How do satellites sense fire?

jose.prieto@eumetsat.int

EUMETSAT

http://www.eumetsat.int/website/home/Images/ImageLibrary/index.html

IMAGE GLOSSARY

FILTER BY

Feature: Fire
Country/Region: All
Satellite: All
Instrument: All
Month: All
Year: All
Product: All
Author: All
Collection: All

APPLY RESET

EUMETSAT USERS TWITTER

Tweets by @eumetsat_users

88 RESULTS

DEVASTATING WILDFIRES IN PORTUGAL

18 June 2017

Hot spots and smoke from a deadly, widespread forest fire in central Portugal could be seen by Meteosat-10, Sentinel-3 and Suomi-NPP on 18, 19 & 20 June 2017

WILDFIRES IN CHILE IN JANUARY 2017

25 January 2017

During the southern hemisphere summer 2017, central and southern parts of Chile were stricken by the most devastating wildfires in the country's history.

SMOKE FROM WILDFIRES IN PORTUGAL

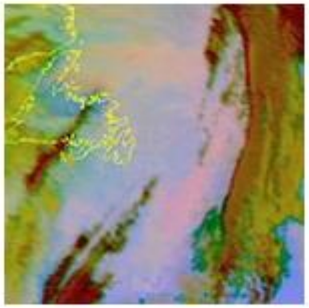
08 August 2016

Smoke from widespread wildfires which ravaged parts of Portugal in early August 2016, was seen by Meteosat-10 on 8 August.

SMOKE OVER RUSSIA

25 July 2016

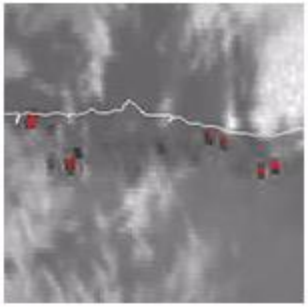
Widespread smoke over Russia clearly seen on Meteosat Natural Colour RGB imagery on the morning of 25 July 2016.



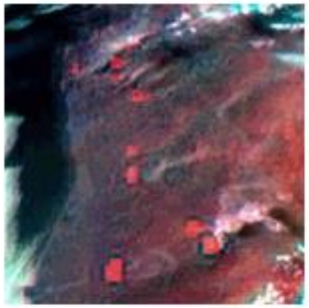
CANADIAN SMOKE MOVES TOWARDS THE NORTH ATLANTIC

2015 - WARM, DRY BUT STORMY YEAR

01 January 2016



FIRES DEVASTATE PARTS OF ASTURIAS AND CANTABRIA



FIRES IN THE IBERIAN PENINSULA

06 August 2015

http://www.eumetrain.org/data/3/30/index.htm

Forest Fires

Table

- The Fire Triangle
- Weather
- The Continuity Equation
- Fuel
- Topography
- Fire Weather Index
- Summary

- Table of Contents
- Print Version
- Download Version
- EUMeTrain

As you have seen in the previous chapter, synoptic patterns are not enough to indicate the locations where forest fires are likely to occur and spread. In fact, aside from the weather, a fire's behaviour also strongly depends on fuel and topography, creating the three sides of what is usually known as the *fire triangle* (Figure 3.1).

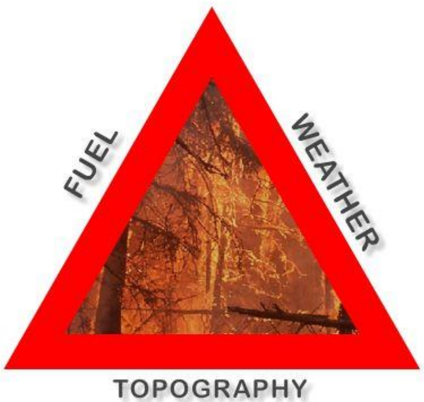


Fig 3.1 – Fire triangle. Fire hazards are influenced by fuel, weather and topography.

In this third chapter the three sides of this triangle will be further explained. After answering the following multiple choice question the chapter will continue with "weather".

Fire ignition depends most on which of the following meteorological factors:

a) Temperature

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Contents

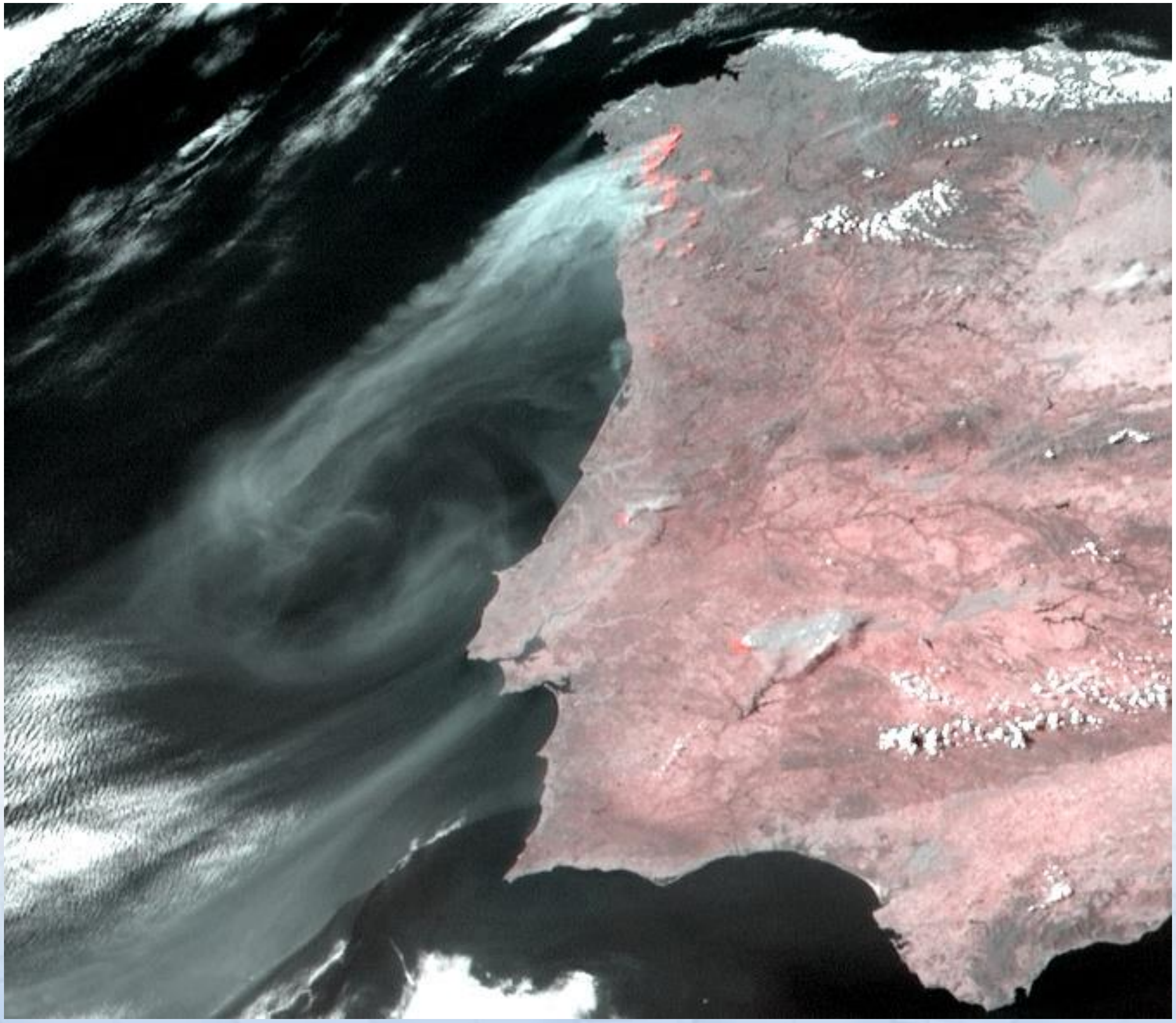
Meteosat SEVIRI channels

Physical concepts

Remote sensing of fires and vegetation

Smoke

Quiz



Meteosat: 30% of channel 3.9µm on top of HRV

2006-July-7 16:00

SEVIRI CHANNELS

Channel	Cloud	Gases	Application	
	Properties			
HRV 0.7	Absorption <-----------> Scattering; 1 ------<------ Emissivity ------>------ 0	Broad band VIS	Surface, aerosol, cloud detail (1 km)	12
VIS 0.6		Narrow band	Ice or snow	1
VIS 0.8		Narrow band	Vegetation	2
NIR 1.6		Window	Aerosols, **snow<>cloud**	3
IR 3.8		Triple window	SST, **fog**<>surface, ice cloud	4
WV 6.2		Water vapour	**Upper** troposphere 300 Hpa humidity	5
WV 7.3		Water vapour	**Mid**-troposphere 600 Hpa humidity	6
IR 8.7		Almost window	Water vapour in boundary layer, **ice<>liquid**	7
IR 9.7		Ozone	Stratospheric winds	8
IR 10.8		Split window	CTH, cloud analysis, **PW**	9
IR 12.0		Split window	Land and **SST**	10
IR 13.4		Carbon dioxide	+10.8: Semitransparent-cloud **top**, air mass analysis	11

Why 3.9µm for fire?

short suggestions please

3.9µm characteristics: mark the true!

Maximum emission by flames

Response to subpixel thermal anomalies

Small sun contribution

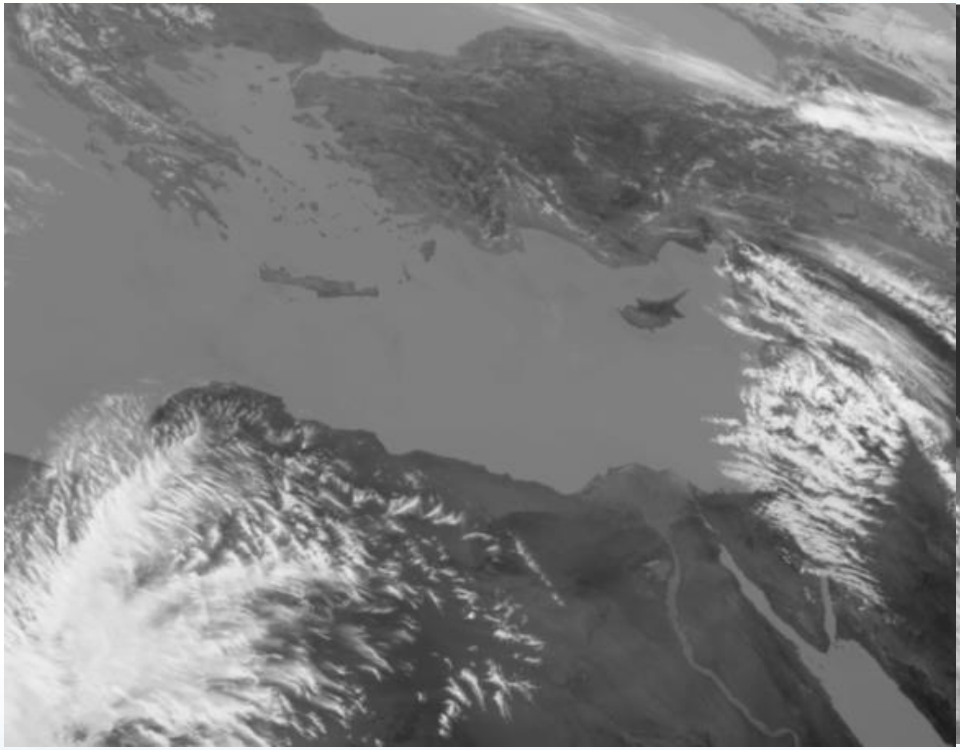
No absorption by water vapour

No absorption by carbon dioxide

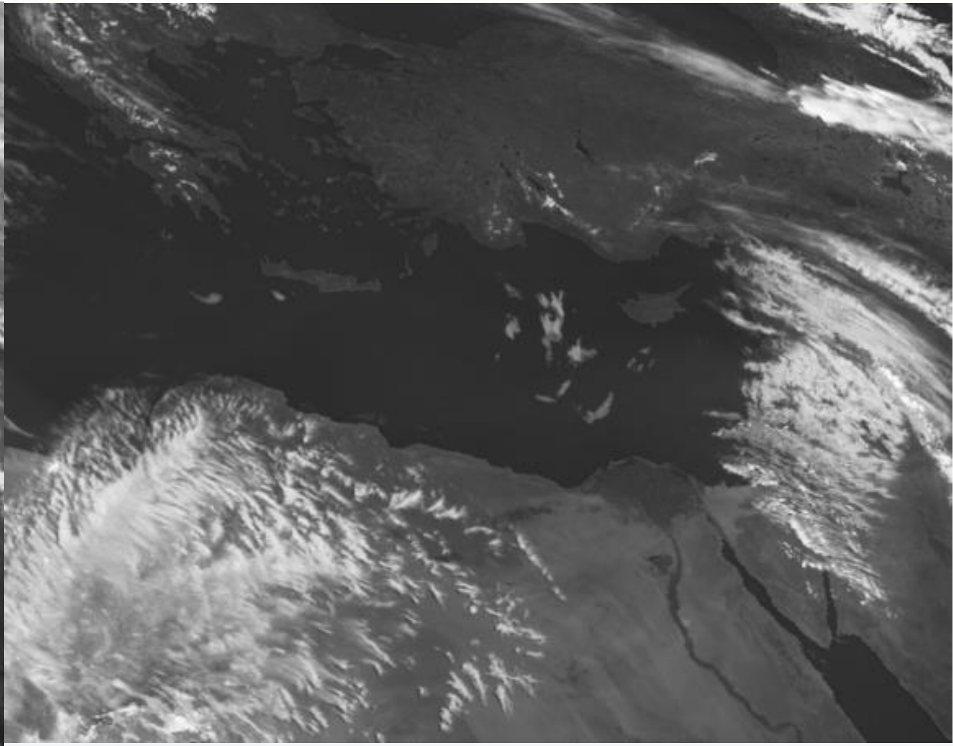
Meteosat pixel saturation for fires

Low ground emissivity

3.9 µm and 10.8µm channels: IR window channels



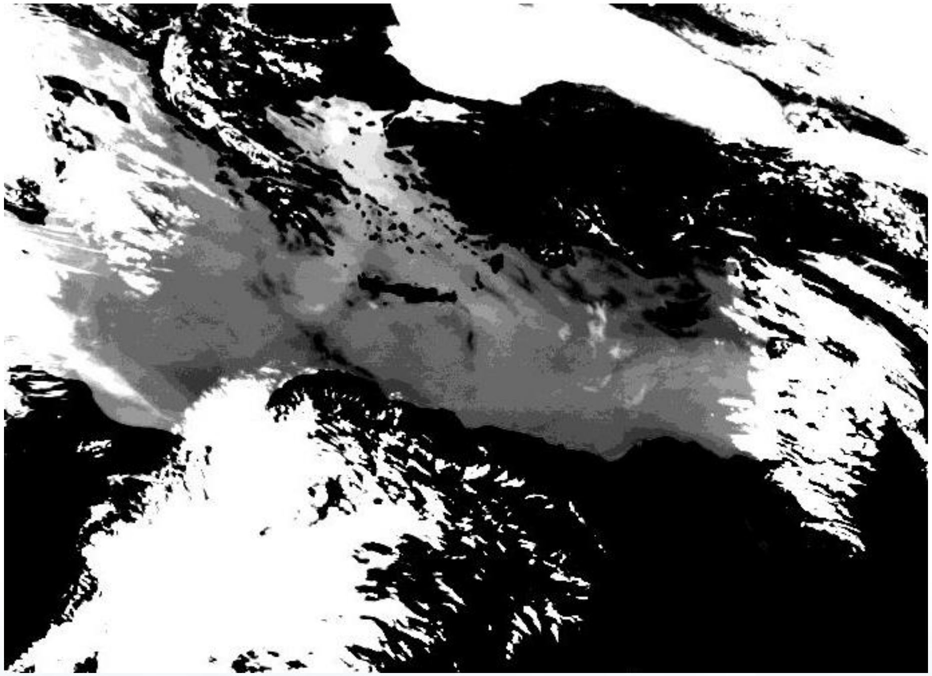
2016_Apr_05 10UTC Channel 10.8µm [215K .. 315 K]



