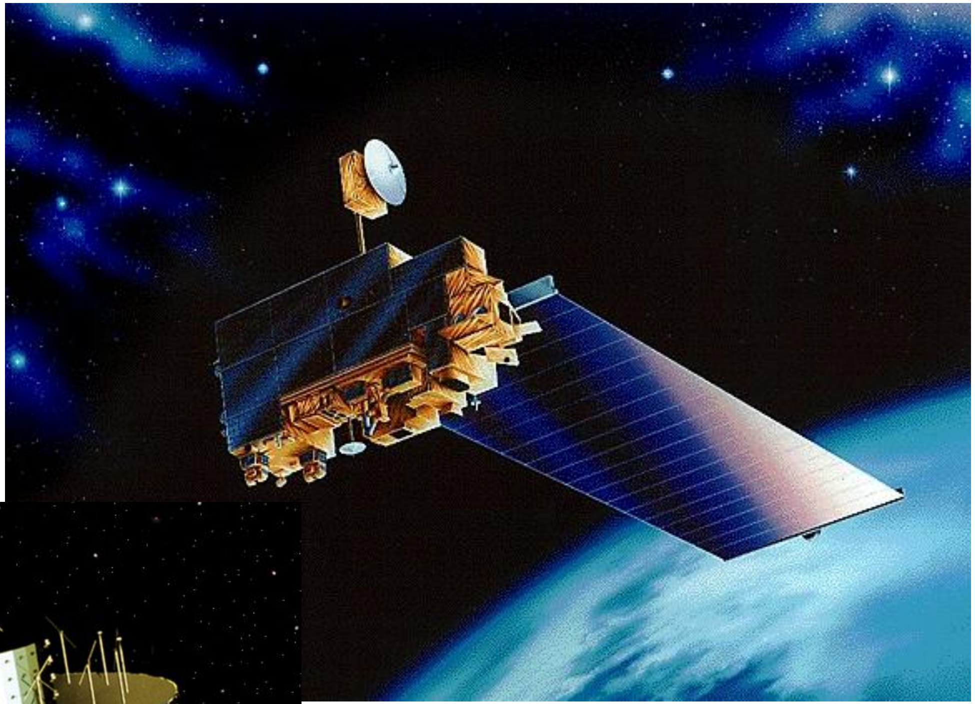
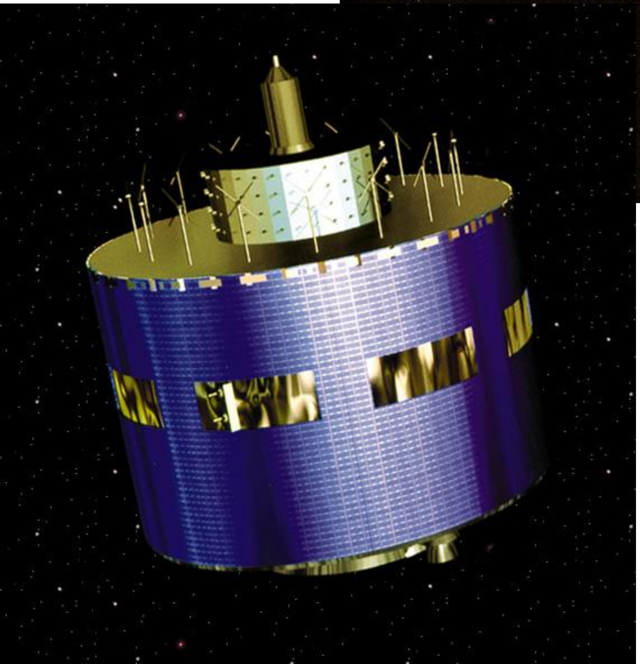
Weather Satellites





Humaid Albadi

ESAC-ME-IX

CoE-Muscat

09 February 2013

Other Contributors: Volker Gärtner, HansPeter Roesli(EUMETSAT)M. König (EUMETSAT), J. Kerkmann (EUMETSAT)D. Rosenfeld (HUJ), V. Zwatz-Meise (ZAMG).

Weather Satellites

- What is a satellite?

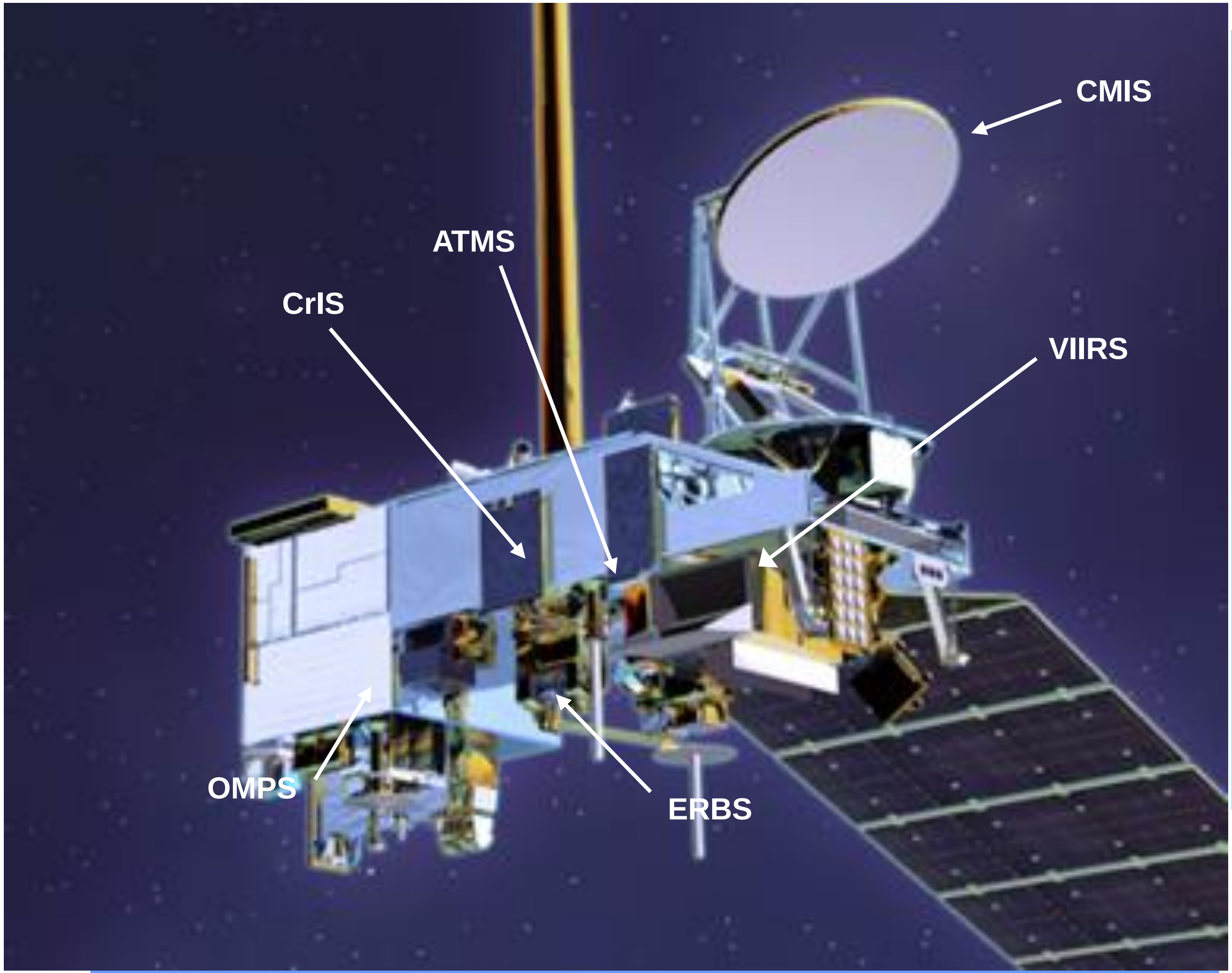
A Spacecraft which has been placed into an orbit around the Earth by human endeavor

