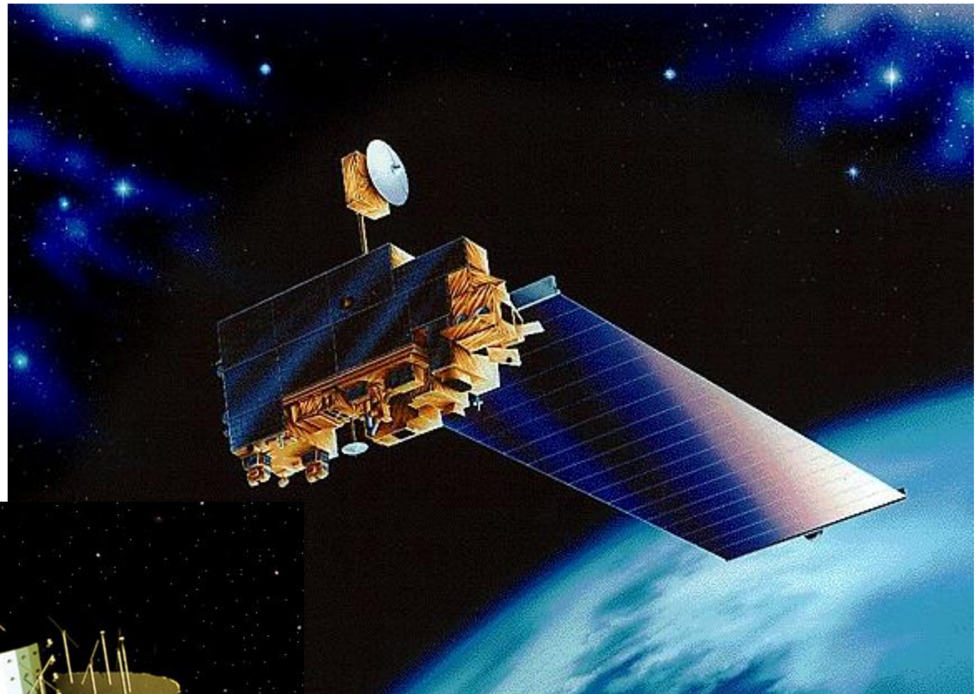
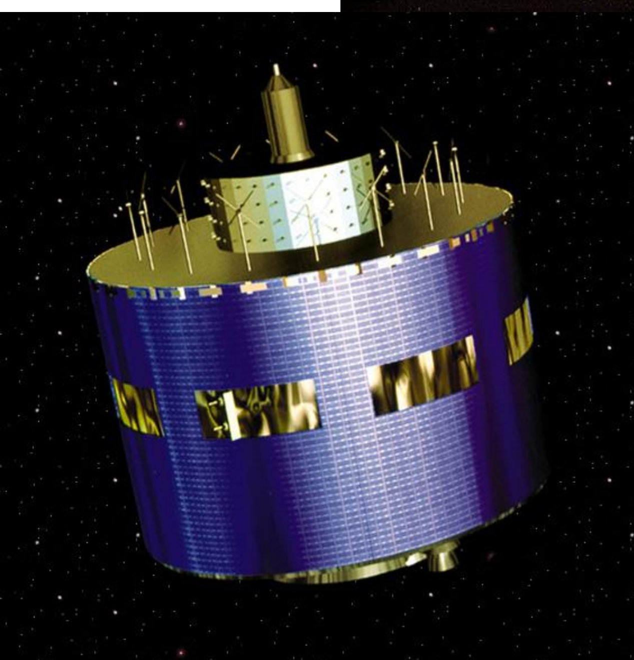
Introduction to Earth Observation Satellites





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Humaid AlBadi

Centre of Excellence for Satellite Applications- Muscat

humaid.albadi@caa.gov.om

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Earth Observation Satellites

- What is a satellite?

A Spacecraft that has an orbit around the Earth

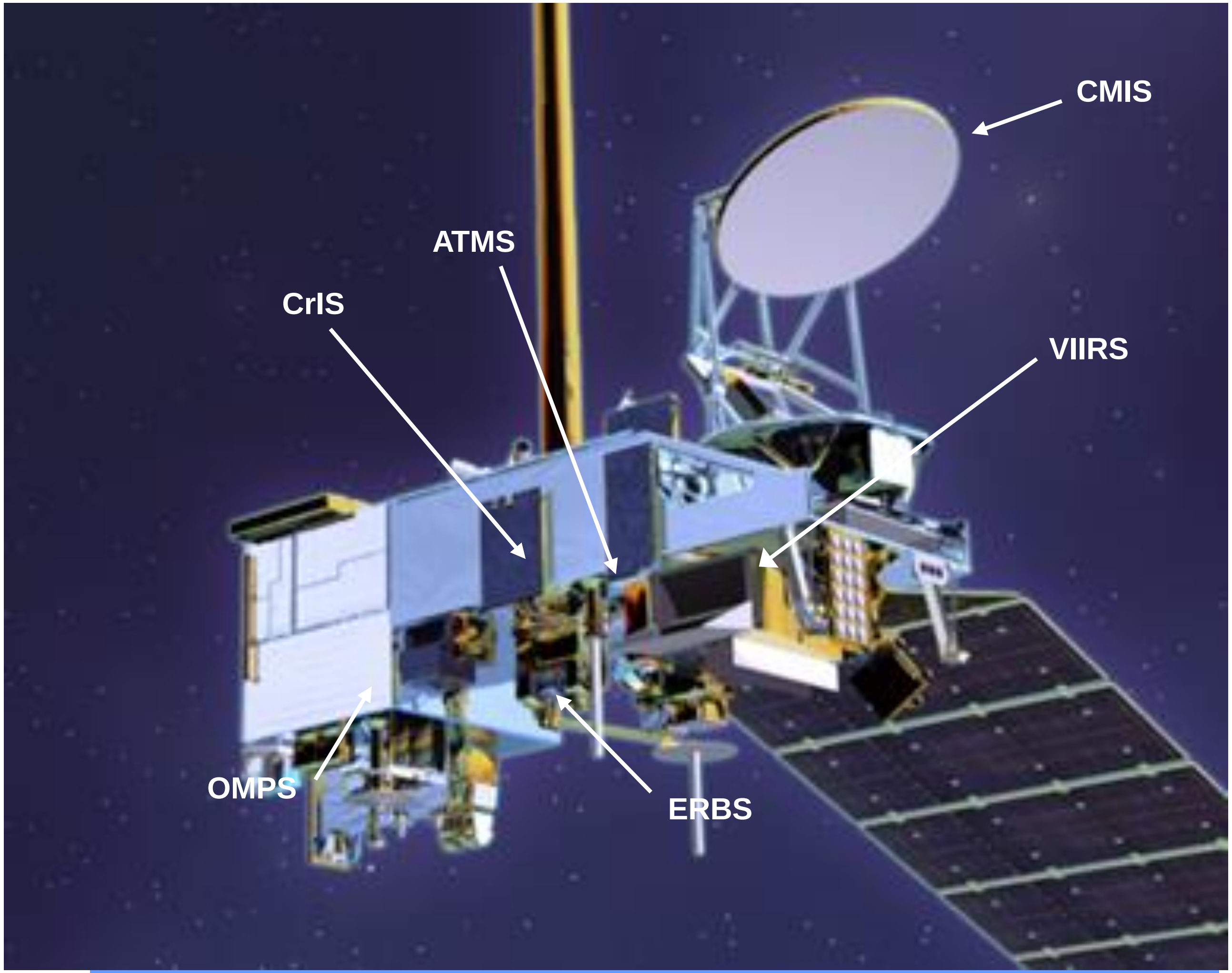
- What is a Radiometer?

A device that measures radiation.

> Earth-observing Satellites usually carries many radiometers

Earth Observation Satellites: Example

NOAA Satellite Series



AVHRR- Vis/IR imager
VIIRS - vis/IR imager
CMIS - µwave imager
CrIS - IR sounder
ATMS - µwave sounder
SESS - space environment
GPSOS - GPS occultation
OMPS - ozone
ADCS - data collection
SARSAT - search & rescue
APS - aerosol polarimeter
ERBS - Earth radiation budget
SS - laser sensor
ALT - altimeter
TSIS - solar irradiance

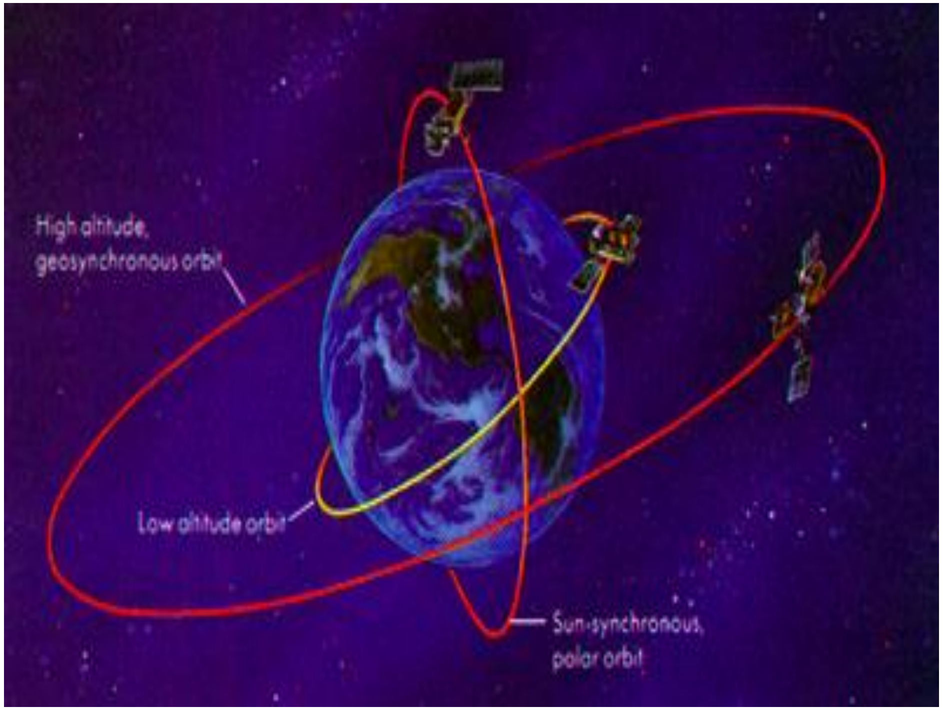
Single satellite design with common sensor locations

Earth Observation Satellites: Types

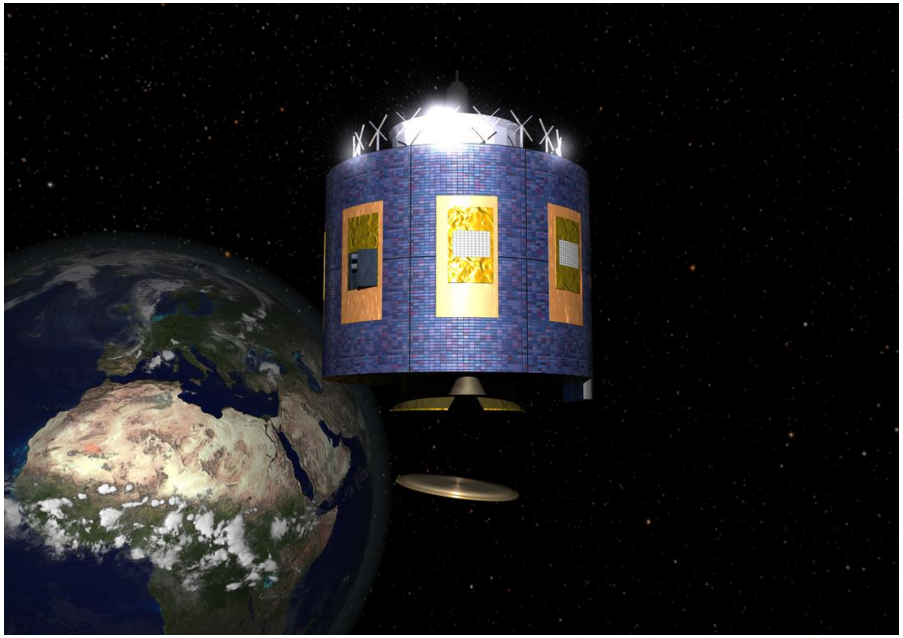
There are two main types of weather satellites

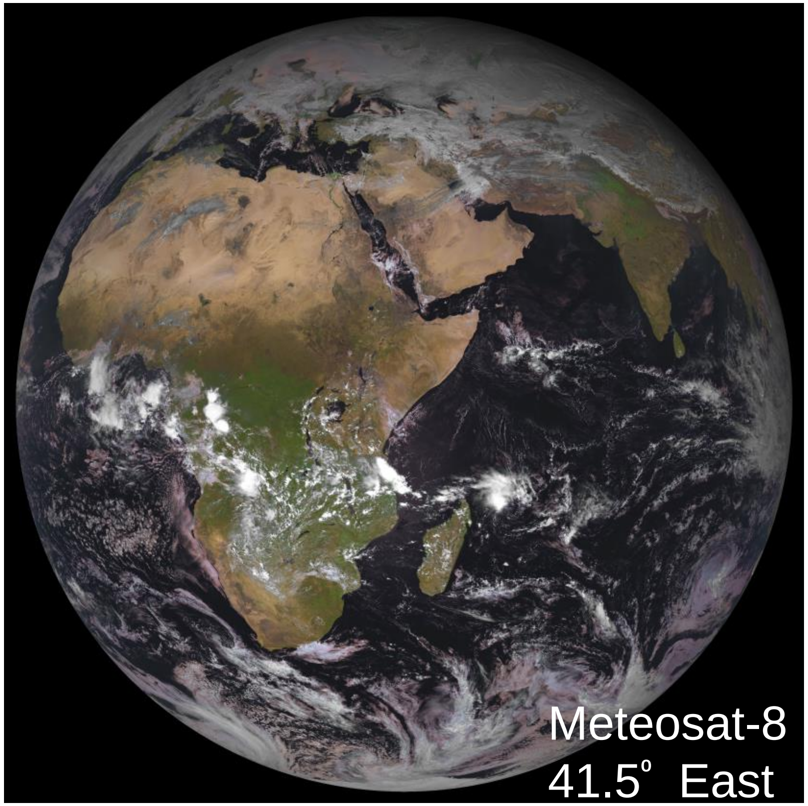
1. **Geostationary**
   (other name: Geo Synchronized)
2. **Low Orbiting**

(other names: Polar orbiting or sun-synchronized)



Earth Observation Satellites: Geostationary





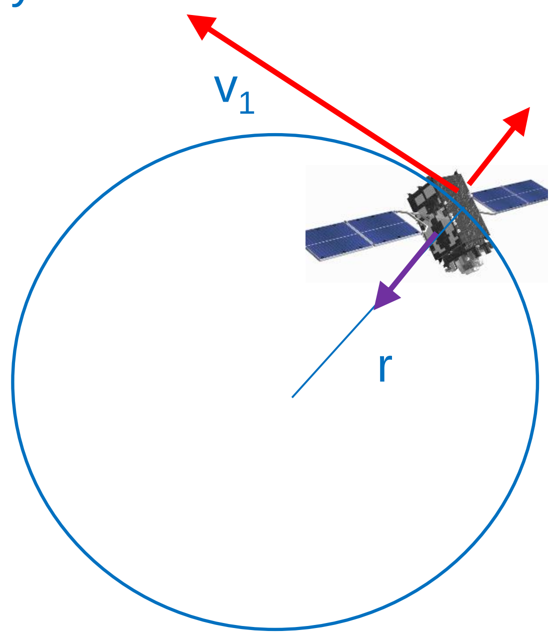
- located over the equator at a height of 36000 km.
- remain stationary with respect to the Earth's surface.
- give images at a high and constant rate (good for animation).

Geostationary Satellites

Why Satellites do not fall on Earth?

Circular Motion

Any object travelling in a circle at constant speed is *always* accelerating away from the centre of the circle by the centrifugal force .



Gravity keeps satellites in circular motion because it acts as a constant force opposing the direction of centrifugal

Geostationary Satellites

The gravitational F_G force and the centrifugal force F_c can be expressed as follows

$$F_G = G\frac{Mm}{r^2}$$
$$F_c = m\frac{v^2}{r}$$

where ***G*** is the universal gravitational constant, M is the mass of the earth and ***m*** is the mass of the satellite.

