Envisat, MERIS image in the solar domain

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

jose.prieto@eumetsat.int

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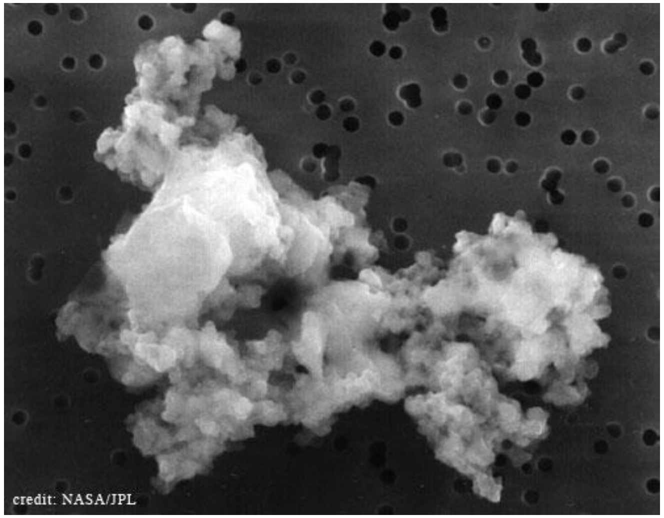
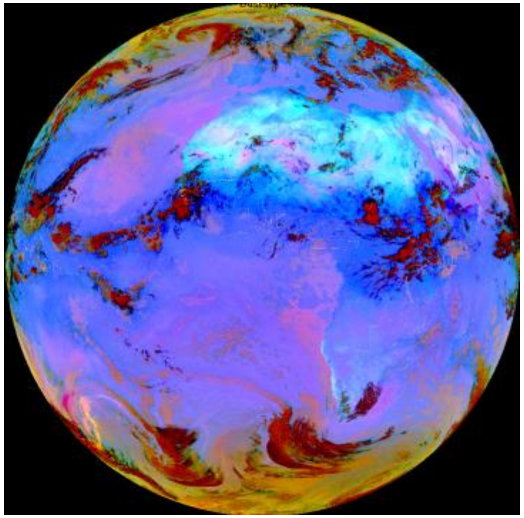
Can a satellite see dust particles ?



← 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)
- Inert tracer for atmospheric circulation
- Life vector (Saharan protozoa and bacteria to the Caribbean)

EUMETSAT

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

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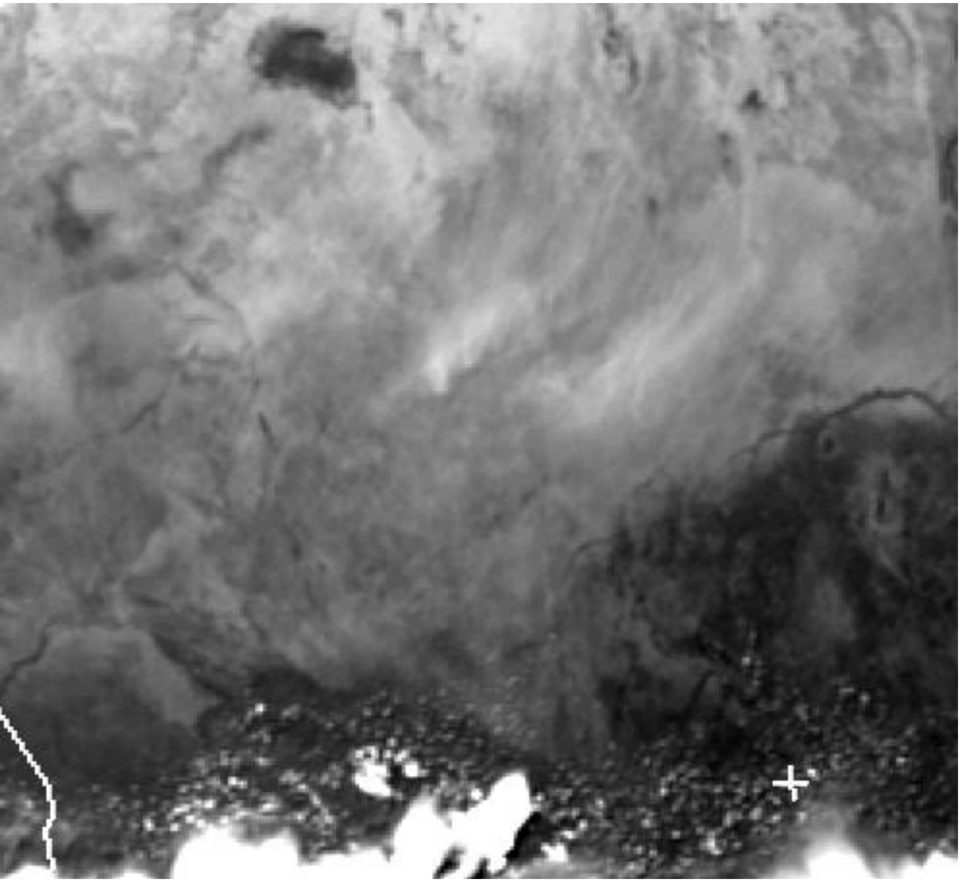
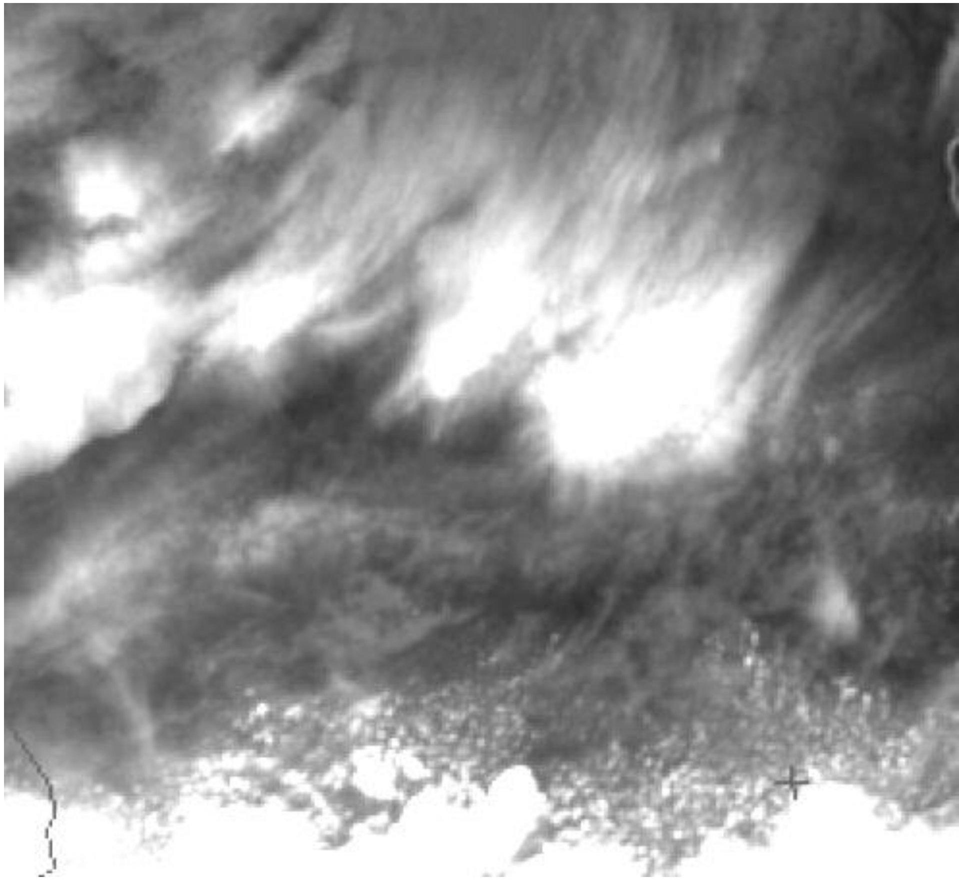
Dust on solar and infrared images



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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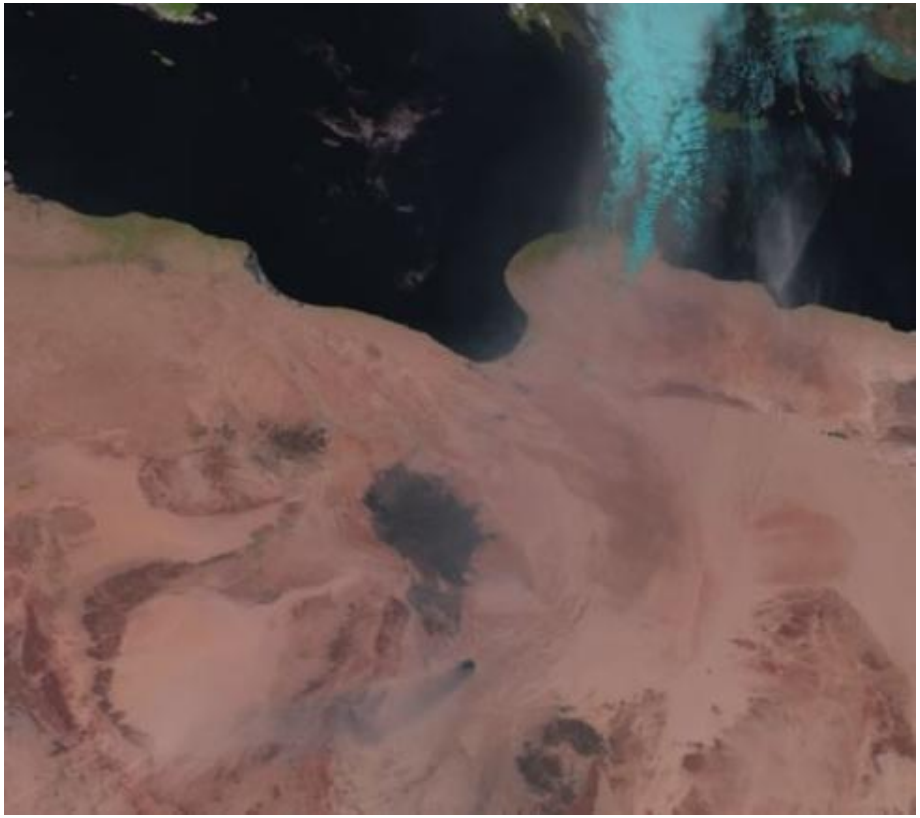
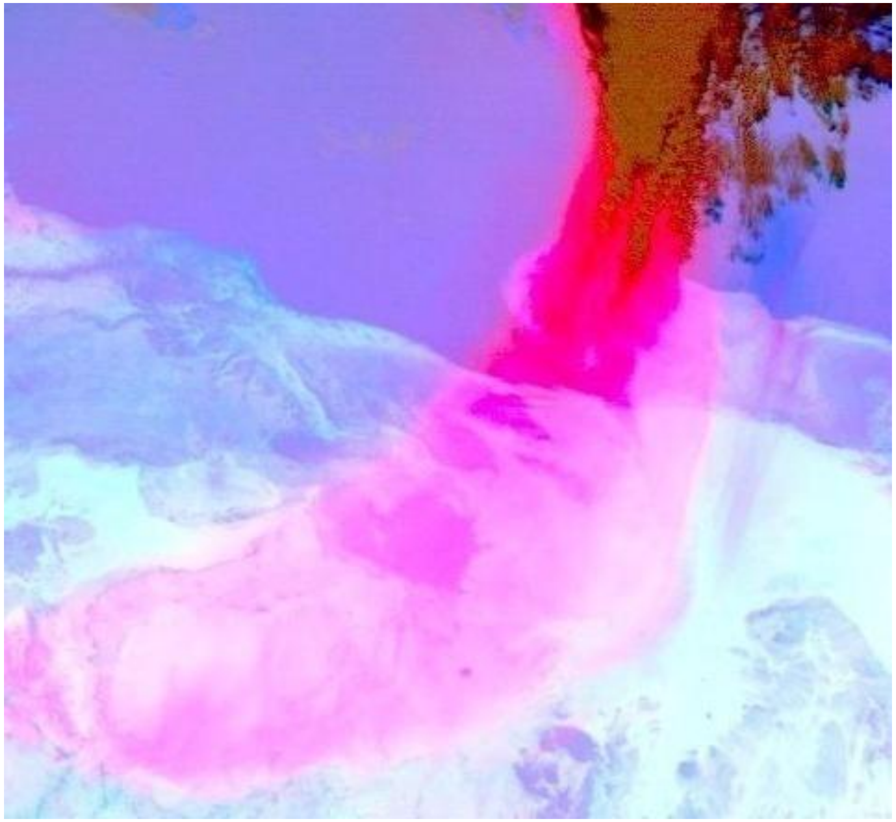
DUST RGB composite:
the strength of infrared for dust detection



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

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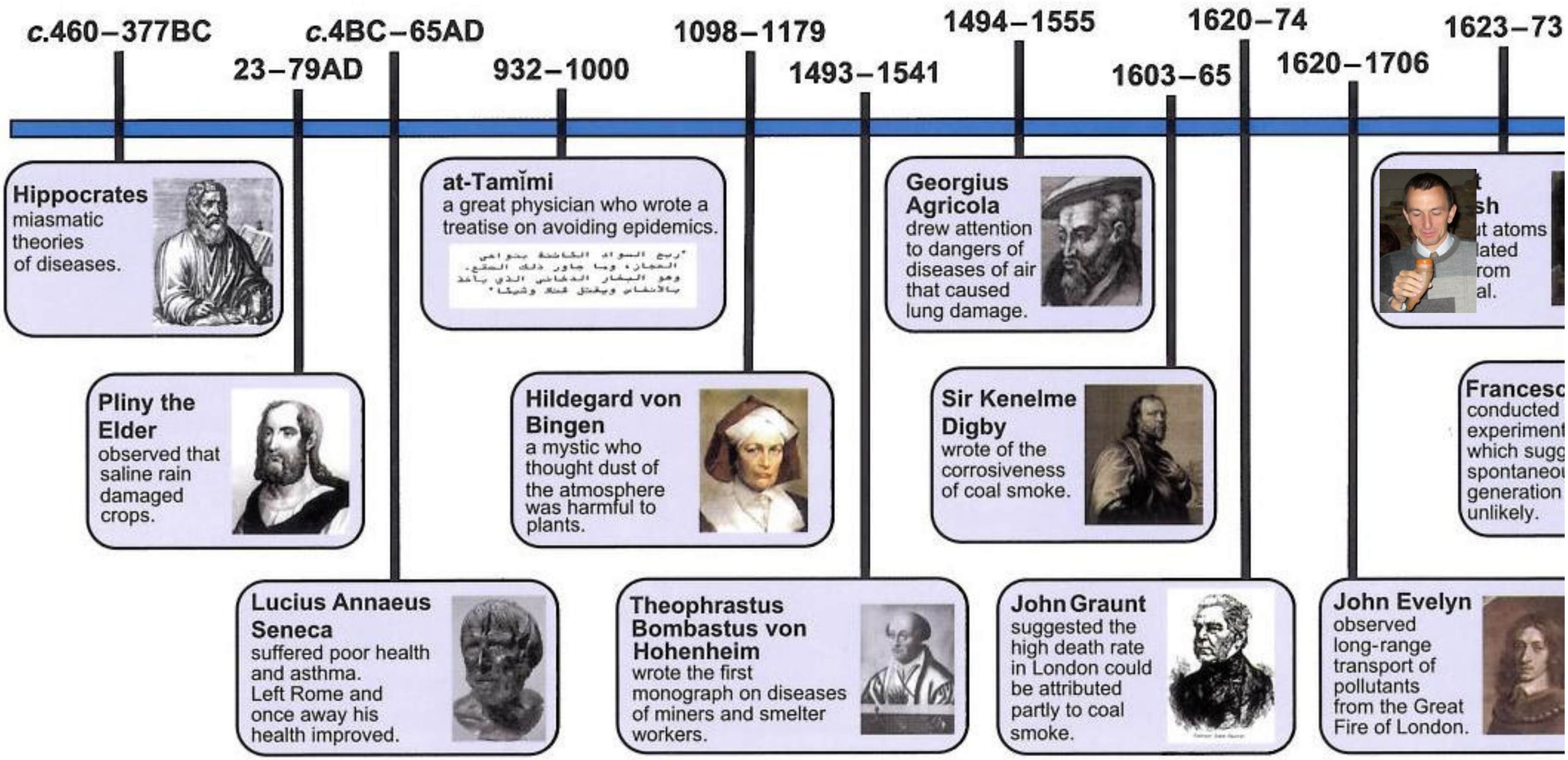
Aerosol and health



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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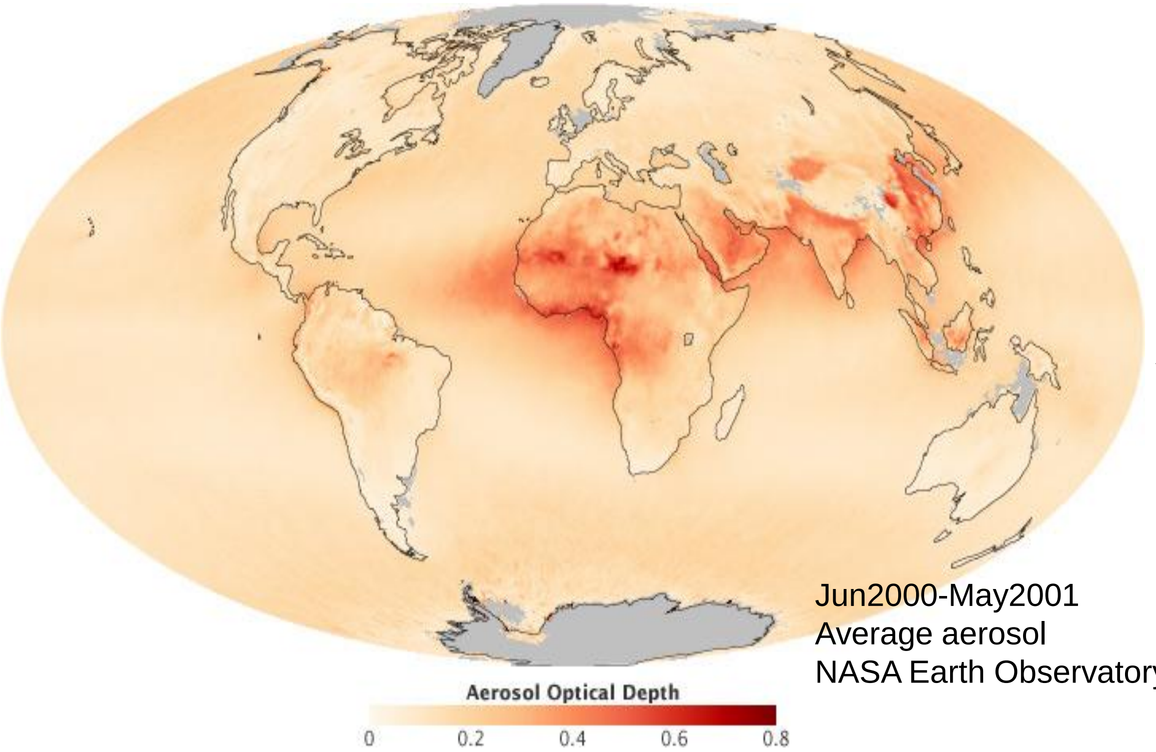
Aerosol is more than dust



Jun2000-May2001
Average aerosol
NASA Earth Observatory

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

HUMAN

Forward fraction=exp(-AOD)

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

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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)

EUMETSAT

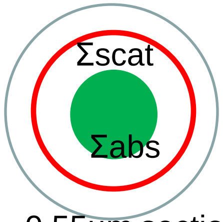
Dust characteristics

- 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.