- What is a Radiometer ?

A device that measures the radiant flux (power) of electromagnetic radiation.

> Satellites can carry many Radiometers (instruments)

NOAA Satellite



Single satellite design with common sensor locations

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

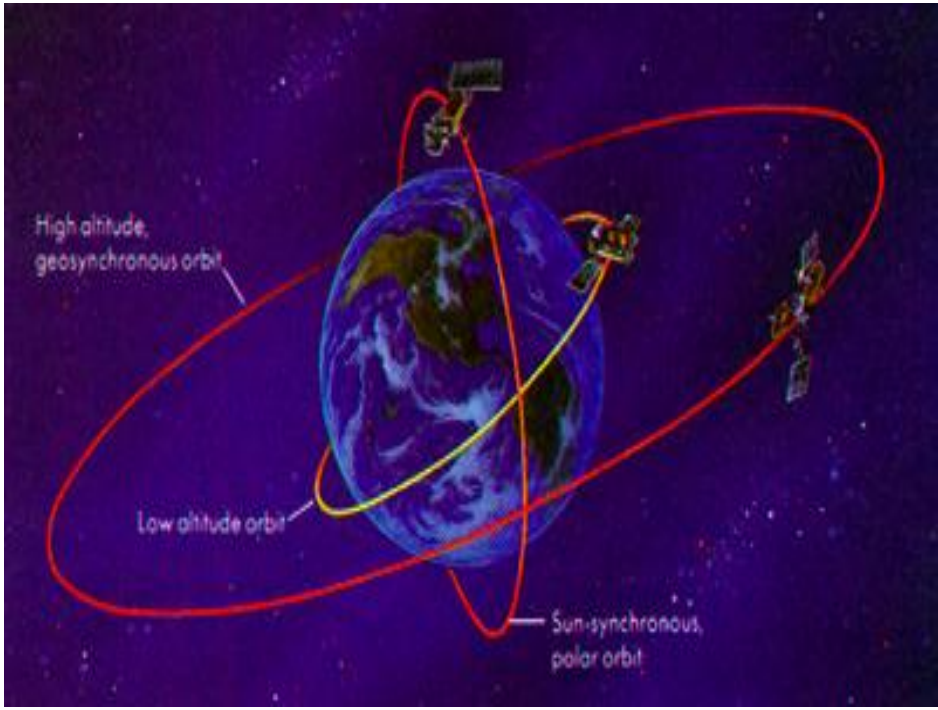
Weather Satellites

There are 2 main types of weather satellite

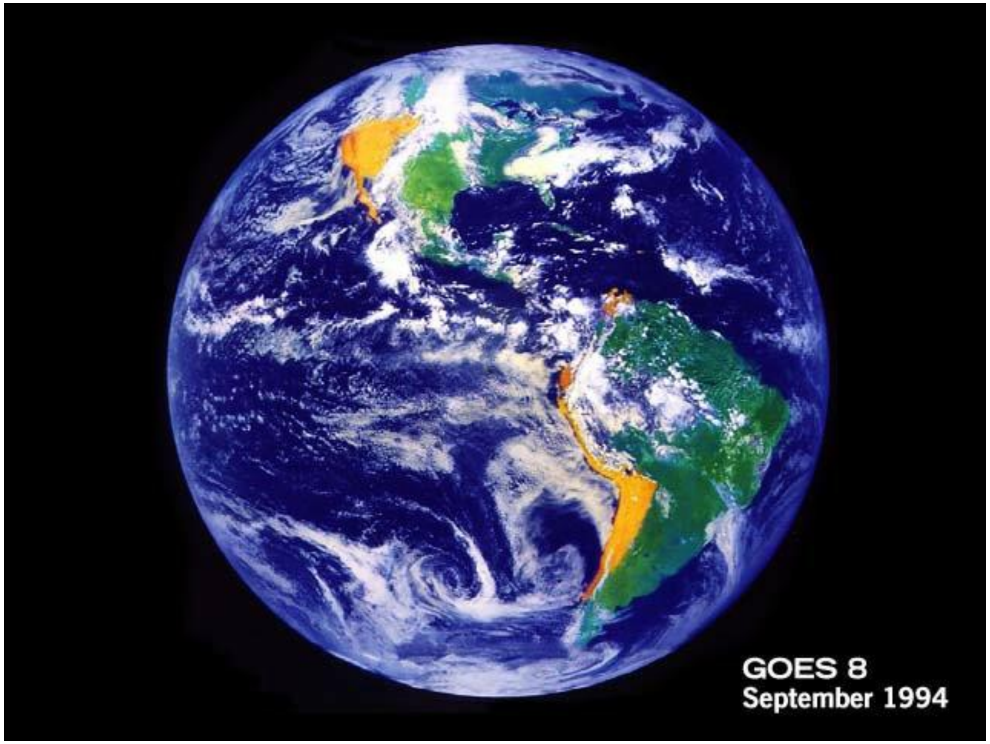
1. Geo Synchronized

2. Polar Orbiting

(sun synchronized)



Geo Synchronized satellites



- located over the equator at a height of 36 000 km.
- remain stationary with respect to the Earth's surface.
- give continuous low detail images (good for animation).

