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Overview of the IR channels and their applications

EUMeTrain, 14 May 2014

Basics in satellite Infrared image interpretation

- The origins of the infrared radiation
- MSG SEVIRI channels introduction – IR channels
- Practical aspects of utilization of MSG SEVIRI data
- Examples of IR images visualization and their applications

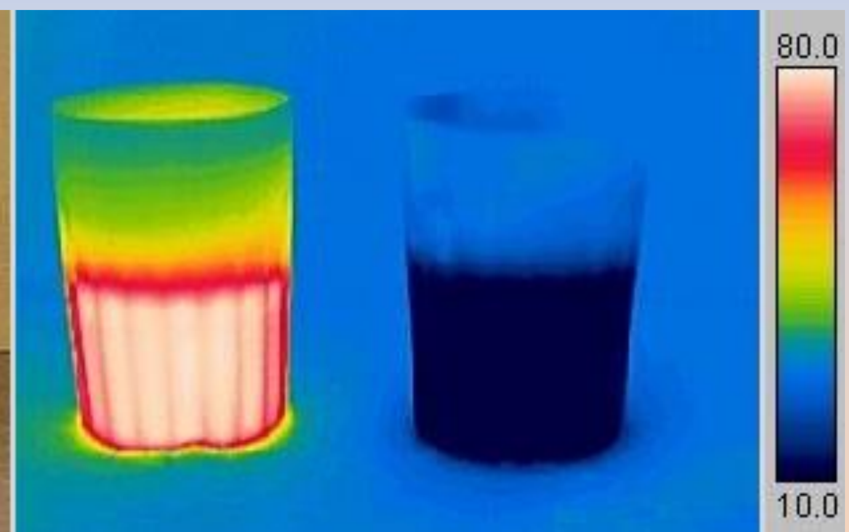
THE ORIGINS OF THE INFRARED SPECTRUM

Thermal radiation is the emission of electromagnetic waves from all matter that has a temperature greater than absolute zero. It represents a conversion of thermal energy into electromagnetic energy.

Thermal energy is the collective mean kinetic energy of the random movements of atoms and molecules in matter.

Visible light:

Thermal radiation:



THE ORIGINS OF THE INFRARED SPECTRUM

(continue 1)

The electronic component is linked to the energy transitions of electrons as they are distributed throughout the molecule, either localized within specific bonds, or delocalized over structures.

The vibrational energy component corresponds to the absorption of energy by a molecule as the component atoms vibrate about the mean center of their chemical bonds.

Rotational energy is observed as the tumbling motion of a molecule, which is the result of the absorption of energy within the microwave region.

In general - every form of energy mentioned above can be emitted if electronic, vibrational or rotational excitation is presented in the mass microstructure.

$$E_{\mathrm{total}} = E_{\mathrm{electronic}} + E_{\mathrm{vibrational}} + E_{\mathrm{rotational}}$$

THE ORIGINS OF THE INFRARED SPECTRUM
(continue 2)

In meteorology - thermal radiation is an important concept in thermodynamics as it is partially responsible for heat transfer between objects, as warmer bodies (Earth surface) radiate more heat than colder ones (clouds).

$$\alpha + \rho + \tau = 1$$

α represents spectral absorption factor

ρ is spectral reflection factor

τ is spectral transmission factor

All these elements depend also on the wavelength λ

The spectral absorption factor is equal to the emissivity ε

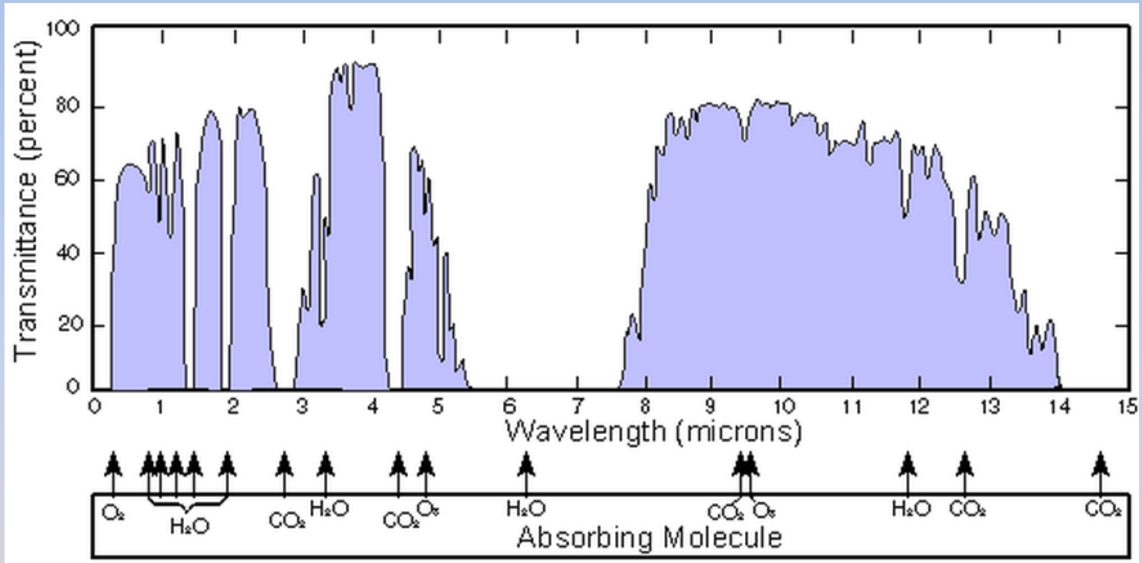
An object is called a black body if, for all frequencies, the following formula can be applied:

$$\alpha = \varepsilon = 1$$

Different regions in the infrared electromagnetic radiation

3 different division schemes – CIE, ISO 20473 and astronomy division scheme; in general We can adopt following scheme:

Near IR	from 0.75 – 1.4 µm
Short IR	from 1.4 – 3 µm
Mid IR	from 3 – 8 µm
Long IR	from 8 – 15 µm
Far IR	from 15 – 1000 µm



In this lesson we will introduce only mid and long IR bands and we will deal especially with the most frequently used IR channels with **<u>wavelength between 10 – 12.4 µm</u>**.

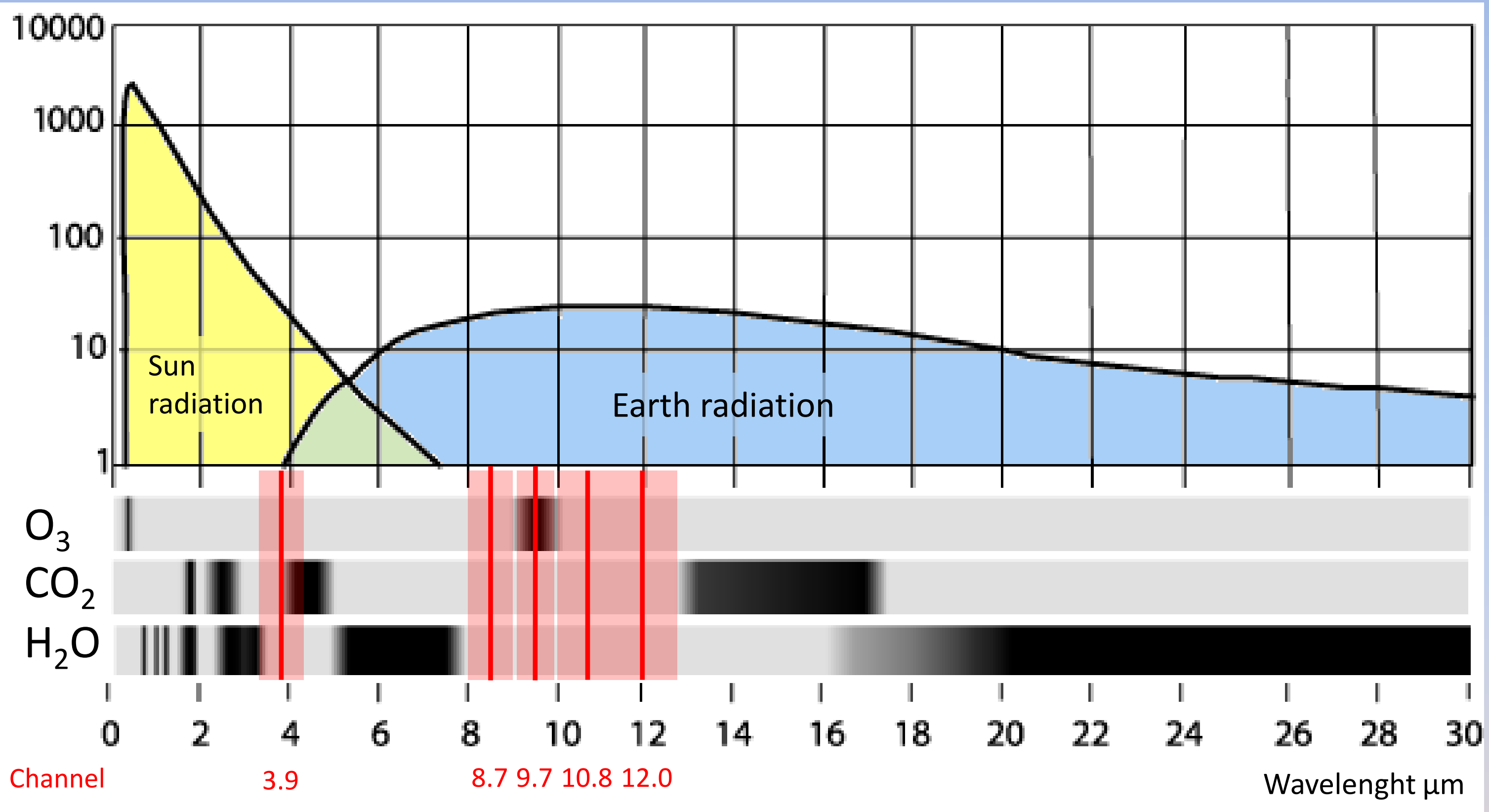
Transmittance refers to radiation passing the atmosphere and can be described by exponential function of the path x:

$$T=e^{-\alpha x}$$

MSG SEVIRI channels introduction

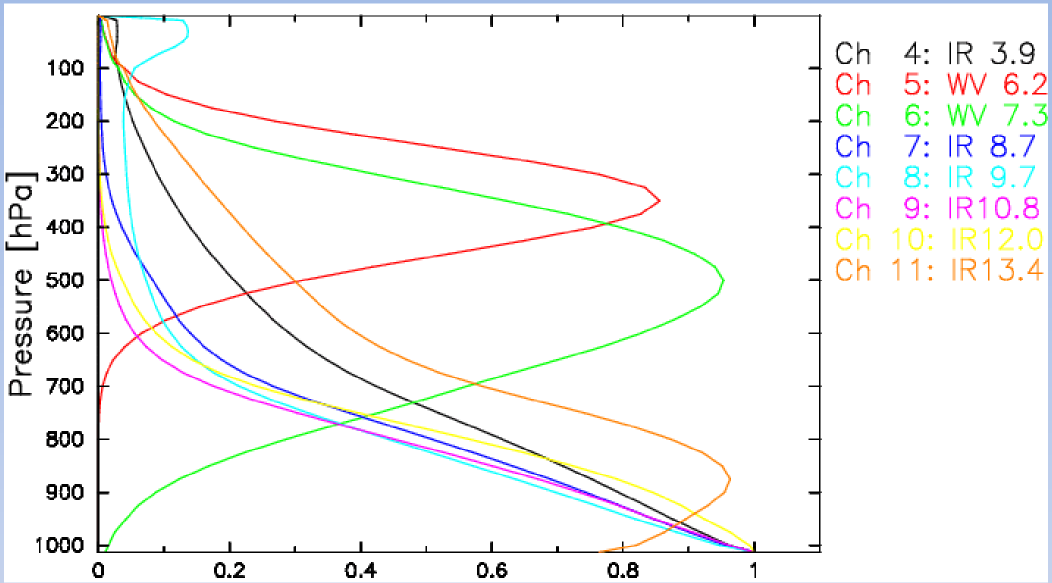
Channel No.	Spectral Band (µm)	Characteristics of Spectral Band (µm)			Main observational application
		λ_{cen}	λ_{min}	λ_{max}	
1	VIS0.6	0.635	0.56	0.71	Surface, clouds, wind fields
2	VIS0.8	0.81	0.74	0.88	Surface, clouds, wind fields
3	NIR1.6	1.64	1.50	1.78	Surface, cloud phase
4	IR3.9	3.90	3.48	4.36	Surface, clouds, wind fields
5	WV6.2	6.25	5.35	7.15	Water vapor, high level clouds, upper air analysis
6	WV7.3	7.35	6.85	7.85	Water vapor, atmospheric instability,upper-level dynamics
7	IR8.7	8.70	8.30	9.1	Surface, clouds, atmospheric instability
8	IR9.7	9.66	9.38	9.94	Ozone
9	IR10.8	10.80	9.80	11.80	Surface, clouds, wind fields, atmospheric instability
10	IR12.0	12.00	11.00	13.00	Surface, clouds, atmospheric instability
11	IR13.4	13.40	12.40	14.40	Cirrus cloud height, atmospheric instability
12	HRV	Broadband (about 0.4 – 1.1 µm)			Surface, clouds

Solar and Earth radiation versus atmospheric components absorption bands:

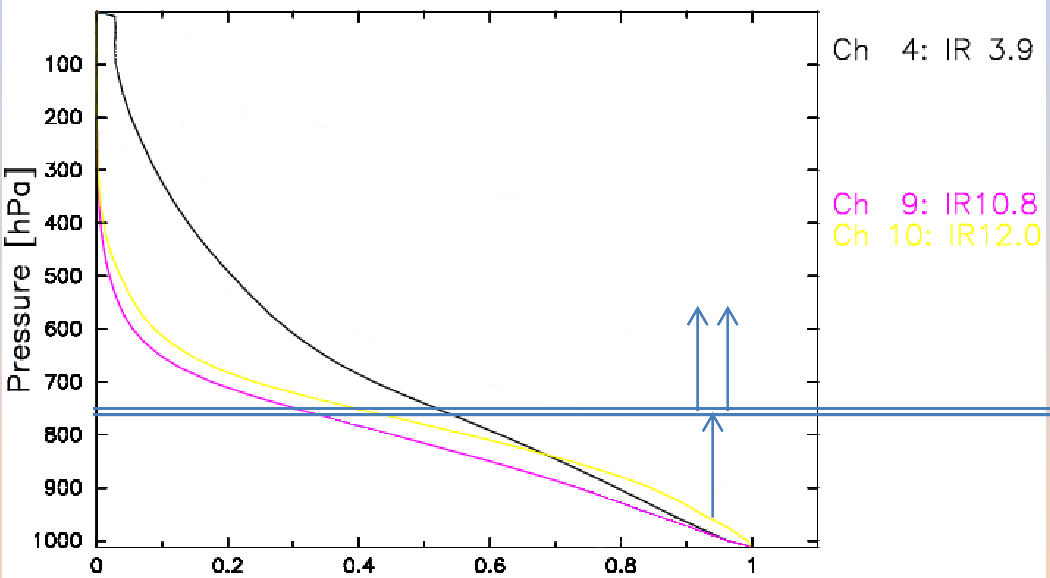


The IR atmospheric windows at 8.7 and from 10 to 13µm provides us with the most simple satellite imagery interpretation during the day and night and are useful for continuous in time and space observation of cloud systems.
Channel 3.9µm is more complicated due to acting Sun and Earth radiation all together and needs different approach of interpretation during the night and during the day.
Channel 9.7µm is intended especially for stratospheric ozone monitoring.