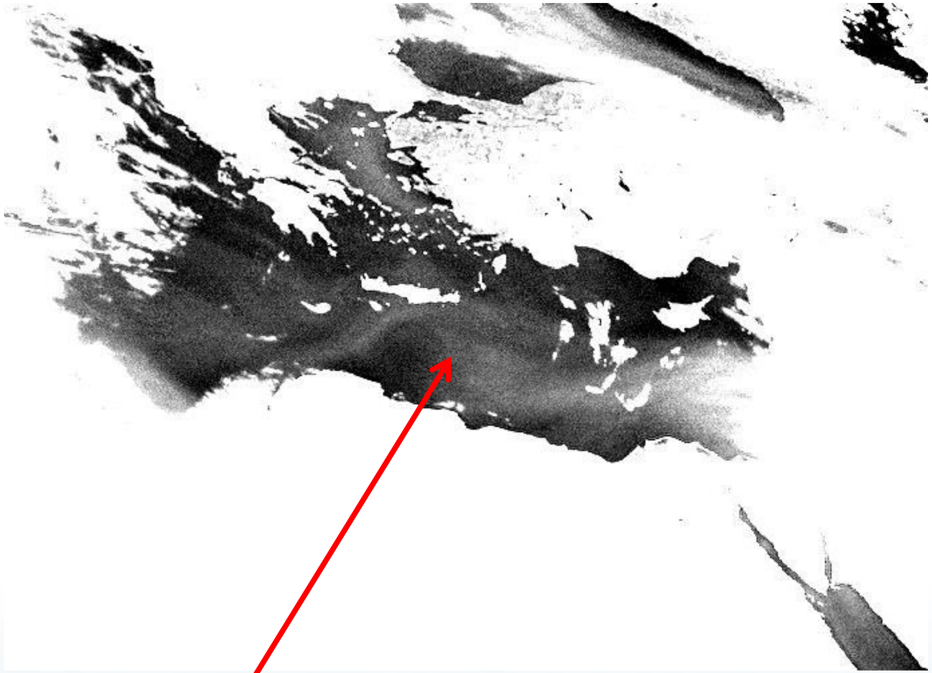
Difference 3.9µm - 10.8µm [-8K .. +60K]

Differences 3.9µm – 10.8µm due to:

Sun (+20K), gas absorption (-5K), ground type(+-3K) and ... Planck (+5K)



2016_Apr_05 10UTC Channel 10.8µm [215K .. 315 K]



Difference 3.9µm - 10.8µm [-8K .. +60K]

Over water, 10.8µm roughly shows SST fields
But 3.9µm – 10.8µm shows humidity at low level

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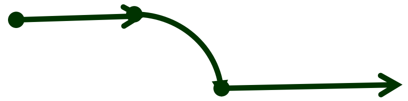
3.9 µm and 10.8µm: window channels

3.9 µm

- ❖**No**t absorbed by atmospheric **humidity**
- ❖Close to a **CO_2 absorption** band, 4-7 Kelvin signal reduction
- ❖High temperature **sensitivity** (big sub-pixel effects) ~14 * ΔT/T
- ❖**Blinding** effect by hot pixels, affecting measurements west of the saturated pixel



- ❖Fog warnings
- ❖**Sun** enhancement during day

10.8 µm

- ❖1-2 Kelvin absorption by atmospheric humidity
- ❖No signal reduction by CO_2
- ❖Lower temperature sensitivity (small subpixel effects) ~ 4 * ΔT/T
- ❖No risk of sensor blinding by fires
- ❖Low values compared with 3.9µm due to semitransparent cloud or smoke.

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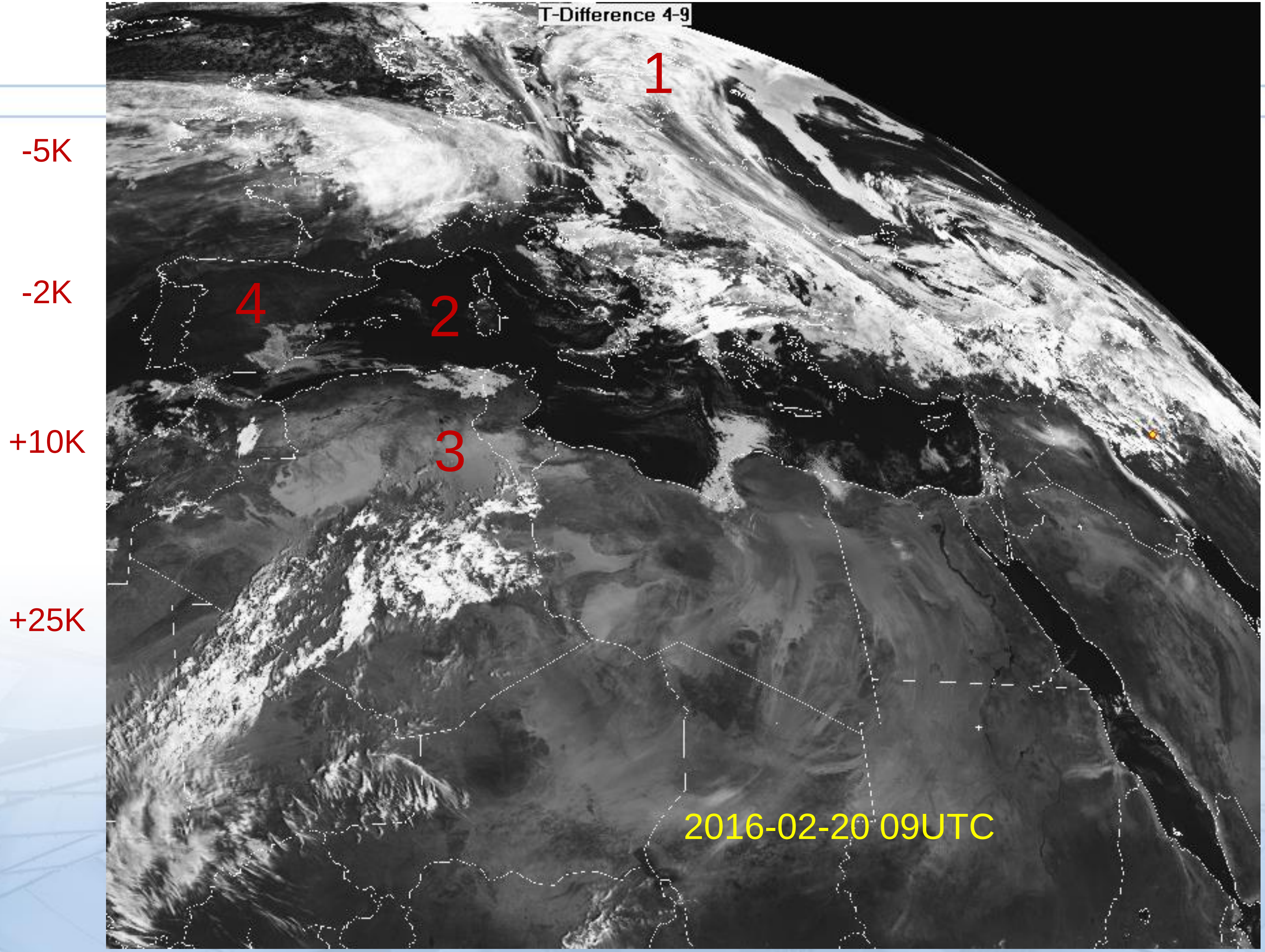
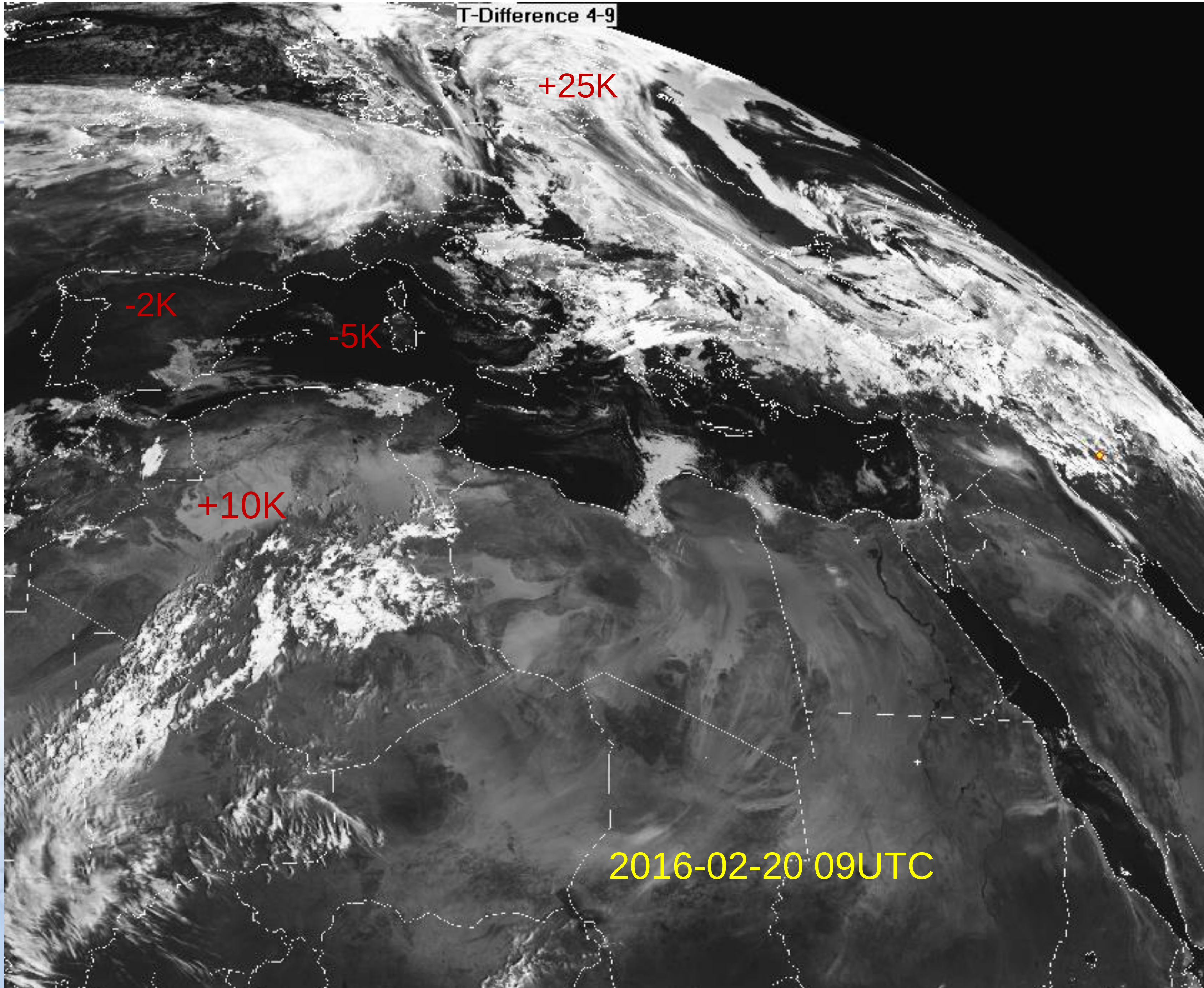
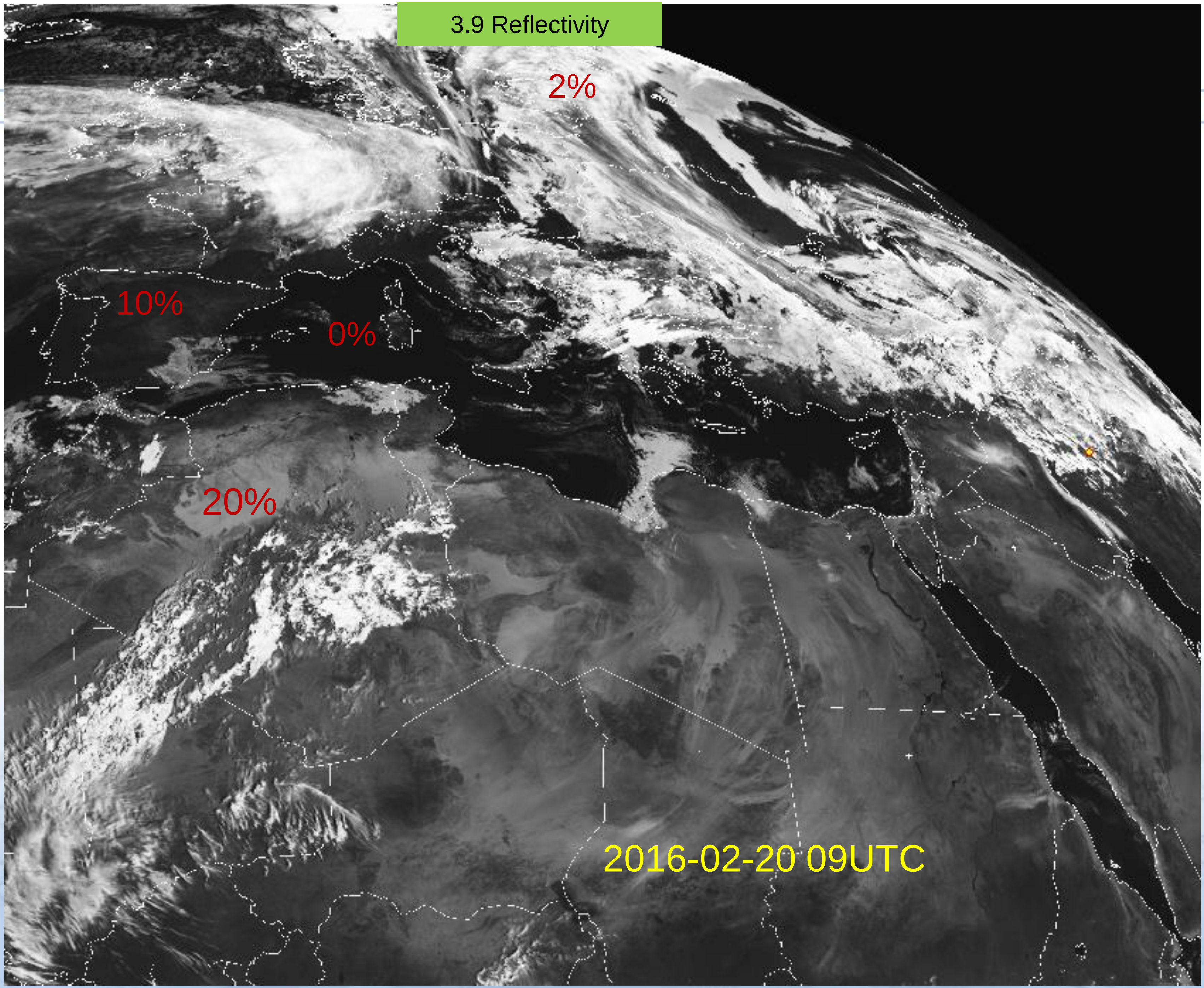
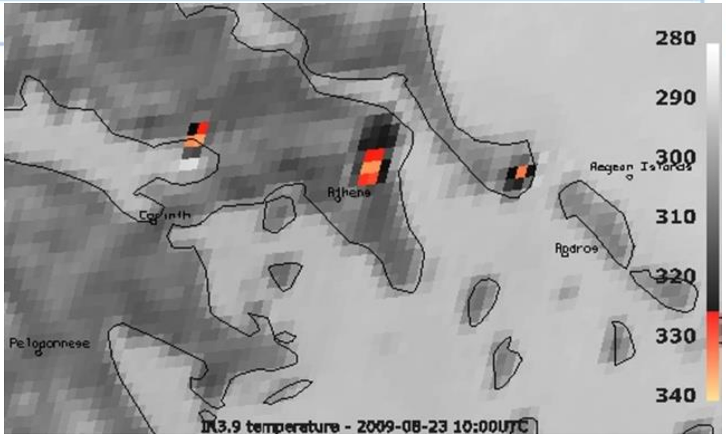
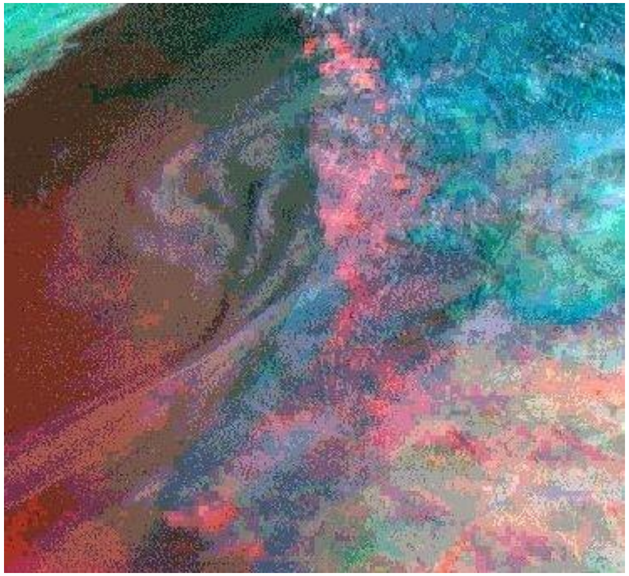

