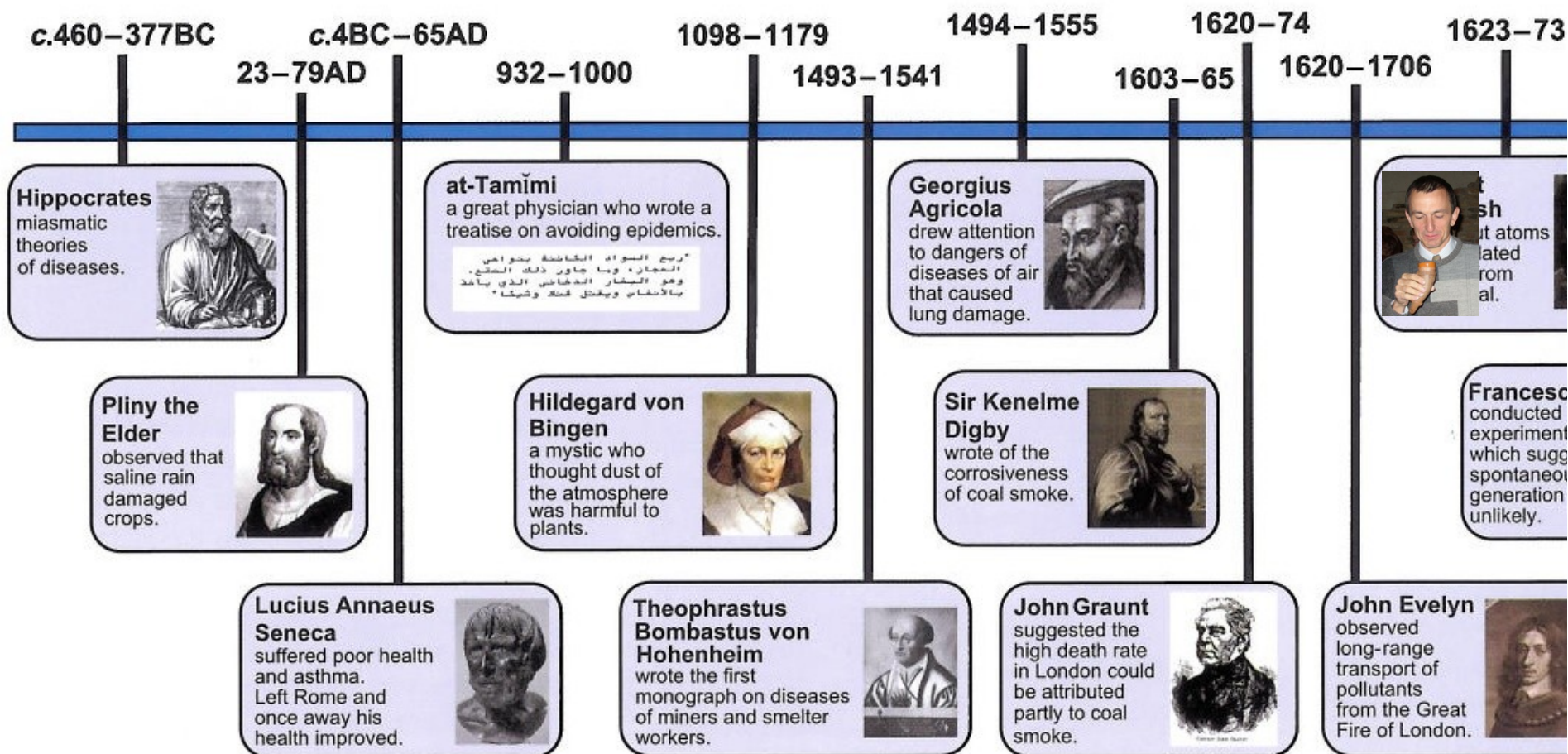


Solar RGB composite based on channels at 1.6, 0.8 and 0.6 μm



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

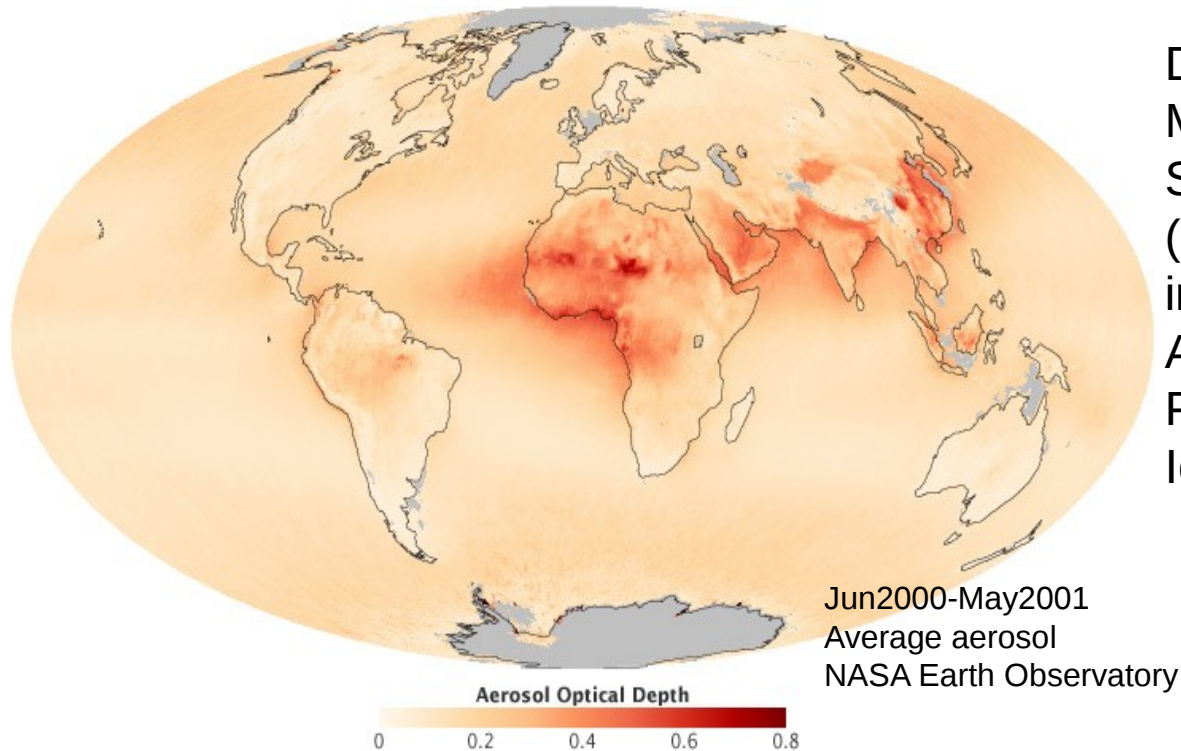
Aerosol and health



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

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

Aerosol is more than dust



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

Forward fraction= $\exp(-\text{AOD})$

➤ 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

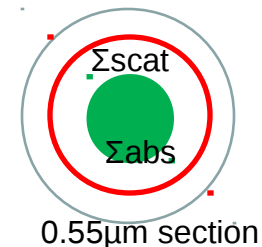
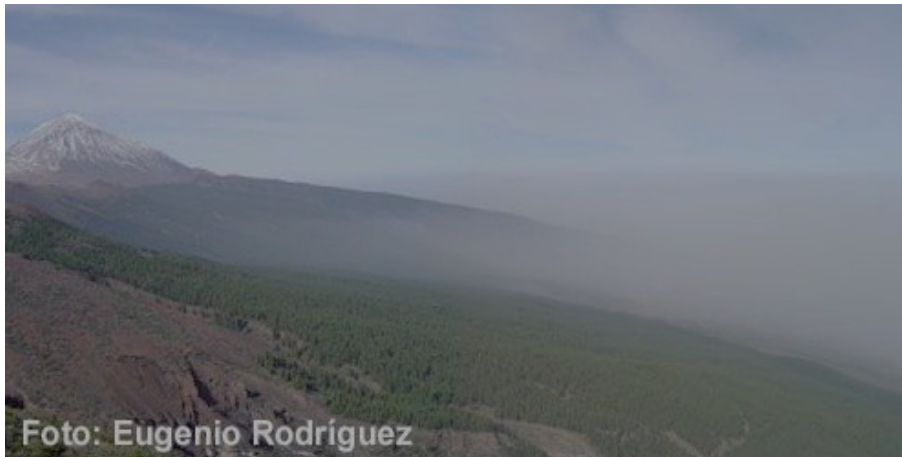
- Where you learn that there is more dust on books than books on dust

Dust characteristics

- Dust storms occasionally reach up to **1km | 5km | 10km height**, and are as thick as **100m | 2km | 5km**
- Over land, dust optical depth is typically around **0.1 | 0.5 | 1** or **2 | 10 | 50** 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 | Rayleigh | optical** region
- Aerosol **density** average in the atmosphere 10^{-7} kg/m³ (equivalent optical depth **0.1 | 1 | 3**)

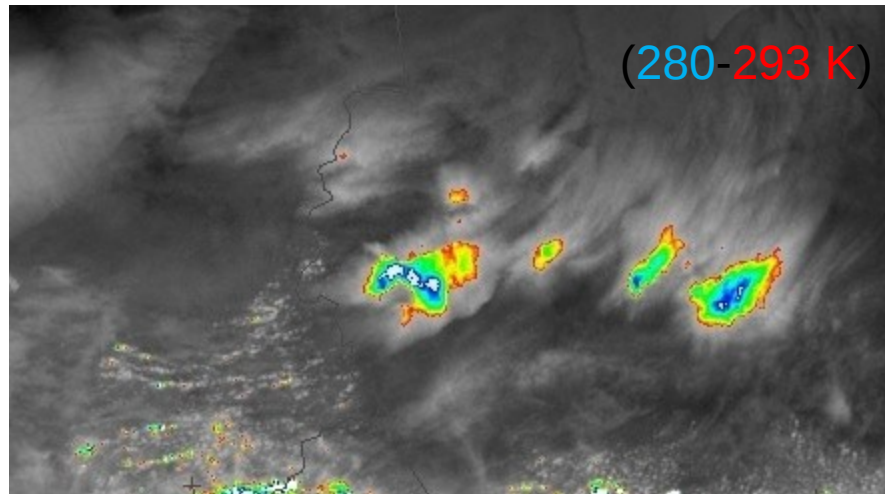
Dust characteristics

- 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/m^3 (optical depth **0.1**)



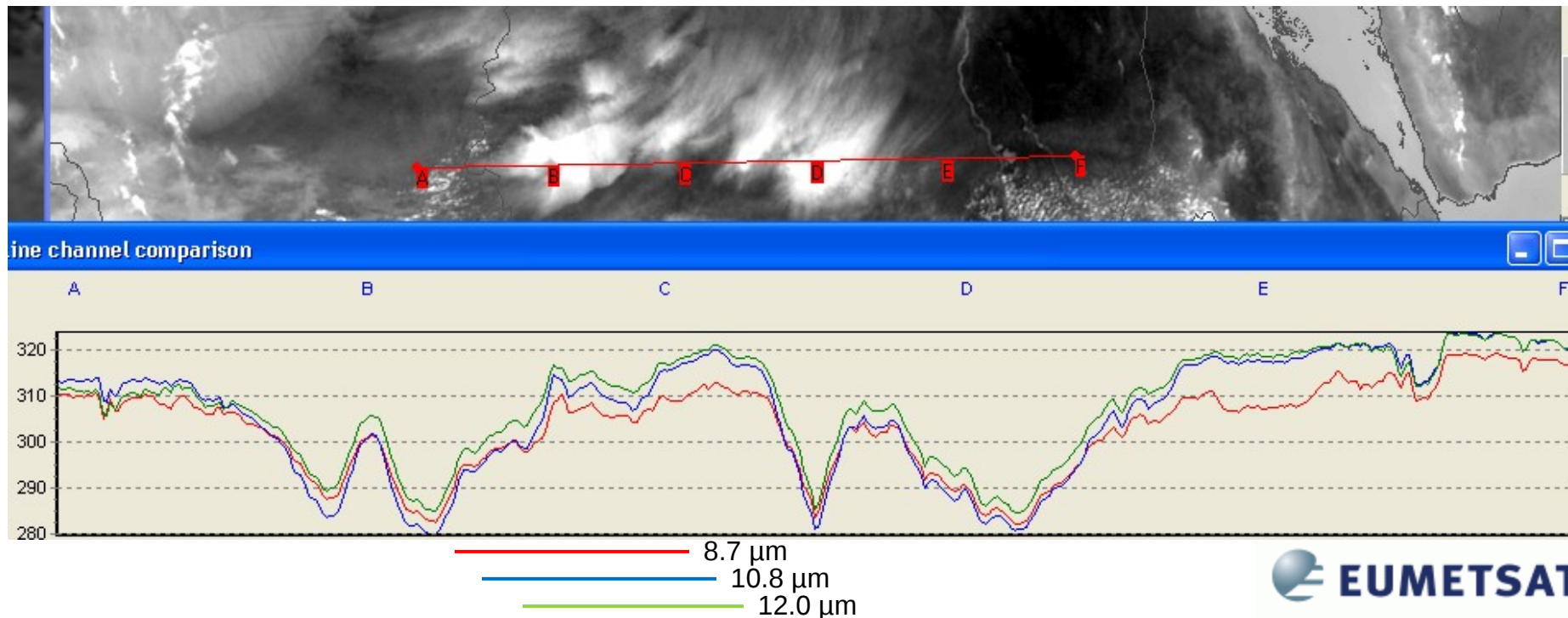
- Dusty air $\sim \text{AOD}=1 \sim 1 \text{ mg/m}^3 \sim 1 \text{ g/m}^2$

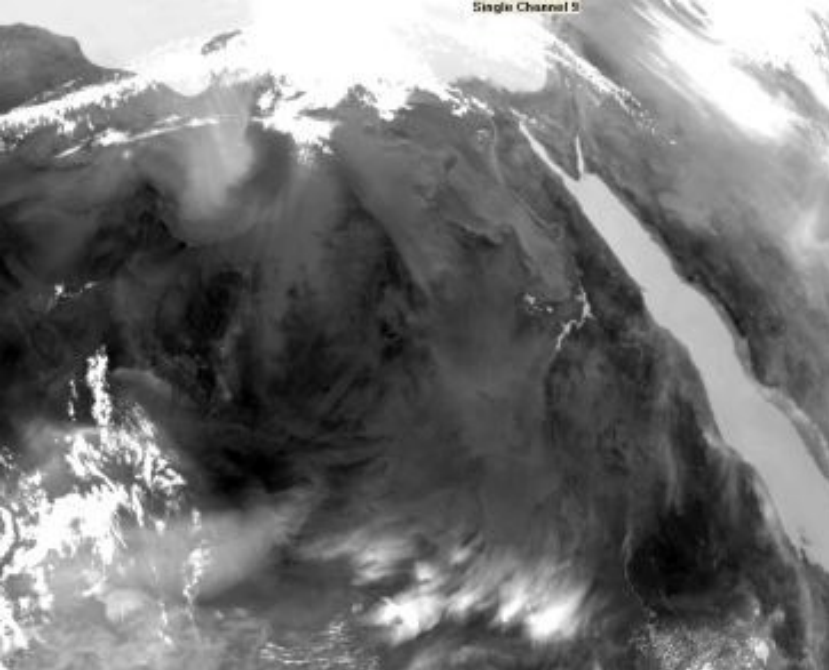
Dust seen at a single IR channel



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

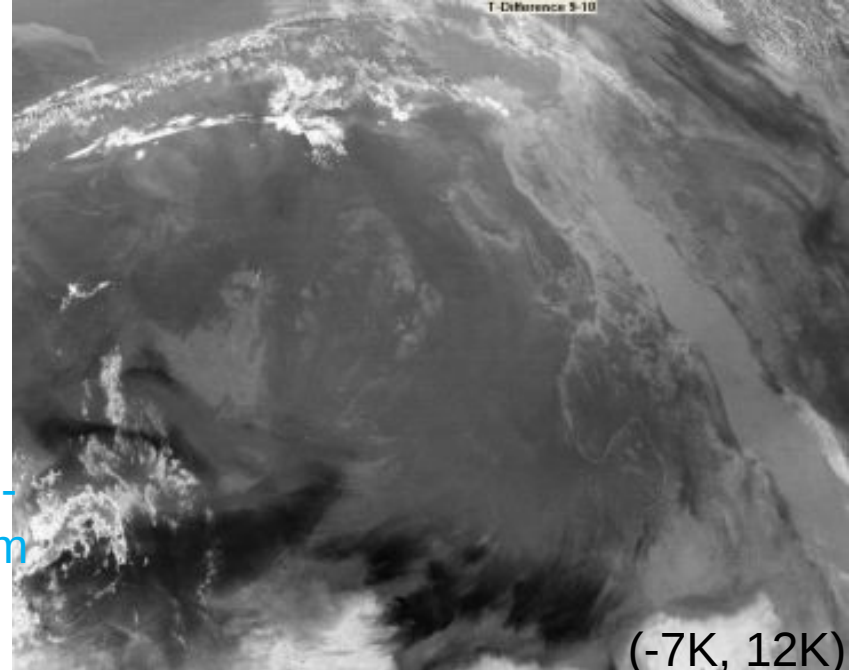
2004 May 13th 13:00 Meteosat **10.8 μ m**
colour-enhanced (left) and gray-enhanced (below)