Theoretical normalised weighting functions in IR spectral bands calculated for summer period and mid-latitudes:



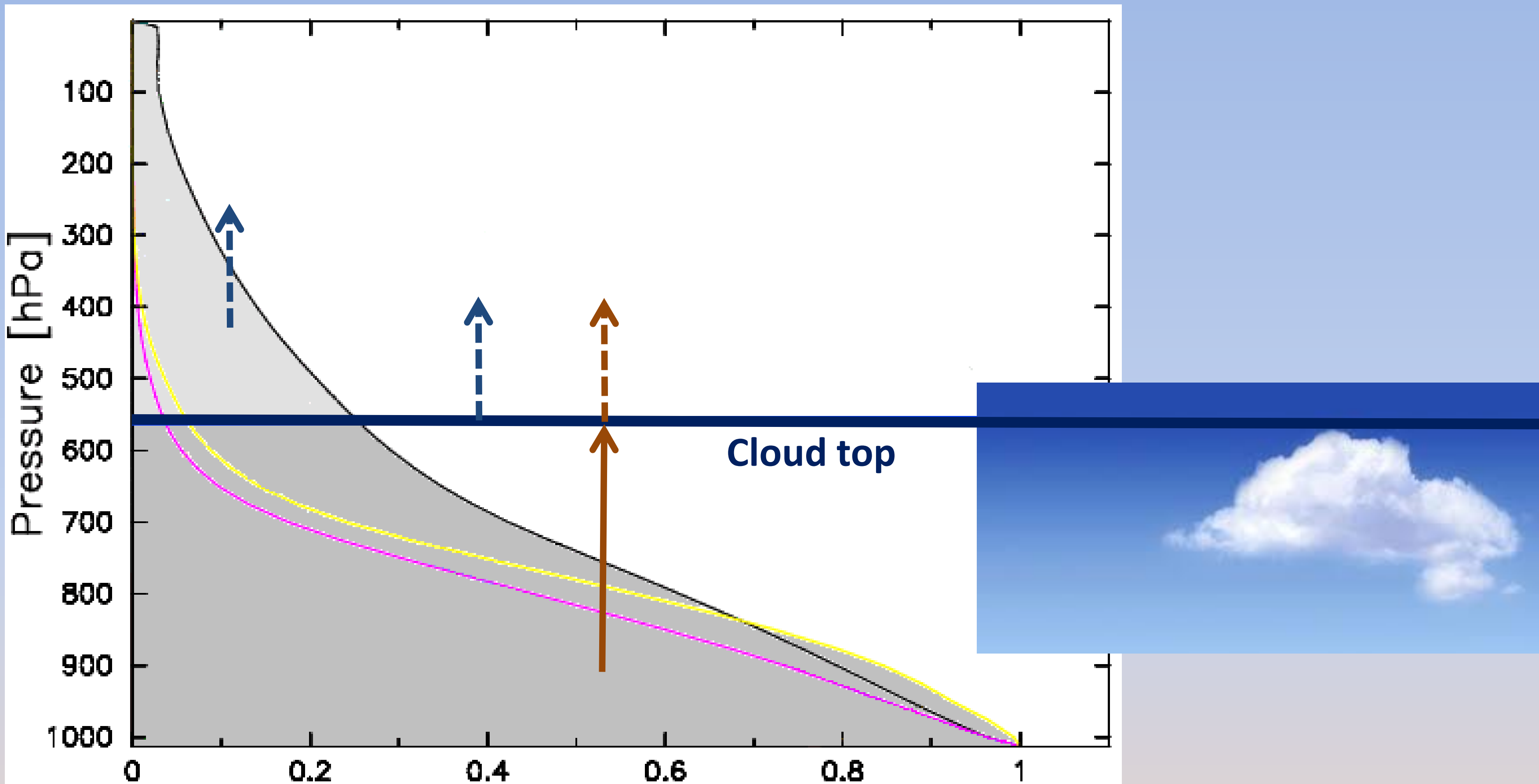
a) For all SEVIRI IR channels of MSG satellite



b) For channels 4, 9 and 10 of MSG satellite

Each horizontal layer acts as:
- a source of emission
- an absorbing filter for radiation from lower layers

Satellite sensor measures integrated radiation at the top of atmosphere:



In case of cloud with black body behavior satellite sensor can measure only radiation coming from cloud top surface and from layers above the cloud top.

In case of semitransparent cloud the radiation measured by satellite is coming from cloud top surface, from layers above the cloud top and partially from layers below the cloud top and from Earth surface but attenuated by semitransparent cloud.

Practical aspects of utilization of IR satellite data

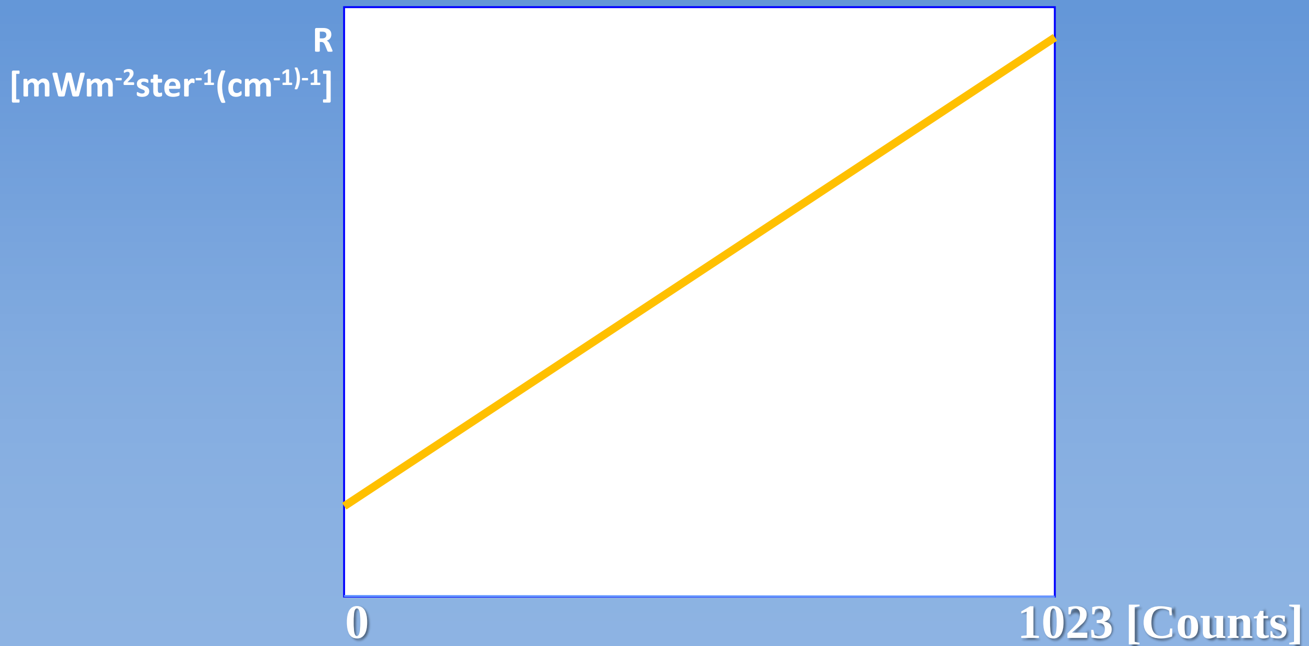
- Instrument/data values – conversion to physical values
- Calibration – calculation of radiances, brightness temperatures
- Mapping – geolocation of scanned data
- Visualisation – imagery with applied look up color tables
- IR image applications – practical use of imagery, detection of meteorological features

Conversion from instrument 10-bit to 16 bit representation:

Count	☐☐☐☐☐☐☐☐☐☐	integer 0..1023	Instrument value
Radiance	☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐	short int->float	Physical value

Conversion from COUNTS to RADIANCES:

$$R = CAL\_offset + CAL\_slope \times Count$$



CALIBRATION parameters are integral part of satellite data sets

Conversion from RADIANCES R to BRIGHTNESS TEMPERATURES T_b:

Planck function $T_b=f(R)$:

$$T_b = \left[C_2 \nu_c / \log\left(\frac{C_1 \nu_c^3}{R} + 1 \right) - B \right] / A$$

Typical precision used in practice:

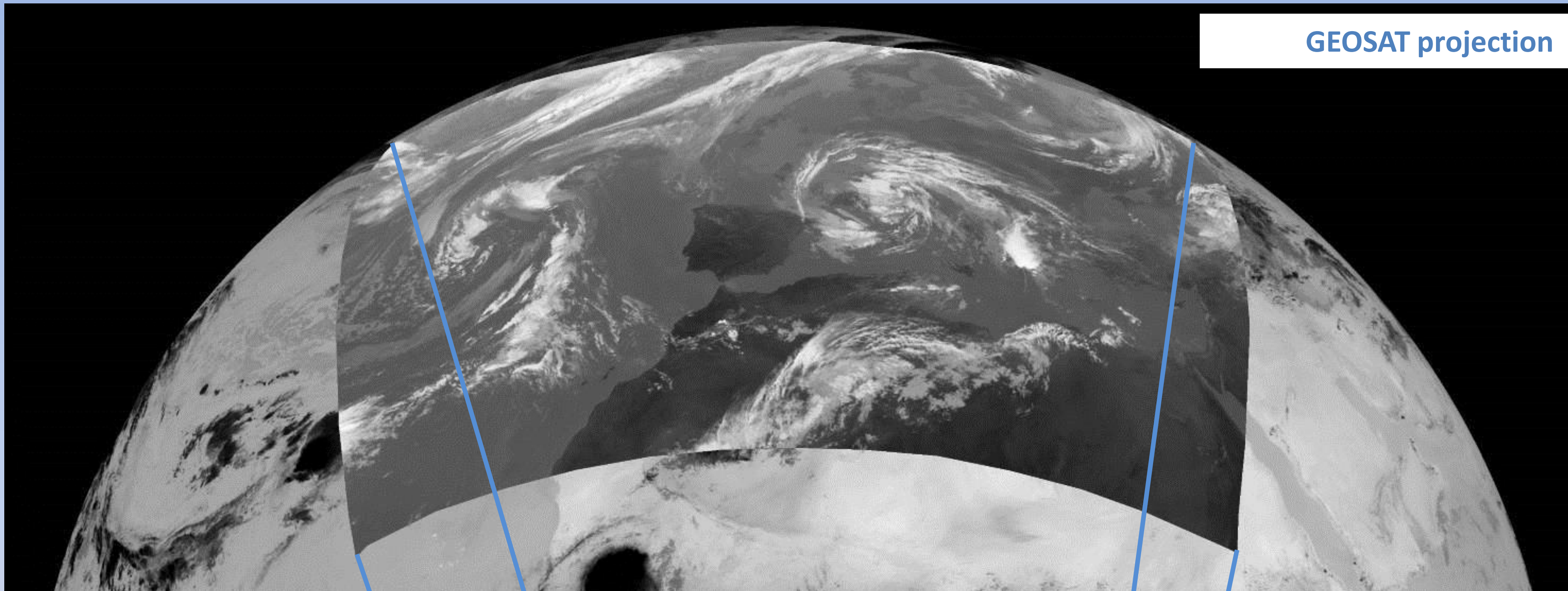
16bit / 0,01K 8bit / 0,5K

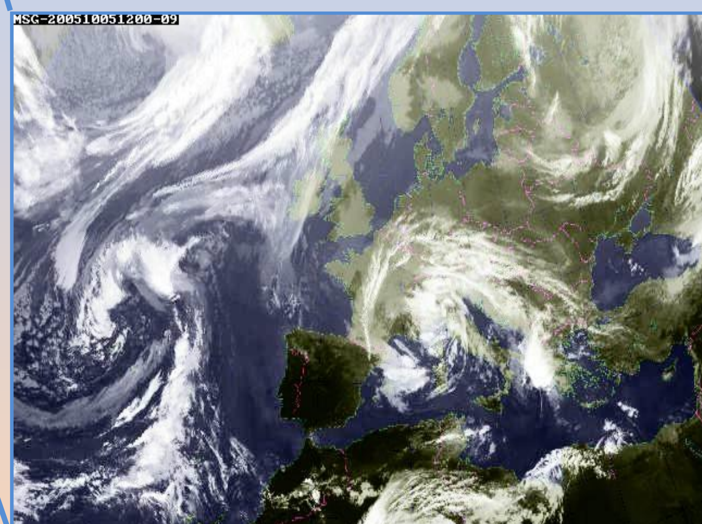
Parameter	Value
Speed of the light in vacuum	**299792458 ms^{-1}**
Planck constant	**6.62606876(52) 10^{-34} Js**
Boltzmann constant	**1.3806503(24) 10^{-23} JK^{-1}**
C_1	**1.19104 10^{-5} $mWm^{-2}sr^{-1}(cm^{-1})^{-4}$**
C_2	**1.43877 $K(cm^{-1})^{-1}$**

Channel	Description	υ_C	A	B
4	IR 3.9	2569.094	0.9959	3.471
5	WV 6.2	1598.566	0.9963	2.219
6	WV 7.3	1362.142	0.9991	0.485
7	IR 8.7	1149.083	0.9996	0.181
8	IR 9.7	1034.345	0.9999	0.060
9	IR 10.8	930.659	0.9983	0.627
10	IR 12.0	839.661	0.9988	0.397
11	IR 13.4	752.381	0.9981	0.576

Applicable for IR channels 4,5,6,7,8,9,10,11

Mapping – geolocation of scanned data:





Math procedure:

For each pixel
in the map to find
matching pixel
in the satellite picture:

$(X_m, Y_m) \rightarrow (\Phi, \lambda) \rightarrow (X_s, Y_s)$

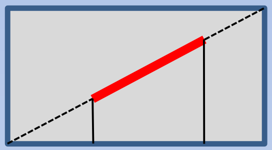
Fast reprojection:

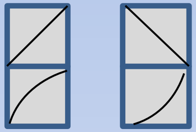
For operational
purposes matrix
of coordinates have
to been pre-computed

Visualisation as a basic tool for IR image applications

For visualization of satellite IR imagery it is necessary to setup some thresholds:

- Minimum brightness temp [K]
- Maximum brightness temp [K]
- Slope +1/-1
- Gamma >1 or <1





Minimum and maximum thresholds are used to specify certain brightness temperature interval to detect certain meteorological features – cloud top temperature, fog or land surface properties

Typical temperature scale in IR satellite imagery

-75°C	Overshooting tops
	Cumulonimbus anvils
	Convective clouds
	High level clouds
	Medium level clouds
	Low level clouds
	Ice over sea and land
0°C	
	Fog
	Sea surface
	Land surface
+50°C	Desert during the day

Examples of IR images visualisation and their applications

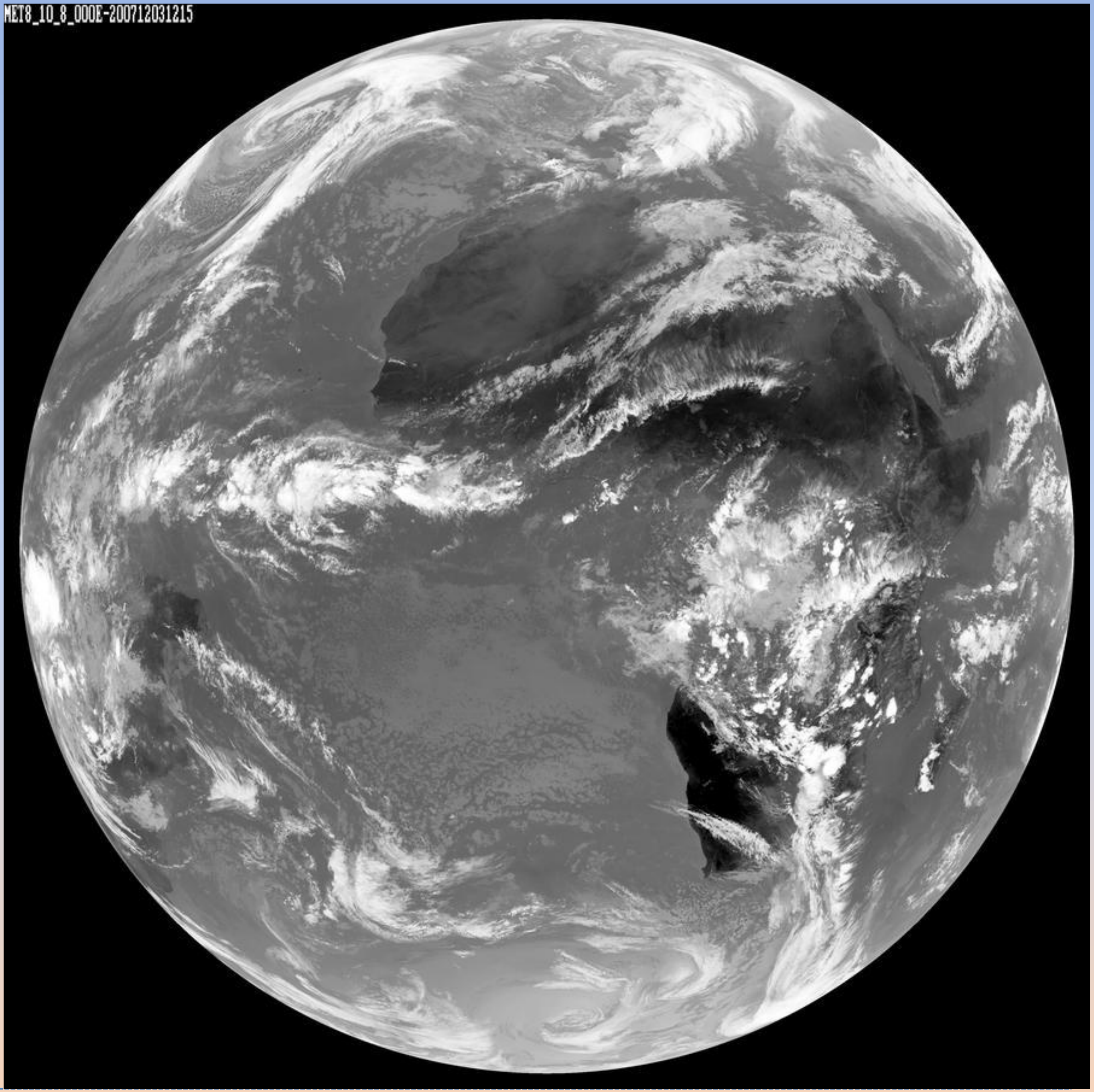
- Global IR monitoring
- Synoptic scale observations using IR imagery
- Observing of warm land surfaces
- Observing of cold cloud surfaces
- Observation of dust, fog, low clods, high level ice clouds
- Synoptic scale observations using IR imagery

  - notes on Solar IR channel 3.9 µm – night versus day performance

EUMETSAT satellite MSG-1 Full Earth disc IR 10.8µm Position 0 Long.