Why Should it be at 36000 KM?
Why Satellites do not fall on Earth ?

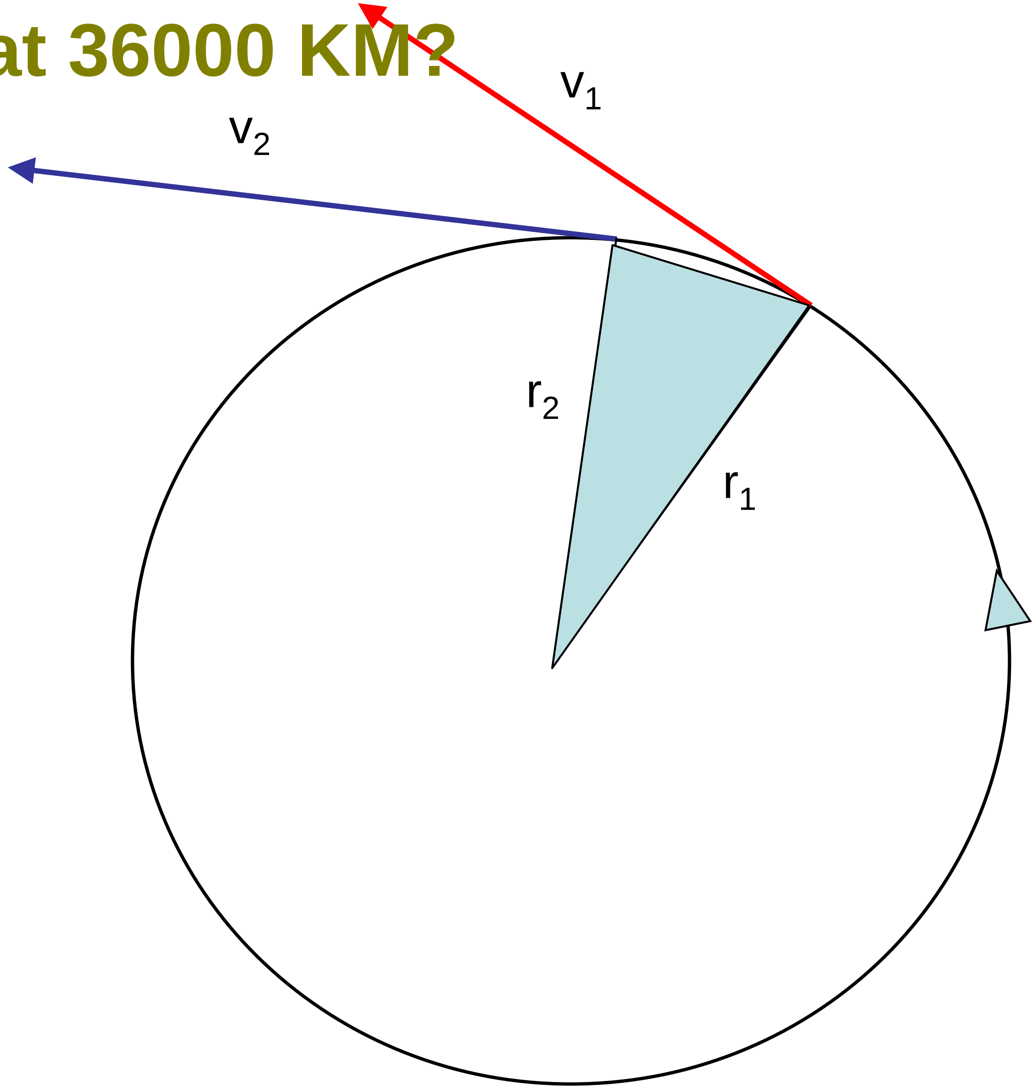
Circular Motion

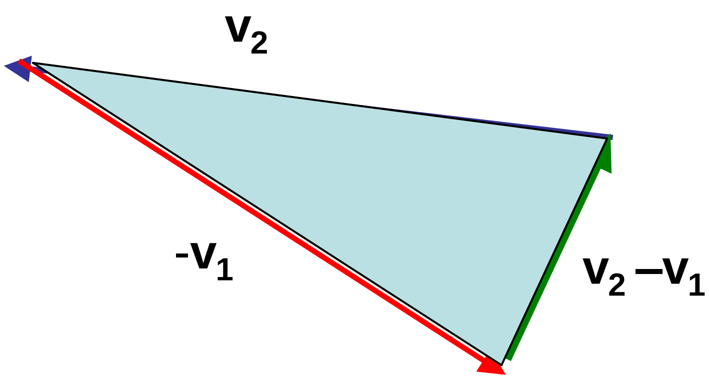
Fact … any object travelling in a circle at constant speed is *always* accelerating towards the centre of the circle.

* This is because acceleration (= **a)** is equal to the rate of change of velocity, and both are *vector* quantities
Vectors have both magnitude *and* a direction

*To have steady circular motion centrifugal acceleration should be considered representing the effects of inertia that arise with rotation

Why should it be at 36000 KM?





$$\mathbf{a} = \frac{\mathbf{v}_2 - \mathbf{v}_1}{t}$$

Why should it be at 36000 KM?

By comparing the quantities that make up the 2 similar triangles, (or by algebraic arguments) it is not hard to show that the acceleration for an object travelling in a circle at constant speed v is given by …..

$$\mathbf{a} = \frac{\mathbf{v}^2}{\mathbf{r}}$$

Where r is the radius of the circle

Since **a** is non-zero there must be a net Centrifugal force acting on the object given by Newton second law (**F** = m**a)**

$$\mathbf{F} = \mathbf{m}\frac{\mathbf{v}^2}{\mathbf{r}} \qquad \text{….. (1)}$$

Why should it be at 36000 KM?

But , a Satellite with a mass (m) is affected by Newton's gravitational F_G force (Centripetal)

$$F_G = G\frac{Mm}{r^2} \quad \text{..... (2)}$$

where G is the universal gravitational constant G = 6.67 x 10^{-11} m^3/kgs^2)

For the Satellite to remain in symmetric orbit the centripetal force should equal the centrifugal force

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

Resulted in that the radius to be constant for constant velocity

$$r = G\frac{M}{v^2}$$

Why should it be at 36000 KM?