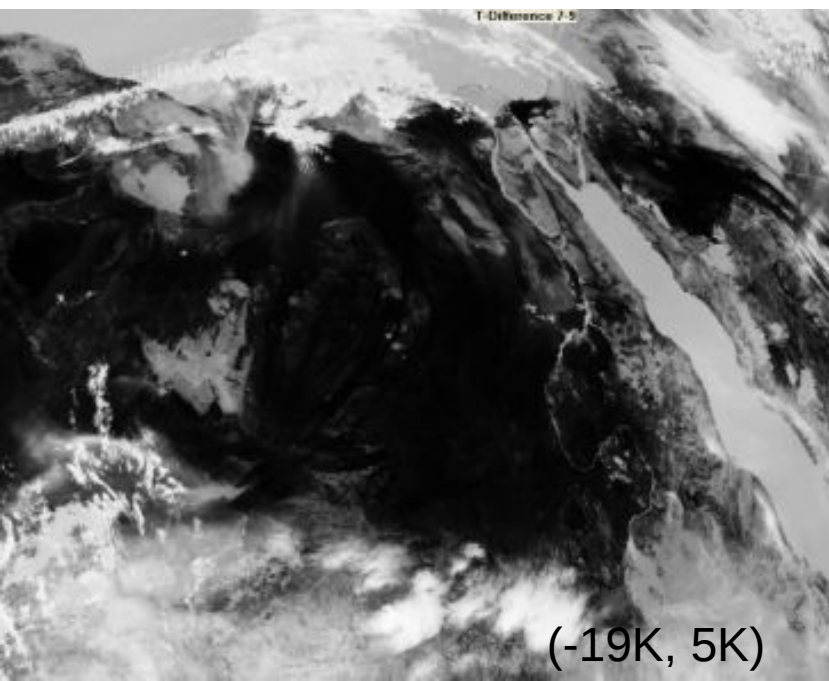
10.8 μ m

10.8-
12 μ m



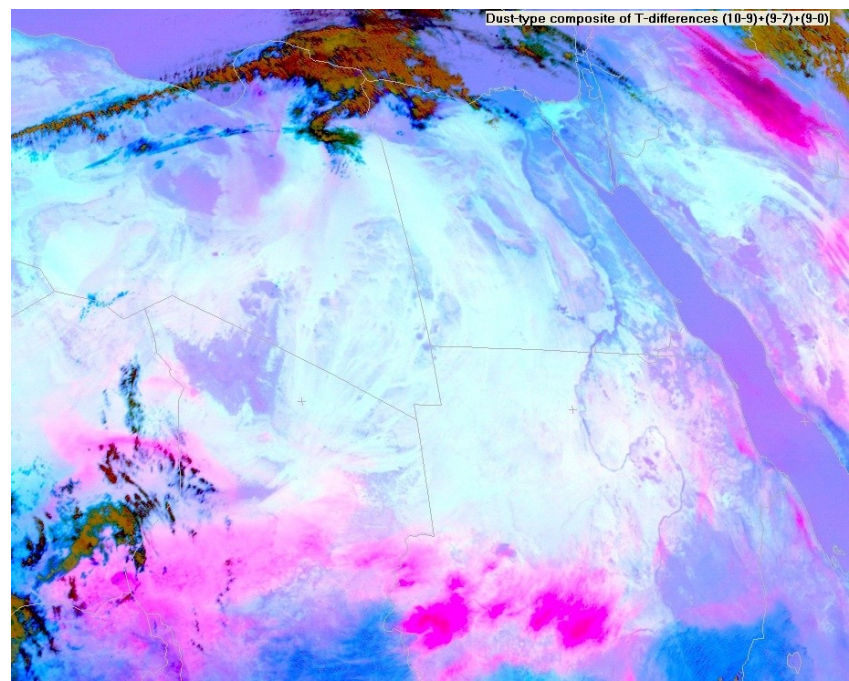
(-7K, 12K)

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

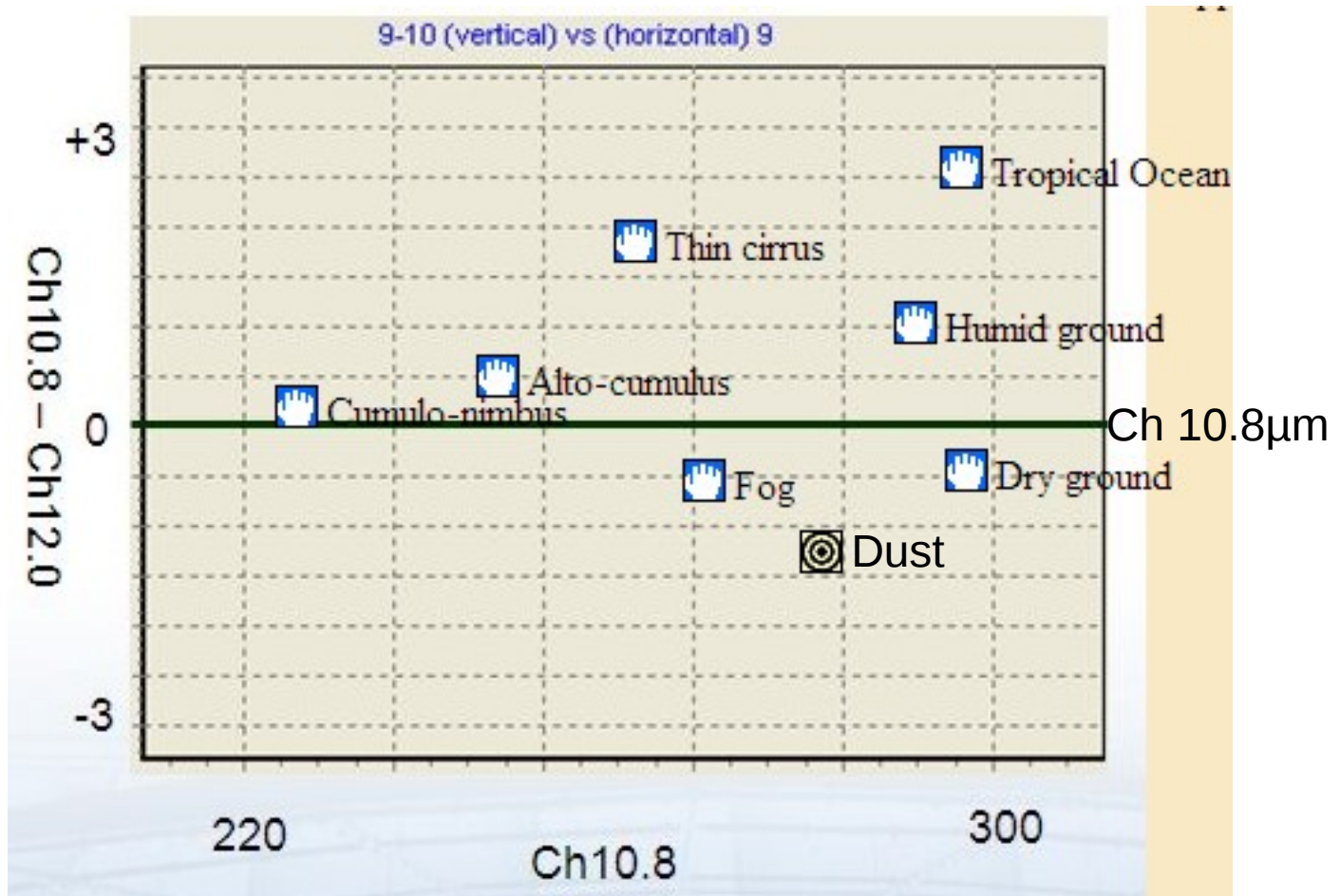


8.7-
10.8 μ m

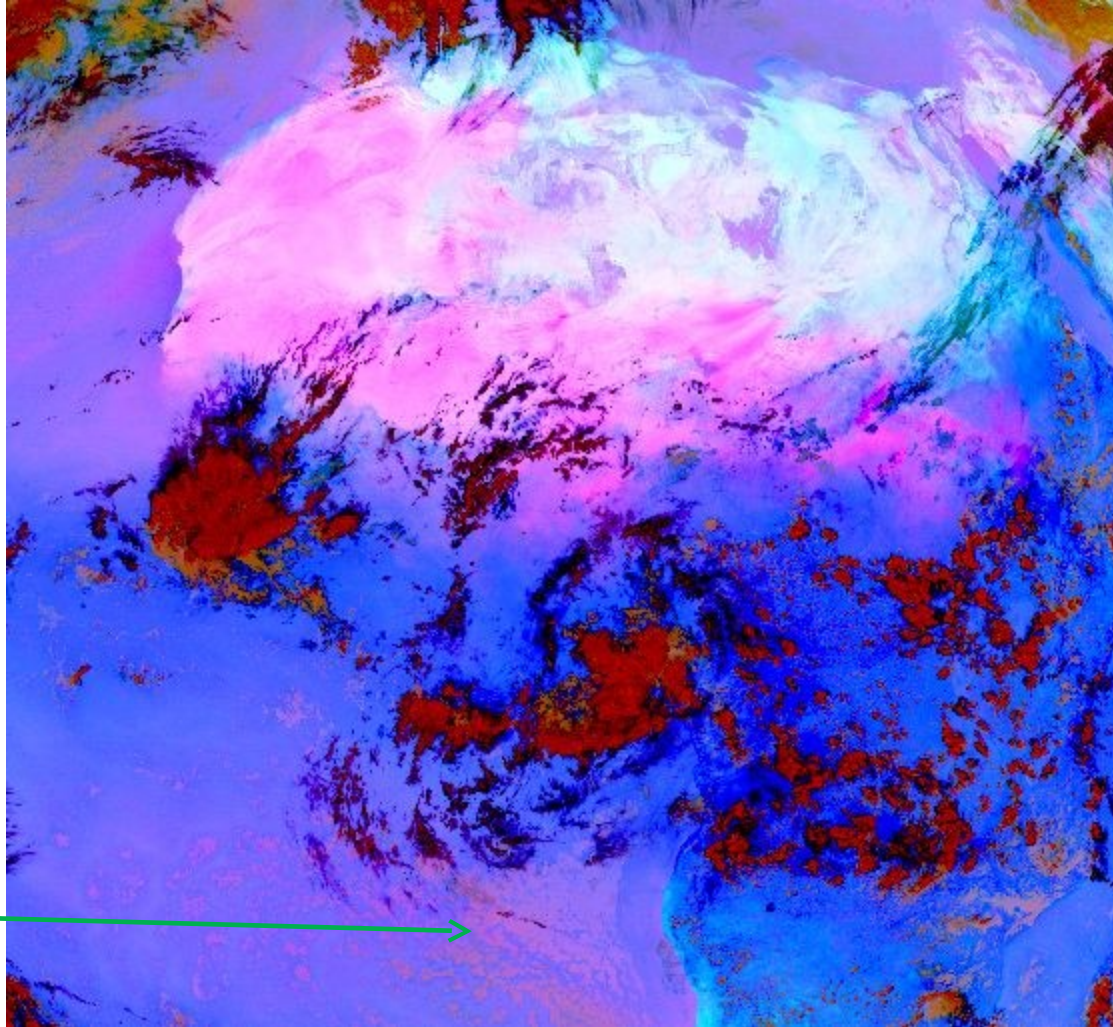
(-19K, 5K)



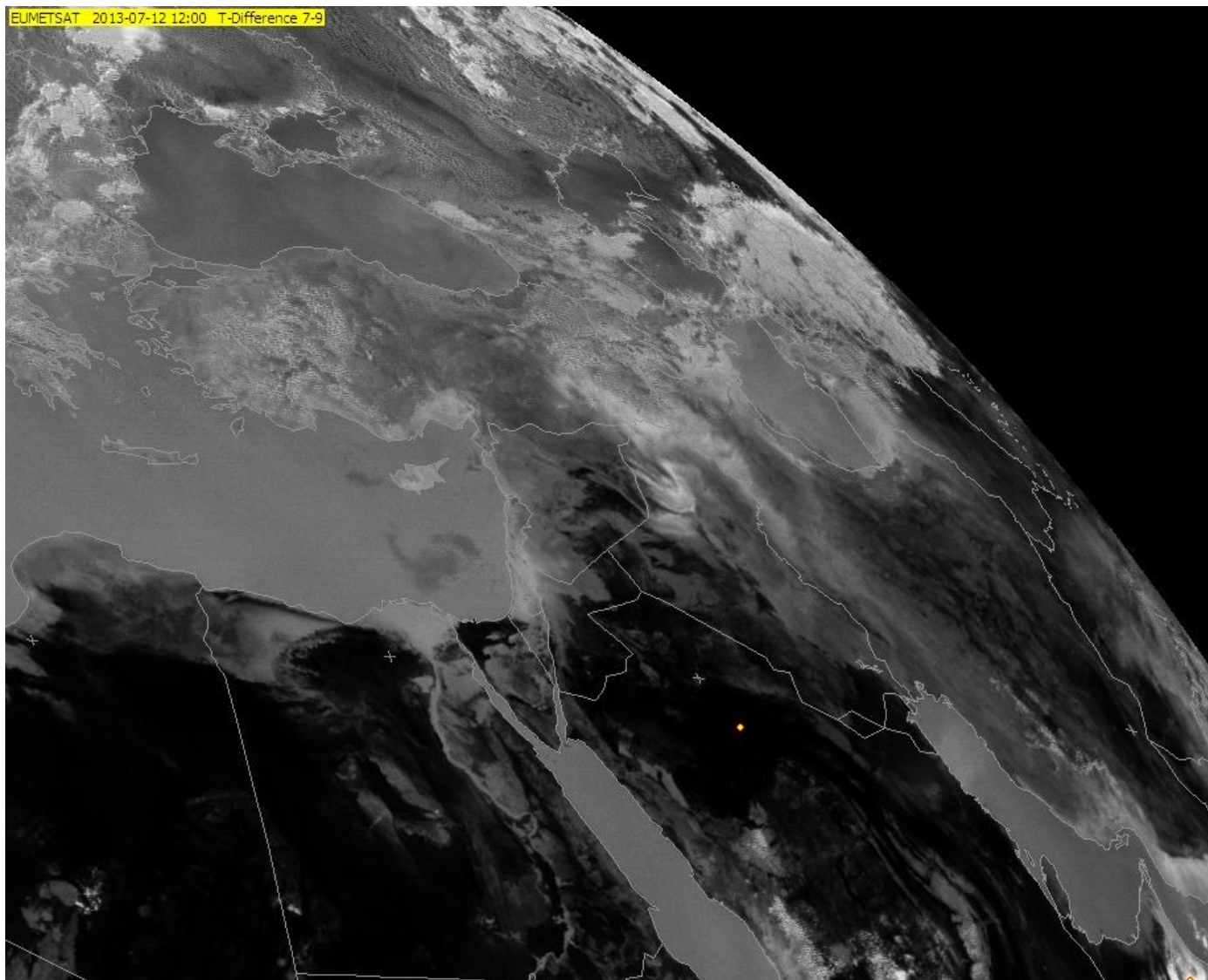
The 10.8 μ m-12 μ m difference (vertical)



Dust RGB 21 March 2010 12UTC

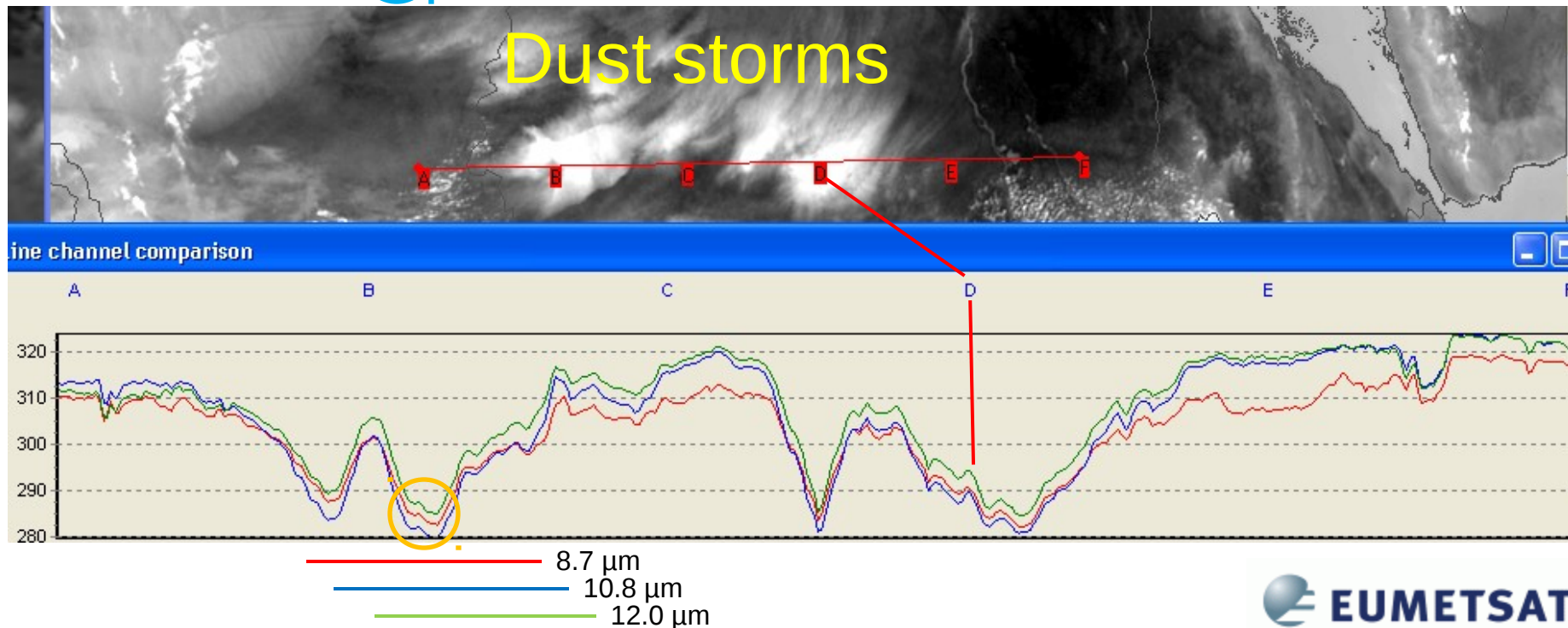
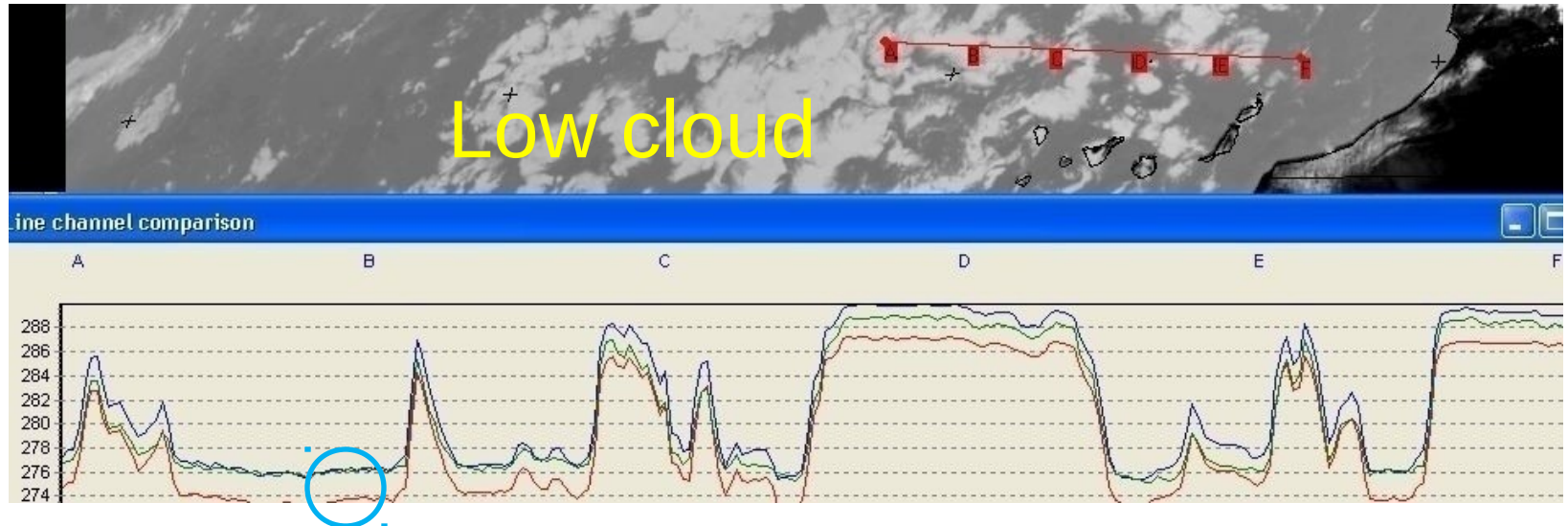


pink is not always dust

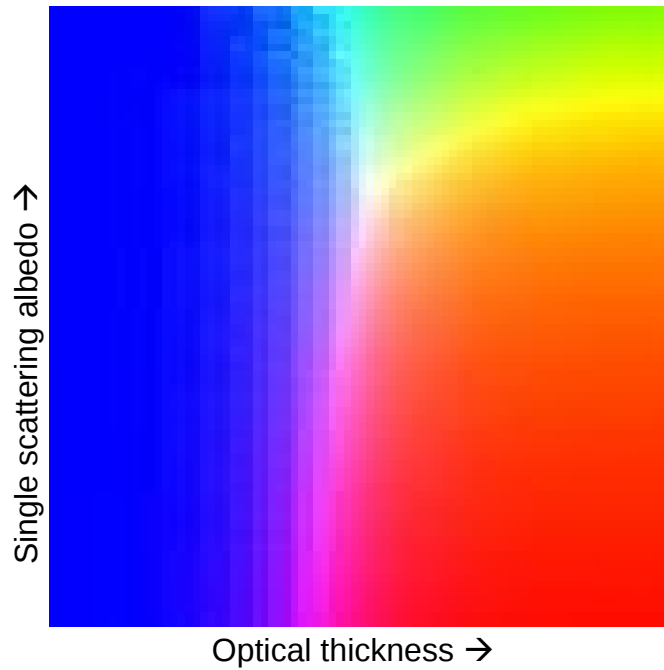


Met-8, 2013 July 12 12UTC, ch9-ch10, ch7-ch9 (-17K to 5K) differences and Dust RGB