Warm land surfaces can be recognized from colder sea surfaces

High and vertically well developed clouds with low brightness temperatures can be recognized from medium and low level clouds with higher brightness temperatures

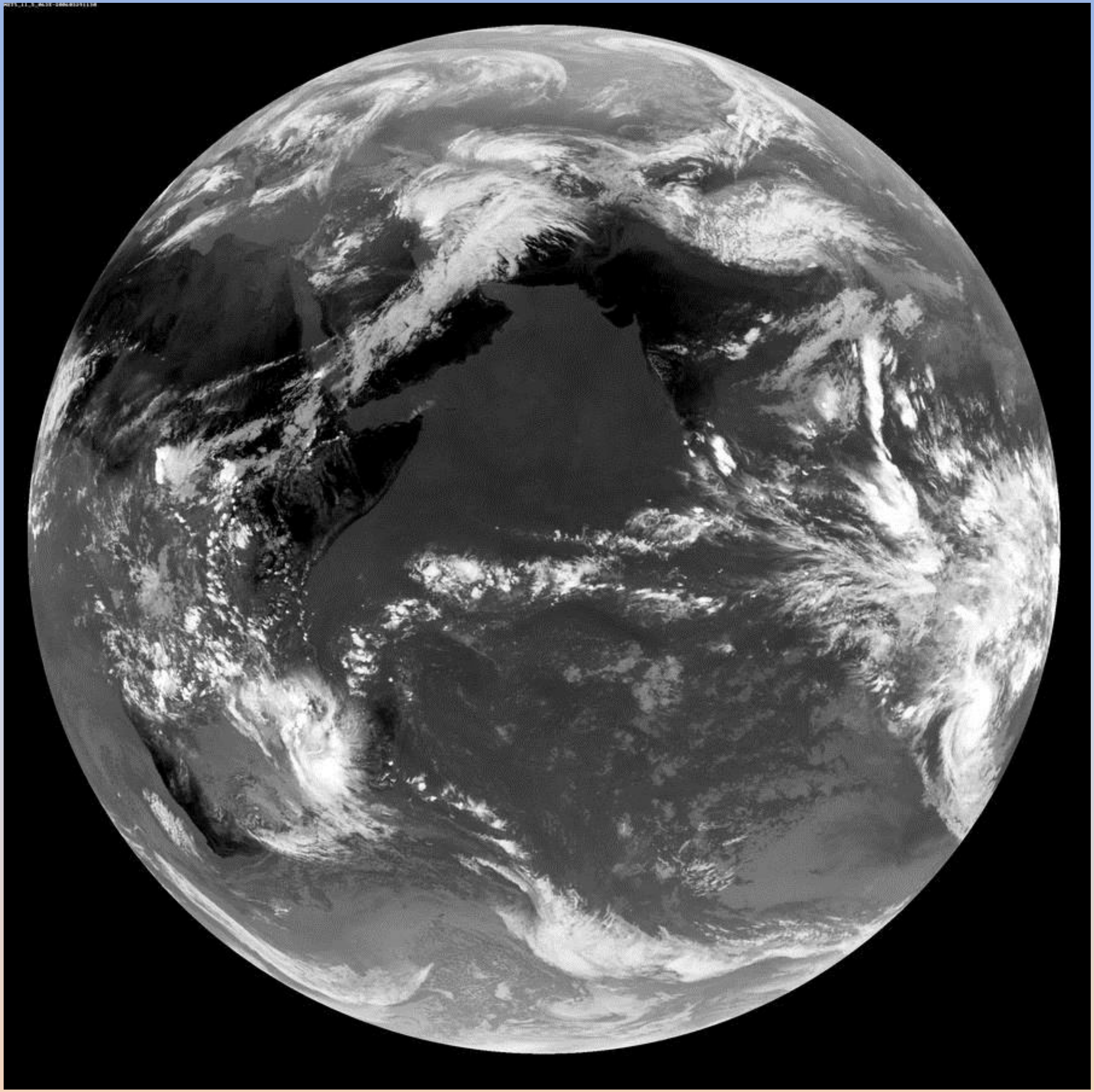


EUMETSAT satellite Meteosat-5 Full Earth disc IR 10.8µm

Position 57 deg.East

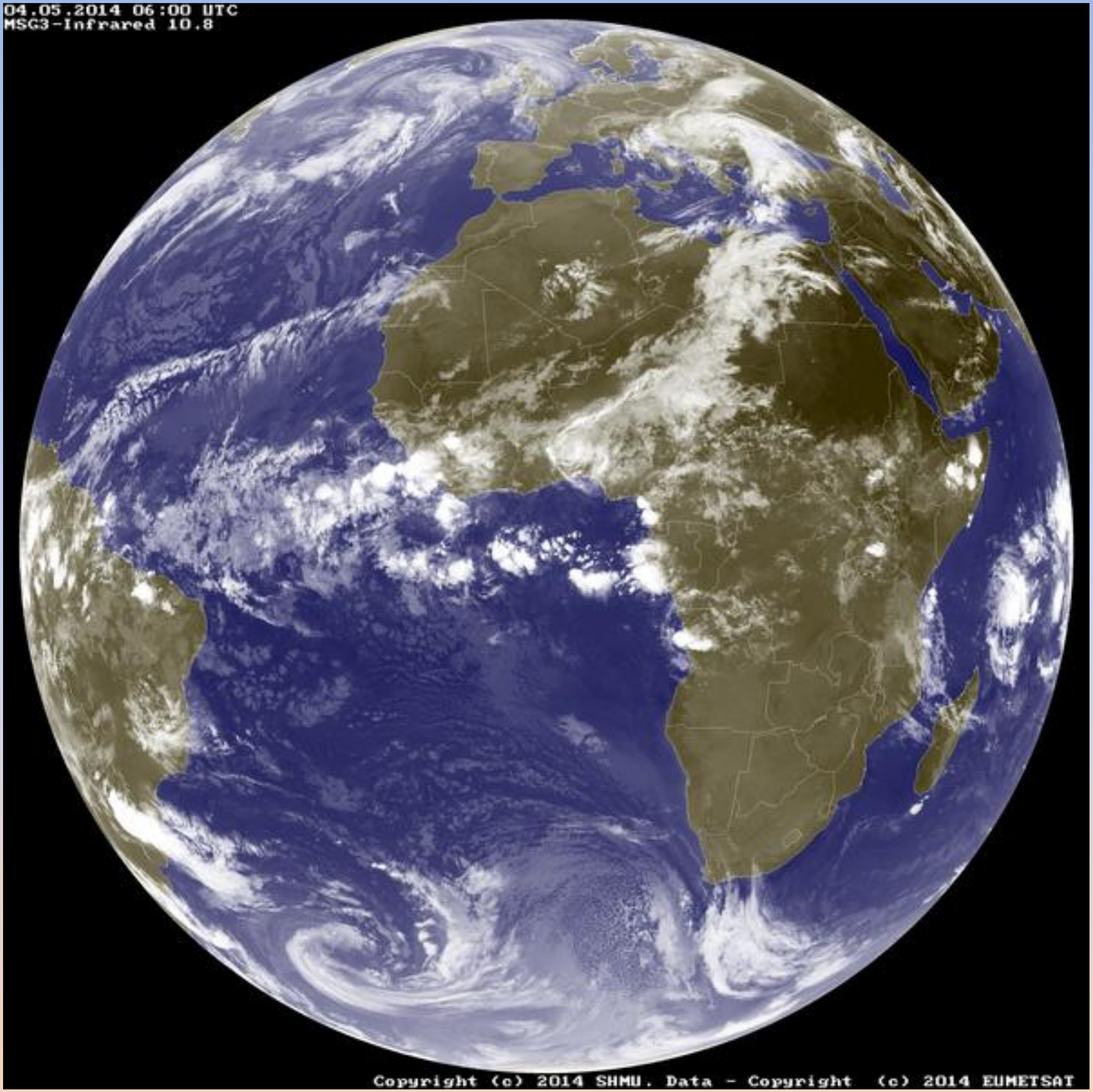
Warm land surfaces can be recognized from colder sea surfaces

High and vertically well developed clouds with low brightness temperatures can be recognized from medium and low level clouds with higher brightness temperatures



Global IR monitoring of the Earth by geostationary satellites

- ✓ **Meteosat 9 0.0°E**
- Meteosat 7 57.5°E
- MTSAT JMA 145.0°E
- GOES 11 135.0°W
- GOES 13 75°W



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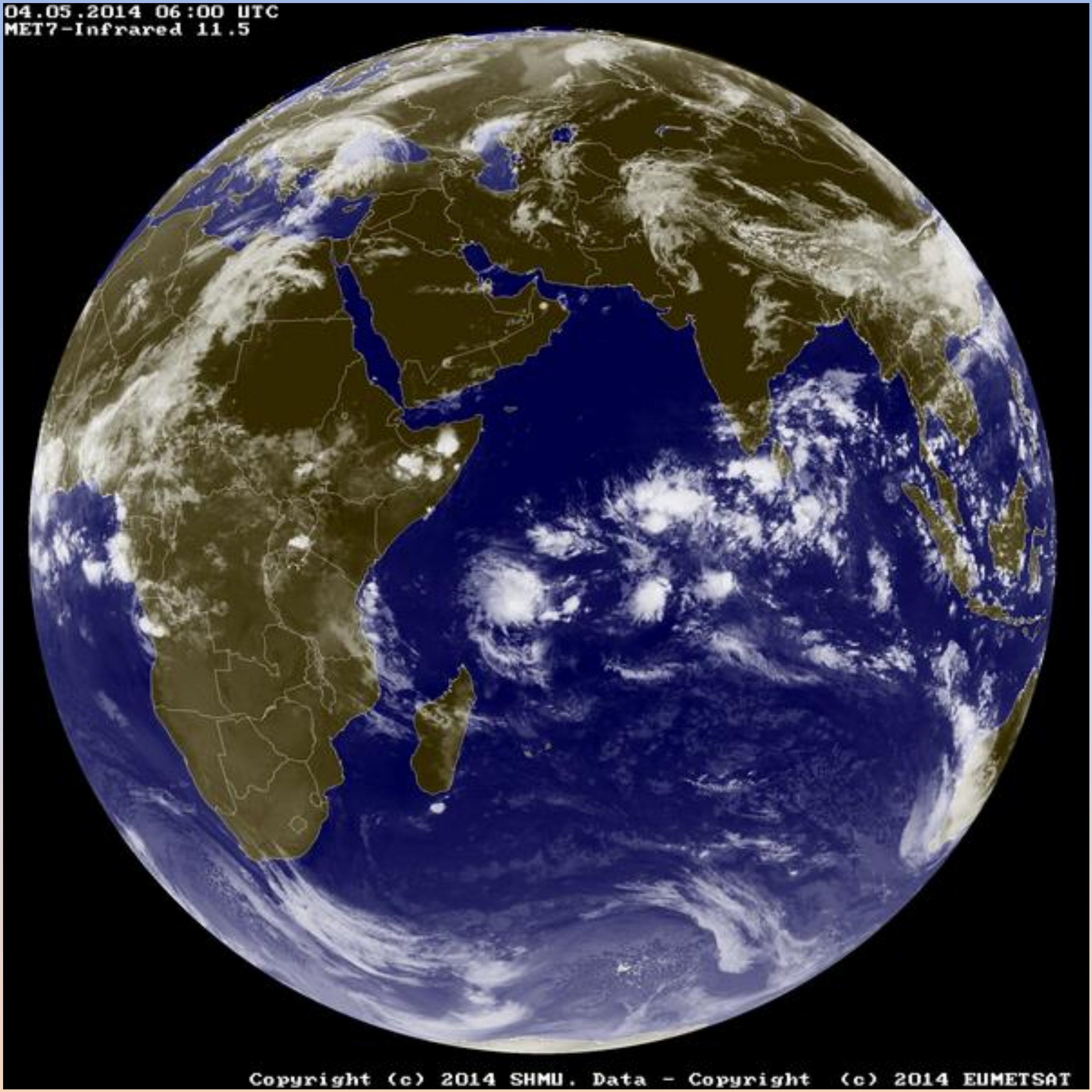

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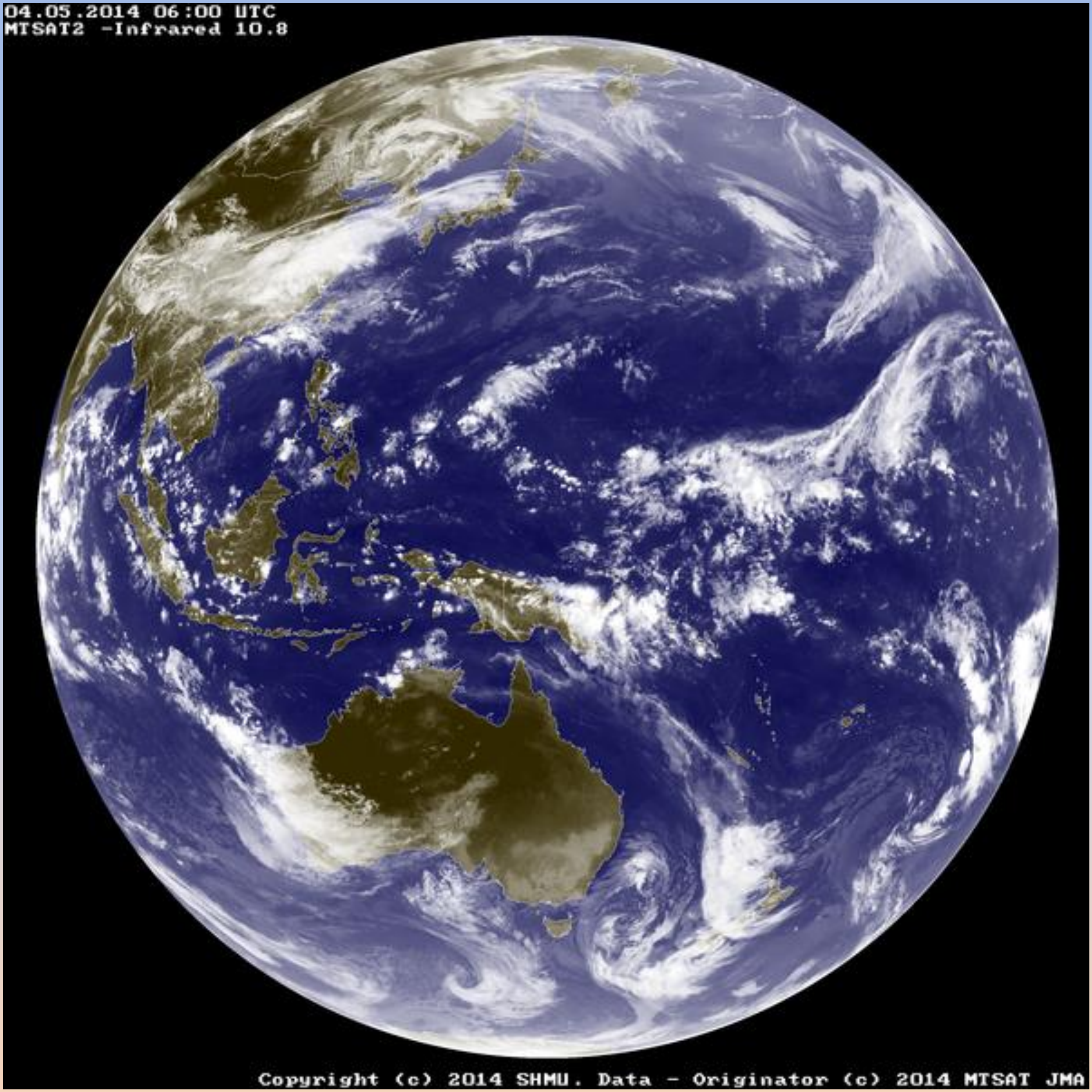

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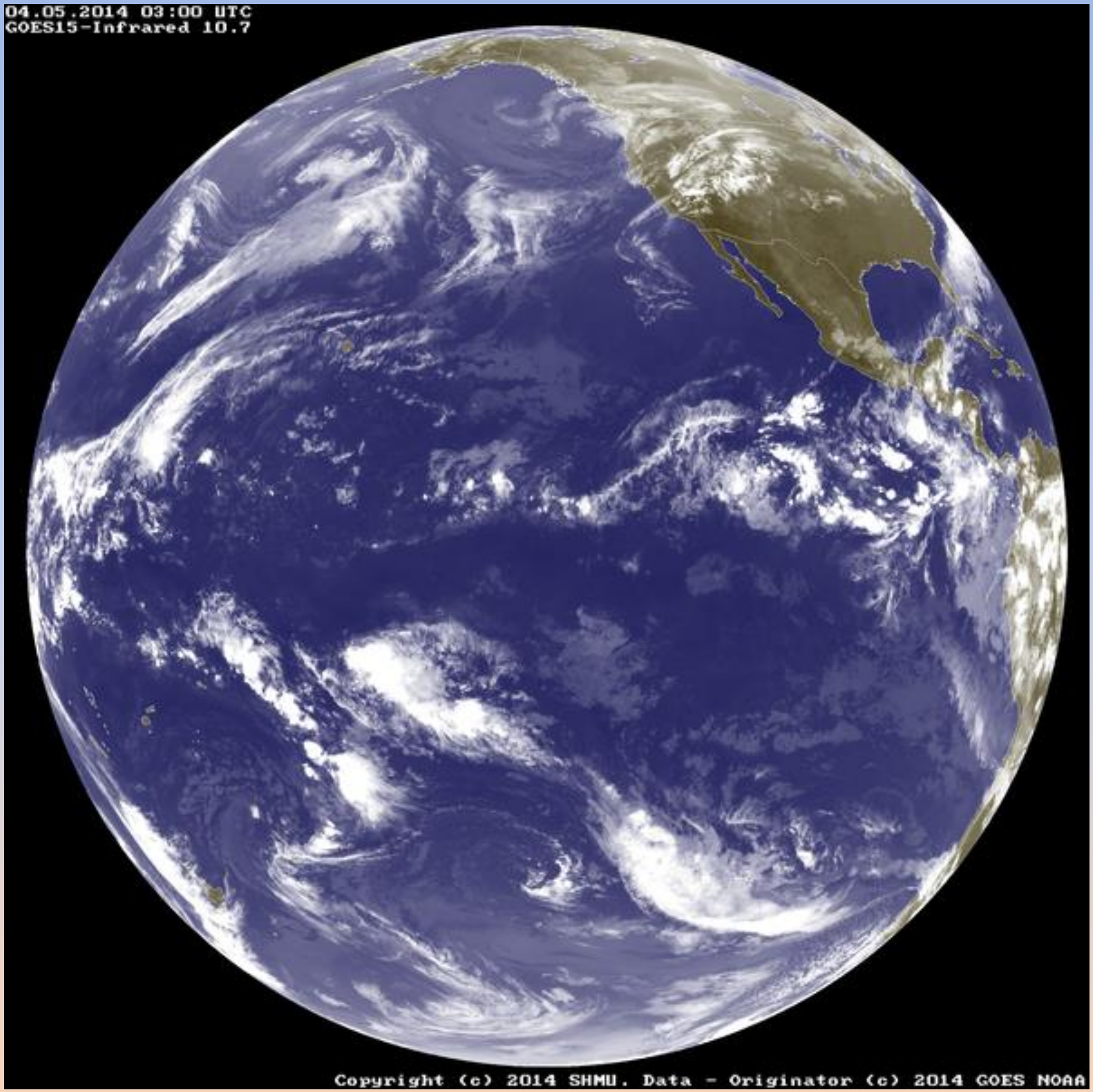

