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# Overview of the IR channels and their applications

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# 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

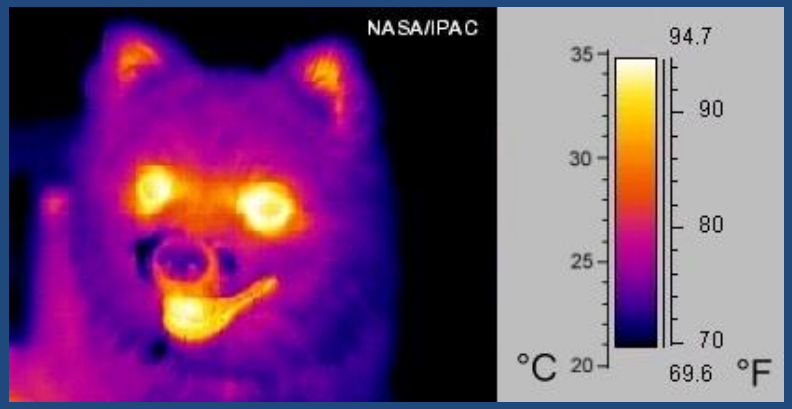
# THE ORIGINS OF THE INFRARED SPECTRUM

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.

First, it is important to reflect on the distribution of energy possessed by a molecule at any given moment, defined as the sum of the contributing energy terms:

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



# 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.

# 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).

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

$\alpha$ represents spectral absorption factor

$\rho$ is spectral reflection factor

$\tau$ is spectral transmission factor

All these elements depend also on the wavelength $\lambda$

The spectral absorption factor is equal to the emissivity $\varepsilon$

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:

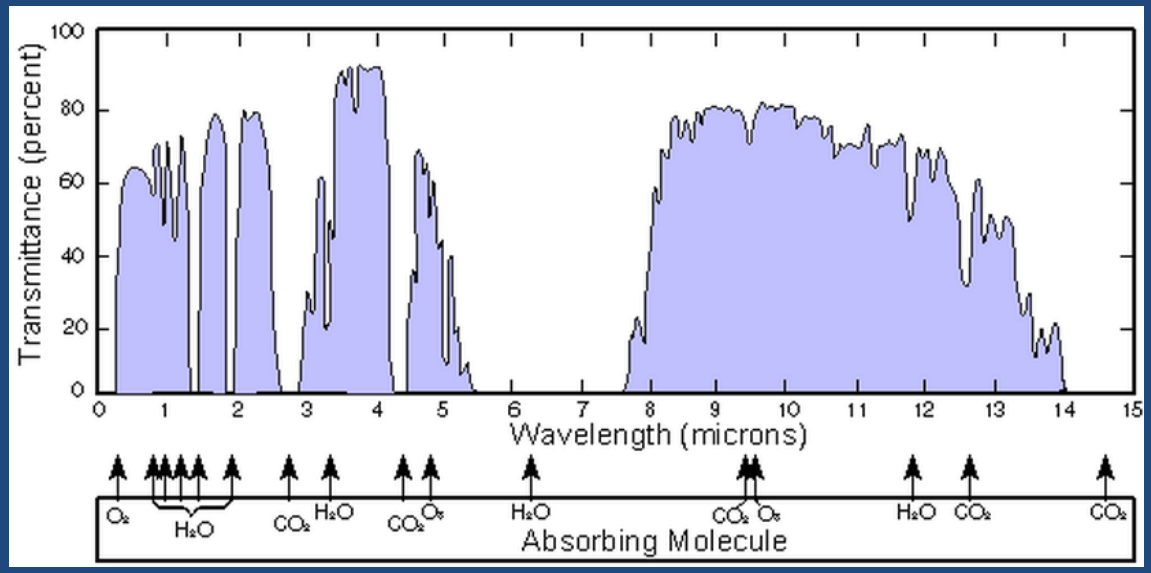
Near IR from 0.75 – 1.4 µm

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>**.

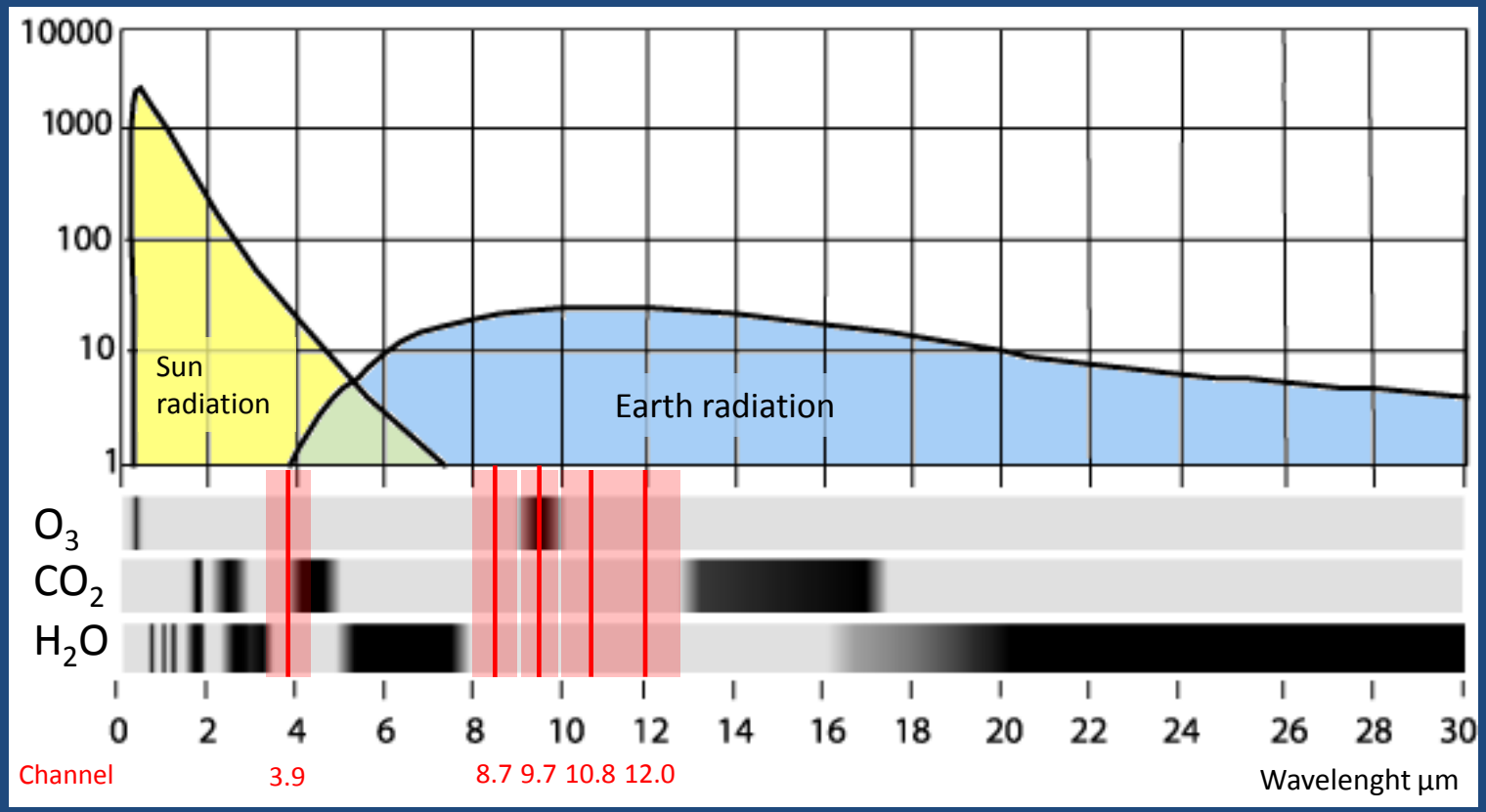
Transmittance refers to radiation passing the atmosphere and can be described by exponential function of the path x:

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

# MSG SEVIRI channels introduction

| Channel No. | Spectral Band (µm) | Characteristics of Spectral Band (µm) | | | Main observational application |
|---|---|---|---|---|---|
| | | $\lambda_{cen}$ | $\lambda_{min}$ | $\lambda_{max}$ | |
| 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:

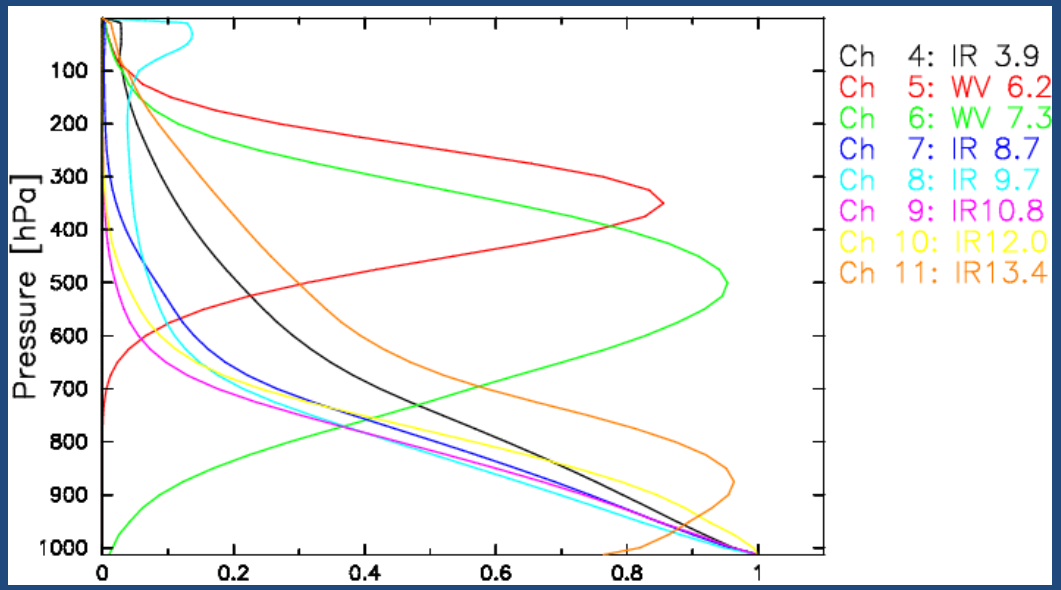



The IR atmospheric windows at 8.7 and from 10 to 13µm provides us with the most simple satellite imagery interpretation during the day and night and are useful for continuous in time and space observation of cloud systems.

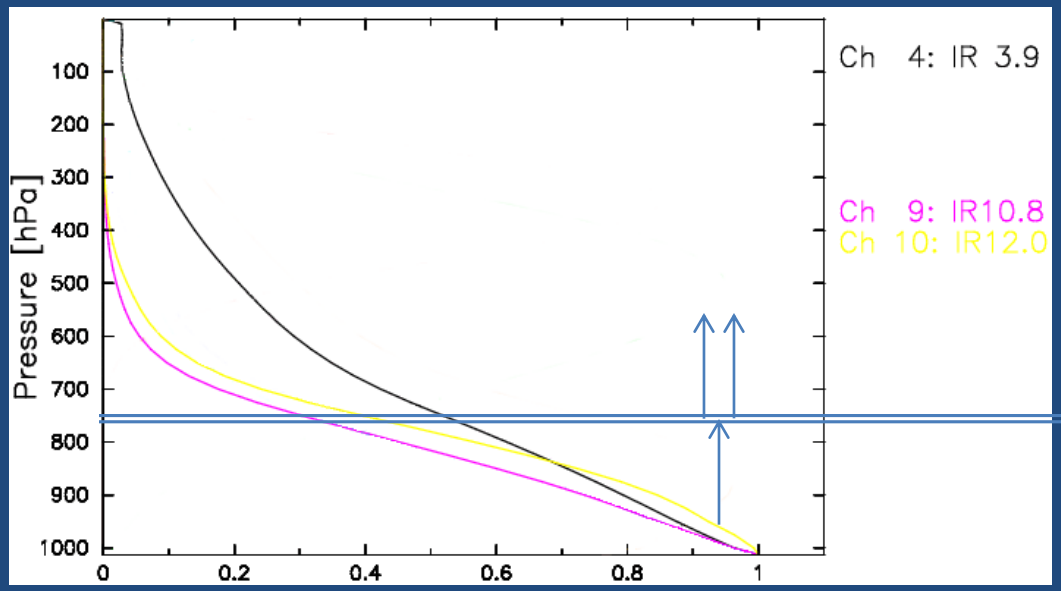
Channel 3.9µm is more complicated due to acting Sun and Earth radiation all together and needs different approach of interpretation during the night and during the day.