Comparison of water cloud and dust in the IR window



Find the colour for each interaction regime

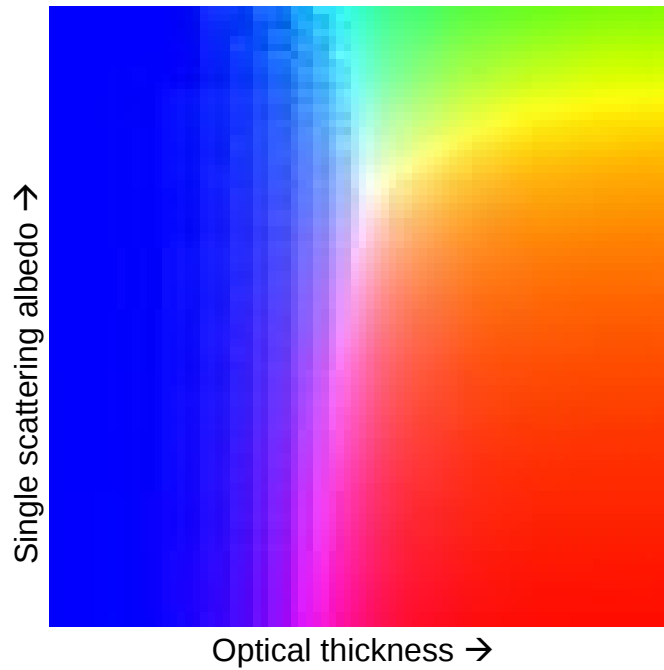


Absorbed

Back scattered

Forward scattered

Find the colour for each interaction regime



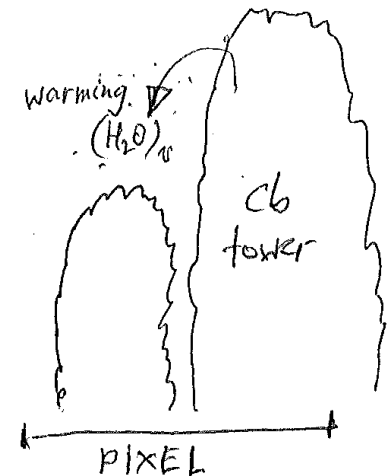
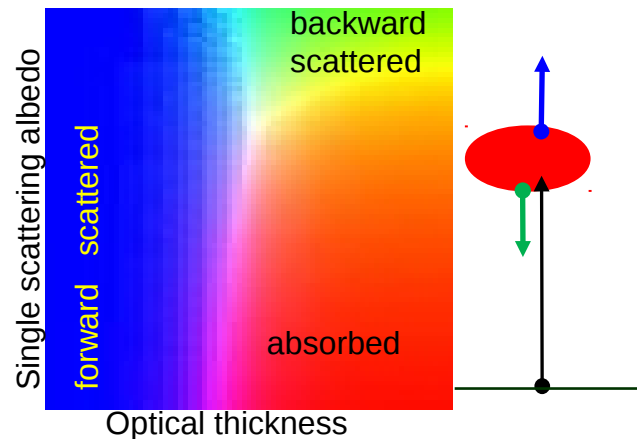
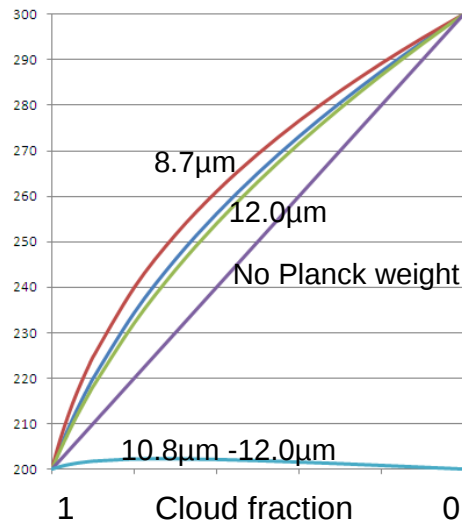
Absorbed

Back scattered

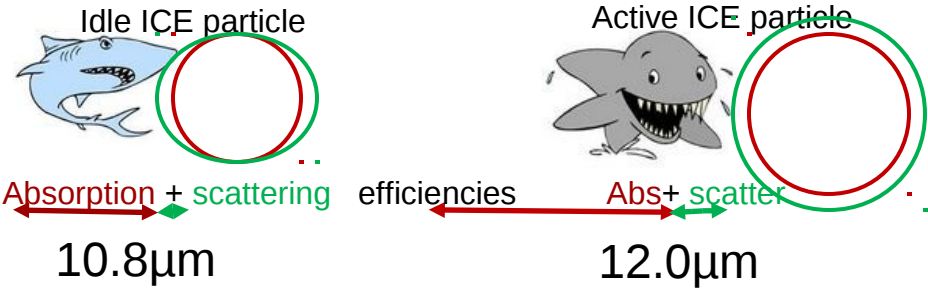
Forward scattered

Channel differences: How do they generate?

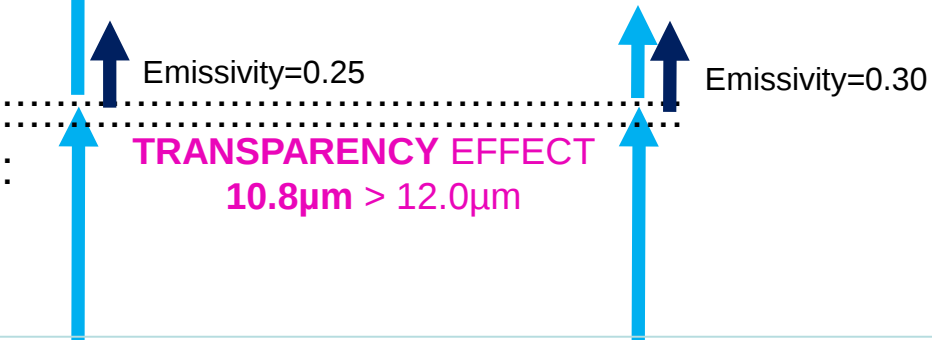
- Emissivity: reduced by *scattering*, increased by **absorption**
- Sub-pixel effect: scene mixture or semi-transparency
- Contribution layer: emission from different depths and temperatures
- Water vapour absorption (thermal inversion above shield cloud, adiabatic cooling inside the Cb tower)



For example: Ice



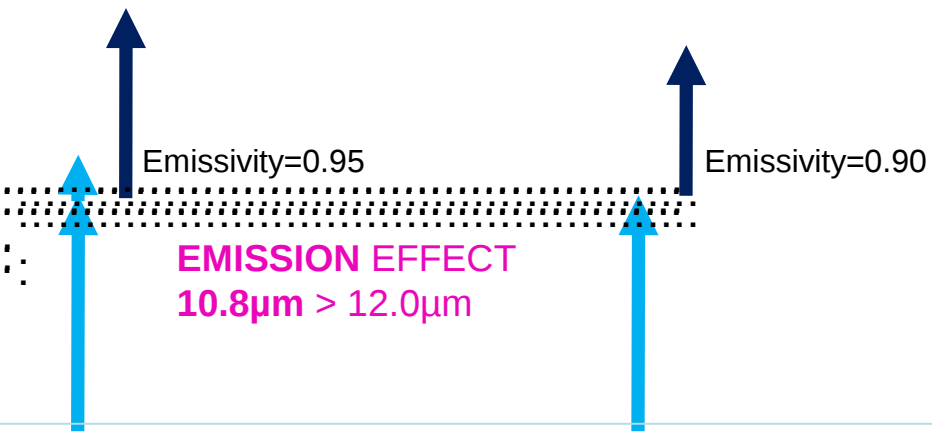
Thin ice < 0.5
absorbs more 12.0μm
10.8μm goes forward :



Main contribution:
Ground, forward scattered~
(1 - Absorption - Scattering)

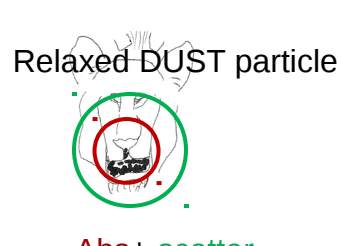
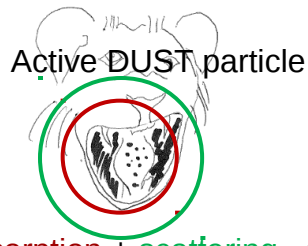


Thick ice > 1.5
emits more 10.8μm



Main contribution:
Cloud, emissivity~
(Absorption / Scattering)

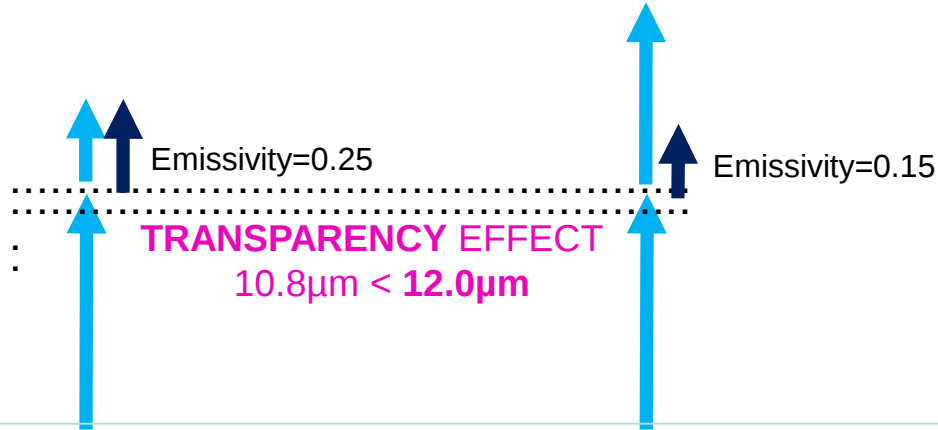
And how
is it with
DUST?



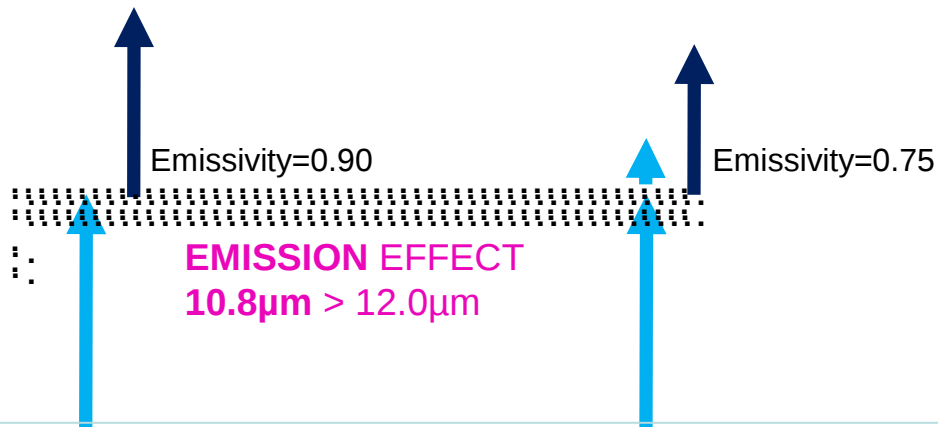
Absorption + scattering efficiencies
10.8 μm

Abs + scatter
12.0 μm

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



Thick dust > 1.5
emits more 10.8 μm



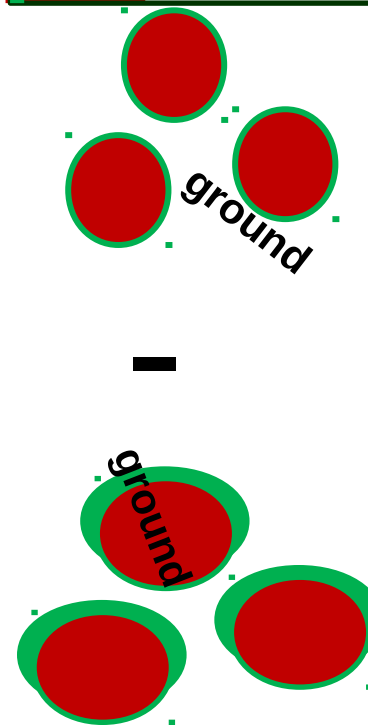
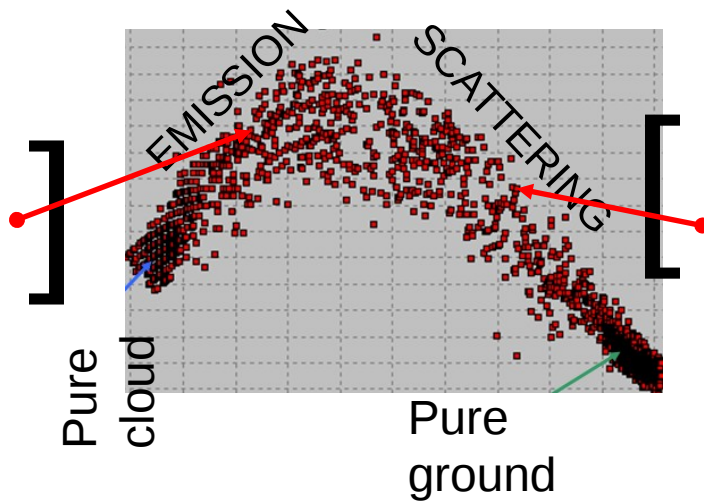
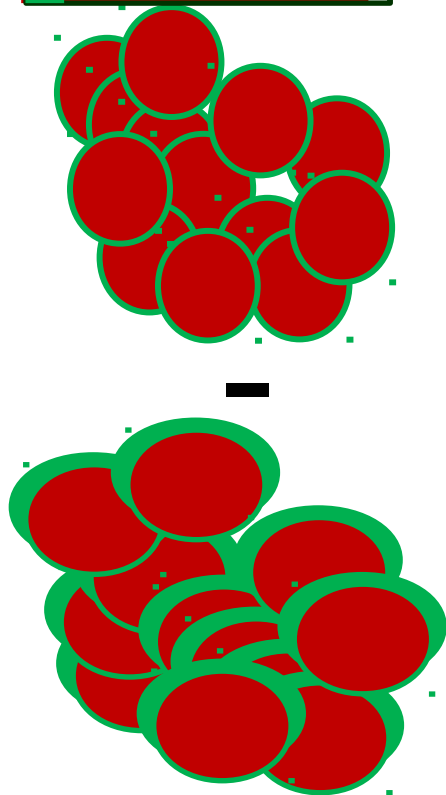
Ground
contribution
Dust
contribution



220 K



280 K



200 K



250 K

Backscattering (only blocking contribution in thermal infrared)

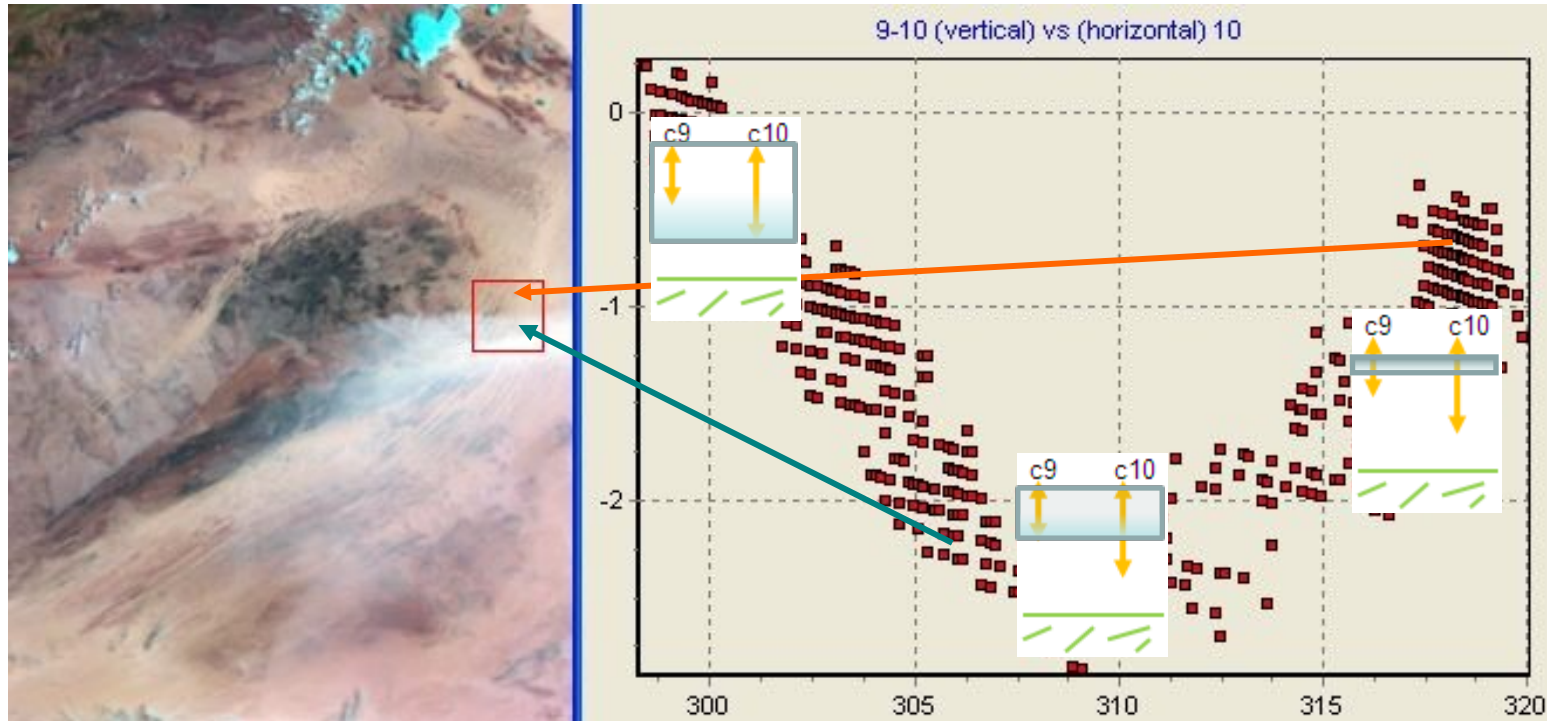
Ground emission

Cloud emission (and absorption)