Period of motion = τ = distance/speed = $\dfrac{2\pi r}{v}$

$$v^2 = \frac{4\pi^2 r^2}{\tau^2}$$

$$r = G\frac{M}{v^2}$$

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

Resulted in that the radius to be constant for certain rotating Period and it is about 36000 KM for One day

Geo Synchronized satellites

- Which Geo Synchronized satellites gives the best view for Middle East ?

-**Meteosat 7**

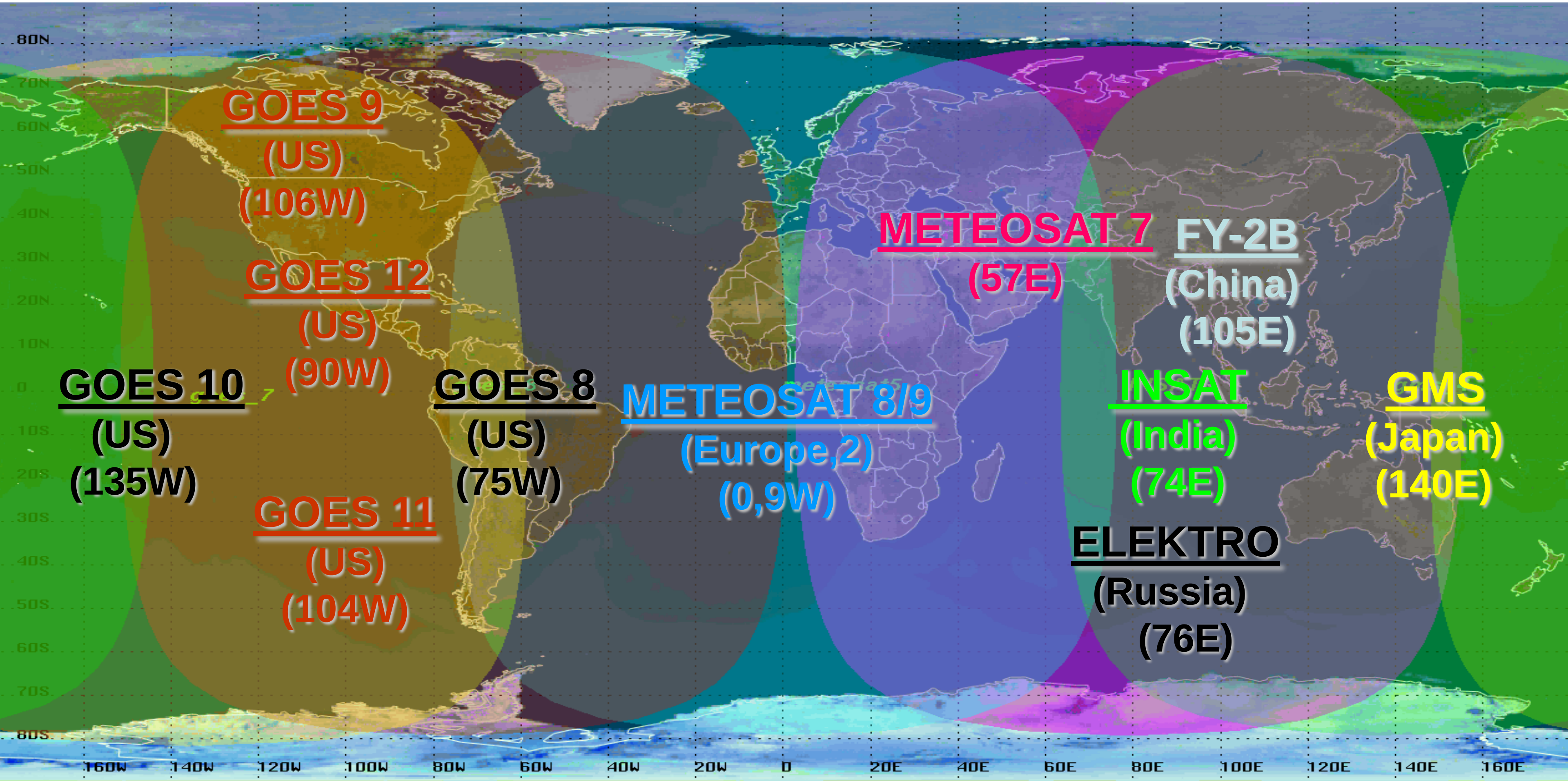
- **INSAT** satellite -> Data Restriction