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

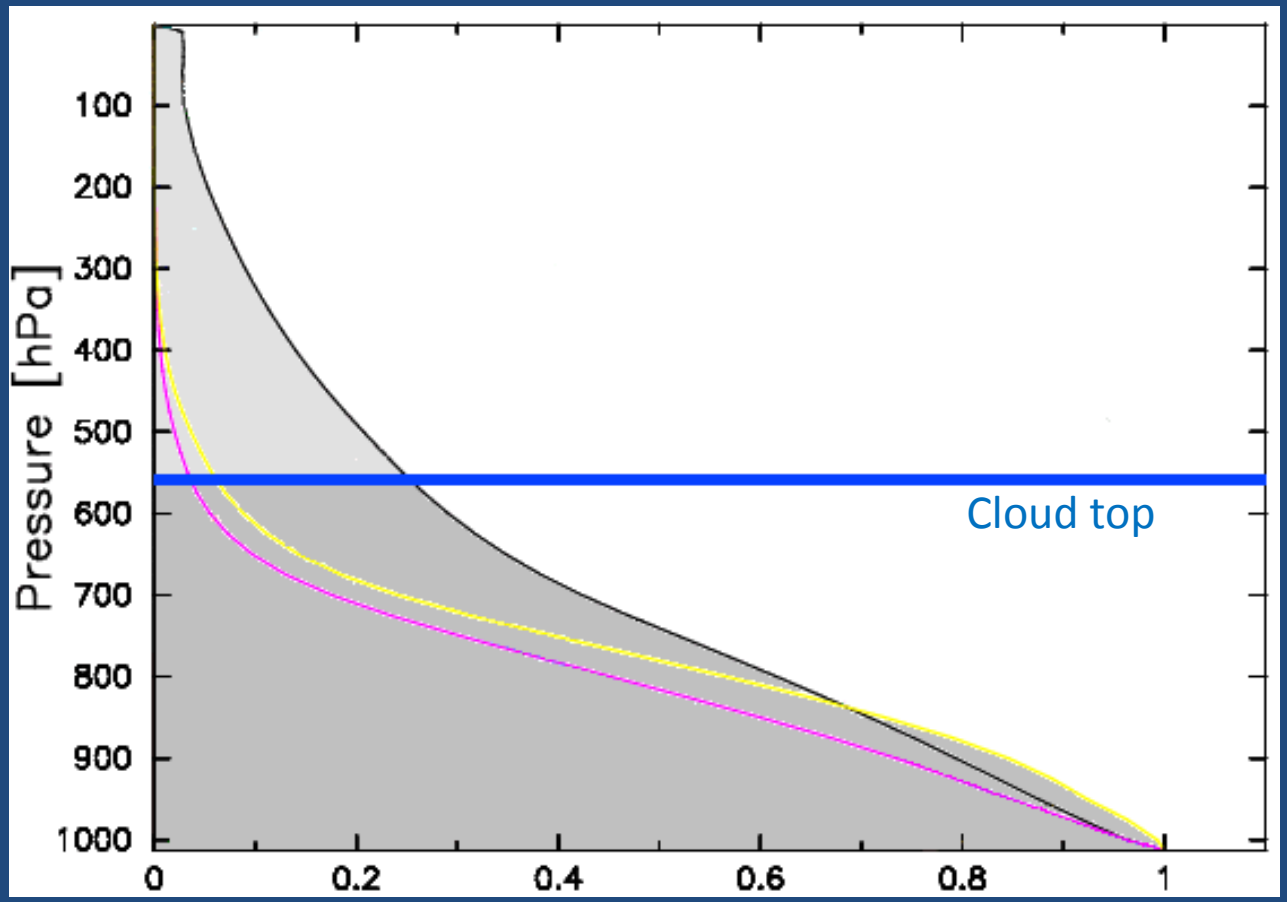



b) For channels 4, 9 and 10 of MSG satellite

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 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

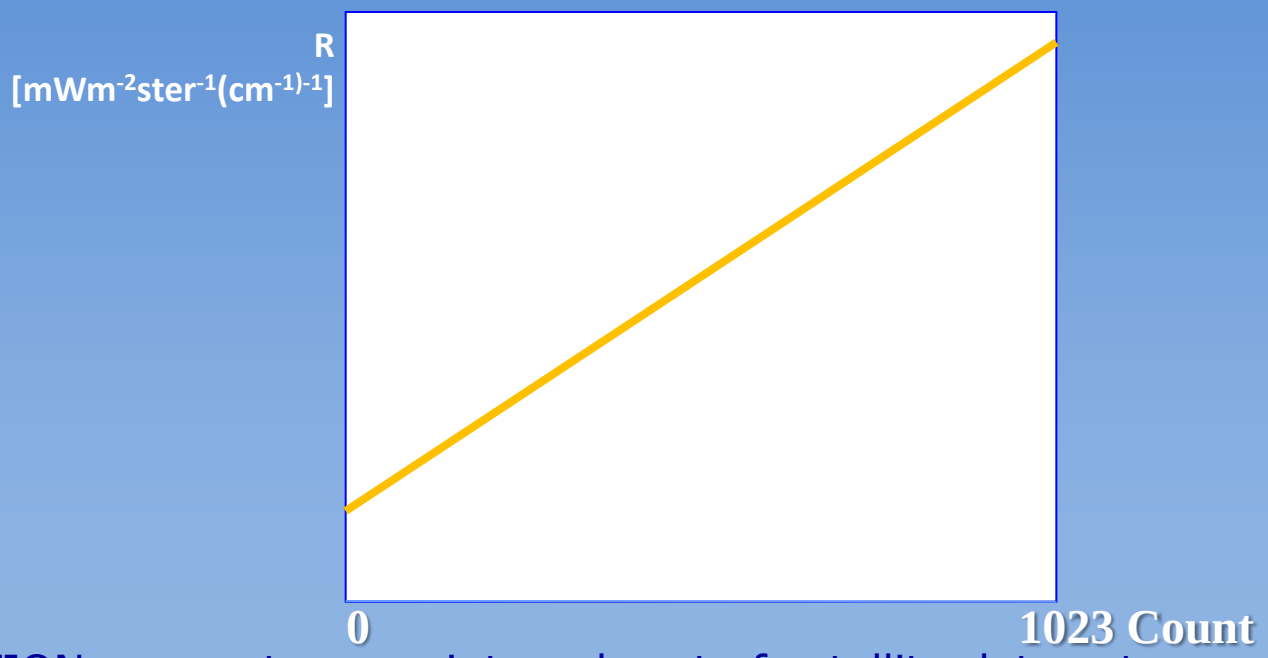
## Conversion from instrument 10-bit to 16 bit representation:

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 $T_b = f(R)$:

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

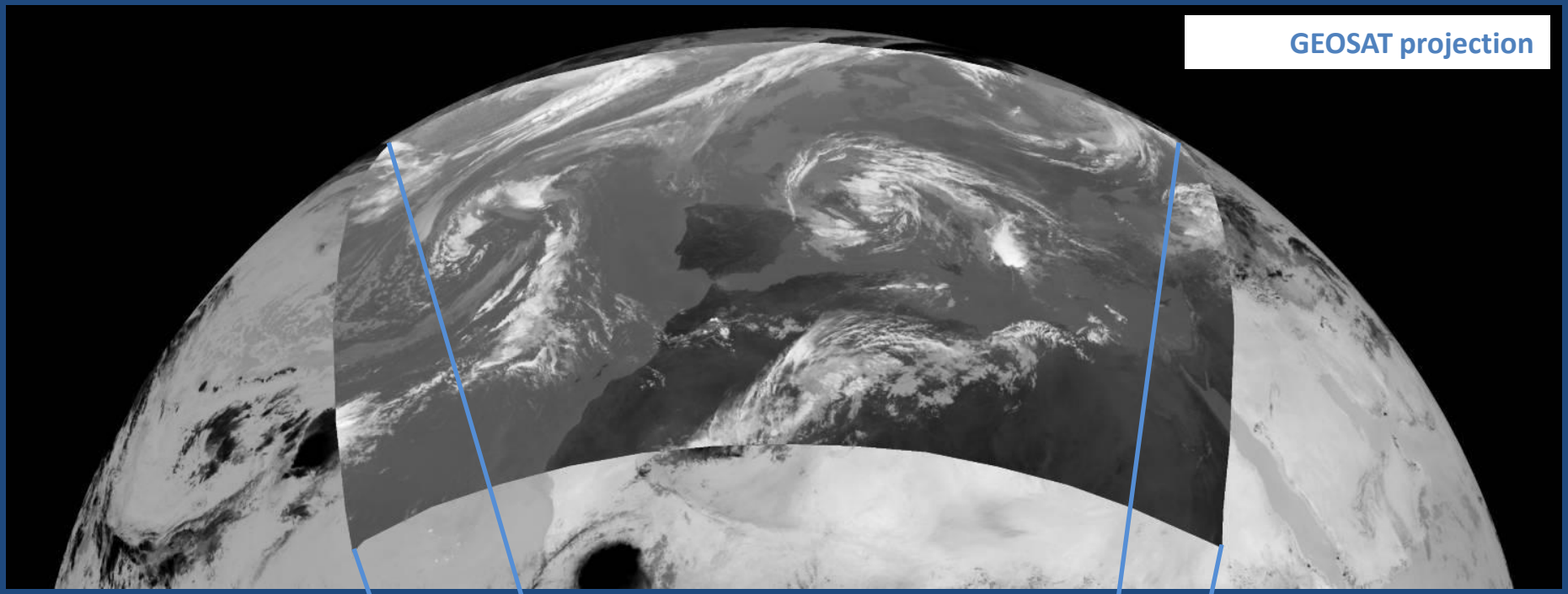
Typical precision used in practice:
16bit / 0,01K  8bit / 0,5K

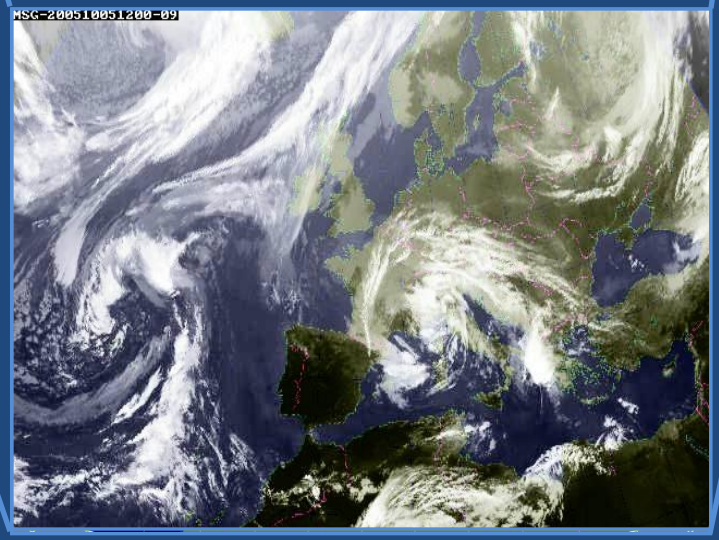
| Parameter | Value |
|---|---|
| Speed of the light in vacuum | 299792458 $ms^{-1}$ |
| Planck constant | 6.62606876(52) $10^{-34}$ Js |
| Boltzmann constant | 1.3806503(24) $10^{-23}$ $JK^{-1}$ |
| $C_1$ | 1.19104 $10^{-5}$ $mWm^{-2}sr^{-1}(cm^{-1})^{-4}$ |
| $C_2$ | 1.43877 $K(cm^{-1})^{-1}$ |

| Channel | Description | $\upsilon_c$ | 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:

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

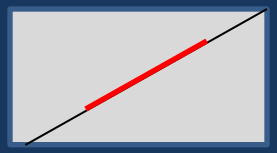
Fast reprojection:

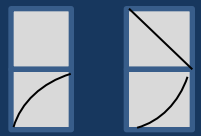
For operational purposes matrix of coordinates have to been pre-computed

# Visualisation as a basic tool for IR image applications

For visualisation 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 interval to detect certain meteorological feature – cloud top temperature, fog or land surface temperature