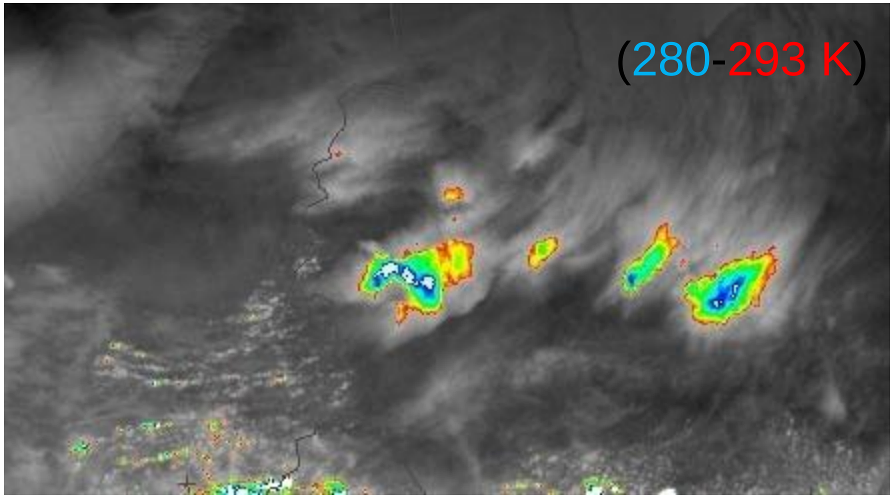
- Dust absorbs and scatters **infrared** radiation in the **Mie** region

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



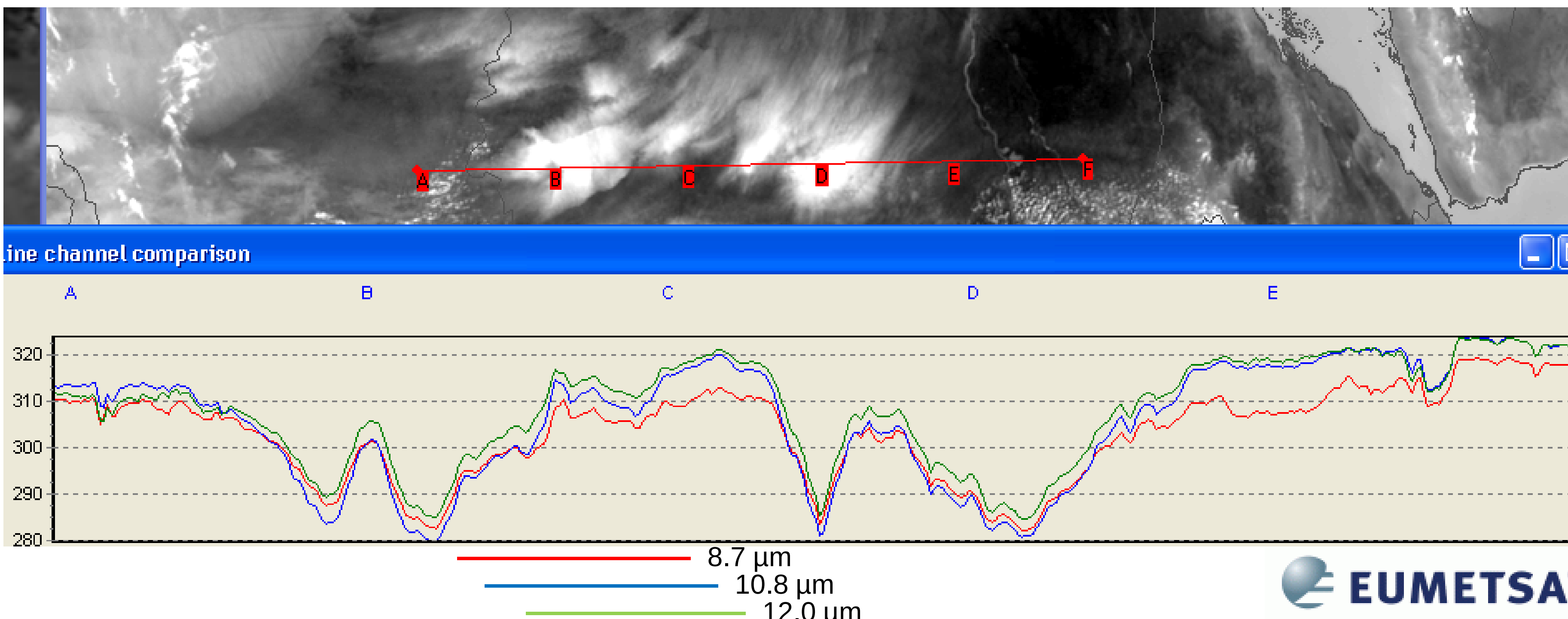
- Dusty air ~ AOD=1 ~ 1 mg/m^3 ~ 1 g/m^2

Dust seen at a single IR channel

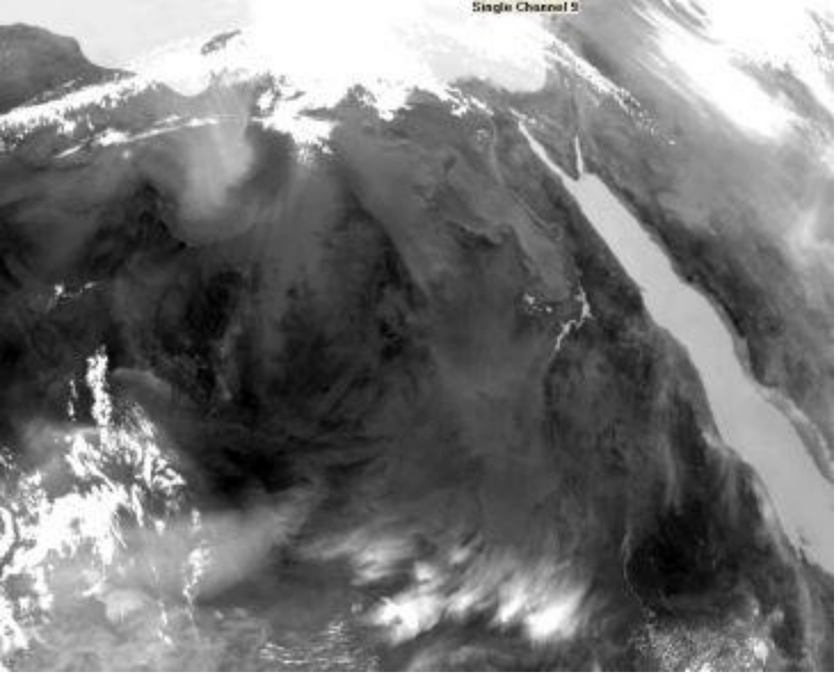


- Variable limits for colour enhancement
- Uncertain nature of the cold area (cloud?)
- Possible mixture of cloud and dust

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

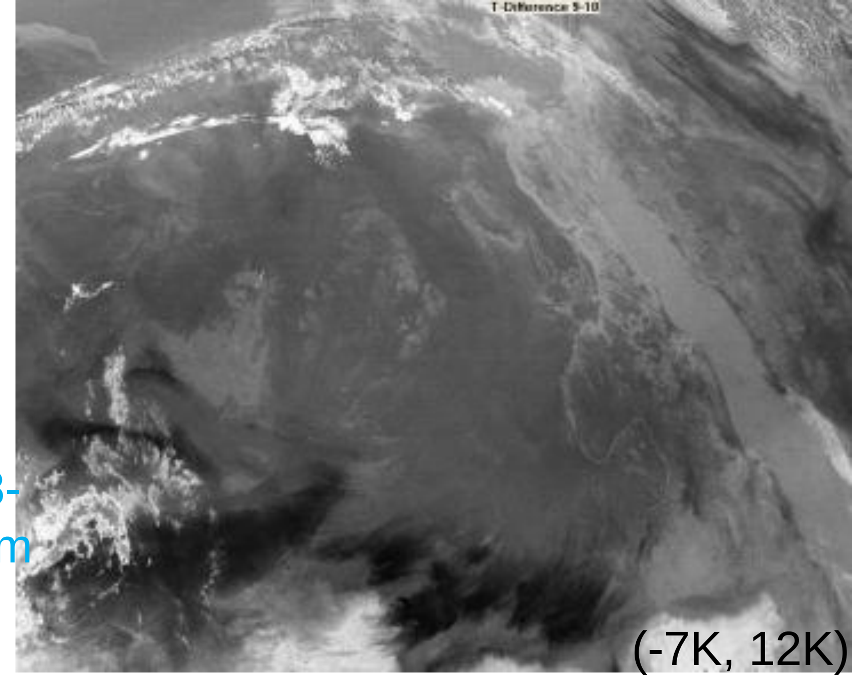


EUMETSAT

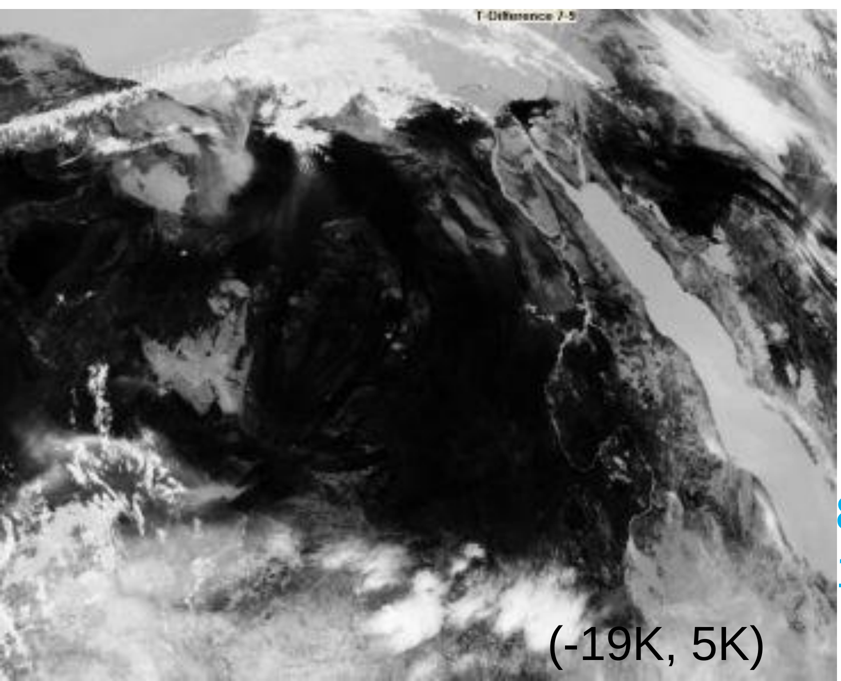


10.8µm

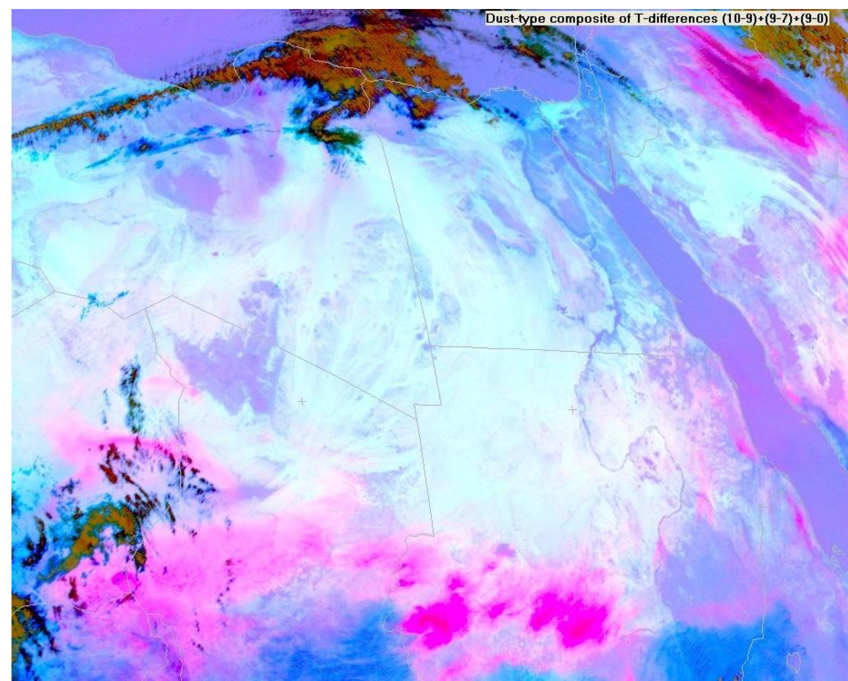
10.8-
12µm



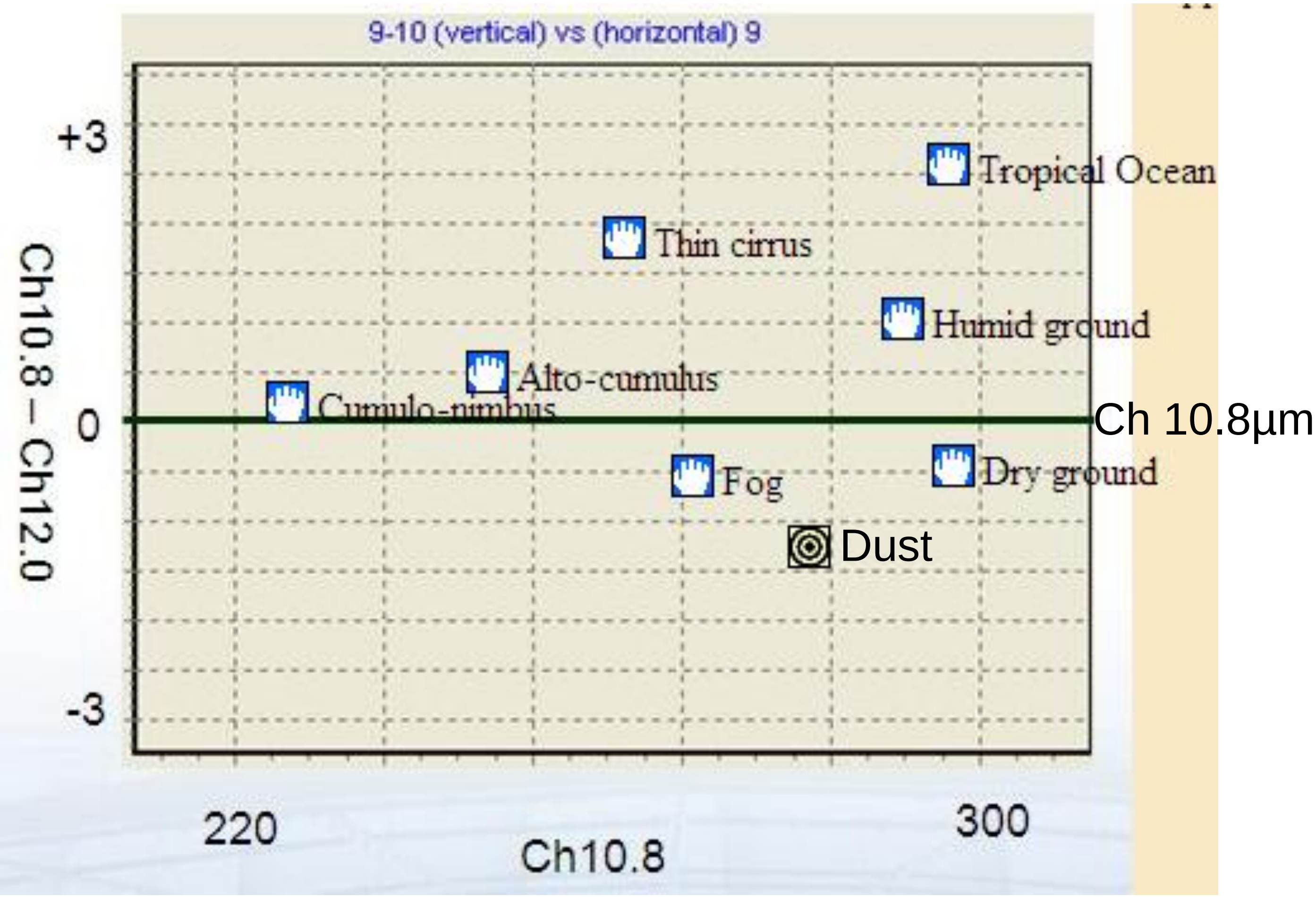
Ch9 (*upper left*), two independent differences, and all together in colour



8.7-
10.8µm



The 10.8µm-12µm difference (vertical)



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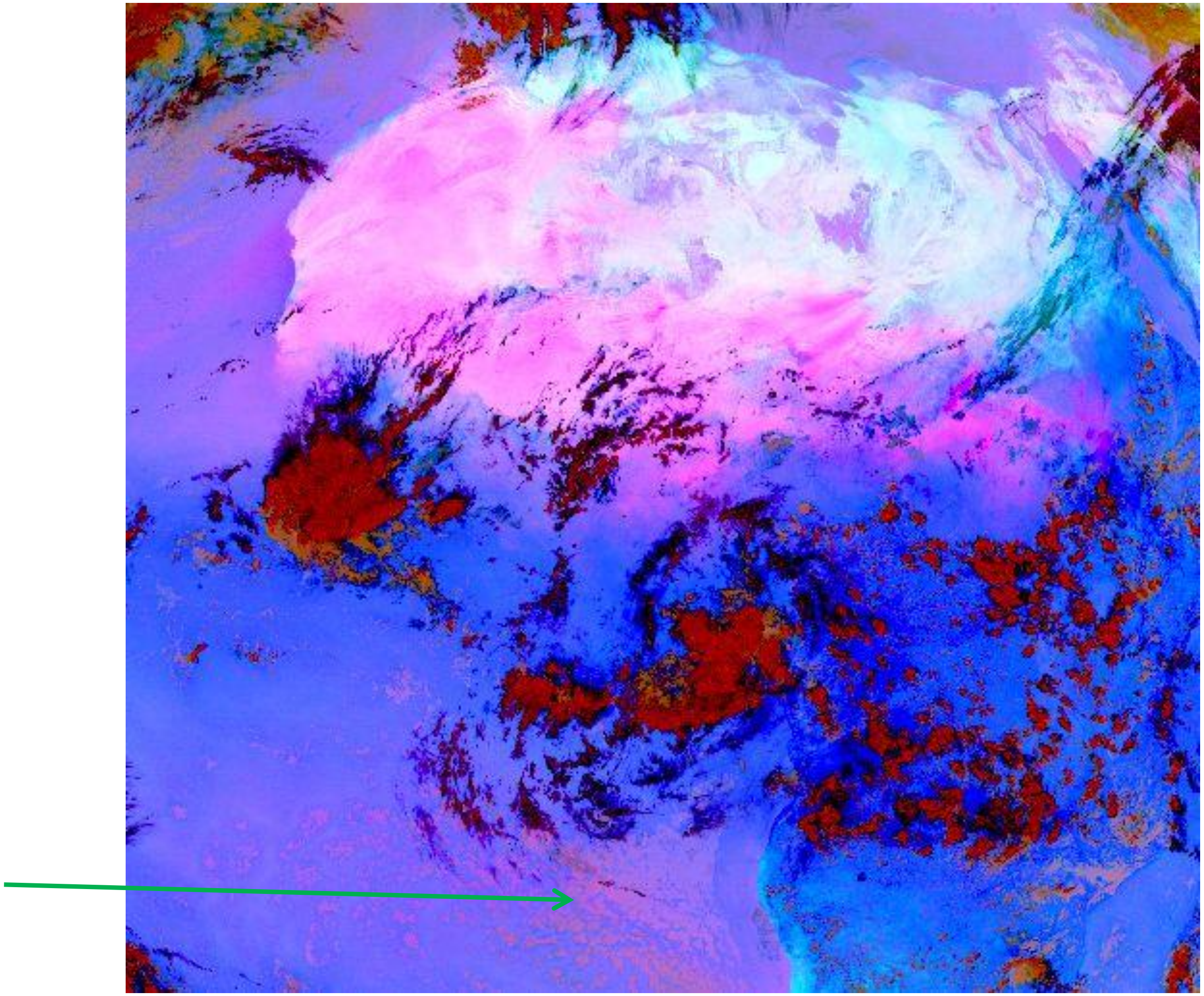
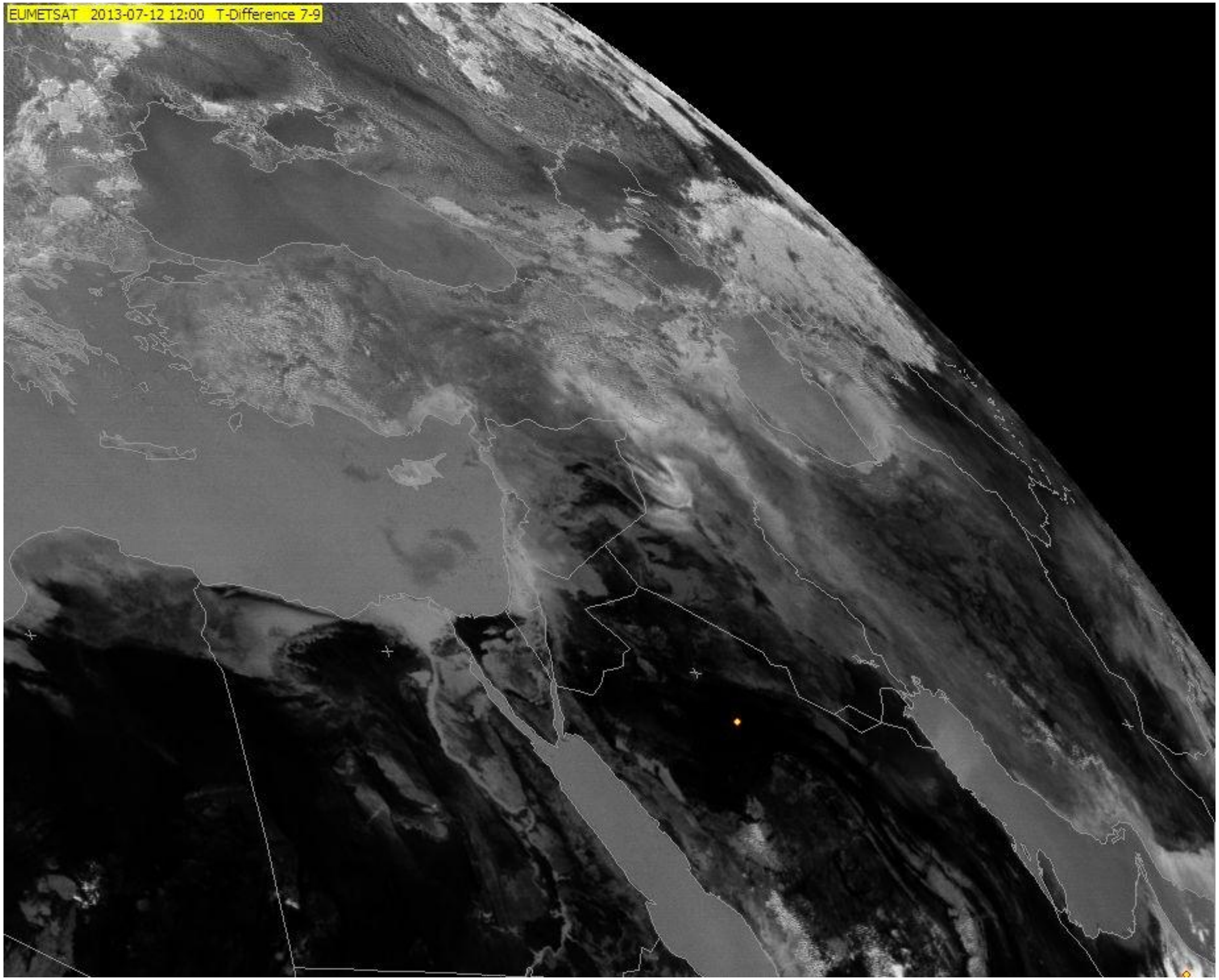
Dust RGB 21 March 2010 12UTC