-**FY-2B** satellite -> Middle East in the Edge

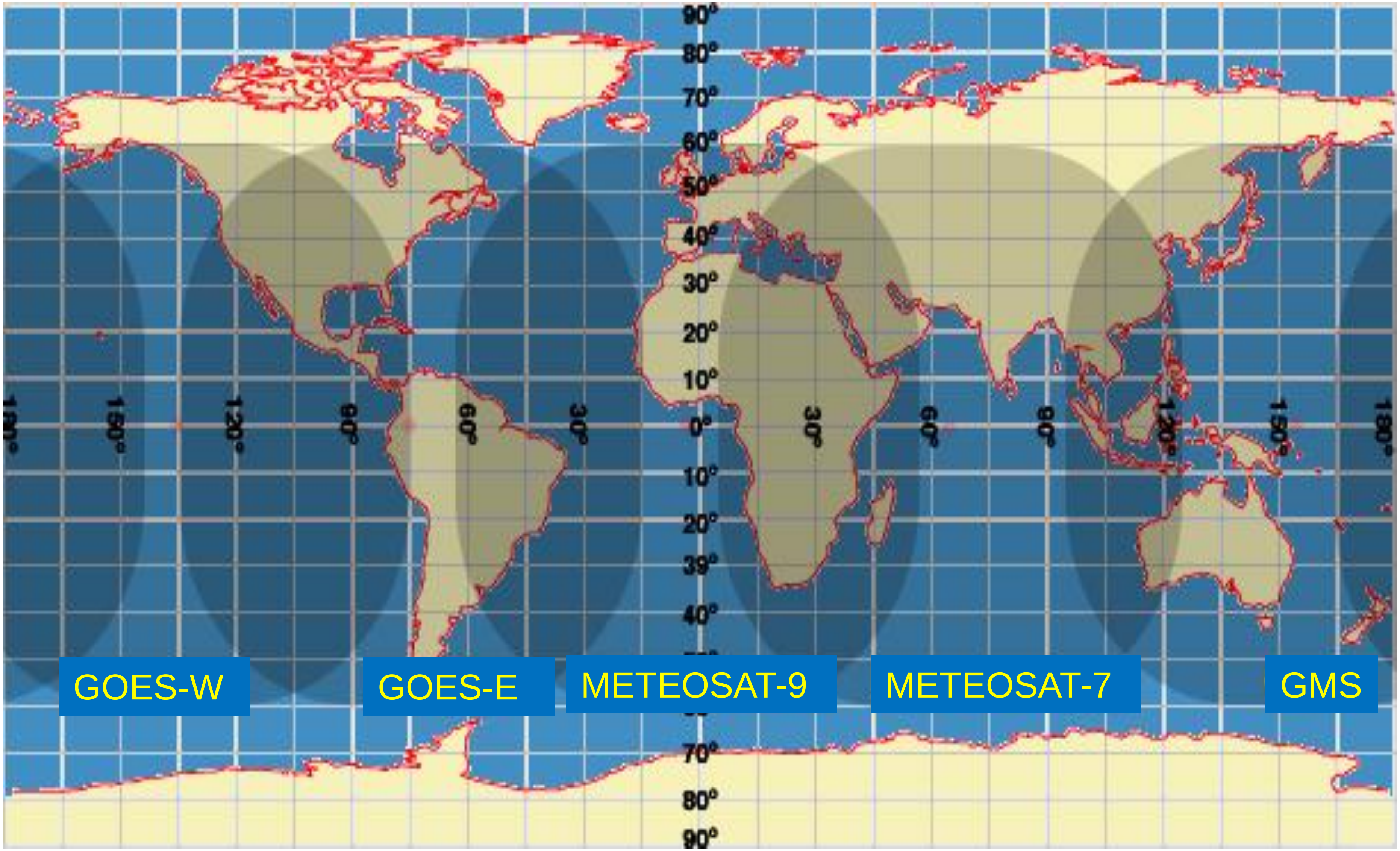
- **Meteosat 8,9** Middle East in the Edge

-Russian **ELEKTRO** is not in operational Mode

Geo Synchronized satellites Coverage

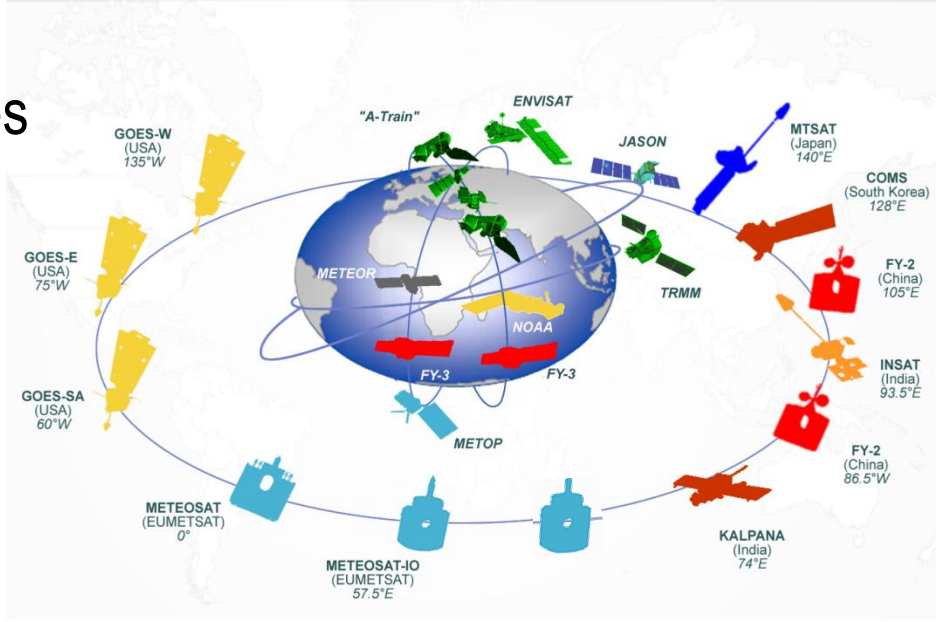


Current Geo Synchronized Operational satellites coverage



Space-based observing system (Sept 2012)