# 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

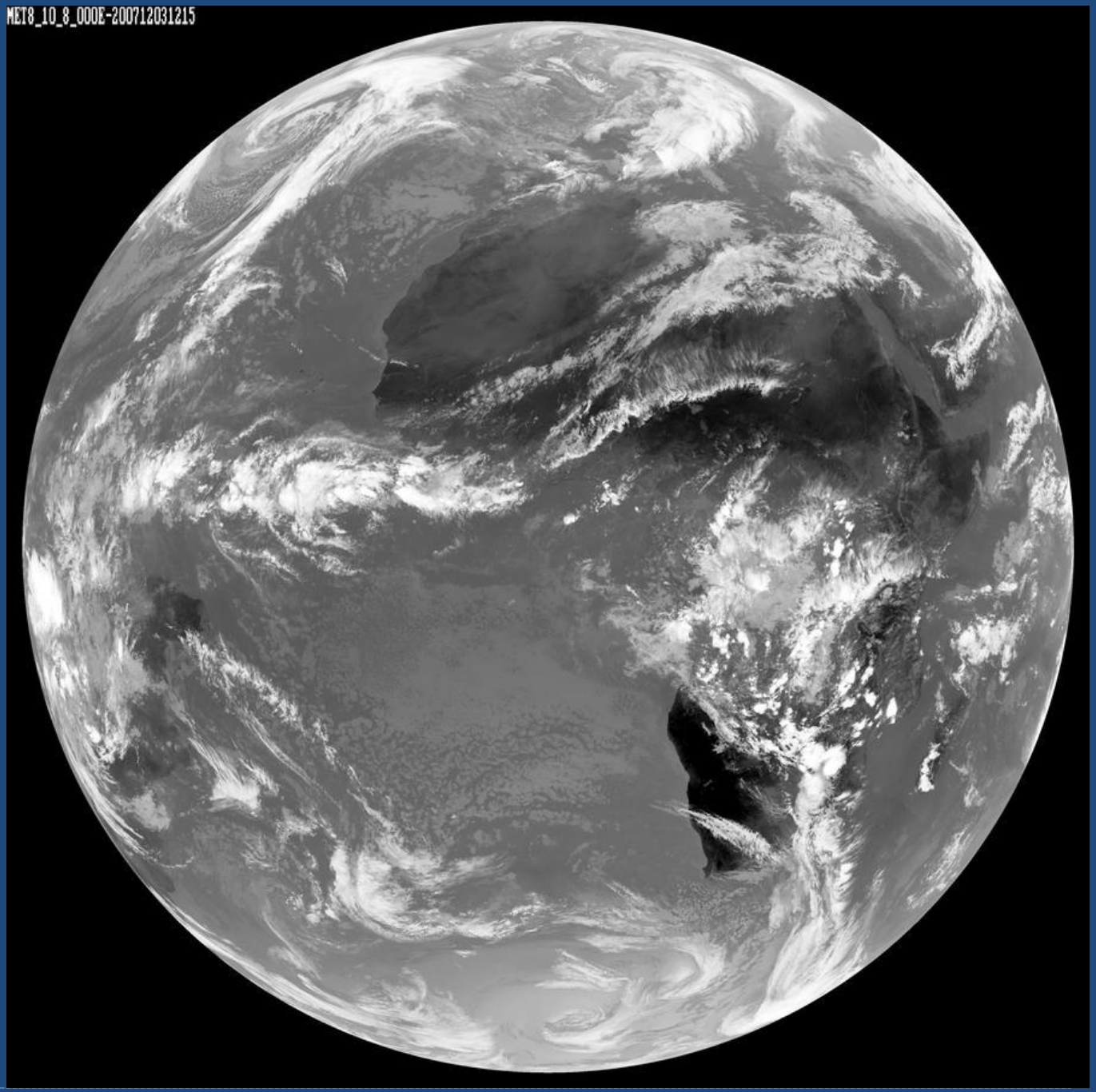
Desert during the day

# 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.

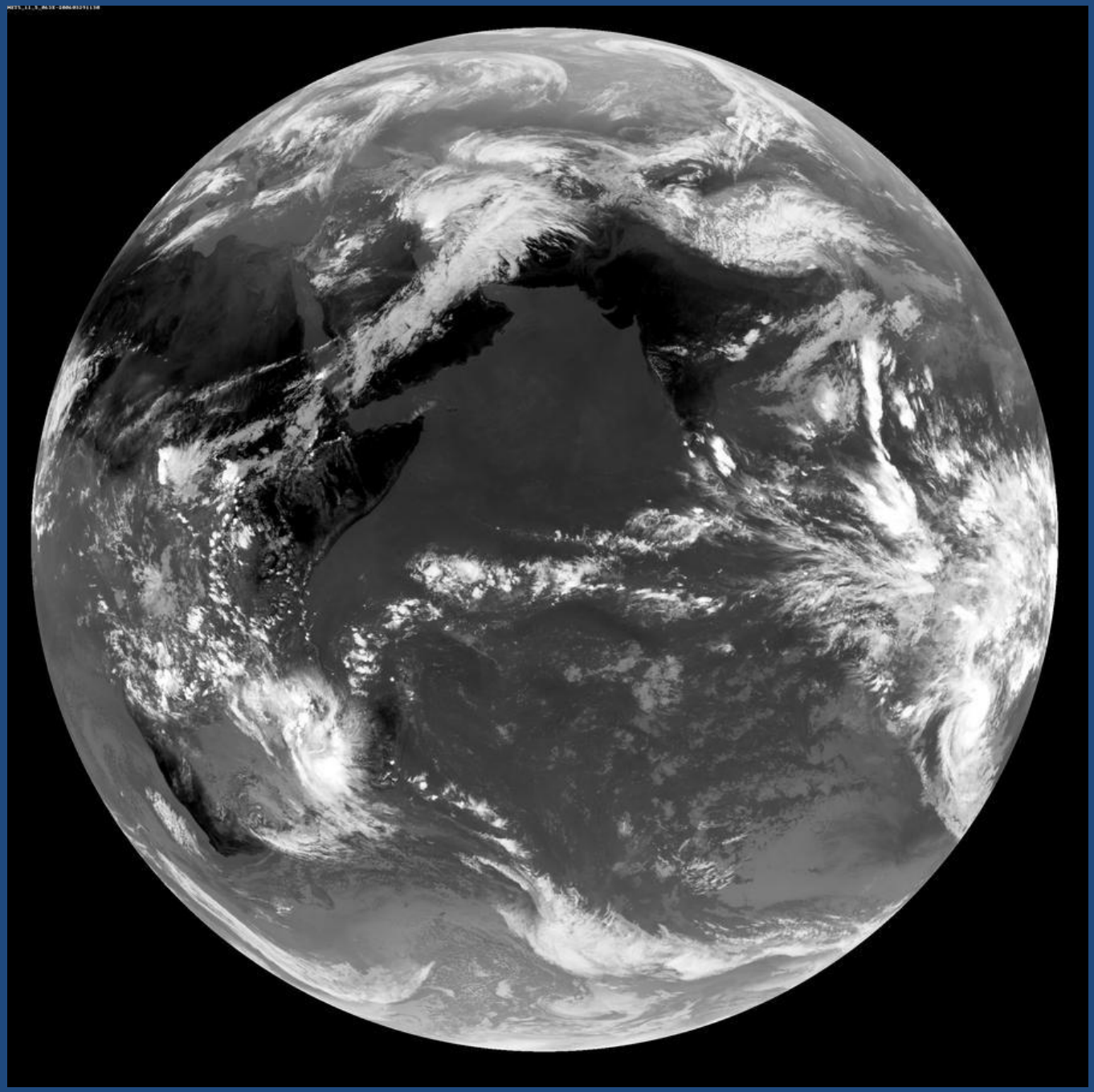



Warm land surfaces can be recognized from colder sea surfaces

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



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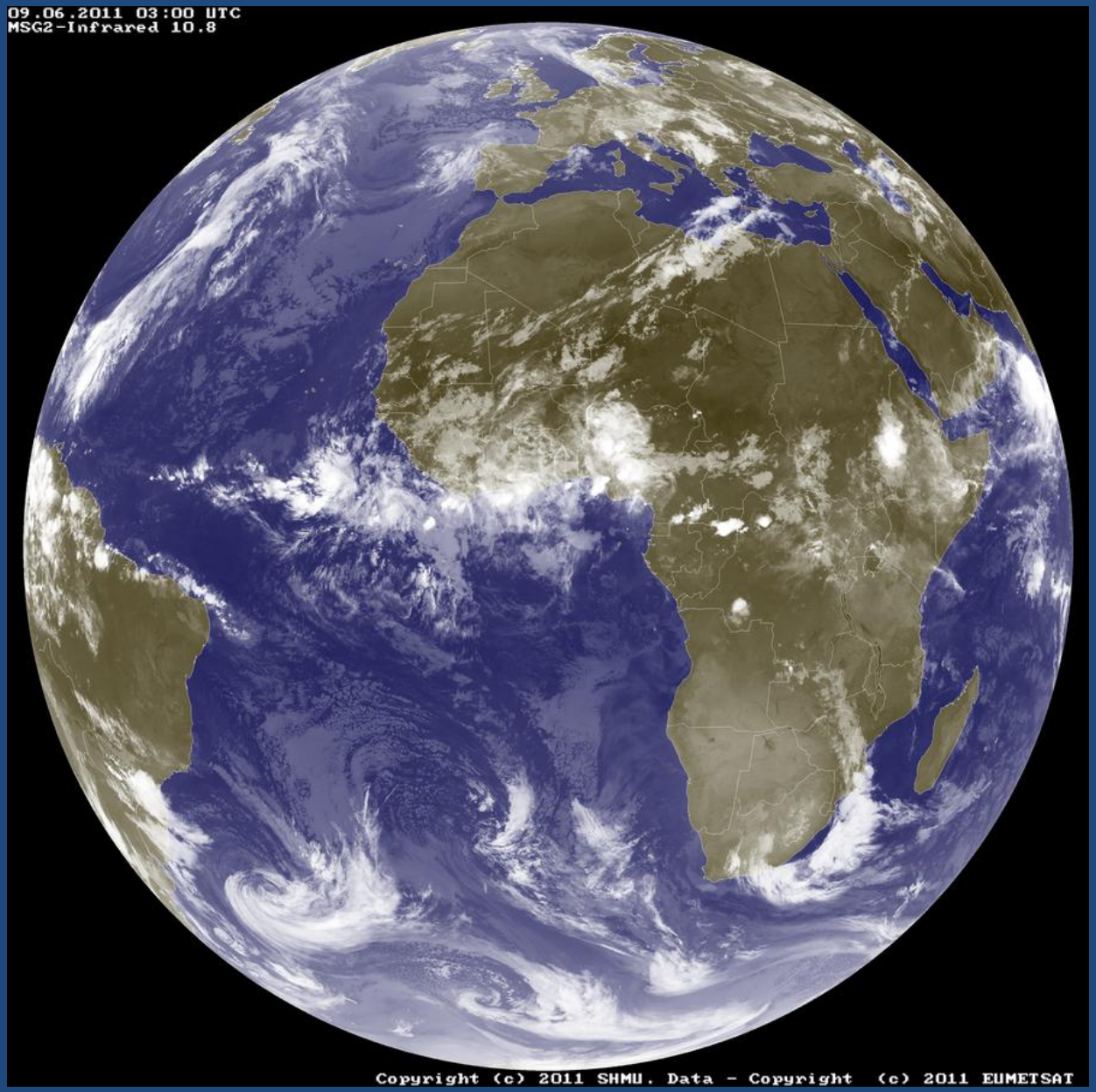
# Global IR monitoring of the Earth by geostationary satellites

- ✓ 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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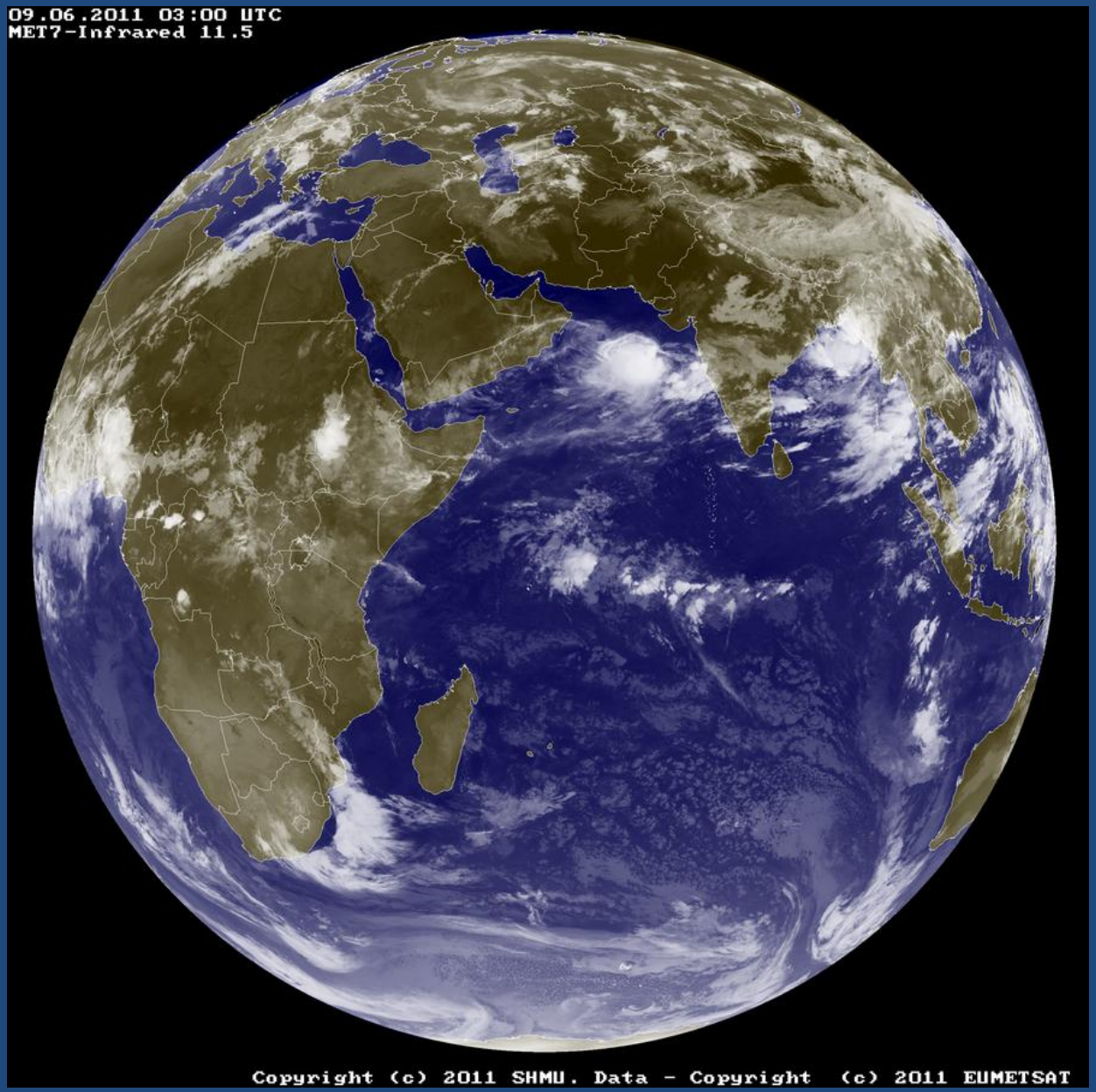