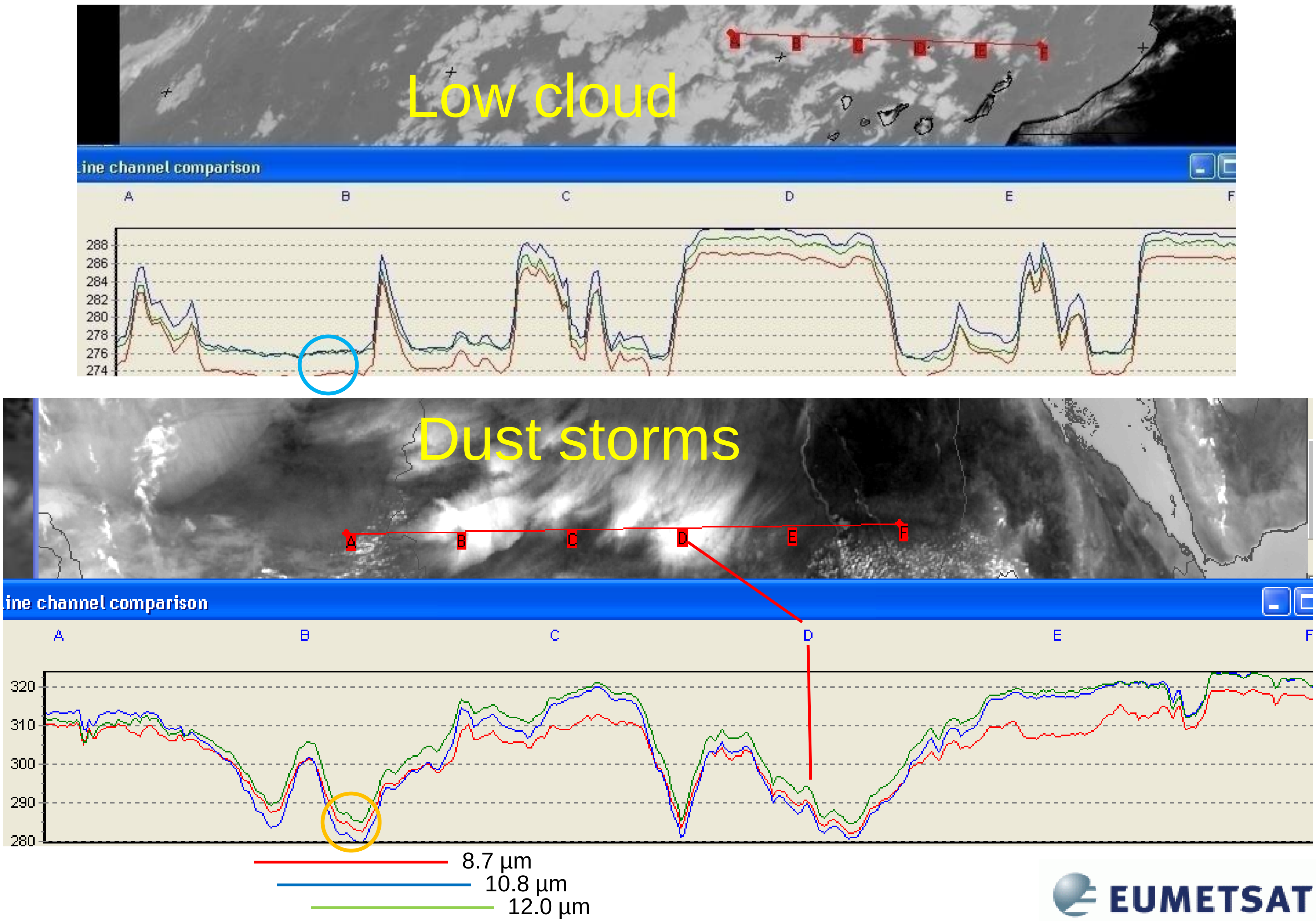


pink is not always dust

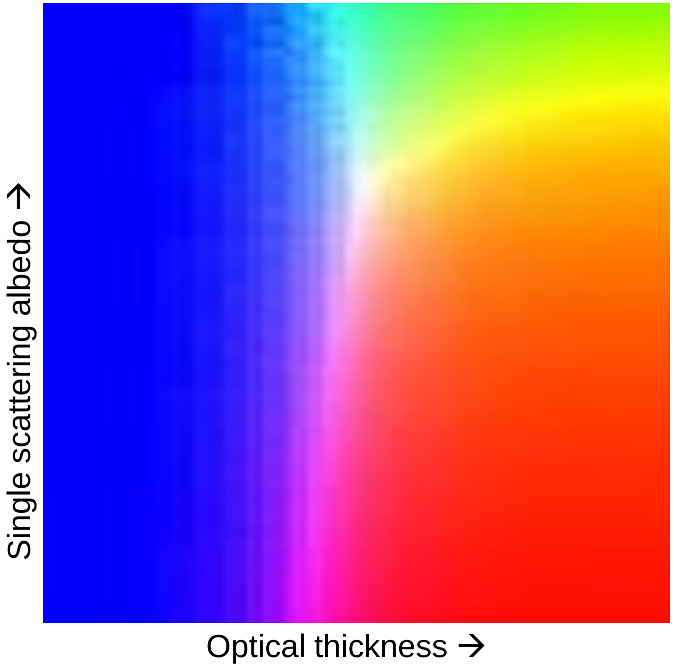


Met-8, 2013 July 12 12UTC, ch9-ch10, ch7-ch9 (-17K to 5K) differences and Dust RGB

Comparison of water cloud and dust in the IR window



Find the colour for each interaction regime

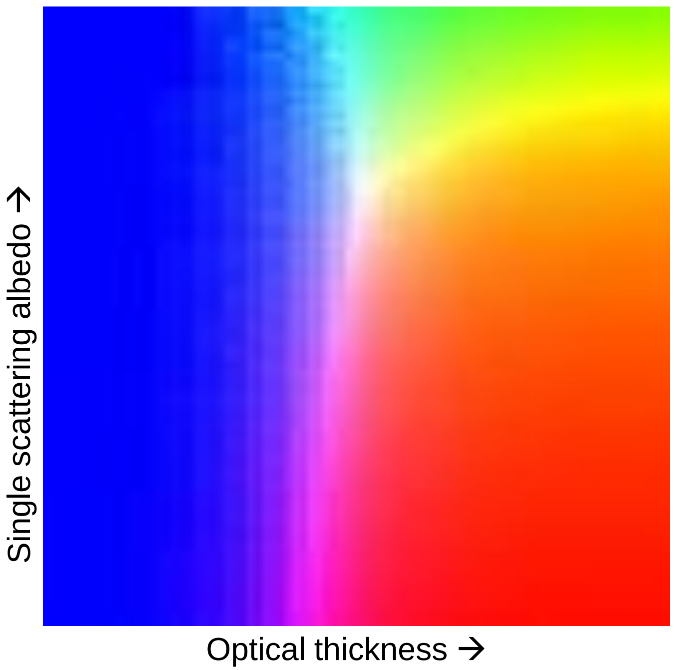


Absorbed

Back scattered

Forward scattered

Find the colour for each interaction regime



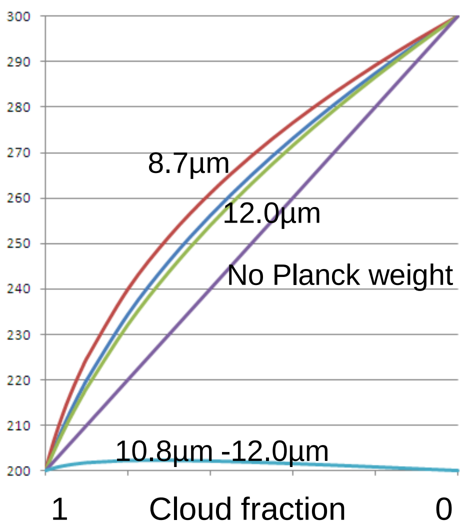
Absorbed

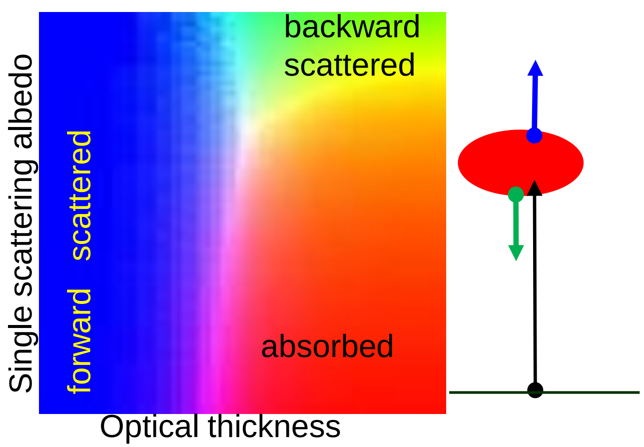
Back scattered

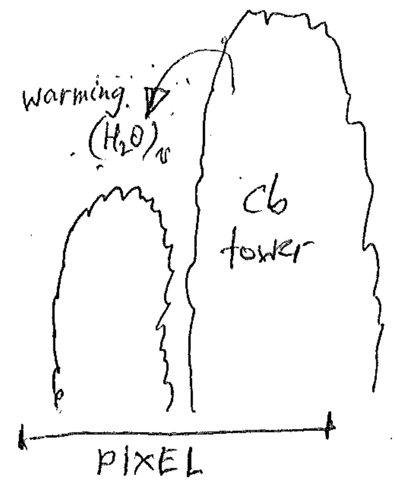
Forward scattered

Channel differences: How do they generate?

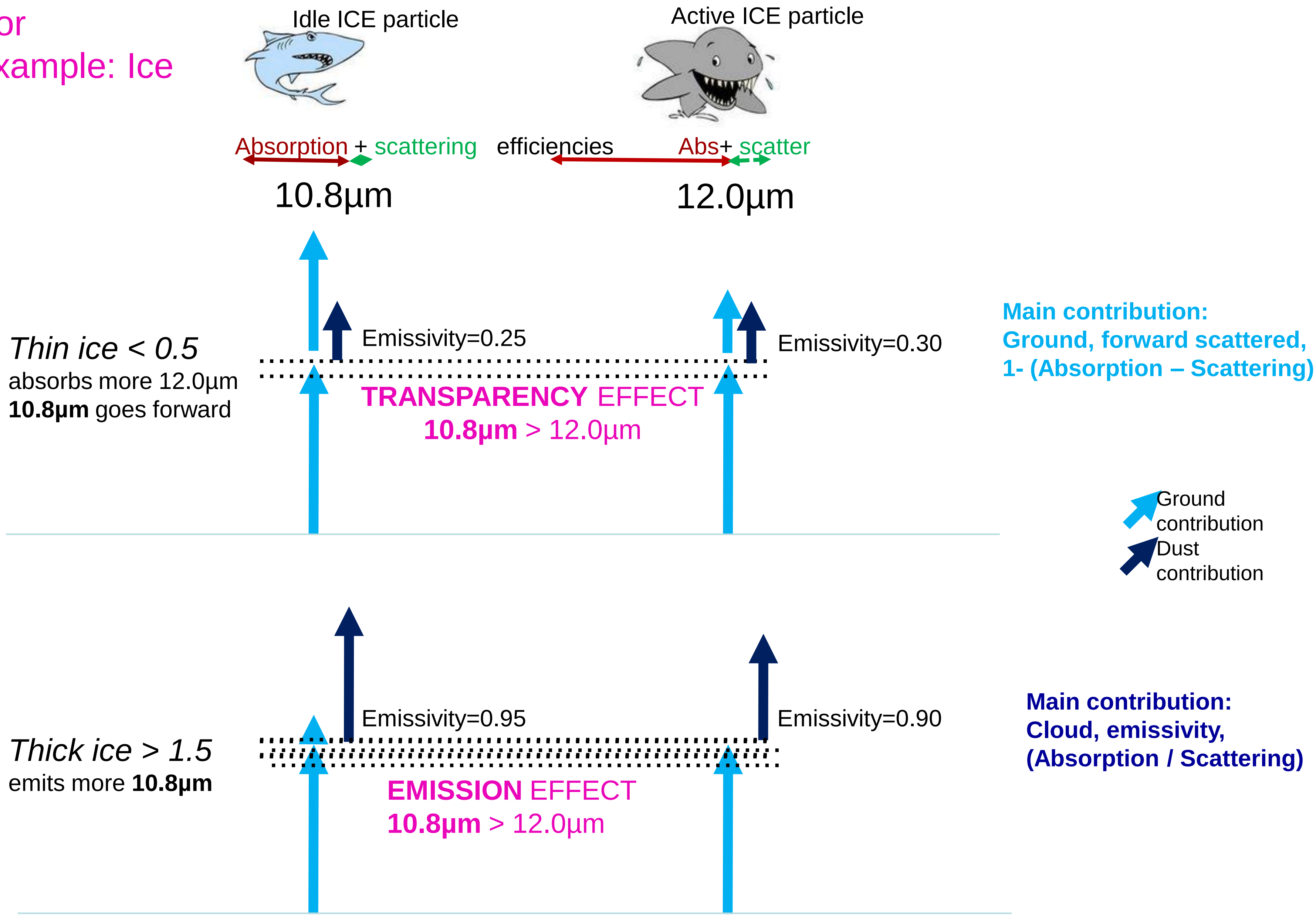
- Emissivity: reduced by *scattering*, increased by **absorption**
- Sub-pixel effect: scene mixture or semi-transparency
- Contribution layer: emission from different depths and temperatures
- Water vapour absorption (thermal inversion above shield cloud,
  adiabatic cooling inside the Cb tower)



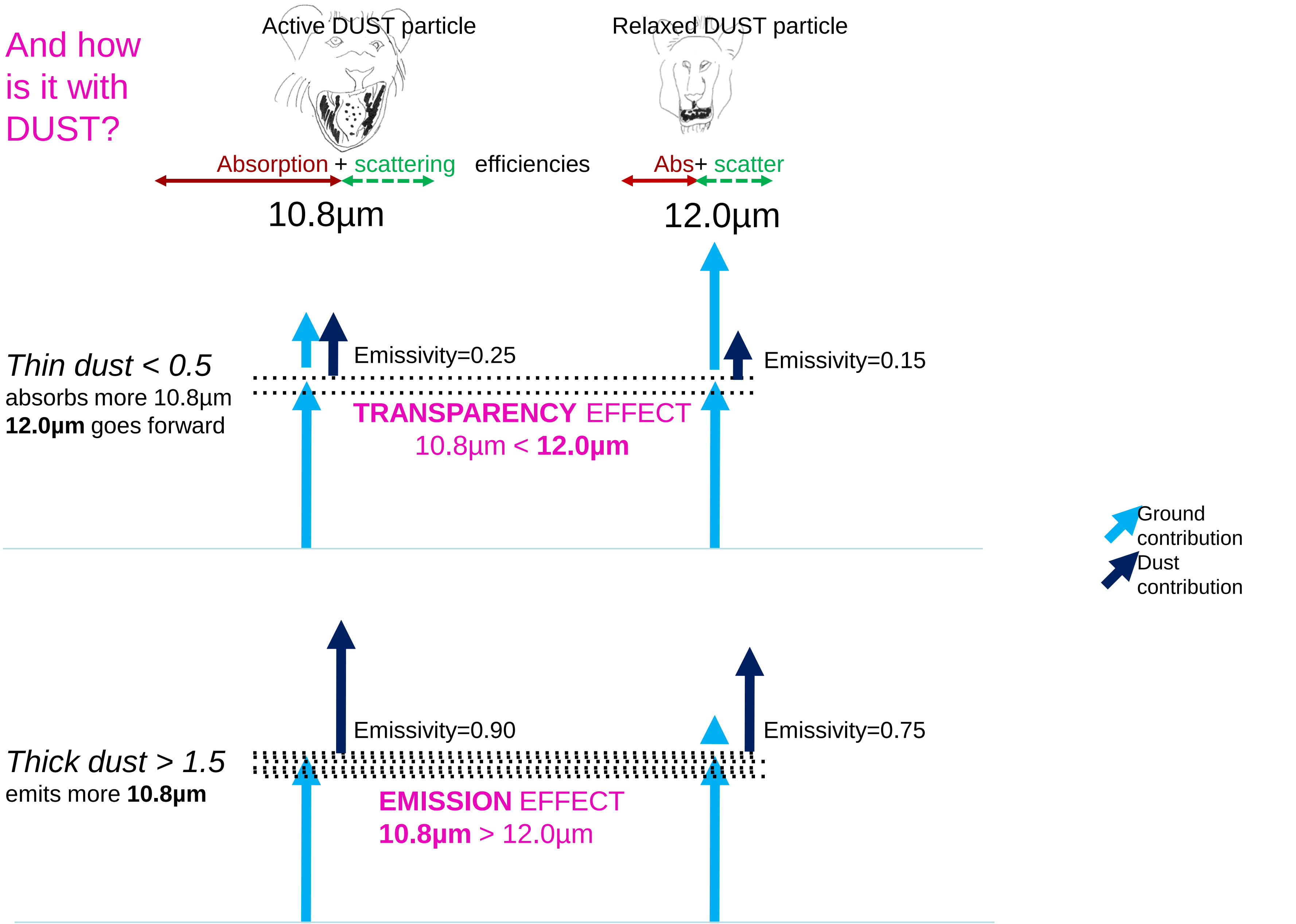




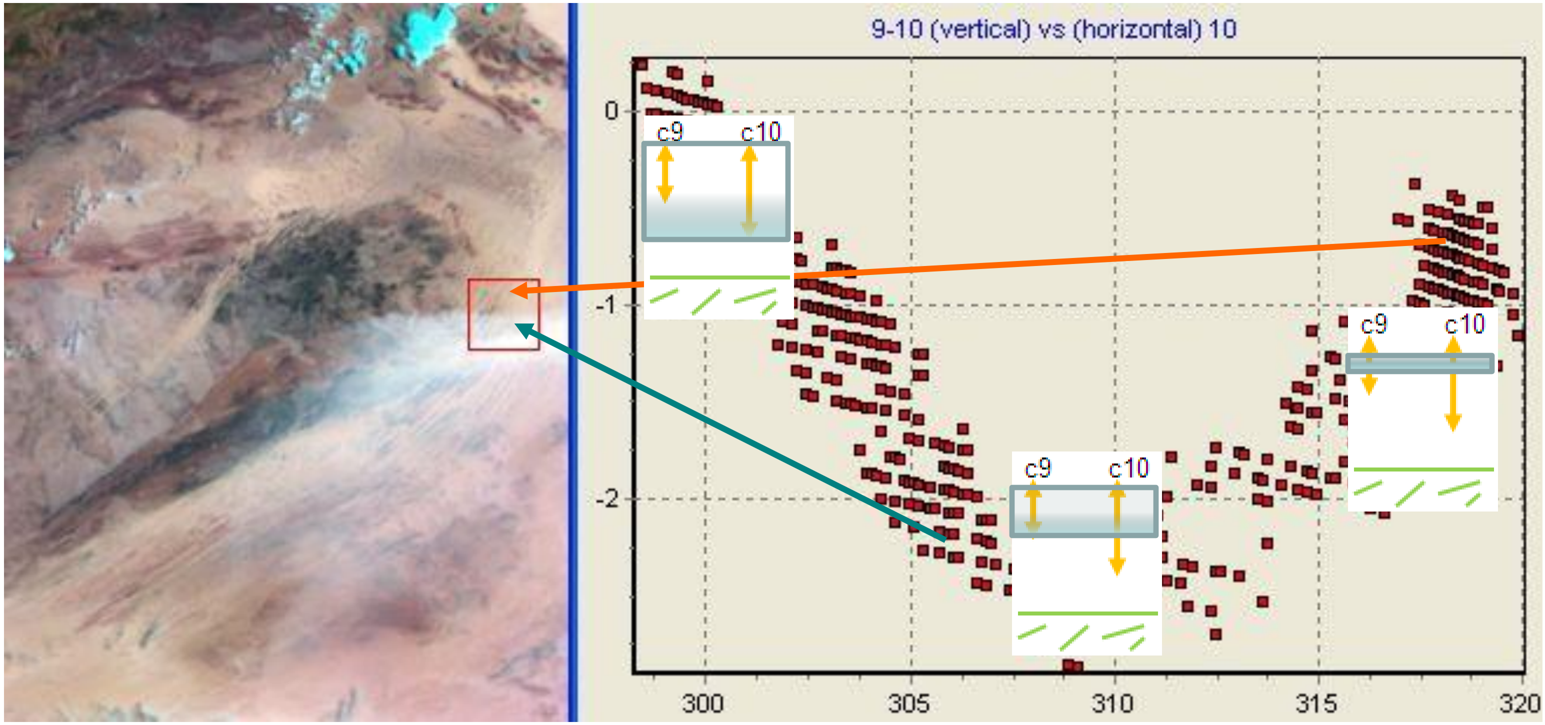
For example: Ice



And how is it with DUST?



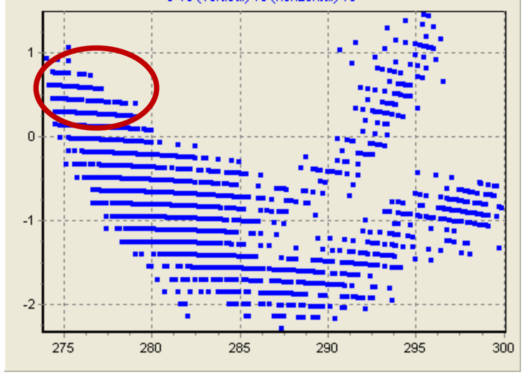
Reversed transparency arc for dust: Ch9-Ch10 versus Ch10



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

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

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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  - Where you learn that life is impossible without water
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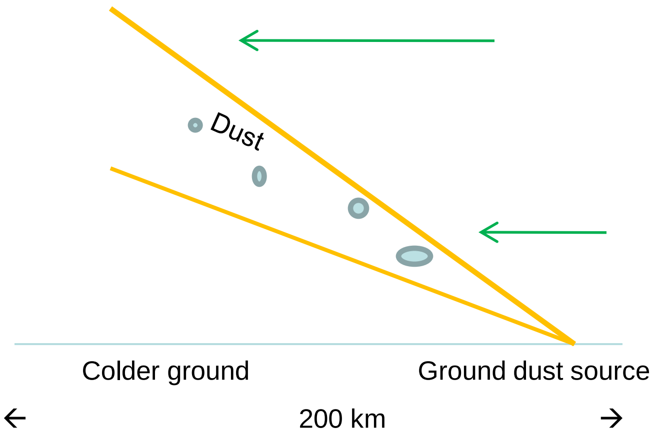
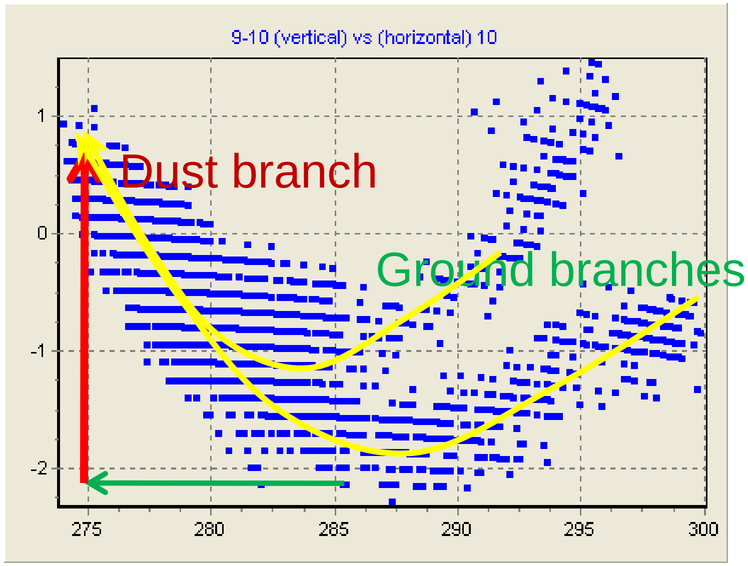
EUMETSAT

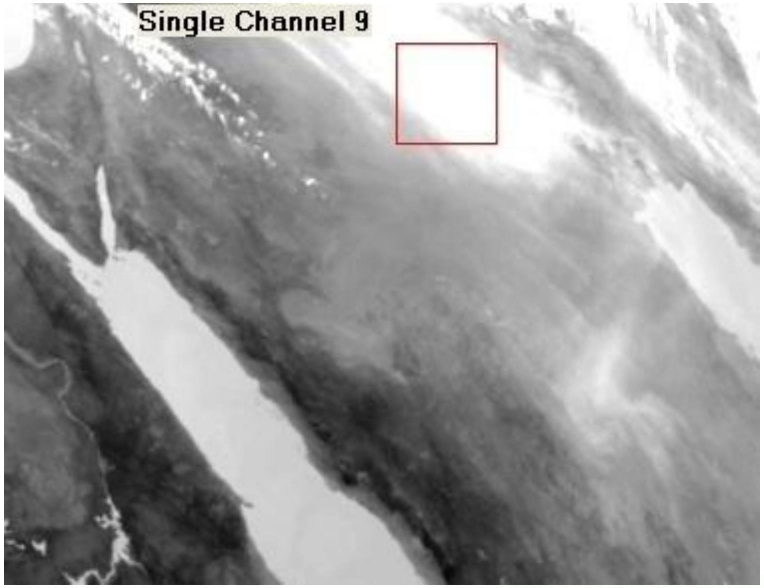
Dust model



- 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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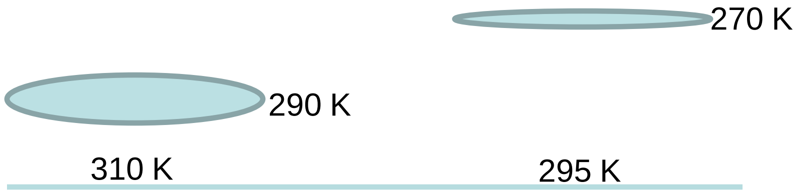
Model assumptions (limitations)