- 12 operational geostationary satellites
- 6 operational sun-synchronous

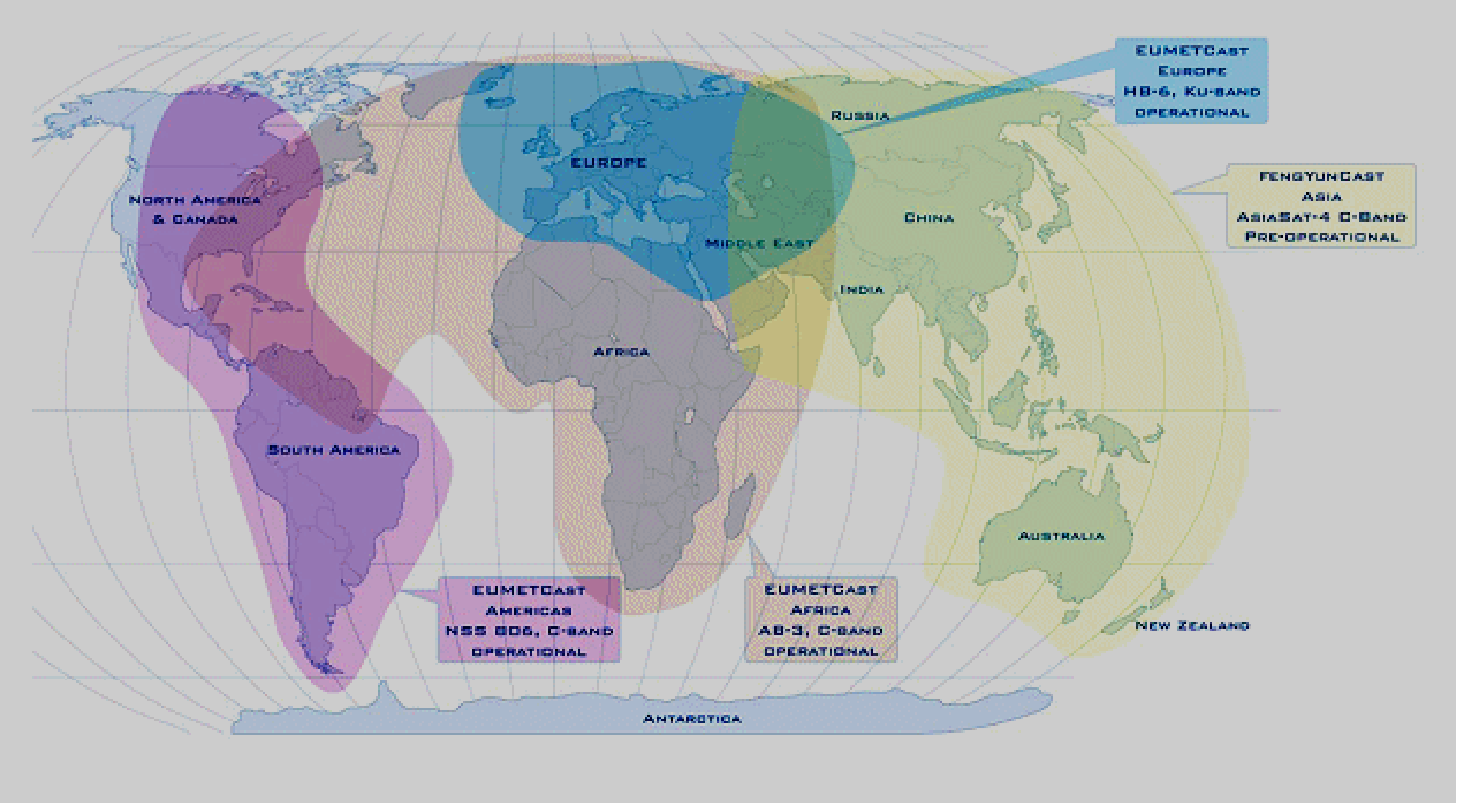


Recent launches:

- Megha-Tropiques (ISRO-CNES)
- Suomi-NPP (NOAA)
- FY-2F (CMA)
- GCOM-W (JAXA)
- MSG-3 (EUMETSAT)
- Metop-B (EUMETSAT)

Facilitating access to data and products

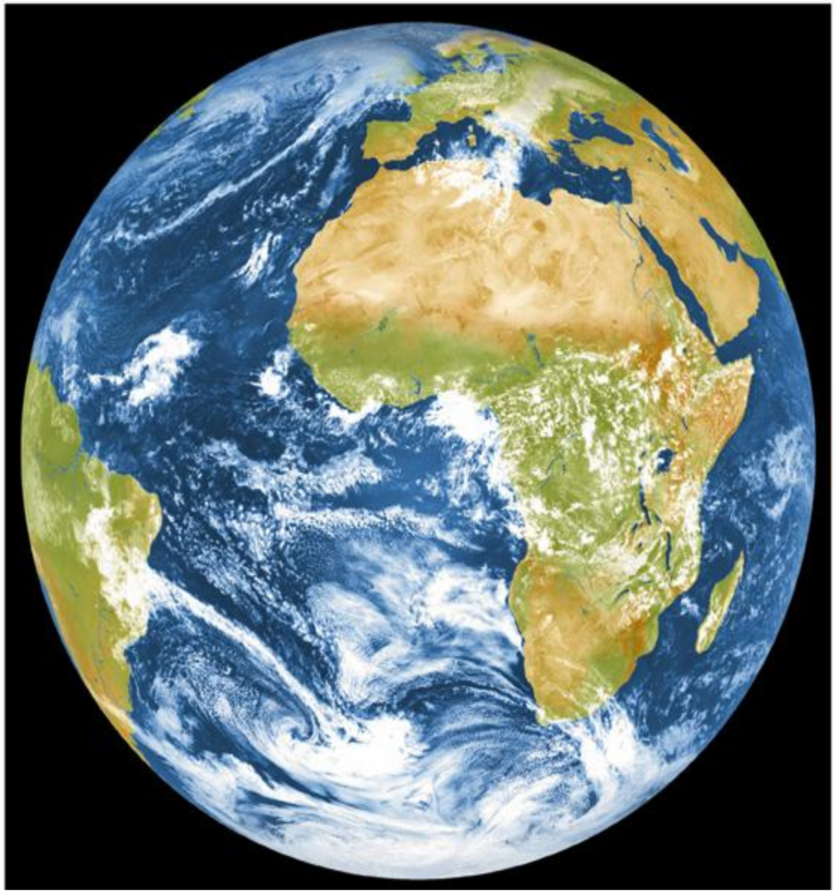
- Promote multi-mission DVB-S retransmission services
  - e.g. GEONETCast(EUMETCast, CMACast, Geonetcast America)
  - Promote Direct Broadcast standards for LEO
  - CBS-XV recommended X-Band + L-Band for future LEO
  - Regional ATOVS Retransmission System (RARS) for near-real time sounding data for NWP
- Product Access Guide http://www.wmo.int/pages/prog/sat/product-access-guide_en.php



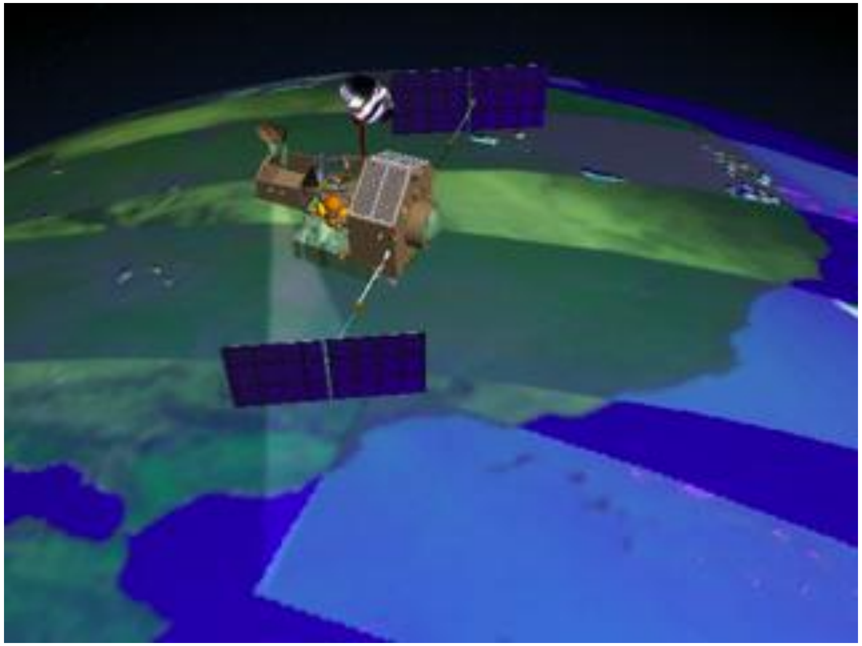
- GEONETCast is a near real time, global network of satellite-based data dissemination systems designed to distribute space-based, air-borne and in situ data, metadata and products to diverse communities.