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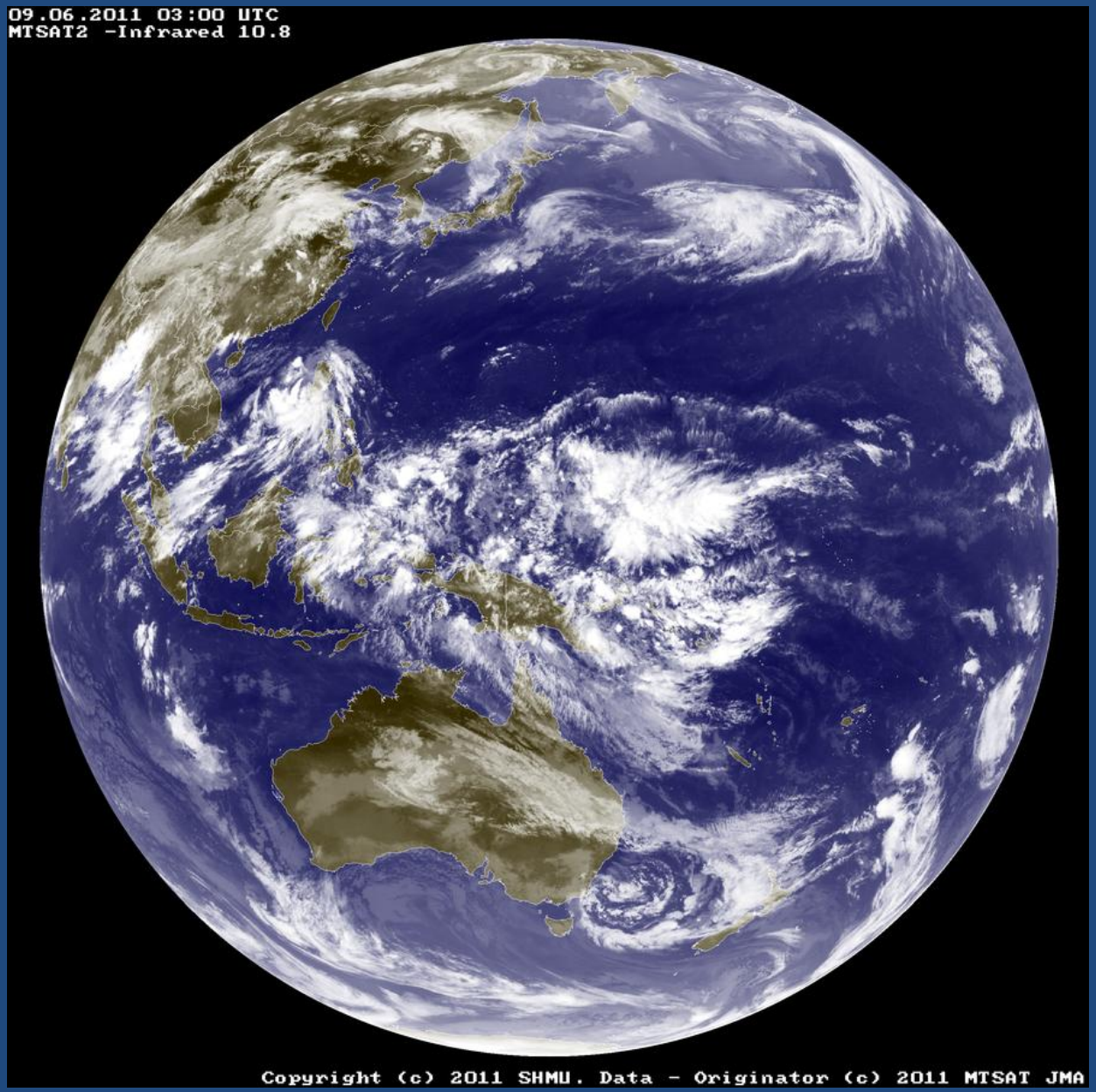

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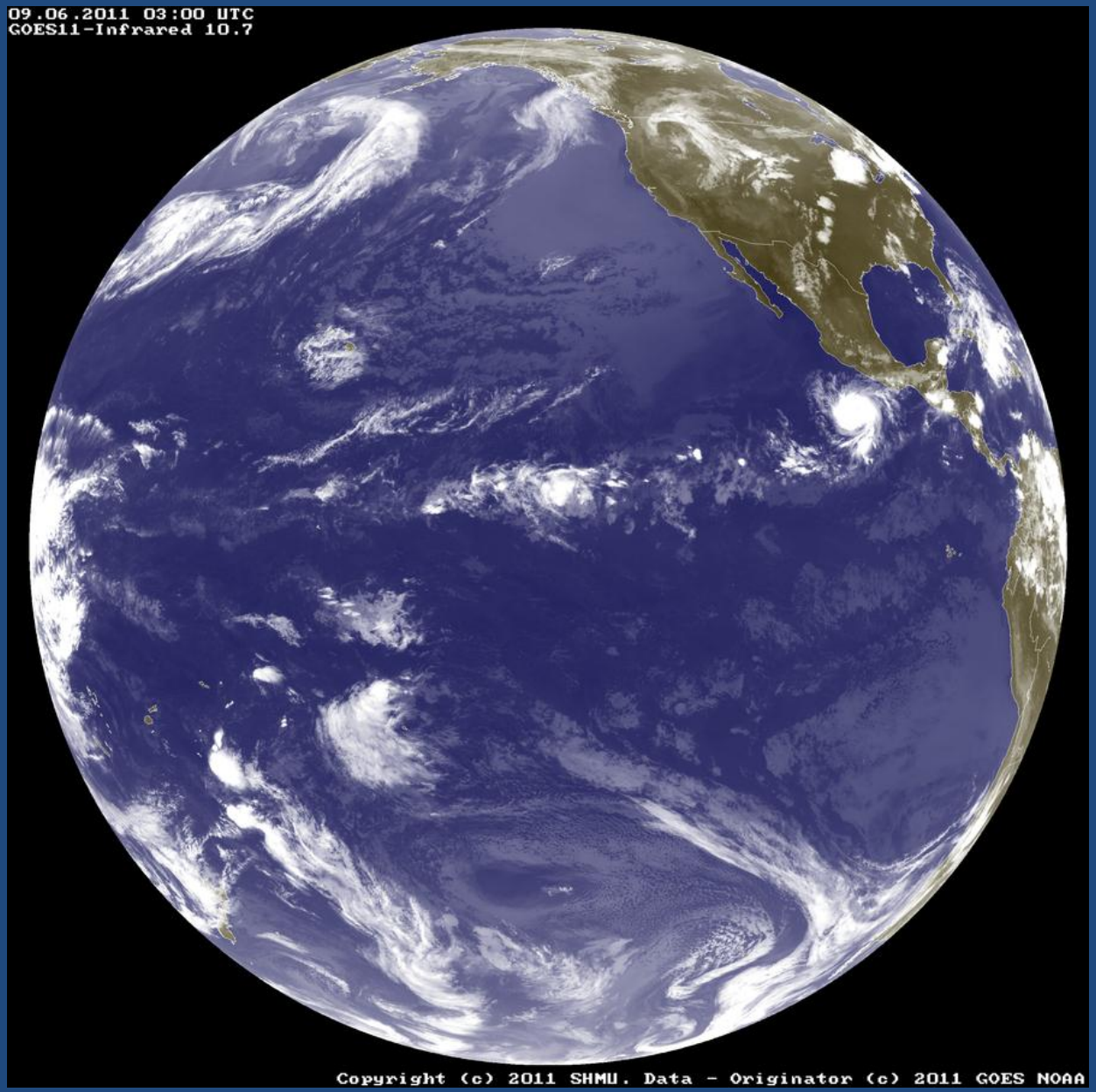

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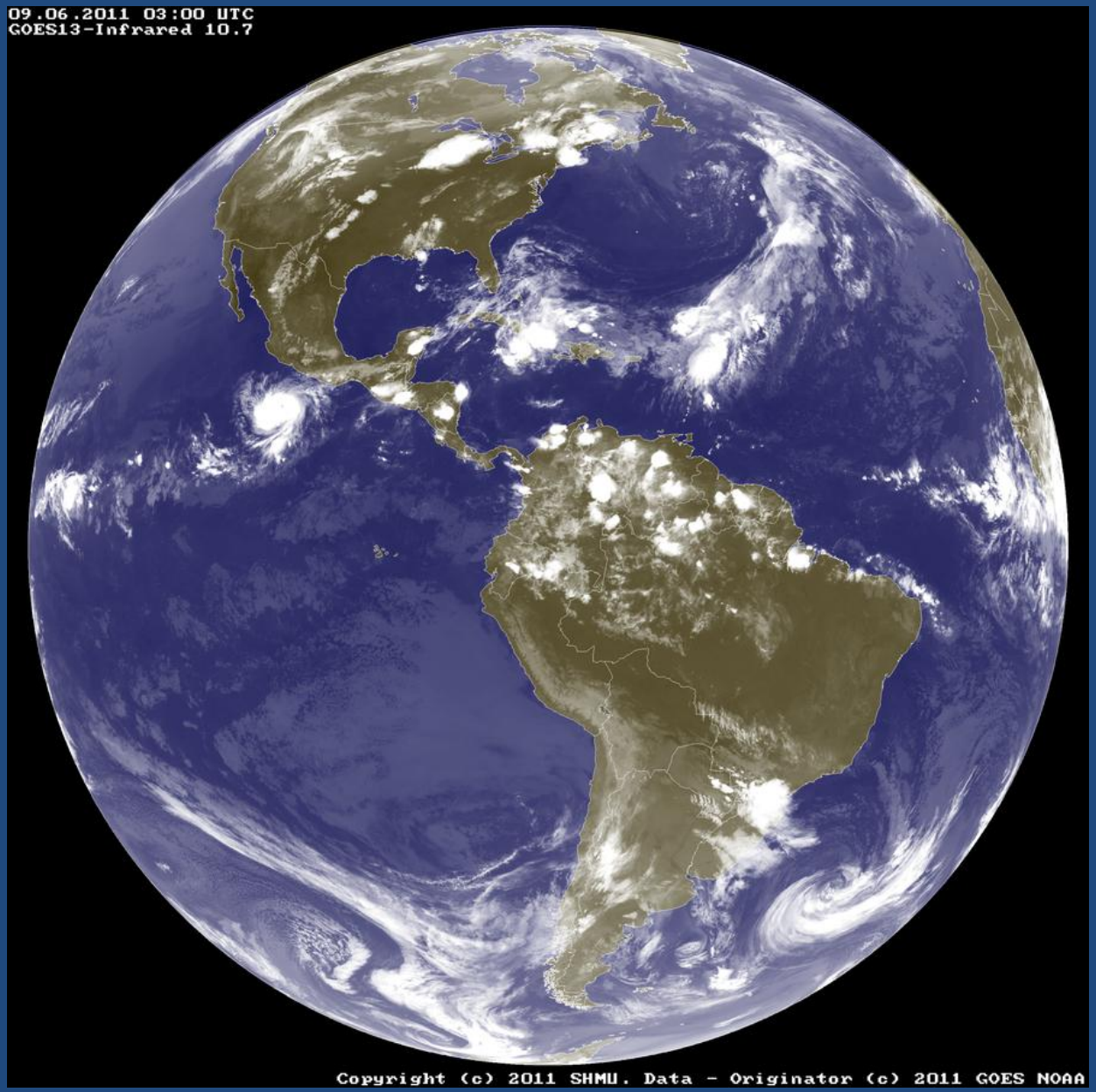
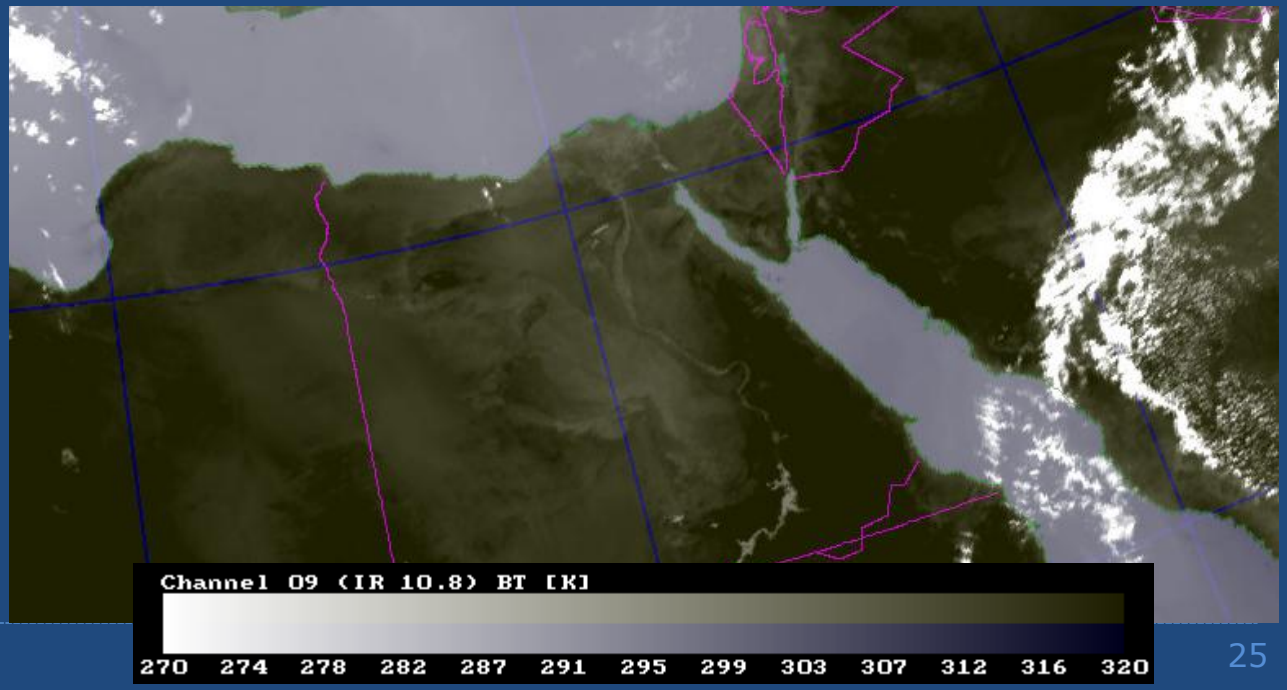