T-Difference 4-9
1
2
3
4
-5K
-2K
+10K
+25K
2016-02-20 09UTC


T-Difference 4-9
+25K
-2K
-5K
+10K
2016-02-20 09UTC

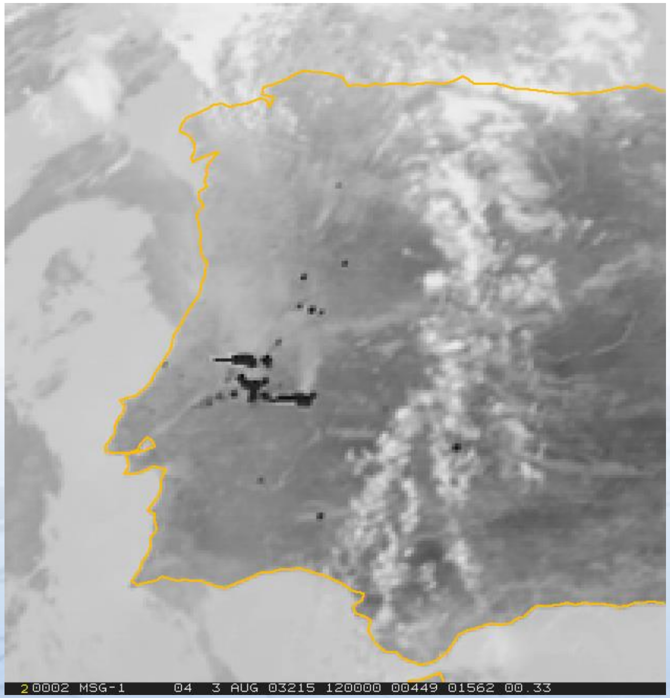

3.9 Reflectivity
2%
10%
0%
20%
2016-02-20 09UTC

3.9 µm and 10.8µm channels: sensor blinding and filters





2006_08_07   06-19UTC
rgb_12 + 4-3-2
HRV can be combined with
lower horizontal resolution for
more spectral information



For pixels west of the fire the
sensors can be blinded, following
geometrical patterns (rings)

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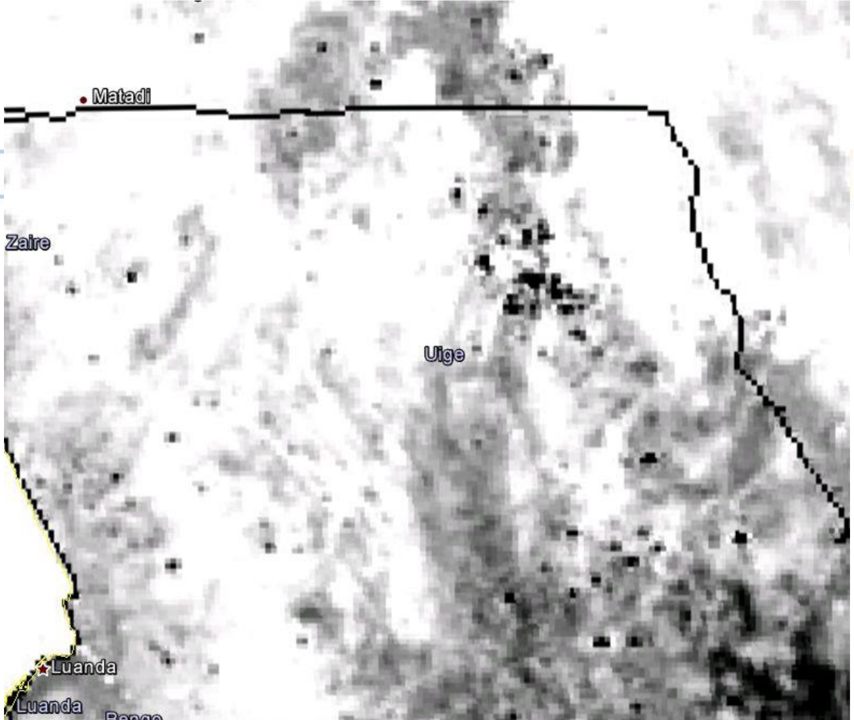
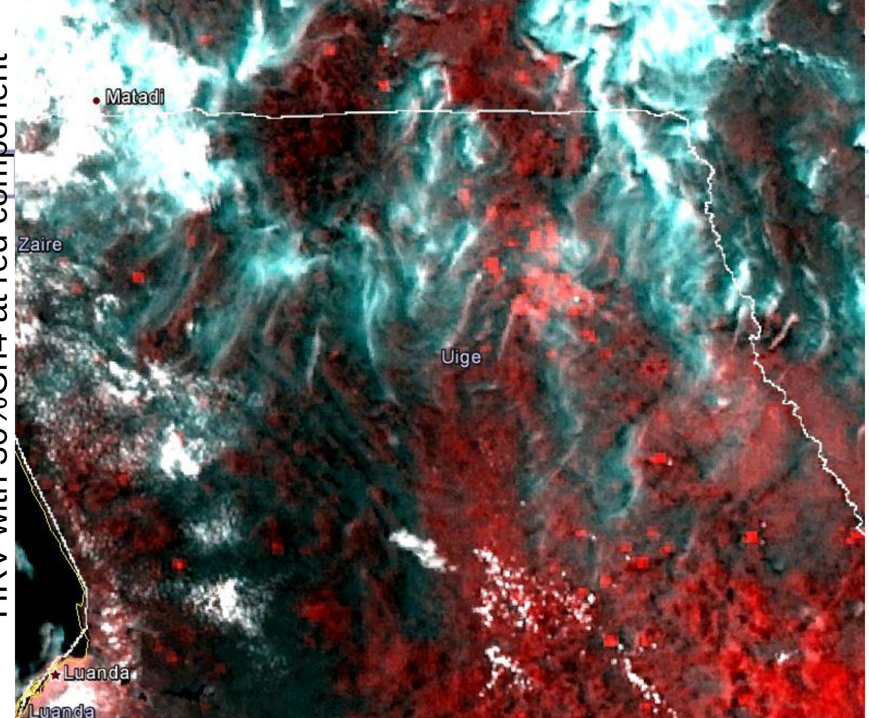
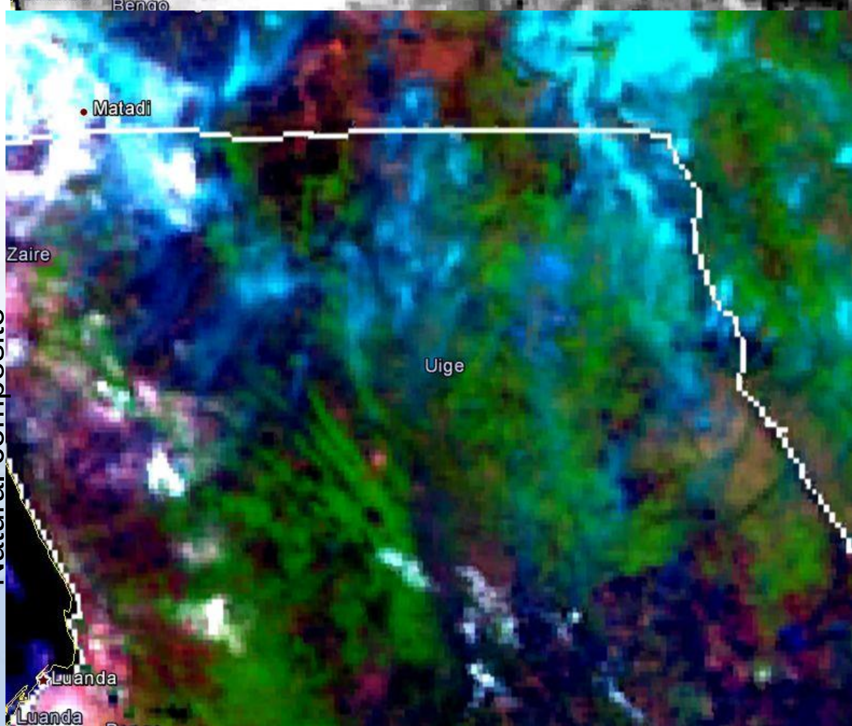
Channel 4 2011-09-01 12:00 M9



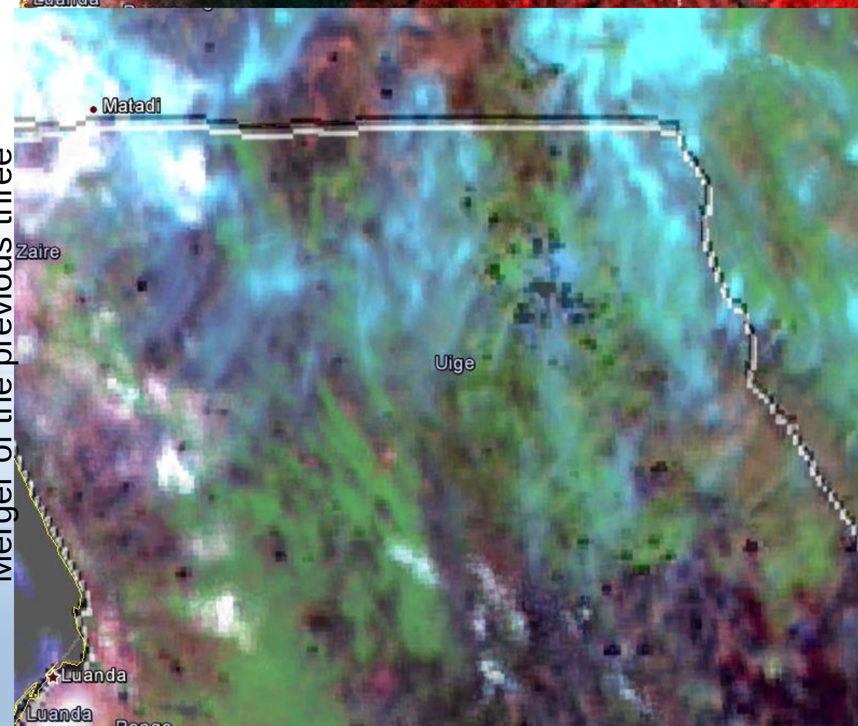
HRV with 30%Ch4 at red component



Natural composite

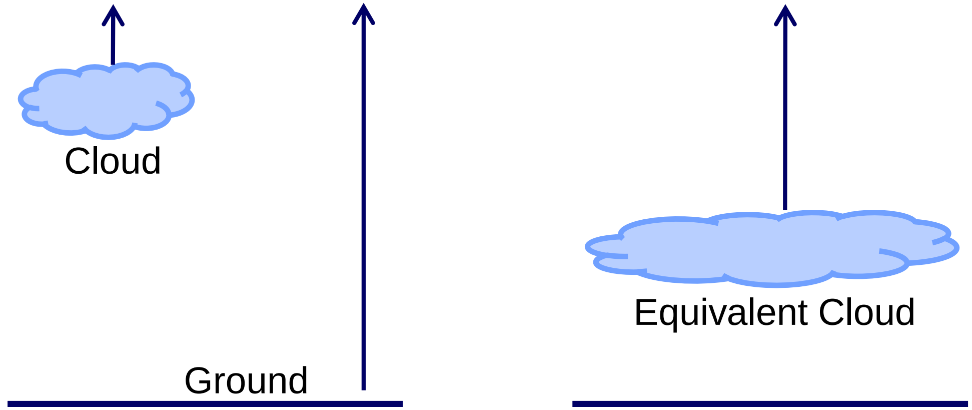


Merger of the previous three

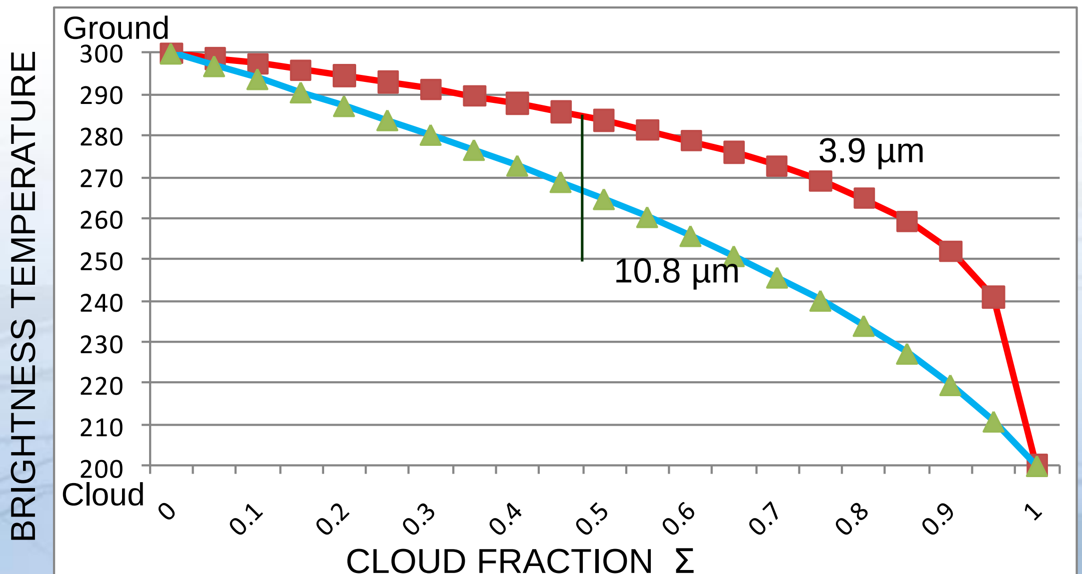


Sub-pixel effects = temperature sensitivity = warm bias

$$\Sigma \bullet B_C \;+\; (1-\Sigma)\cdot B_G \;=\; B_{EC}$$



The equivalent temperature is not the average temperature, but shows a WARM BIAS!