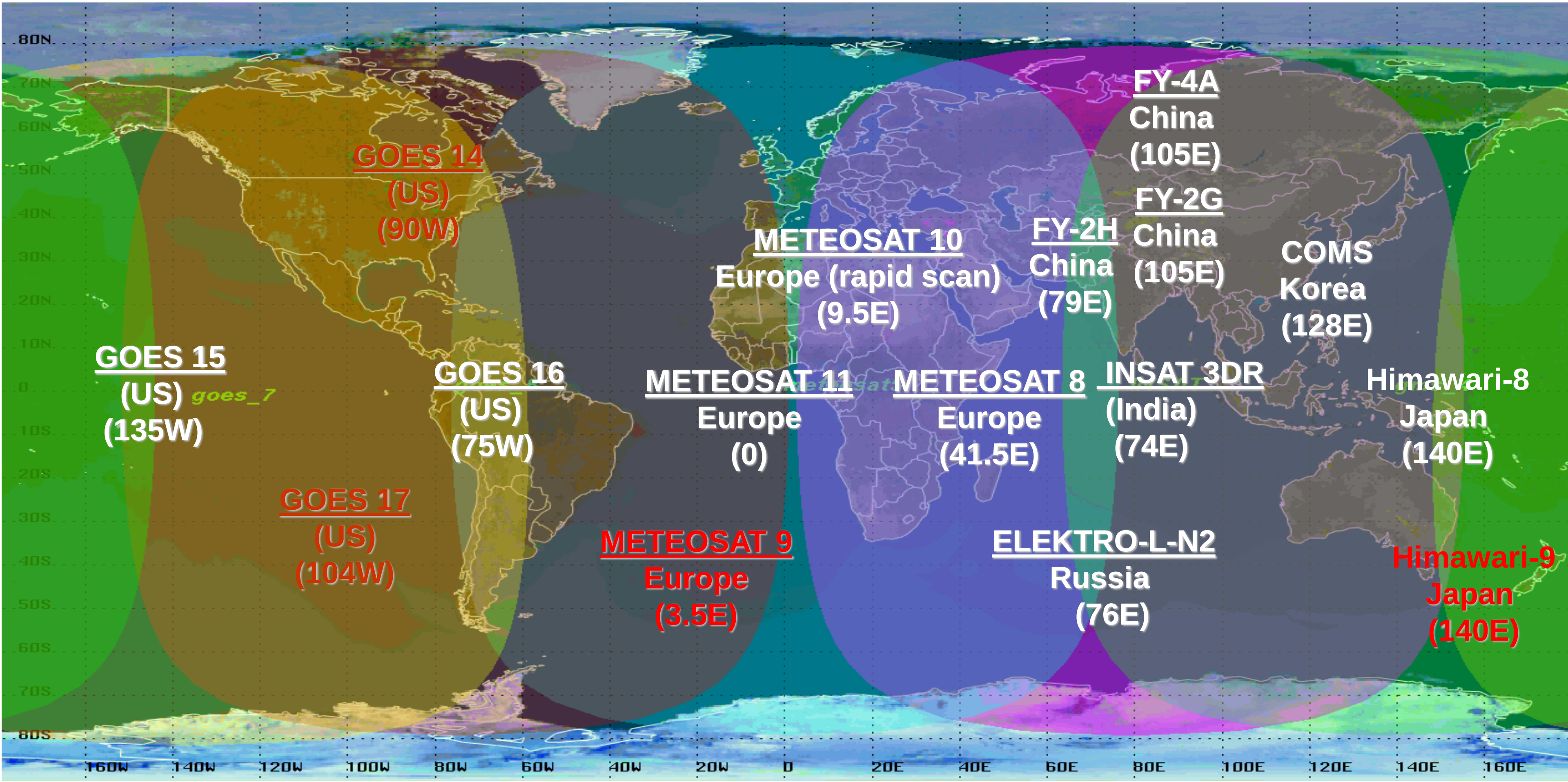
Using the expression of the two forces it can be shown that ***r*** ; the distance between the earth and the satellite, can be calculated from τ**;** the period of rotation around the earth

$$r = \sqrt[3]{G\frac{M}{4\pi^2}\tau^2}$$

For τ = 24 hours the distance is 36000 km

Geostationary Satellites

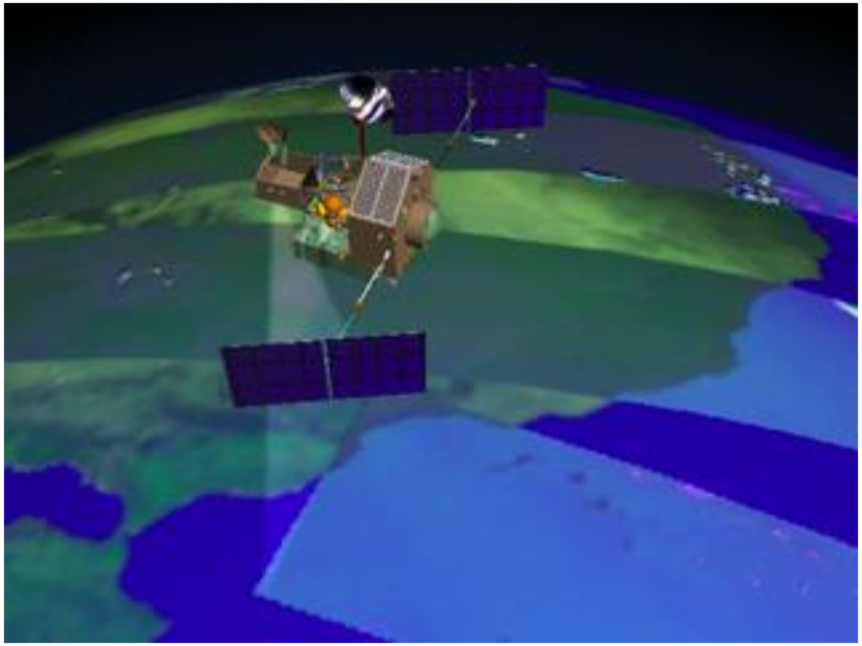
Current coverage of the WMO Integrated Global Observing System (WIGOS)



Earth Observation Low Orbiting Satellites

Low Orbiting Satellites

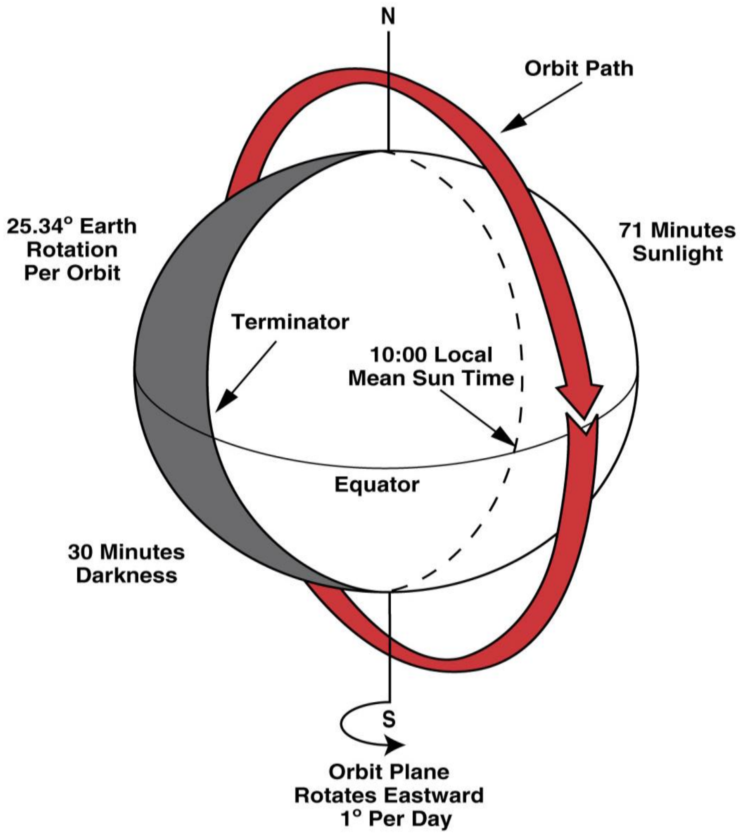
Features

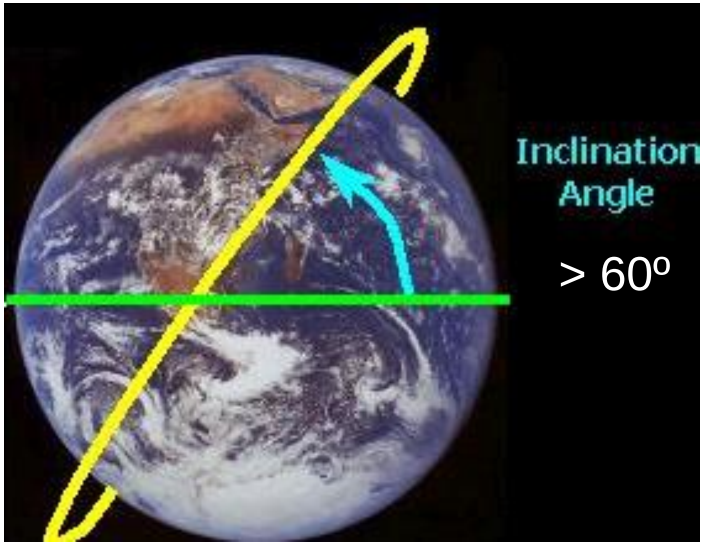


- lower altitude of 500 to 2000 km.
- orbit from pole to pole in about 100 minutes.
- more detailed but less frequent images.

Low Orbiting Satellites

Features





- lower altitude of 500 to 2000 km.
- orbit from pole to pole in about 100 minutes.
- more detailed but less frequent images.

Low Orbiting Satellites

How many Low Earth Orbiting satellites are currently operational?

https://space.oscar.wmo.int/satellites

Low Orbiting Satellites

MetOP
Europe - EUMETSAT

- IASI - Infrared Atmospheric Sounding Interferometer
- MHS - Microwave Humidity Sounder
- GRAS - Global Navigation Satellite System Receiver for Atmospheric Sounding
- ASCAT - Advanced Scatterometer
- GOME-2 - Global Ozone Monitoring Experiment-2
- AMSU-A1/AMSU-A2 - Advanced Microwave Sounding Units
- HIRS/4 - High-resolution Infrared Radiation Sounder
- AVHRR/3 - Advanced Very High Resolution Radiometer
- A-DCS - Advanced Data Collection System
- SEM-2 - Space Environment Monitor
- SARP-3 - Search And Rescue Processor
- SARR - Search And Rescue Repeater

Spacecraft	Mission Operational Status
METOP-A	Decommissioned
METOP-B	AM Primary
METOP-C	Commissioning

https://www.youtube.com/watch?v=JJfi18Y6Kpw

Low Orbiting Satellites

NOAA Series

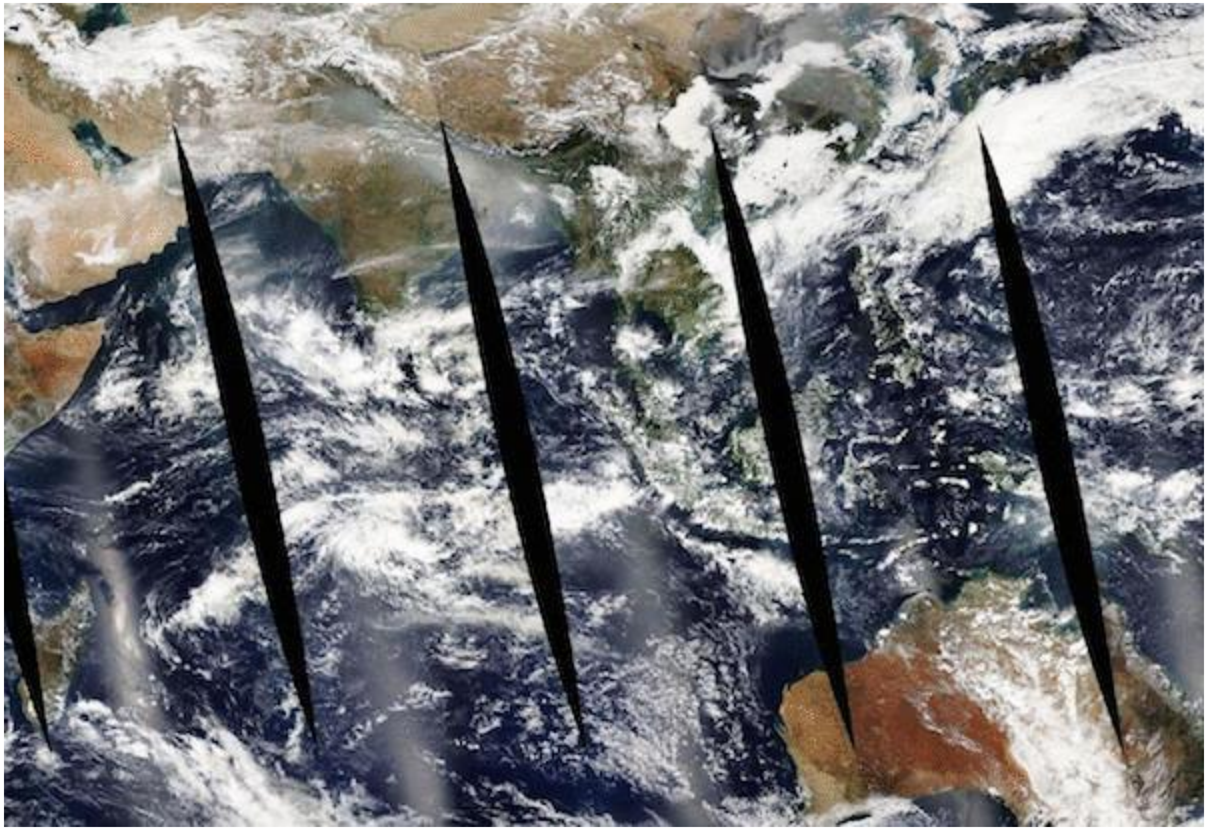
AVHRR

- Collecting data since 1978
- Currently 6 in orbit (
- 2 to 15 images a day
- Whiskbroom scanning pattern
- 1.1 km^2 resolution
- 5+ spectral channels
  - Infrared - channels 3, 4, 5
  - Visible - channels 1, 2

Spacecraft	Mission Operational Status
NOAA 15	AM Secondary
NOAA 18	AM Backup
NOAA 19	PM Primary
NOAA 20	PM Primary