- (32x32 surroundings): min T10.8-T12.0 $<$ *-1.3K*
- Empirical AOT estimates for channel saturation:

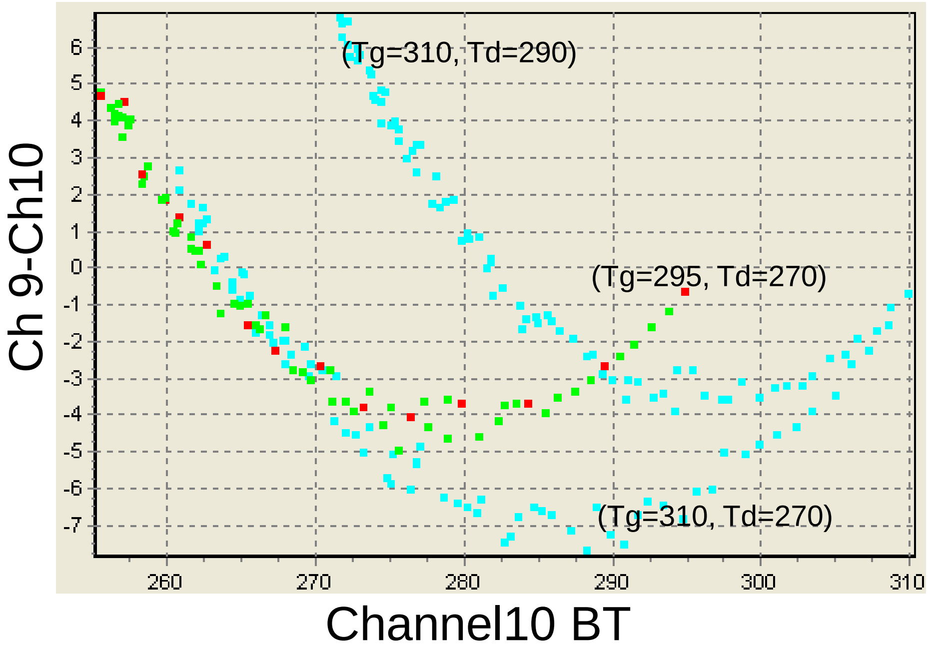
  0.14----1.3----3.5----4.8
- Uniform dust type
- Dust in the pixel at a single height
- Size not dependent on height
- Ground temperature affected by thick dust above
- Good results in areas 200 km across

- 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

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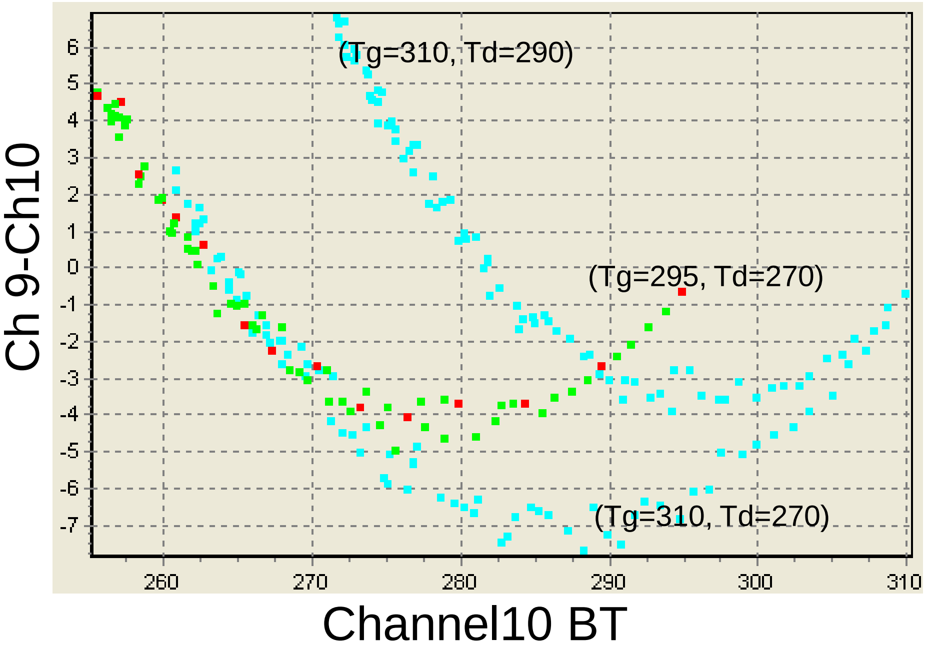
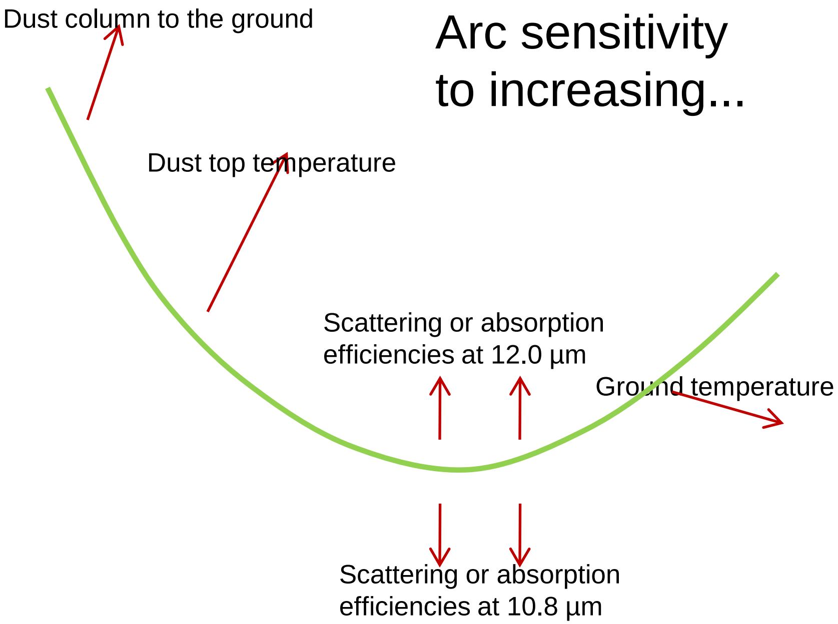
Graphical analysis

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





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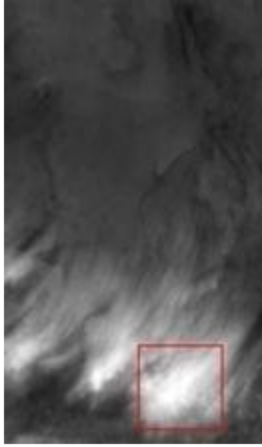
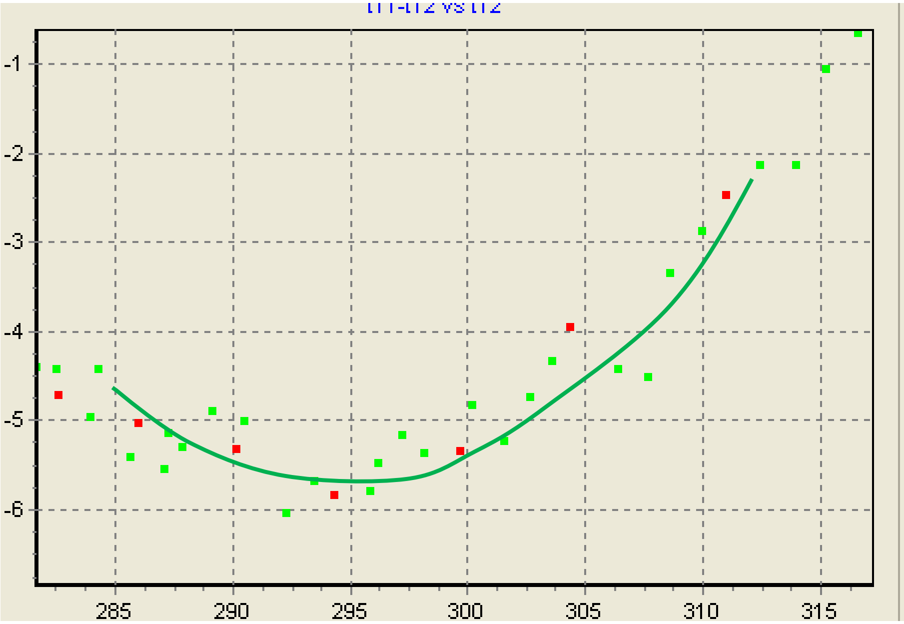
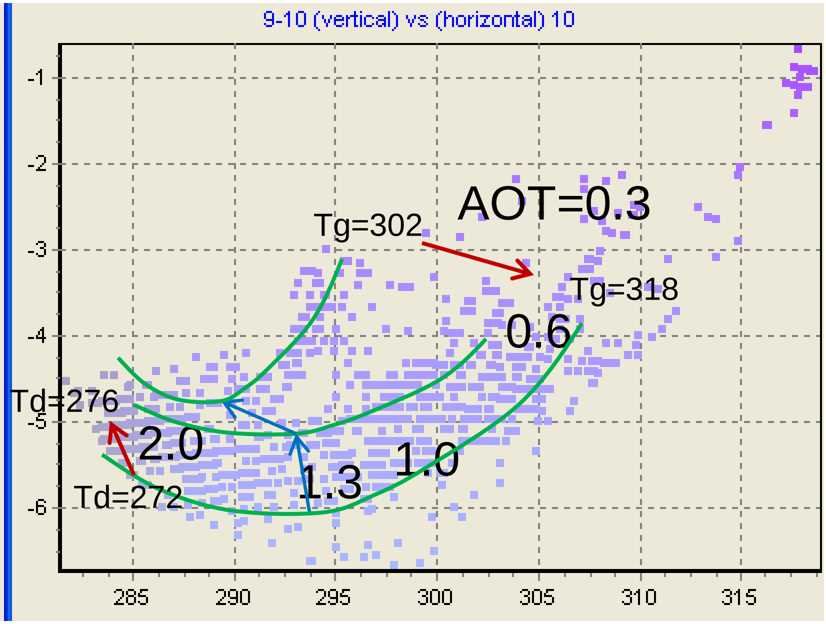
Dust (Td) and ground (Tg) temperatures estimates





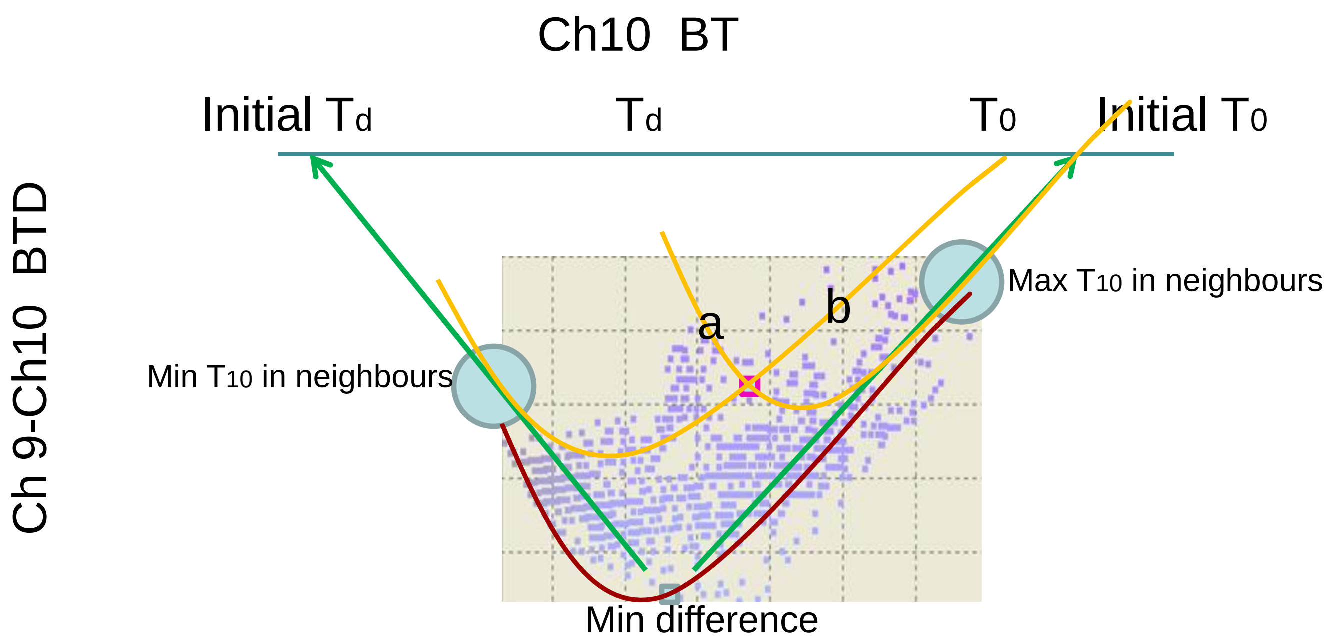


Real (blue dots, right h.s.) compared with simulated (green-red dots left h.s. and lines) scatterograms based on Tg=318 Td=272 Σ11=0.6, 0.3 Σ12=0.2, 0.25

Dust column down to 50% of that temperature difference

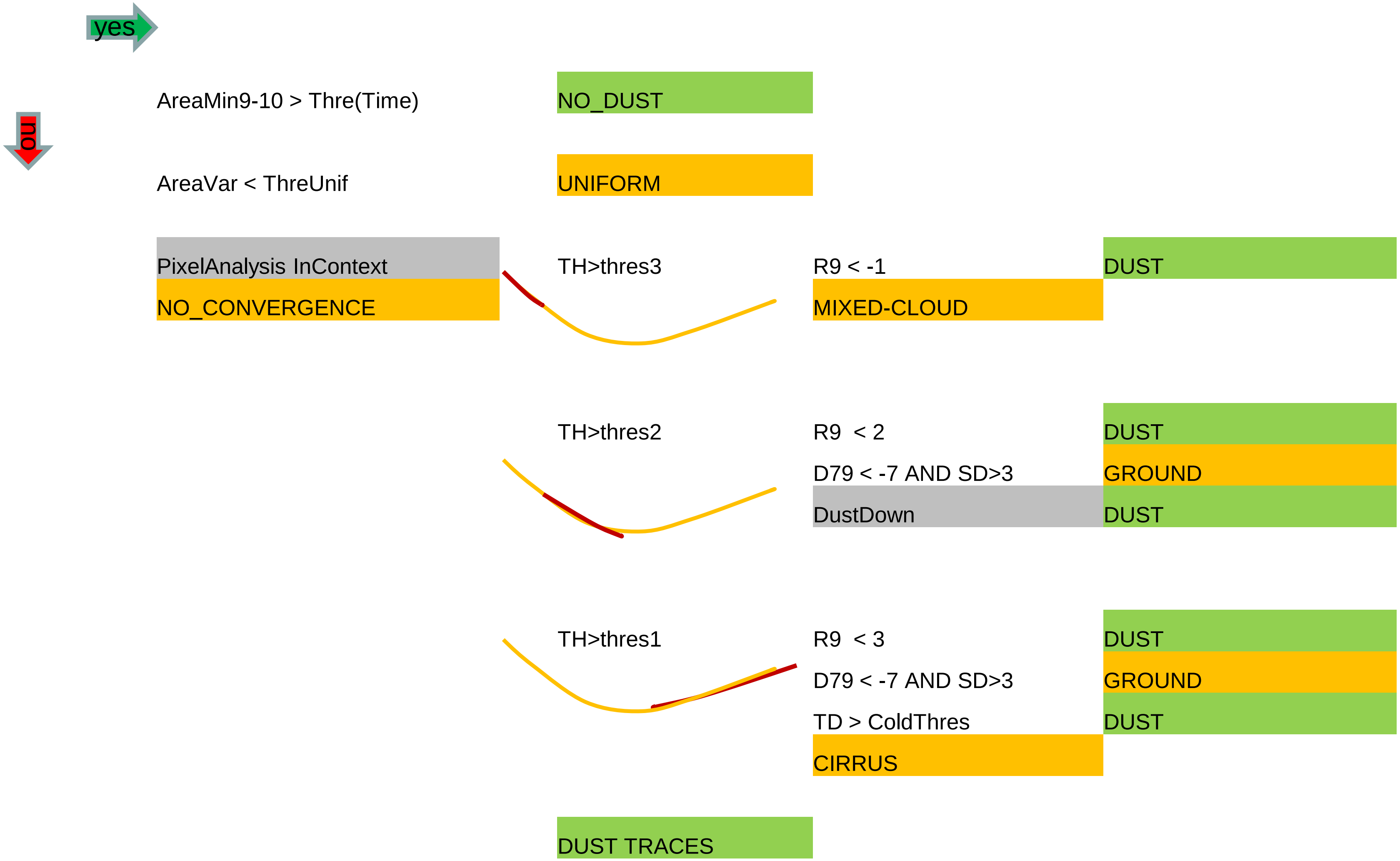
Smaller arcs, higher in the scatterogram, indicate less temperature contrast (Tg – Td)

IR model operation



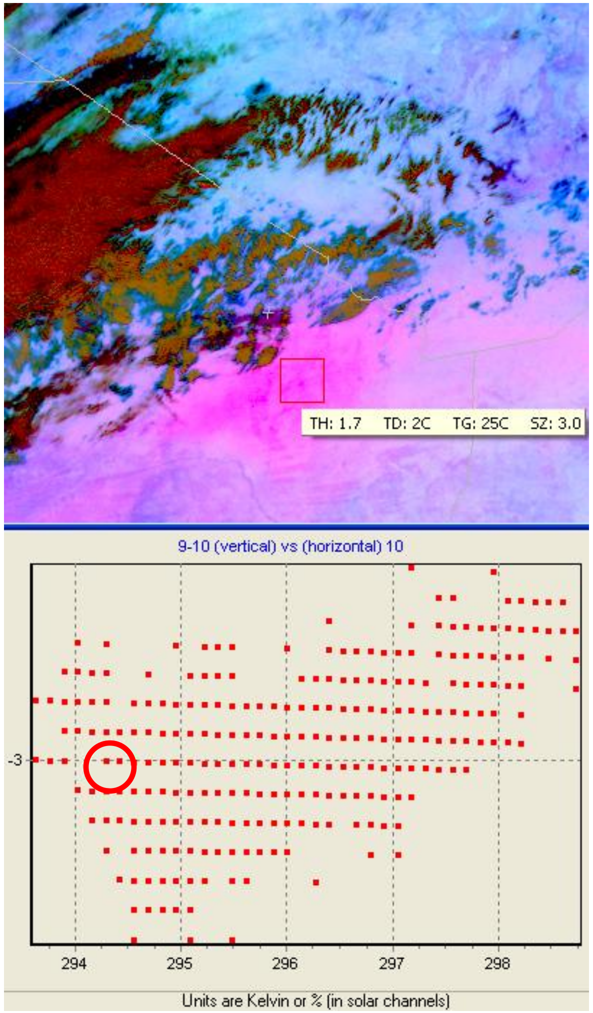
If slope=b, refresh T_0
If slope=a, refresh T_d

Decision tree

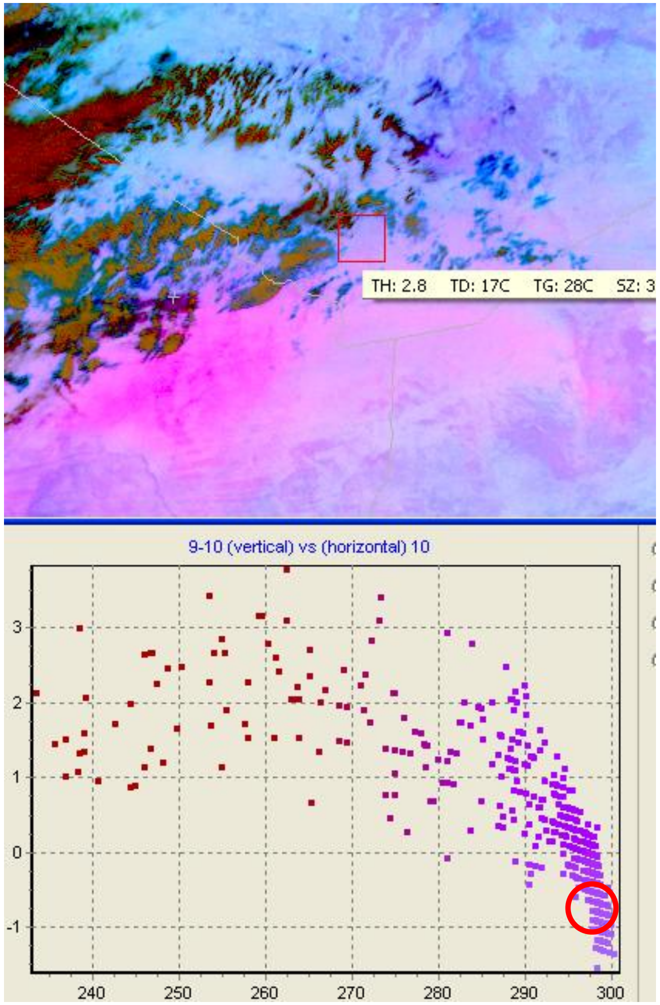


1. Subjective **verification** against masks, images and news media: Done
2. **Verification** from other sources (AERONET, LIDAR): In progress
3. **Inter-comparison** with other methods (Solar): Starting