50% cloud gives:

282 K (at 3.9 µm)

264 K (at 10.8 µm)

and NOT the average 250 K

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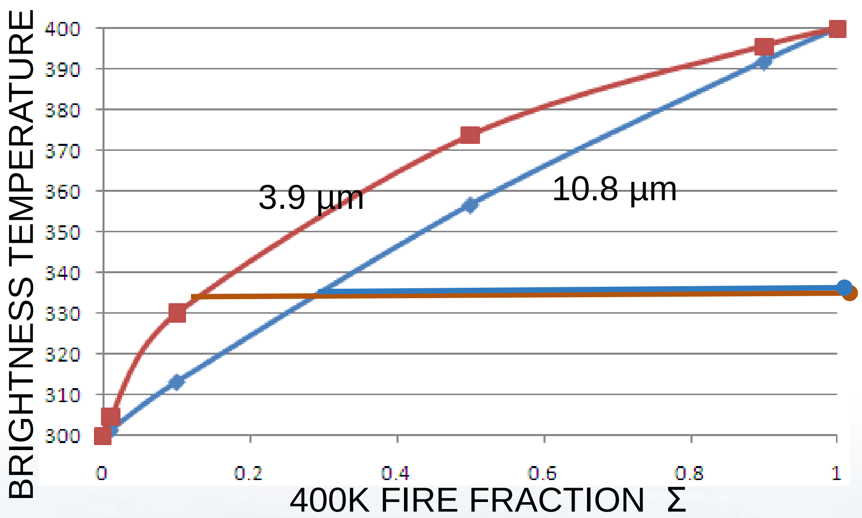
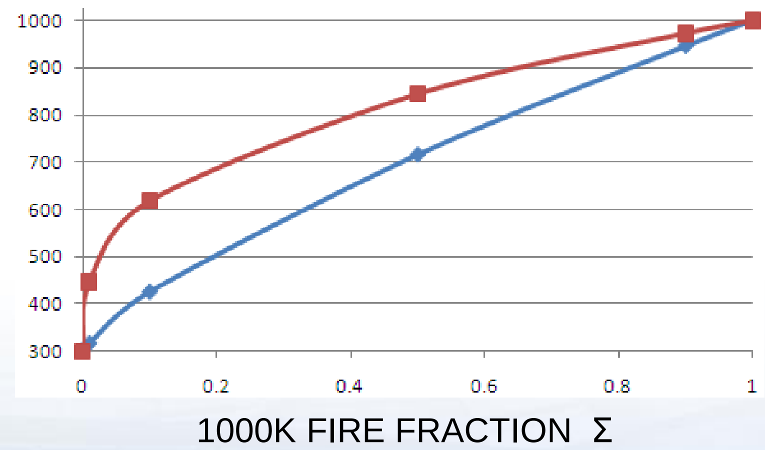
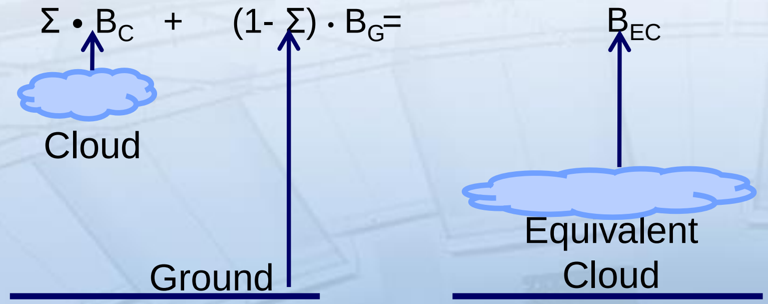
Subpixel effects = temperature sensitivity = warm bias

Widespread fires (15%) show less difference 3.9µm – 10.8µm than small ones (5% of the pixel)







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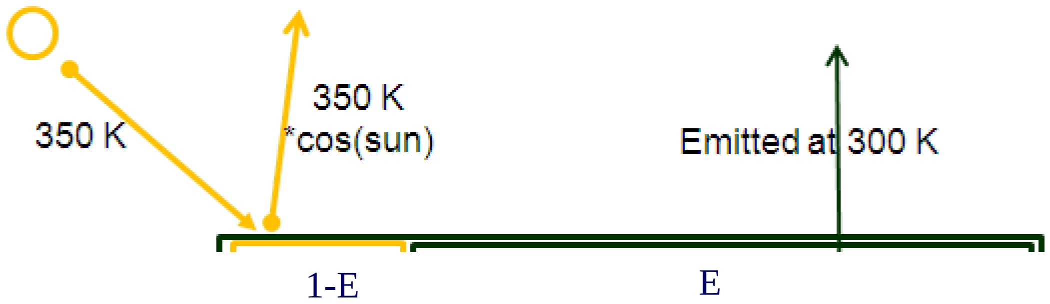
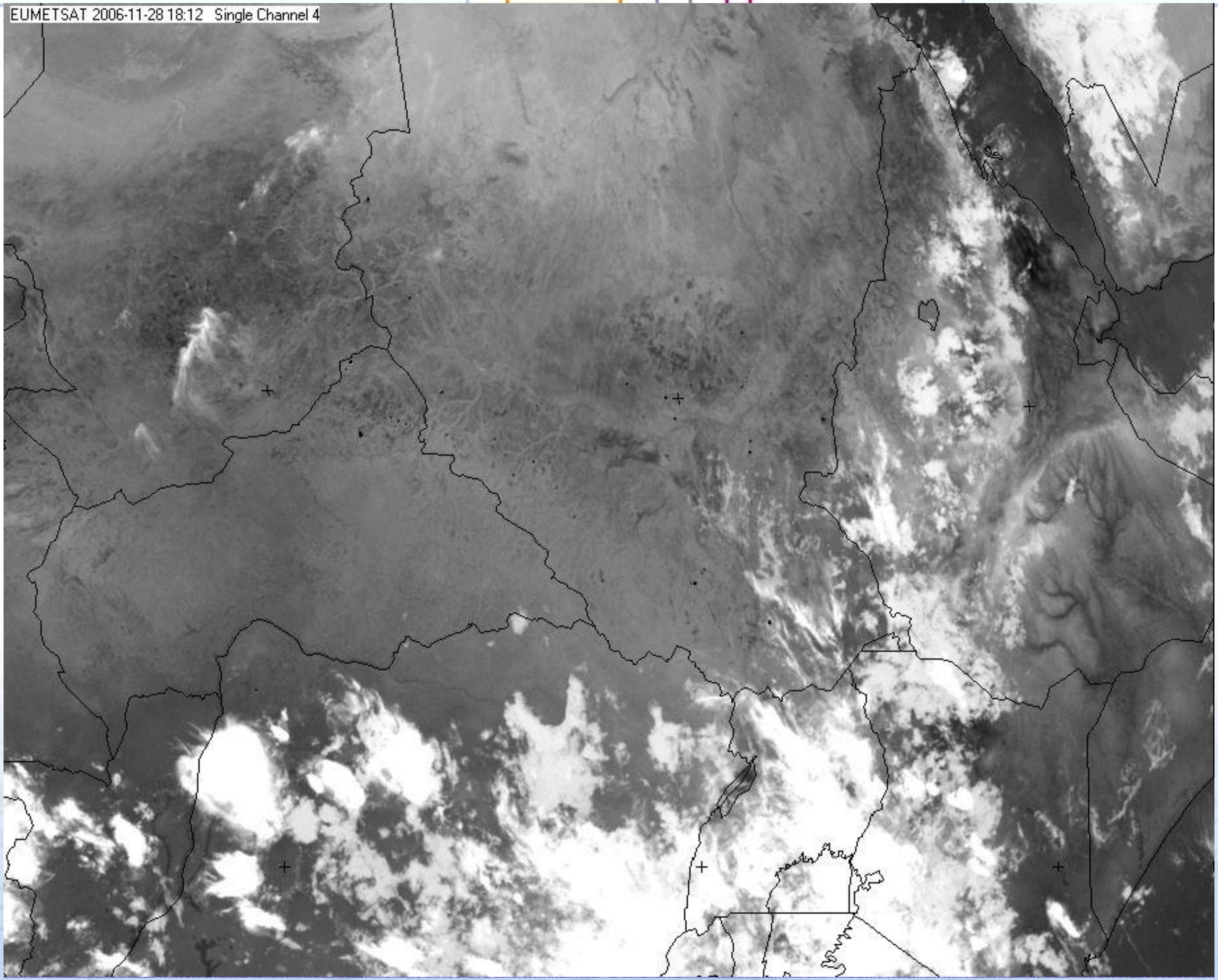
Solar reflection and emission together (3.9µm)



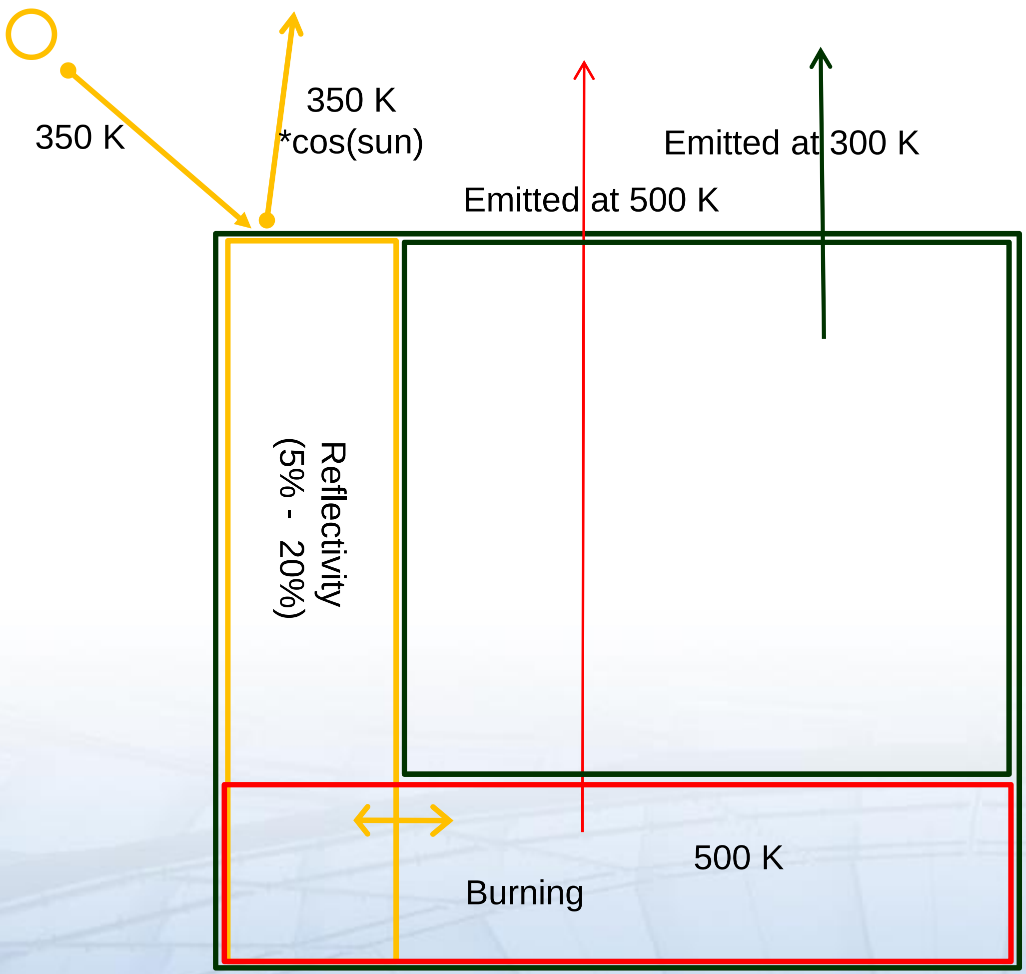
$$B(BT) = (1-E) * B(350K) + E * B(300K)$$

- Warm bias in brightness temperature towards 350K (depends on illumination)
- During night, brightness temperature (BT) is lower than 300K
- Albedo (1-E) varies with type of soil: 20% (savannah) to 5% (forest)
- Cloud (1-E=2%) is usually present in burning areas

Fires on 1.6µm images



Hot spots contributions in a pixel (3.9µm)



DAY BT	Reflectivity 3.9µm 5% Forest	20% Savannah
Fraction burning		
0	314	333
0.01	328	339
0.1	380	370
0.5	449	425
1	490	460

NIGHT BT	Reflectivity 3.9µm 5%	20%
Fraction burning		
0	296	284
0.01	318	304
0.1	377	356
0.5	448	421
1	489	457

Sunrise and sunset change 3.9µm BT but normally **outside of the detection** range of SEVIRI

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Not only 3.9µm allows fire detection: 1.6µm at night does!

NEAR INFRARED (e.g. 1.6µm)

•More adequate for smoke detection than 3.9µm
•Only big fires, above sun light
•No CO_2 absorption (higher “fire temperature”)
•Higher sub-pixel sensitivity!

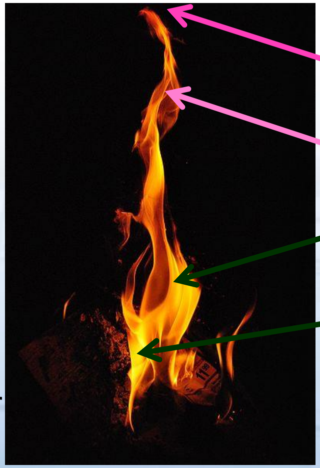
3.9µm

•Hotspots are easily detected
•Total absorption of ground radiation by CO_2
• BT is temperature of the **CO_2 layer** above the fire
•100m minimum fire size for Meteosat pixel
•Sun noticeable (~20 K), but truncated by 3.9µm channel dynamic range limit (333K)
•Difficult statistics due to man-made fire generation (e.g. after harvest)

Karthala, Met-8, 29 May 2006, 12:15 UTC
Natural colours RGB 1.6µm-0.8µm-0.6µm

How hot is lava?

Abundant CO_2
..and soot...



500K, air nearby
800K, orange gas
1100K, yellow
1400K, white tones
300K, neighbour pixels

Which one is the “fire temperature”?