# Observing of warm areas:

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

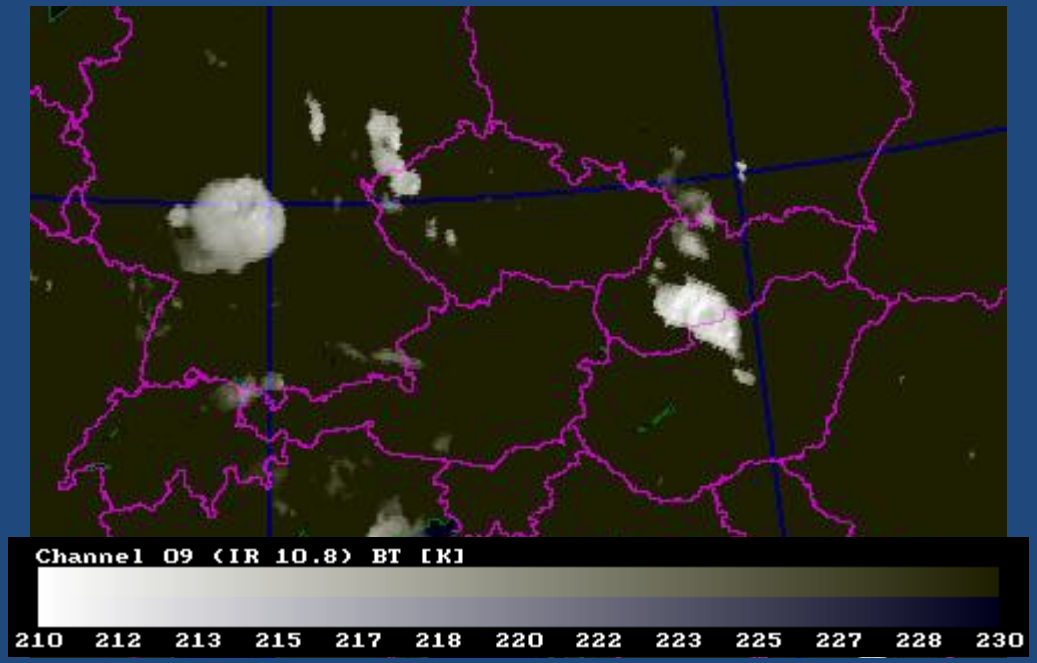

Color scale from 270 to 320 K increase contrase of warm areas, details can be observed on the Earth surface, but cold clouds are too white



# 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

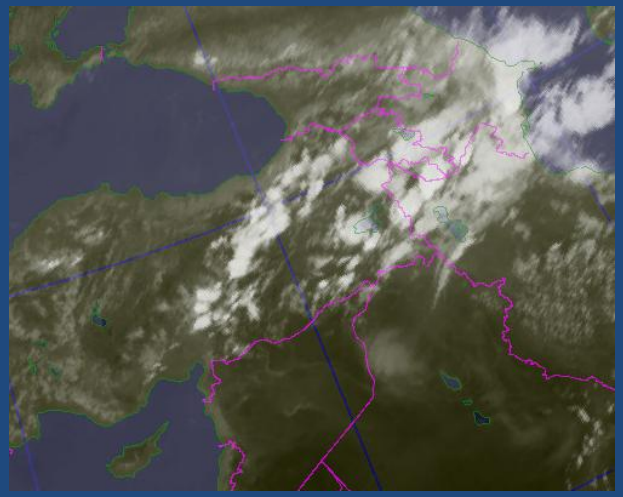

Narrow color scale from 210 to 230 K
increase contrast of cold areas,
details of cloud tops can be well observed



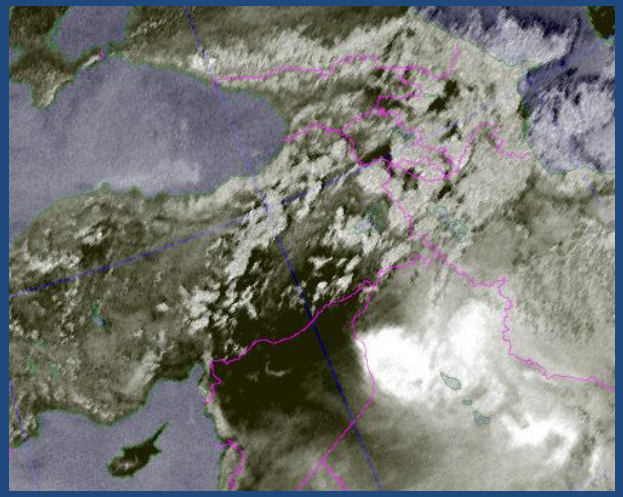
# Visualisation of dust storm using channels 10 – 9 difference