EARTH VIEW FROM

METEOSAT-9 and METEOSAT-7



Polar orbiting satellites

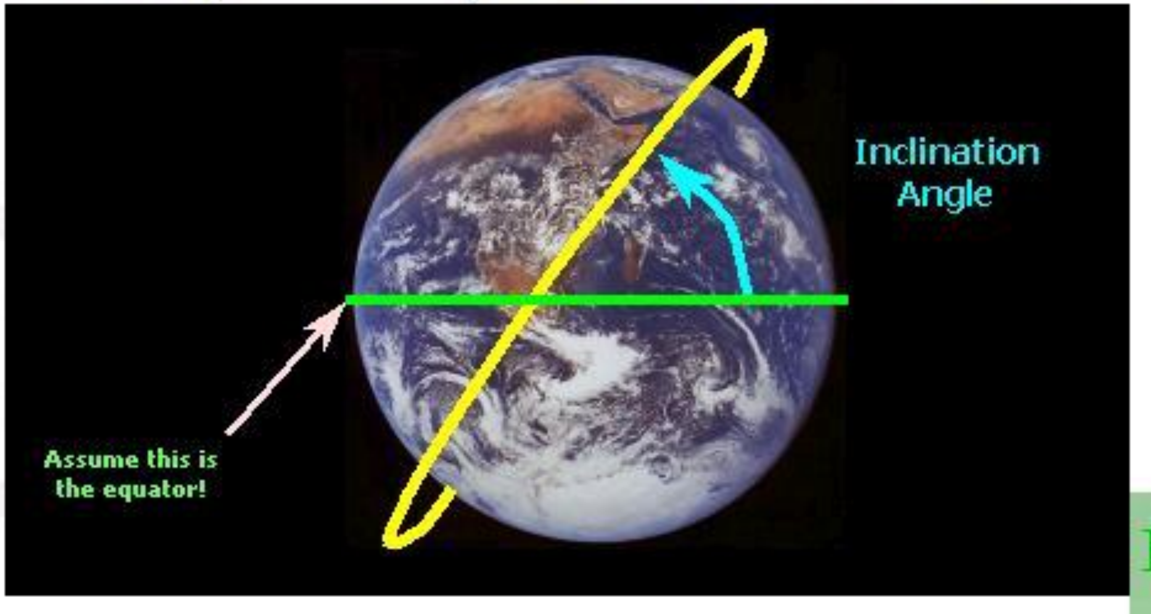


lower altitude of 850km.

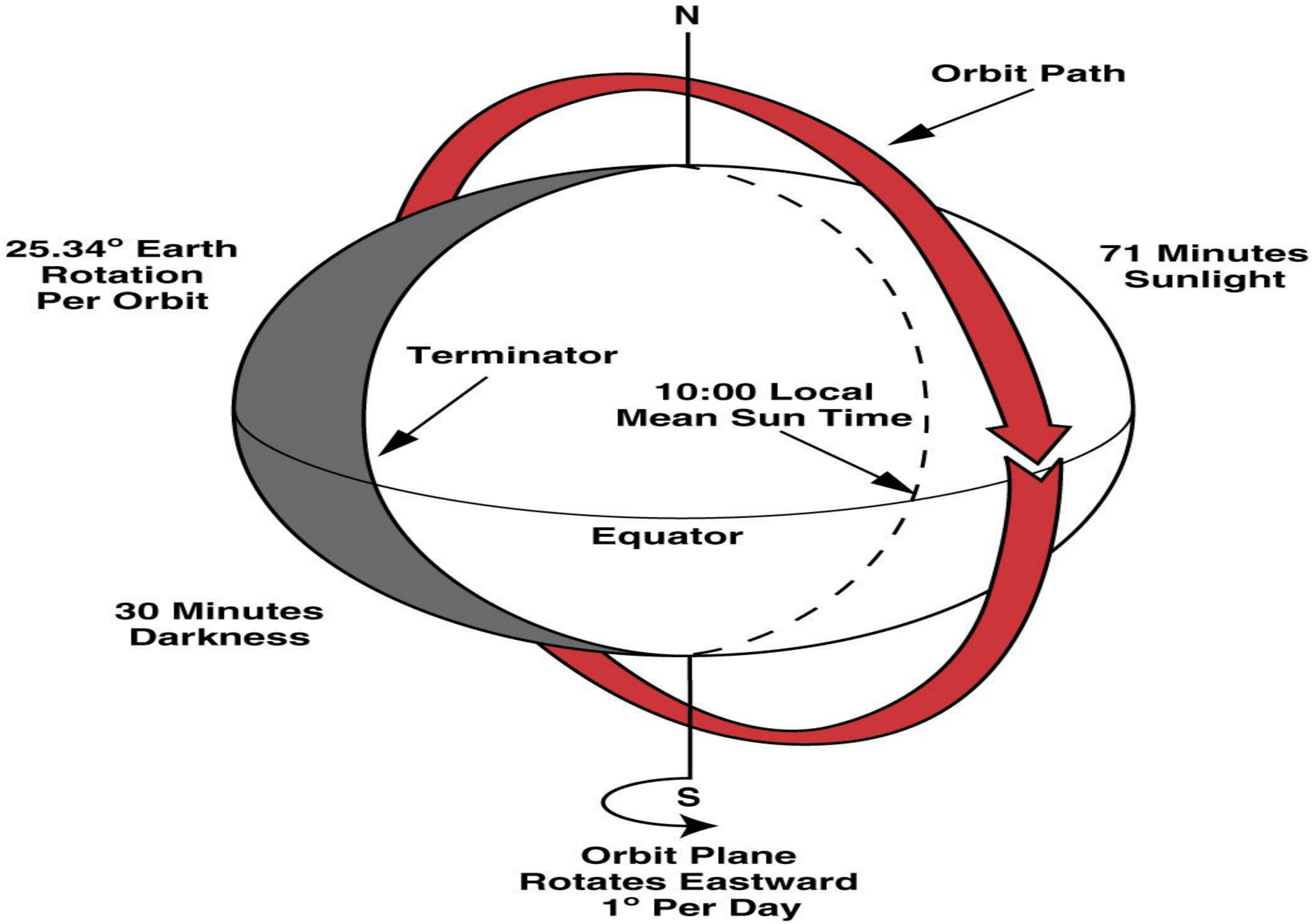
- **orbit from pole to pole in about 100 minutes.**
- **more detailed but less continuous images.**
- **do not always fly over the same regions.**

Polar Orbits

- We define a polar orbit if the inclination is greater than 60°. Normally polar orbits have inclinations near 90°.
- We define the inclination of an orbit as the angle between the equatorial plane and the orbital plane.