Low Orbiting Satellites

Instrument: MODIS
on board Aqua & Terra Satellites

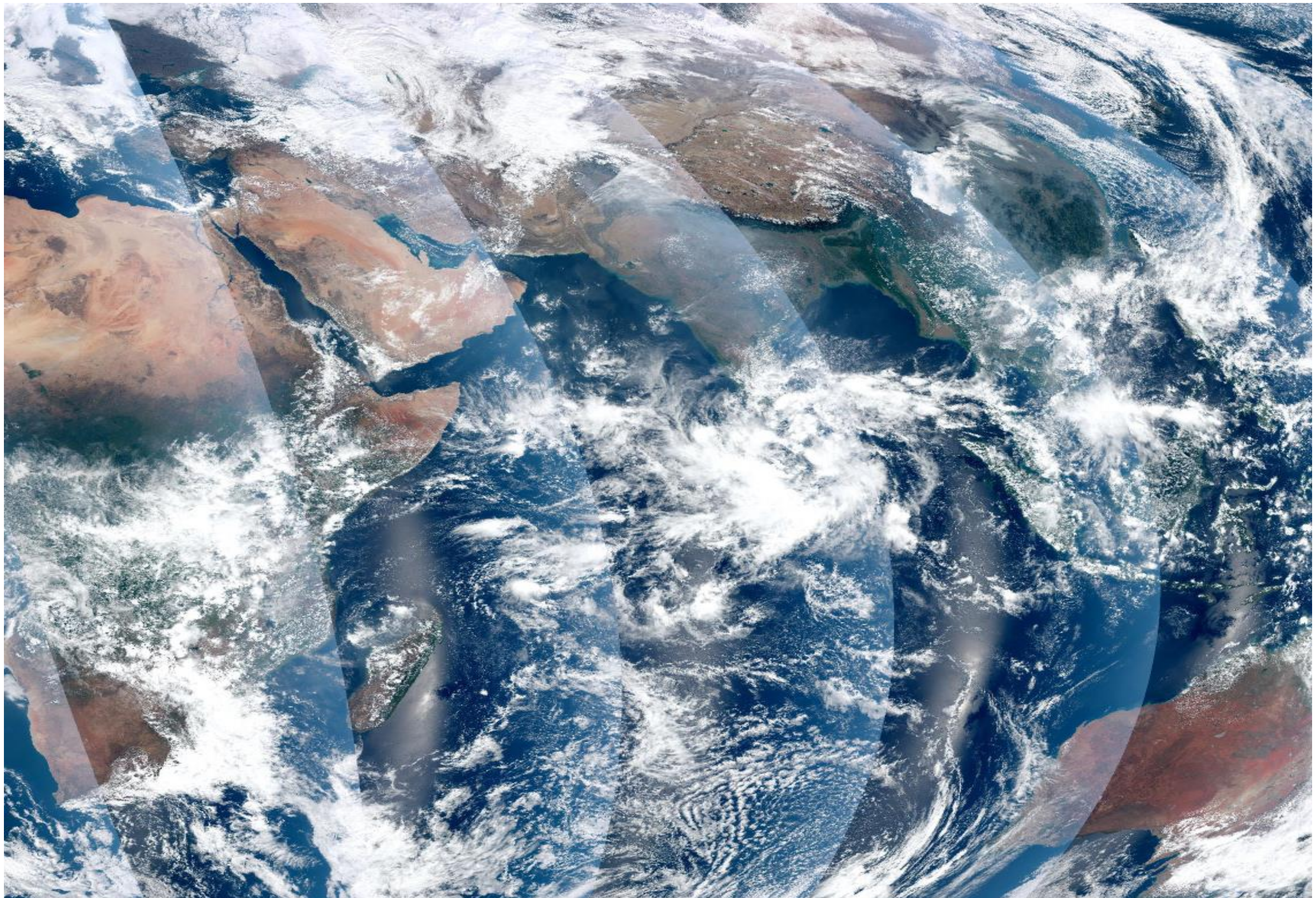


Low Orbiting Satellites

VIIRS

on board Suomi NPP and NOAA-20

MODIS and AVHRR successor, high resolution with wide swath
VIIRS swath – 3040km



Low Orbiting Satellites

VIIRS

on board Suomi NPP and NOAA-20

MODIS and AVHRR successor, high resolution with wide swath
VIIRS swath – 3040km

VIIRS bands

	Band	Primary parameter	Wave length (μm)	Spatial resolution [km]		Gain	Typical value [W/m2/sr /μm or K]	Max value [W/m2/sr/ μm or K]	Specs SNR/ NΔT	Observed SNR/ NΔT
				Nadir	Edge					
	Imaging bands									
reflective	I1	Vis Imagery/NDVI	0.600 - 0.680	0.375	0.8	Single	22	718	119	214
	I2	Land Imagery/NDVI	0.846 - 0.885	0.375	0.8	Single	25	349	150	251
	I3	Snow/ice	1.580 - 1.640	0.375	0.8	Single	7.3	72.5	6	149
emis sive	I4	Imagery clouds	3.550 - 3.930	0.375	0.8	Single	270	353	2.5	0.4
	I5	Imagery clouds	10.50 - 12.40	0.375	0.8	Single	210	340	1.5	0.4
	Moderate resolution bands									
reflective	M1	Ocn color/Aerosol	0.402 - 0.422	0.75	1.6	H/L	44.9/155	135/615	352/316	578/974
	M2	Ocn color/Aerosol	0.436 - 0.454	0.75	1.6	H/L	40/146	127/687	380/409	564/975
	M3	Ocn color/Aerosol	0.478 - 0.498	0.75	1.6	H/L	32/123	107/702	416/414	611/989
	M4	Ocn color/Aerosol	0.545 - 0.565	0.75	1.6	H/L	21/90	78/667	362/315	522/846
	M5	Ocn color/Aerosol	0.662 - 0.682	0.75	1.6	H/L	10/68	59/651	242/360	321/631
	M6	Atrm correction	0.739 - 0.754	0.75	1.6	Single	9.6	41	199	355
	M7	Ocn color/Aerosol	0.846 - 0.885	0.75	1.6	H/L	6.4/33.4	29/349	215/340	435/631
	M8	Cloud particle/ snow grain size	1.230 - 1.250	0.75	1.6	Single	5.4	165	74	221
	M9	Ci cloud detection	1.371 - 1.386	0.75	1.6	Single	6	77.1	83	227
	M10	Snow fraction	1.580 - 1.640	0.75	1.6	Single	7.3	71.2	342	550
	M11	Clouds/Aerosol	2.225 - 2.275	0.75	1.6	Single	0.12	31.8	10	22
emissive	M12	SST	3.660 - 3.840	0.75	1.6	Single	270	353	0.396	0.13
	M13	SST/Fire detection	3.973 - 4.128	0.75	1.6	H/L	300/380	343/634	0.107/0.423	0.042
	M14	Cloud Top	8.400 - 8.700	0.75	1.6	Single	270	336	0.091	0.06
	M15	SST	10.263 - 11.263	0.75	1.6	Single	300	343	0.07	0.03
	M16	SST	11.538 - 12.488	0.75	1.6	Single	300	340	0.072	0.03
	DND	Day/ Night Band	0.5 – 0.9	0.75	0.75					

Low Orbiting Vs. Geostationary Satellites

Geostationary Orbit Advantages:

- large coverage area (about a third of Earth's surface)

- High image frequency -> Allows sampling as often as technically possible (every few minutes at best), enabling monitoring of rapidly-evolving events.

Low Orbiting Vs. Geostationary Satellites

Geostationary Orbit Disadvantages:

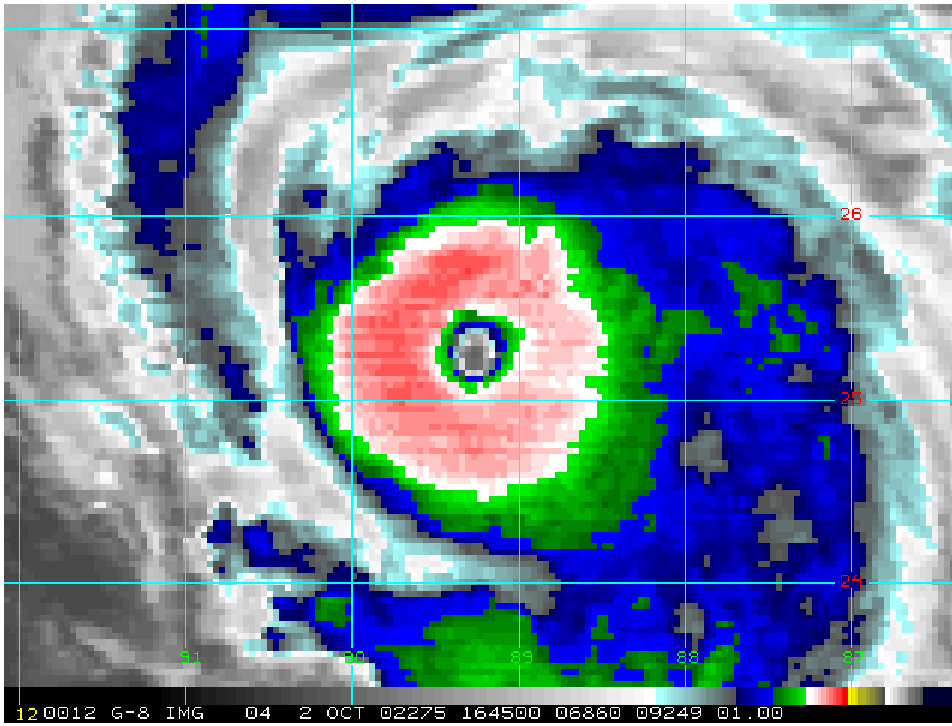
- Polar regions are not observed.
- Relatively Low ground spatial resolution. The high orbit imposes a limit of about 1 km at best with current instrument technology.

Low Orbiting Vs. Geostationary Satellites

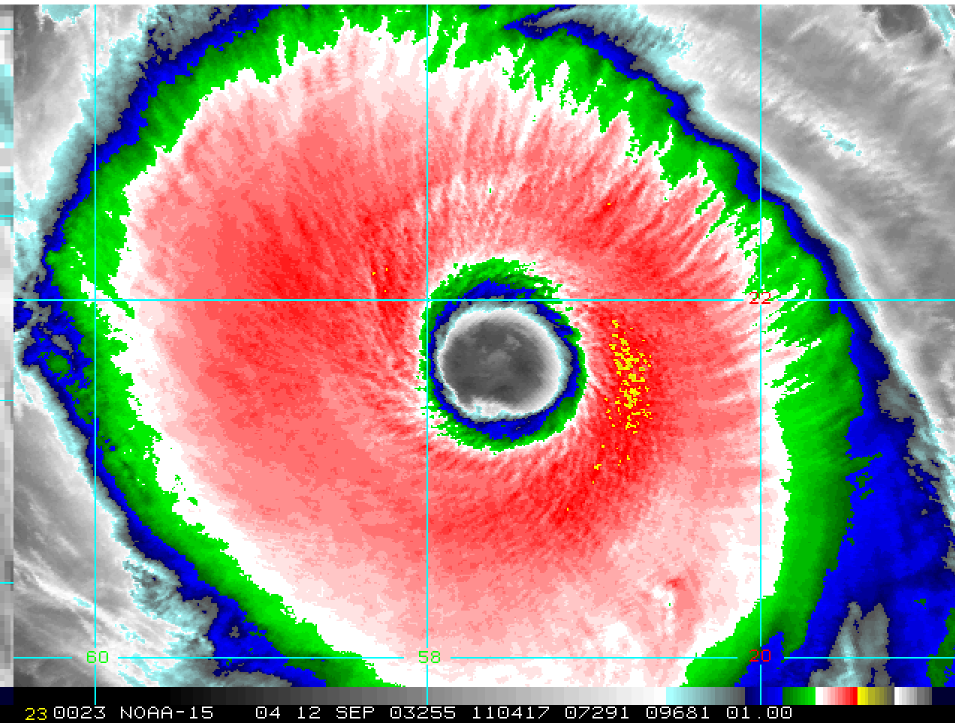
Low Orbit Advantages:

- Global coverage.
- Good ground resolution because of low orbit.
- Sun-synchronism produces consistent illumination conditions for observed surfaces, with only seasonal changes.

Low Orbiting Vs. Geostationary Satellites



Geostationary Satellite



Polar Orbiting

Low Orbiting Vs. Geostationary Satellites

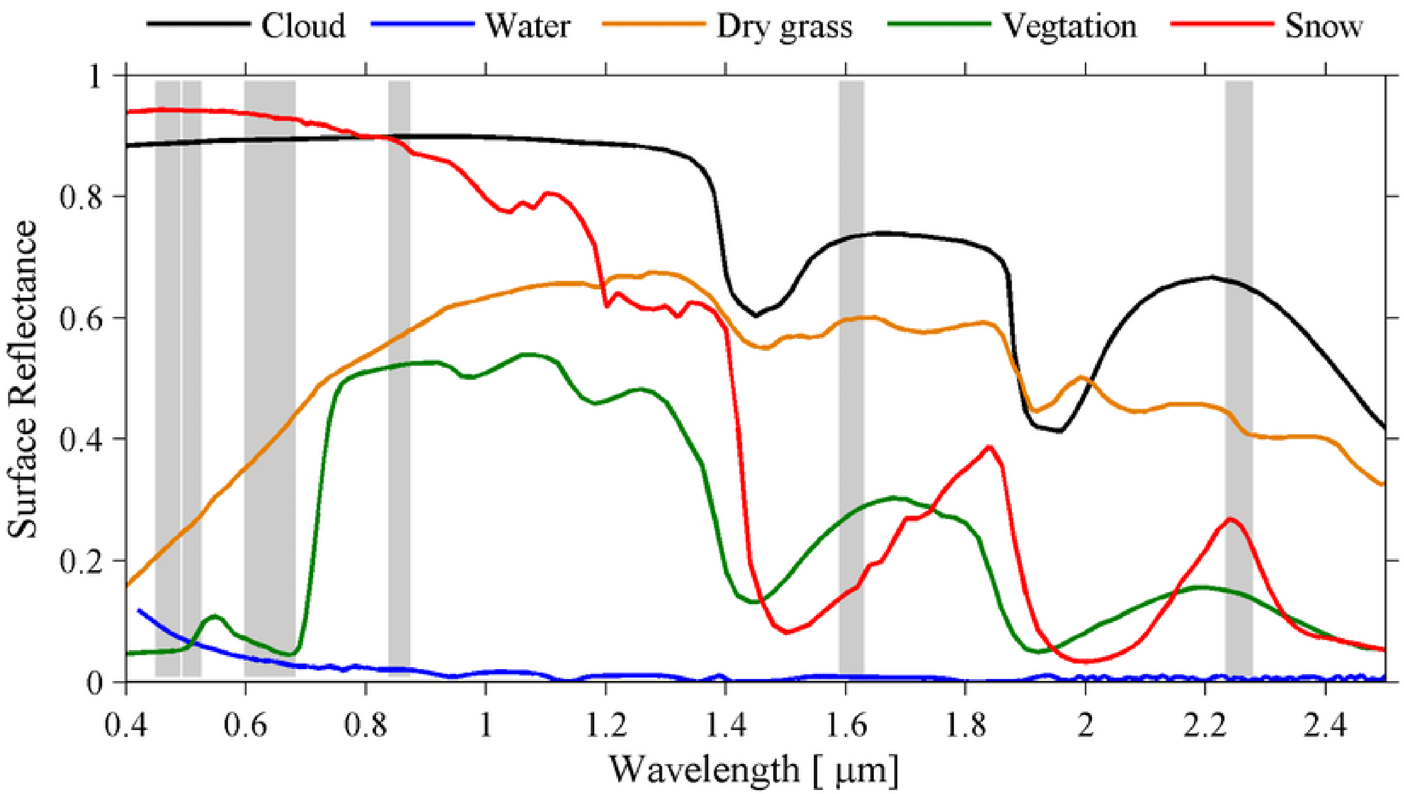
Low Orbit Disadvantages:

- Low image Frequency -> Each point on Earth's surface is observed at best every 90 minutes for polar regions, at worst twice per day for equatorial regions. Multi-satellite systems solve this problem.