Channel 9, 10.8µm

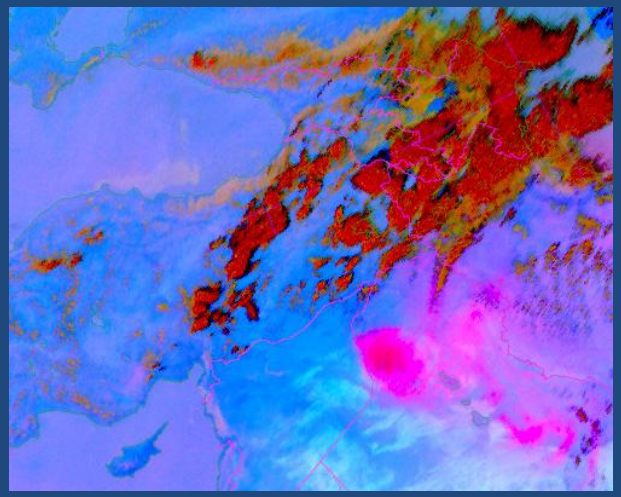
Channel 10, 12.0µm



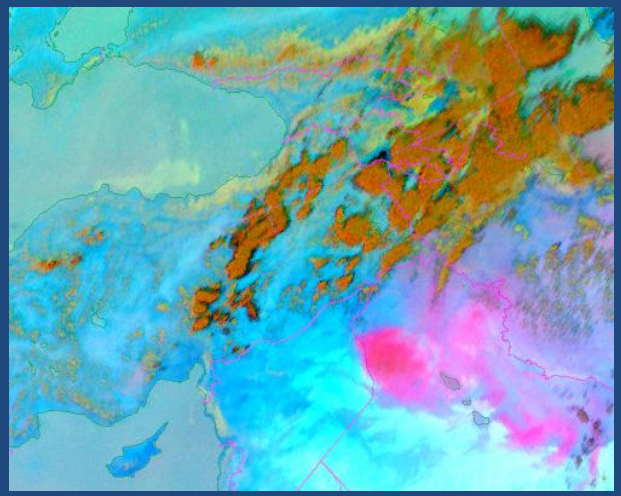
Difference ch 10 – ch 9



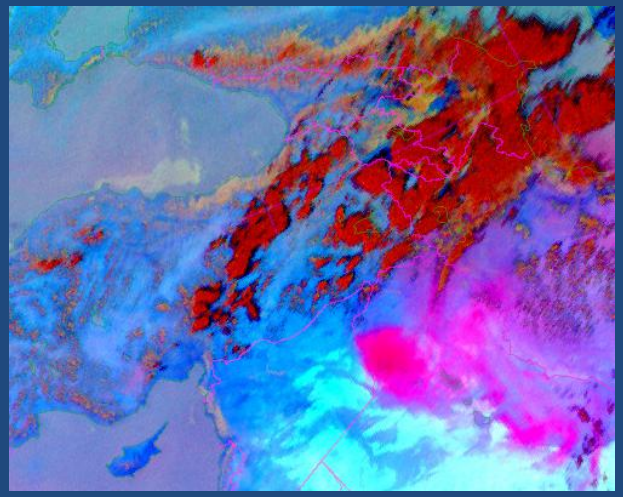
Dust RGB



Ash RGB

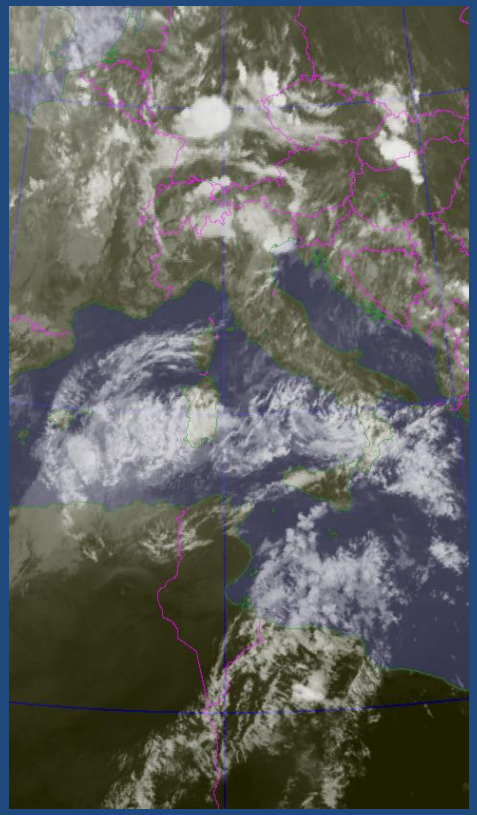


24-hours microphysical RGB

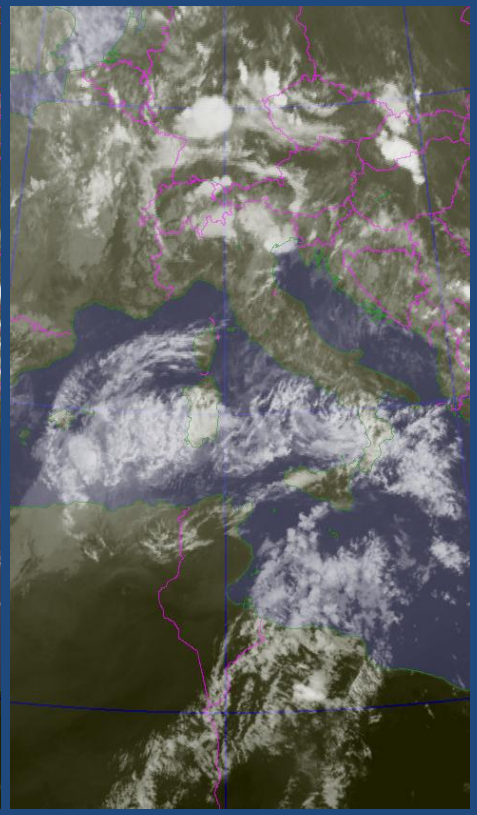


# Visualisation of high cirrus using channels 10 – 9 difference

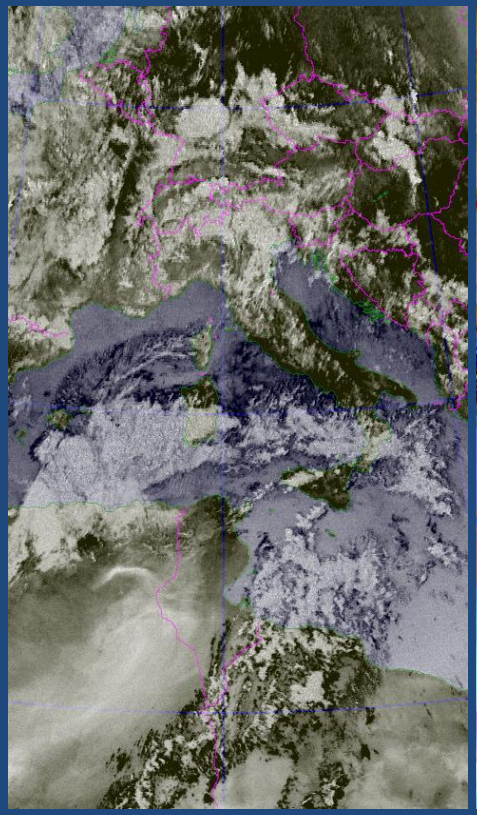
Channel 9, 10.8µm



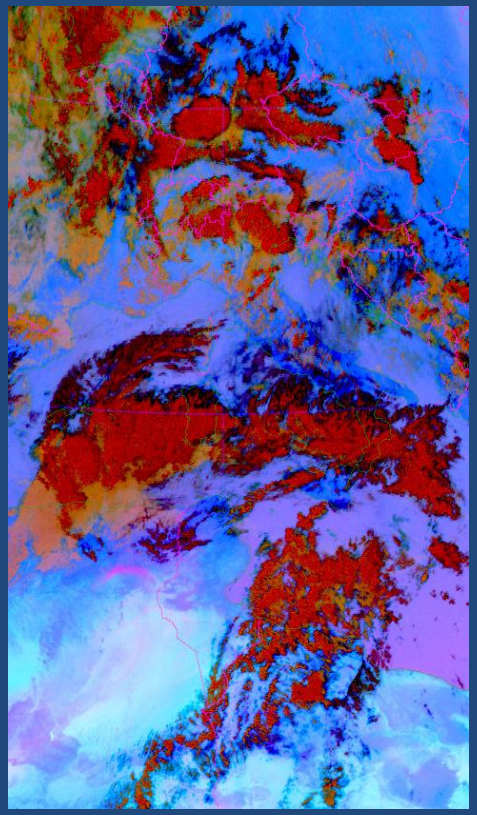
Channel 10, 12.0µm



Diff ch 10 – ch 9

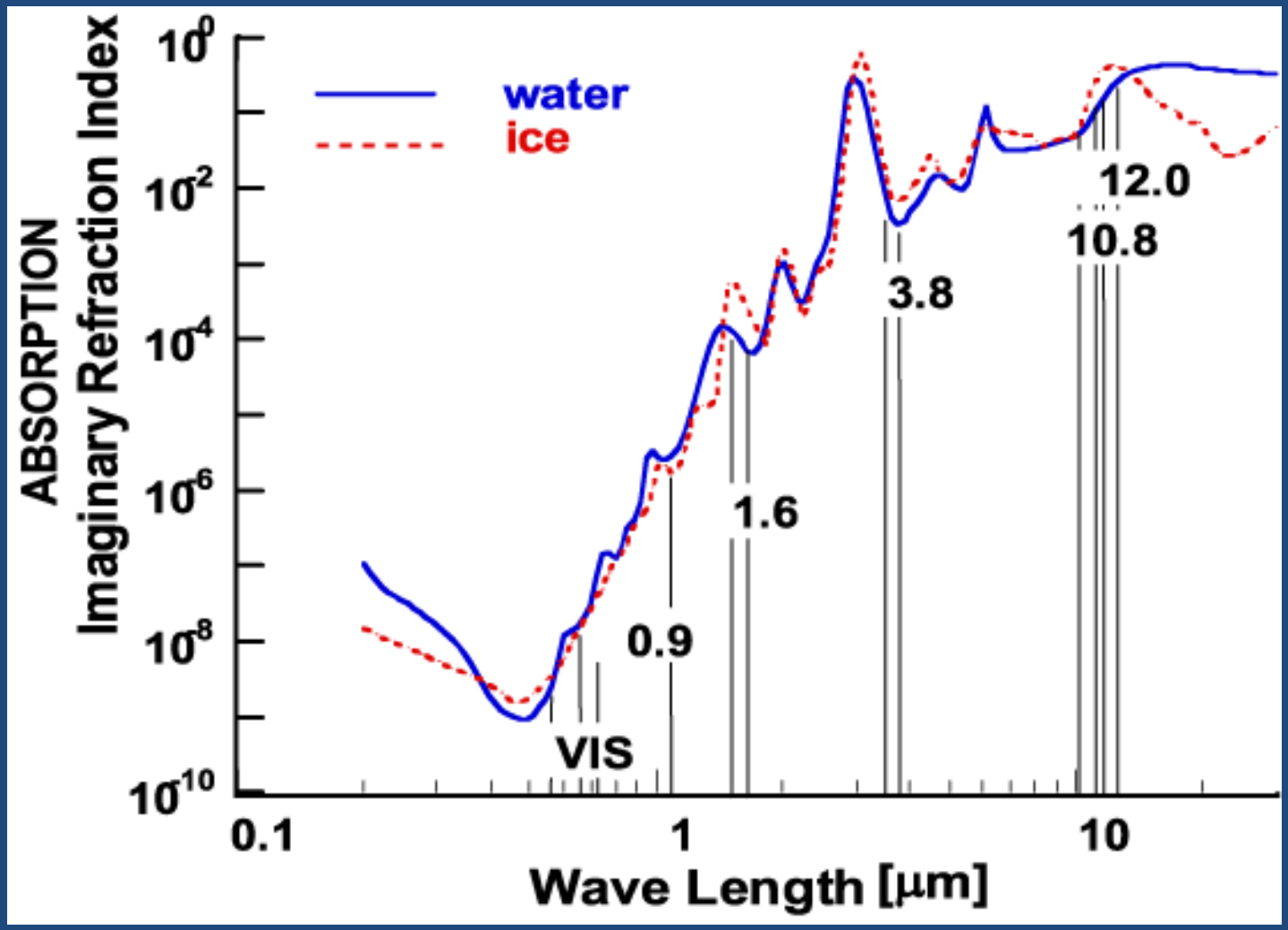


Dust RGB



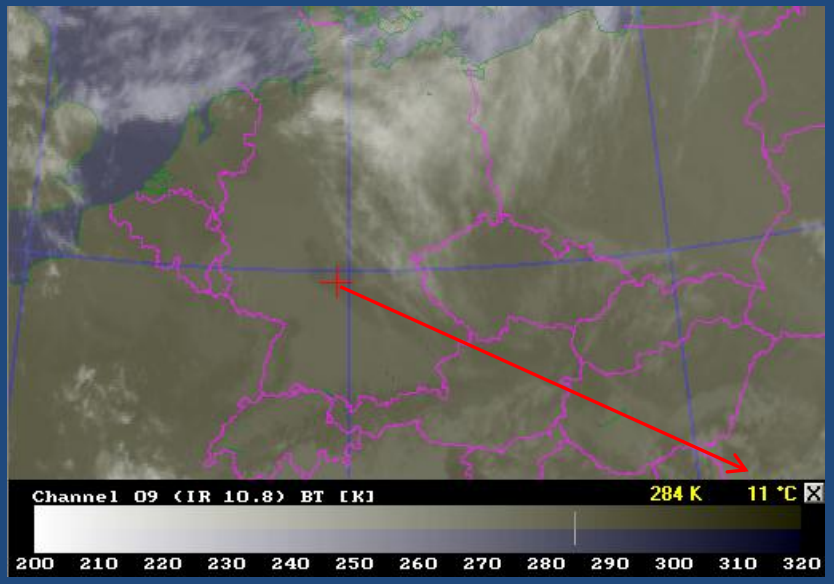
High cirrus cloud detection is based on a different absorption of ice and water cloud between 10.8 and 12.0 µm - higher absorption is for ice phase in 12.0 µm

# Absorption of Ice and Water cloud according D. Rosenfeld:

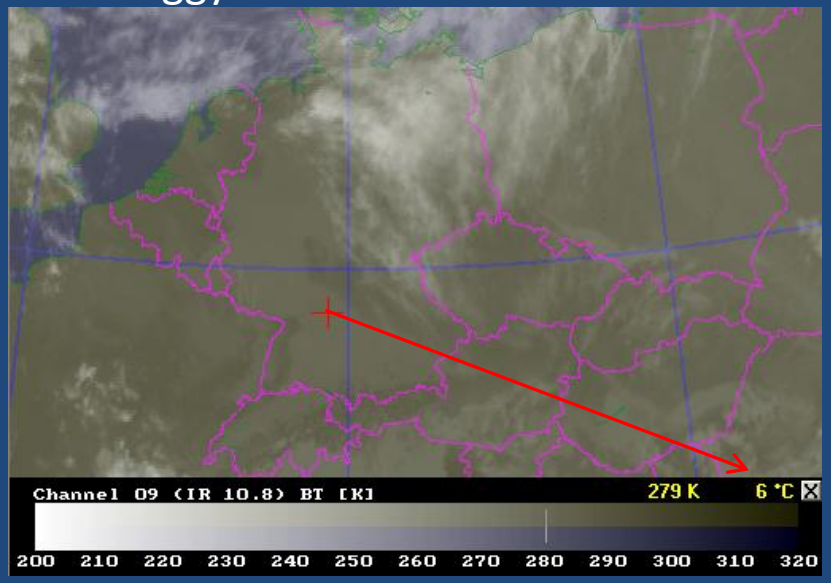


# Observation of fog using IR channel 9 and 10

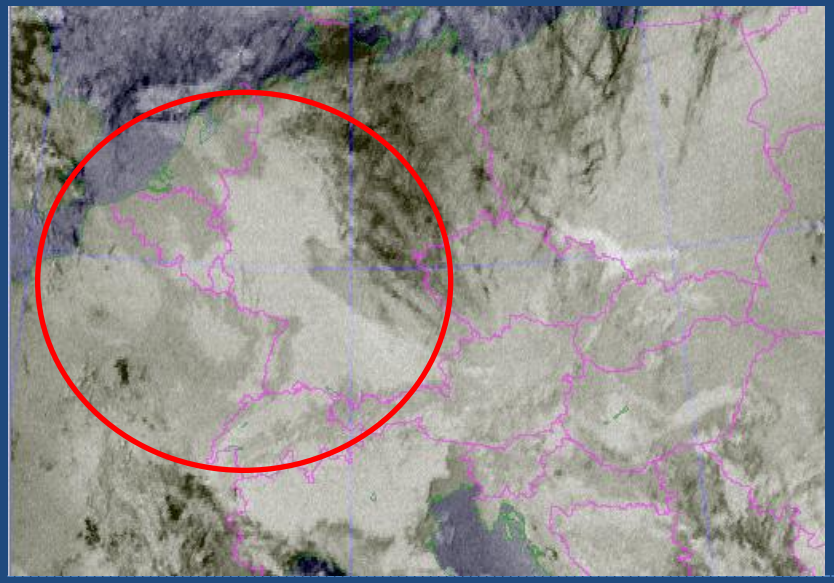
BT of land surface is around 11°C



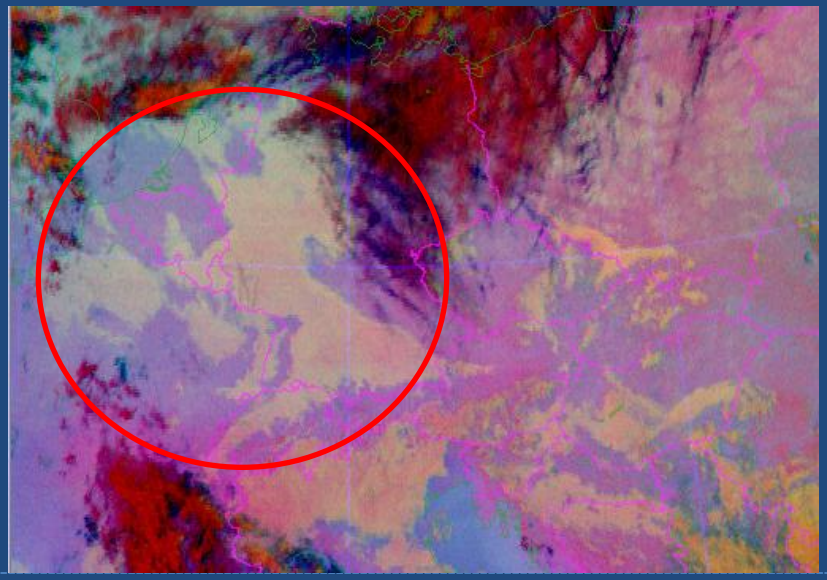

BT of foggy area is around 6°C




Difference of IR channel 10 and 9



24-hours microphysical RGB



# Synoptic scale observations using IR imagery

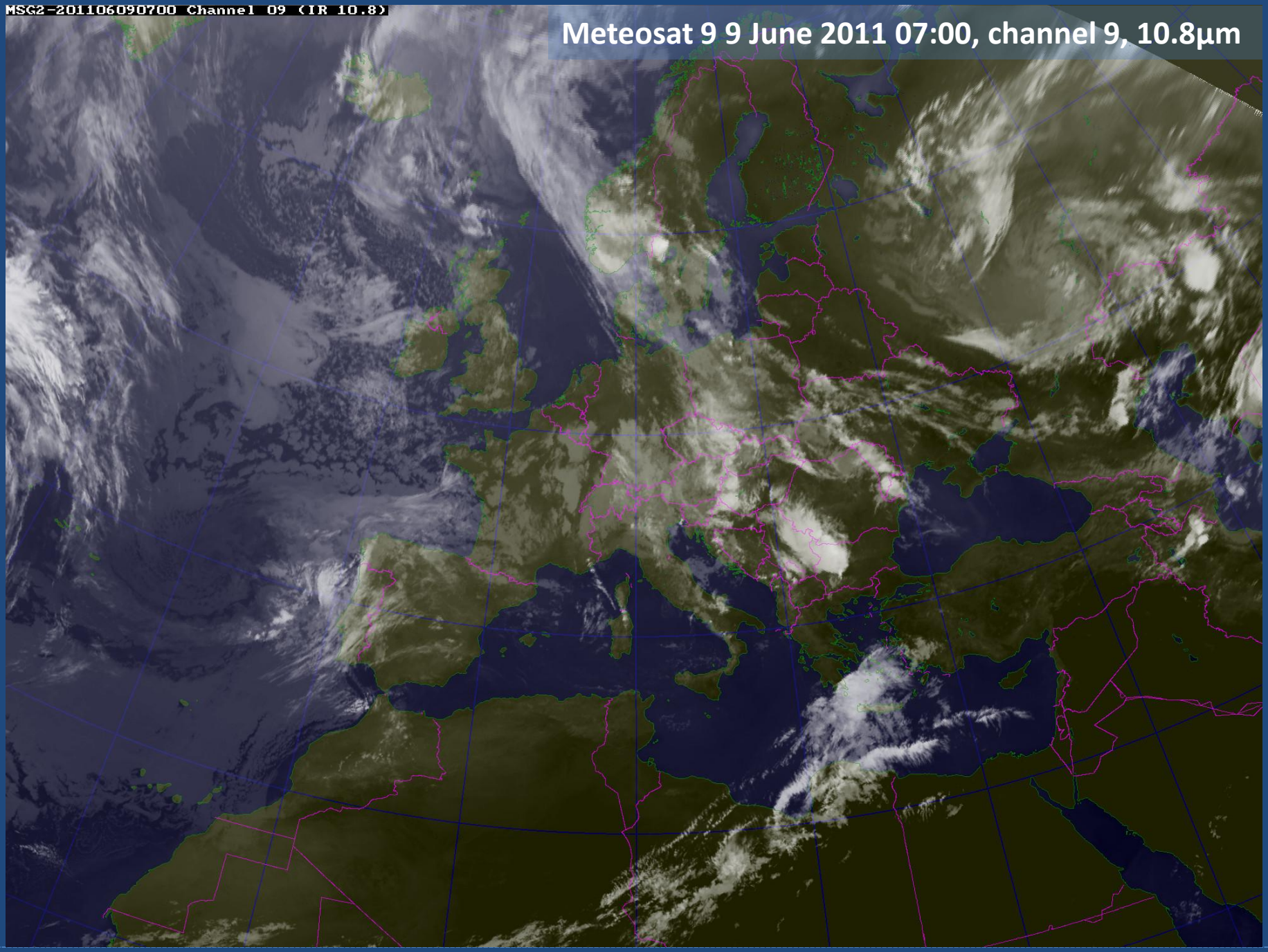
-the most widely used application of IR imagery;

-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:

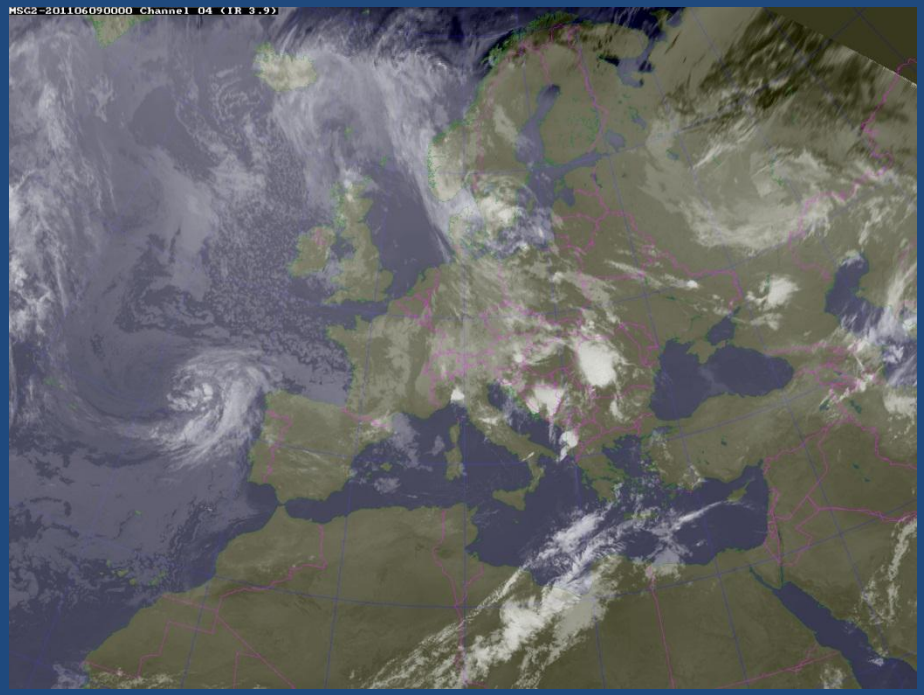
- airmasses
- cyclones and anticyclones development
- Recognition of frontal weather patterns and their movement

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

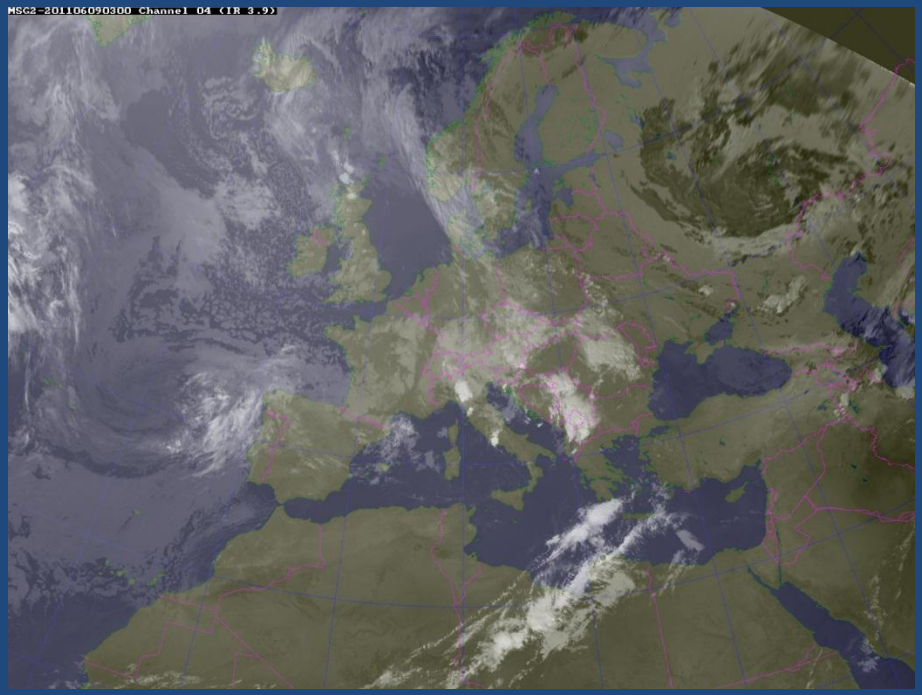


# Meteosat 9 9 June 2011, channel 4, 3.9µm

00:00 UTC

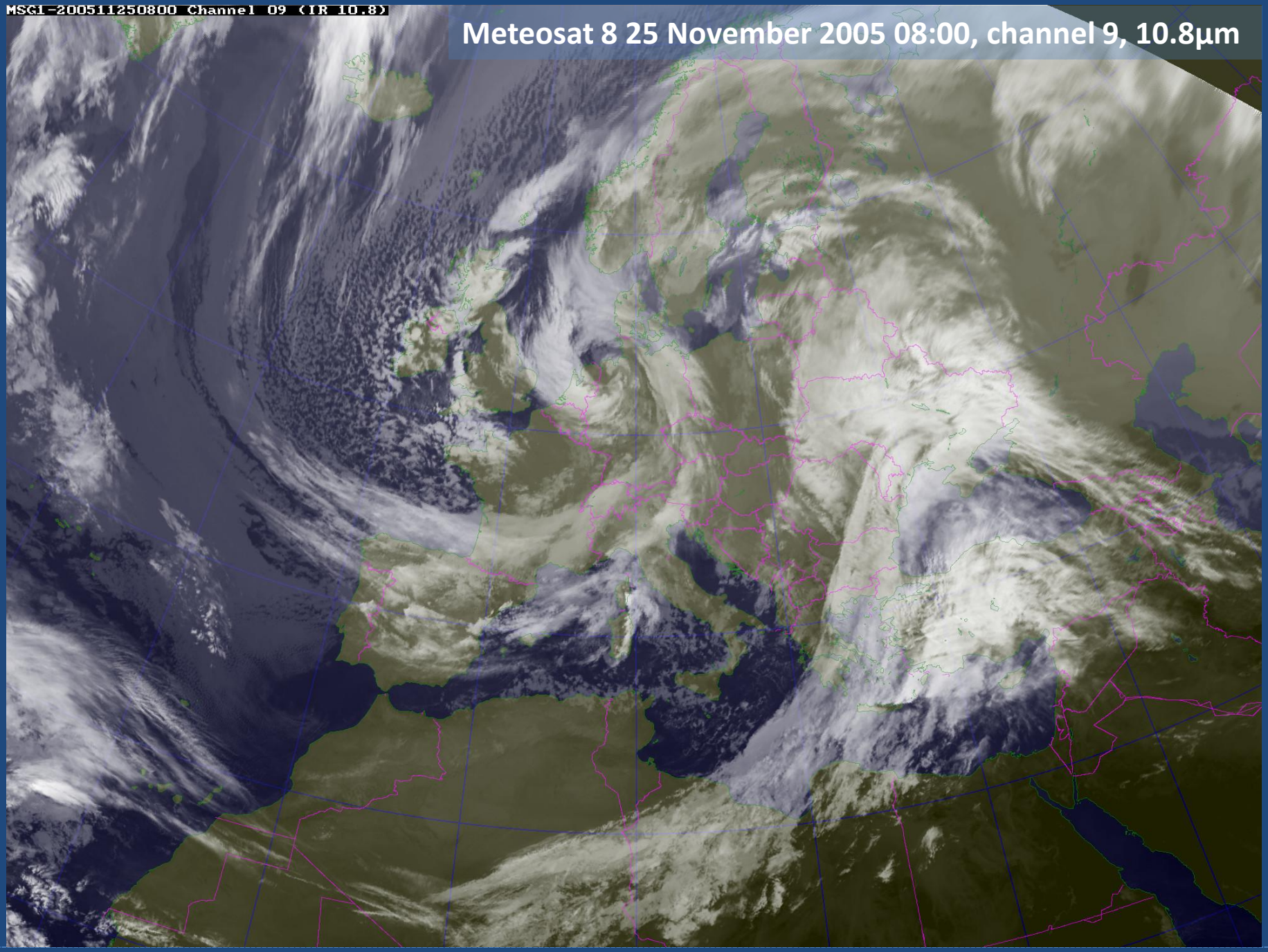


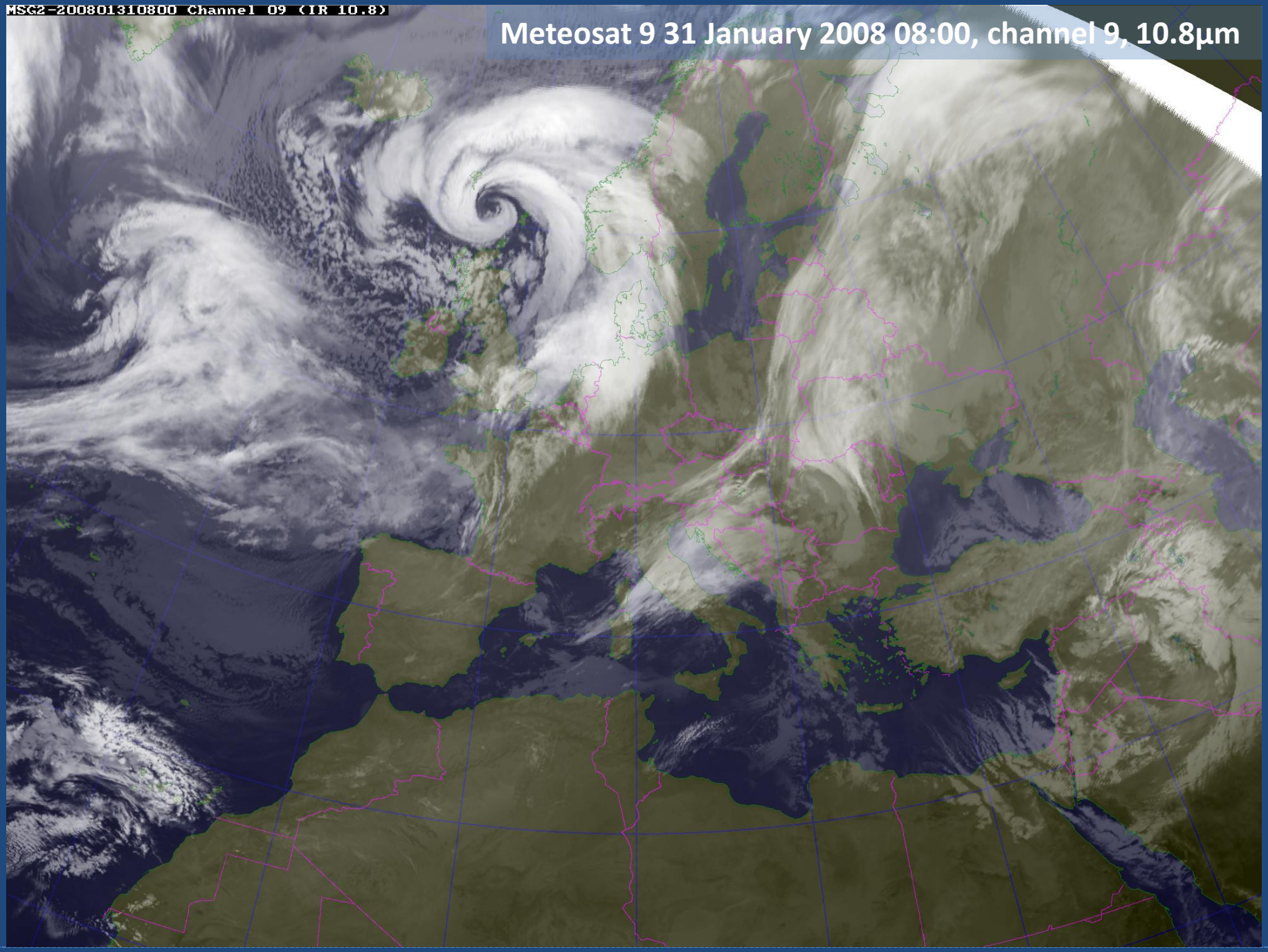

03:00 UTC




The same scene 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. For day part solar component must be taken into account.