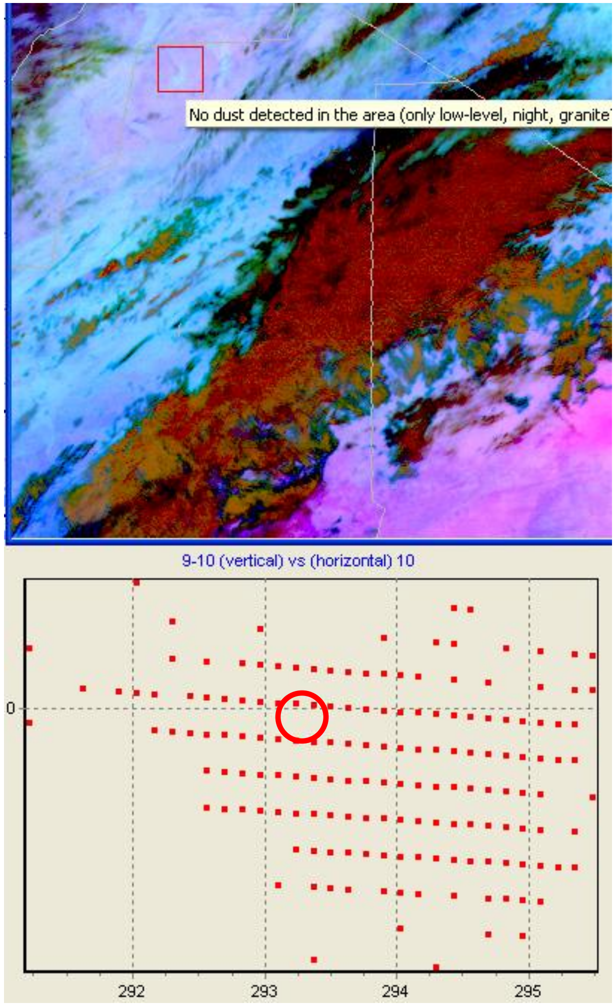
Graphical validation



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



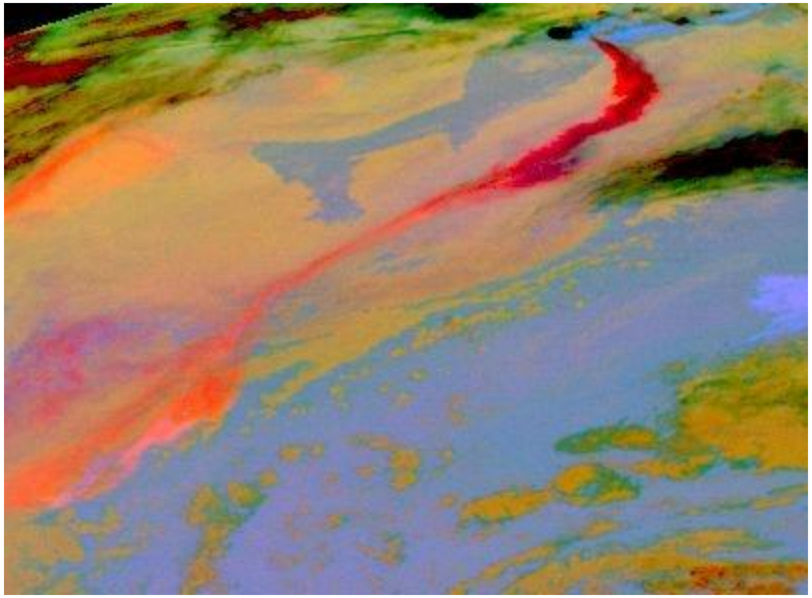
threshold ch9-ch10 < -1.3K
AOT =2.8, too strong depth
Due to location of minimum



threshold NOT < -1.3K
AOT not calculated

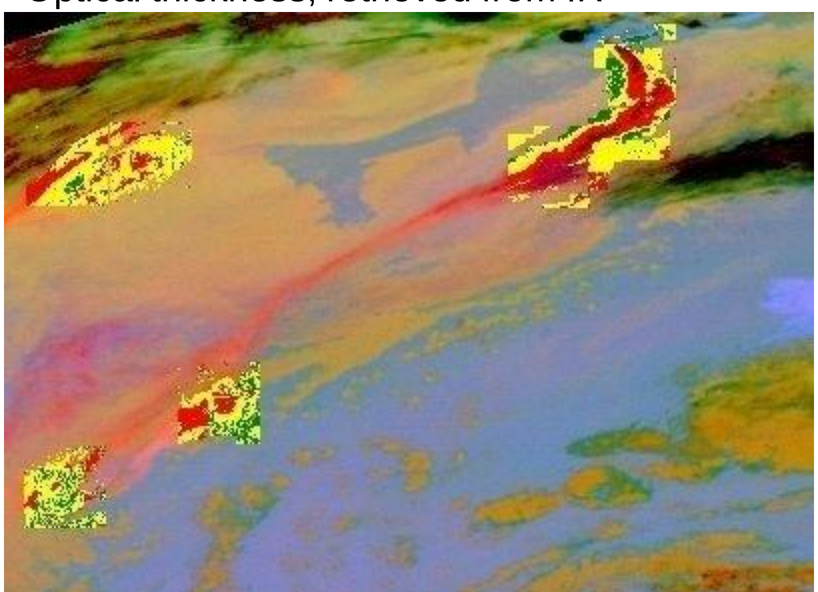
EUMETSAT

Applicable to volcano ash



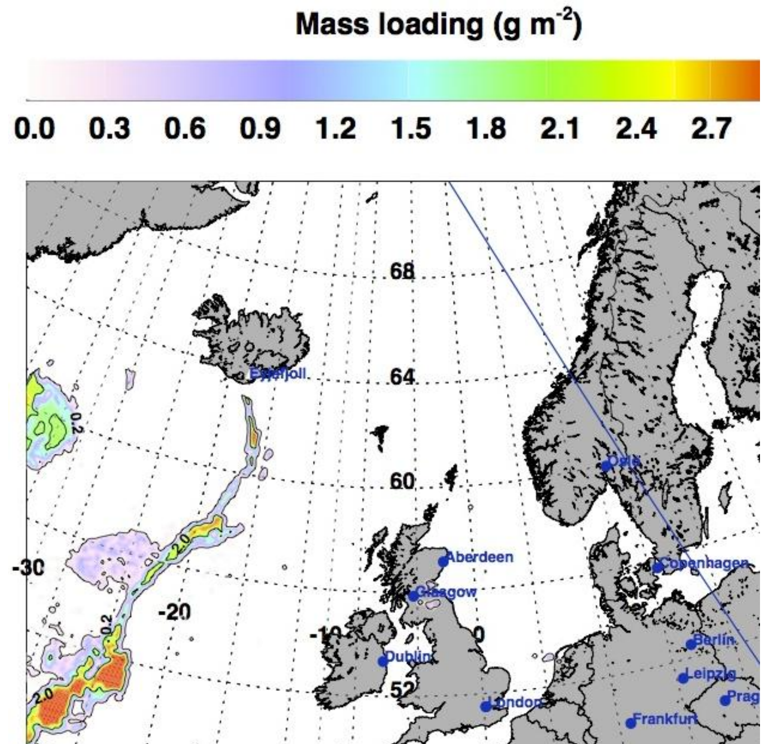
Dust RGB 2010-05-08 12UTC Icelandic ash

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

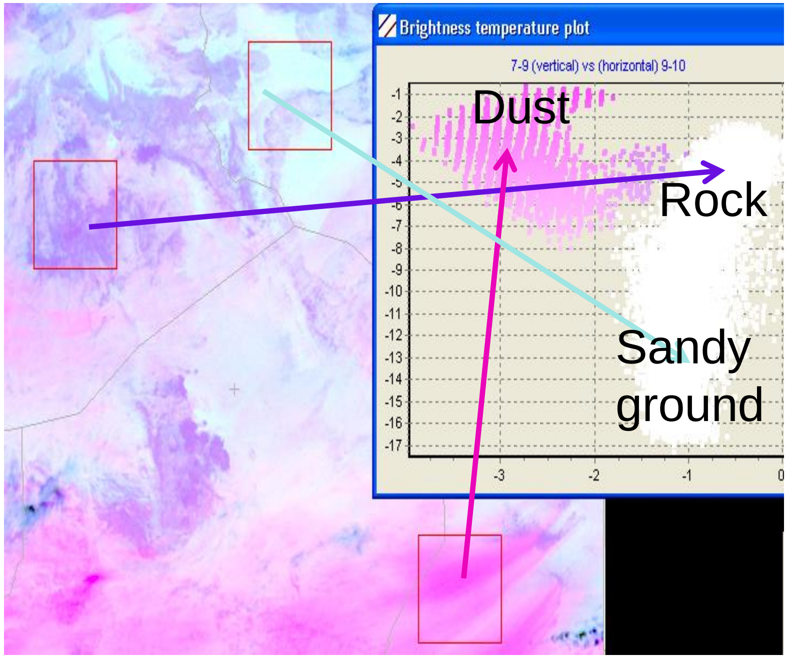
•No direct comparison with mass loading (uncertain ash density estimate)



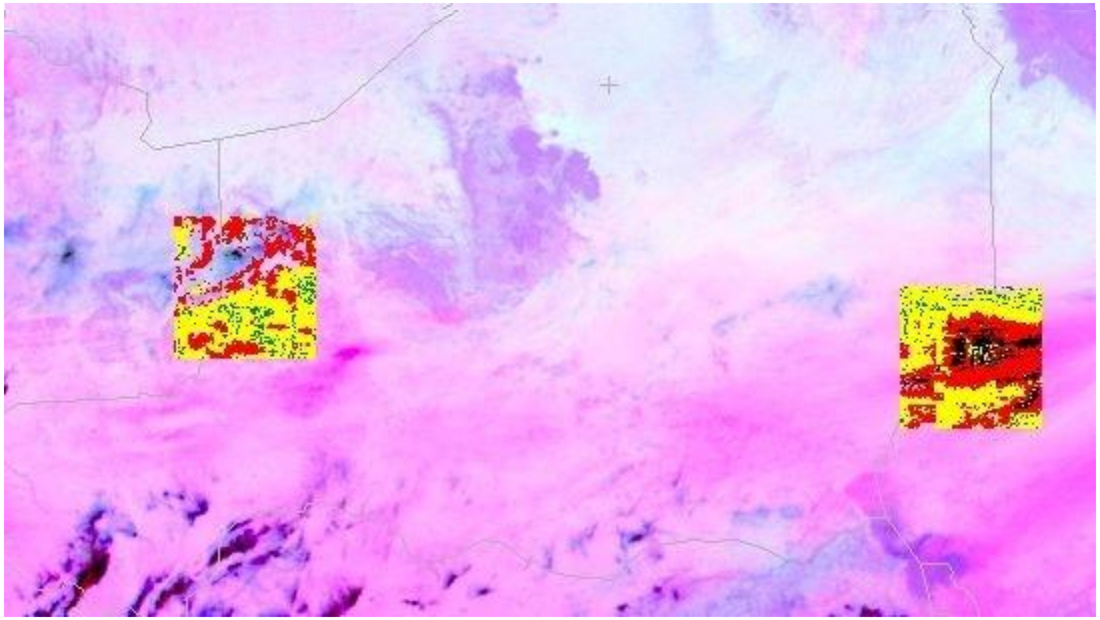
courtesy of F Prata

Ground versus dust skill

IR model does not usually pick on rock or sand areas



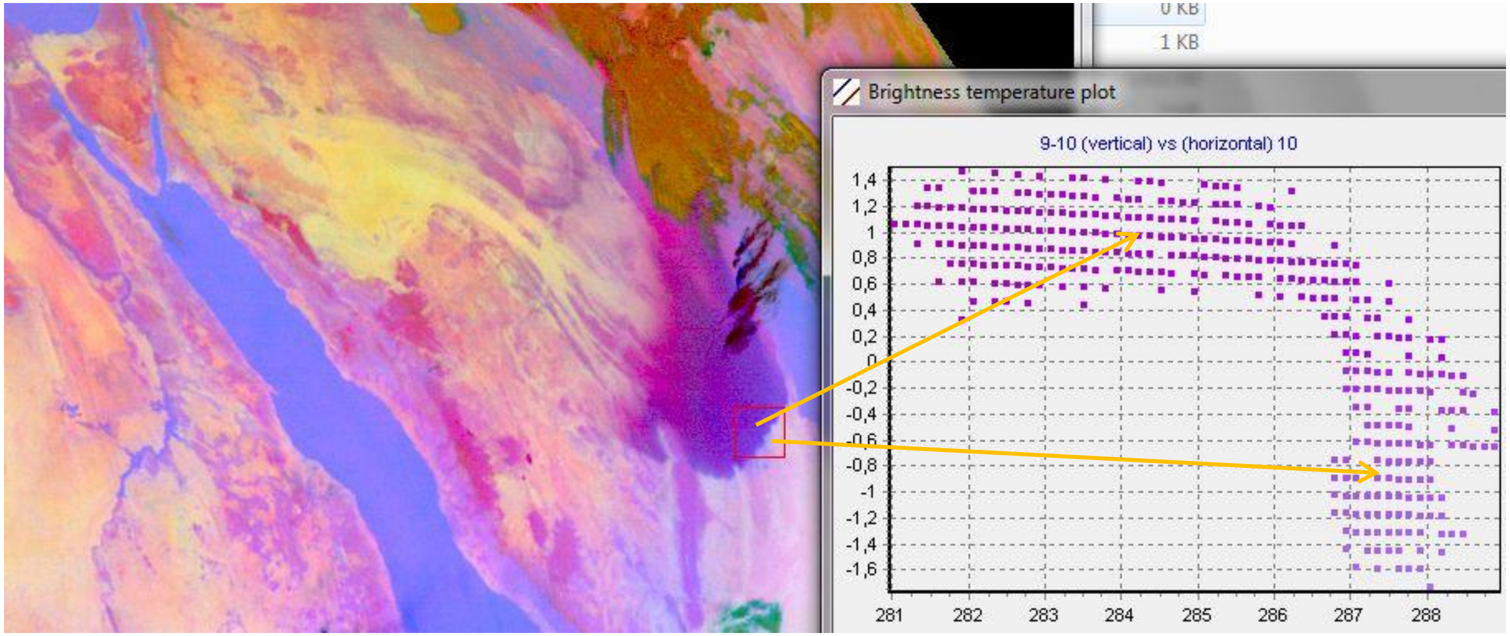
21Mar2010 12UTC Meteosat-9



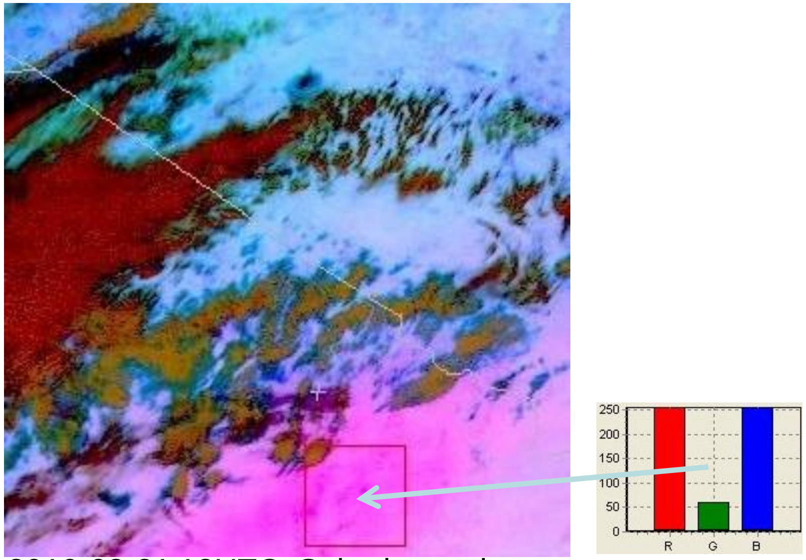
The IR model separates the **dust** areas from the **ground** dry areas

Model fails for atmospheric inversions

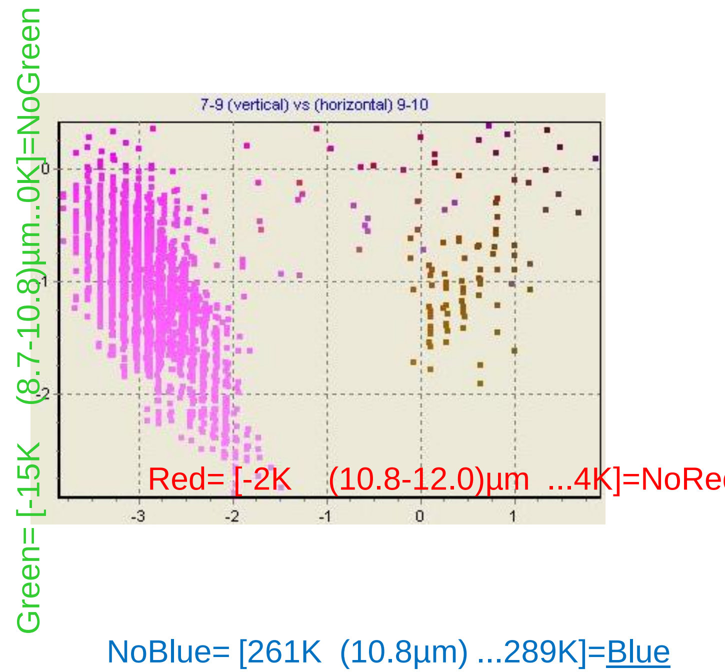
- Occasionally, during night, thermal inversions duct dust at high speed
- Due to the thickness, no negative 10.8µm – 12 µm difference appears above the dust
- However, negative differences appear over clear ground



Dust RGB

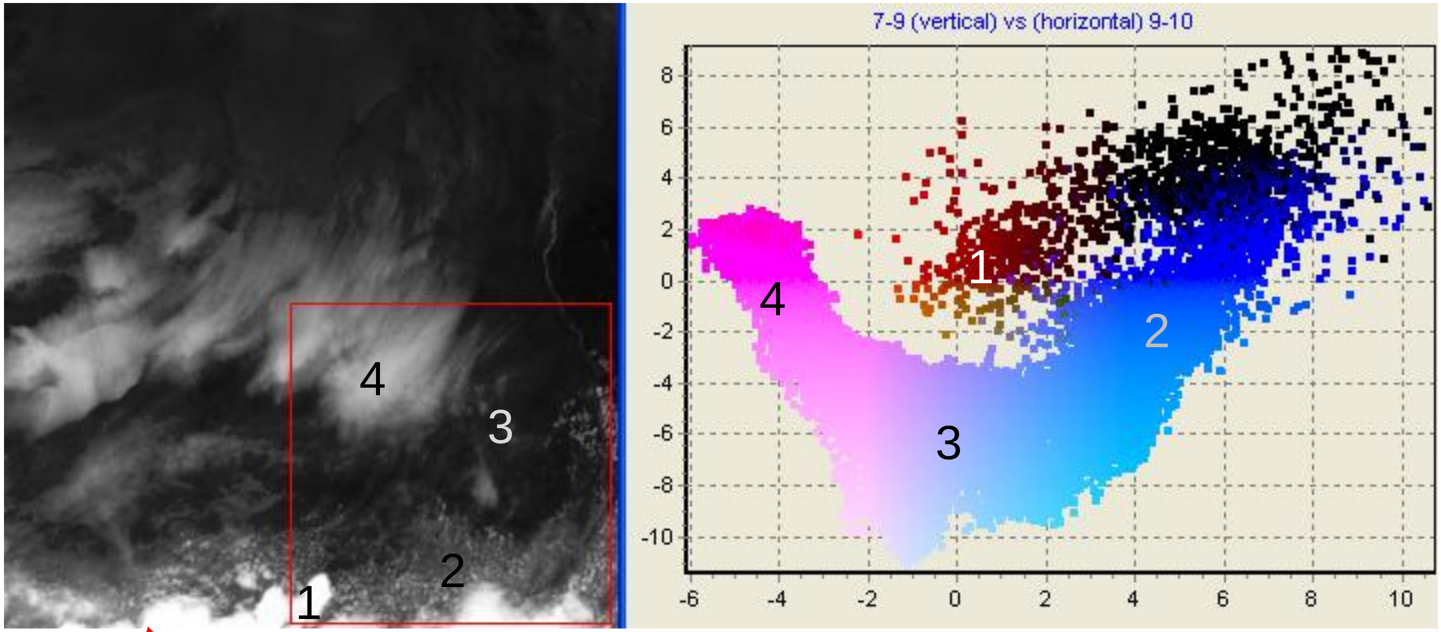


2010-03-21 12UTC, Saharian region

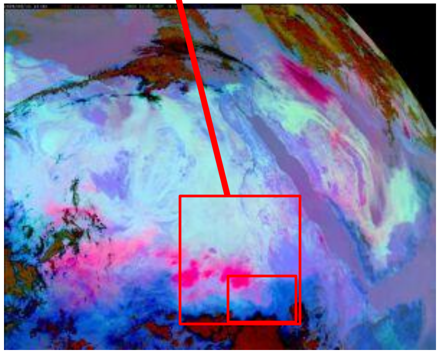


•Magenta areas are typically dusty: neither necessary nor sufficient condition
•Inside **magenta** areas, **darker** (less green) pixels show a smaller difference c7-c9 which means **higher AOD**
•The threshold in the red component (-2K) is exceeded in most pixels of the dust storms.
•Blue component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

The cloud-to-dust spiral in the differences diagram



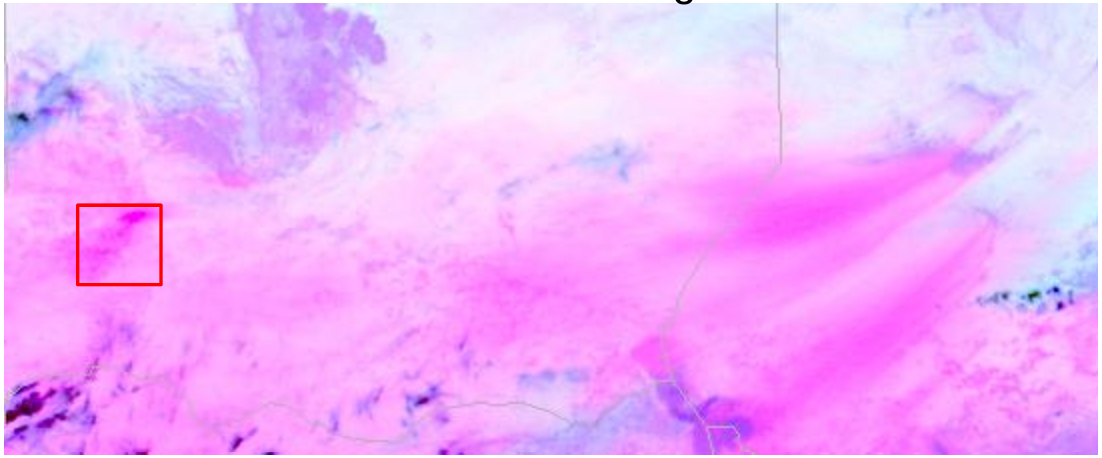
2004-05-13 13:00 UTC, 10.8 µm



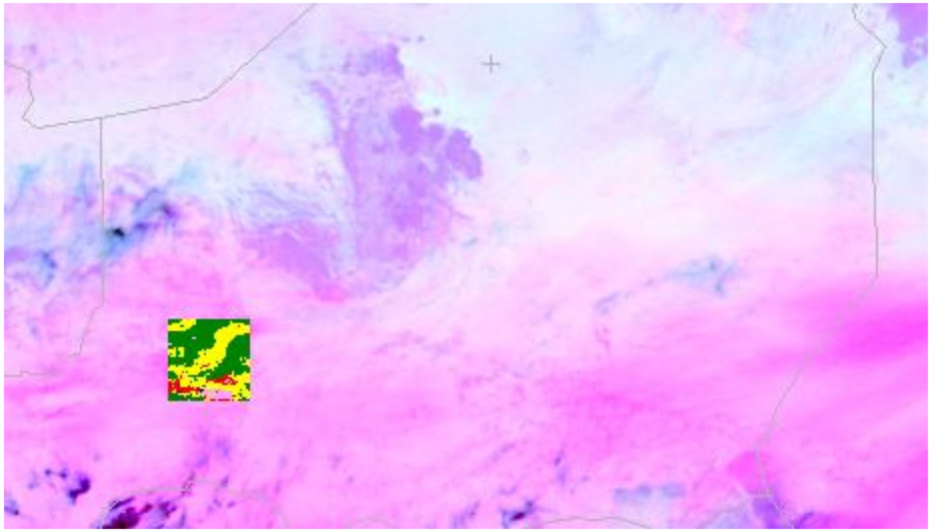
1: Thick high cloud
2: Broken low cloud
3: Ground, drier air towards 4
4: Dust cloud