10.8 ice particle **absorption** and **scattering** sections

12.0 (exaggerated for concept illustration)

Reversed transparency arc for dust: Ch9-Ch10 versus Ch10

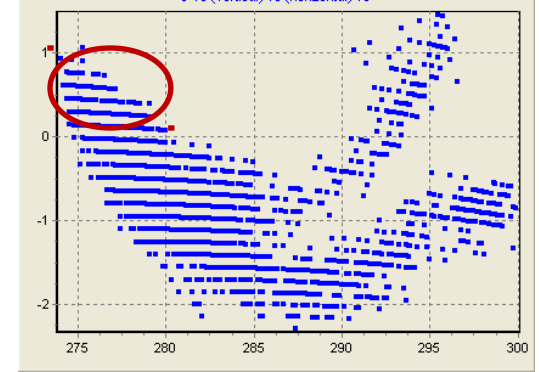


MSG Natural (solar) RGB composite

4-July-2003 10:00 UTC

- ❑ $10.8\mu\text{m}$ radiation is more absorbed and more backscattered by dust than $12.0\mu\text{m}$
- ❑ For dust or ash, arc is inverted due to the thinner contribution layer (CL) at $10.8\mu\text{m}$
- ❑ $10.8\mu\text{m}$ channel shows higher BT than $12\mu\text{m}$ for thick dust due to higher emissivity

Exercise: plot 9-10 versus 10



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

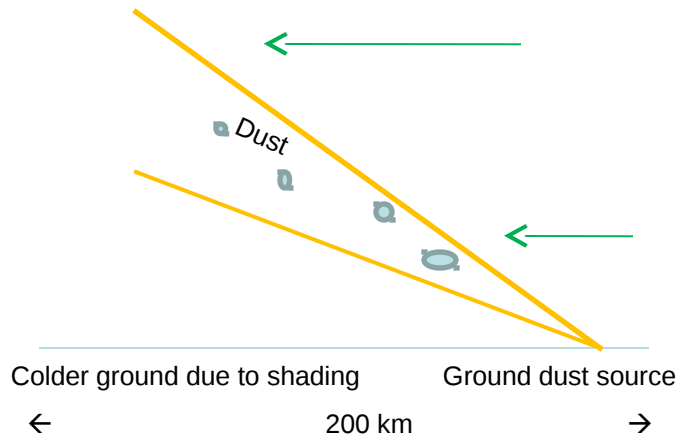
- T Ex ☐ Dust shows a higher emissivity at Ch9 than at Ch10
- T NEx ☐ Dust has a scattering component, higher at Ch9 than at Ch10
- T NEx ☐ Dust Ch10 signal comes from a thicker (on average warmer) top layer

Ex: explains

NEx: does not explain

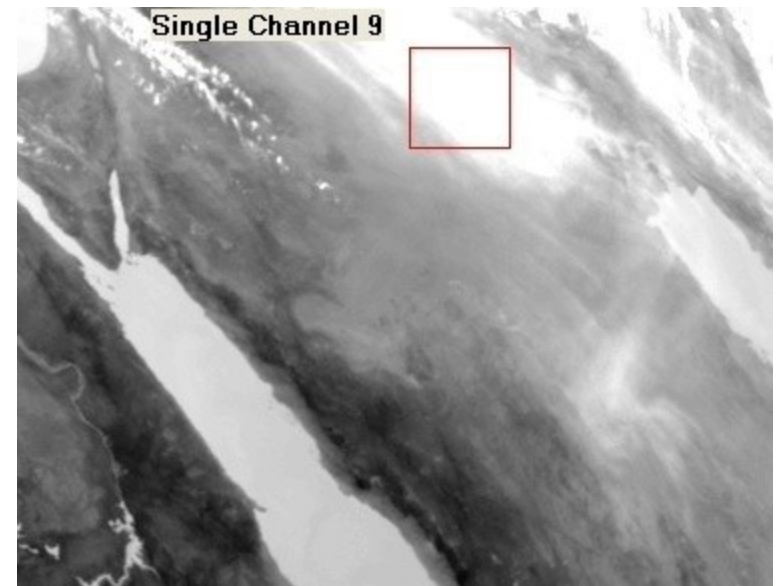
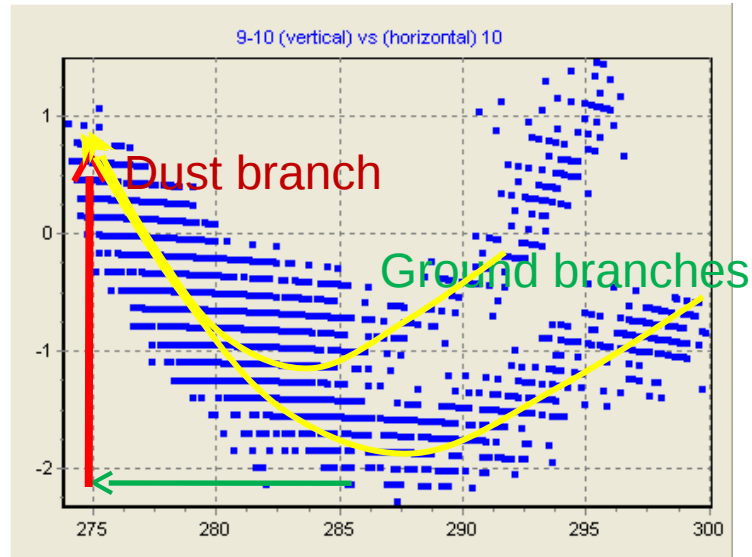
- Infrared dust properties
 - Where you learn how cool dust really is
- A model of atmospheric dust
 - Where you learn to distinguish high but thin from low fat
- Validation via AERONET
 - Where you learn that models can help your eyes
- Mixed scenes: cloud and dust
 - Where you learn that life is impossible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

Dust model



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

❑ Decrease in $12.0\mu\text{m}$ BT due to height and dust thickness (and size and...)

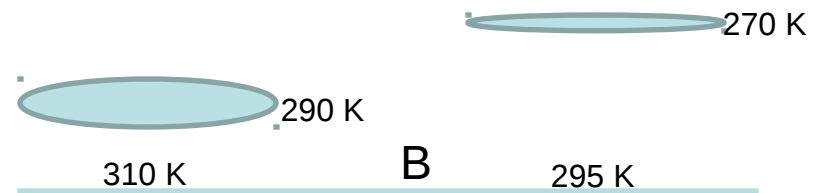


Model assumptions-limitations

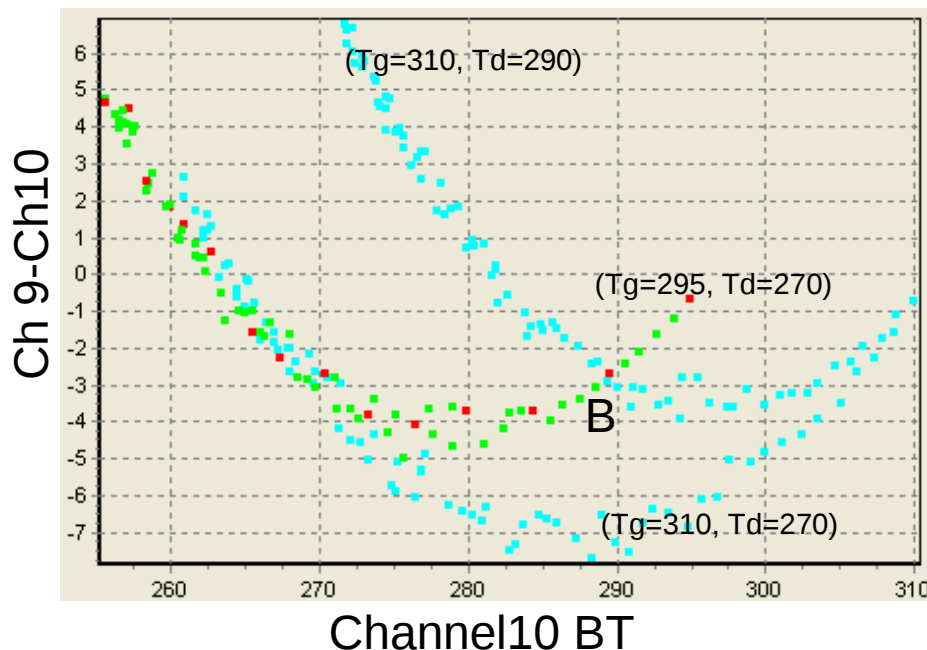
- ❖ (32x32 surroundings): min T10.8-T12.0 < -1.3K
- ❖ Empirical AOT estimates for channel saturation:
AOT= 0.14 (detection)----1.3 (for 10.8 μ m)----3.5(for 12.0 μ m)----4.8(cloud contaminated)
- ❖ Uniform dust **type**
- ❖ Dust in the pixel at a single **height**
- ❖ Size **not** dependent on height
- ❖ Ground temperature reduced 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
 - ❖ Measurable dust
 - ❖ 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 **$8.7\mu\text{m} - 10.8\mu\text{m}$** (negative for thin, positive for thick)



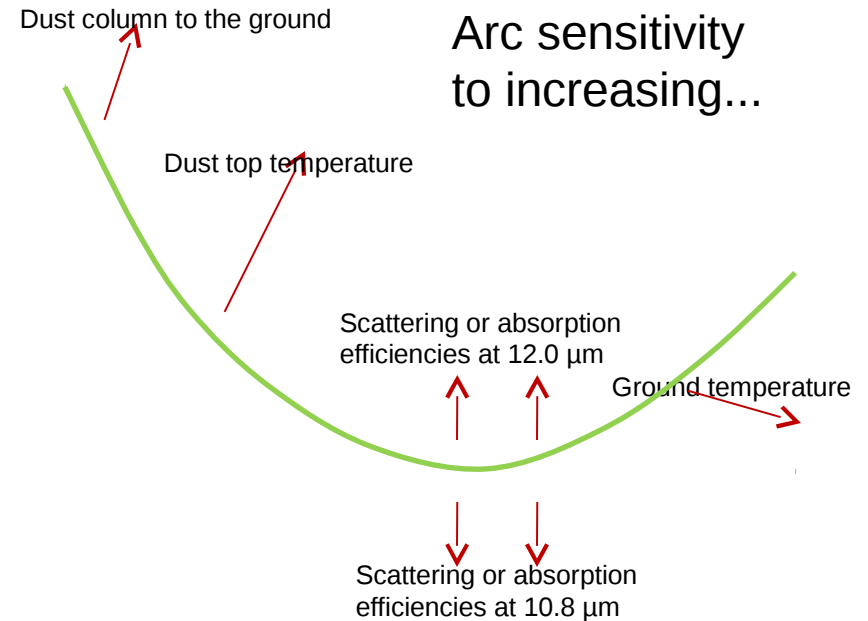
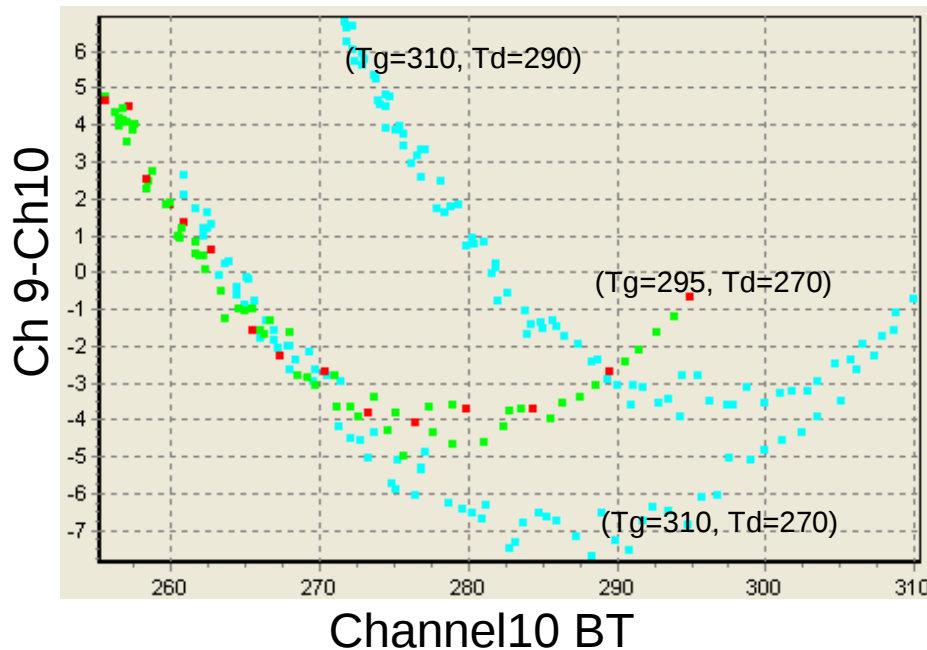
Green-red dotted curve for ($T_{\text{ground}}=295$, $T_{\text{dust}}=270$)
 Cyan curves for $T_g=310$, and two values of $T_d=270$ and 290 (which is which?)

Graphical analysis

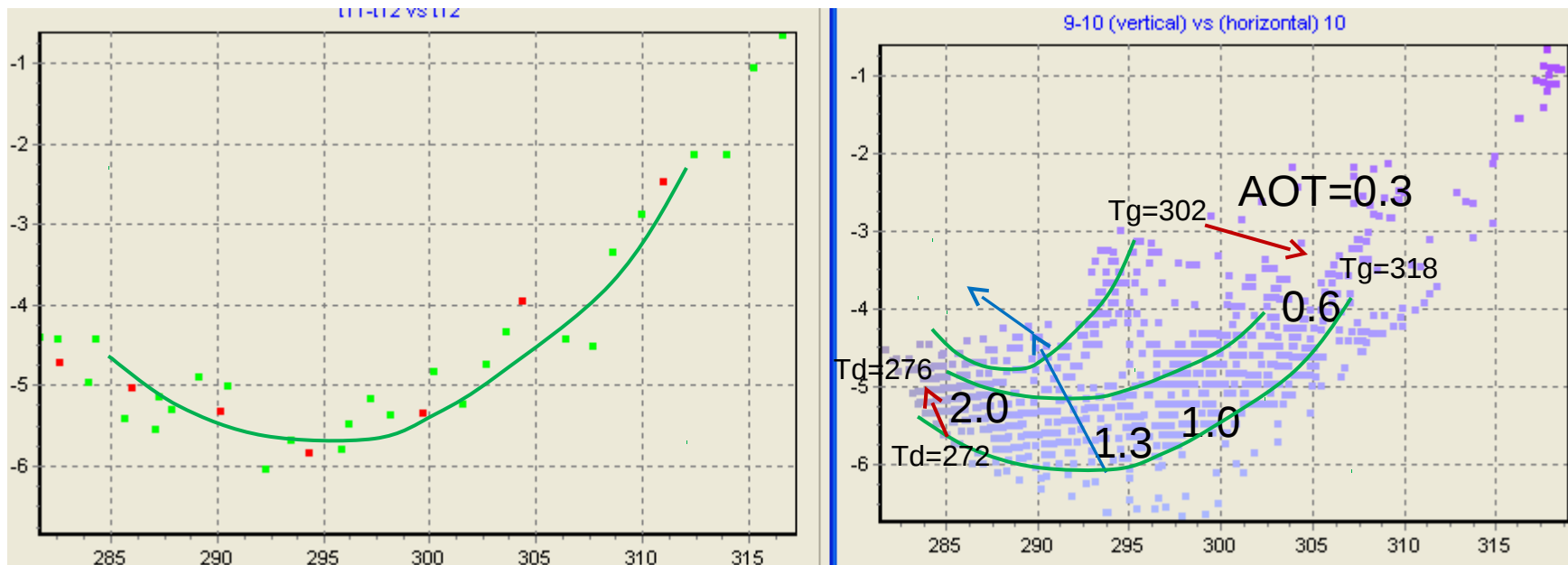
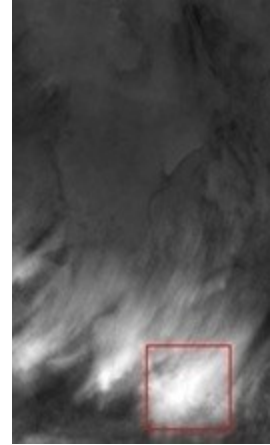
The arc shape depends on temperatures (dust top, ground, dust vertical extension) and

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



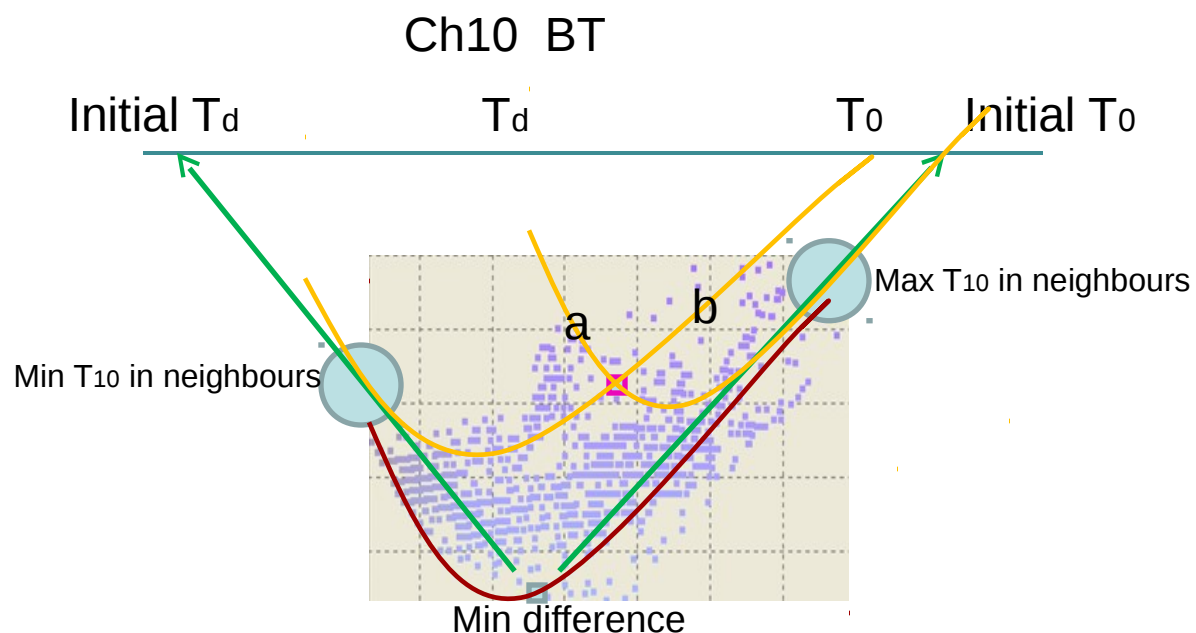
Real (blue dots, right h.s.) compared with simulated (green-red dots left h.s. and lines) scattergrams based on $T_g=318$ $T_d=272$ $\Sigma_{11}=0.6, 0.3$ $\Sigma_{12}=0.2, 0.25$