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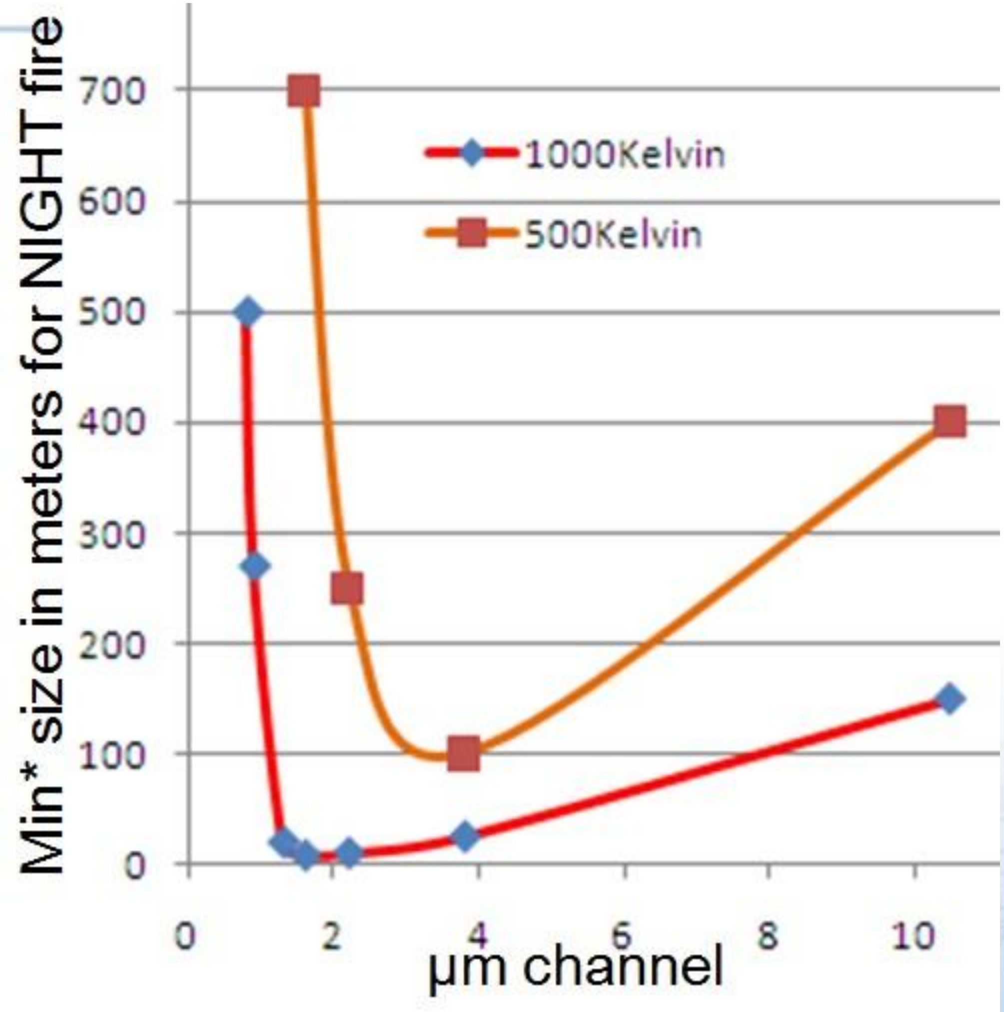
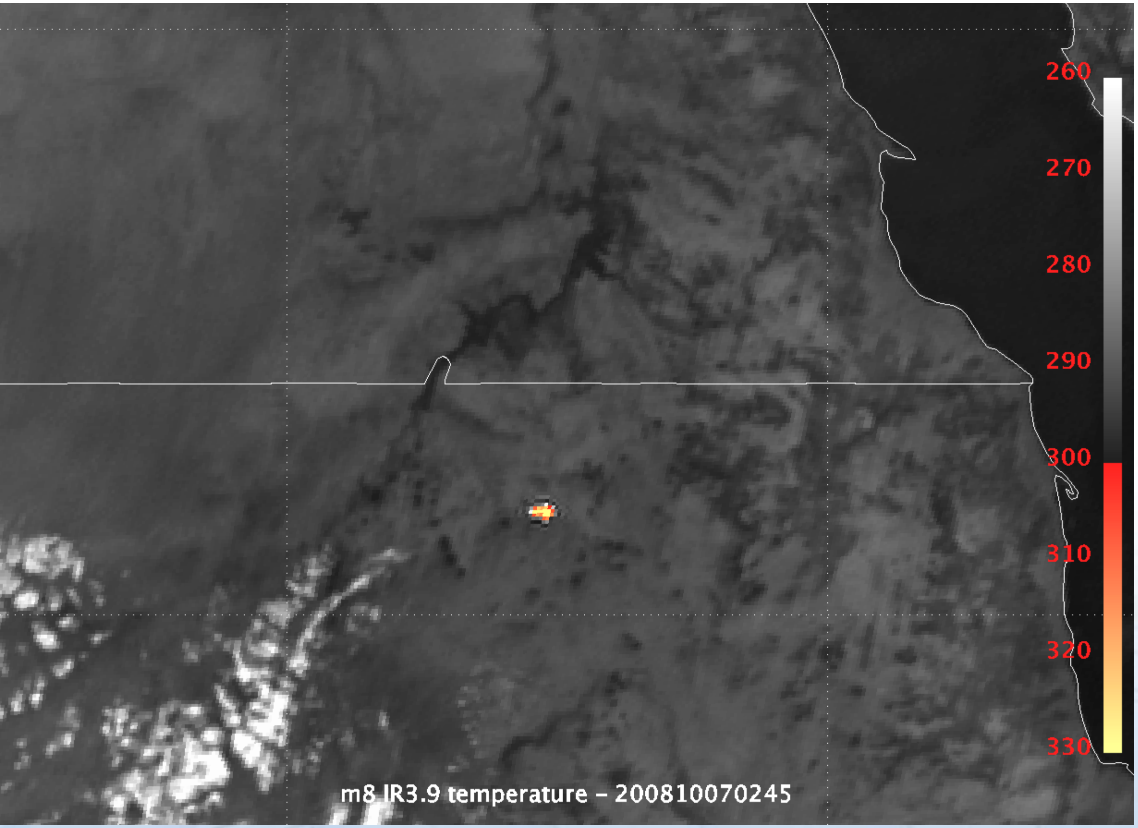
The fire traffic-lights

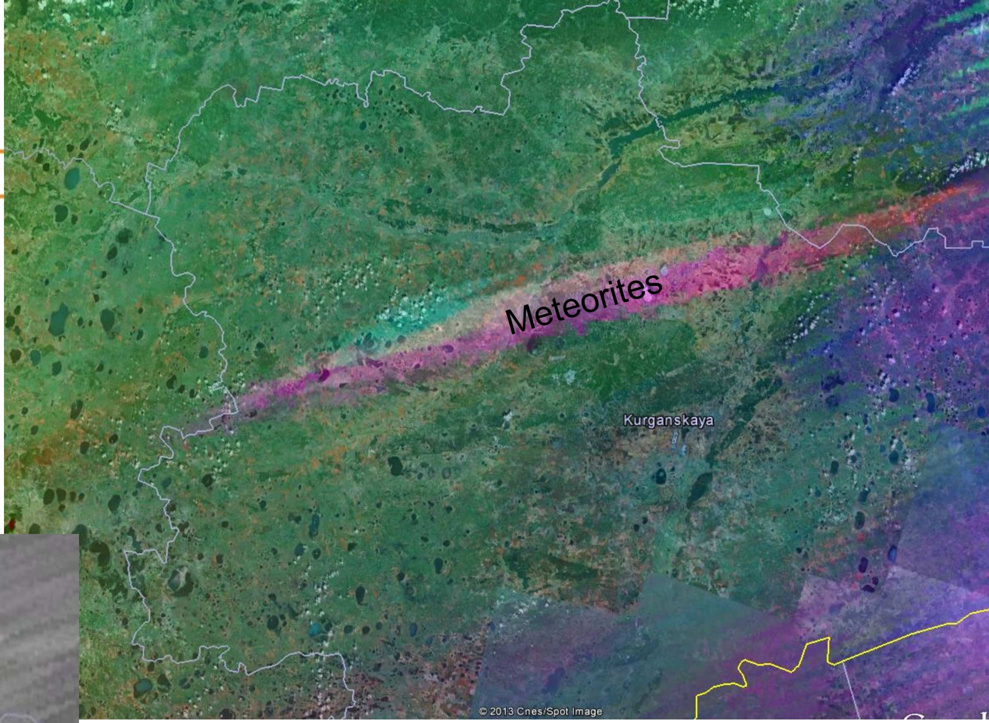
- A fire at 500K will be sensed, as it grows
- first by 3.9µm(at ~100m)
- second by 2.2µm (250m)
- third by 10.8µm (400m)
- An RGB=(3.9;2.2;10.8) might be a good indicator for severity of a fire.
- For a hotter fire (1000K), typically gas flares, channels in the solar domain react faster than 3.9µm

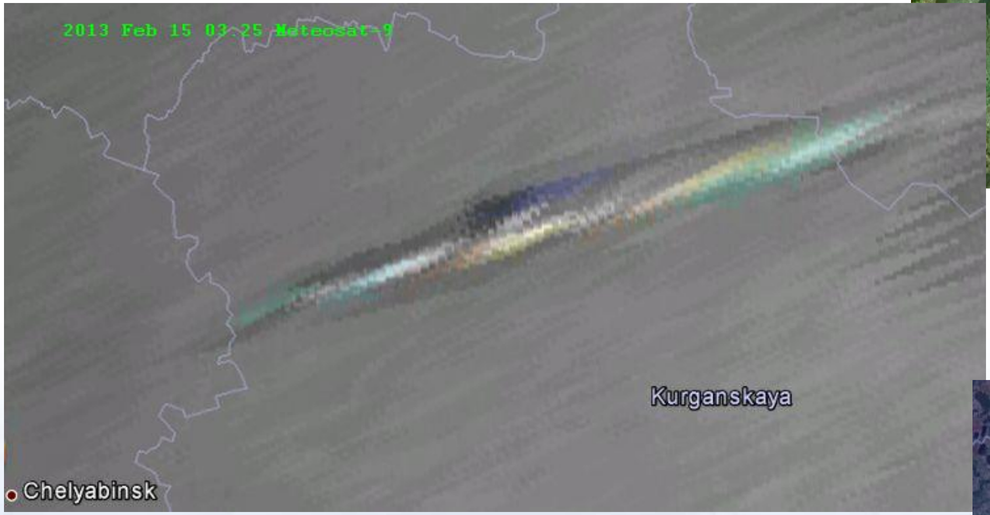


Meteorites on 3.9 µm images



Subpixel detection at 3.9µm: Meteorites

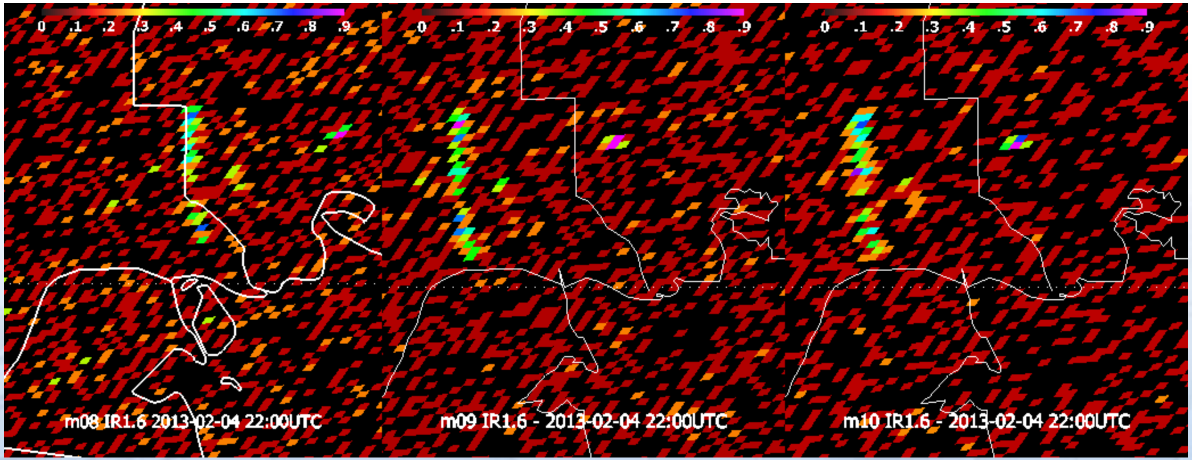




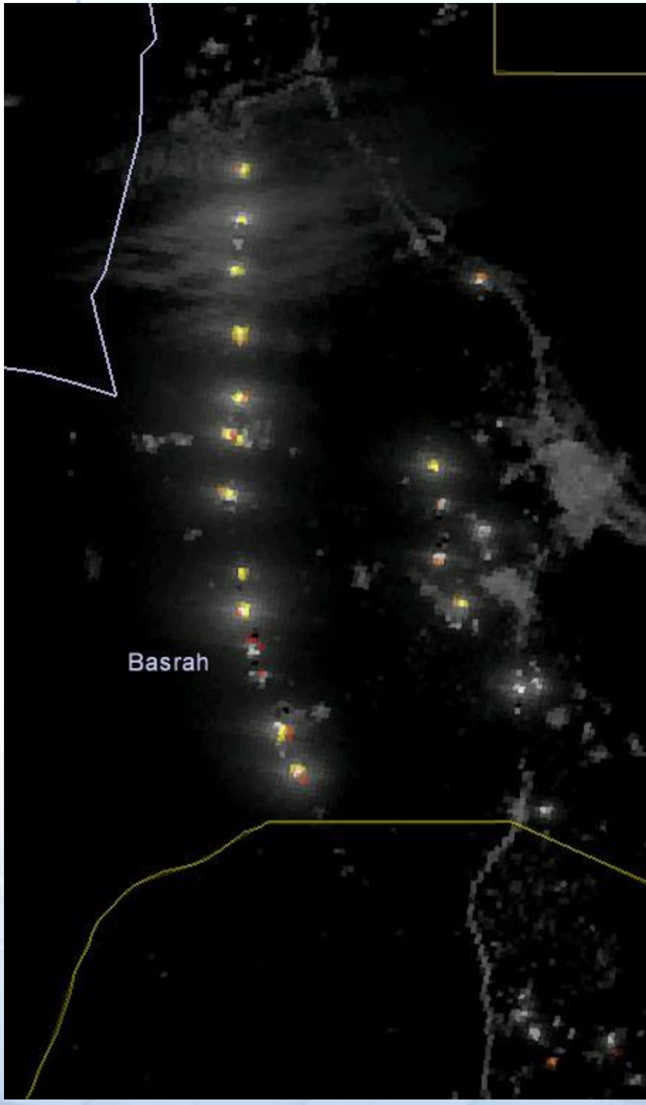
Colour from Meteosat-9 channel 3.9µm.
Blue=270K Red=280K

Meteosat IR dynamic range top limits (kelvin)

Channel (µm)	3.8	8.7	9.7	10.5	12.3	13.3
Absorber	CO2	Sx	O3	small	H2O	CO2
Dynamic MSG	335	300	310	335	335	300
Dynamic MTG	580	330	310	340	340	300



Meteosat-8,9,10 looking concurrently at gas flares in Kuwait through channel 1.6µm