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)



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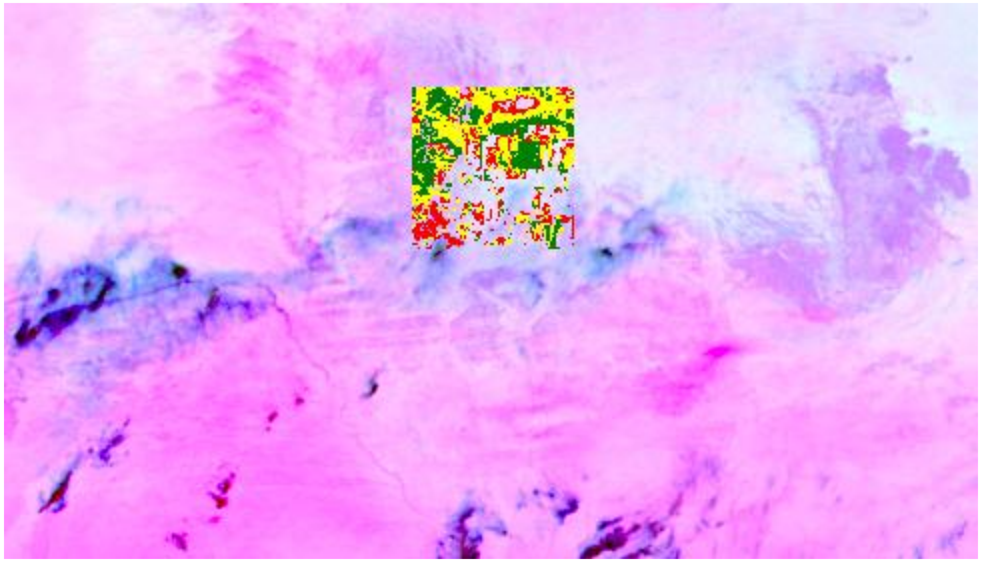
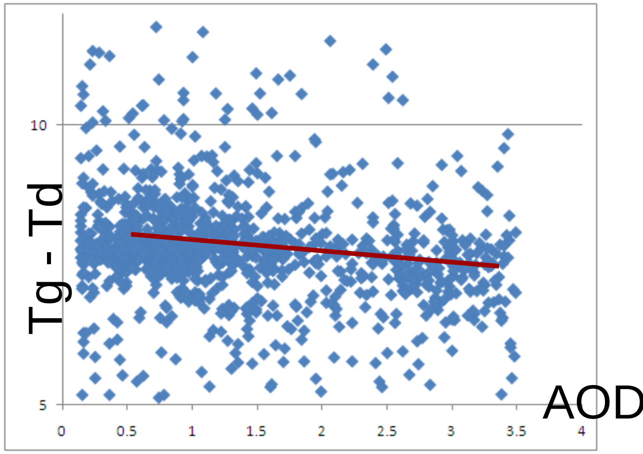
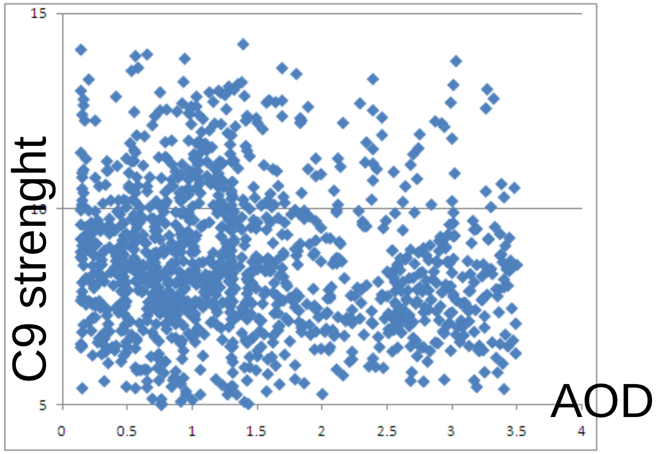
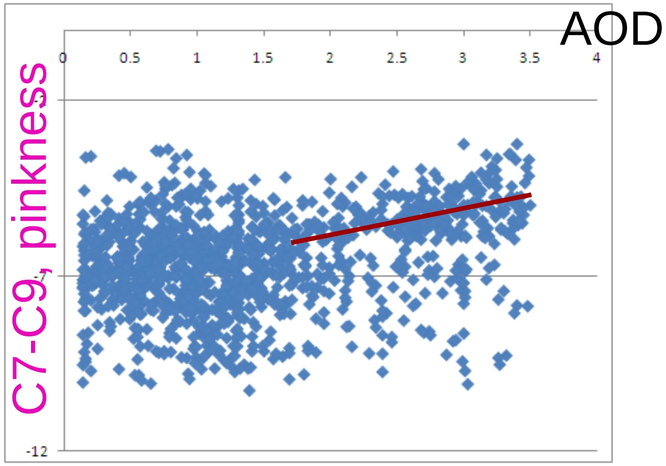
Channel versus model parameter: correlations





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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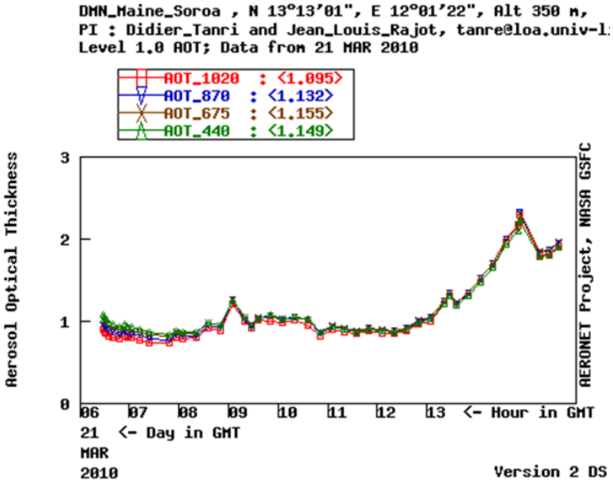
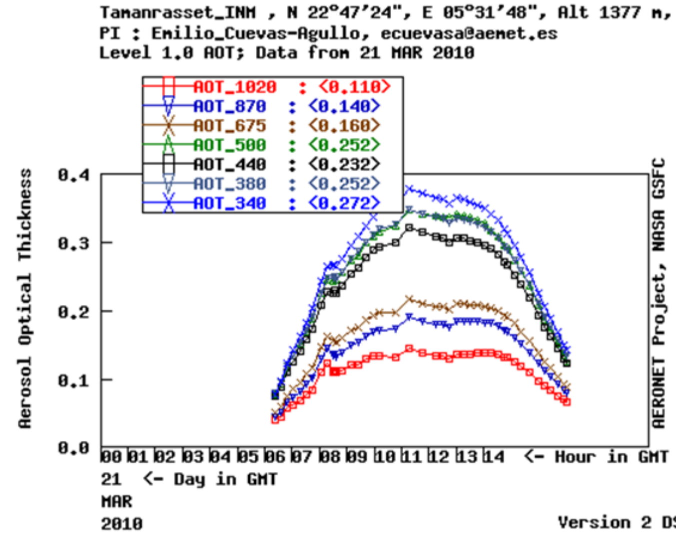
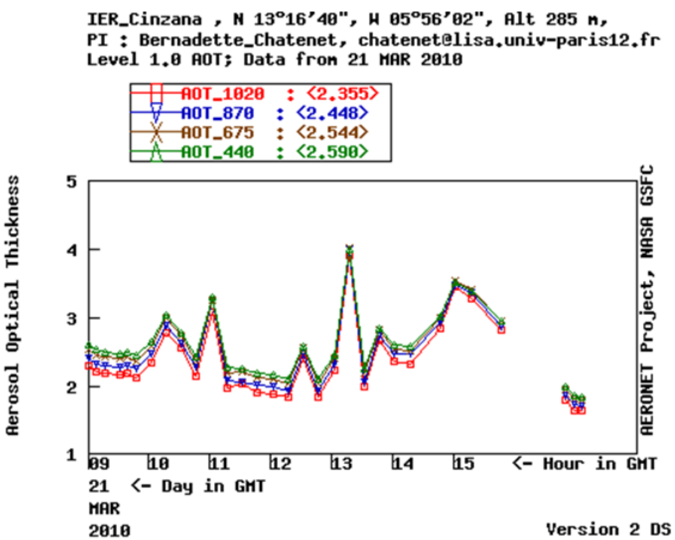


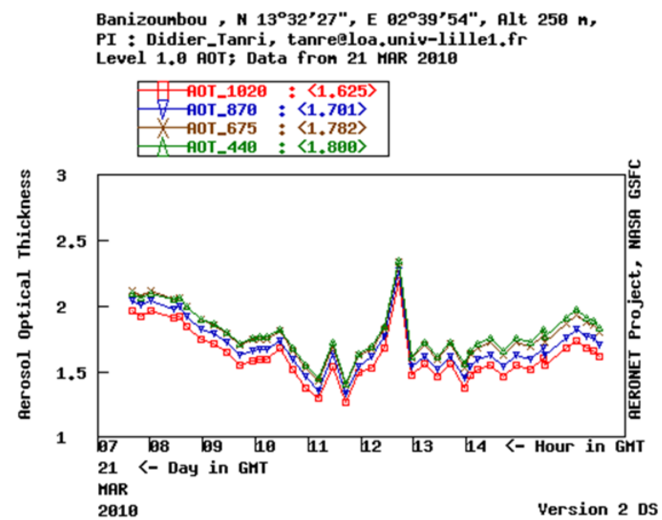
12.02E 13.22N, model on image **at 12UTC**: theta=0.6 31C-39C size=29



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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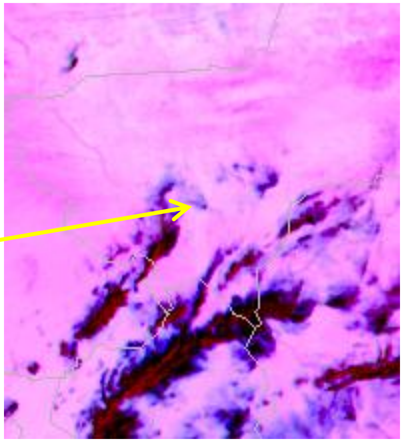
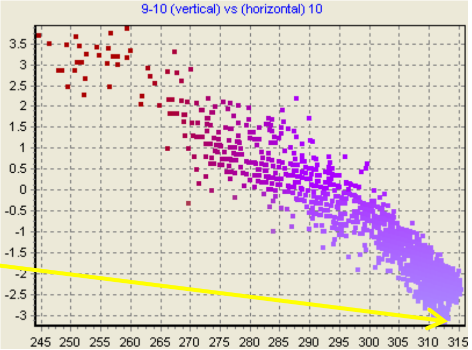
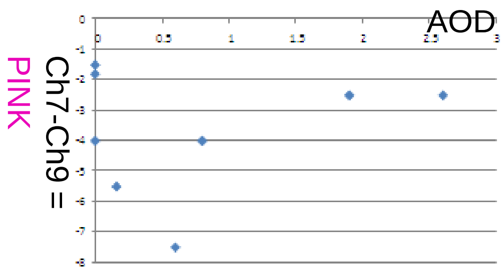
Validation based on ground measurements (AOD units)

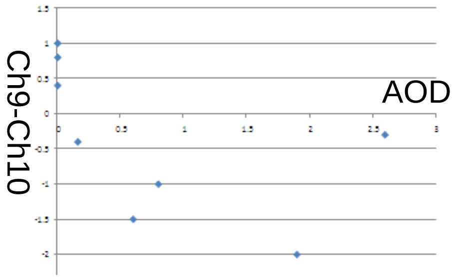
AEROMET	IR-MODEL		
✓ 0.9	0.6	31-39 C	29 µm
✓ 0.35	0.2	40-47 C	31 µm
✓ 2.1	1.9	31-42 C	
❖ 1.6	0.8	33-42 C	14 µm
❖ 0.4	NO DUST (too uniform)		
✓ 0.1	NO DUST		
✓ 1.7	2.6	30-38 C	
✓ 0.03	NO DUST		





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





SAMPLE VALIDATION

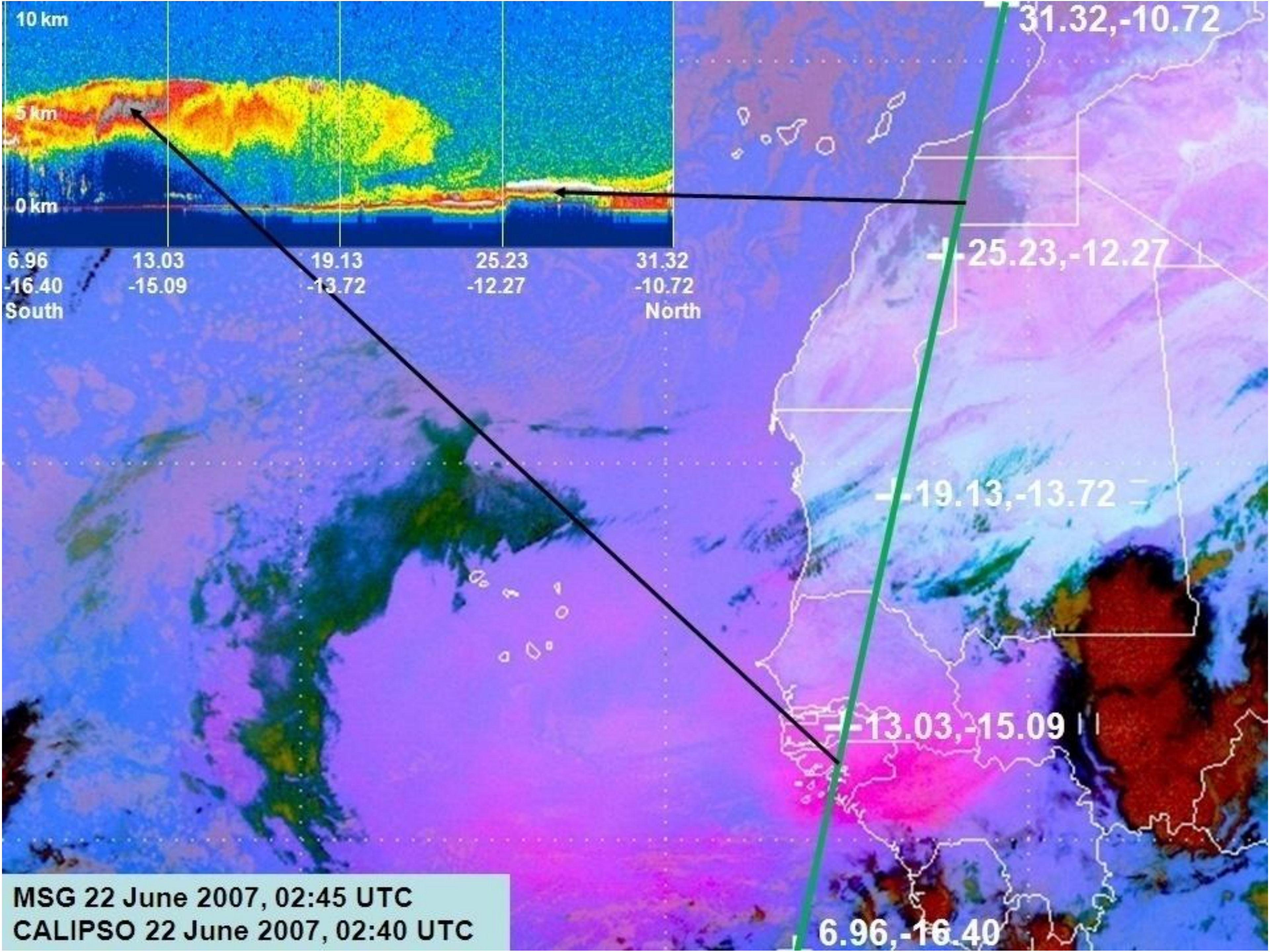
based on AERONET ground measurements

- 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

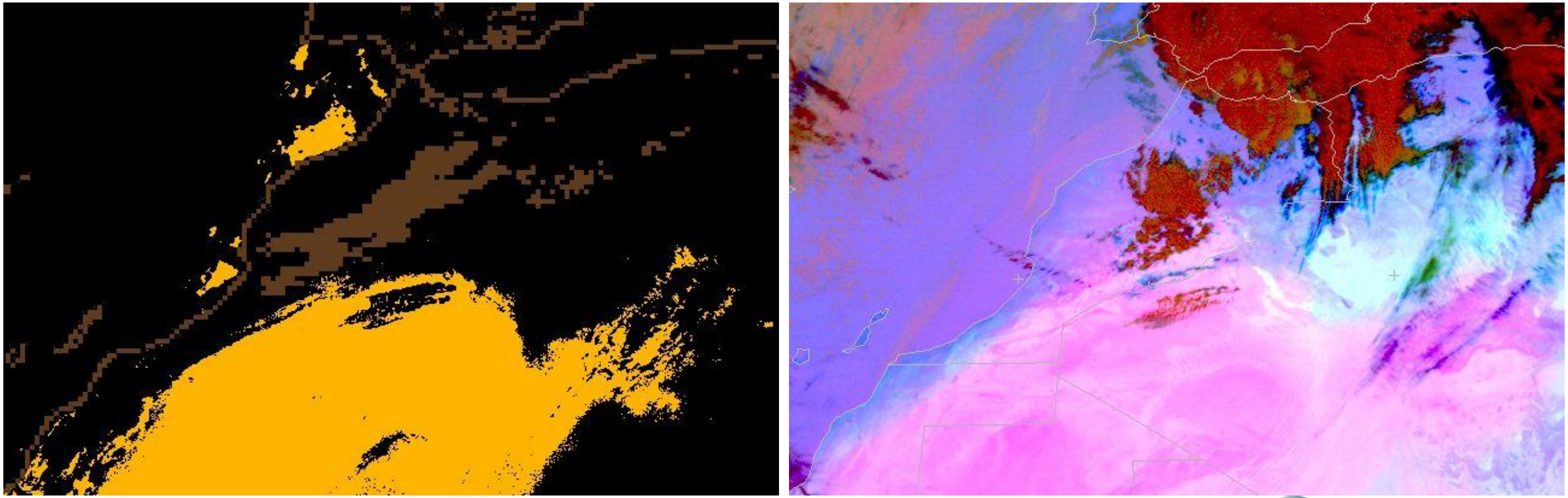
- No sample validation done so far for dust temperatures (heights), using ground temperature. This is essential for evaluation of the thermal deficit



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

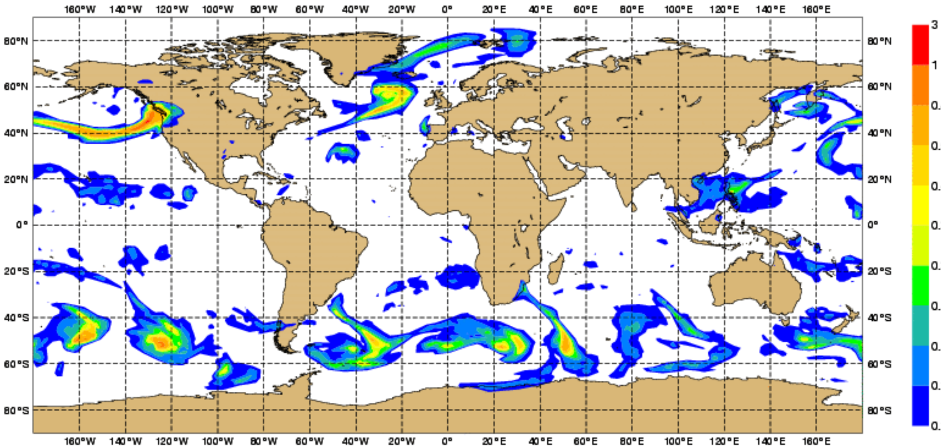
Other validation source: Nowcasting SAF dust flag

- *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

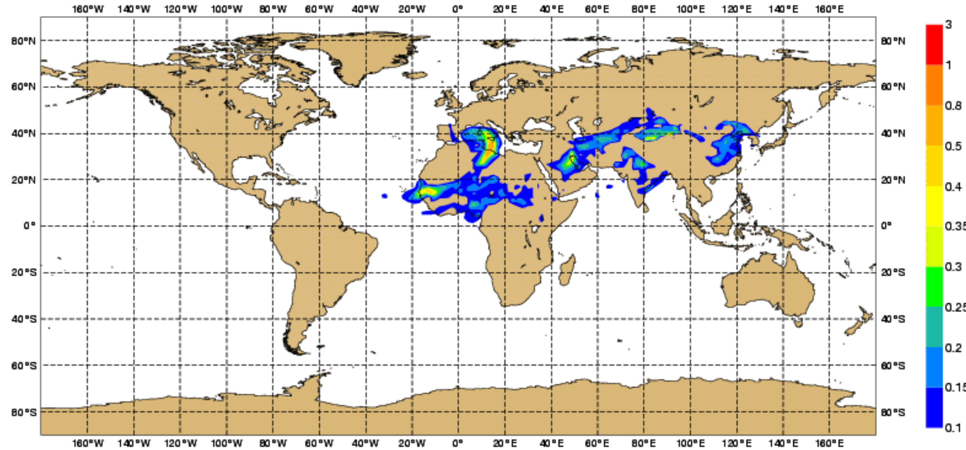


Nowcasting SAF dust flag and Dust RGB 21-Mar-2010 12 UTC

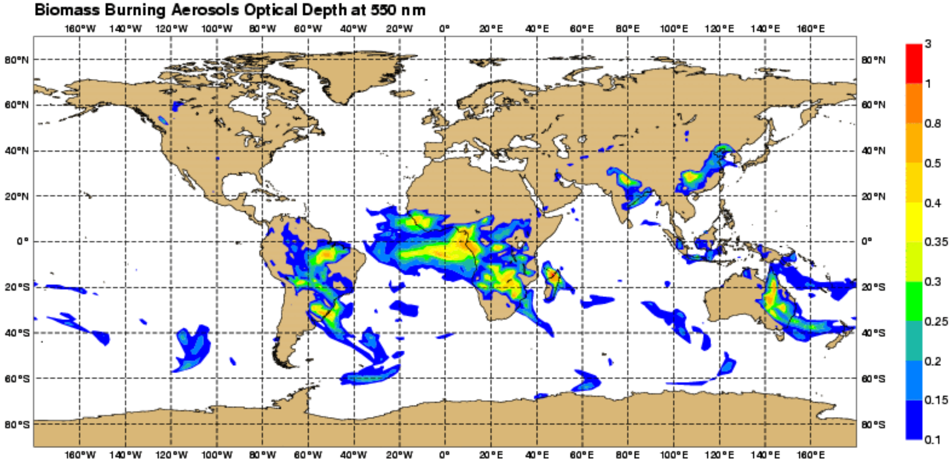
Sea-salt Aerosols Optical Depth at 550 nm