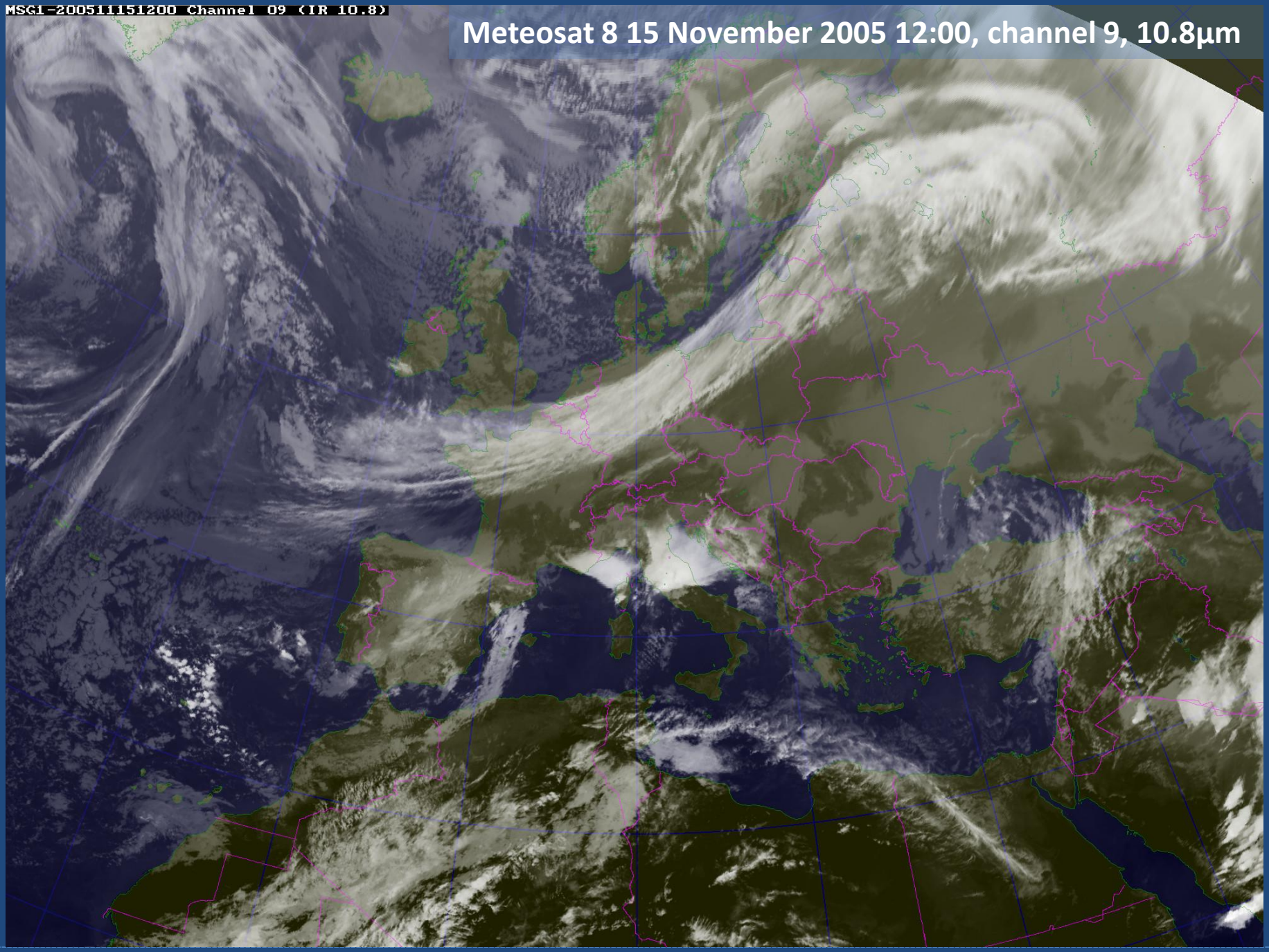
# Meteosat 8 25 November 2005 08:00, channel 9, 10.8µm



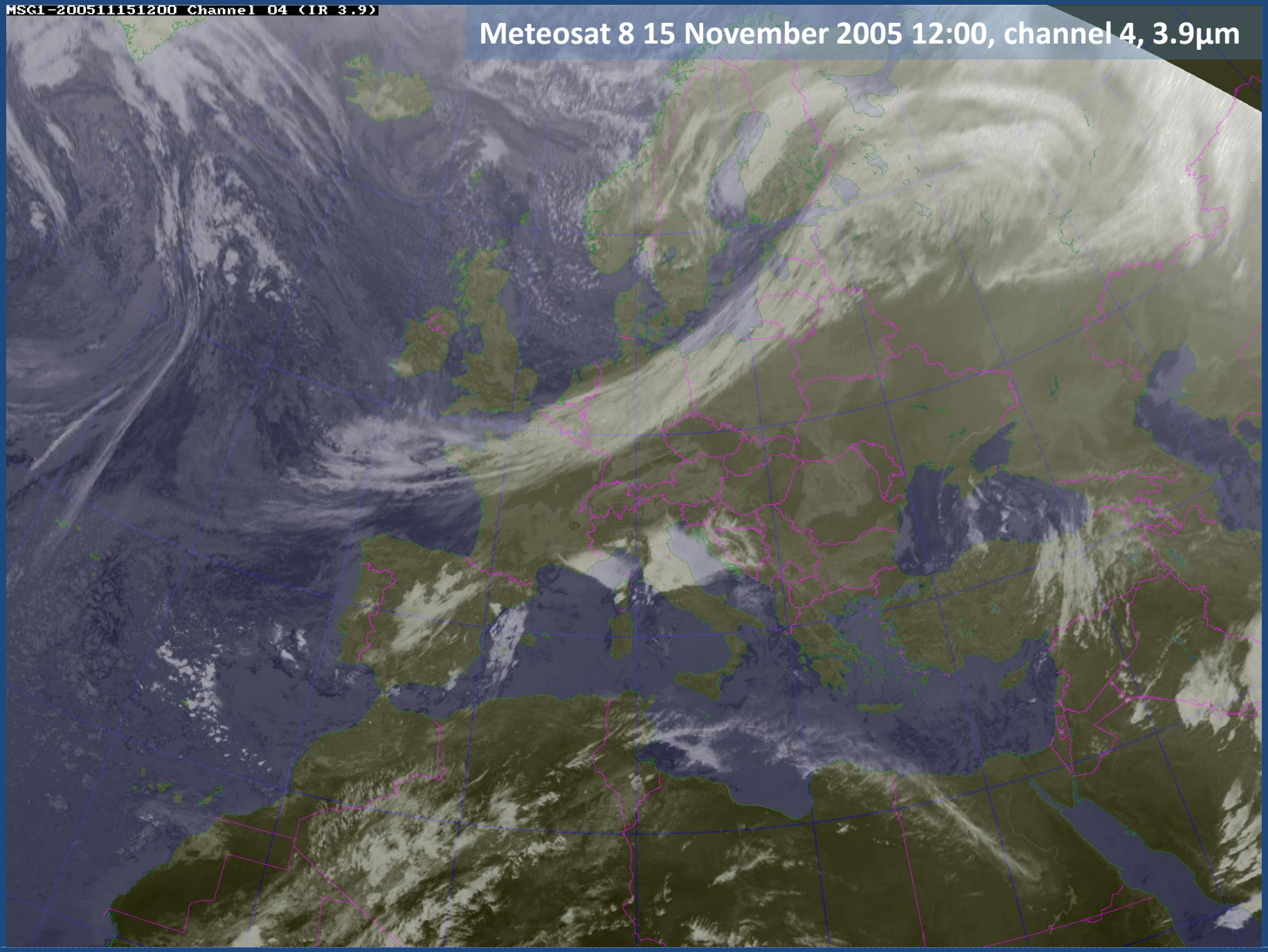


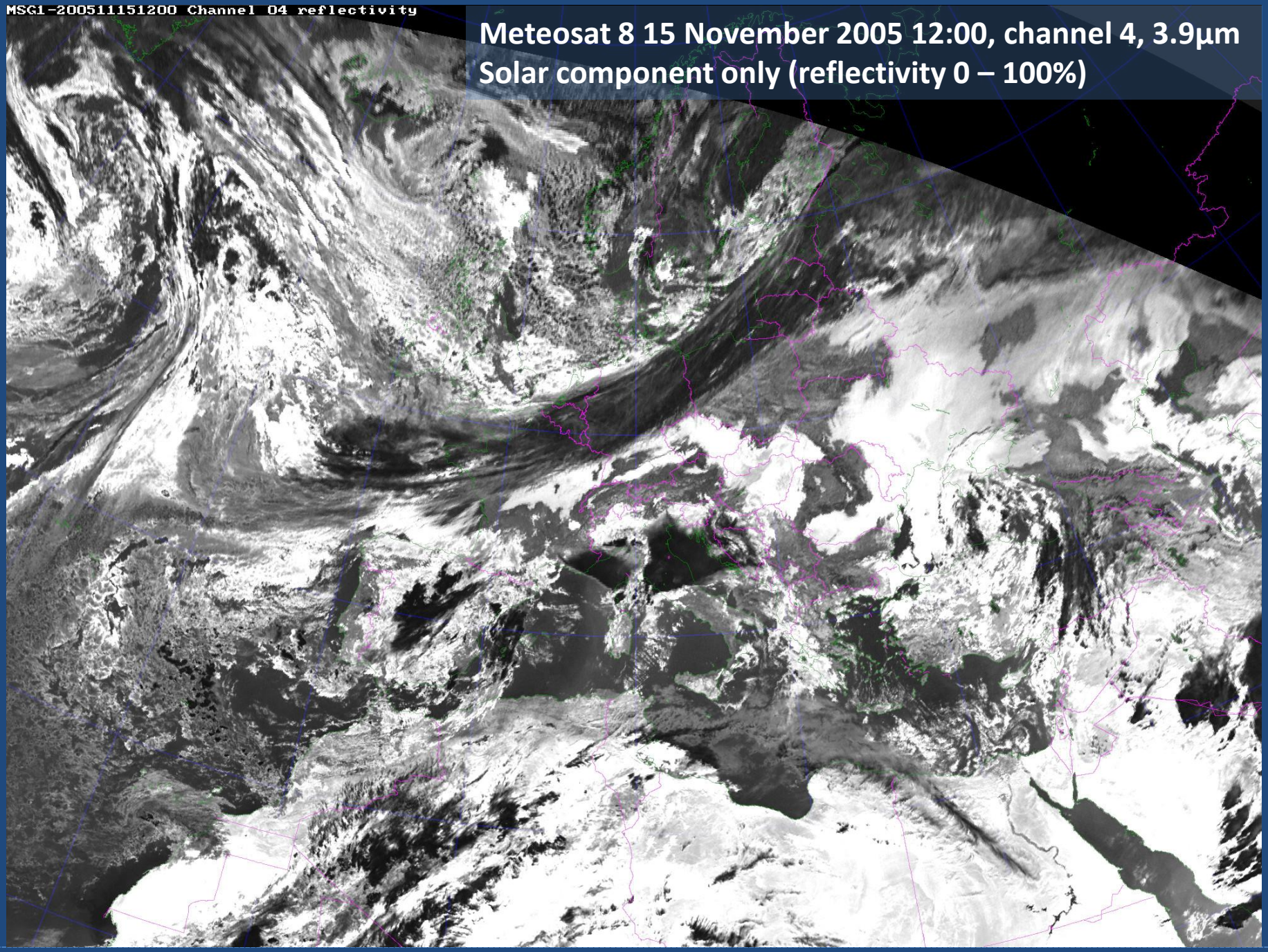

Meteosat 9 31 January 2008 08:00, channel 9, 10.8µm

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



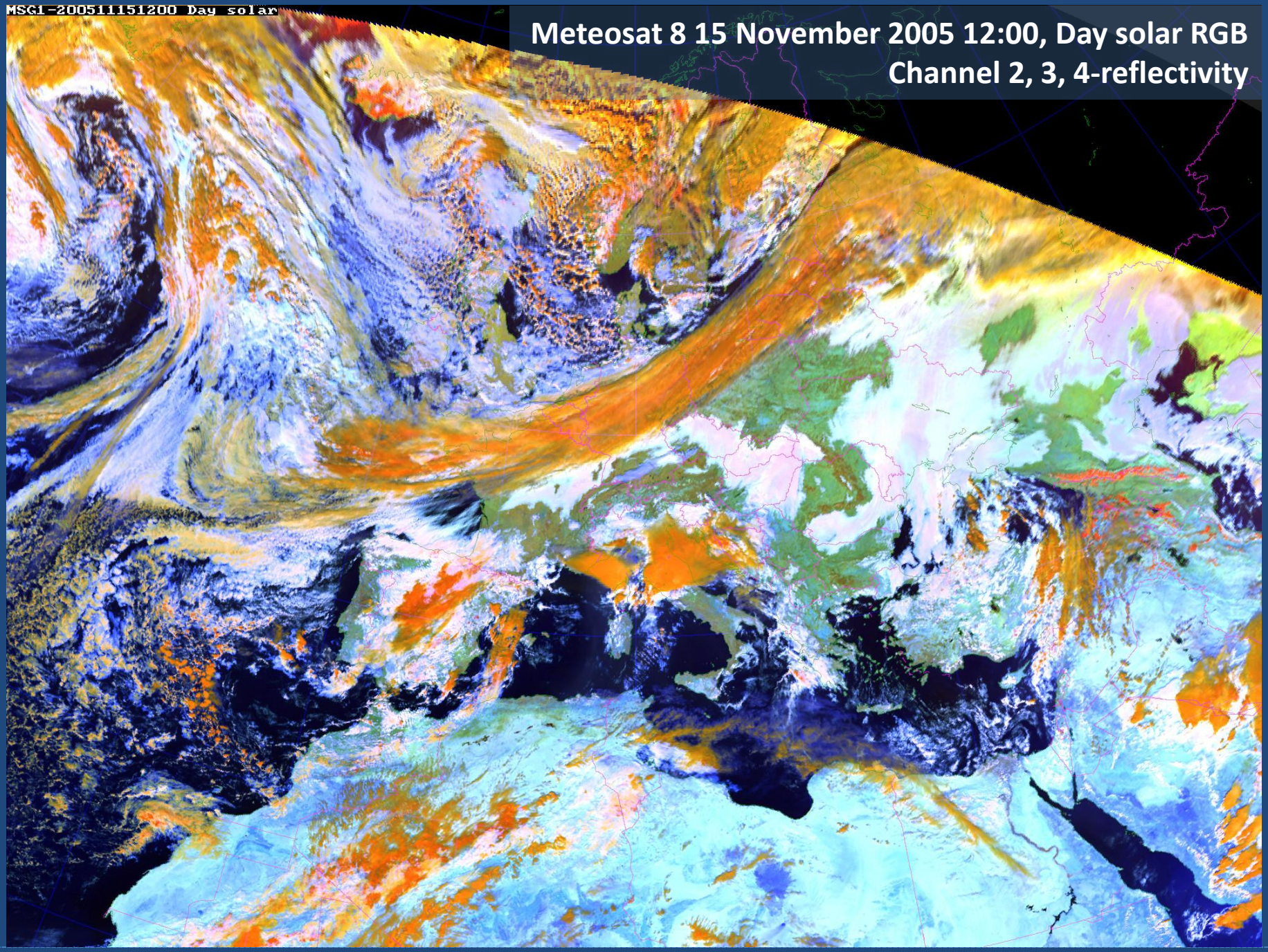
# Meteosat 8 15 November 2005 12:00, channel 4, 3.9µm






**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



# 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