VIIRS 2013-02-17:2200

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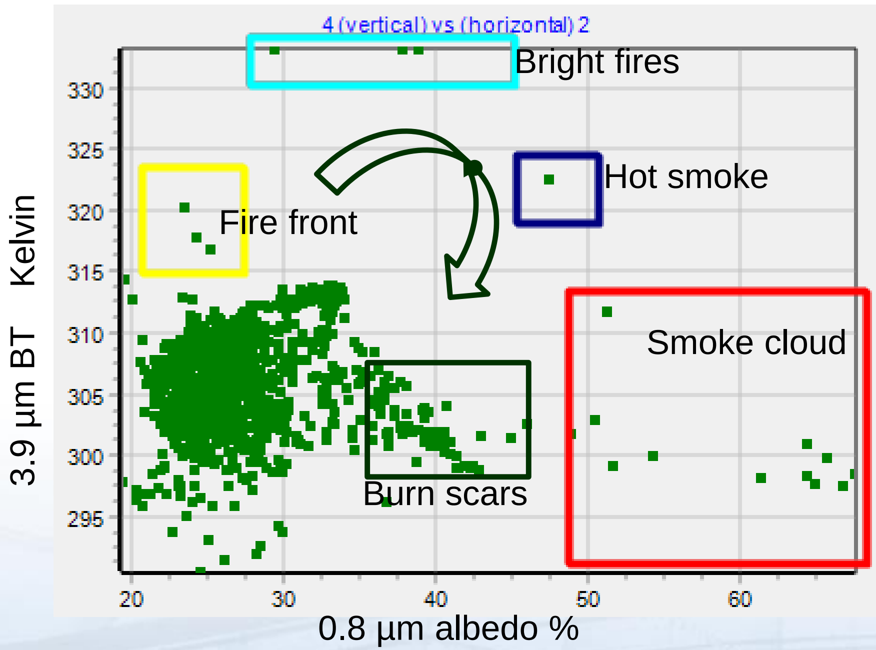
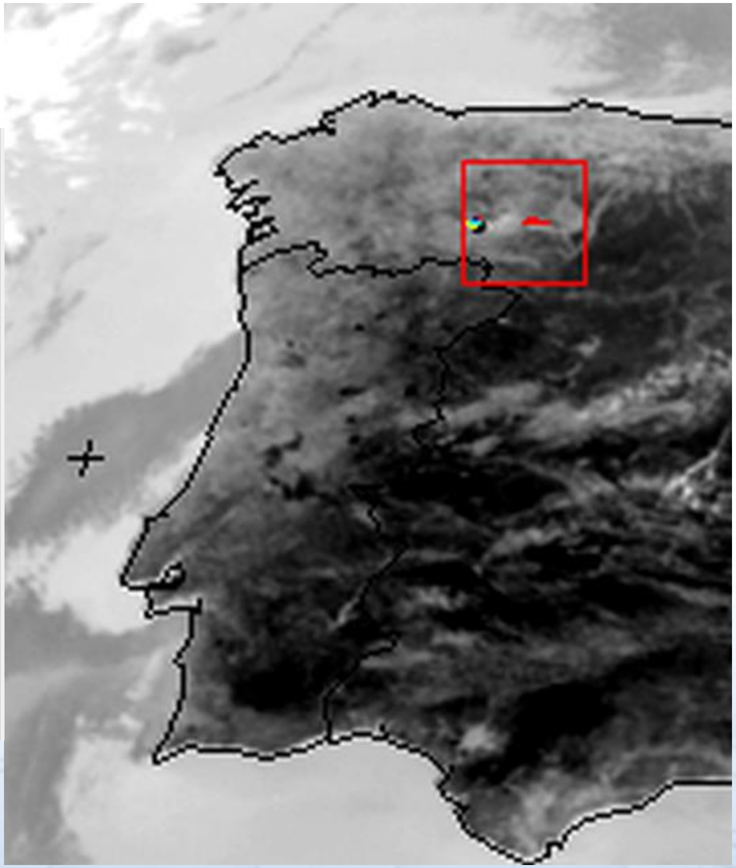
The pixel cycle

Met-10 Ch4 2017-08-22 14Z

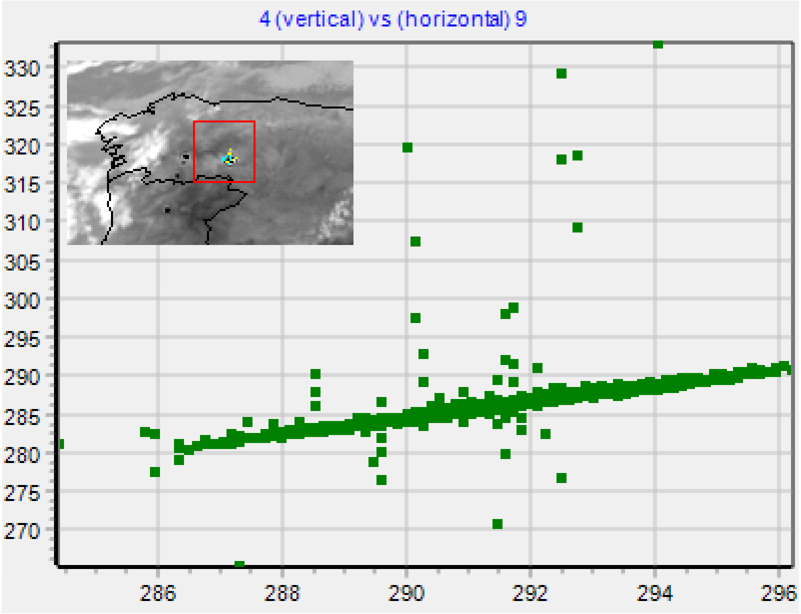


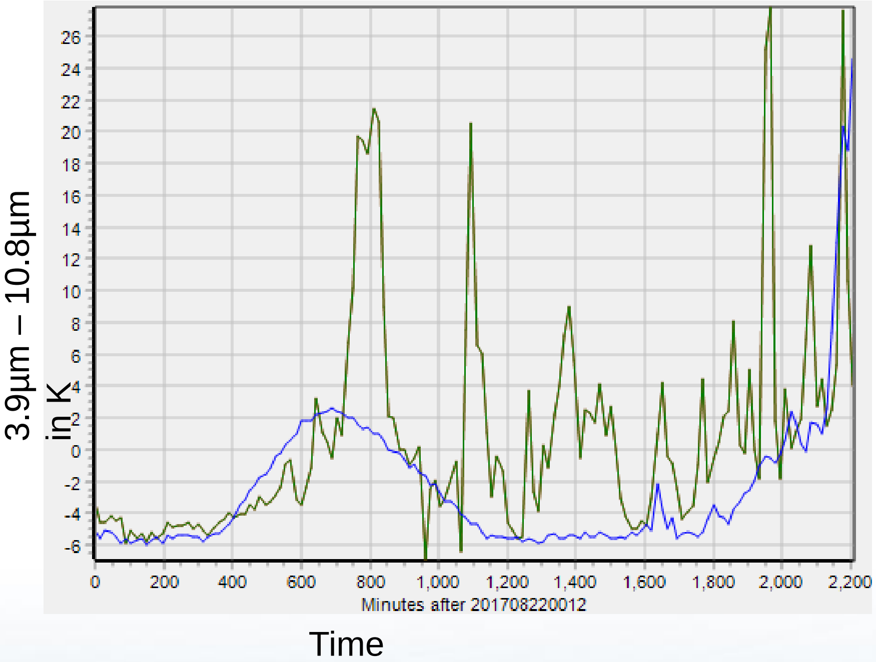


Fire fronts can increase the pixel albedo, first by the flames emission, later by changing the ground into a burnt surface, more reflective than a forest.

West wind

Burnt pixels and hot pixels





The diagram shows in green values for pixels inside the red square (inset)

What are the pixels above the main long cluster?

What are those pixels under the cluster?

When was the main burning phase for the pixel in green? (blue pixel is fire and cloud free, 200 km south)

What are the other peaks in the green curve?

Does the fire get variable in intensity?

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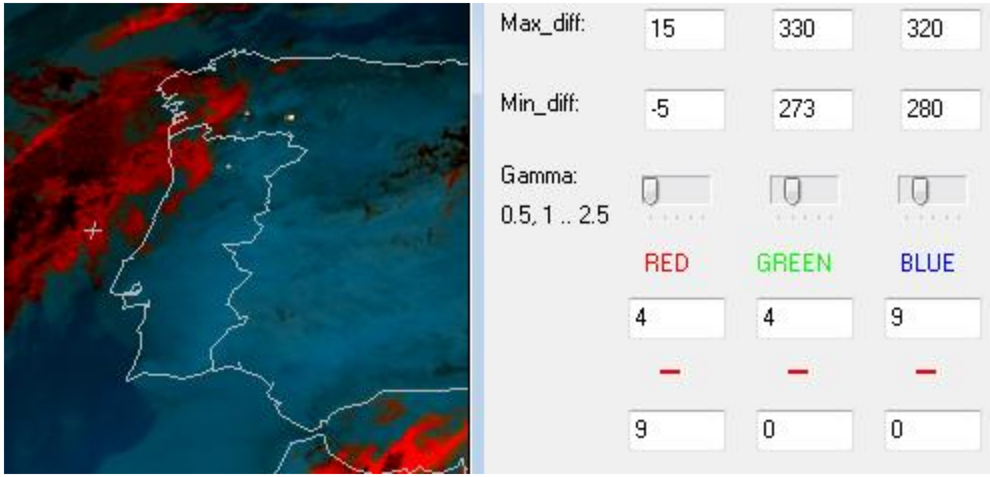
A fire RGB (4-9, 4, 9)



Cloud, as a hiding factor, in reddish hues
Fire in yellow, more intense for stronger fire.
fermoselle.gif

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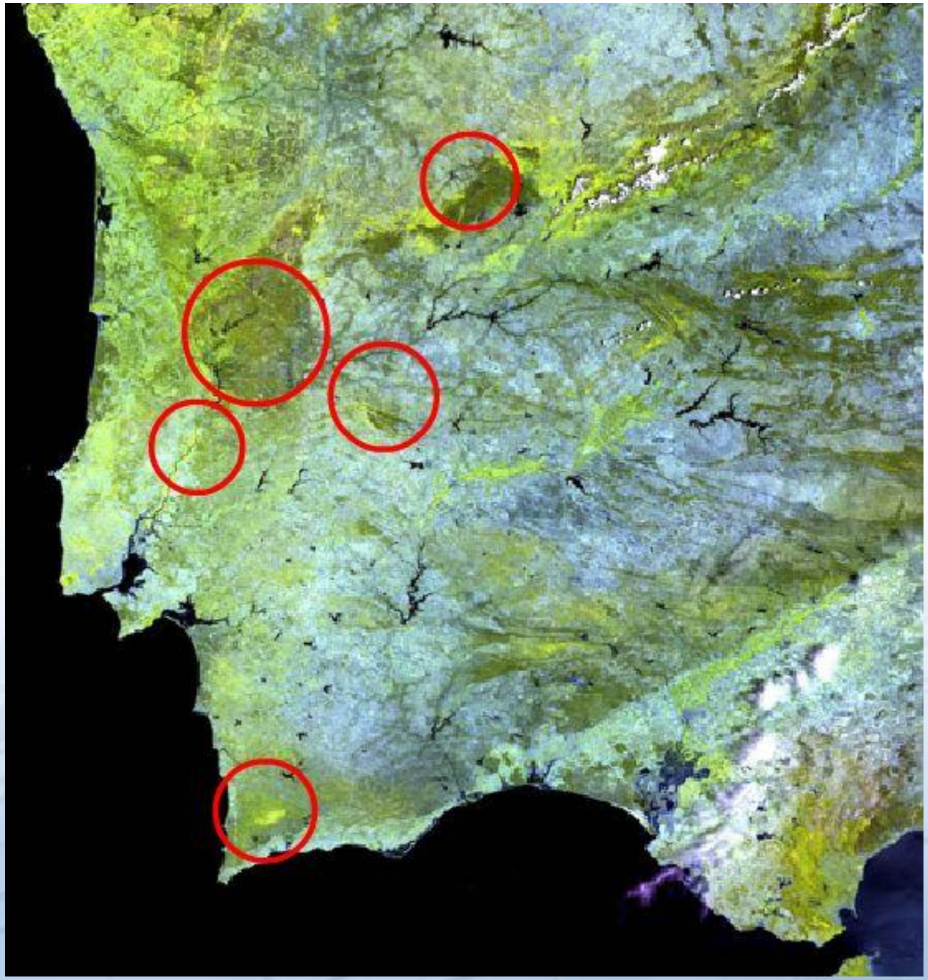
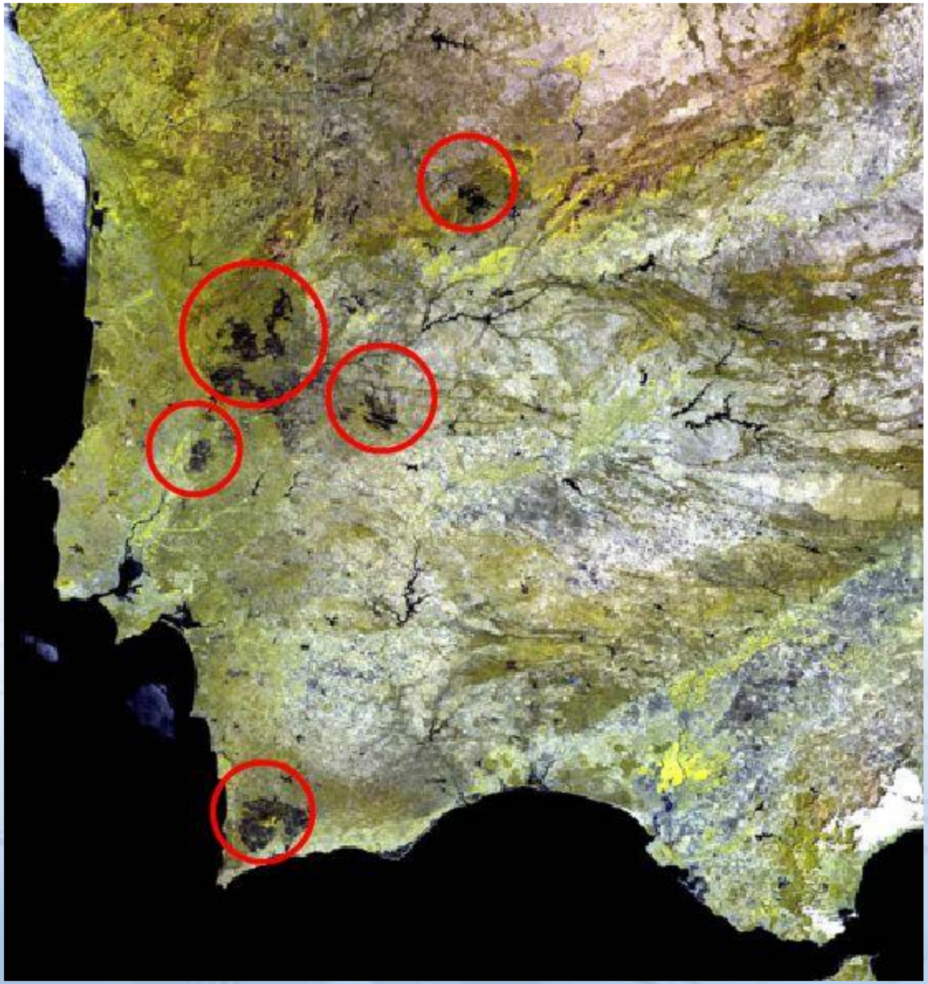
Effect of fire on vegetation can be measured by satellite