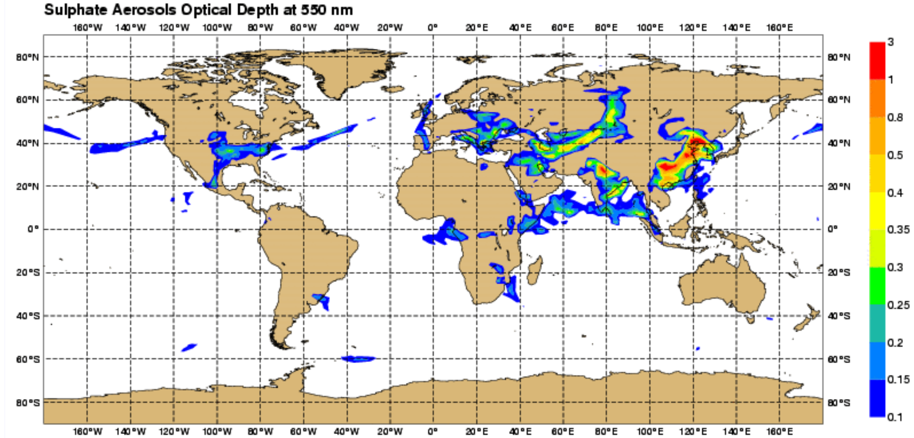
Dust Aerosols Optical Depth at 550 nm



Biomass Burning Aerosols Optical Depth at 550 nm



Sulphate Aerosols Optical Depth at 550 nm



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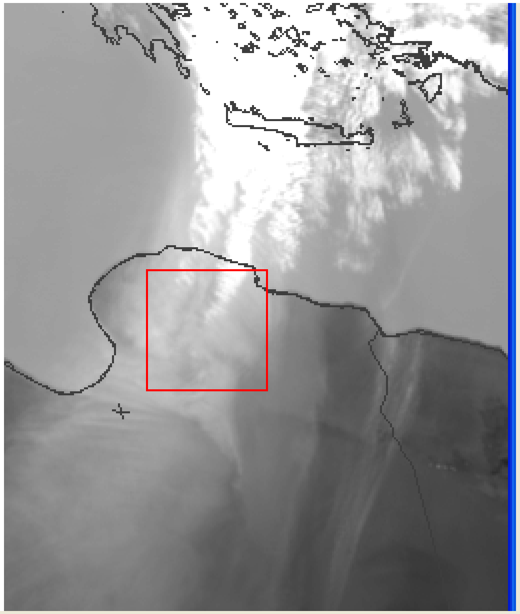
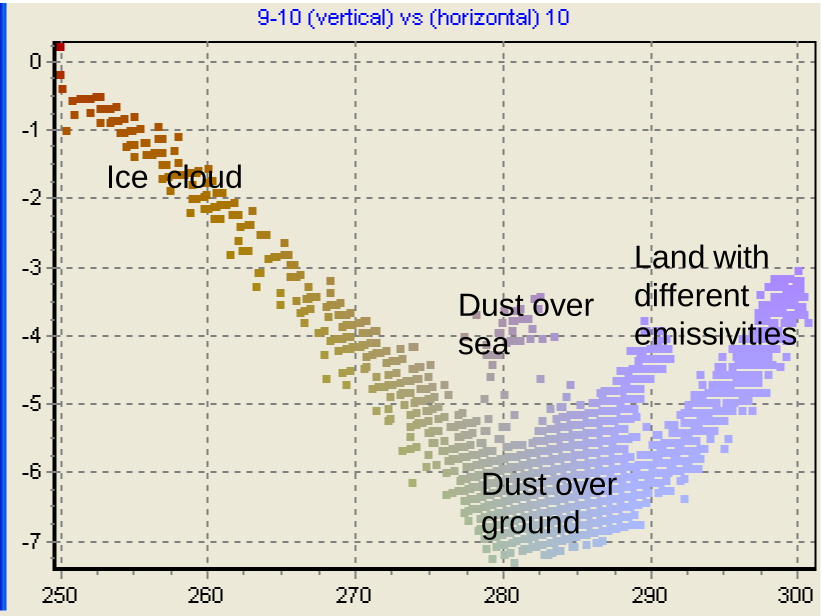
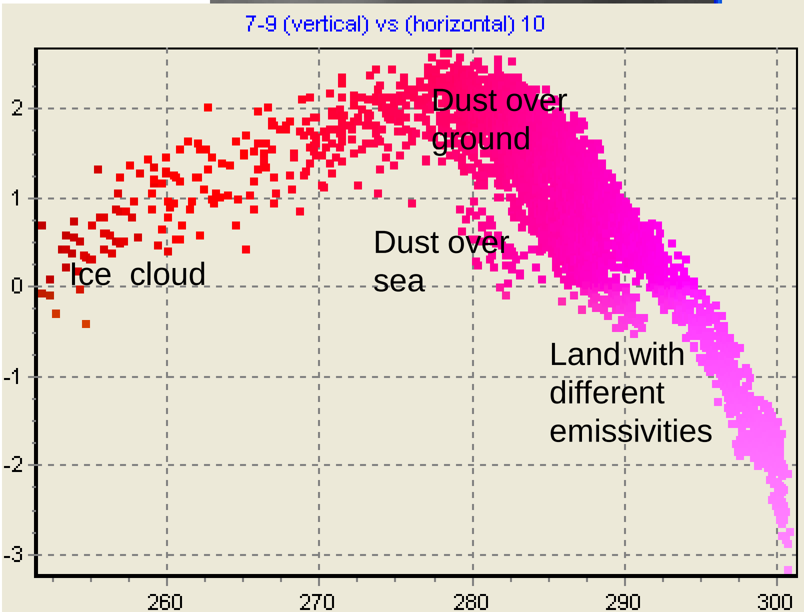
Low level dust forming a dust wall in Niamey (courtesy of E. Kploguede)

Dust-cloud interaction

2008-03-23 11:30 UTC Meteosat Ch9





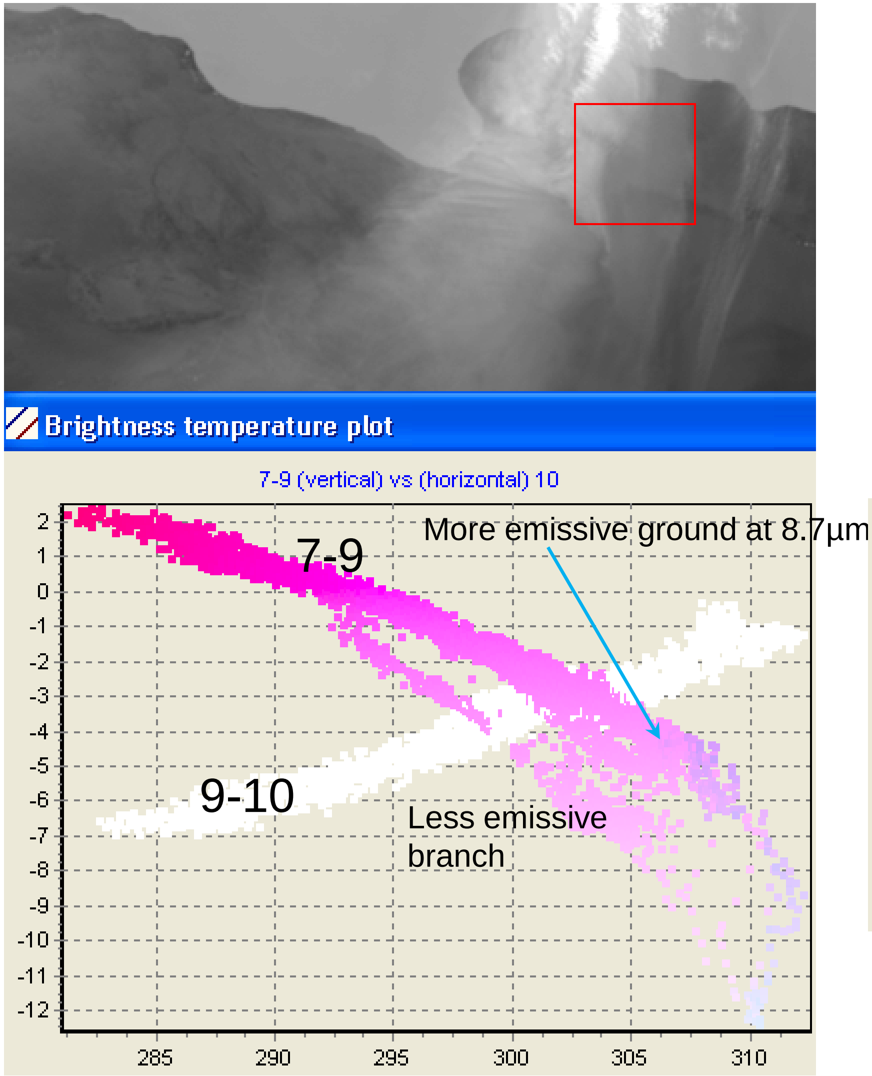


What is the ice temperature at the cloud boundaries?

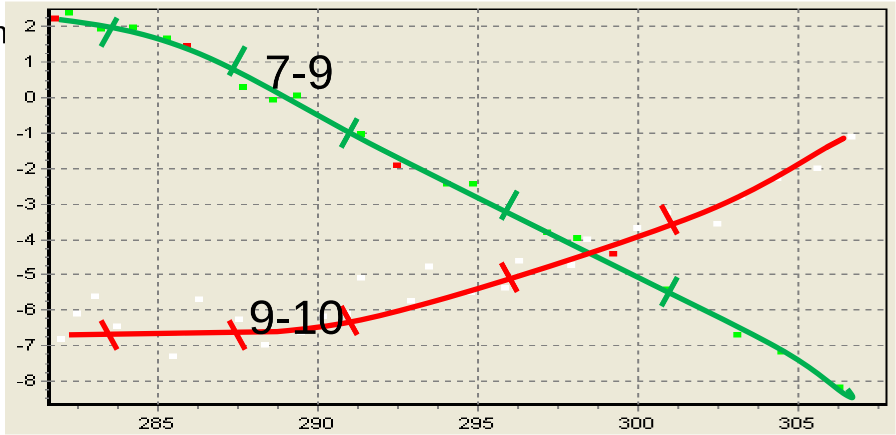
265 K
275 K
285 K

EUMETSAT

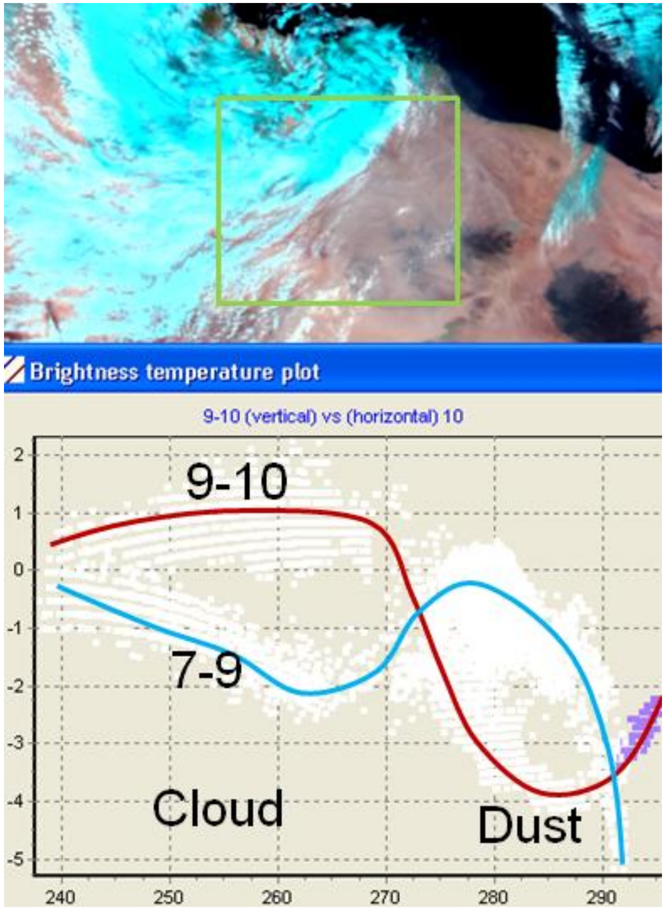
Value added by the channel 8.7µm



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



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!).

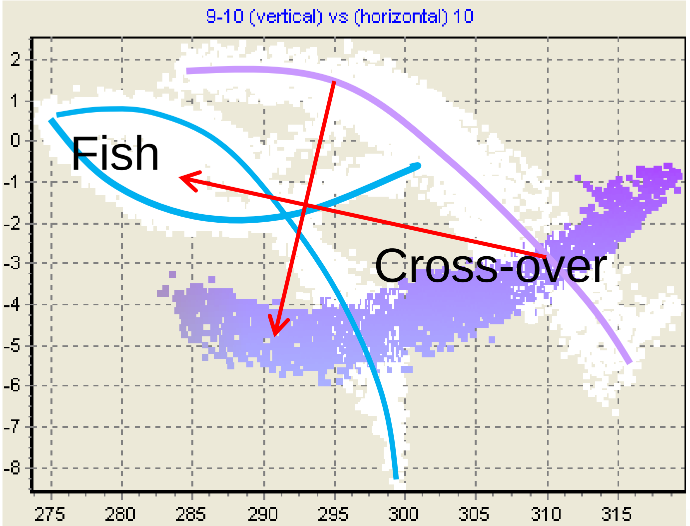
•Coupling IR technique with existing methods for **solar** channels will allow the simultaneous retrieval of surface **albedo** and **aerosol optical depth**

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

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



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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?

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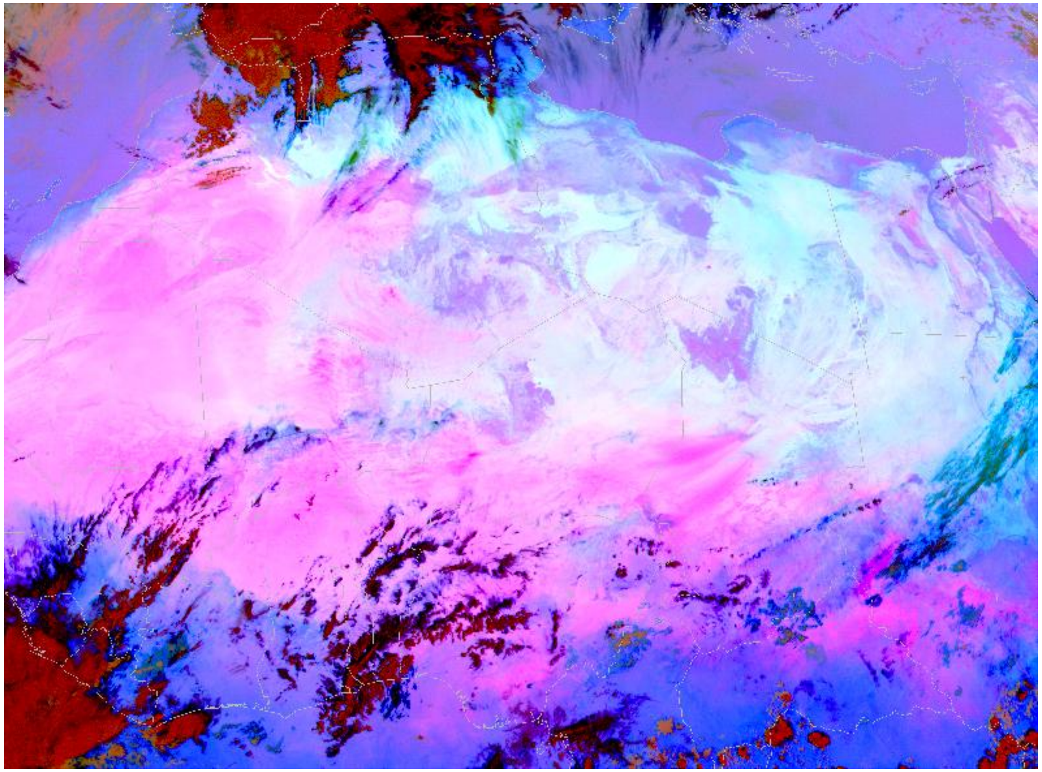
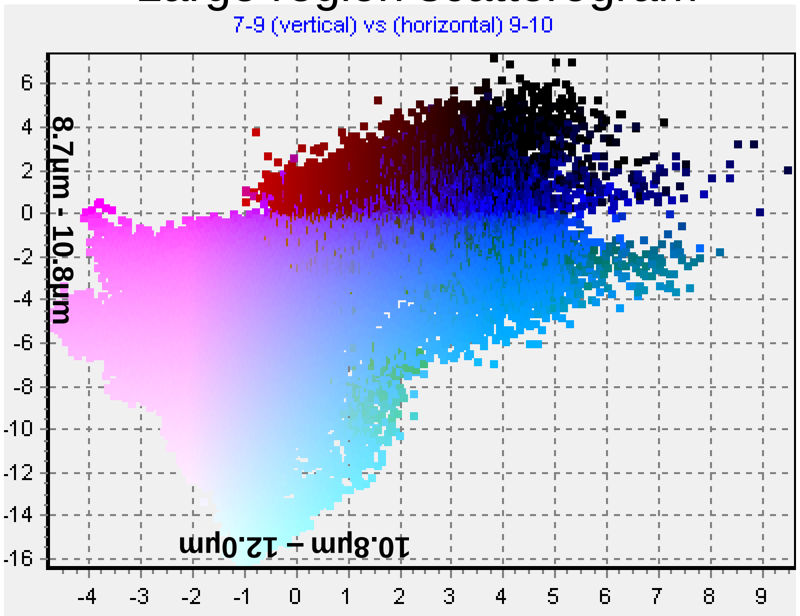


Large region scatterogram



-Global distribution avoid some value areas (e.g. large 9-10 with low 7-9)
-Abrupt transitions due to jump to the different clouds in Blue dimension (10.8 µm)
-

EUMETSAT

SULTANATE OF OMAN
DIRECTORATE GENERAL OF PASSPORTS & RESIDENCE
ENTRY VISA

سلطنة عُمان
الإدارة العامة للجوازات والإقامة
تأشيرة دخول

Name / الاسم	JOSE IGNACIO PRIETO FERNANDEZ -- Male		
Issue Date / تاريخ الإصدار	2013/12/04	Visa Number / رقم التأشيرة	445981/69 1 MONTH
Number of Entries / عدد الرحلات	SINGLE	Visa Type / نوع التأشيرة	OFFICIAL
Nationality / الجنسية	SPAIN	Passport Number / رقم جواز السفر	XDA790932
Number of Dependants / عدد المرافقين في جواز السفر	0	Issue Date of Passport / تاريخ إصدار جواز السفر	2012/09/18
Visa to be endorsed at / مكان ختم التأشيرة	Muscat Muscat International Airport Arrivals		

Sponsor's Name & Address / اسم الكفيل وعنوانه

الهيئة العامة للطيران المدني

ص ب ١٣٨٨
السيب , سلطنة عمان

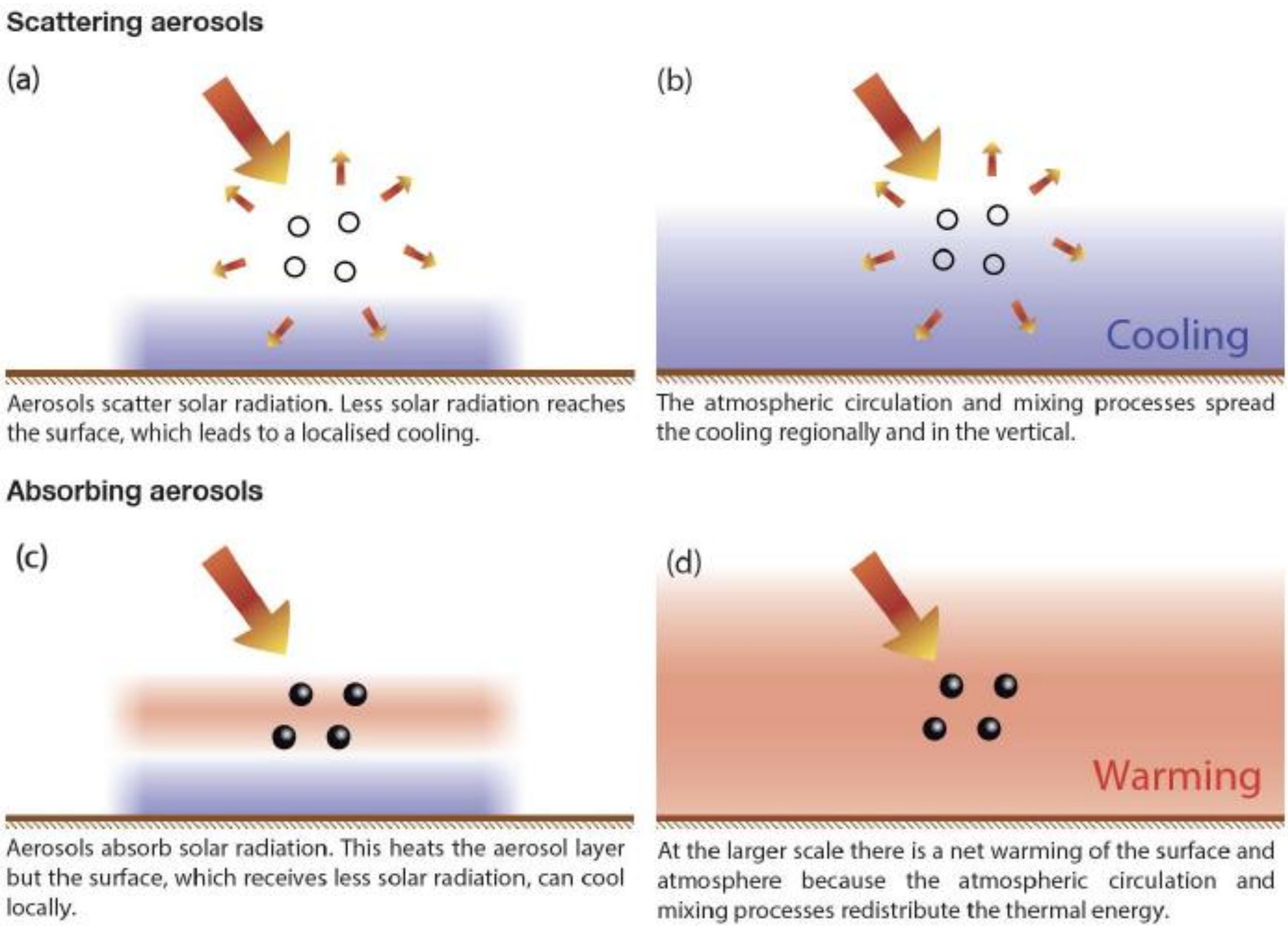
NOTE Entry will not be allowed with different passport details other than those mentioned on the visa