Global IR monitoring of the Earth by geostationary satellites

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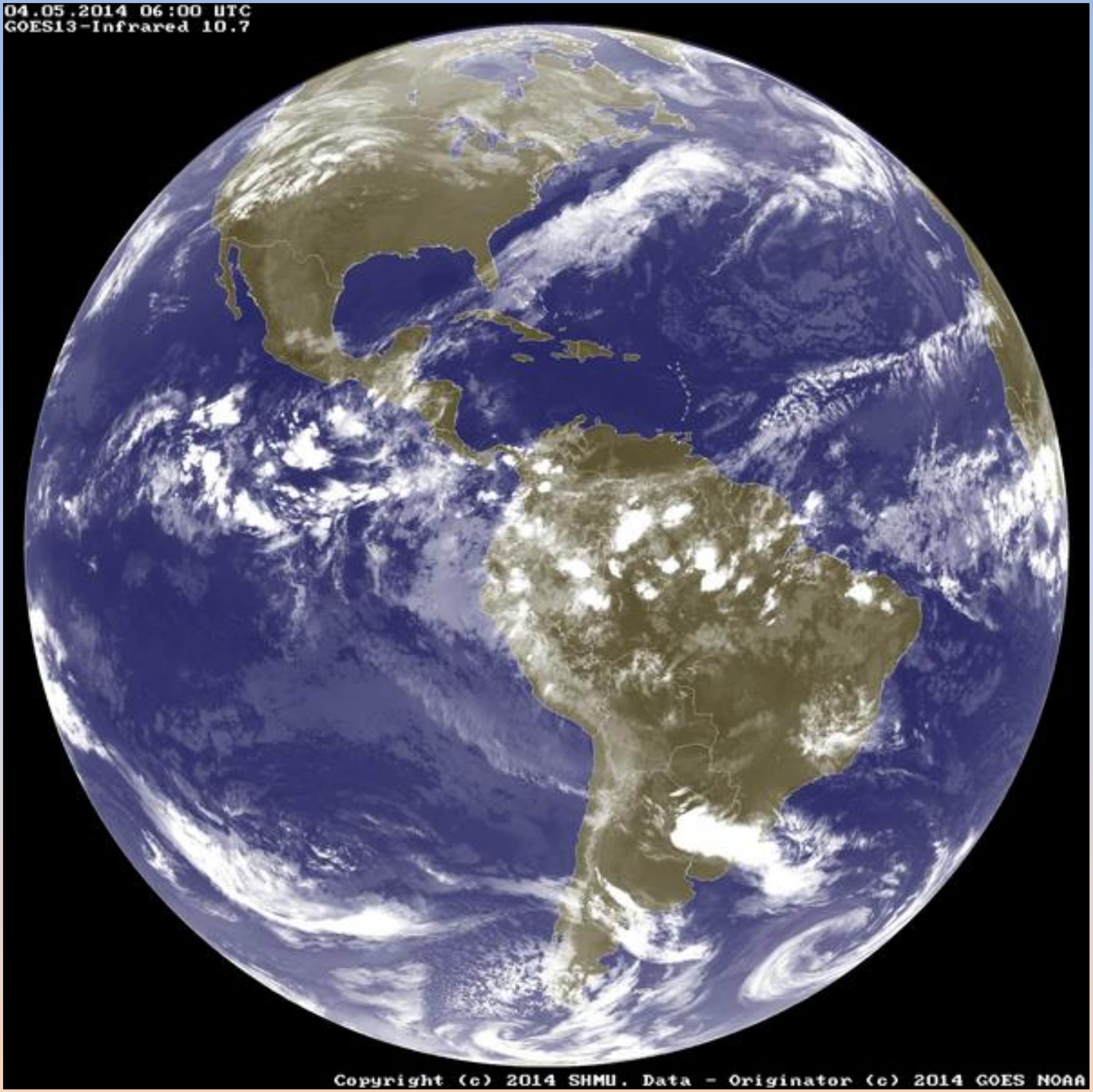
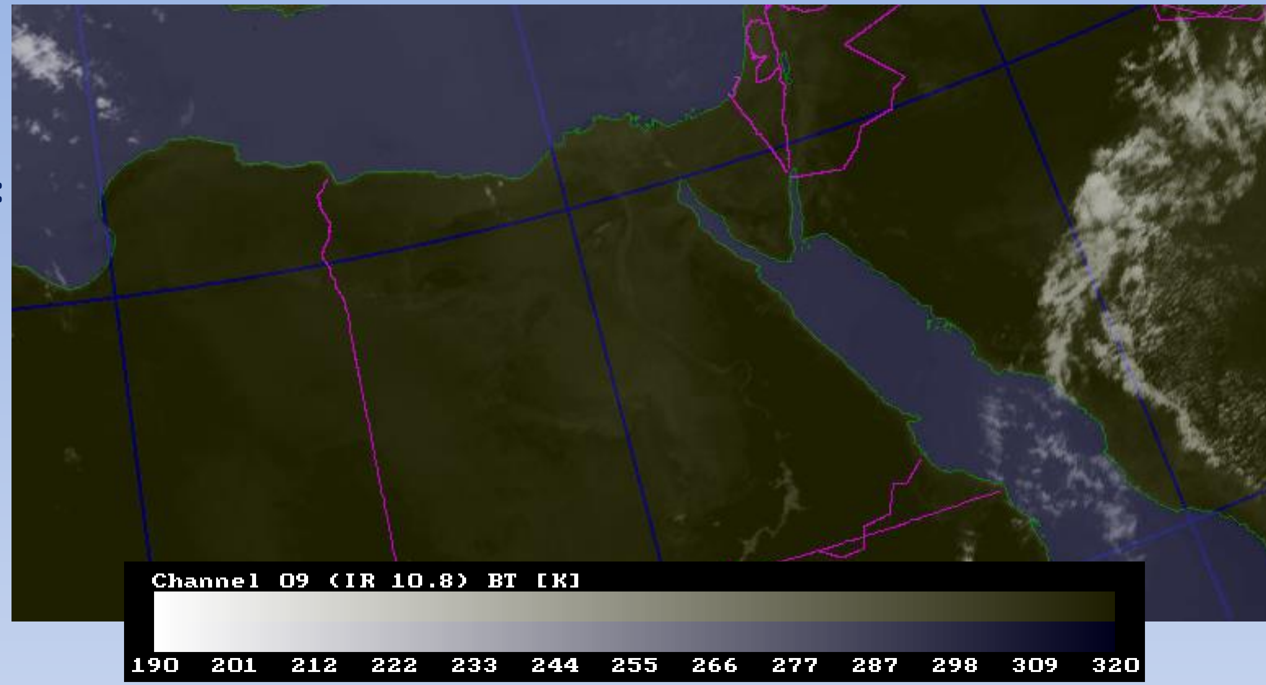
✓ **GOES 13 75°W**

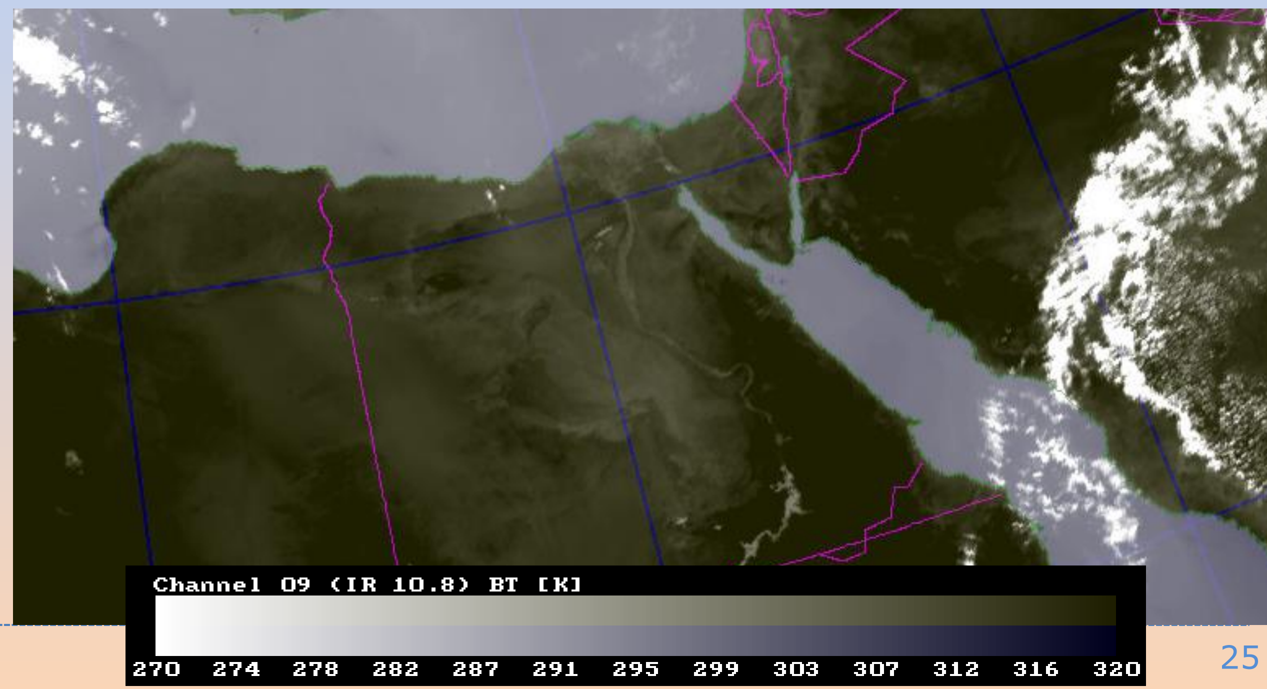


Observing of warm areas

Wide color scale from 190 to 320 K:
suppress contrast of warm areas, details can not be observed on the Earth surface, clouds can be recognized well in degrees of shades

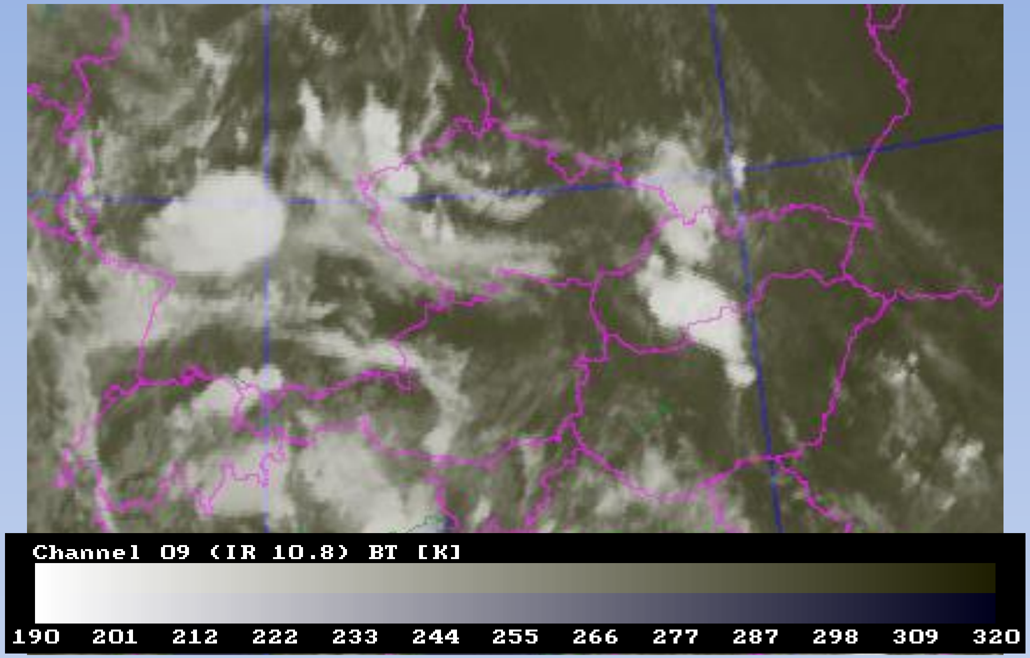


Color scale from 270 to 320 K:
increase contrast of warm areas, details can be observed on the Earth surface, but cold clouds are too white

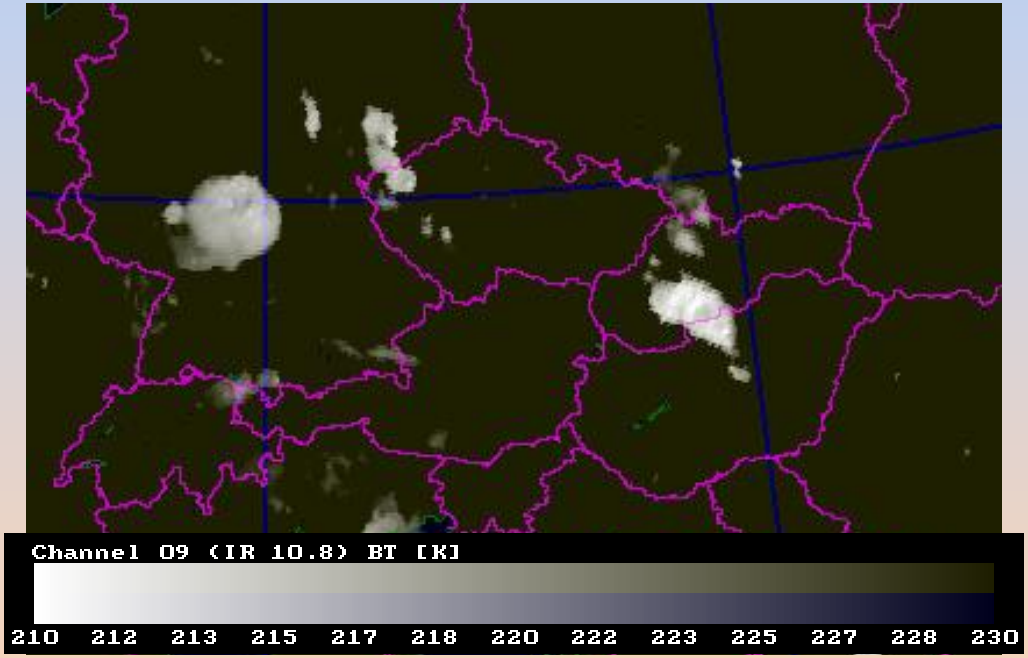


Observing of cold cloud tops:

Wide color scale from 190 to 320 K
suppress contrast of cold areas,
details of cloud tops can not be observed

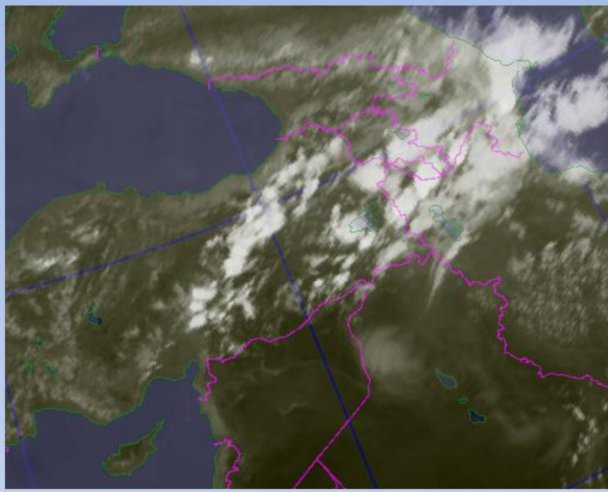


Narrow color scale from 210 to 230 K
increase contrast of cold areas,
details of cloud tops can be well observed