Spectral Signature

Spectral Signature

- Spectral signature of an object is the variation of reflectance or emittance of the object with respect to wavelengths
- Spectral signature is the principle behind the satellite remote sensing applications



Satellite Image processing & RGB composites

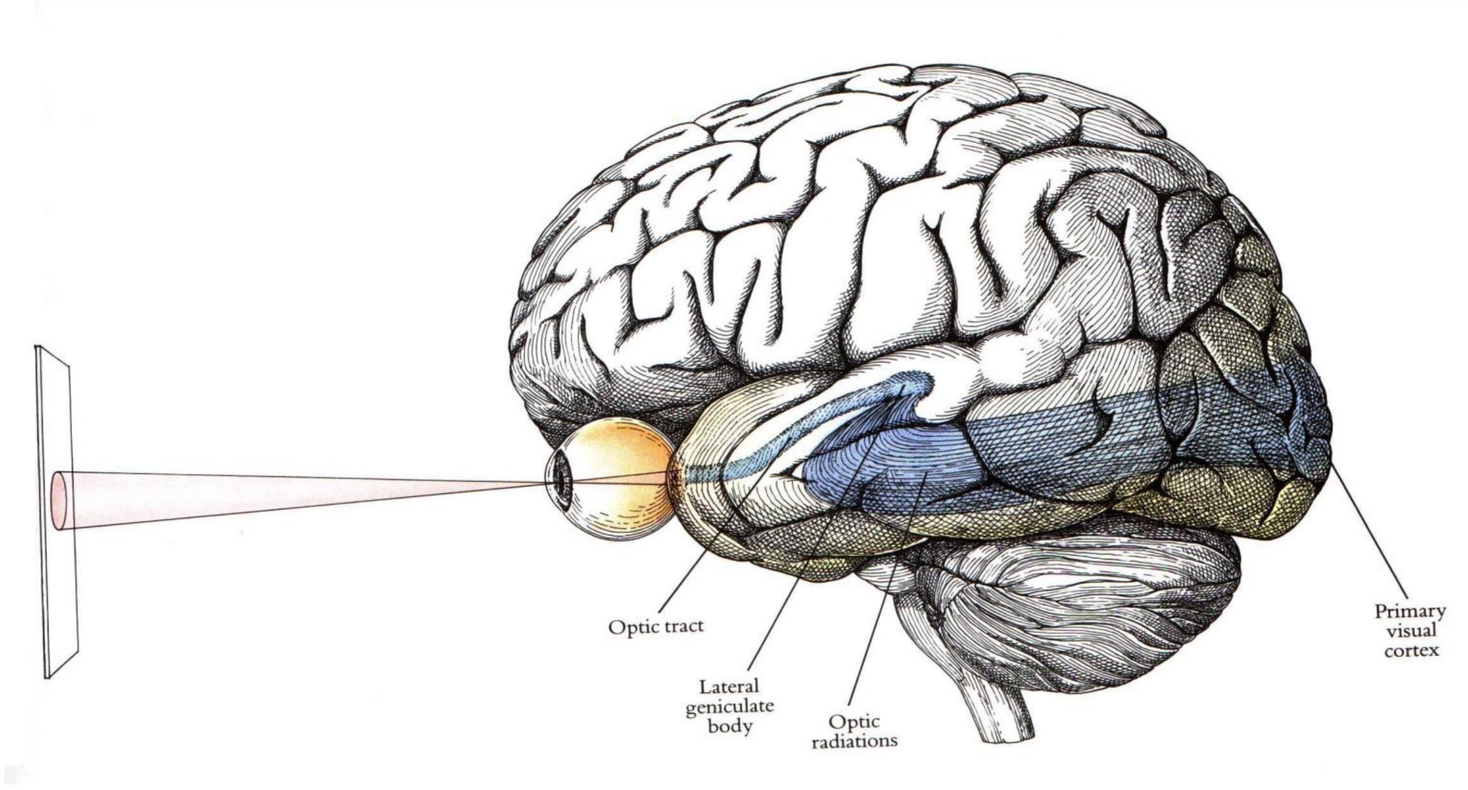
Human Natural Remote Sensing Device

In the beginning…

we'll have a look at the human eye

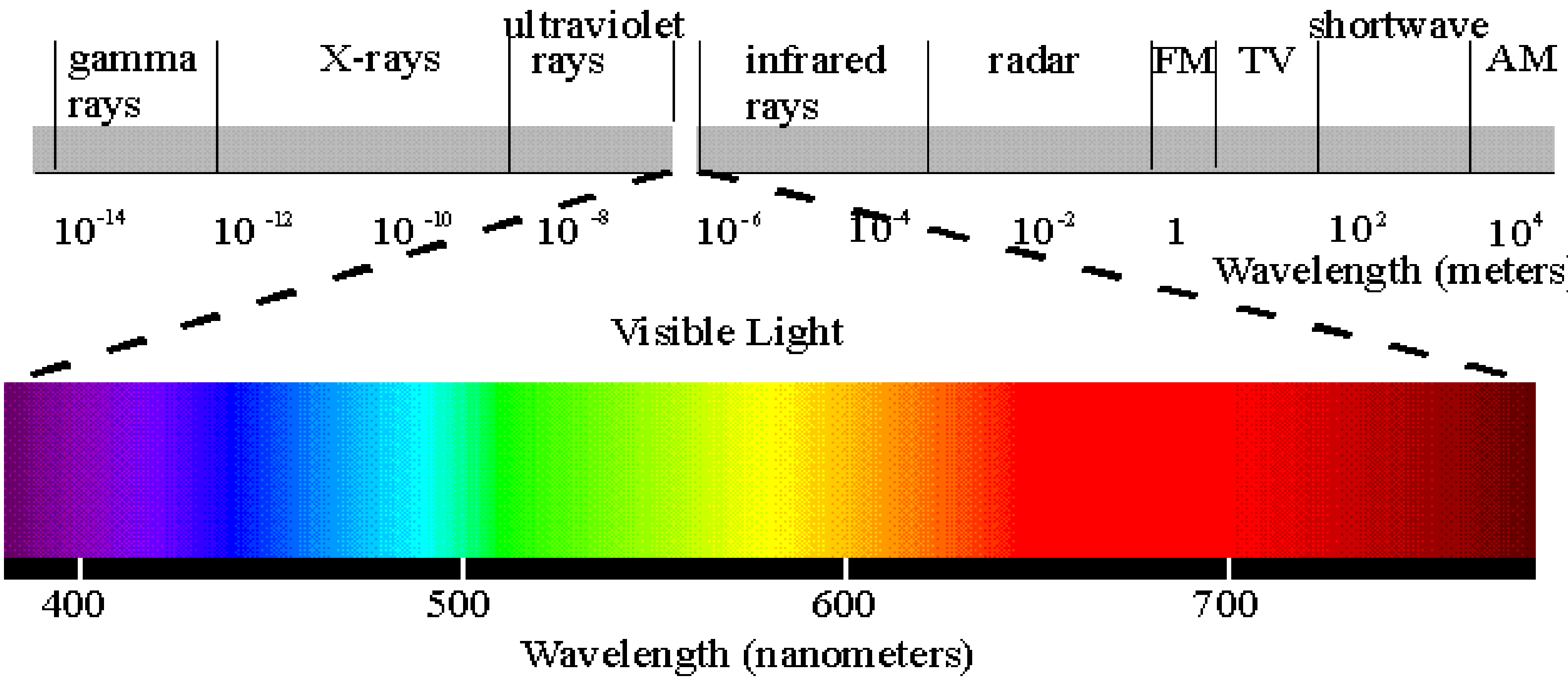
Human Natural Remote Sensing Device

Our Vision



Human Natural Remote Sensing Device

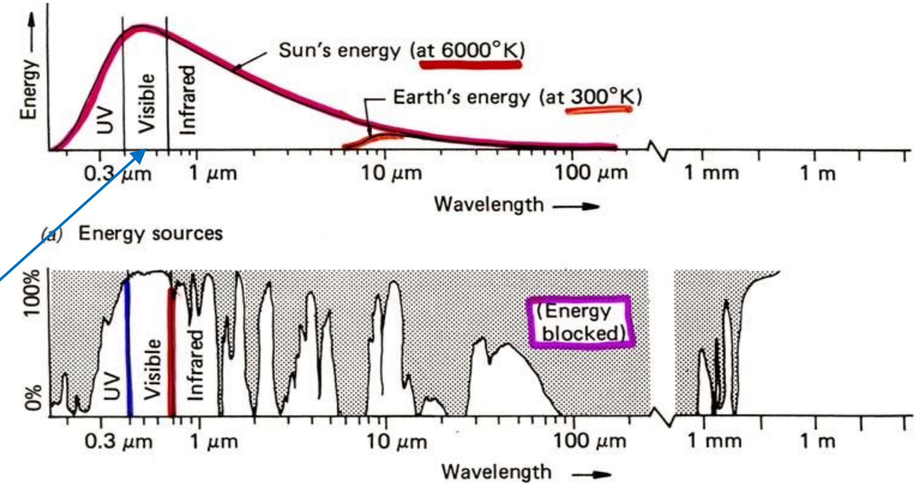
Vision and the "Electromagnetic Spectrum"



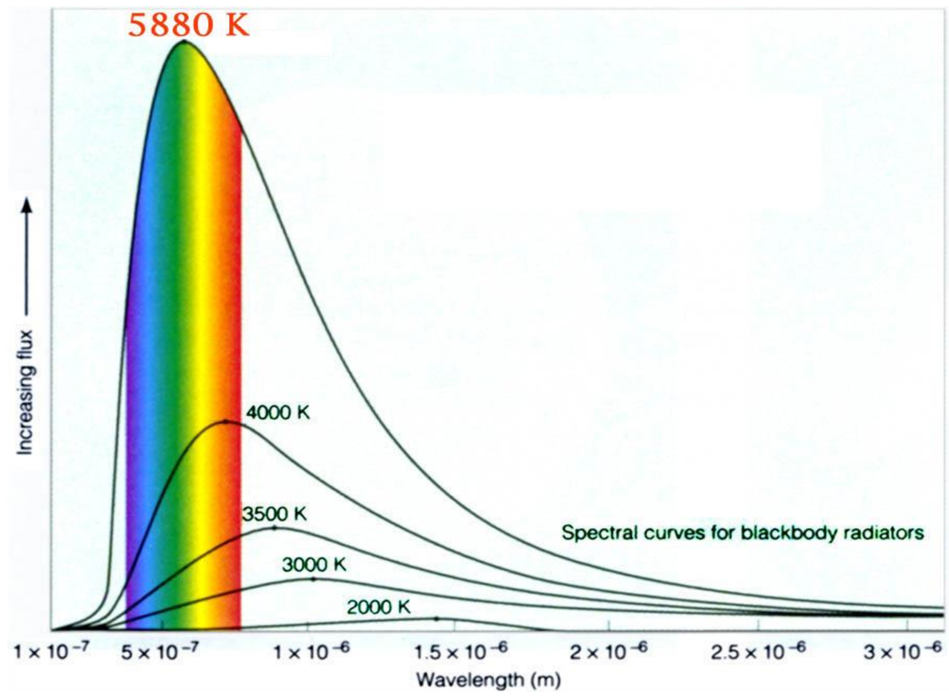
The electromagnetic spectrum
from "The Joy of Visual Perception: A Web Book"
http://www.yorku.ca/eye/

Lesson: We directly perceive a tiny fraction of the world

Human Natural Remote Sensing Device

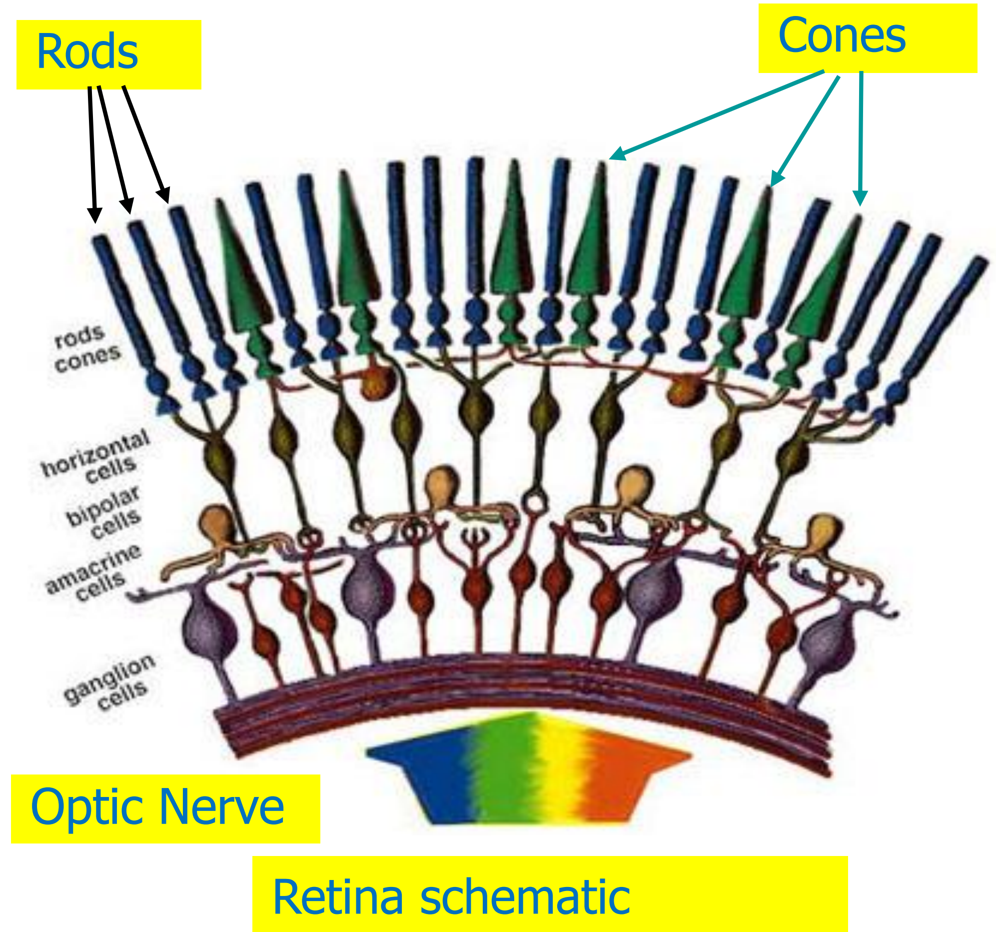


Our vision is optimized for receiving the <u>most abundant spectral radiance</u> our star emits.