Dust column down to 50% of that temperature difference

Smaller arcs, higher in the scattergram, indicate less temperature contrast ($T_g - T_d$)

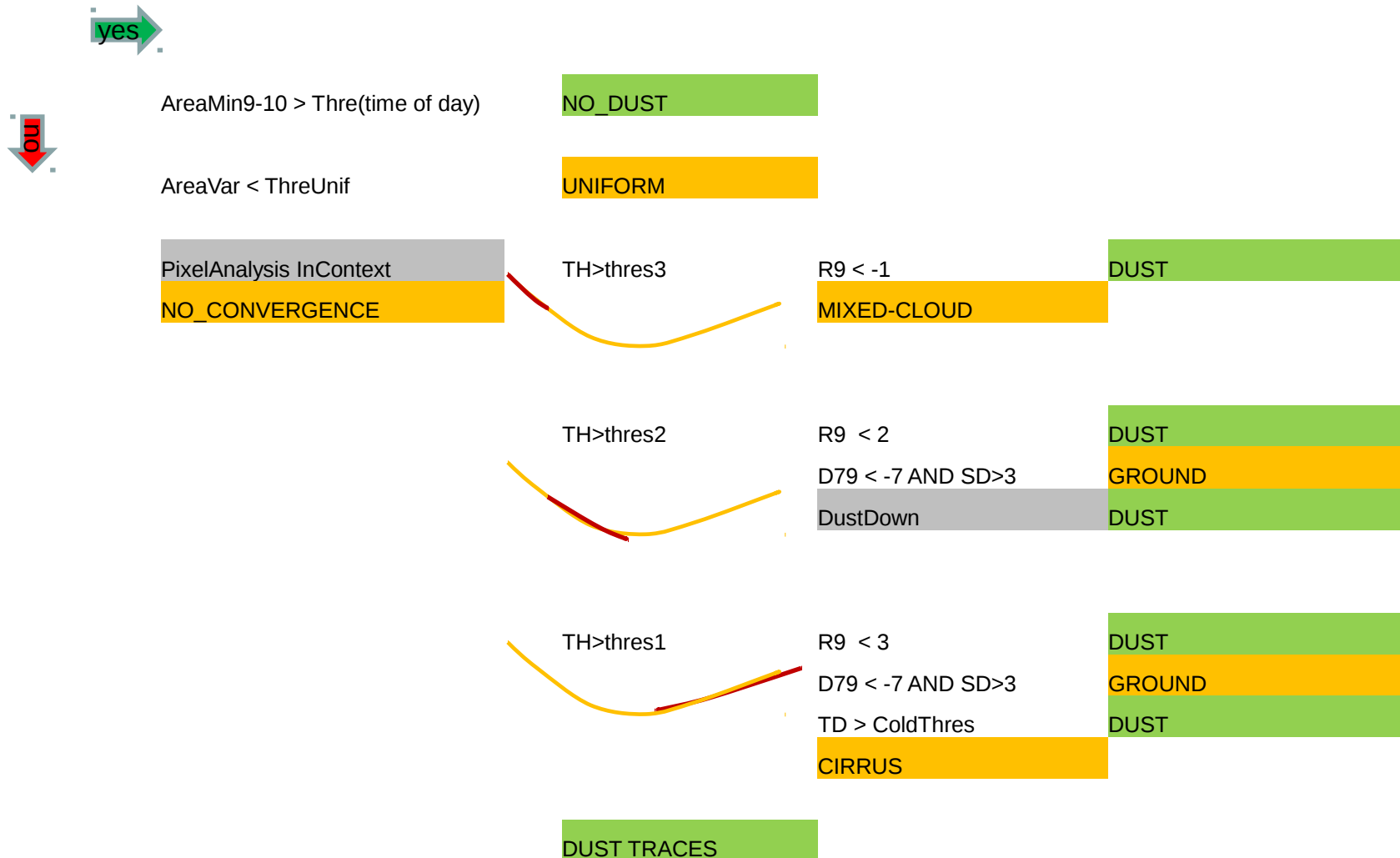
IR model operation

Ch 9-Ch10 BT



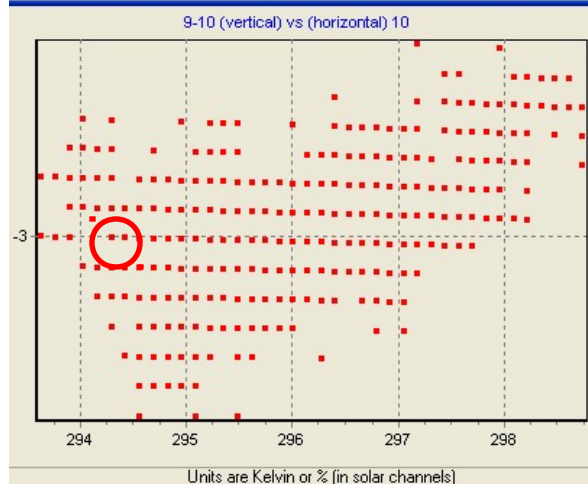
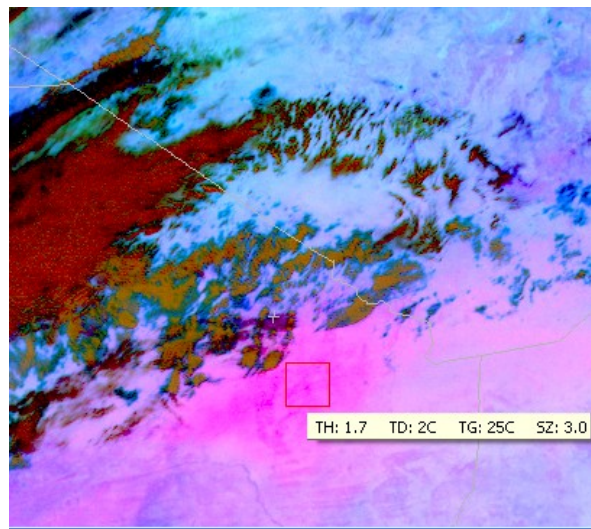
If slope=b, refresh T_o
If slope=a, refresh T_d

Decision tree

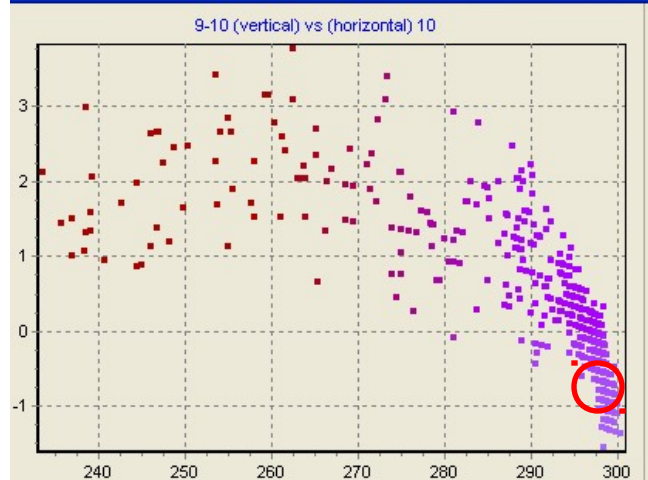
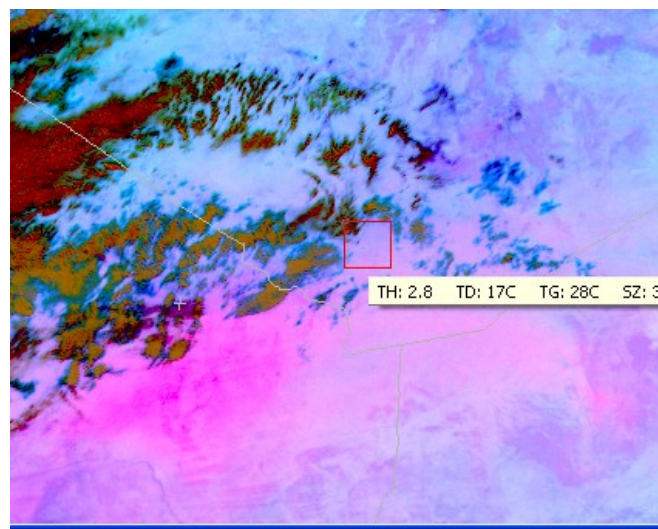


1. Subjective **verification** against masks, images and news media: Done
2. **Verification** from other sources (AERONET, LIDAR): In progress
3. **Inter-comparison** with other methods (Solar): Starting

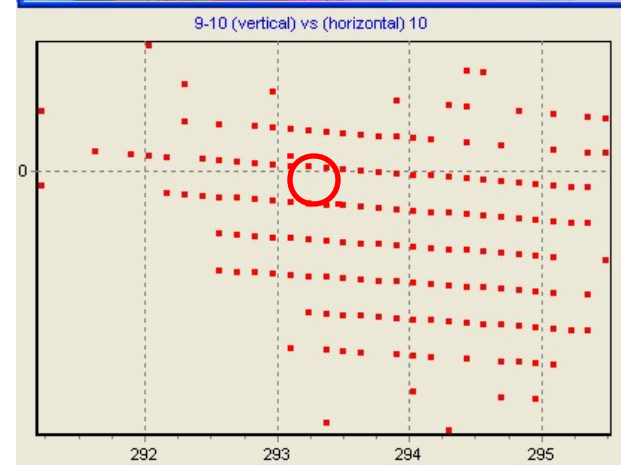
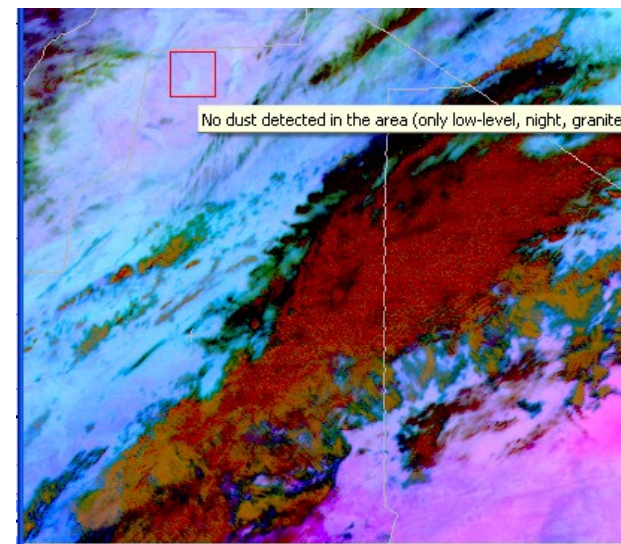
Graphical validation



threshold $\text{ch9-ch10} < -1.3\text{K}$
AOT = 1.7, strong depth



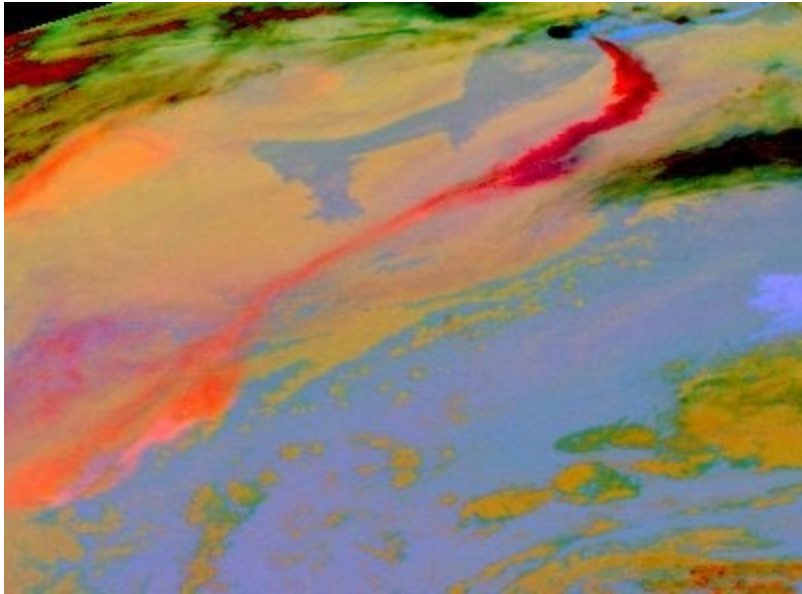
threshold $\text{ch9-ch10} < -1.3\text{K}$
AOT = 2.8, too strong depth
Due to location of minimum



threshold NOT $< -1.3\text{K}$
AOT not calculated

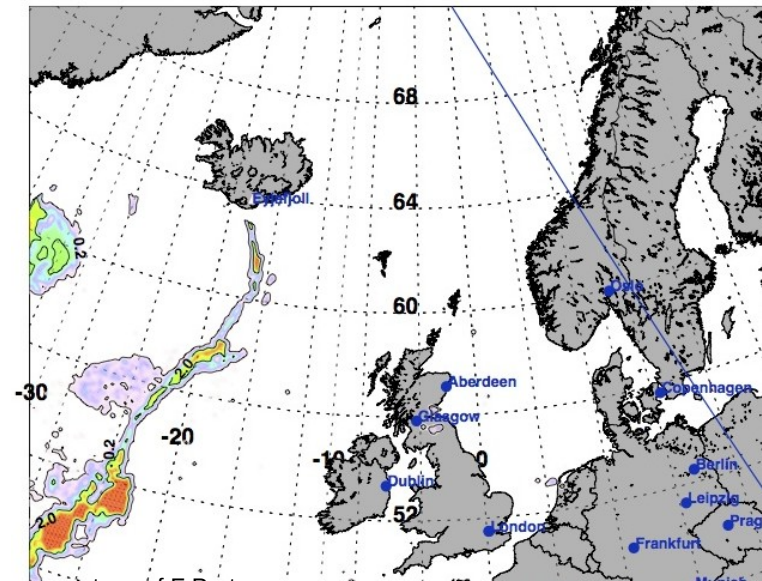
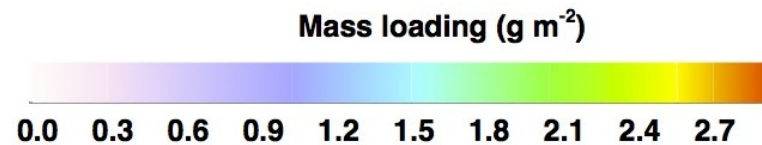
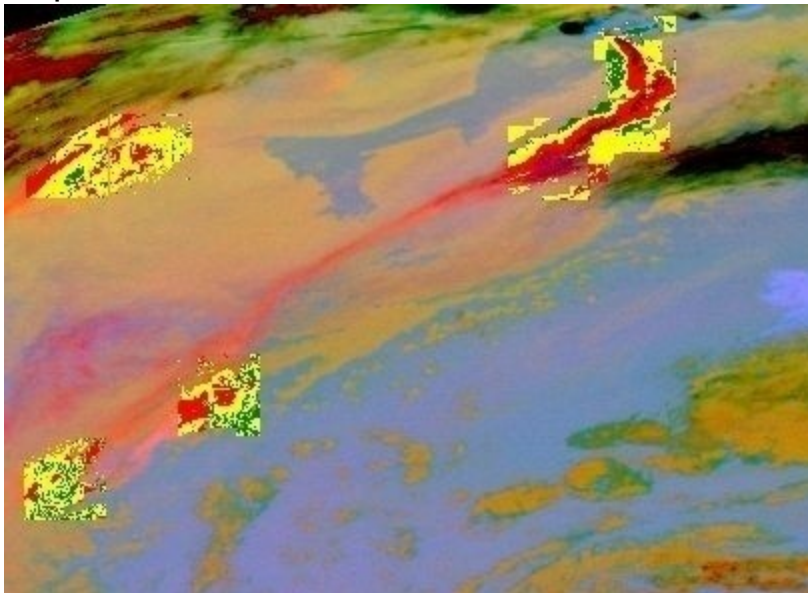
Applicable to volcano ash

- 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 (uncertain ash density estimate)