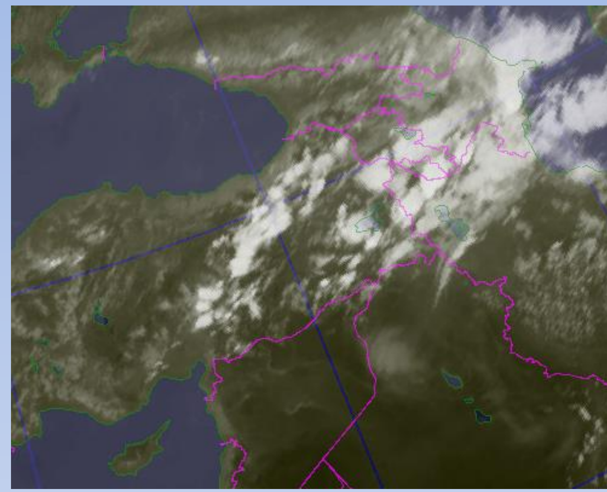


Visualisation of dust storm using channels 10 – 9 difference

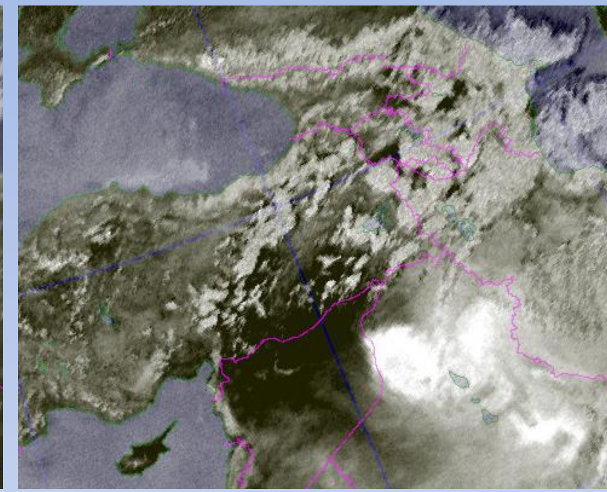
Channel 9 (10.8µm)



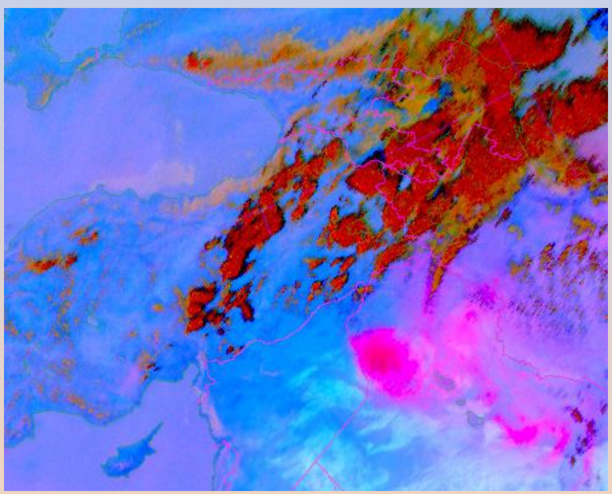
Channel 10 (12.0µm)



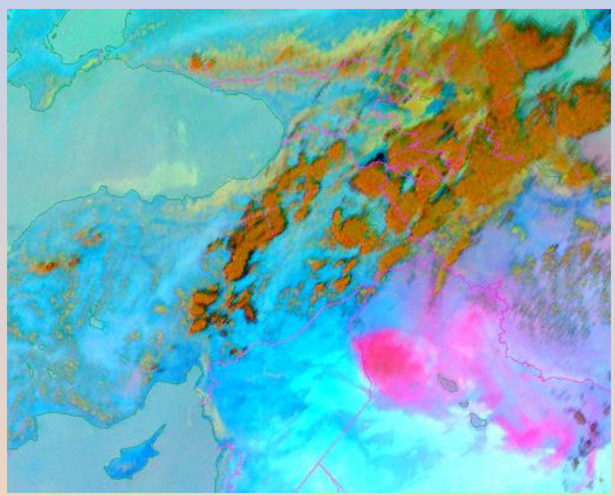
Difference ch 10 – ch 9



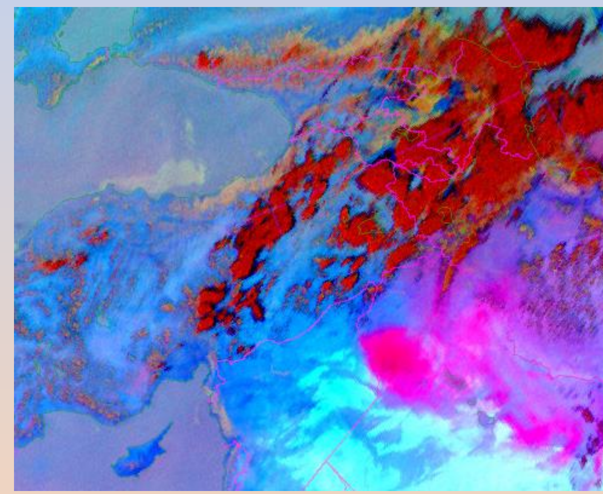
Dust RGB



Ash RGB

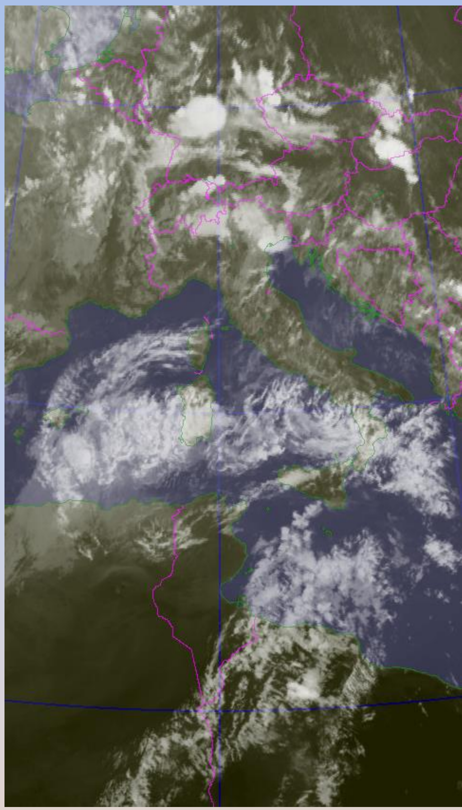


24-hours microphysical RGB

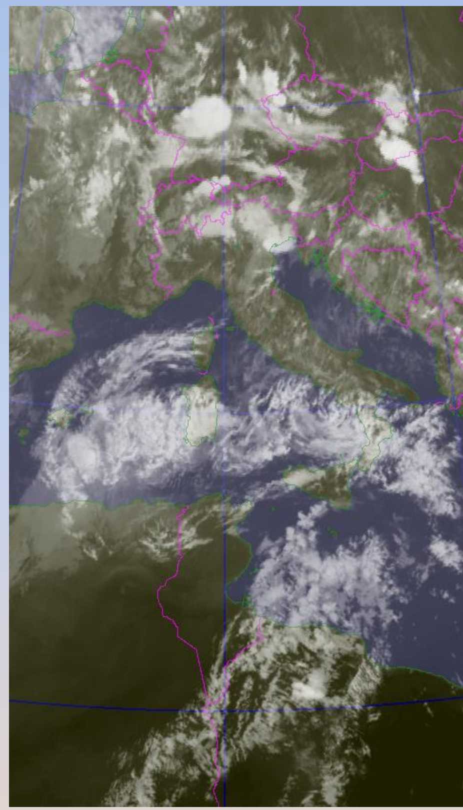


Visualisation of high cirrus using channels 10 – 9 difference

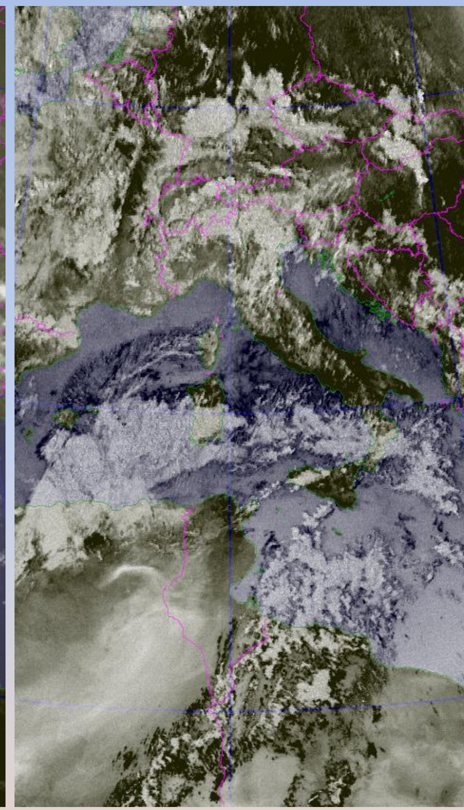
Channel 9 (10.8µm)



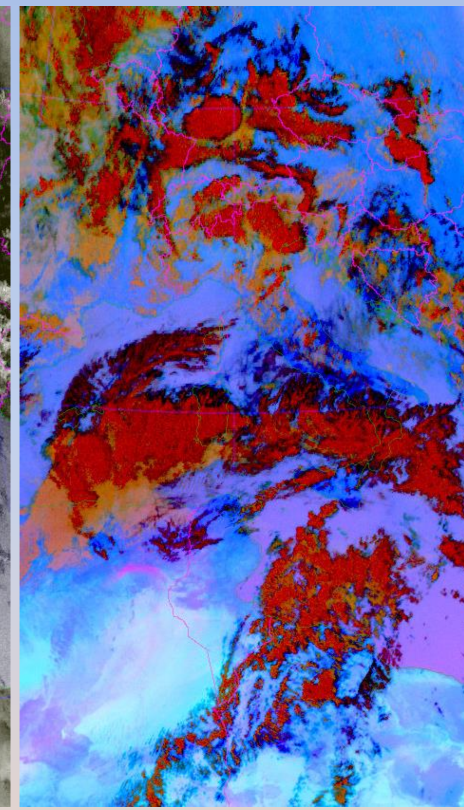
Channel 10 (12.0µm)



Diff ch 10 – ch 9

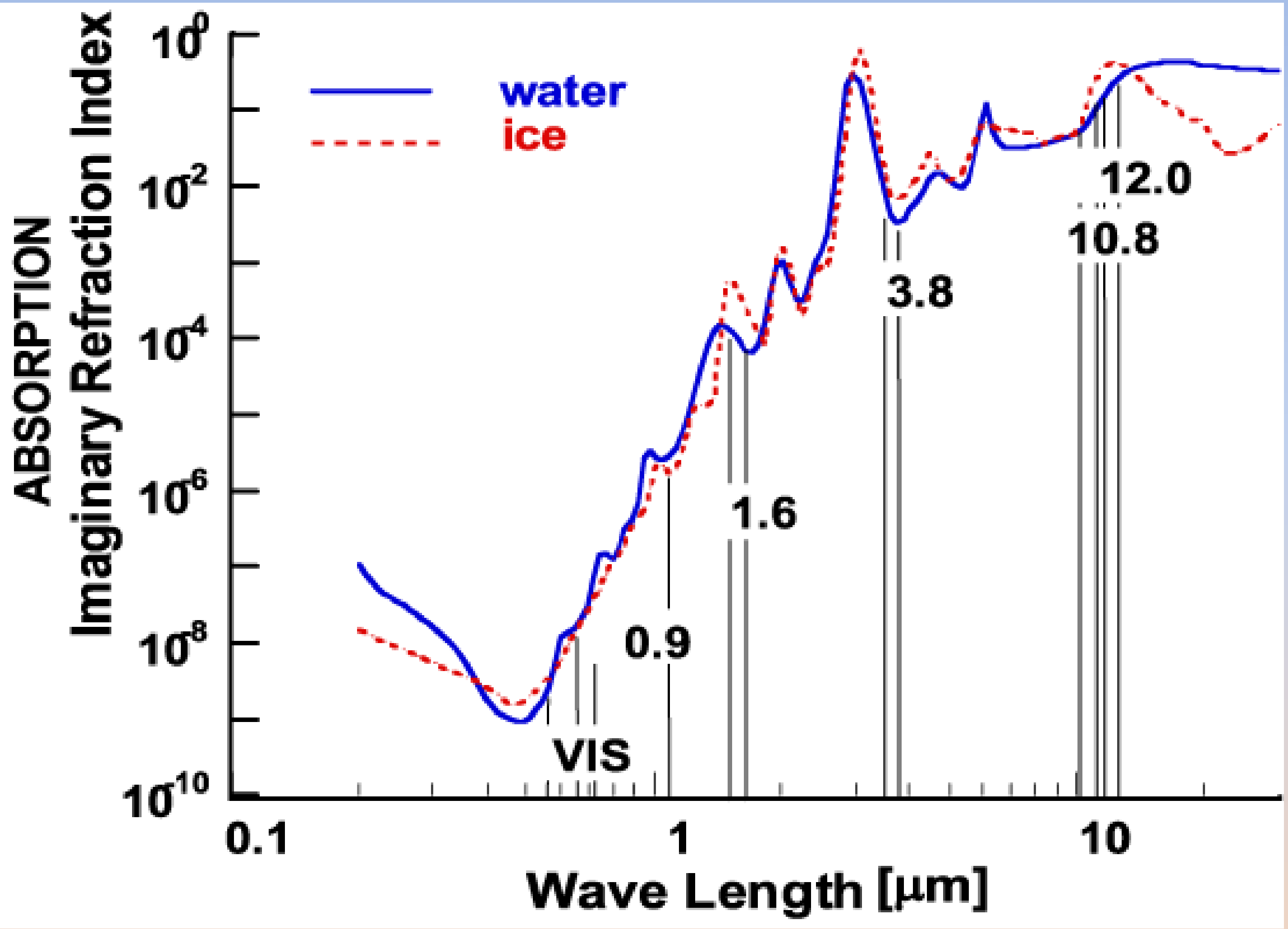


Dust RGB



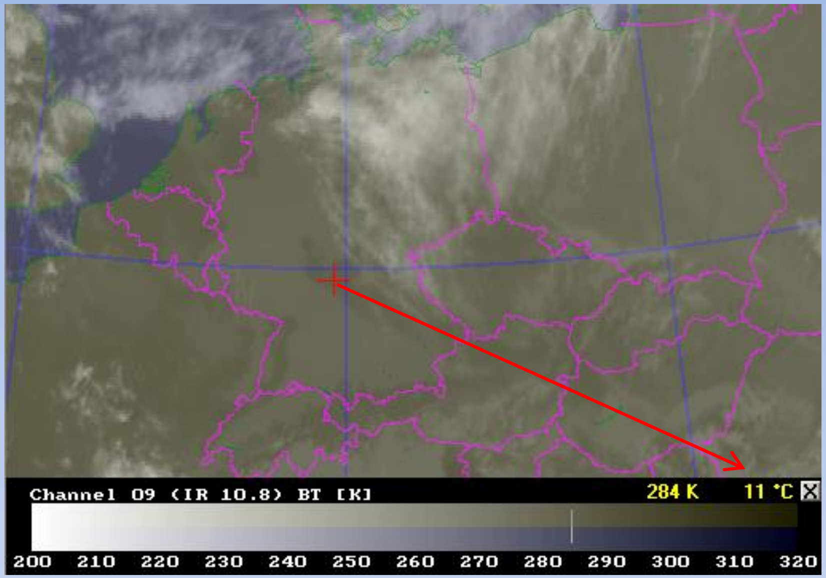
High cirrus cloud detection is based on a different absorption of ice and water cloud between 10.8 and 12.0 µm - higher absorption is for ice phase in 12.0 µm

Absorption of Ice and Water cloud according D. Rosenfeld:

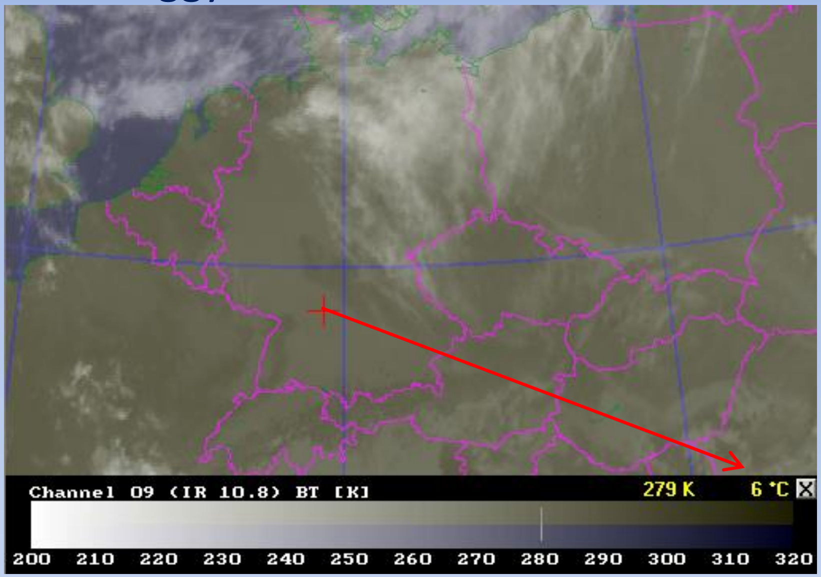


Observation of fog using IR channel 9 and 10

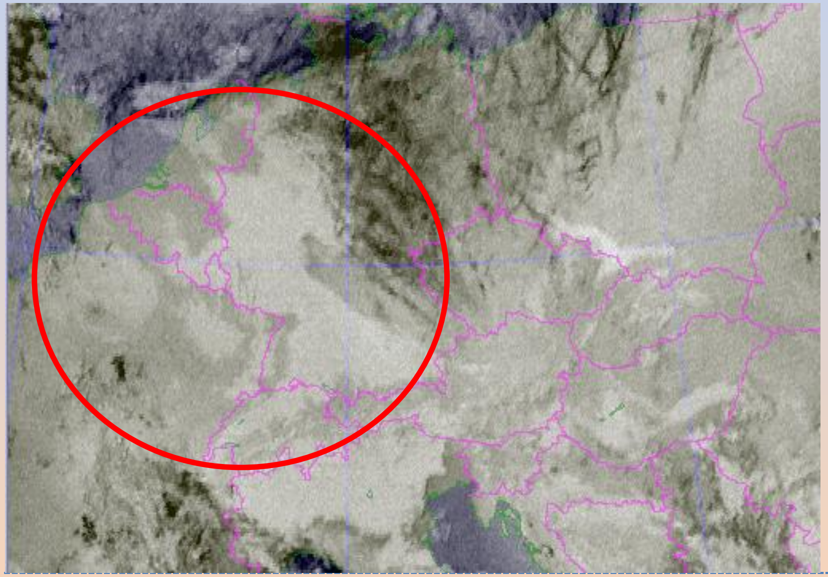
BT of land surface is around 11°C



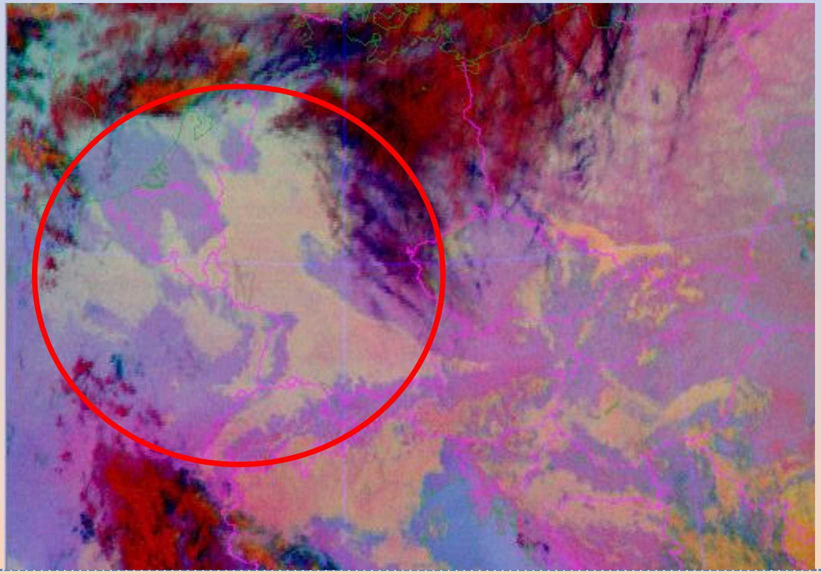
BT of foggy area is around 6°C



Difference of IR channel 10 and 9



24-hours microphysical RGB



Synoptic scale observations using IR imagery

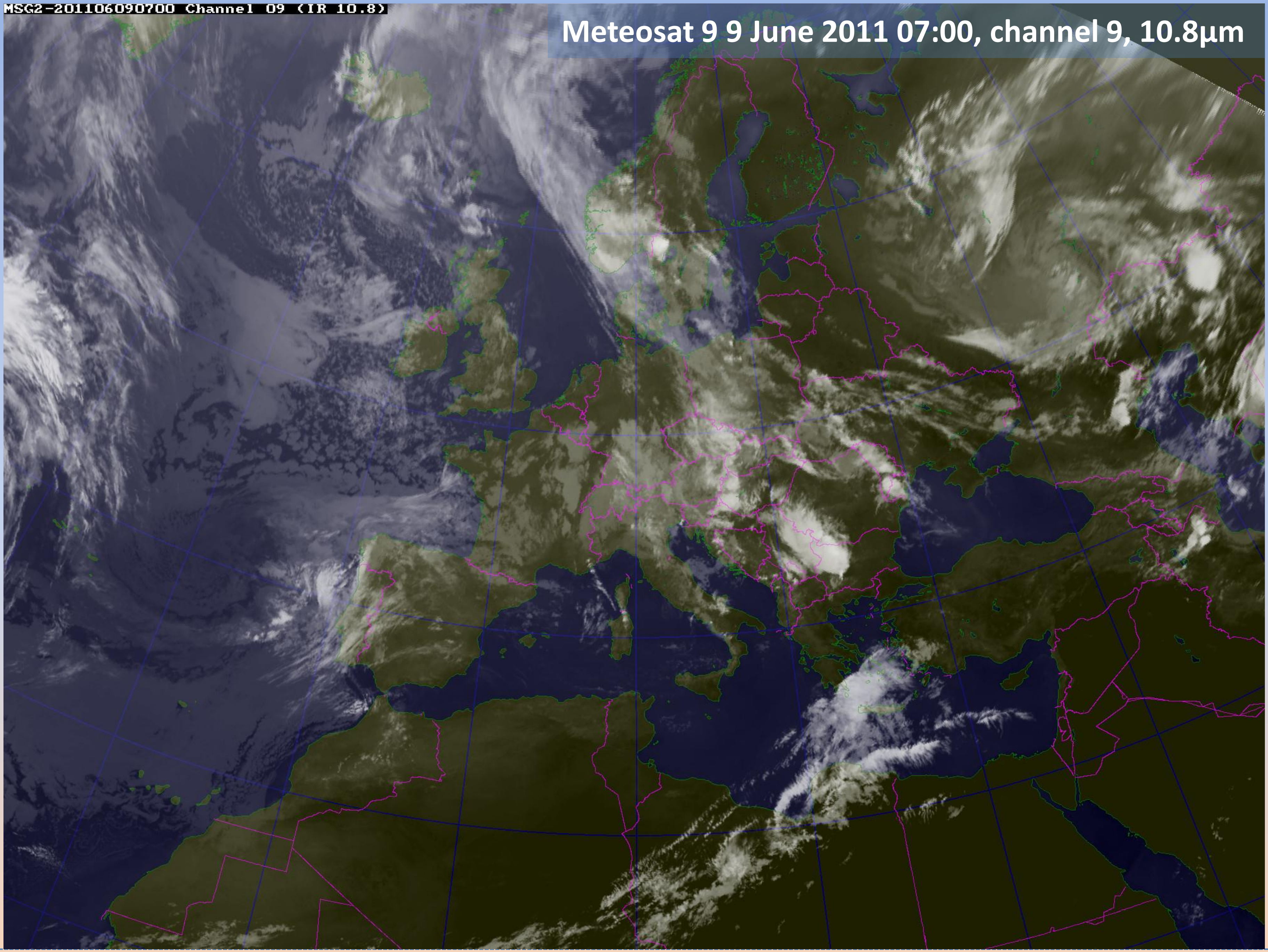
-the most widely used application of IR imagery;

-IR images 10-13μm does not depend on day/night time, therefore can be used 24-hours per day; exception is channel 3.9μm containing Sun irradiance during the day

-continuous monitoring can be done for:

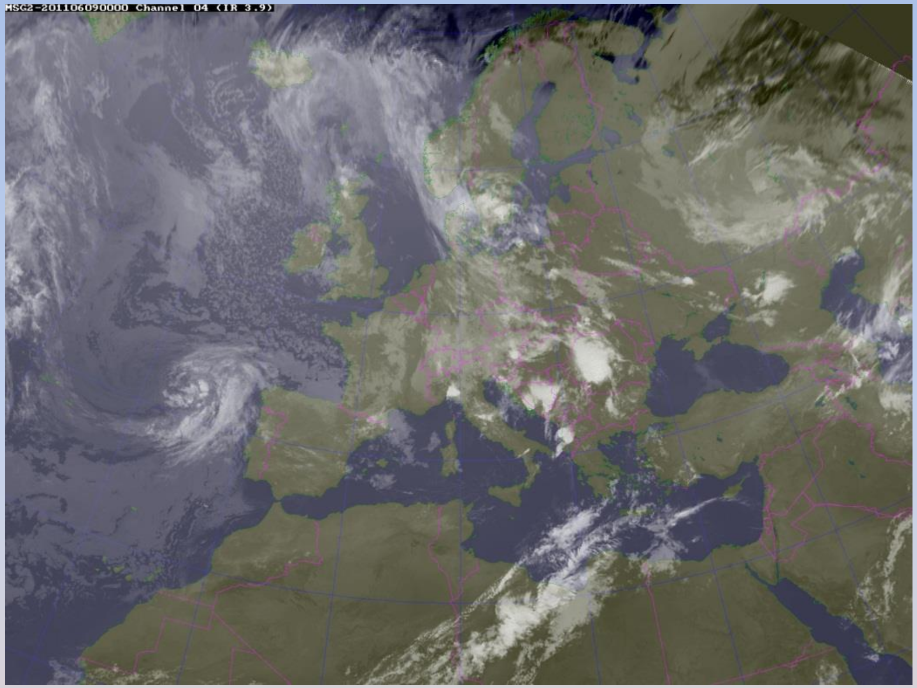
- airmasses
- cyclones and anticyclones development
- Recognition of frontal weather patterns and their movement