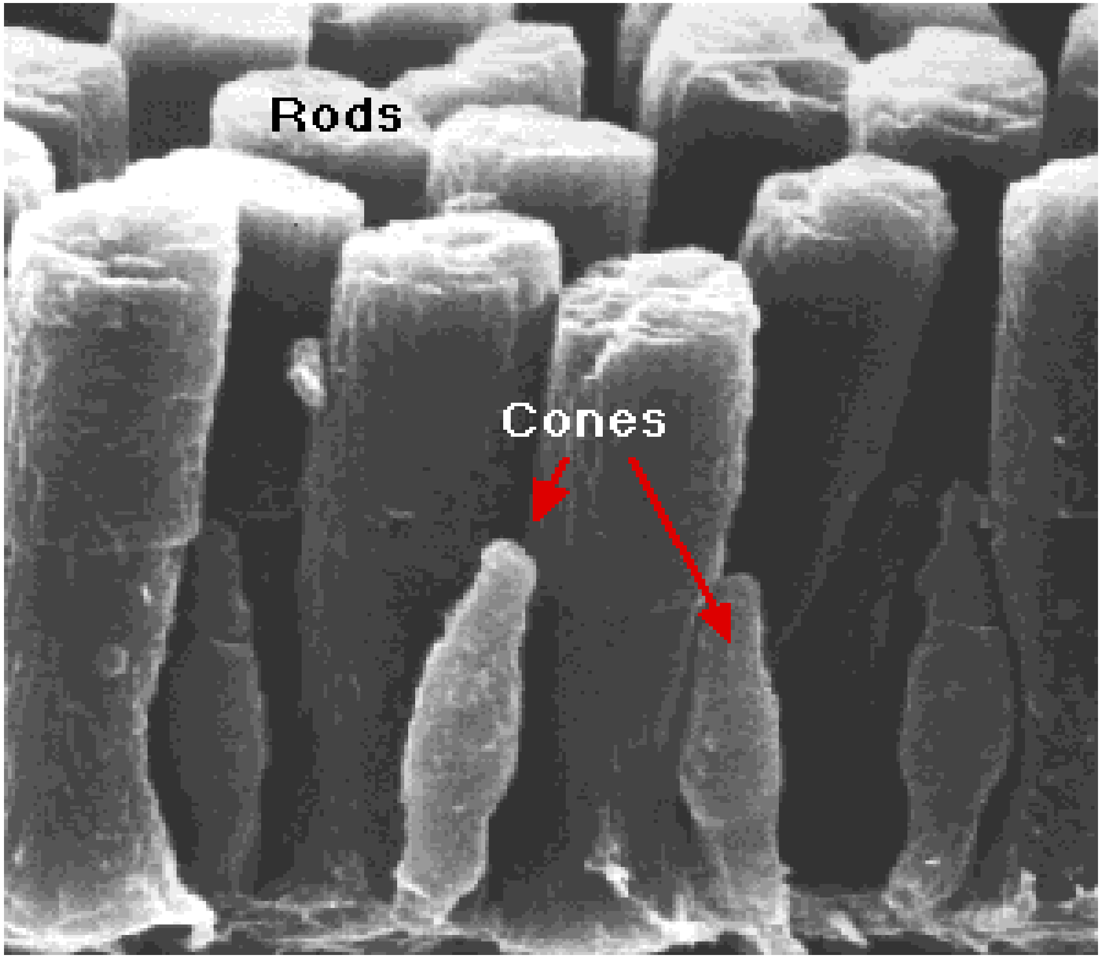


Human Natural Remote Sensing Device

Photoreceptors: Rods and Cones

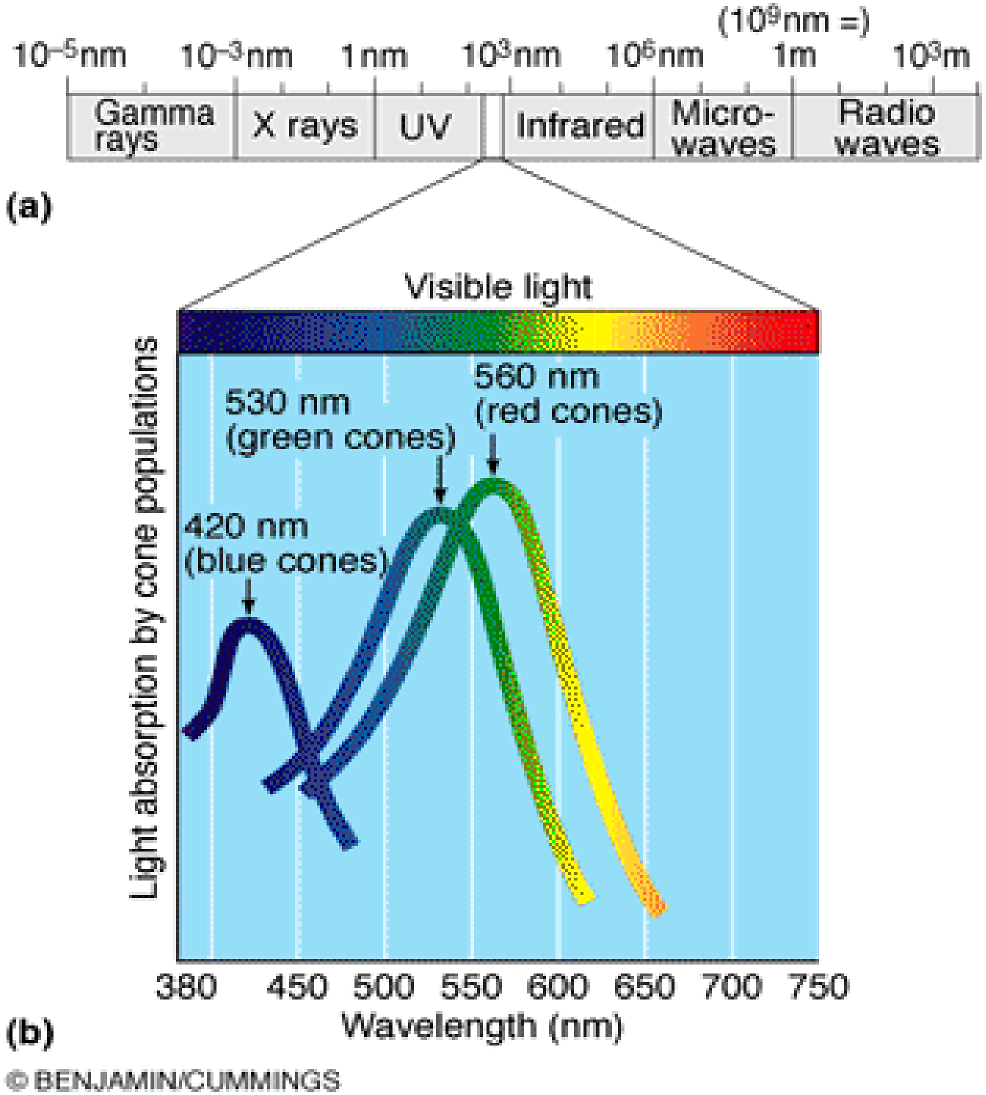


Human Natural Remote Sensing Device



Human Natural Remote Sensing Device

Three Cone Types

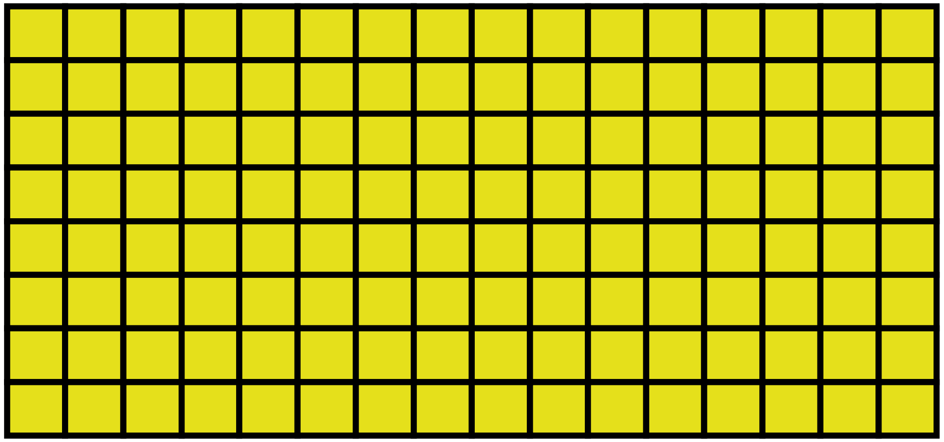


Basic digital images concepts

Digital Images

What is a digital image ?

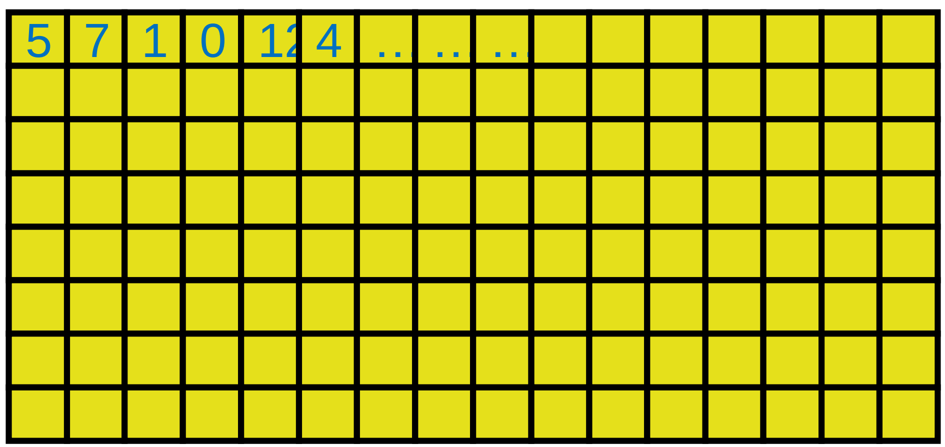
2D array of cells, modelling the retina in natural eye



Each cell contains a numerical value (e.g. between 0-255 for 8 bit)

Digital Images

The *numerical value* of the cell represents the illumination received by the receptor

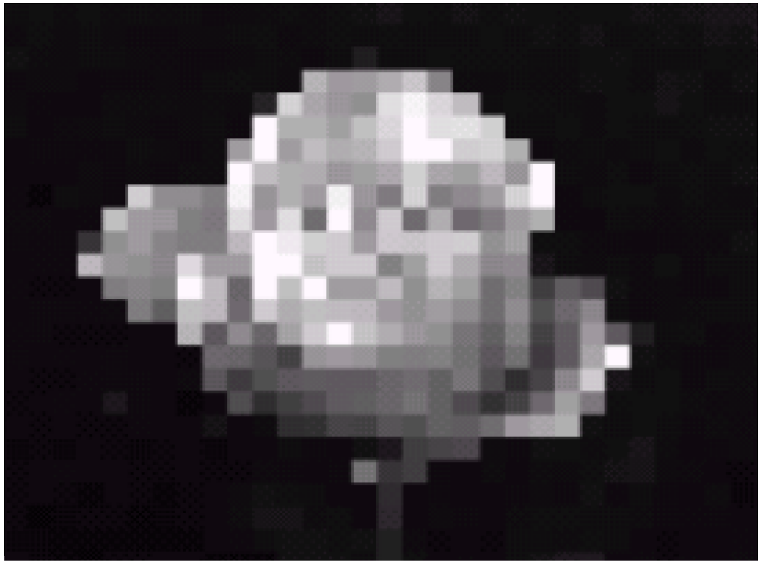


Digital Images

With this model, we can create GRAYVALUE images

Value = 0: BLACK (no illumination / energy)

Value = 255: White (max. illumination / energy)



Digital Images

Usual Array Mathematatic can be Applied resulted into what is called enhanced image!

6	8	2	0
12	200	20	10

→

3	4	1	0
6	100	10	5

Digital Images

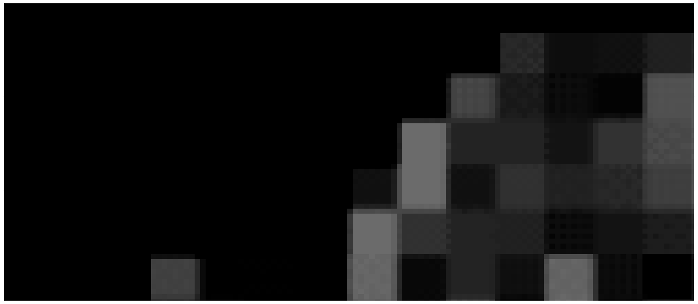
Remember: the value of the cells is the illumination (or brightness)

6	8	2	0
12	200	20	10

→

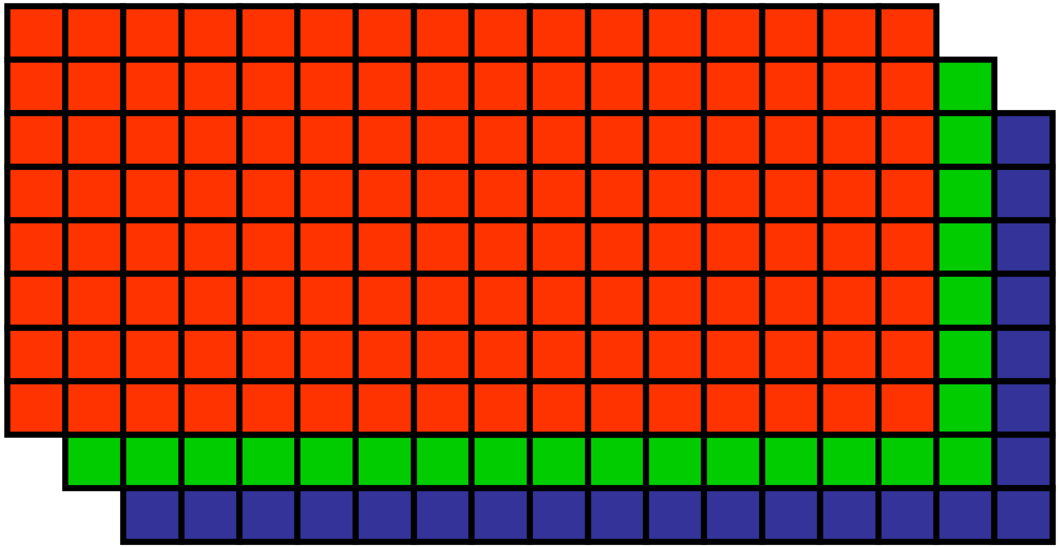
3	4	1	0
6	100	10	5

→



Digital Images

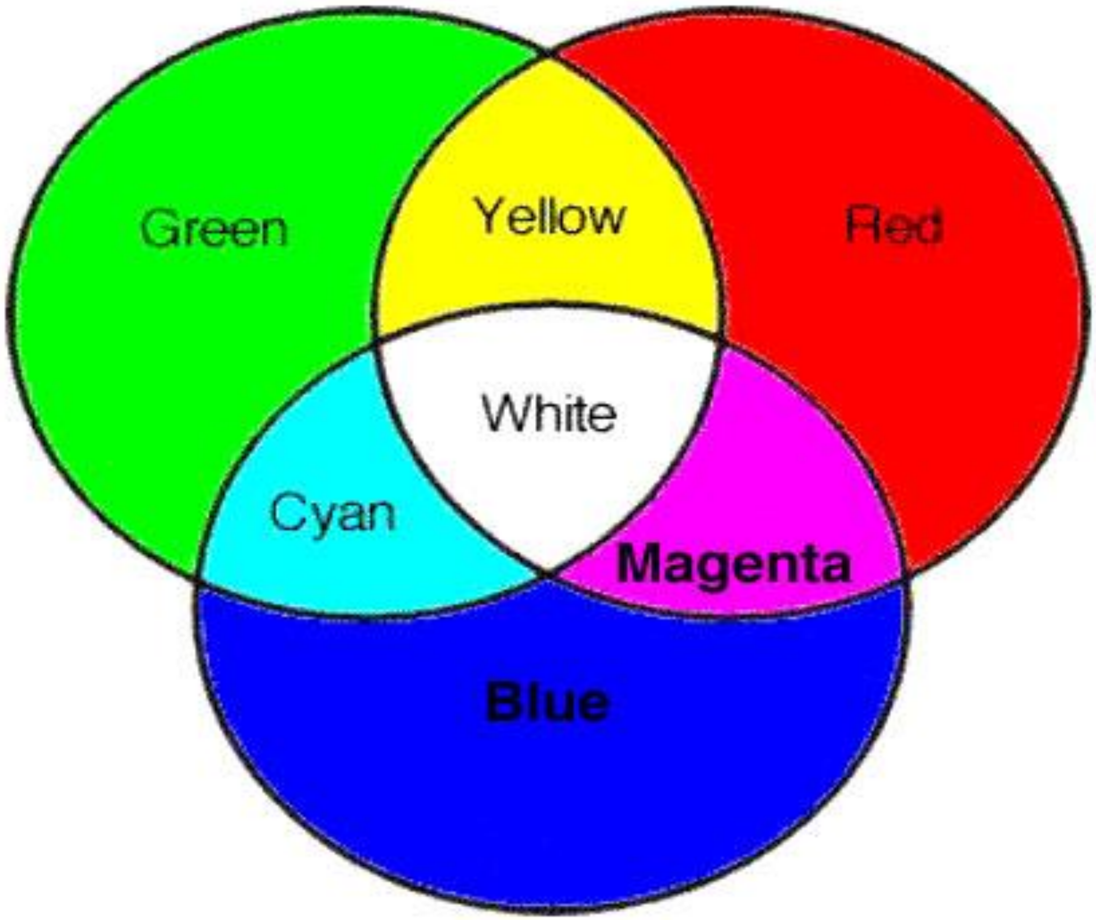
Color images can be represented by 3 Arrays (e.g. 320 x 240 x 3)