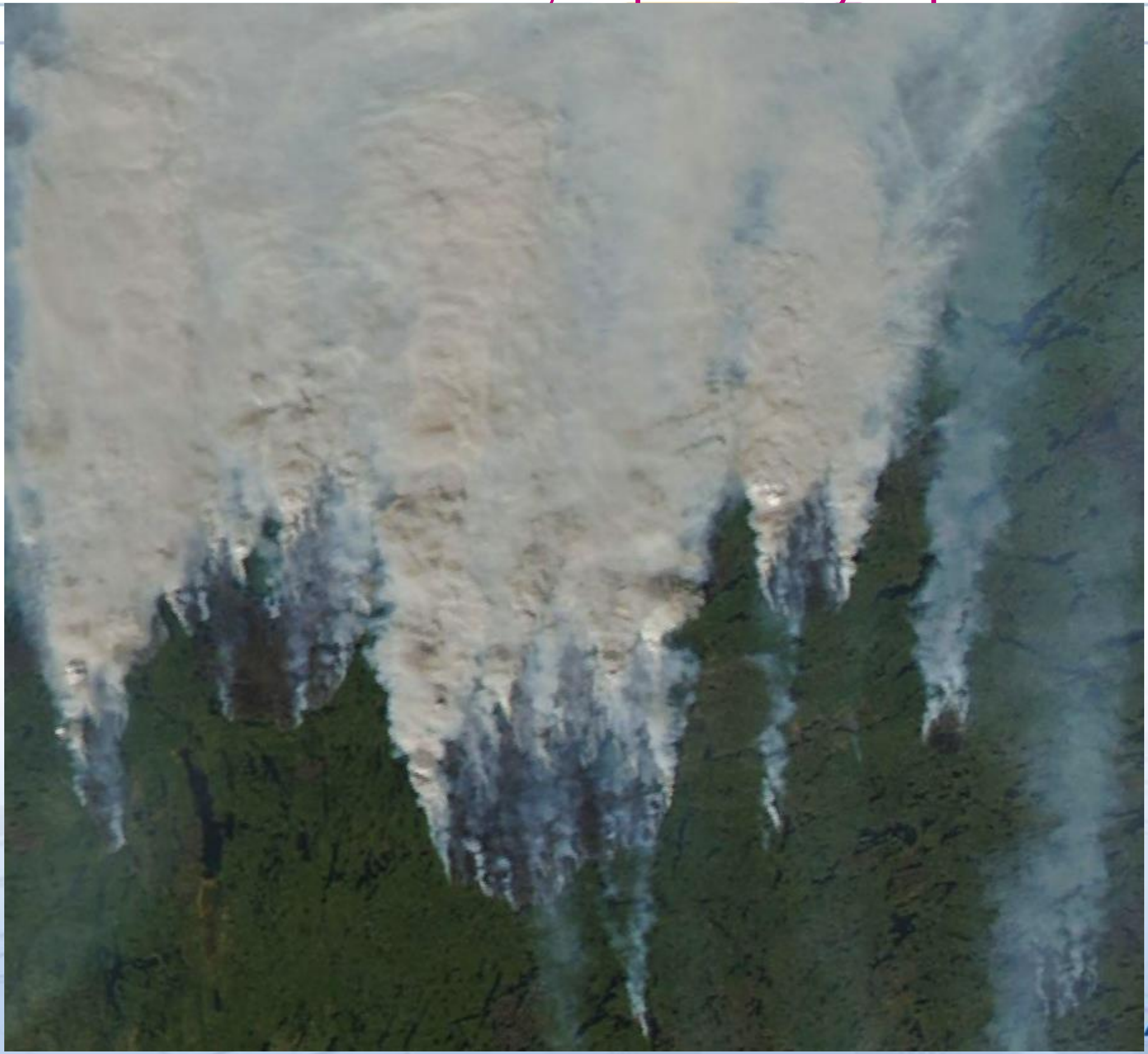
- Fires August 2003 Portugal: 5% of portuguese territory
- Scars can be evaluated on solar channels





Fires in Canada (2017 Aug 14)

North of lake Athabasca, captured by Aqua



100km

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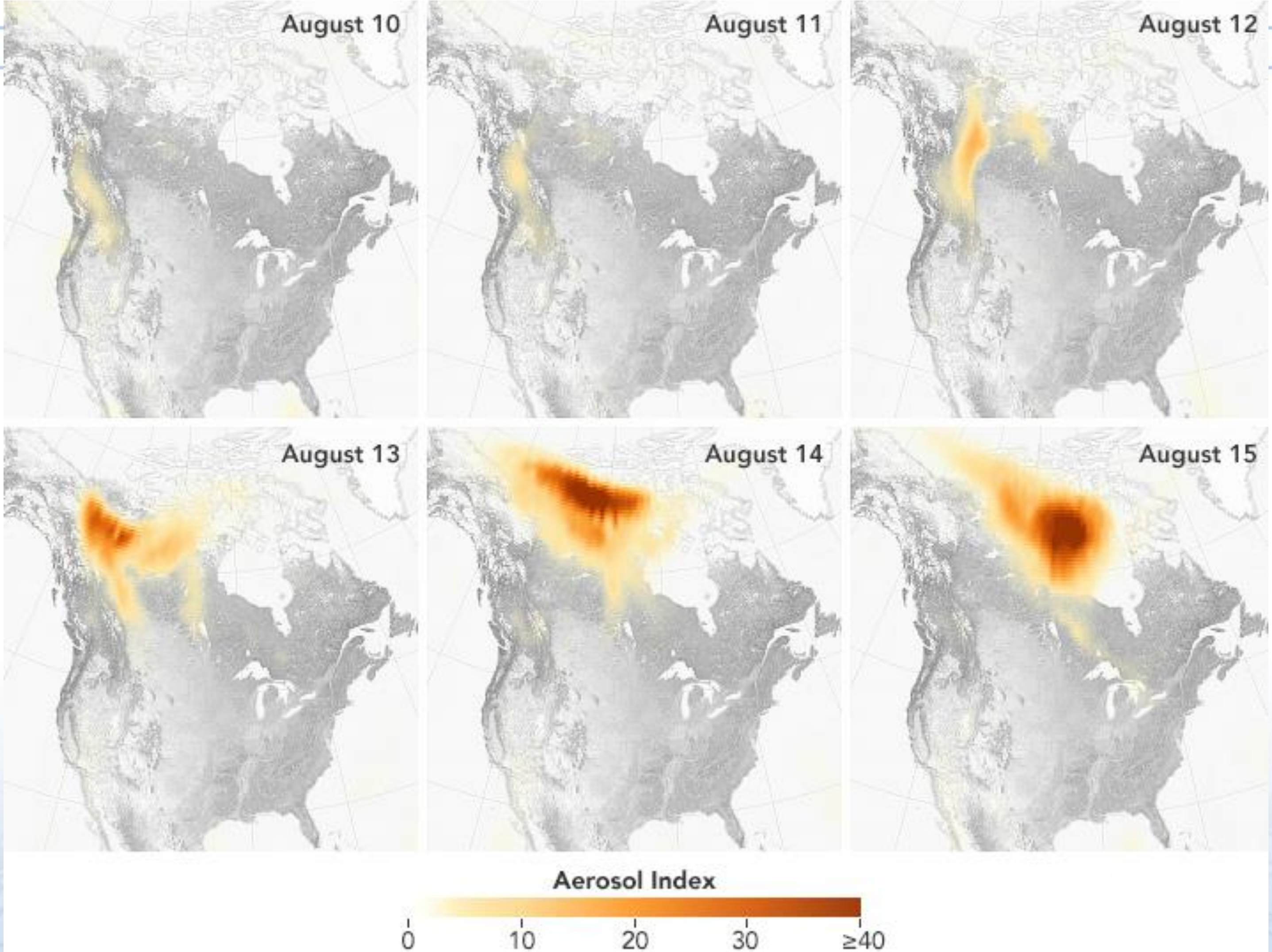
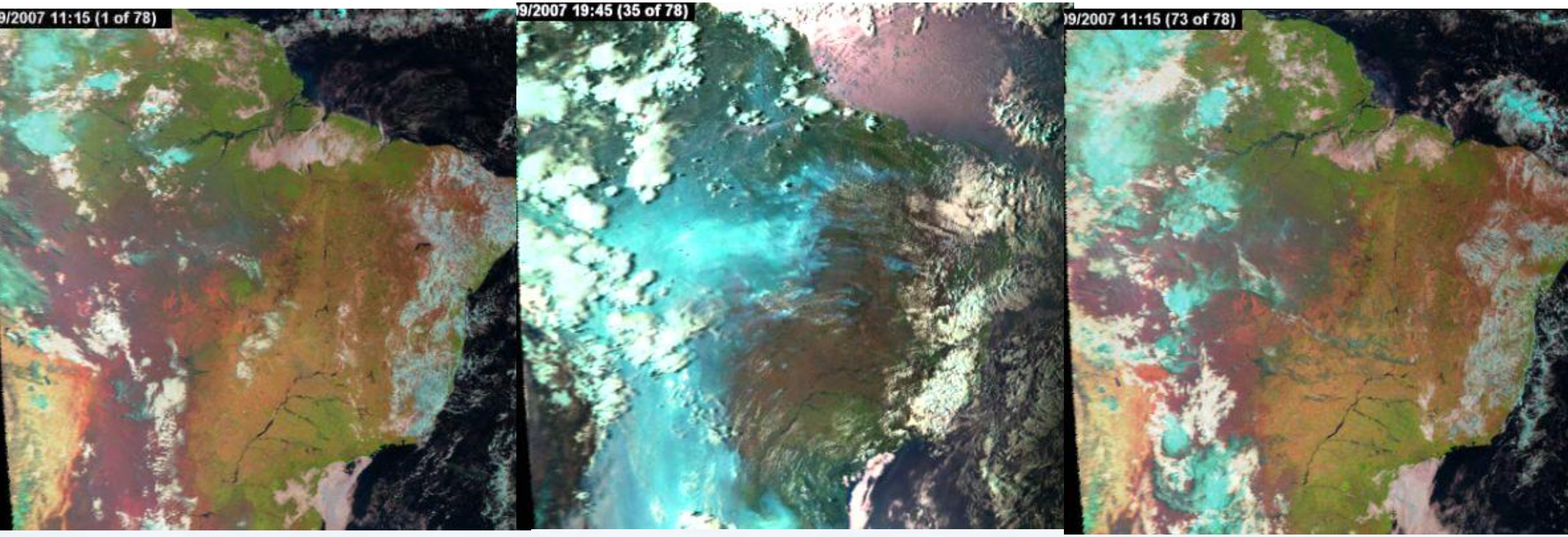
Smoke: British Columbia (Canada) fires August 2017



-Aerosol Index (340/380 nm) is affected by height, AOT and absorption (SSA), plus mixing with cloud.
-Pyrocumuli do not appear for low values of AI (AI<6), but they spout ash into the troposphere.

EUMETSAT

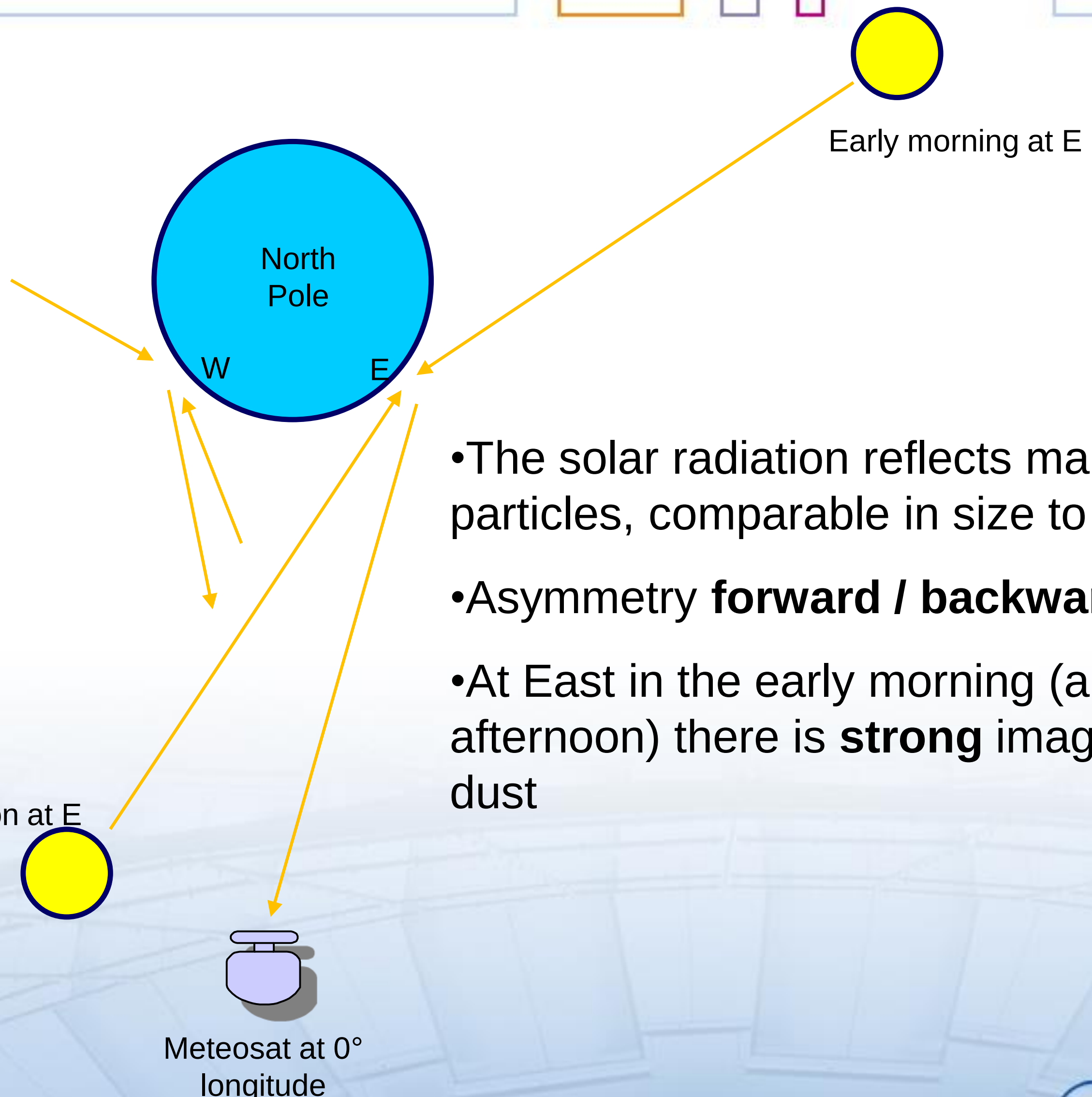
Smoke



5-6 September 2007, Meteosat-9
Around sunrise and sunset times for central south America