Meteosat 9 9 June 2011 07:00, channel 9, 10.8µm

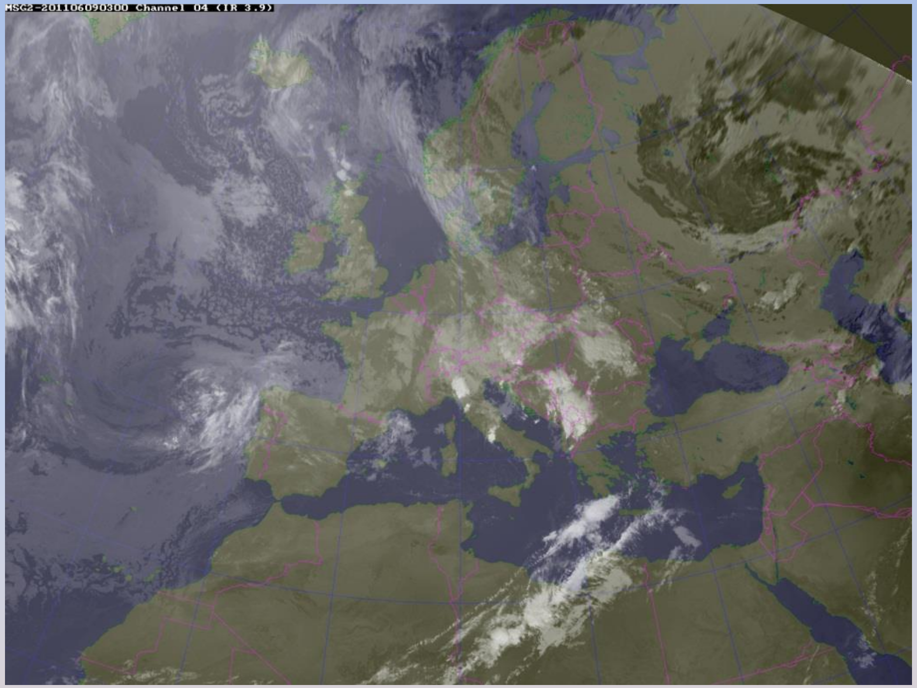


Meteosat 9 9 June 2011, channel 4, 3.9µm

00:00 UTC

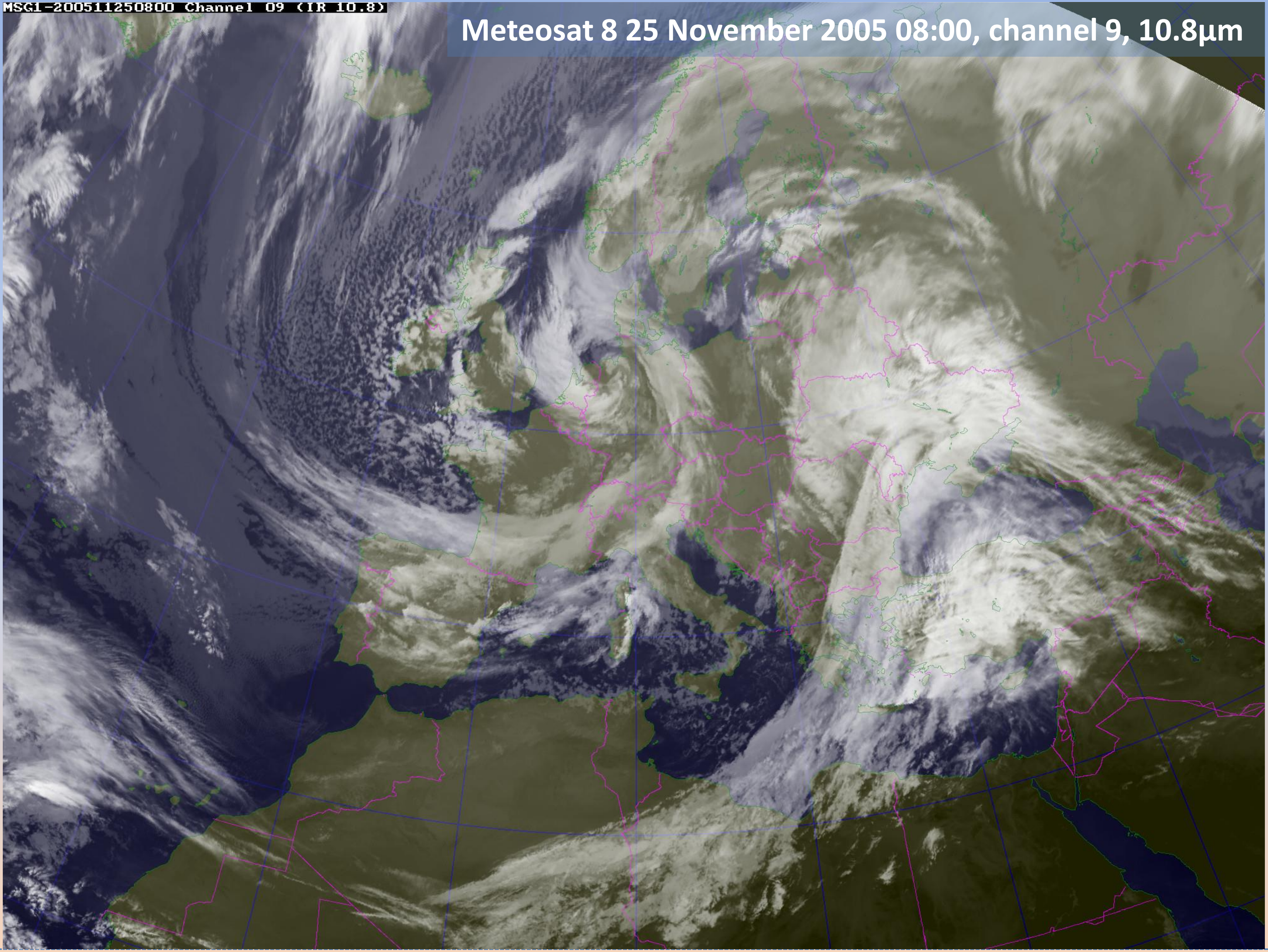


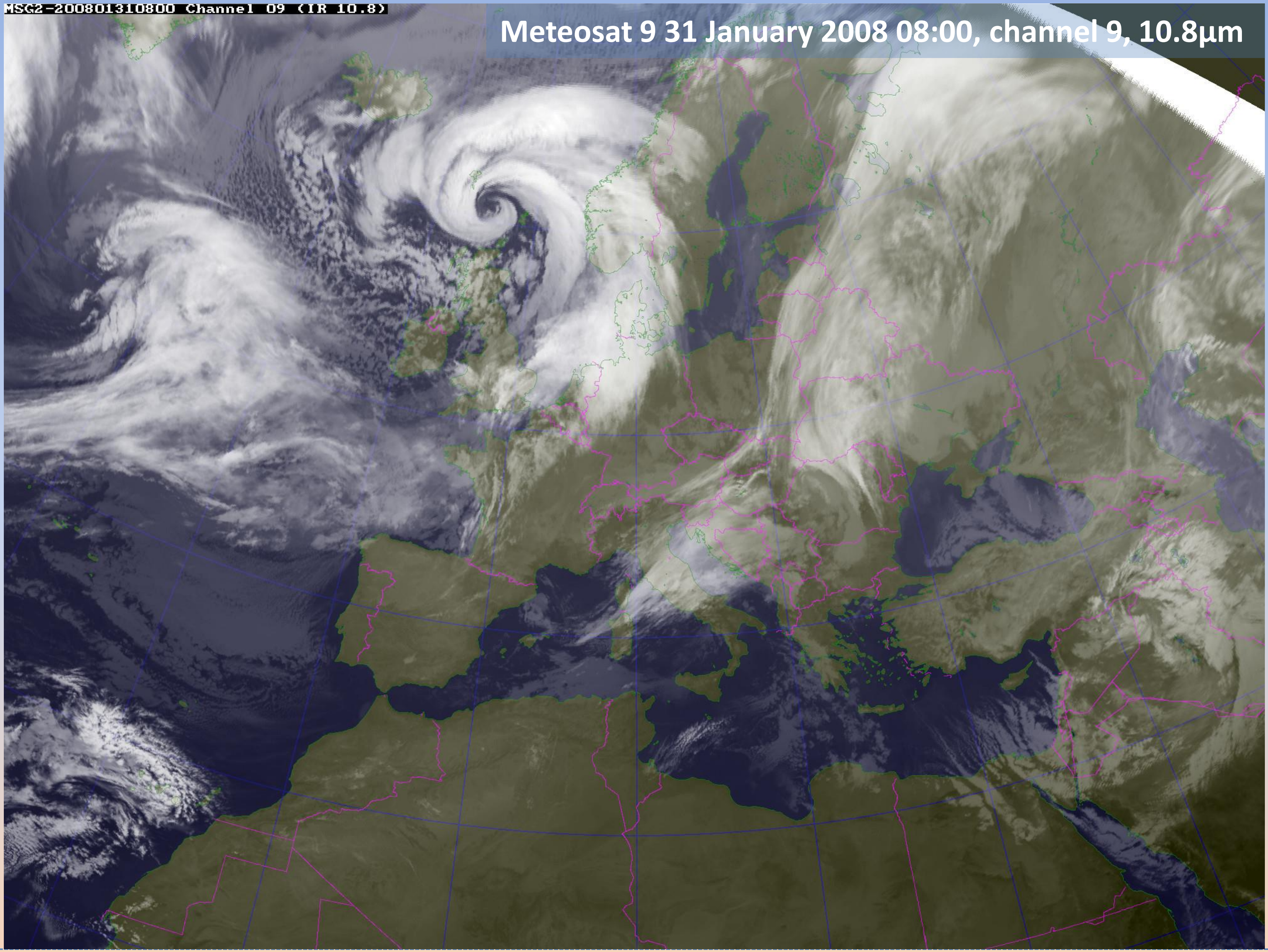
03:00 UTC



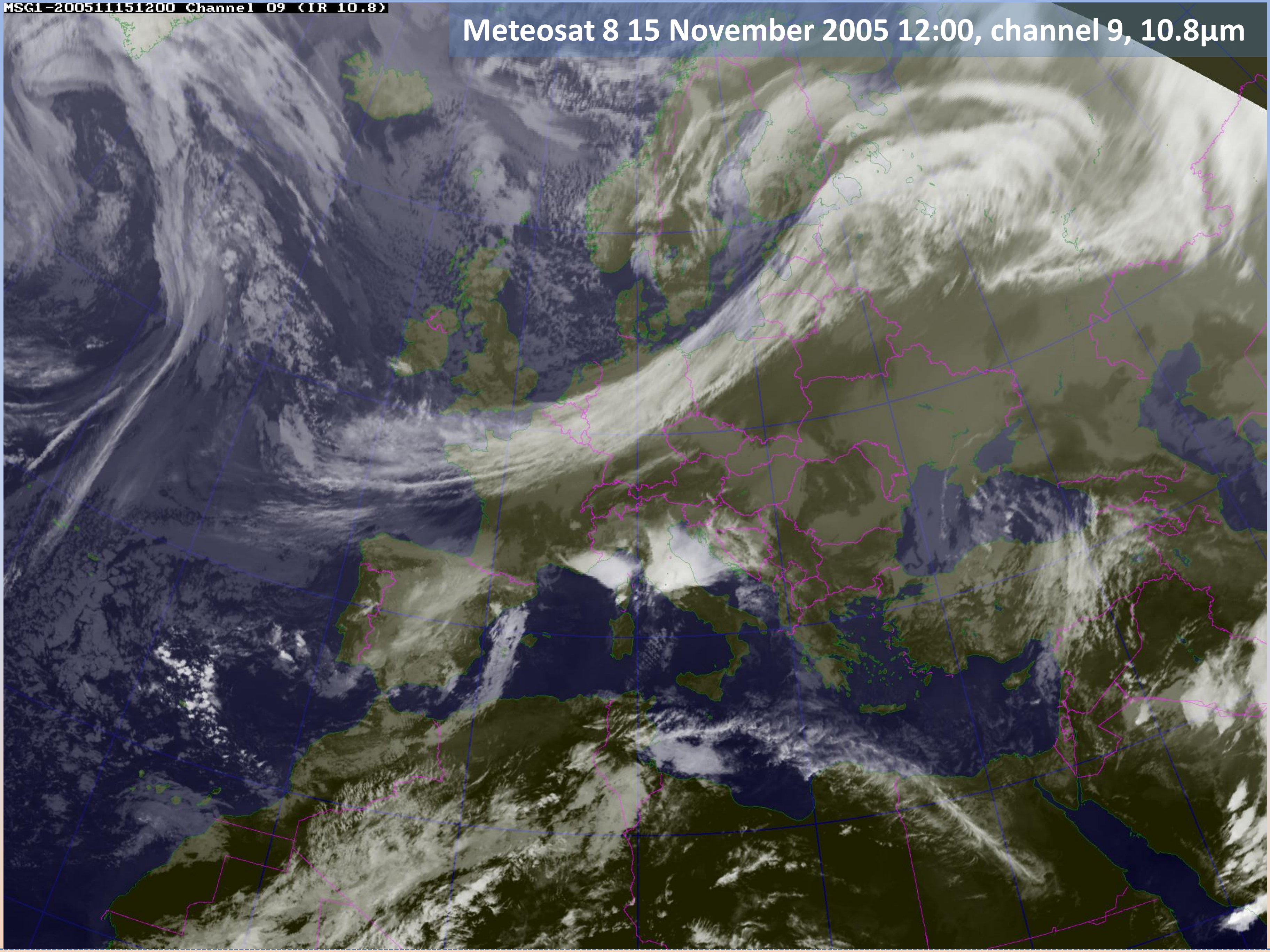
The same case can look quite different in channel 4: while at 00:00 UTC Sun irradiance can be observed close to the North only, at 03:00 UTC is observable also in eastern Europe. Only night part of the image (without Sun illumination) can be interpreted with standard IR interpretation approach. During day time solar component must be taken into account.

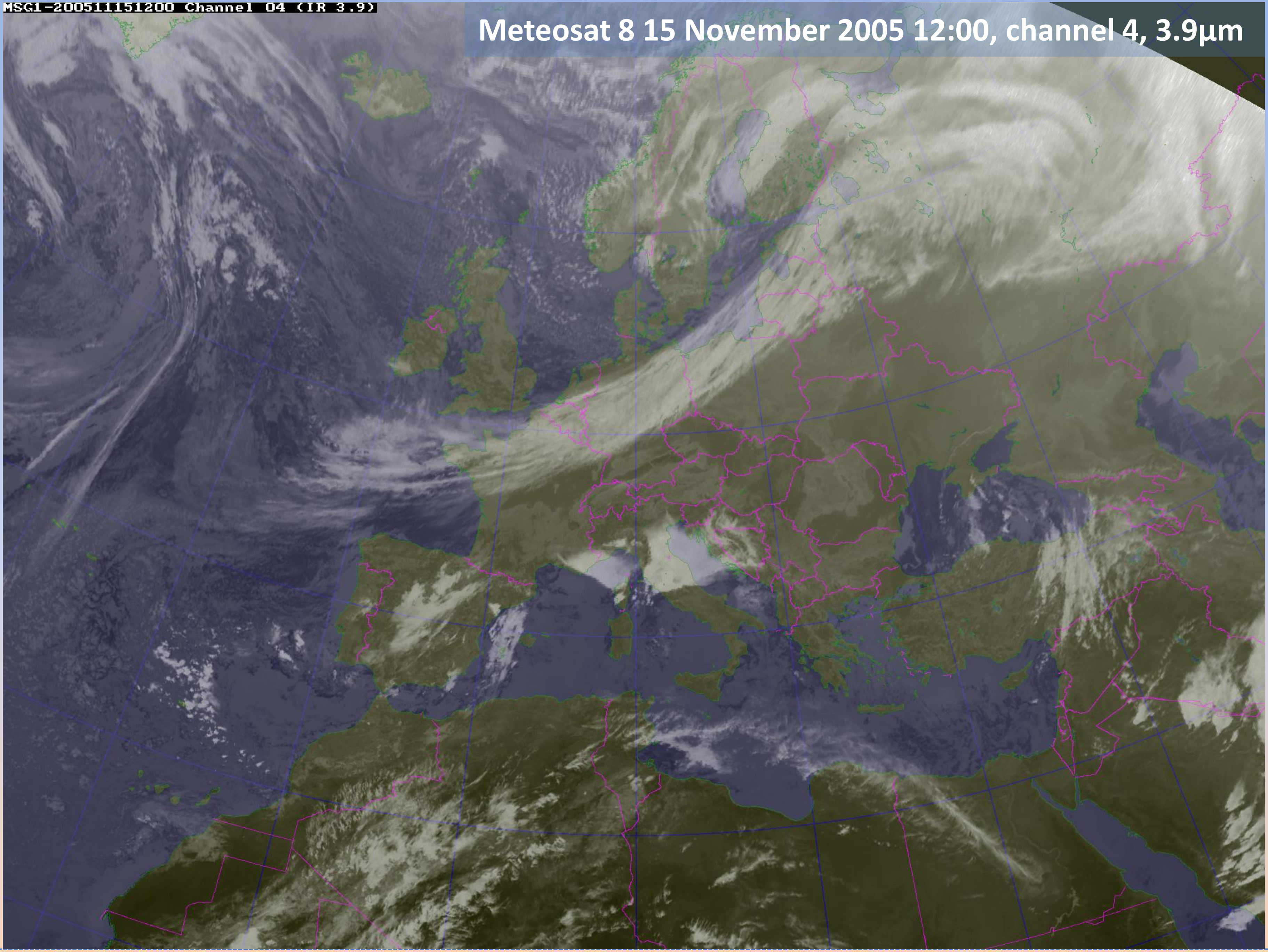
Meteosat 8 25 November 2005 08:00, channel 9, 10.8µm



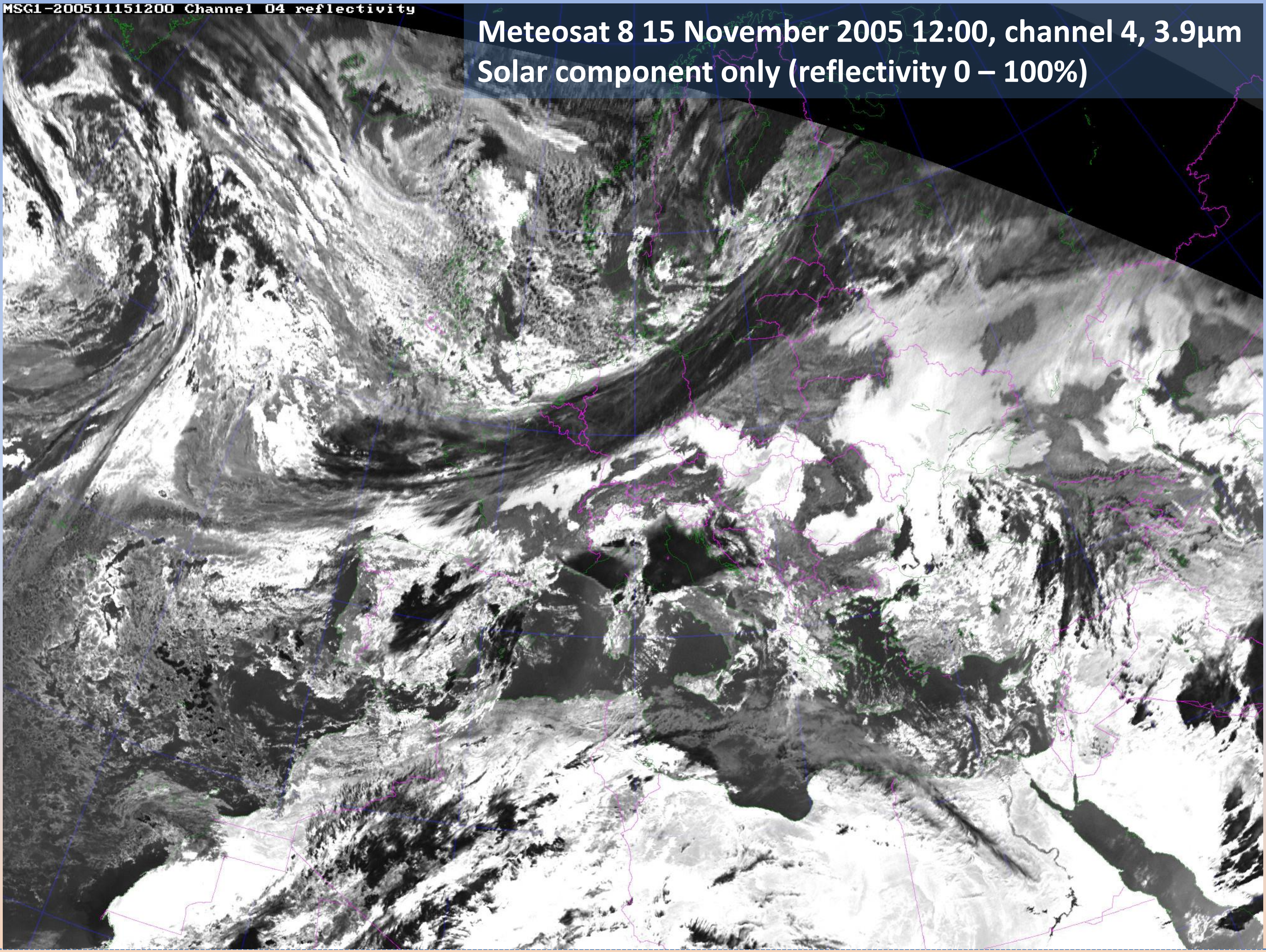

MSG2-200801310800 Channel 09 (IR 10.8)
Meteosat 9 31 January 2008 08:00, channel 9, 10.8µm

Meteosat 8 15 November 2005 12:00, channel 9, 10.8µm

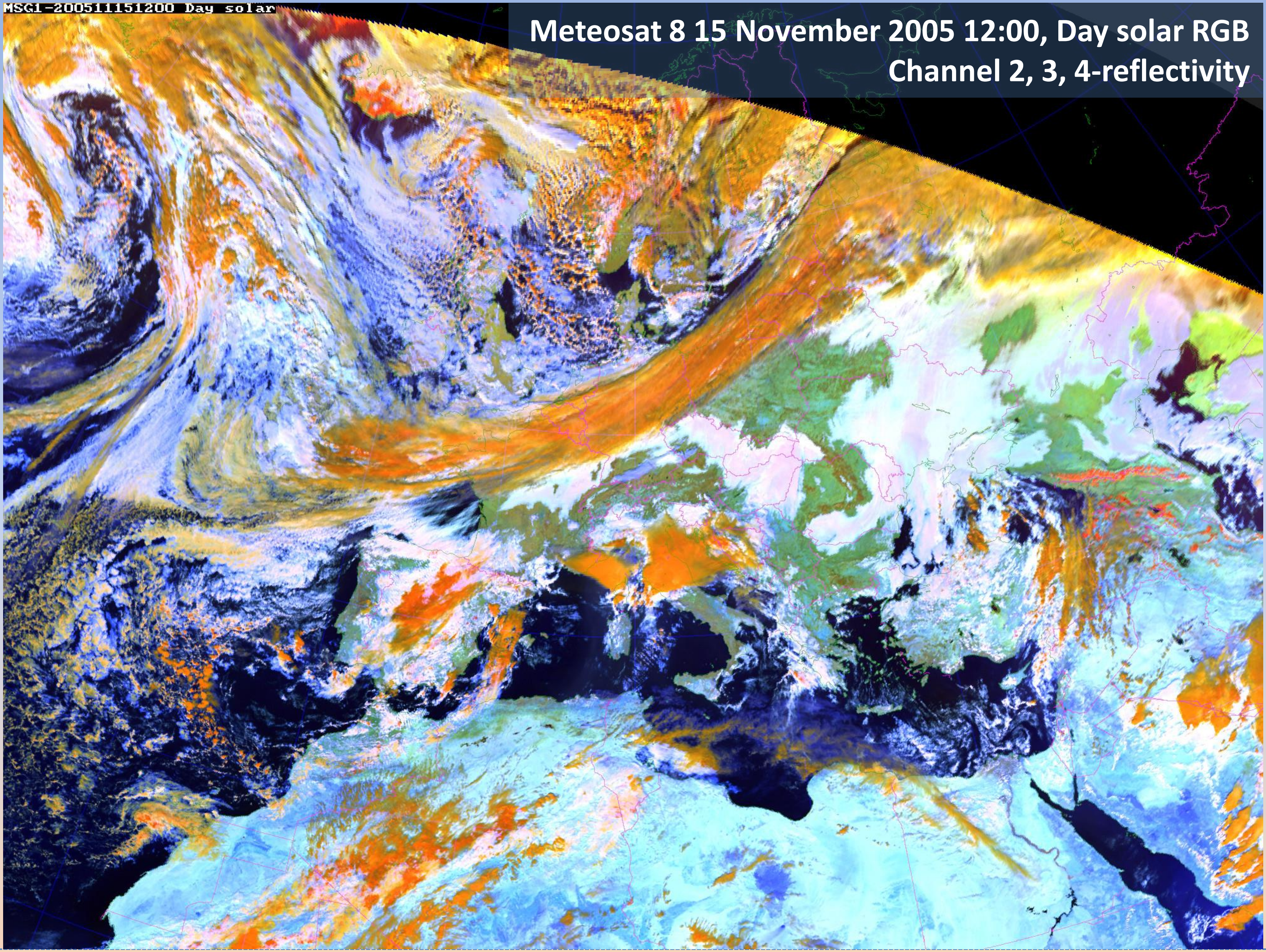



MSG1-200511151200 Channel 04 (IR 3.9)
Meteosat 8 15 November 2005 12:00, channel 4, 3.9µm

Meteosat 8 15 November 2005 12:00, channel 4, 3.9µm
Solar component only (reflectivity 0 – 100%)



Meteosat 8 15 November 2005 12:00, Day solar RGB
Channel 2, 3, 4-reflectivity



Anisotropy of the atmosphere and its influence to IR imagery

Anisotropy means that for multilayer-semitransparent atmospheric system radiance measured from space depends on viewing/zenith angle of satellite. This angle varies over the Earth surface and is different for different satellite positions.
When we compare measurements from different MSG satellites at the same time for the same place, we will measure slightly different values of radiances. Results are shown in plots on next slides.