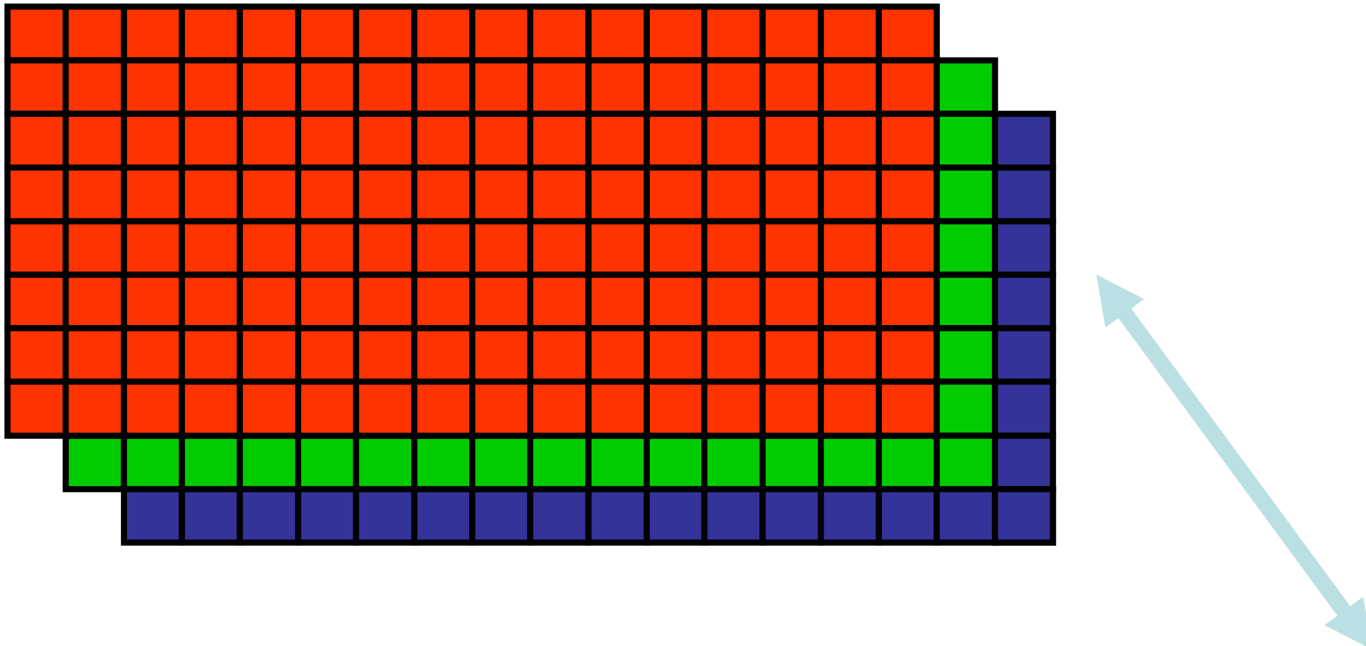
Digital Images

Physics of light

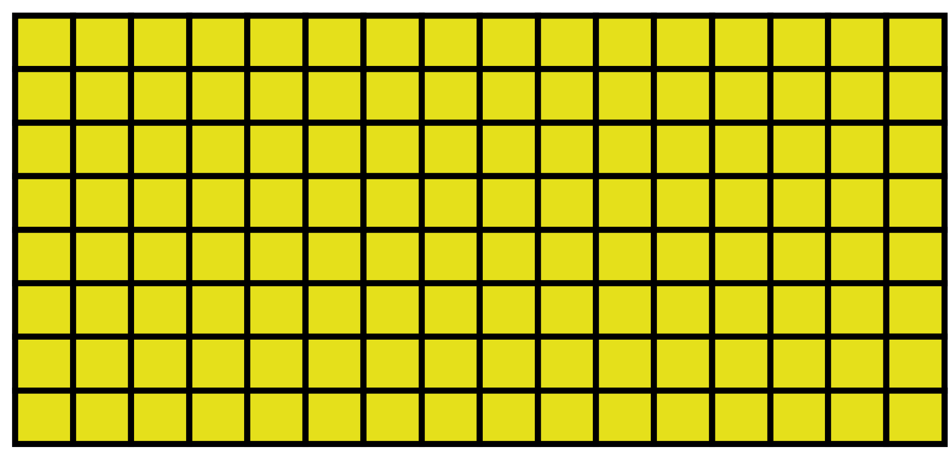
Additive colour mixing - light



Digital Images

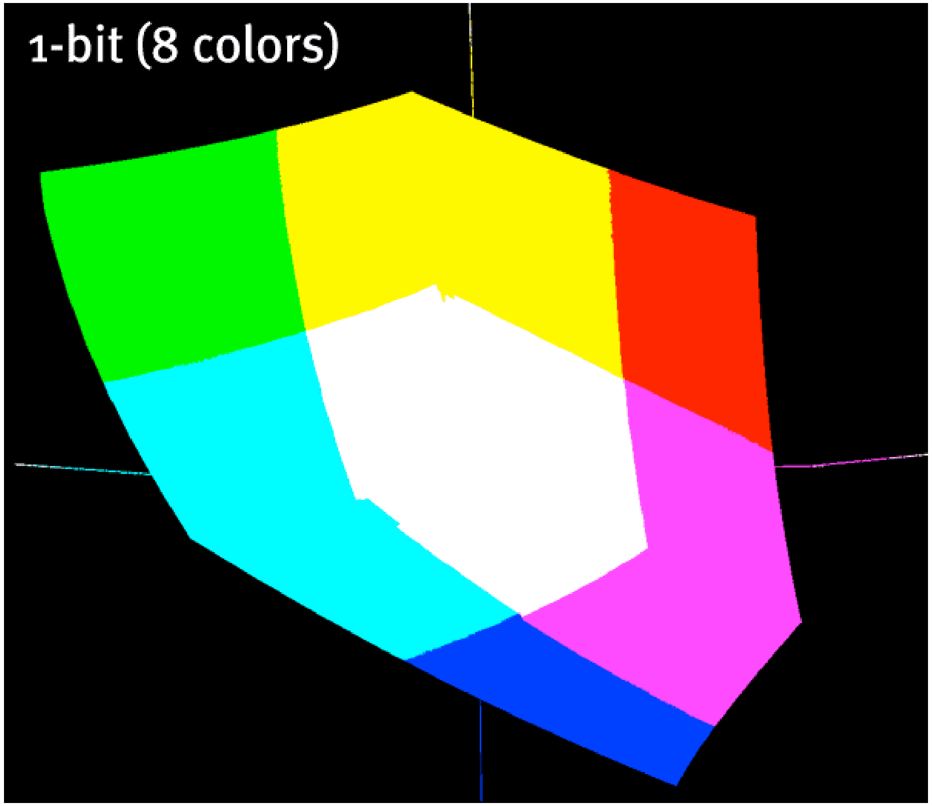


Corresponded pixels are added to form the coloured image



Digital Images

Number of Colours= (X) = $(2^{Y})^{3}$ (where Y equals the bit depth rating)



Colour Coding - CIE System (1931)

COMMISSION INTERNATIONALE DE L'ECLAIRAGE

INTERNATIONAL COMMISSION ON ILLUMINATION

- Based on visual perception measurements
- Basic principle
  - *Any* color stimulus can be matched *exactly* by a combination of three primary lights. Match is *independent of intensity*

R = 51

G =168

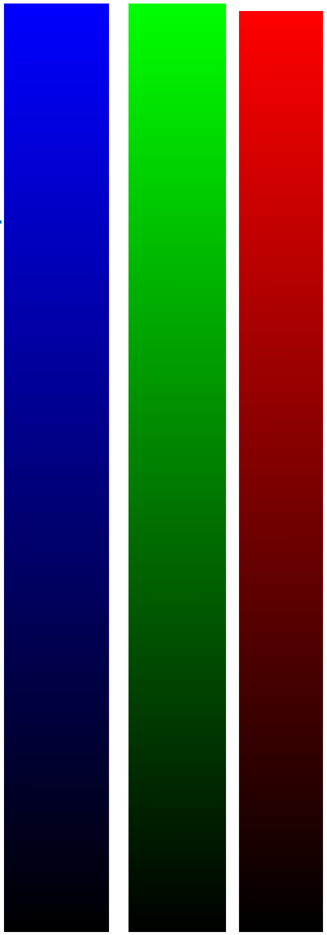
B =205

(51,168,205)

R = 255

G =255

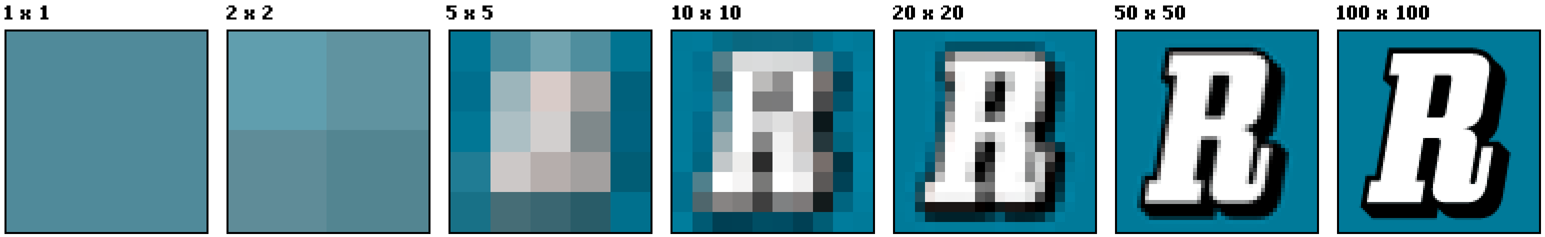
B =255



Satellite instrument Resolutions

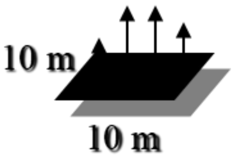
Digital Image resolution

number of Pixels



Satellite Resolutions

Definitions



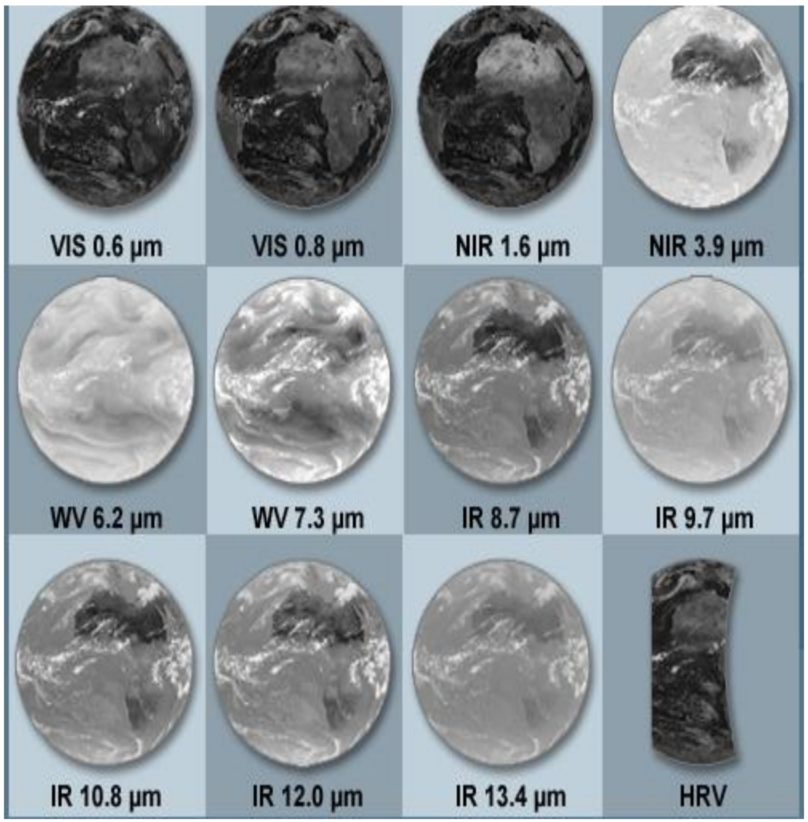
•**Spatial** - the size of pixel represented in the field-of-view, e.g. 10 x 10 m.

• **Spectral** - the number and size of spectral regions the sensor records data in, e.g. blue, green, red, near-infrared thermal infrared, microwave (radar).

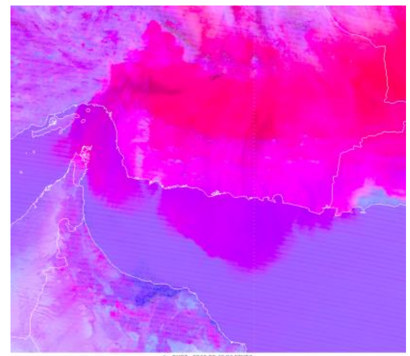
Rendering of Satellite Images

Rendering of Satellite Images

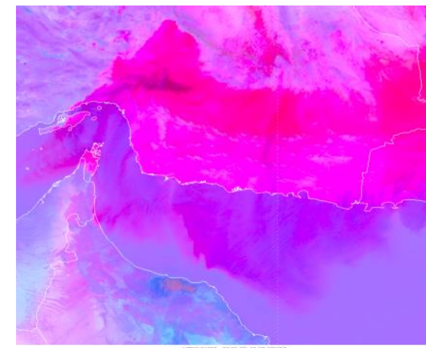
How?



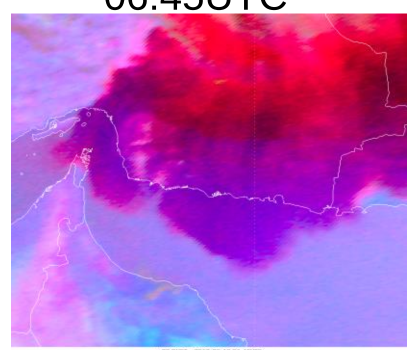
MODIS
06:50UTC



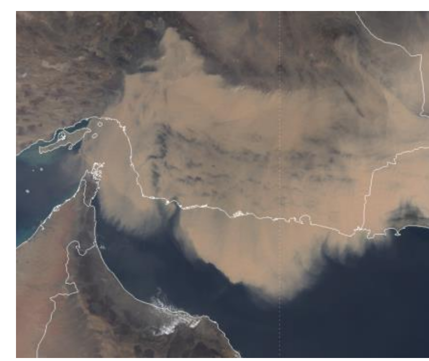
VIIRS
08:58UTC



SEVIRI
06:45UTC



VIIRS
08:45UTC



Dust – Sea of Oman

Rendering of Satellite Images

Methods for Feature Enhancement

1. Simple Grey scale
2. Look Up Table (LUT) for pseudo colours
3. Difference of Two Channels (Bands)
4. RGB composites by attributing specific channels or channel combinations to Red, Green, and Blue colours