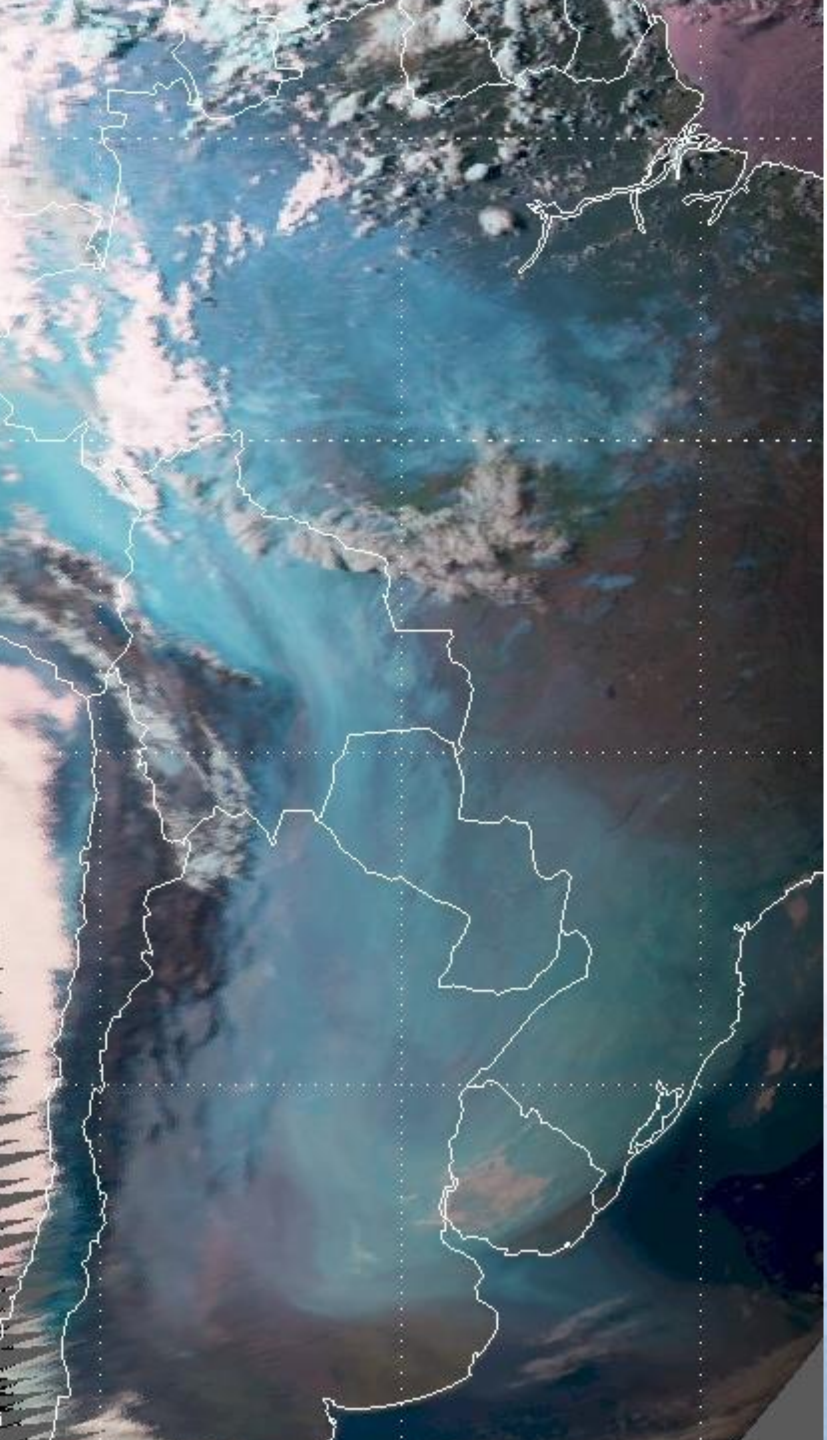
Assuming no major smoke sink or source in 24 hours, the intensity difference is due to the sun angle

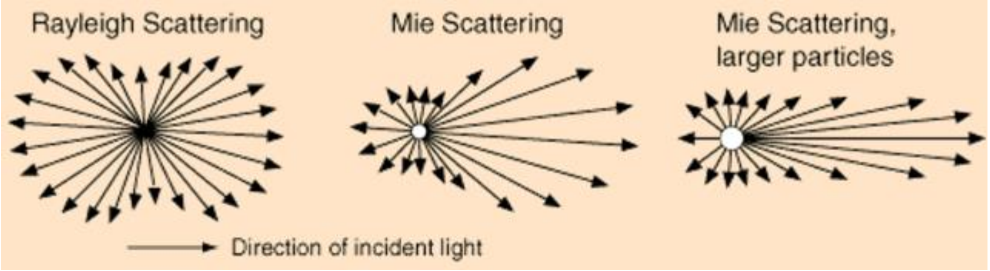
Image contrast for smoke or dust in solar images



- The solar radiation reflects mainly **forwards** on smoke particles, comparable in size to the wavelengths (Mie)
- Asymmetry **forward / backward** for a.m and p.m.
- At East in the early morning (and at West in the late afternoon) there is **strong** image contrast for smoke or dust

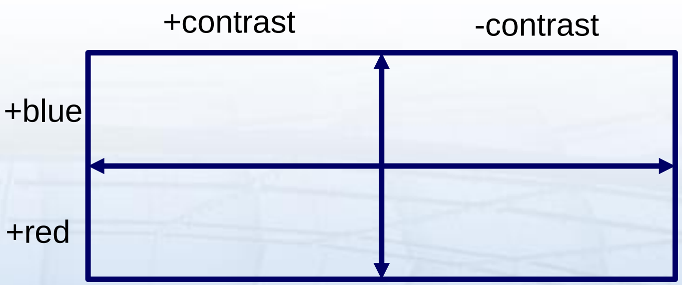
Meteosat9, 2010-08-21 2015 UTC

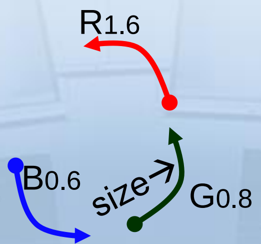




- Smaller wavelengths favoured by forward scattering
- Blue-cyan colour due to 1.6 µm rather Rayleigh
- Scattering intensity higher in the western late afternoon

What if smoke particles were **smaller**?
More contrast (intense)? Redder or bluer in hue?

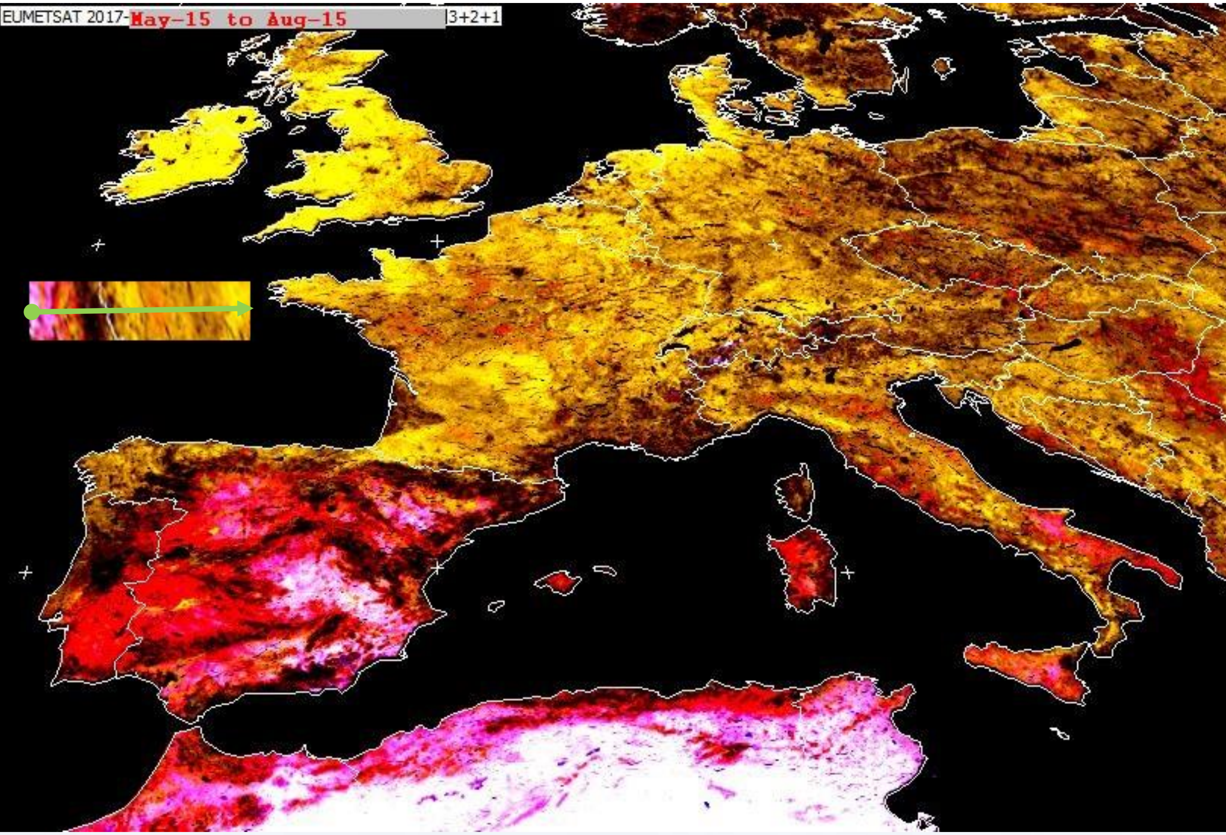




Smaller Bigger

EUMETSAT

Drought as a fire risk indicator



Dry + Vegetation = Fire risk

Algorithm based on RGB=(min_in_period(max_on_pixel(c3,c2))
min_in_period(c2)
min_in_period(c1))

Fire risk areas in brown or red.

Conclusions

- Channel 3.9µm in Meteosat is an excellent detection tool for active fires above 100m across (1 Ha), and for measuring the burnt area as reflectivity changes in large areas

- Statistics on fires (natural or man-made) are missing or affected by sensor saturation. However, an approximate retrieval can be attempted based on frequency curves below saturation

- The Land SAF offers a large choice of vegetation products to assess vegetation stress and **fire risk**

THANK YOU FOR YOUR ATTENTION!

EUMETSAT

http://training.eumetsat.int/pluginfile.php/12356/mod_resource/content/8/fire.html

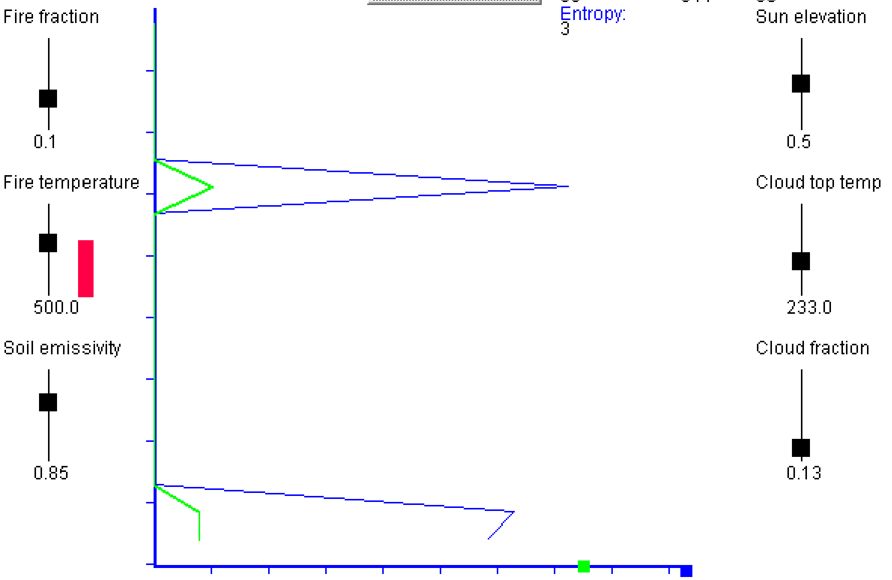
In the EUMETSAT moodle repository above. Not displayable in Chrome

Fires brightness temperature (BT)
This applet interface describes with sliders the characteristics of the atmosphere, and provides the BT at 3.9µm (or 10.8µm with the button) for different types of soil, times of the day (sun elevation), intense and extensive fires and cloud above.
Green indicates the amount of cloud, fire and soil emissivity (bottom green square). Blue is the fraction of radiation from different sources exiting the Earth, the rest being absorbed by the Earth-atmosphere. The global value is given in upper line. The reddish square close to the Fire Temperature slider gives an idea of the extent and intensity of the fire and its size depends on the first two sliders. Its colour is given by the brightness temperature difference (fire impact) with and without the fire. Red indicates that the difference is above 5 K, so the satellite could see the fire.
The bottom table specifies the actual amounts of energy exchanged by the elements in the scene, relative to 100000 photons emitted in total by all surfaces, upwards and downwards.
Back to work:
1. First, set all sliders to 0, but “Soil emissivity” to 1 (absolutely non-reflective ground. Usually, it should be between 0.50 for desert or savannah and 0.85 for thick forest). Notice 100% of the emitted radiation reaches the satellite. This proportion will decrease when new sources are added.
2. Set the Cloud thickness to some intermediate value, and observe the changes. What do you expect for a brightness temperature, as a function of the Cloud top temperature? Are you correct? If not, why?
3. Back to Cloud thickness zero, try with Sun elevation, the sun rising over the horizon and sending radiation at 3.9µm into the atmosphere and back to the satellite. Any changes when you move the slider? How does BT vary when we change Soil emissivity on the ground?

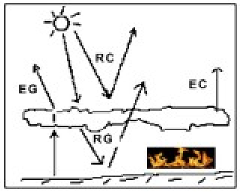
EUMETSAT

Brightness temperature at 3.9 micron for detecting fire in the pixel

FIRE DETECTION AT 3.9µm | At 10.8µm instead! | % exiting: 36 | Entropy: 3 | BT: 344 | fire impact: 39



	ToGround	ToFire	ToSmoke	ToCloud	ToSatel
From Ground	15	625	587	644	4370
From Fire	13548	230	1807	2081	14134
From Smoke	12163	1802	209	2419	15207
From Cloud	21	1	1	1	32
From Sun	17974	2627	2854	4299	2343



jose.prieto@eumetsat.int

Have you paid attention?

- Fire analysis from satellites is a complex matter
  - Yes
  - No
- Channel at 3.9µm on Meteosat is useful because
  - It responds to small thermal anomalies in the pixel
  - It works day and night (but better at night)
  - It offers continuous coverage on the fire evolution
- Smoke can be seen in Meteosat images
  - At solar channels
  - At 3.9µm
  - Better at boundaries of the field of view
- Average images of previous months provide for risk maps
  - Yes

EUMETSAT

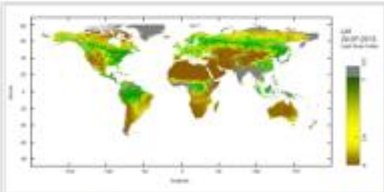
land.copernicus.vgt.vito.be/PDF/portal/Application.html#Home

Copernicus Global Land Service

Providing bio-geophysical products of global land surface

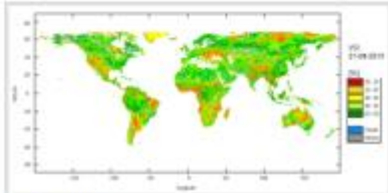
Vegetation State

VEGETATION PROPERTIES



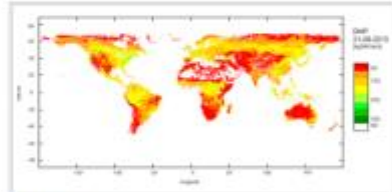
Collections

VEGETATION INDICATORS



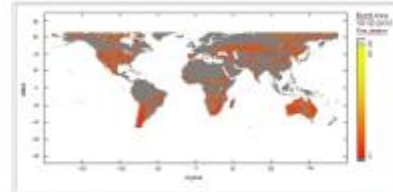
Collections

BIOMASS



Collections

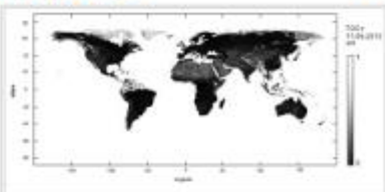
FIRE DISTURBANCE



Collections

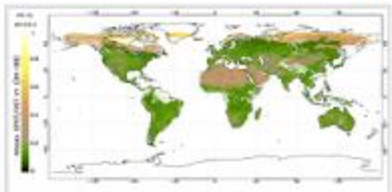
Energy Budget

TOP OF CANOPY REFLECTANCE



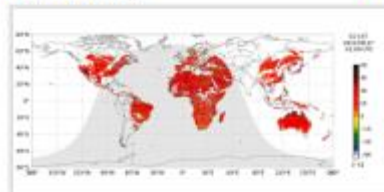
Collections

ALBEDO



Collections

LAND SURFACE TEMPERATURE



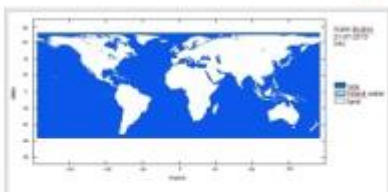
Collections

Water Cycle

SOIL WATER

Collections

WATER BODIES



Collections