Dust RGB 2010-05-08 12UTC Icelandic ash

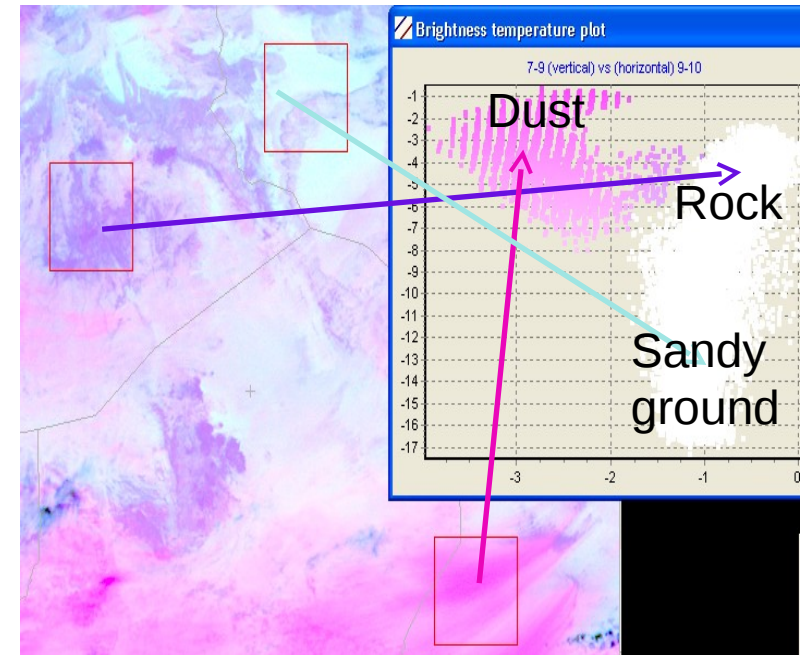
Optical thickness, retrieved from IR



courtesy of F Prata

Ground versus dust skill

IR model does not usually pick on rock or sand areas



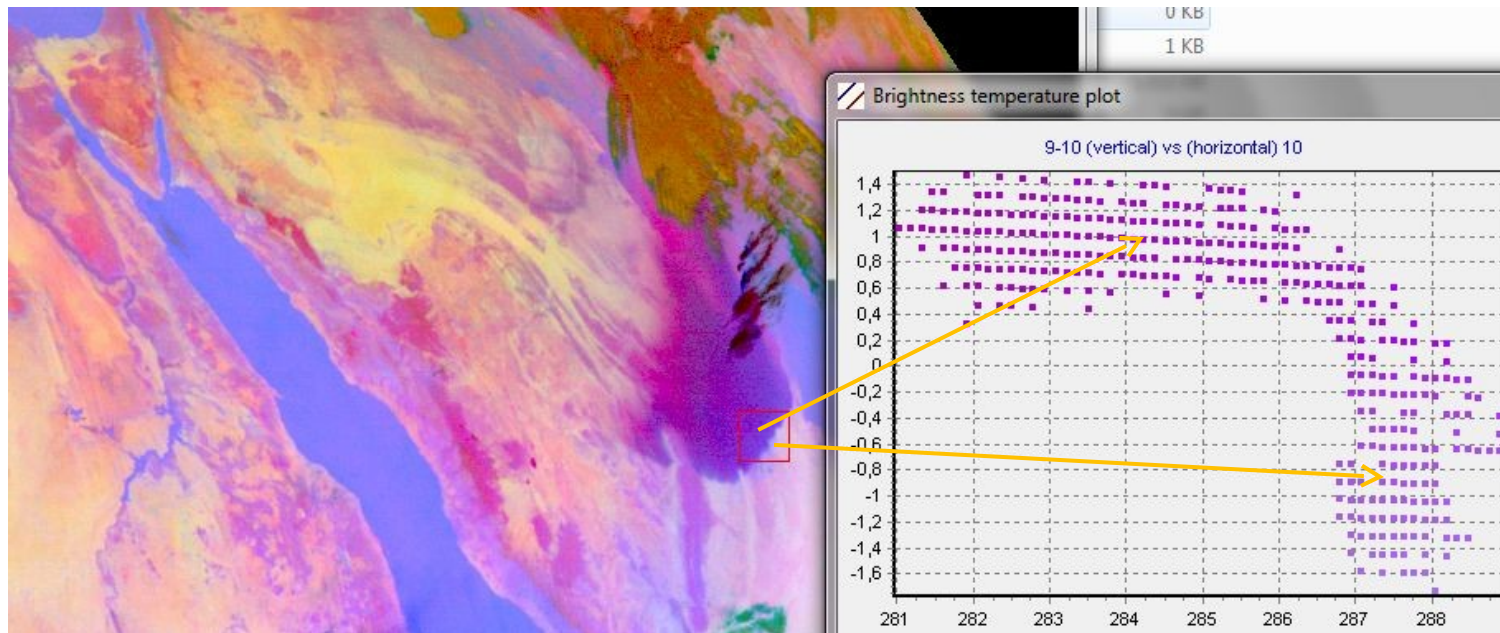
21Mar2010 12UTC Meteosat-9

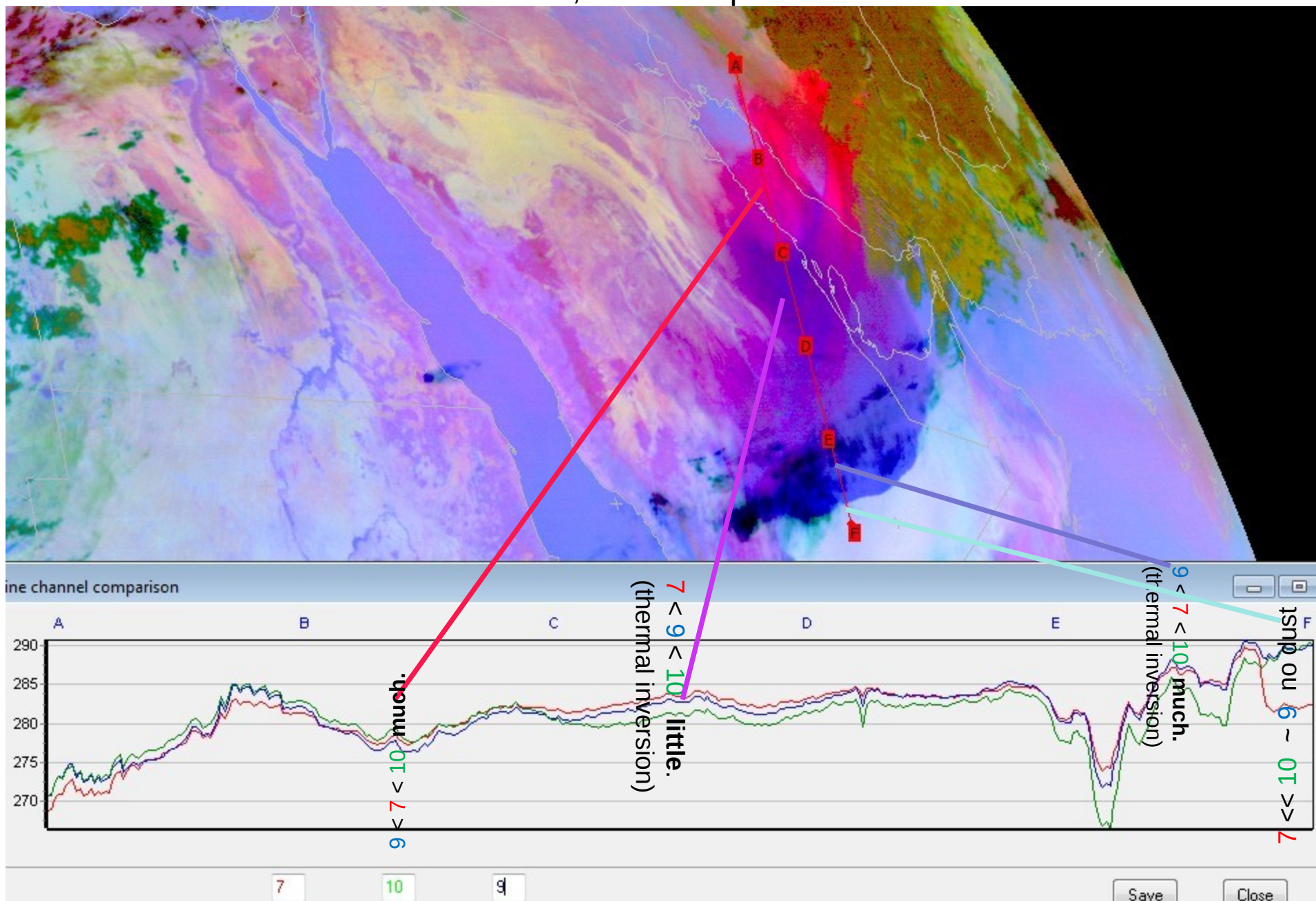


The IR model separates the **dust** areas from the **ground** dry areas

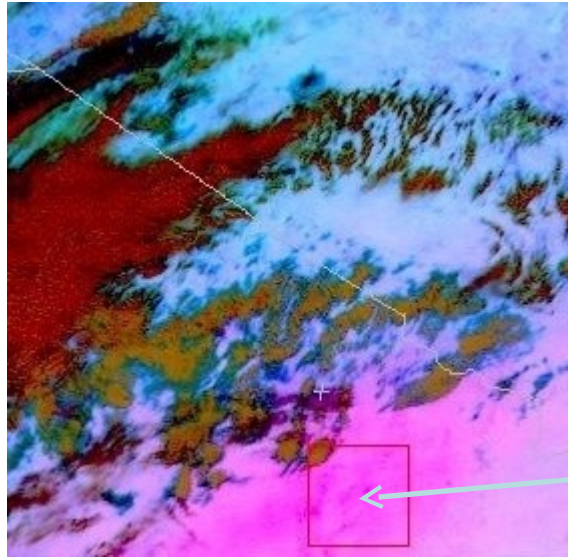
Model fails for atmospheric inversions

- Occasionally, during night, thermal inversions duct dust at high speed
- Due to the thickness, no negative $10.8\mu\text{m} - 12\mu\text{m}$ difference appears above the dust
- However, negative differences appear over clear ground

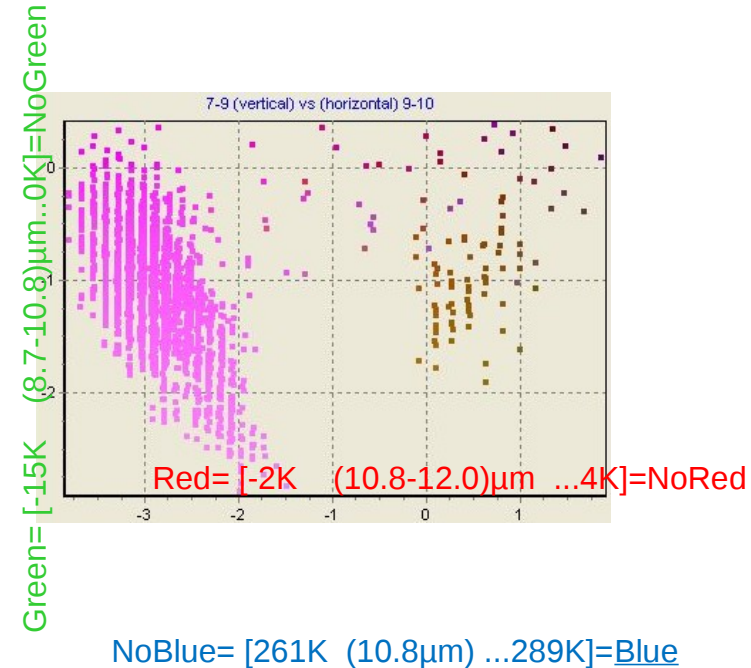
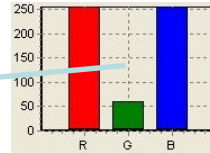




Dust RGB

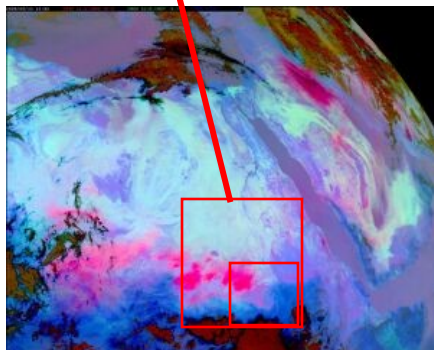
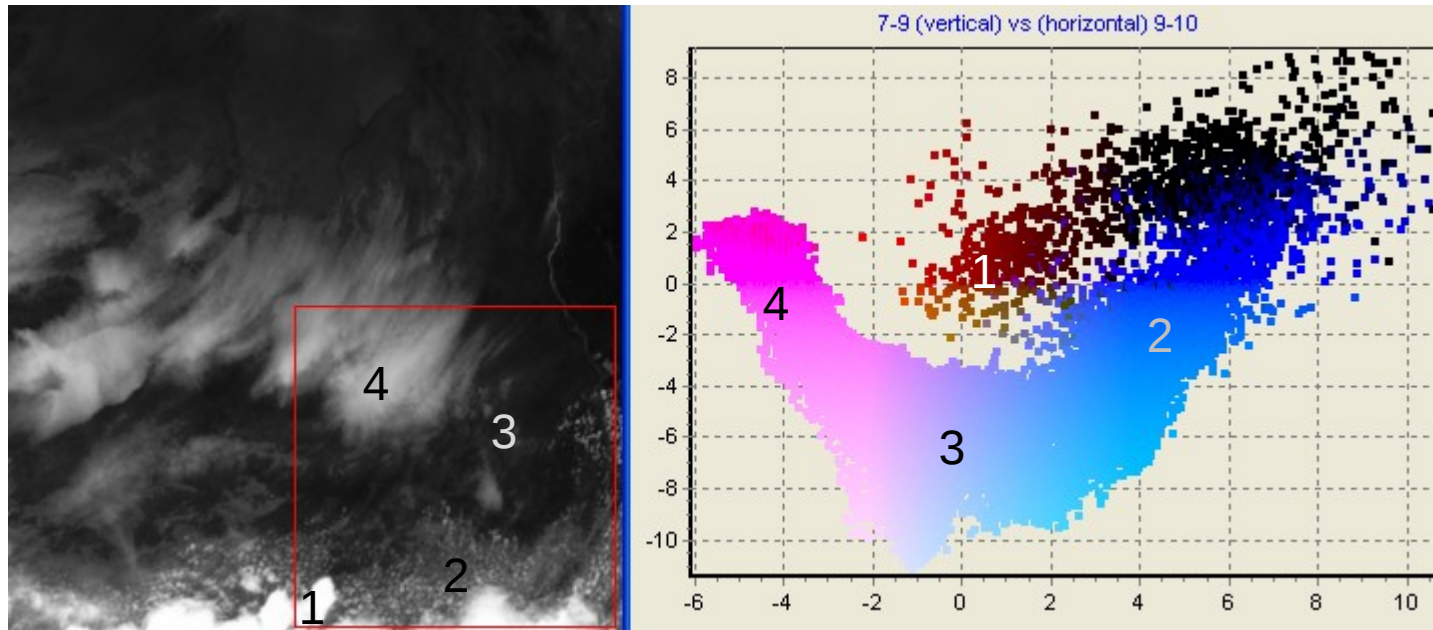


2010-03-21 12UTC, Saharian region



- 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 ($>16^{\circ}\text{C}$) over desert areas during day. During night it generates a yellow hue for desert.

The **cloud-to-dust spiral** in the differences diagram



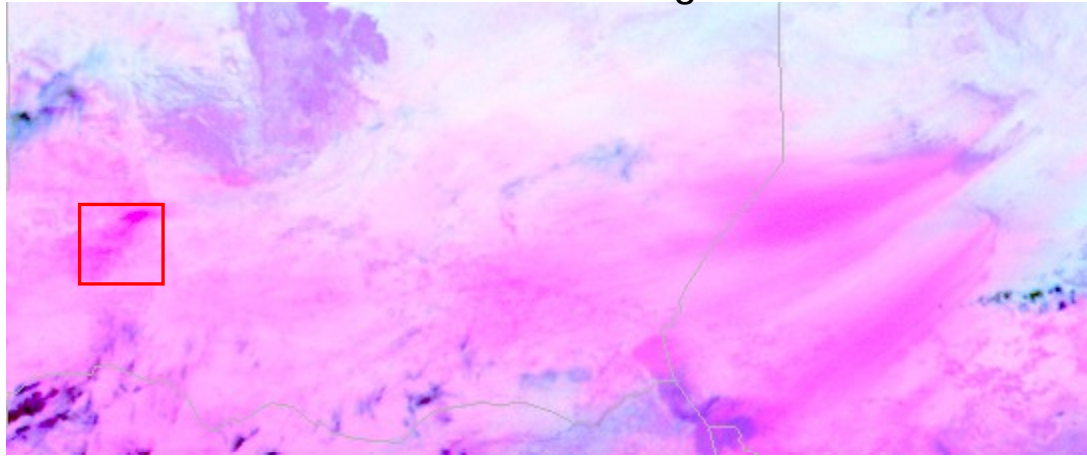
- 1: Thick high cloud
- 2: Broken low cloud
- 3: Ground, drier air towards 4
- 4: Dust cloud

RGB worse than IR-MODEL ?

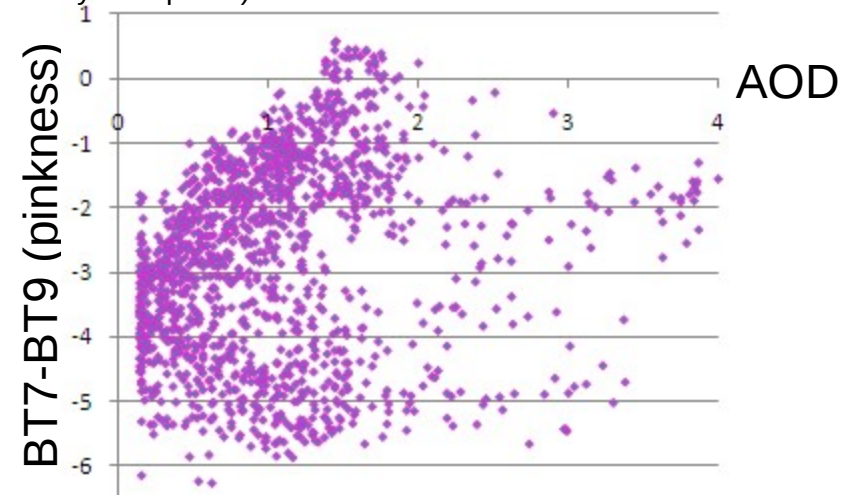
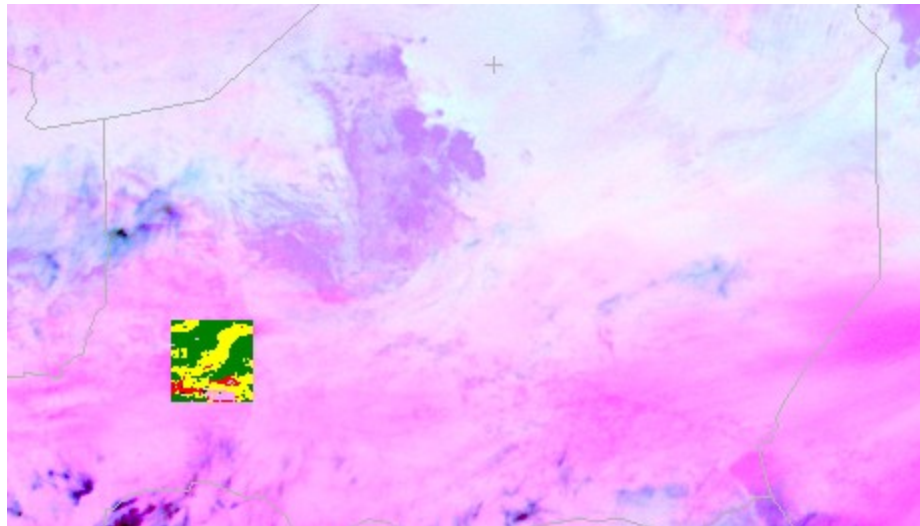
IR-MODEL discriminates significantly several (>4) levels of AOD

RGB discriminates <4 levels

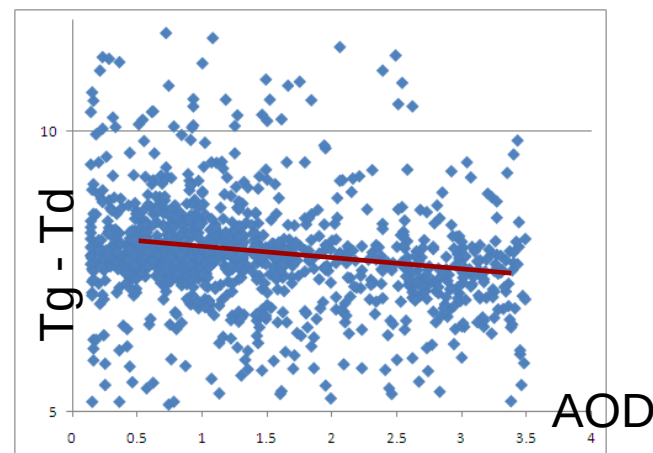
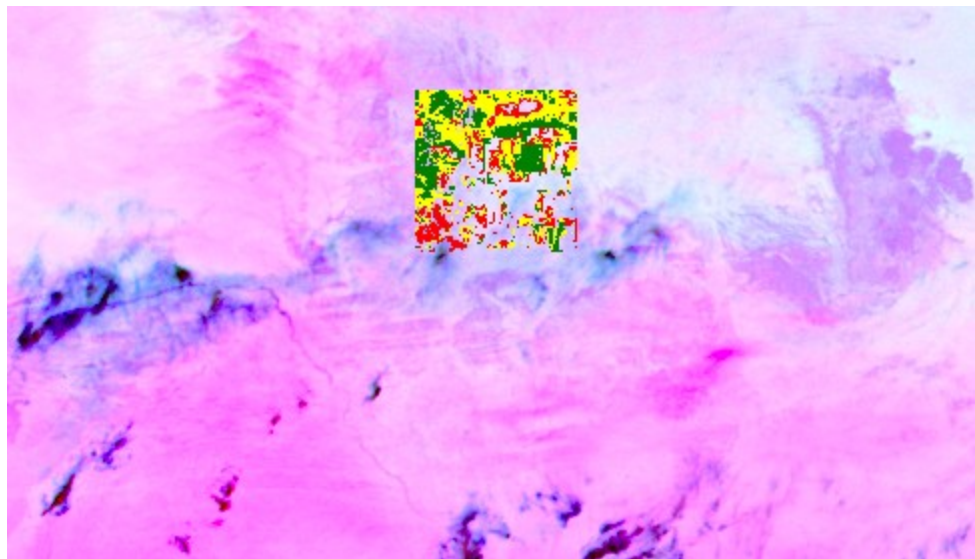
Pinkness is not a direct measurement of AOD at high AOD values