Parallel measurements of three MSG satellite:

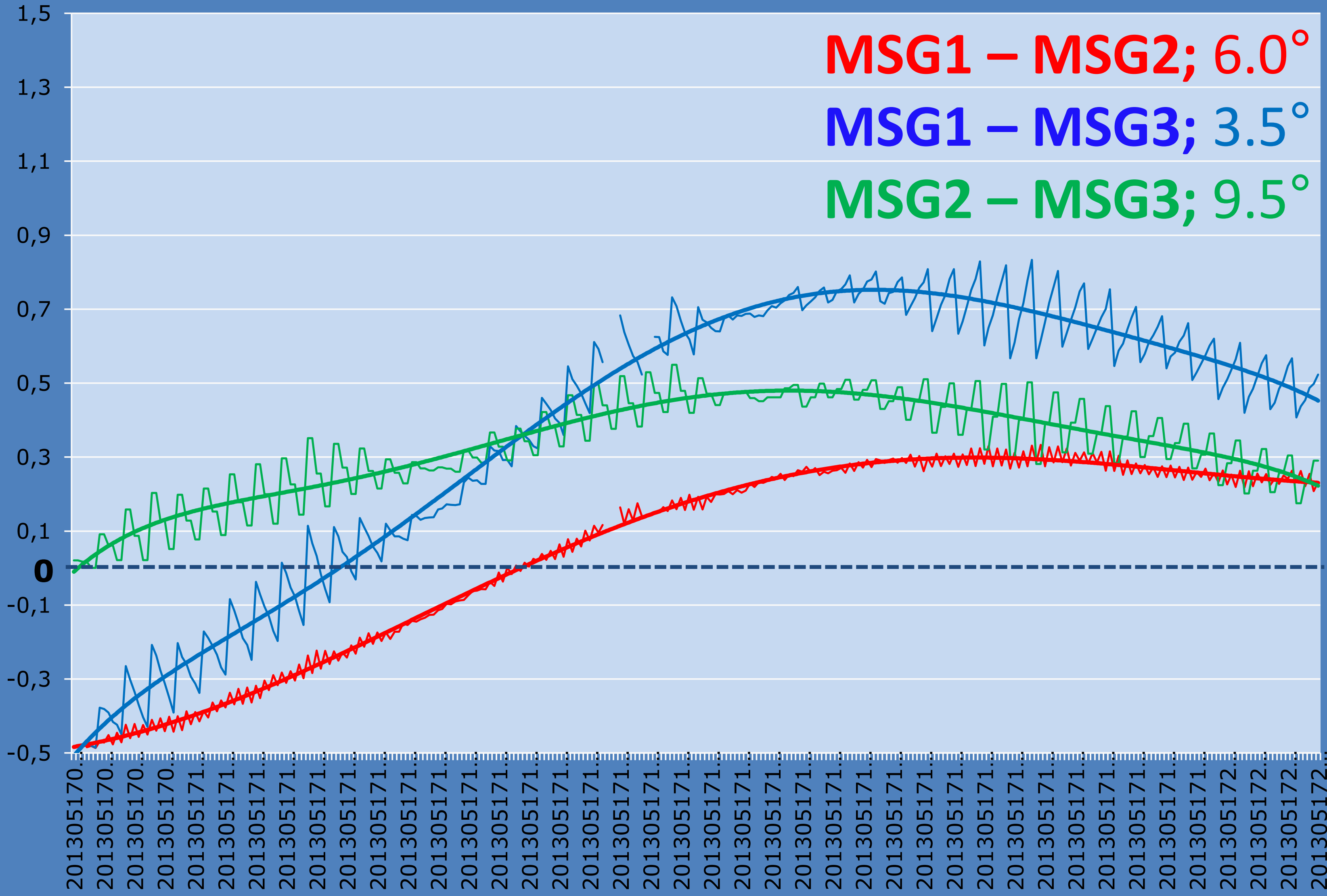
2.5min	MSG-1 3.5E
5min	MSG-2 9.5E
15min	MSG-3 0.0E

Angular distance between satellites:

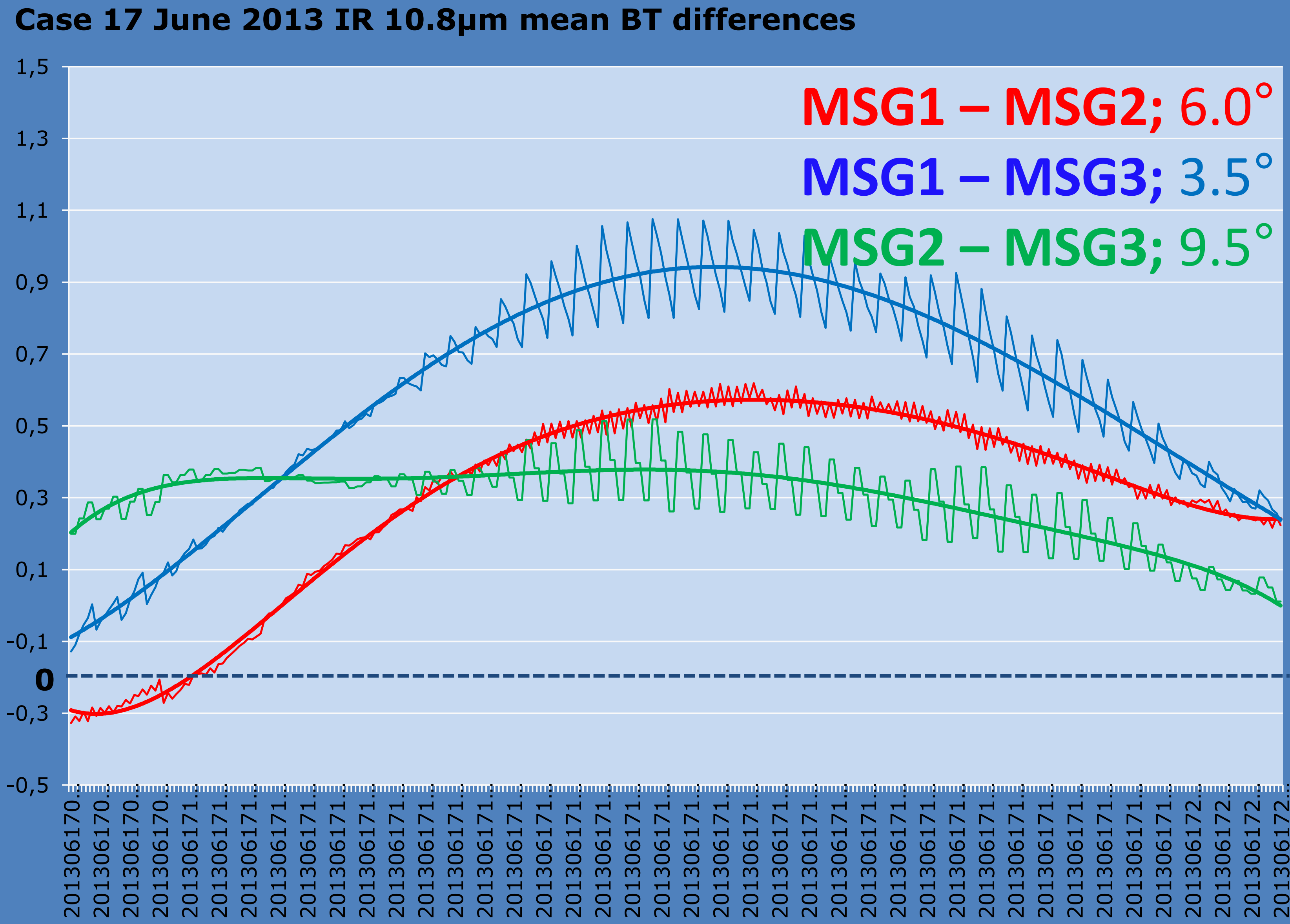
"2.5-5": 6.0° "2.5-15": 3.5° "5-15": 9.5°

Comparison of mean BT differences between different satellites during the day

Case 17 May 2013 IR 10.8µm mean BT differences

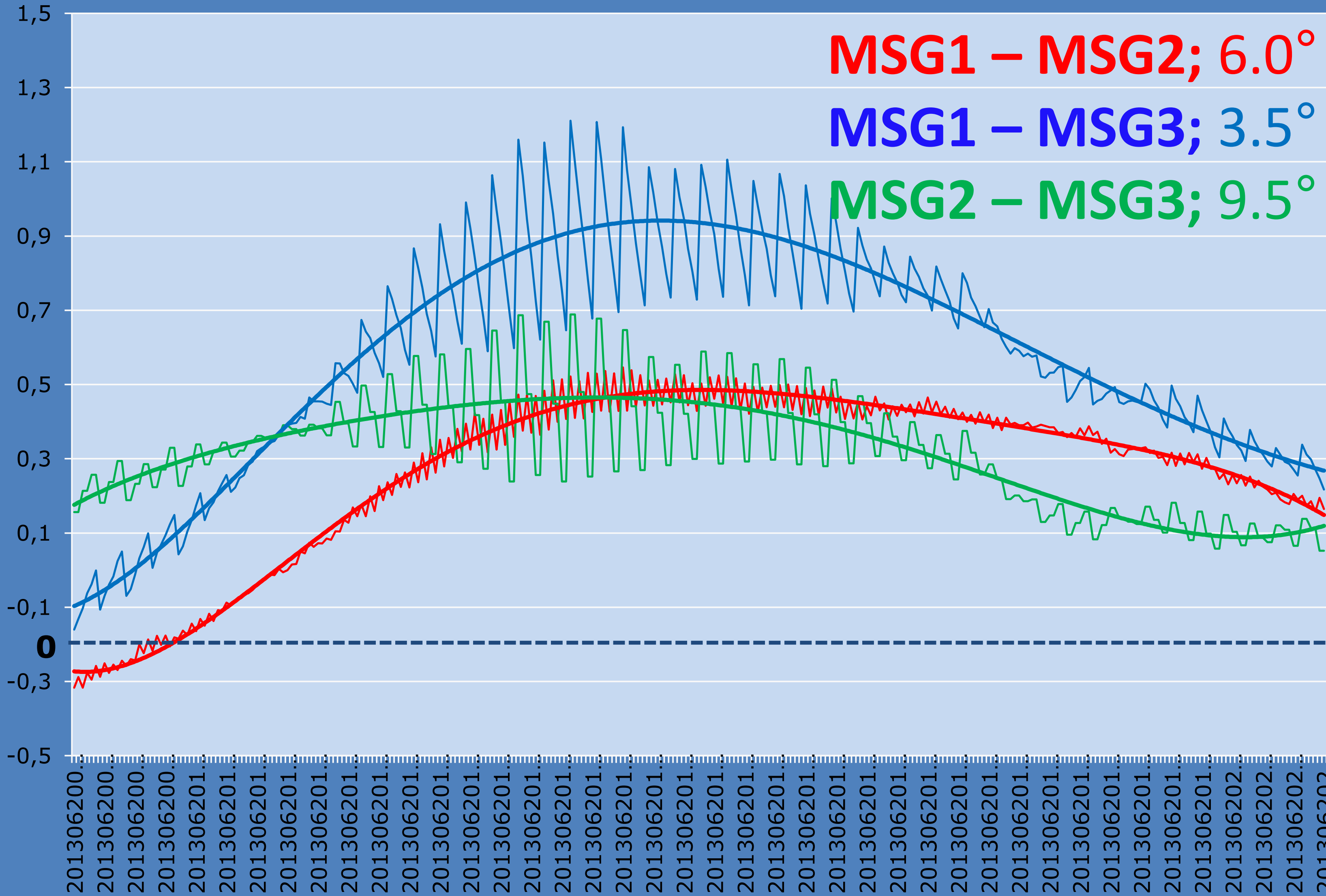


Comparison of mean BT differences between different satellites during the day

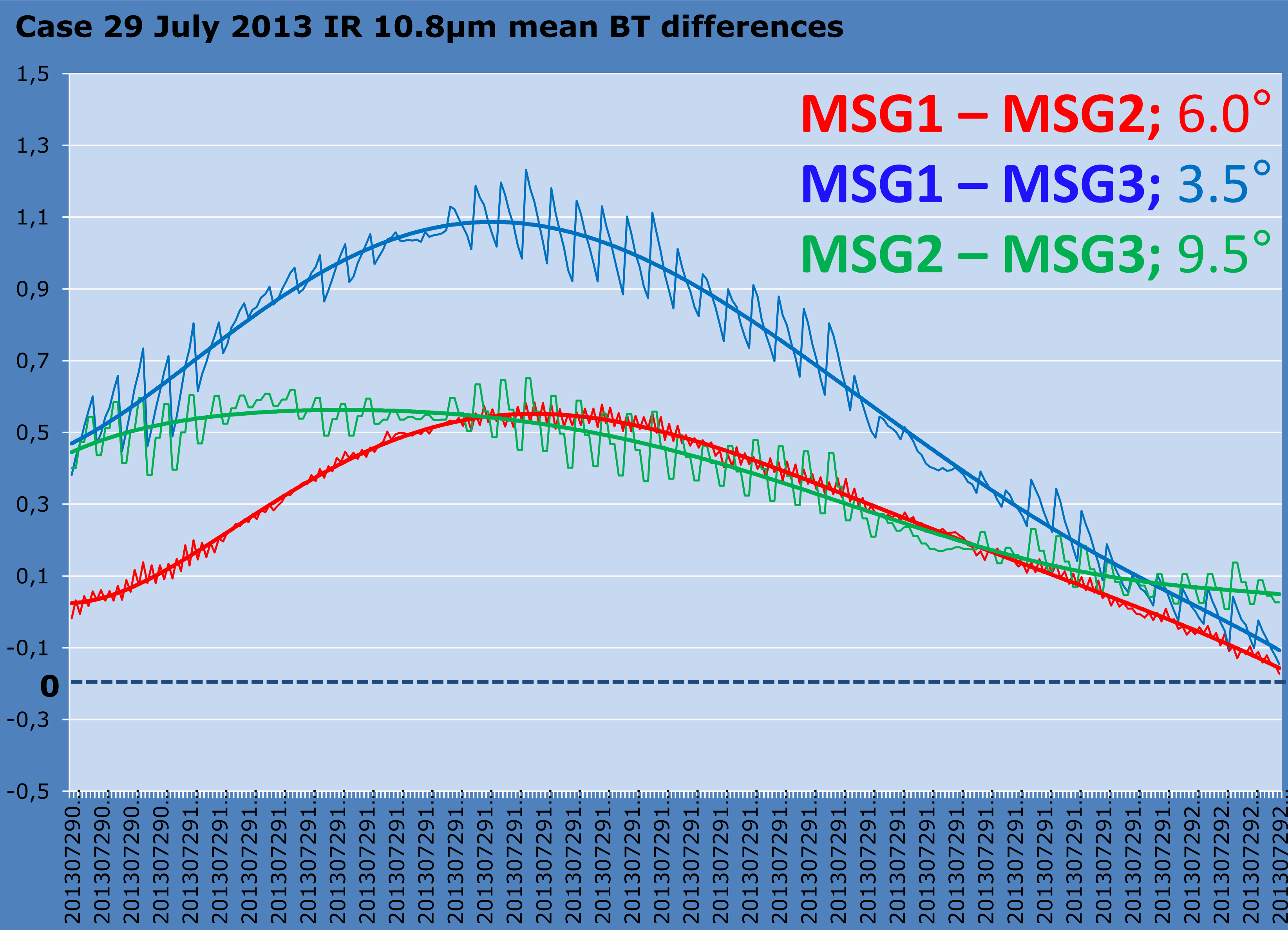


Comparison of mean BT differences between different satellites during the day

Case 20 June 2013 IR 10.8µm mean BT differences



Comparison of mean BT differences between different satellites during the day



Notes to analyzes of IR BT differences

- Shapes of all curves are very similar with evident diurnal changes
- Position of maximum of each curve depends on angular distance between satellites and season (May, June, July)
- Maximum temperature difference during the day, minimum during the night
- Anisotropy of atmosphere is the most common feature responsible for diurnal changes of BT differences between two satellites viewing from different space positions
- Anisotropy effects are not evident by simple visual observation of imagery, but can influence results of channel differences and resulting RGB combinations as well as quantitative applications like NOWCSAF products. This should be considered as important source of malfunctions in special cases.

Final remarks on IR imagery

IR imagery is very basic observation method of atmosphere and clouds from space using satellite instruments

Together with observations in visible spectral band IR imagery acts as complement for number of RGB products for satellite image analysis

Set of IR brightness temperatures serves for estimation/correction of forecasted vertical temperature and humidity profiles and consequently for atmospheric instability detection

Using specific information on precipitating clouds IR imagery can be used for continuous space and time mapping of precipitation in global scale

Finally IR imagery is widely used in number of satellite application facilities (SAF):

- Nowcasting applications
- Land surface analysis
- Climatological applications
- Support to hydrology