ملاحظة هامة : لا يسمح بدخول السلطنة ببيانات جواز سفر مختلف عن بيانات التأشيرة التي صدرت بموجبها

FOR OFFICIAL USE / للاستعمال الرسمي

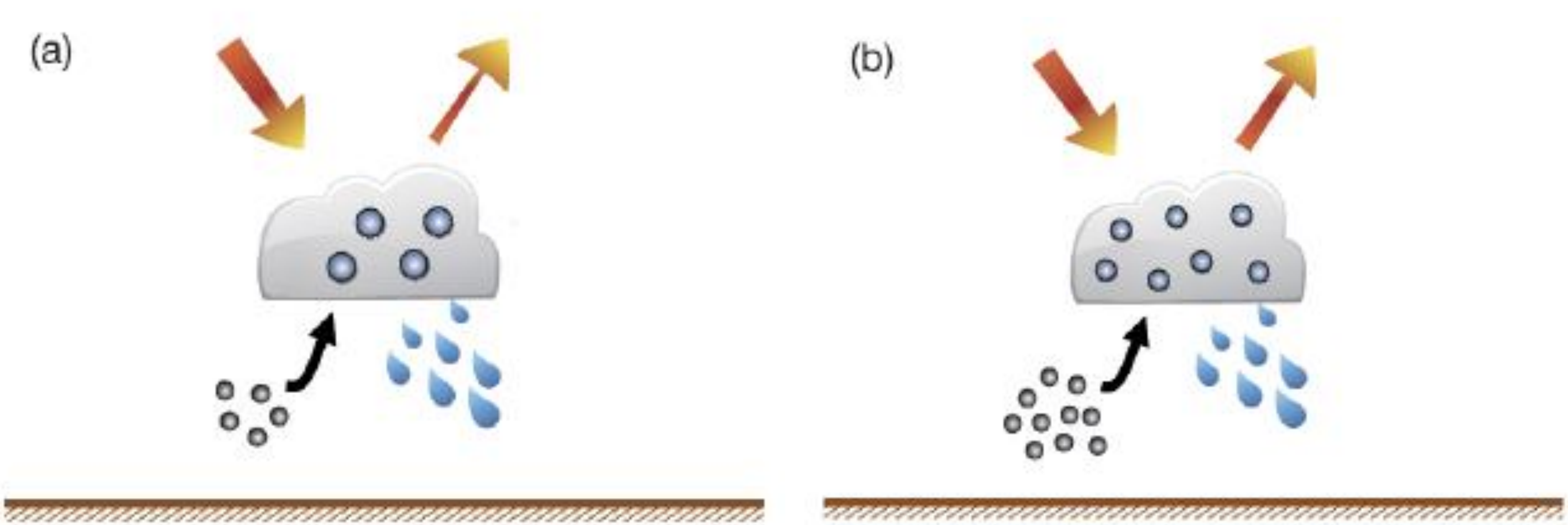
EXPIRY DATE 2014/06/02
FEE = 20 R. O.

Aerosol-radiation interactions



Aerosol-cloud interactions

Aerosol-cloud interactions

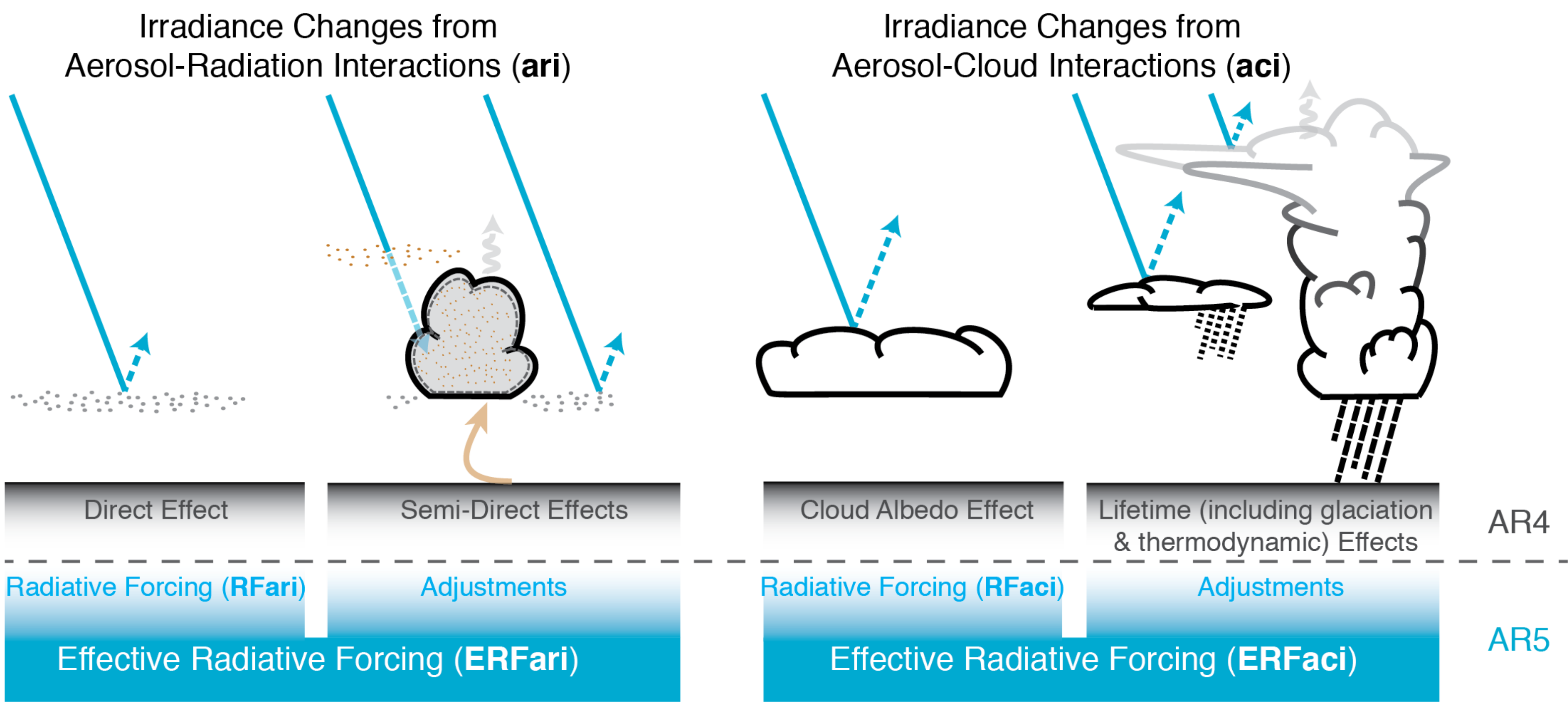


(a) Aerosols serve as cloud condensation nuclei upon which liquid droplets can form.

(b) More aerosols result in a larger concentration of smaller droplets, leading to a brighter cloud. However there are many other possible aerosol-cloud-precipitation processes which may amplify or dampen this effect.

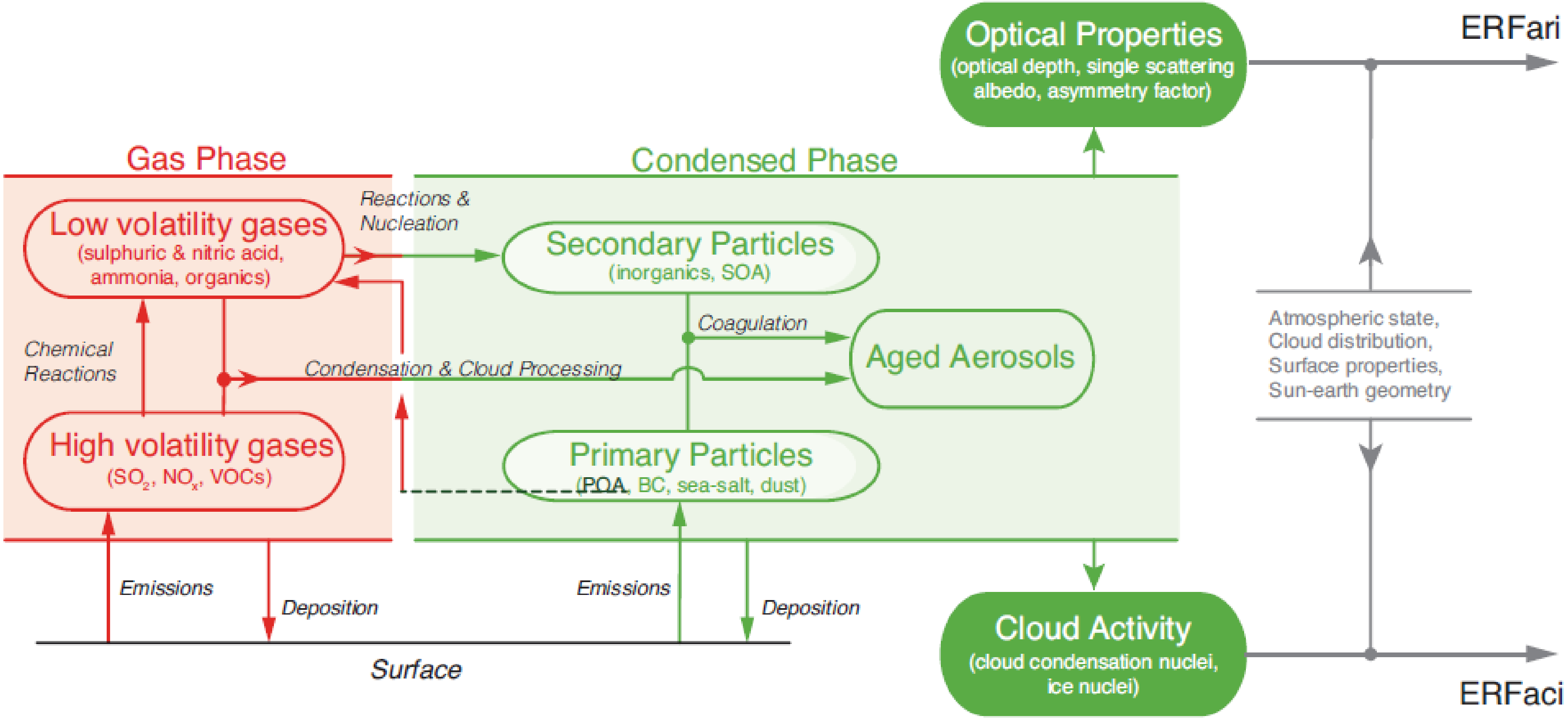
IPCC AR5, Chapter 7, 2013

Aerosol radiative forcings



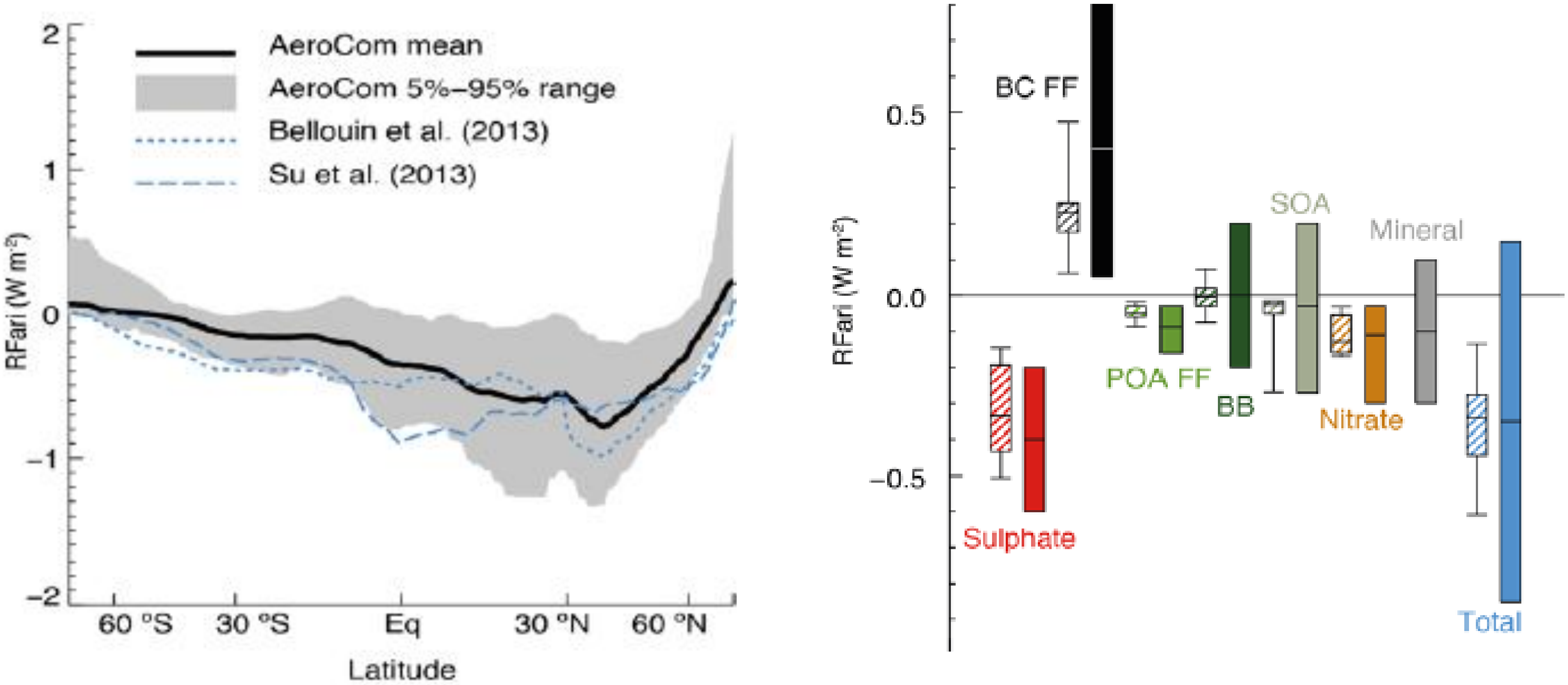
IPCC AR5, Chapter 7, 2013

Aerosol radiative forcings



IPCC AR5, Chapter 7, 2013

Aerosol RFari assessment

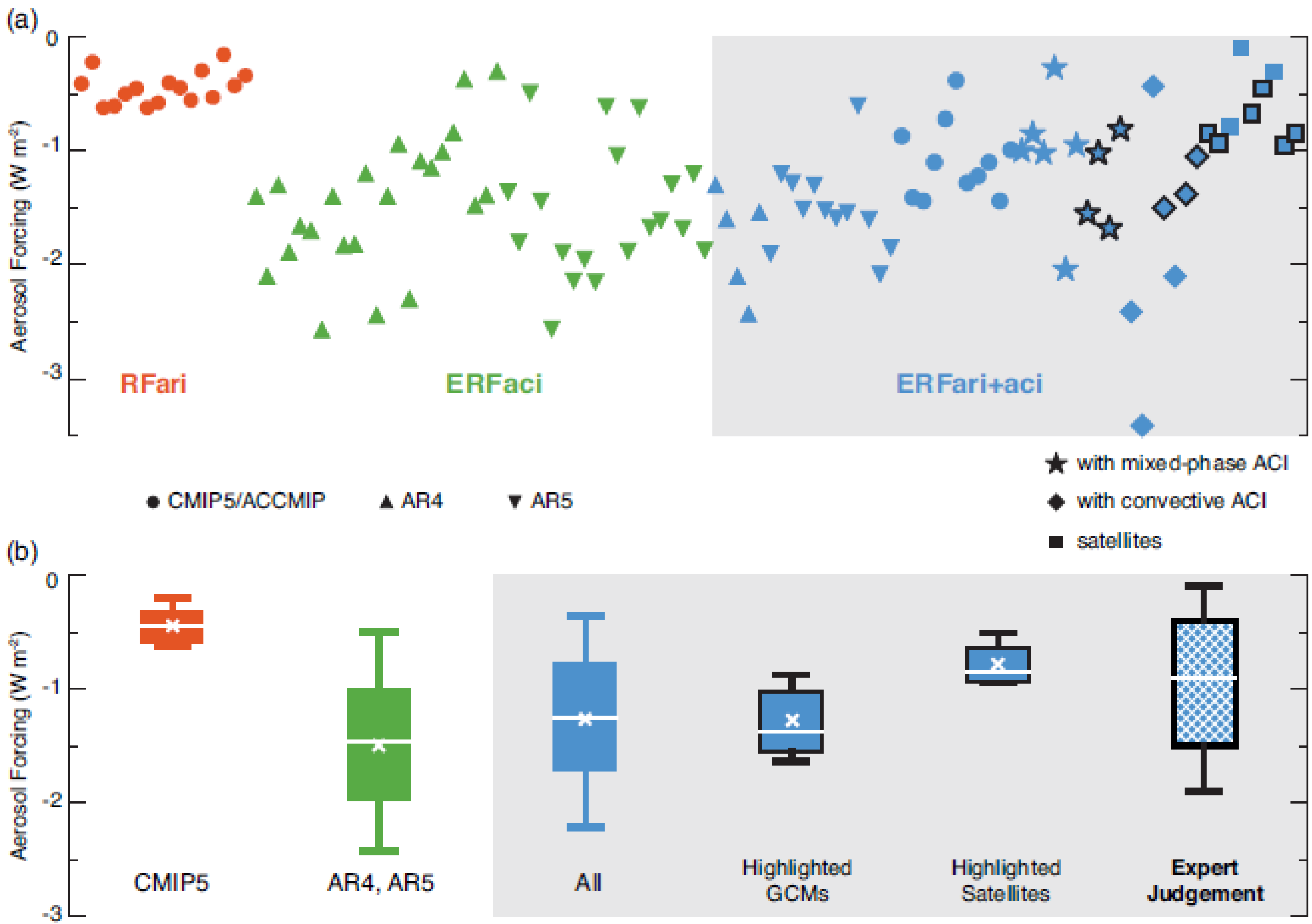


RFari = –0.35 (–0.85 to +0.15) Wm^{-2}

ERFari = –0.45 (–0.95 to +0.05) Wm^{-2}

IPCC AR5, Chapter 7, 2013

Aerosol ERFari+aci assessment



IPCC AR5, Chapter 7, 2013

ERFari+aci = –0.9 (–1.9 to –0.1) Wm^{-2}

Most uncertain ERF - Dominates total ERF uncertainty

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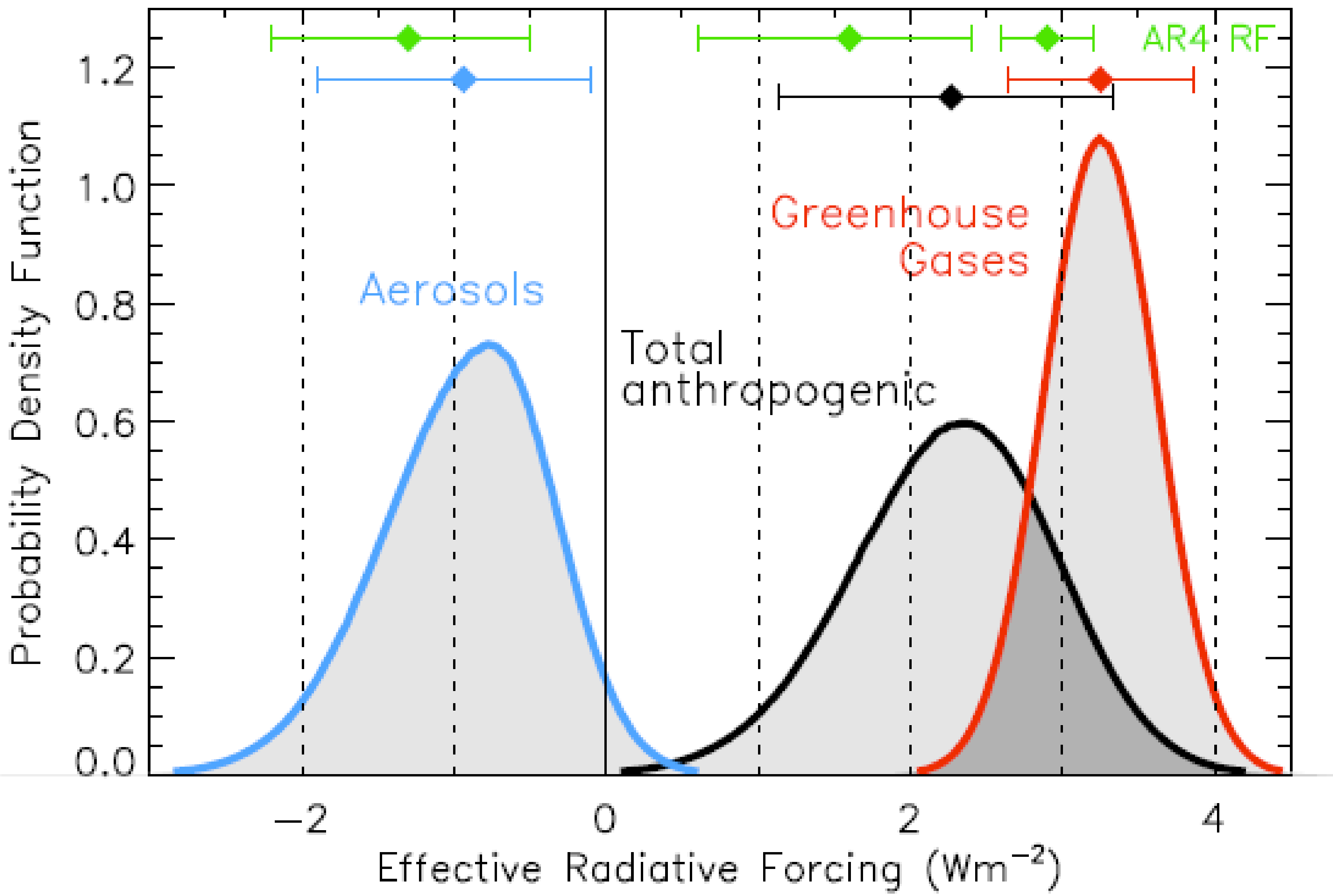
Climate forcings



IPCC AR5, Chapter 8, 2014