Reduced **ground temperature** under the thicker layer of dust (-5K to -10K for yellow pixels)



Channel versus model parameter: correlations

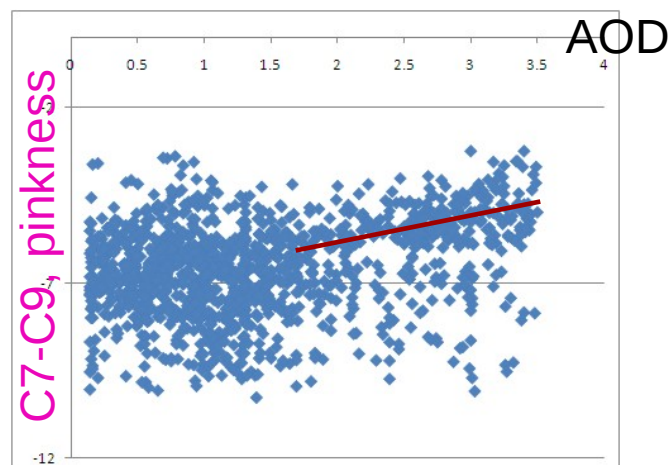
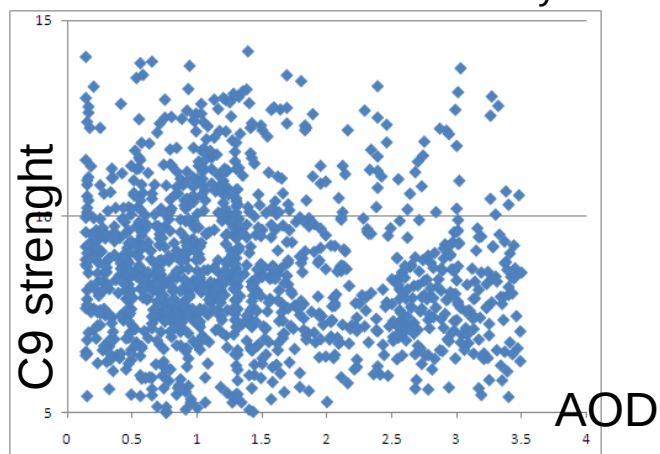


Correlations are stronger for $AOD > 2$

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



- Infrared dust properties

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 - Where you learn that models can help your eyes

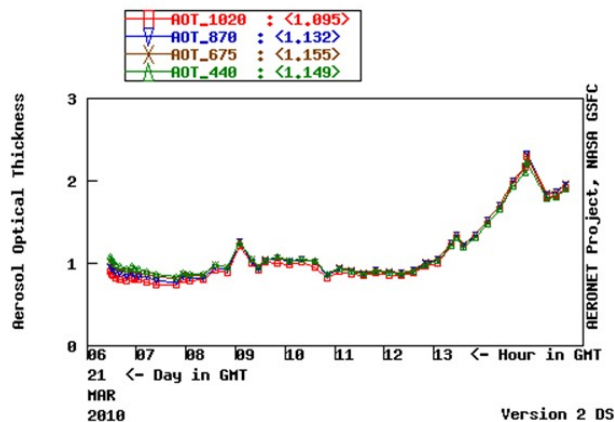
- Mixed scenes: cloud and dust

 - Where you learn that life is impossible without water

- Conclusions

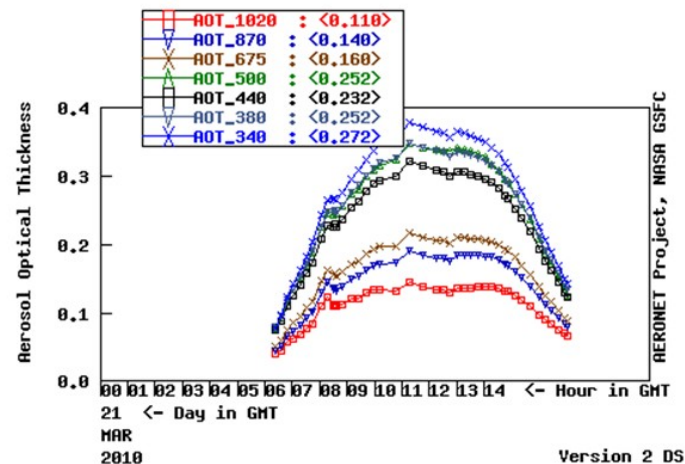
 - Where you learn that there is more dust on books than books on dust

DMN_Maine_Soraa , N 13°13'01", E 12°01'22", Alt 350 m,
PI : Didier_Tanri and Jean_Louis_Rajot, tanre@loa.univ-l.
Level 1.0 AOT; Data from 21 MAR 2010



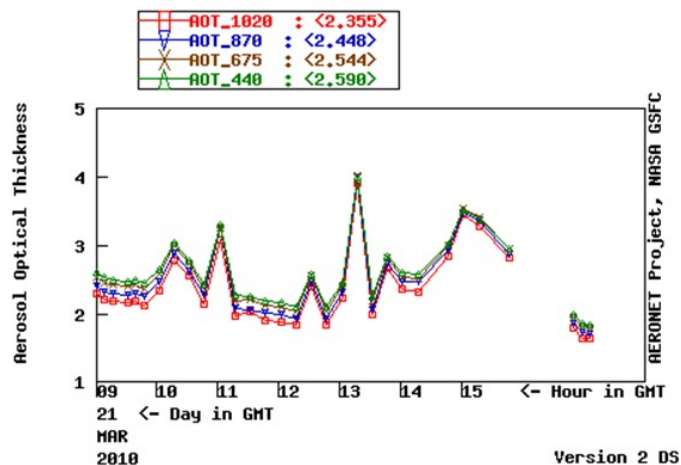
12.02E 13.22N, model on image at 12UTC: theta=0.6 31C-39C
size=29

Tamanrasset_INM , N 22°47'24", E 05°31'48", Alt 1377 m,
PI : Enilio_Cuevas-Agullo, ecuevas@aenet.es
Level 1.0 AOT; Data from 21 MAR 2010



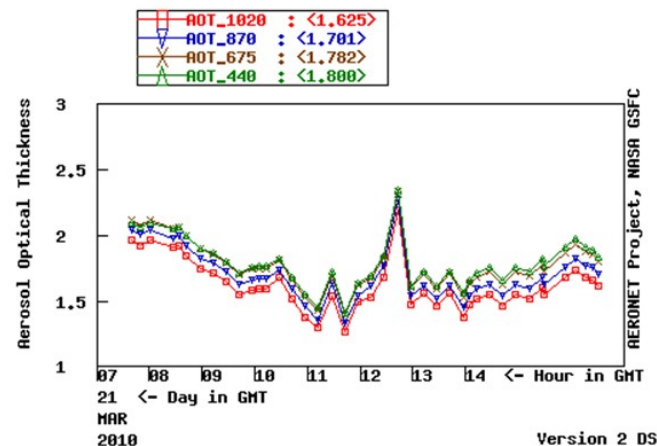
5.52E 22.77N, model on image: theta=0.16
40C-47C size=31

IER_Cinzana , N 13°16'40", W 05°56'02", Alt 285 m,
PI : Bernadette_Chatenet, chatenet@lisa.univ-paris12.fr
Level 1.0 AOT; Data from 21 MAR 2010



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

Banizoumbou , N 13°32'27", E 02°39'54", Alt 250 m,
PI : Didier_Tanri, tanre@loa.univ-lille1.fr
Level 1.0 AOT; Data from 21 MAR 2010



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

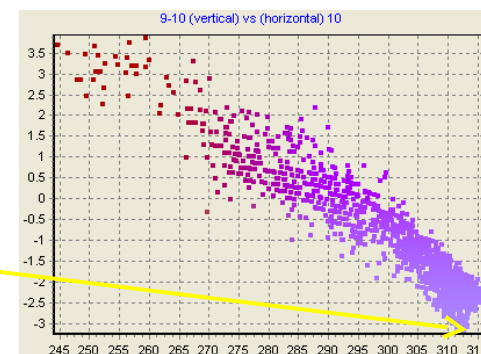
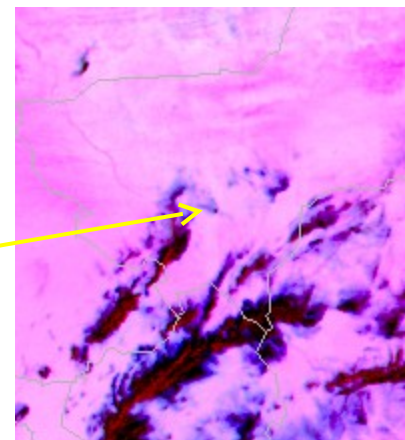
Validation based on ground measurements (AOD units)

AERONET

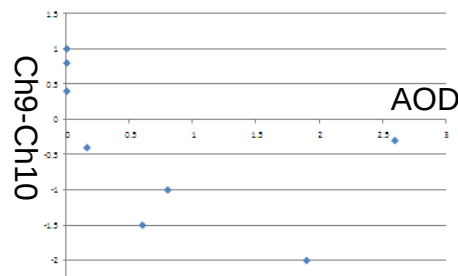
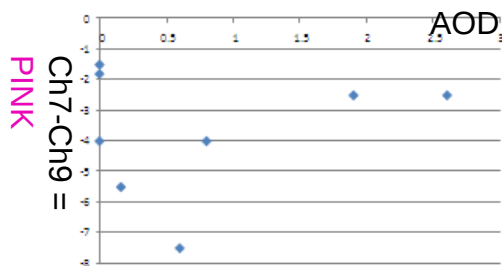
- ✓ 0.9
- ✓ 0.35
- ✓ 2.1
- ❖ 1.6
- ❖ 0.4
- ✓ 0.1
- ✓ 1.7
- ✓ 0.03

IR-MODEL

- 0.6 31-39 C 29 μm
- 0.2 40-47 C 31 μm
- 1.9 31-42 C
- 0.8 33-42 C 14 μm
- NO DUST (too uniform)
- NO DUST
- 2.6 30-38 C
- NO DUST



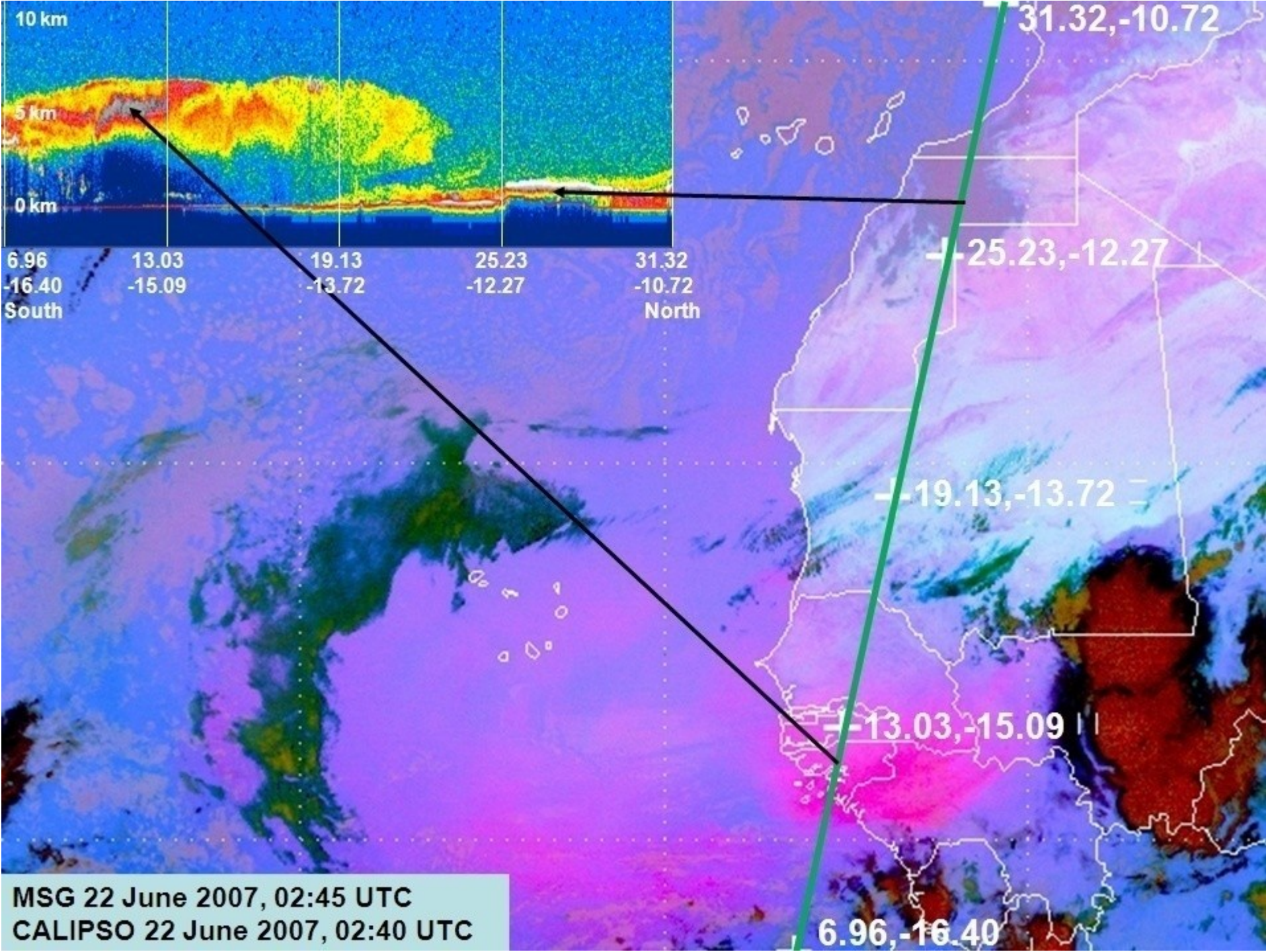
IR-MODEL is too sensitive to temperature at the arc minimum



SAMPLE VALIDATION

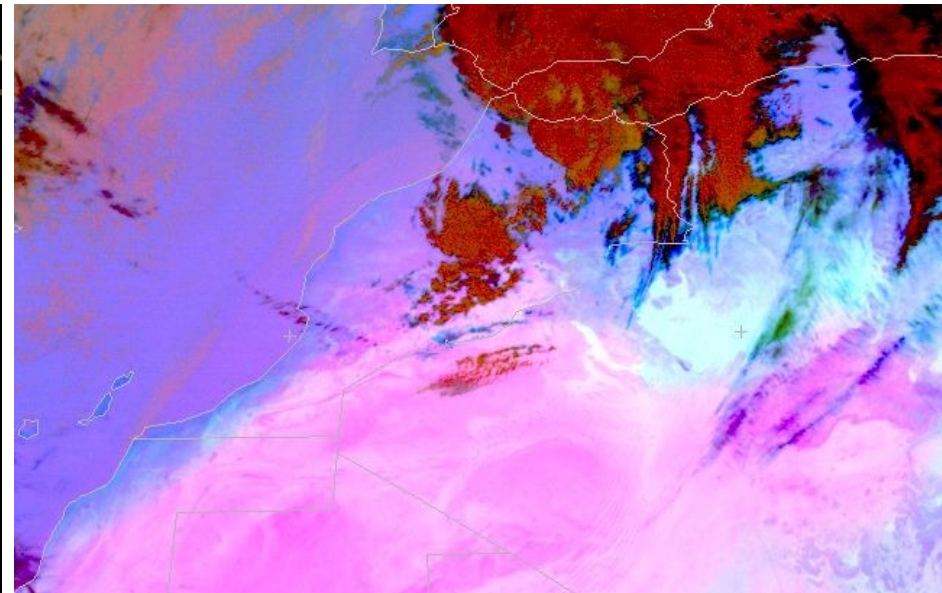
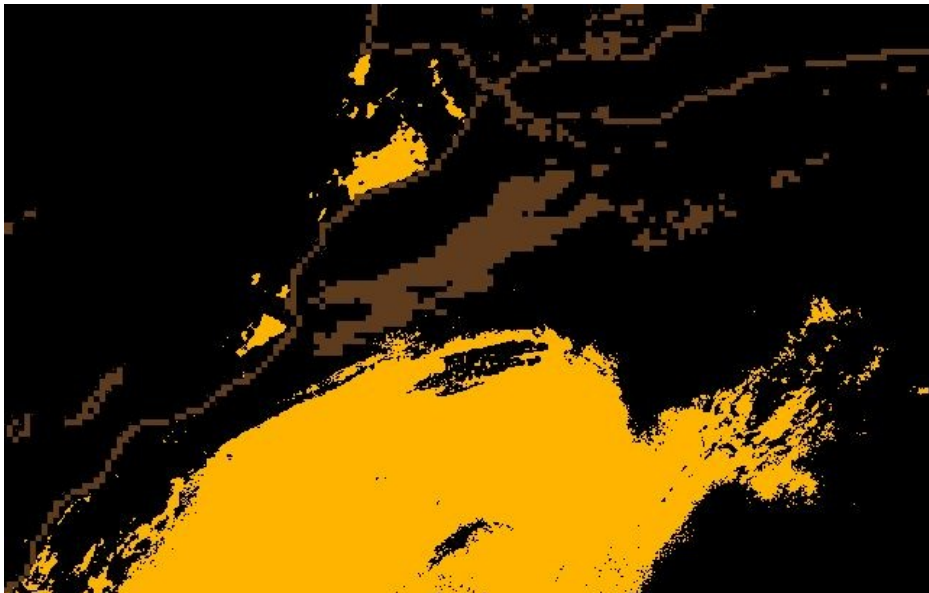
based on AERONET ground measurements

- ❑ Good agreement ($\pm 30\%$) 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



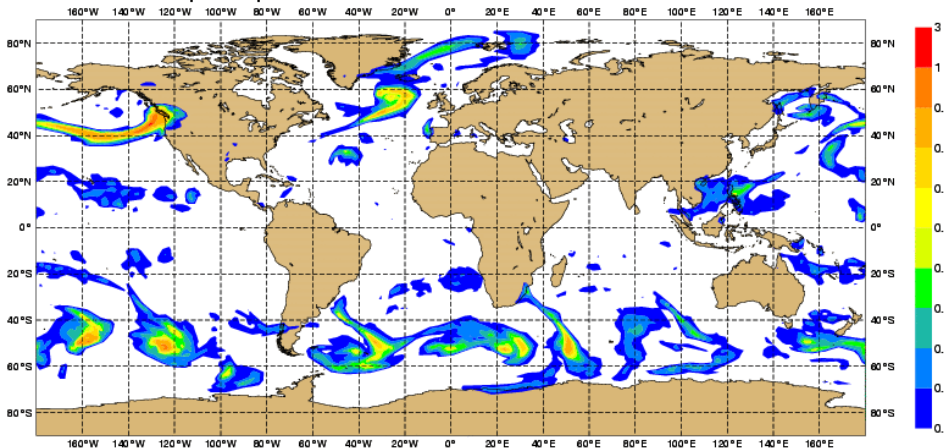
Other validation source: Nowcasting SAF dust flag