Rendering of Satellite Images

1. Simple grey scale

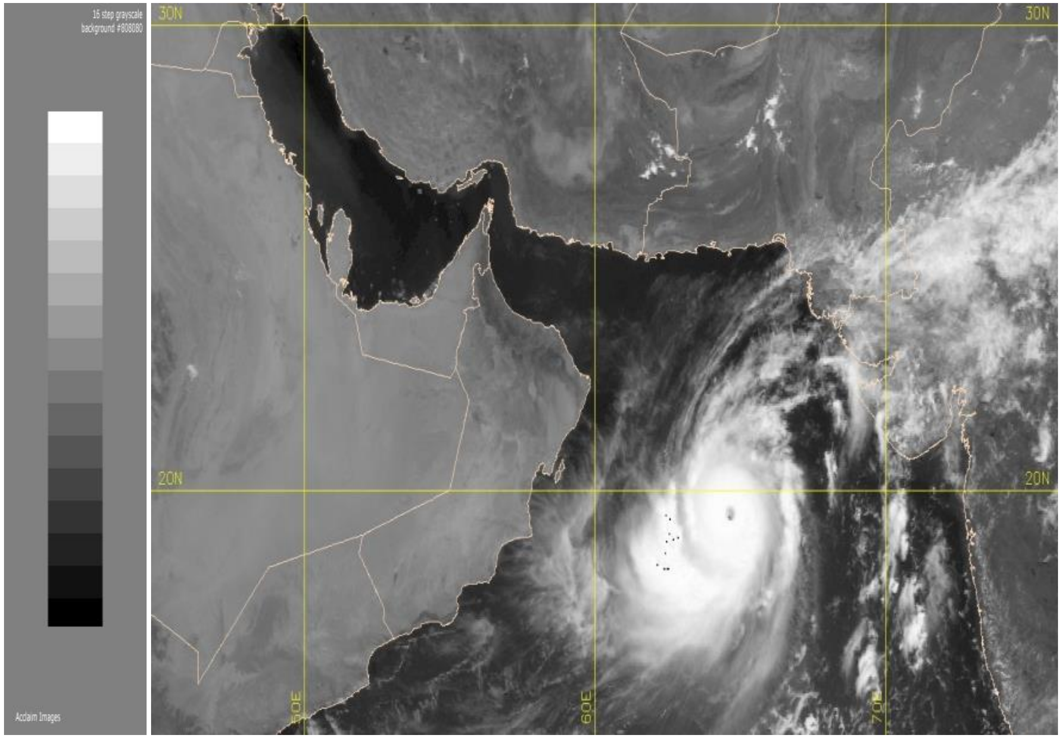
Rendering of IR channels

IR: emission / brightness temperature

Inverted mode

Bright/ cold

Low Temperature



clouds / more absorption

Dark/ warm

High Temperature

Rendering of Satellite Images

Rendering of an individual channel

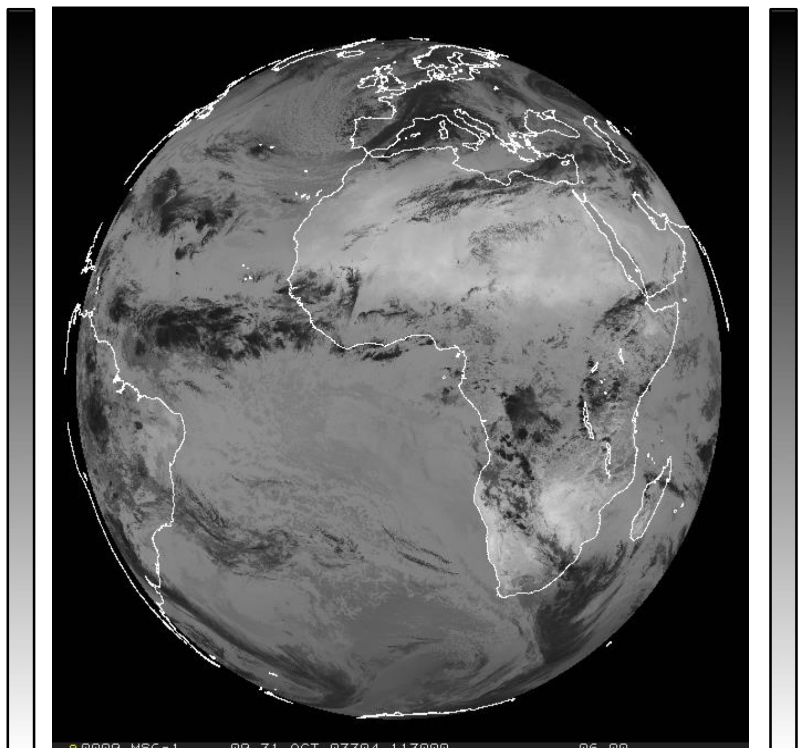
1. Simple Grey scale

IR: emission / brightness temperature

Physical mode

Dark / cold

clouds / more absorptio



Bright / warm

land / sea / less absorption

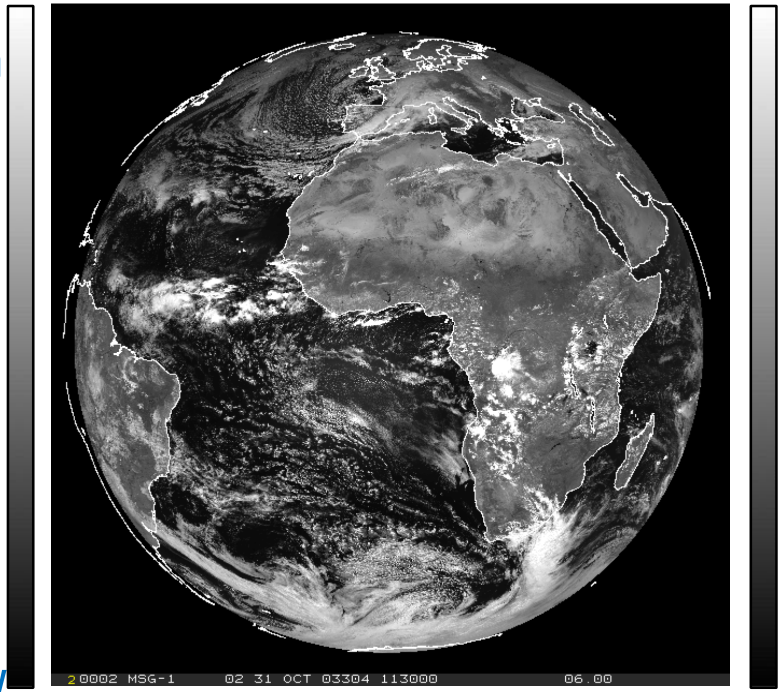
Rendering of Satellite Images

Rendering of an individual channel

1. Simple Grey scale

Solar bands: Use reflected solar radiation

High reflective: Bright
Low reflective : Dark



Rendering of Satellite Images

Rendering of an individual channel

1. Simple Grey scale

What is the difference between Satellite infrared images and visible images?

Answer :

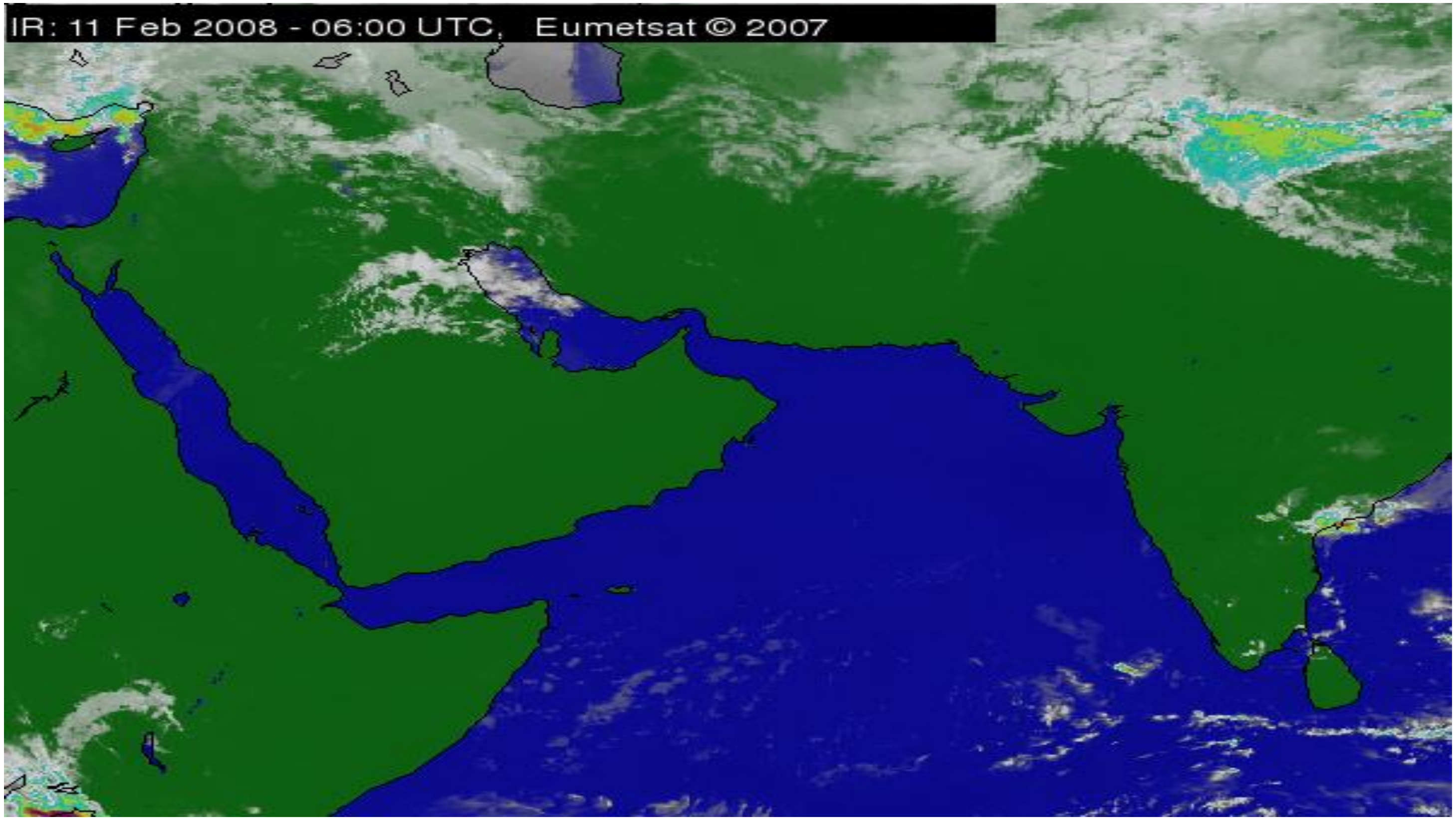
- Visible images are based on reflectivity while infrared images are based on brightness temperature.
- Objects in a visible images has texture such as apparent cloud depth and shadows.
- infrared images appear smother without shadows.

Rendering of Satellite Images

Methods for Feature Enhancement

2. LUT – lookup table

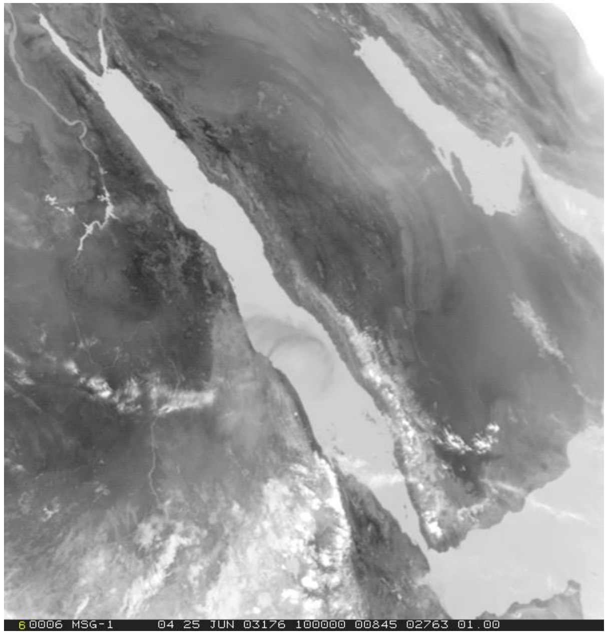
- Table allowing a display system to map pixel values into colours or grey scale values with a convenient range of brightness and contrast.



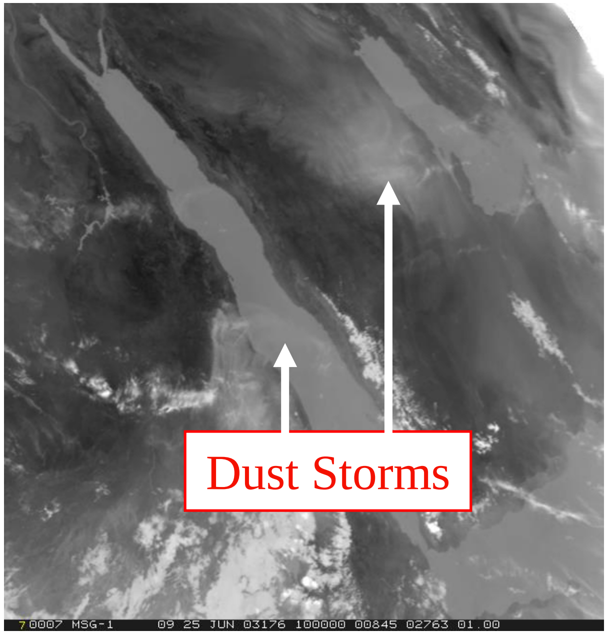
Rendering of Satellite Images

Methods for Feature Enhancement

3. Difference of Two Channels



Channel 04 (3.9 μm)



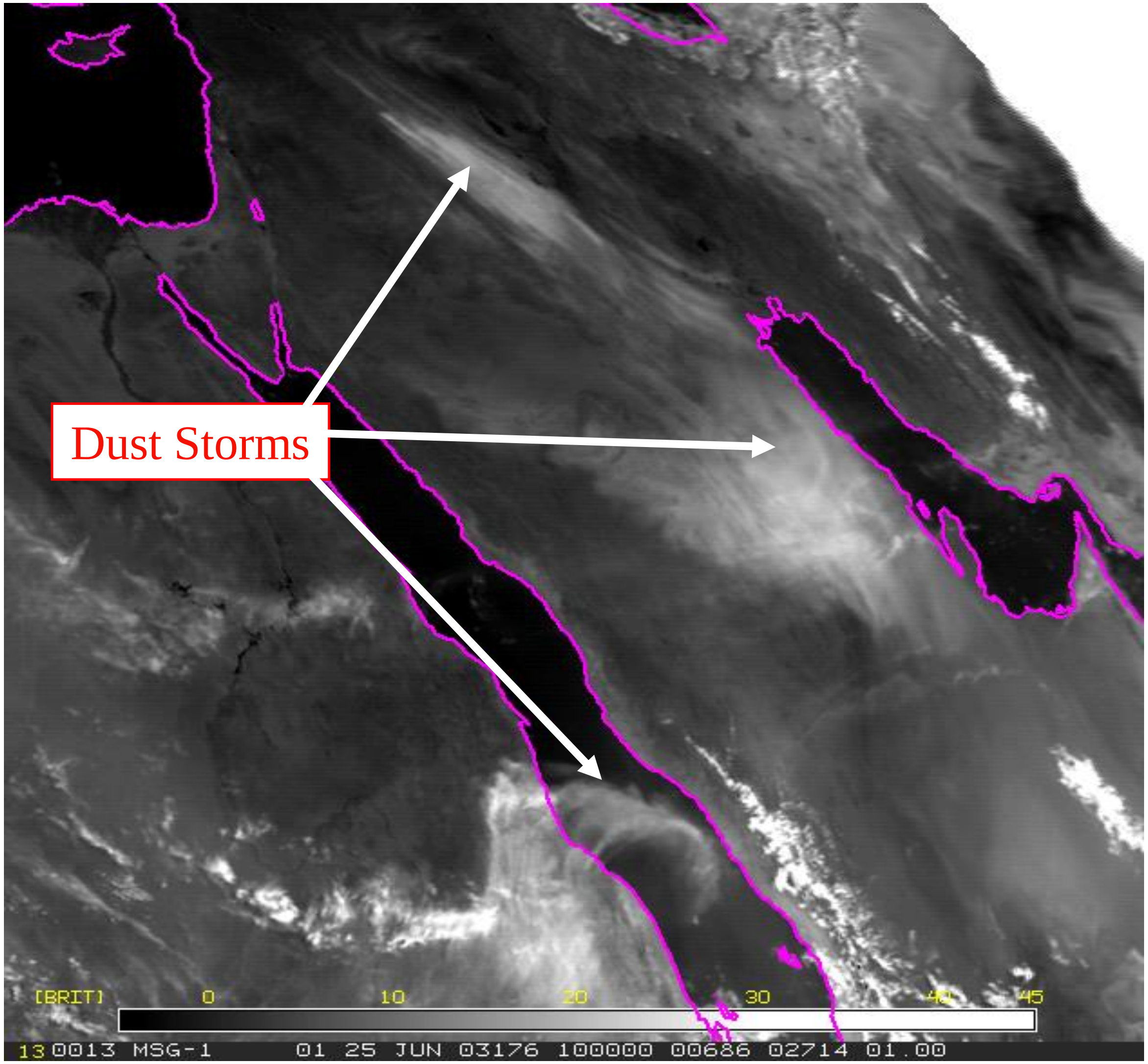
Channel 09 (10.8 μm)

Meteosat-8 **IR** imagery on 25 June 2003 at 10:00 UTC showing a **dust storm** over the Arabian Peninsula.

Rendering of Satellite Images

Methods for Feature Enhancement

3. Difference of Two Channels



MSG-1
25 June 2003
10:00 UTC
Difference Image
Channels IR3.9 - IR10.8

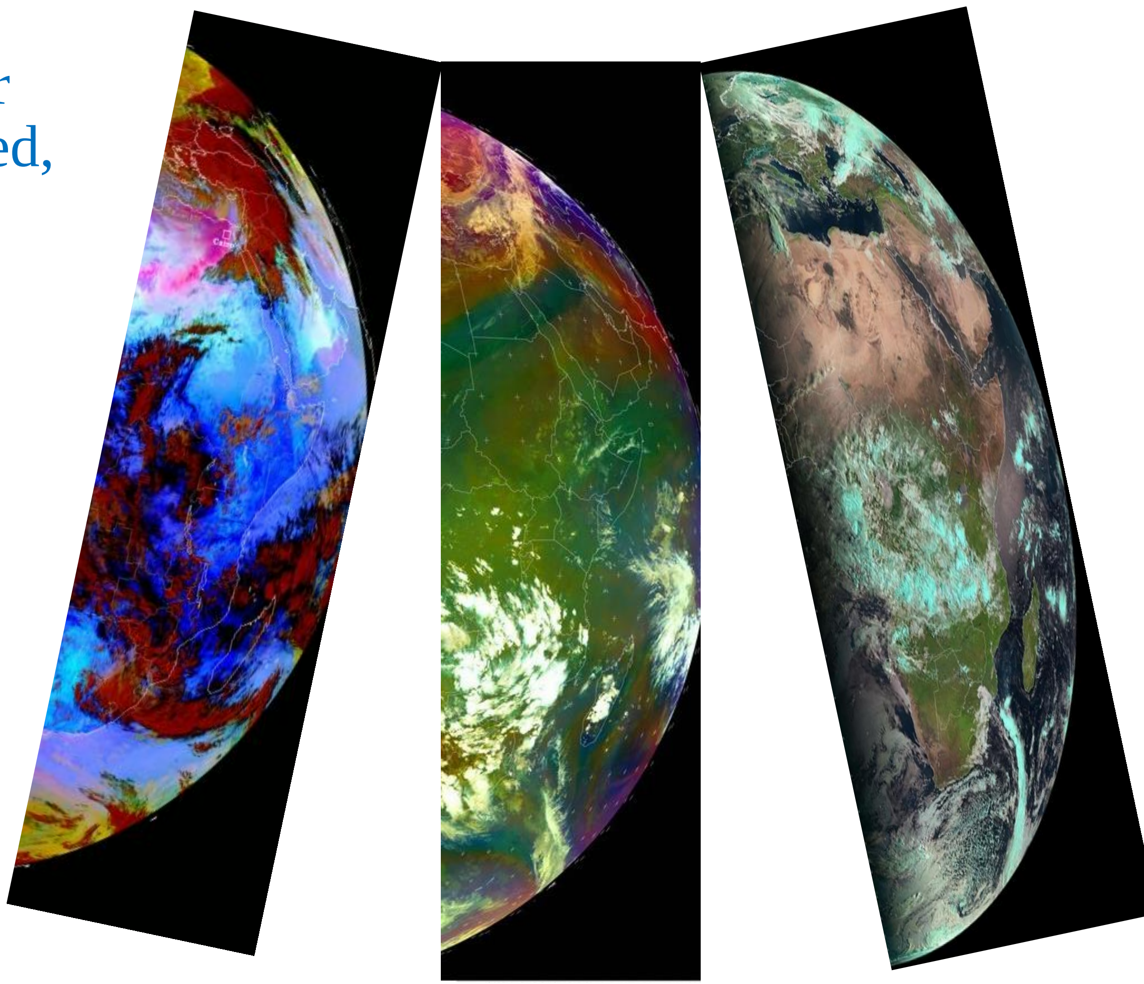
Monitoring of fires and fog, but also useful for the detection of dust storms over deserts.