- *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

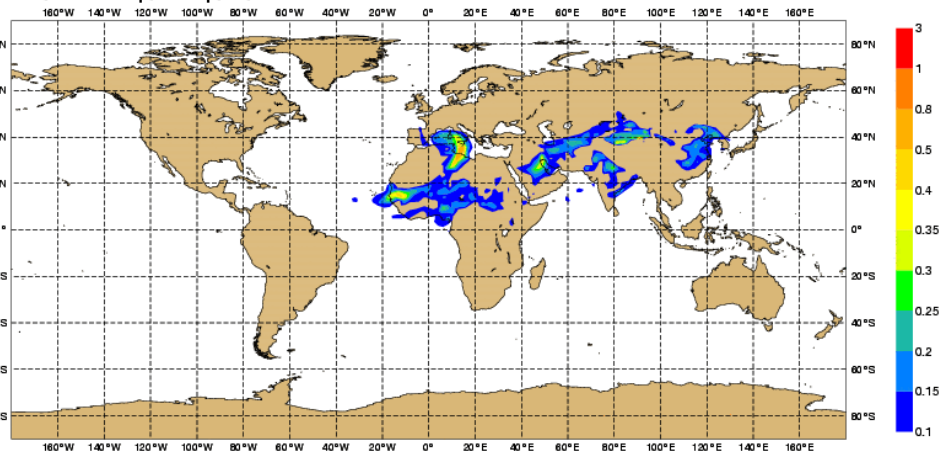


Nowcasting SAF dust flag and Dust RGB 21-Mar-2010 12 UTC

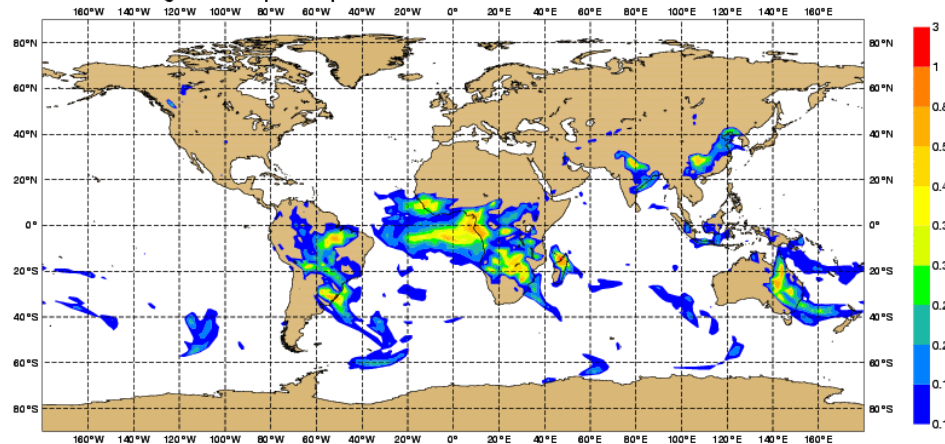
Sea-salt Aerosols Optical Depth at 550 nm



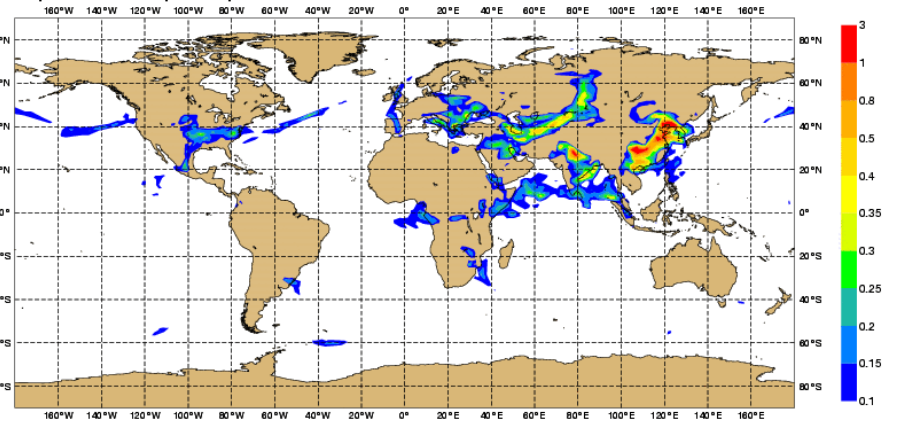
Dust Aerosols Optical Depth at 550 nm



Biomass Burning Aerosols Optical Depth at 550 nm



Sulphate Aerosols Optical Depth at 550 nm



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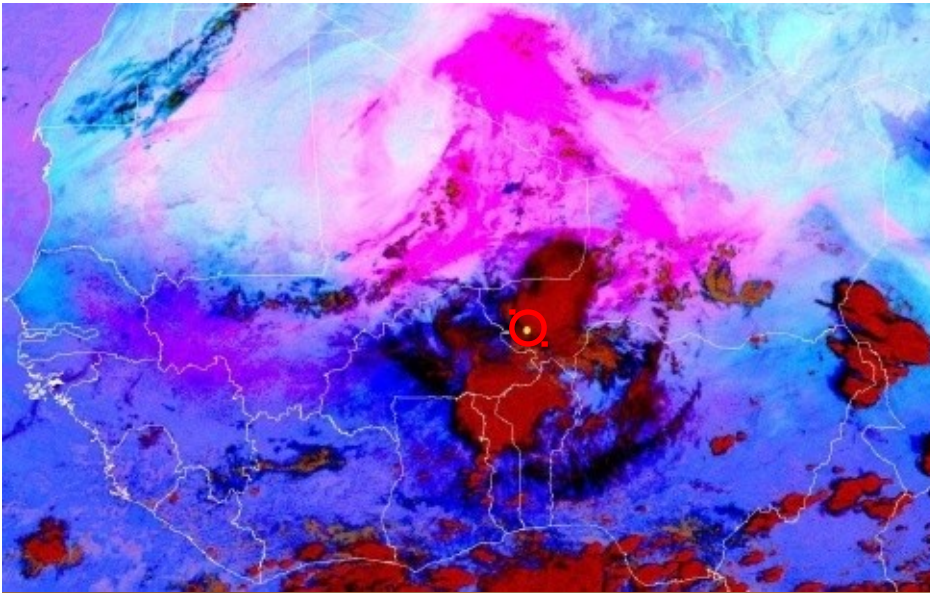
- Where you learn that models can help your eyes

- Mixed scenes: cloud and dust

- Where you learn that dust tends to soak

- Conclusions

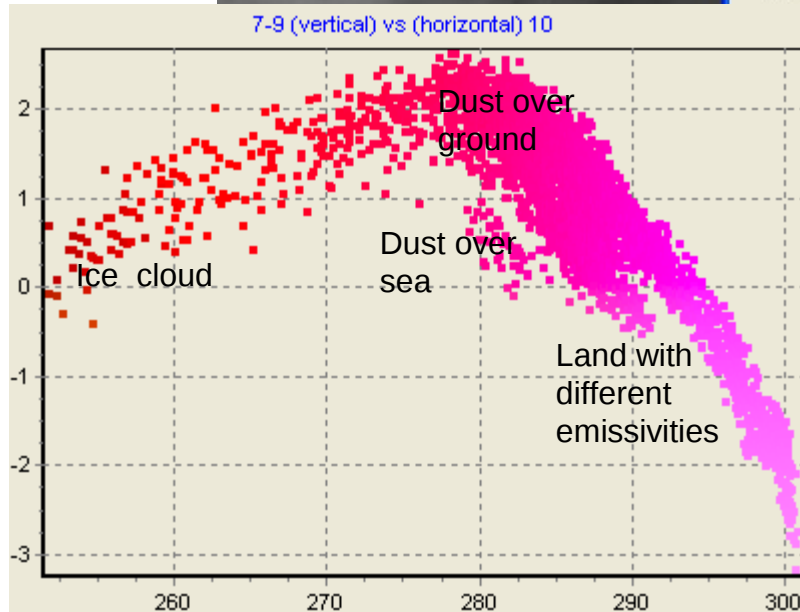
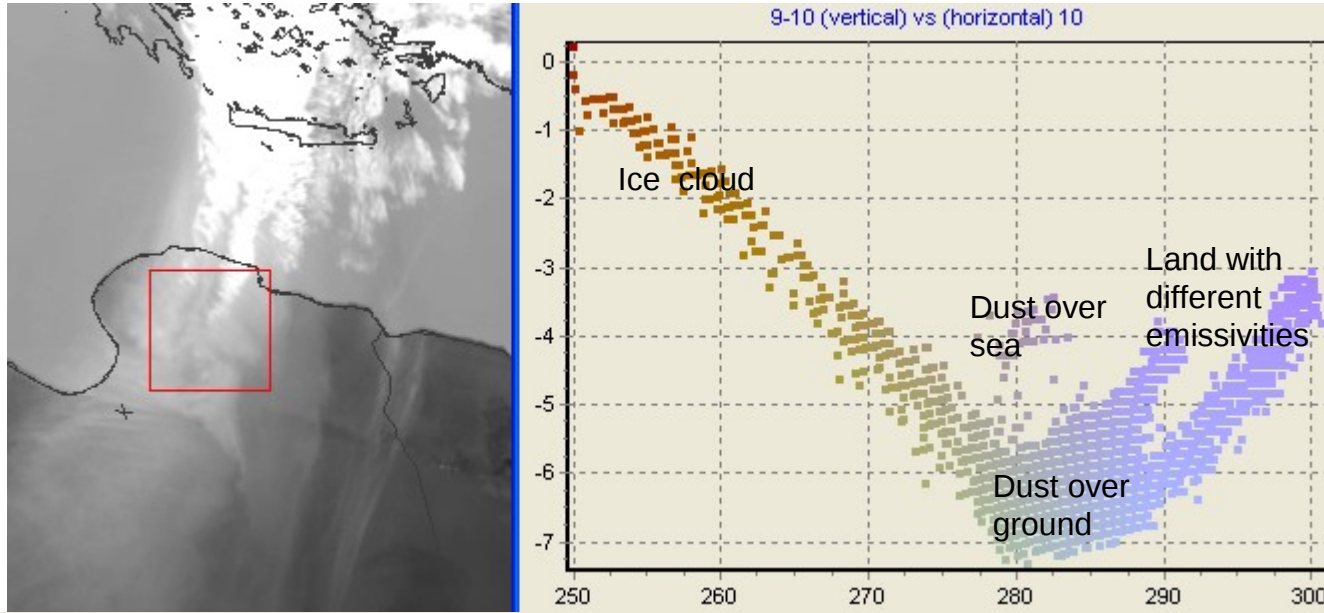
- Where you learn that there is more dust on books than books on dust



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

Dust-cloud interaction

2008-03-23 11:30 UTC Meteosat Ch9



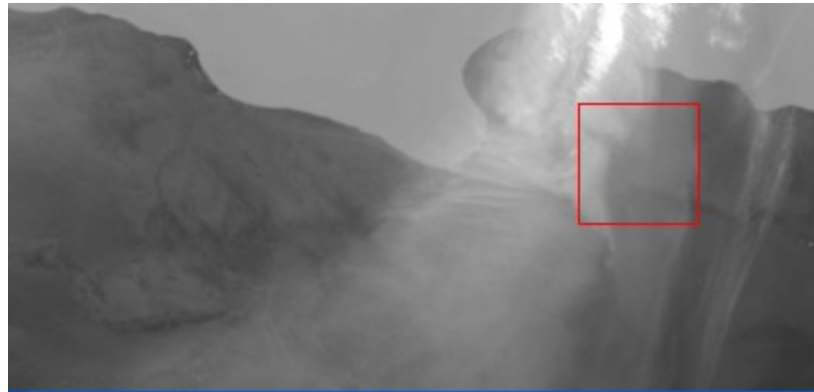
What is the ice temperature at the cloud boundaries?

265 K

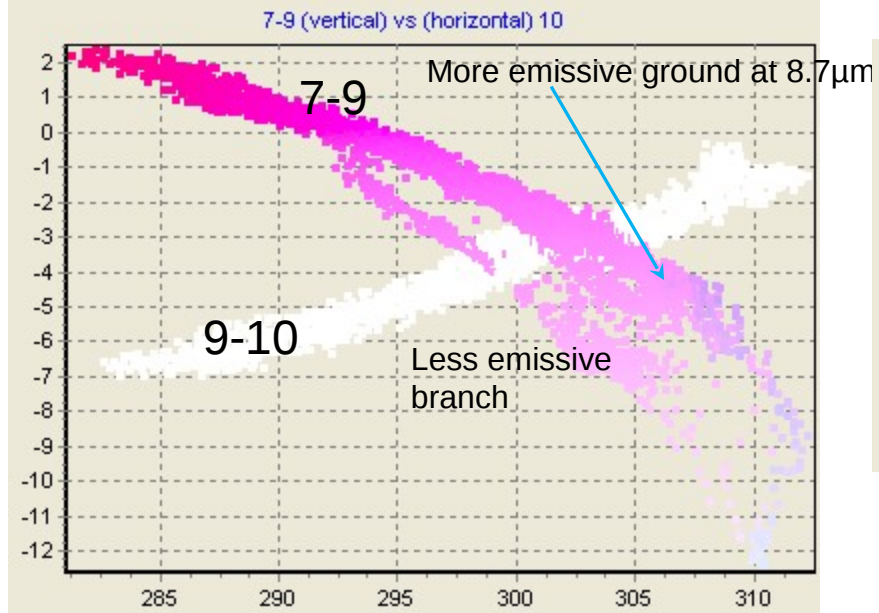
275 K

285 K

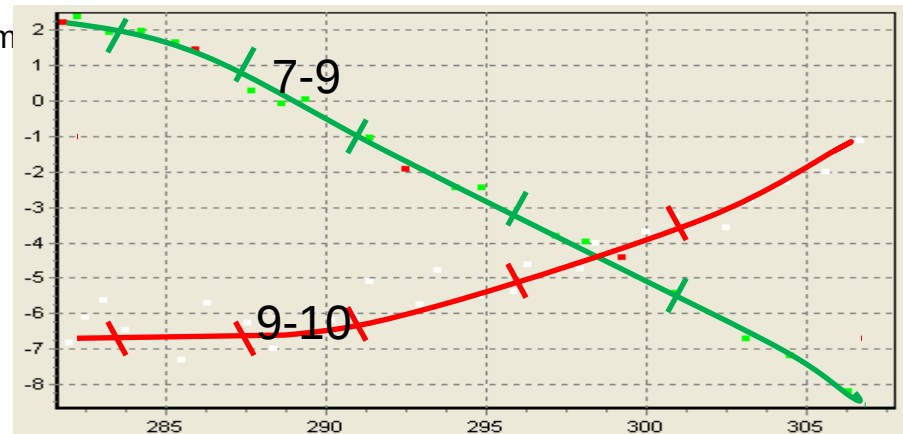
Value added by channel $8.7\mu\text{m}$



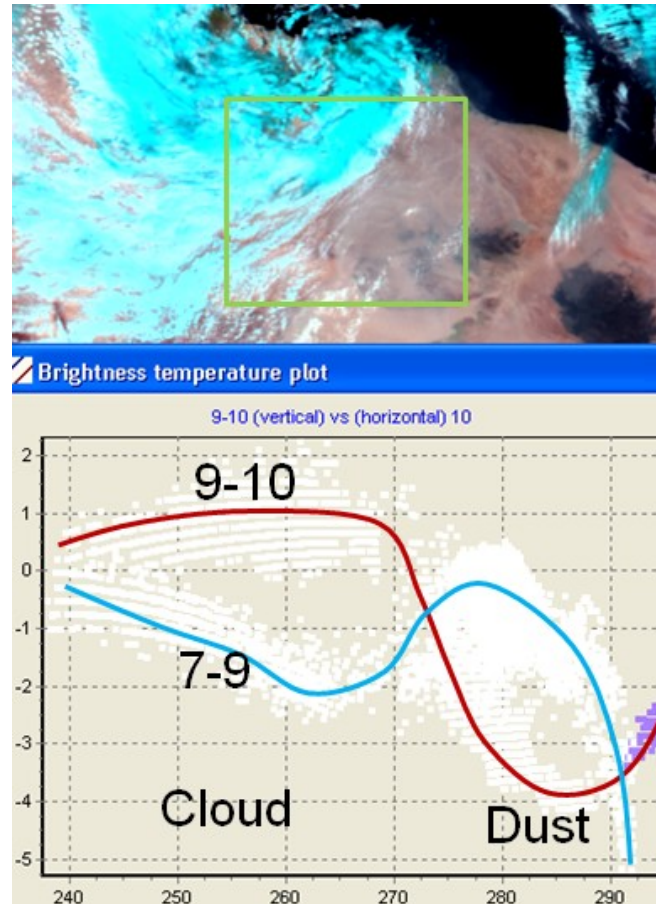
Brightness temperature plot



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



Dust-cloud interaction



Cloud-dust index: $2 \cdot \text{ch9} - \text{ch7} - \text{ch10}$

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Conclusions

- A model based on three **infrared** window channels provides a set of parameters for dust storm severity
- *T_{dust}*, *T_{ground}* and *Depth* values are essentially derived from **10.8 μ m** and **12 μ m**
- Channel at **8.7 μ m** 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

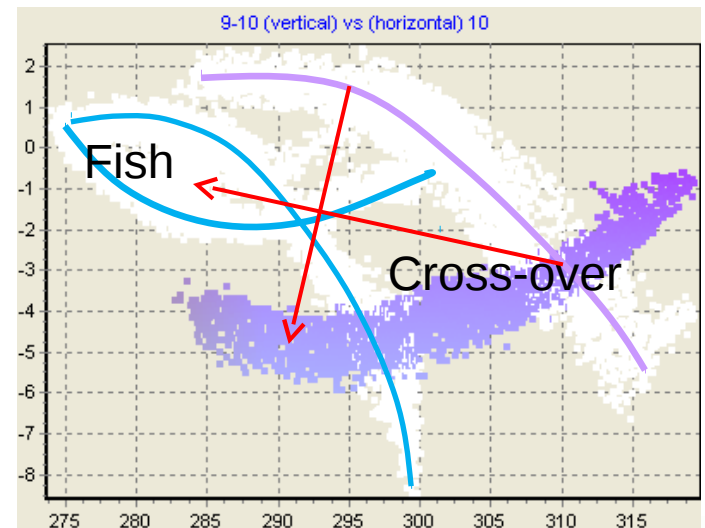
Outlook

- 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

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



Can you not think of a question?

No problem. Just choose one from the following:

1. Why do we 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?