Rendering of Satellite Images

Methods for Feature Enhancement

4. RGB image composites

attributing specific channels or channel combinations to Red, Green, and Blue colors



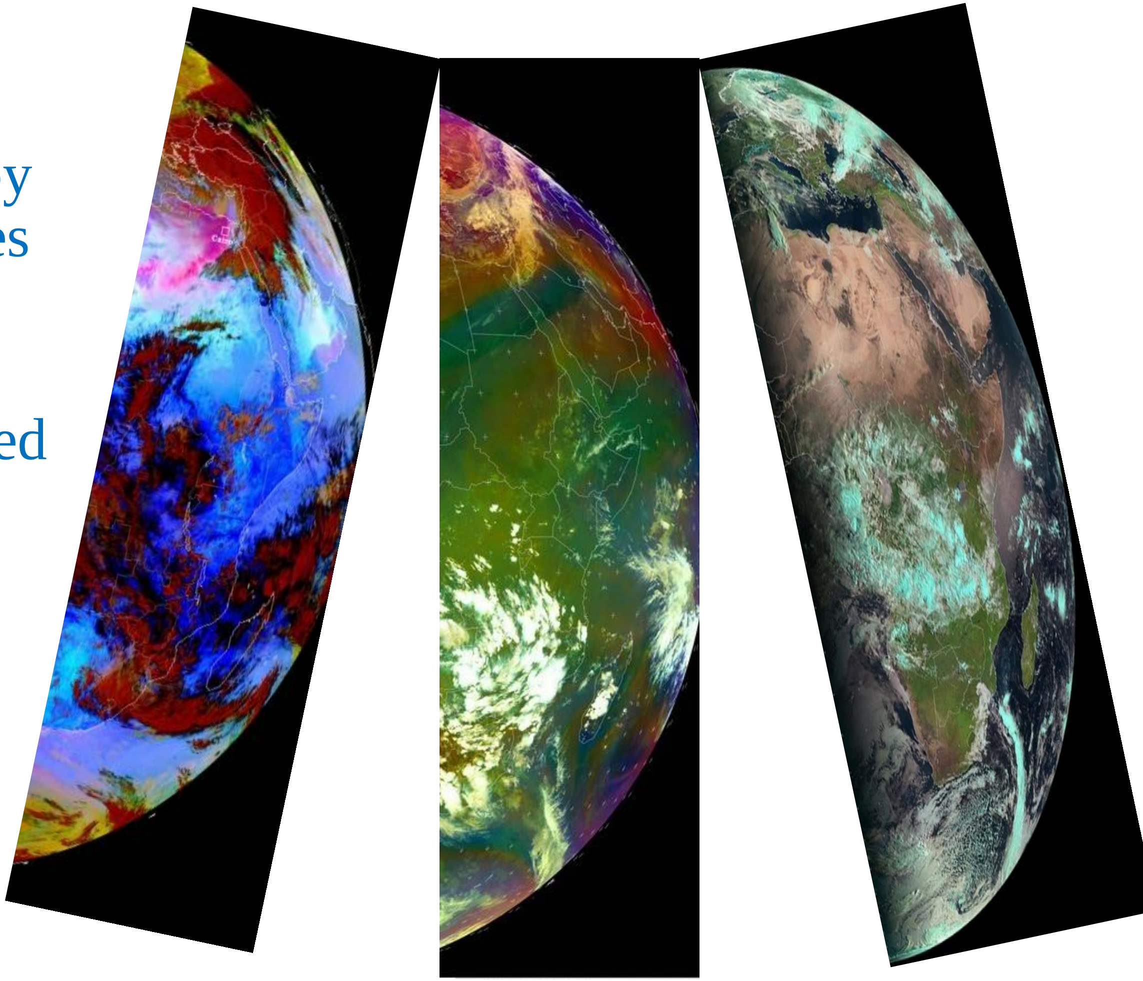
Rendering of Satellite Images

Methods for Feature Enhancement

4. RGB image composites

RGB display produces colors by adding the relative intensities of their color beams.

Certain optical features are enhanced through the resulted color addition.

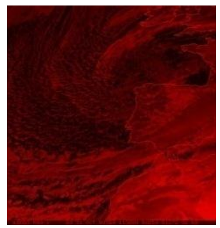


Rendering of Satellite Images

Methods for Feature Enhancement

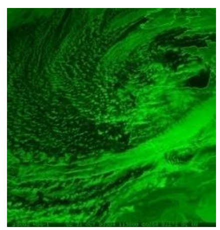
4. RGB image composites

Channel 03



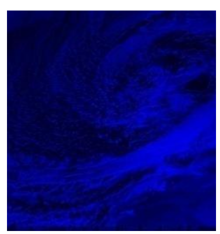
+

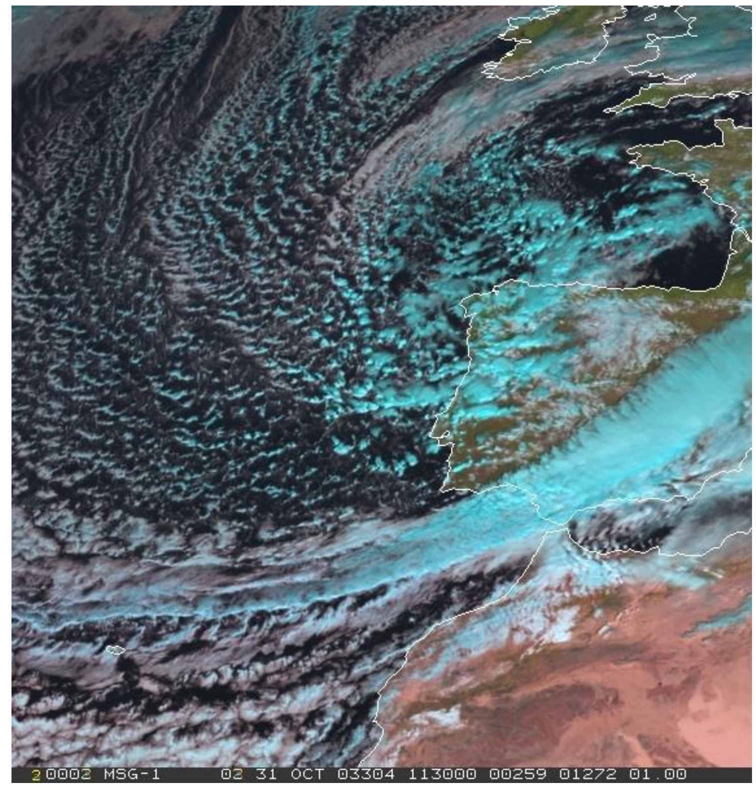
Channel 02



+

Channel 01





Color Selector.exe

Rendering of Satellite Images

Methods for Feature Enhancement

4. RGB image composites

RGB 10-09, 09-07, 09
(“24-hour Dust Microphysics")

devised by: D. Rosenfeld

Recommended Range and Enhancement:

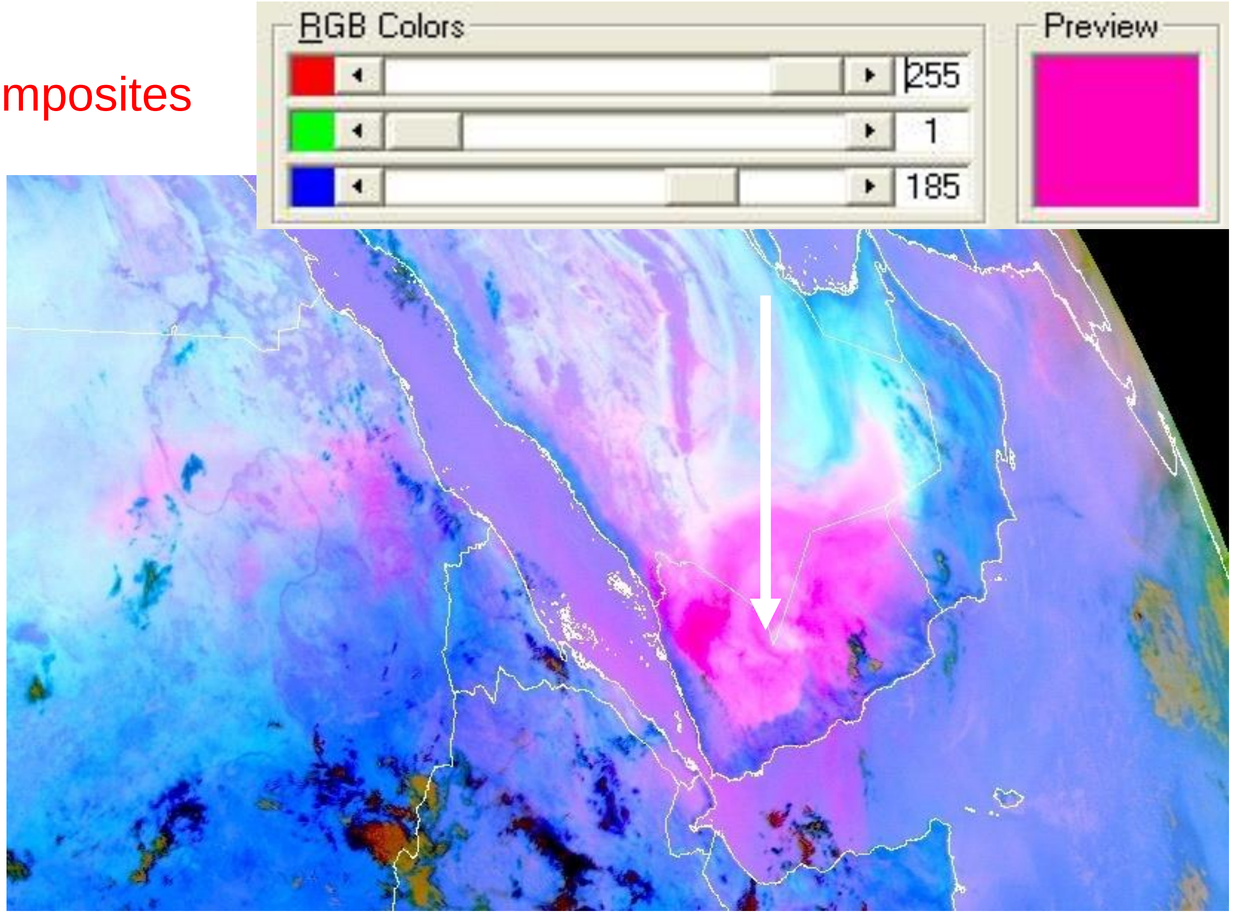
Beam	Channel	Range	Gamma
Red	IR12.0 - IR10.8	-4 … +2 K	1.0
Green	IR10.8 - IR8.7	0 … +15 K	2.5
Blue	IR10.8	+261 … +289 K	1.0

Rendering of Satellite Images

Methods for Feature Enhancement

4. RGB image composites

Example: Dust RGB



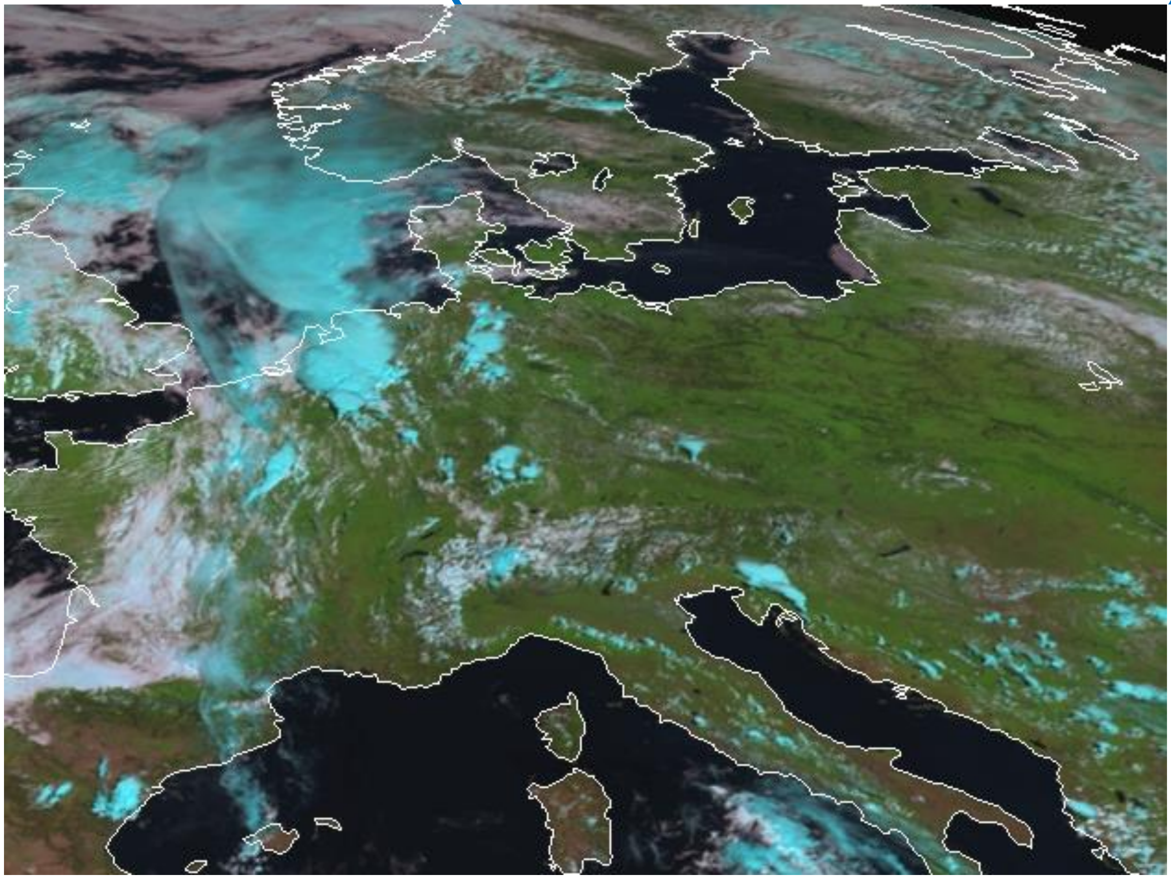
MSG-1, 14 June 2006, 08:00 UTC

Rendering of Satellite Images

Methods for Feature Enhancement

4. RGB image composites

Example: RGB Natural Colours (Meteosat channels 03-02-01)



MSG-1, 8 June 2003, 11:00 UTC, RGB 03-02-01

Rendering of Satellite Images

Methods for Feature Enhancement

4. RGB image composites

Summary

- RGB display is a fast technique for feature enhancement exploiting additive colour scheme.
- RGB require simple manipulation to obtain optimum colouring (choice of P or Inverted mode for IR channels...ect!)

Practical
Task 1

Go to
http://www.eumetrain.org/ePort_MapViewer/index.html
or
https://view.eumetsat.int/productviewer?v=default
or
https://worldview.earthdata.nasa.gov/
https://meteologix.com/

- identify convective and layer clouds of today over Arabian Peninsula!
- What is the difference between infrared images and visible images?

Practical
Task 1

Go to
http://www.eumetrain.org/ePort_MapViewer/index.html
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or
https://worldview.earthdata.nasa.gov/
https://meteologix.com/

- identify convective and layer clouds of today over Arabian Peninsula!
- What is the difference between infrared images and visible images?
- **Answer :** Visible images has texture such as apparent cloud depth and shadows

Practical
Task 2

Go to https://worldview.earthdata.nasa.gov/

- For 01/06/2007 12 UTC and 06/06/2007
  - add layer -> Sea Surface Temperature (*Multi-mission / GHRSST)*

  - Compare Oman Sea Surface Temperature for the two days. Which is higher? What do you think is the cause of the difference?