Polar Satellites

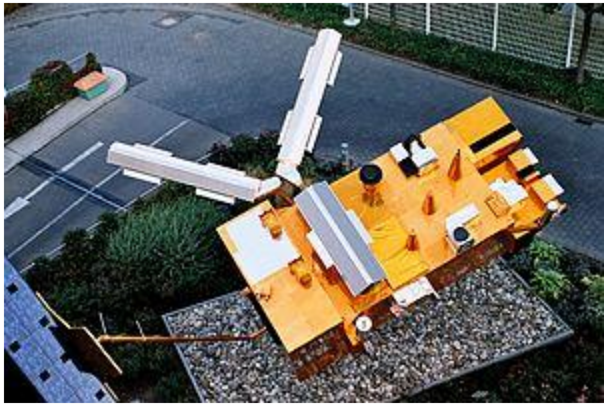


Polar Satellite- AVHRR

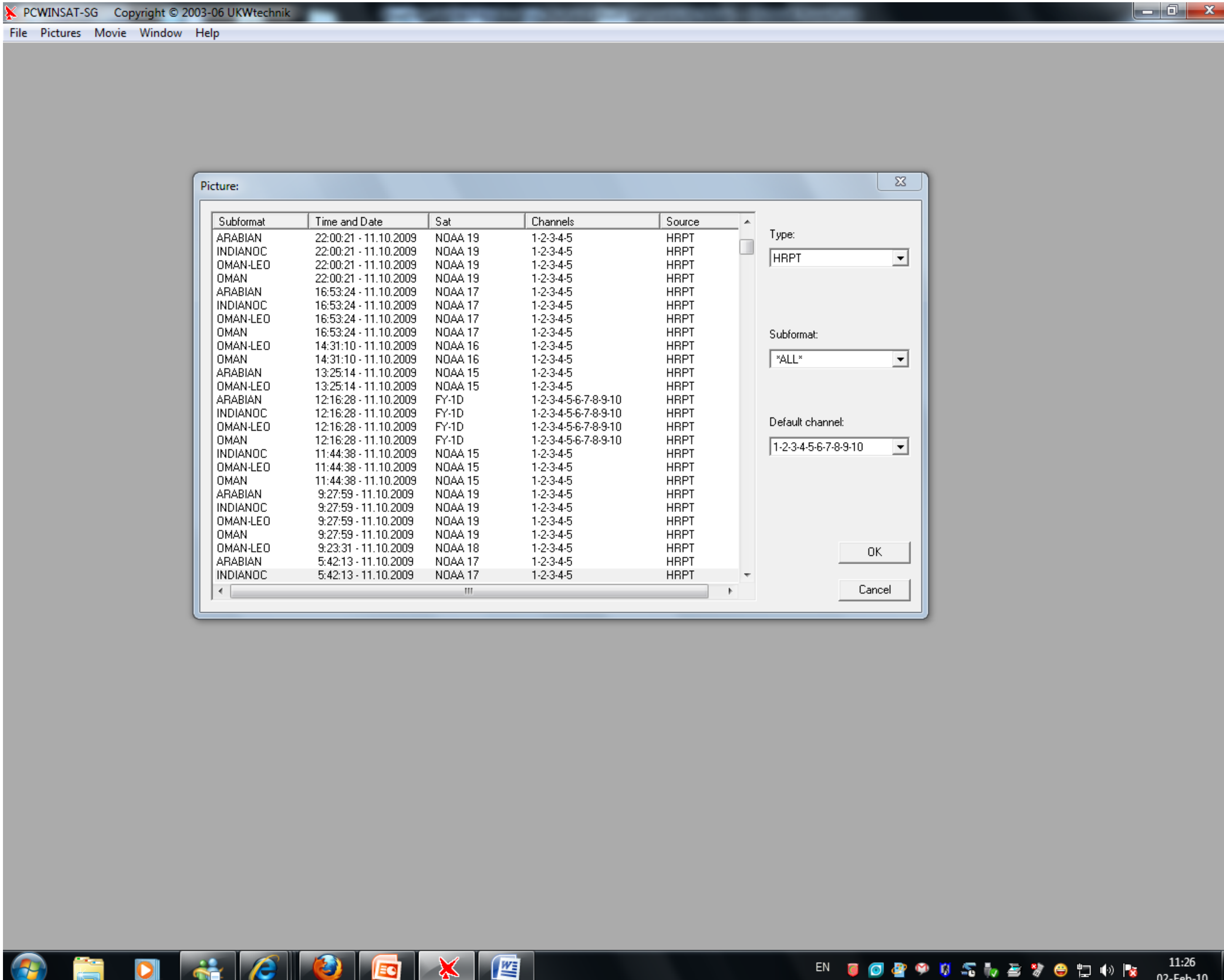
- Collecting data since 1978
- Currently 6 in orbit (
- 2 to 15 images a day
- Whiskbroom scanning pattern
- 1.1 km^2 resolution
- 5+ spectral channels
  - Infrared - channels 3, 4, 5
  - Visible - channels 1, 2

Spacecraft	Mission Operational Status
METOP-A	AM Primary
NOAA 12	Decommissions 10 Aug 2007
NOAA 14	Decommission on 23 May 07
NOAA 15	AM Secondary
NOAA 16	PM Secondary
NOAA 17	AM Backup
NOAA 18	PM Primary
NOAA 19	

Polar Satellite- MetOP



- 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


PCWINSAT-SG Copyright © 2003-06 UKWtechnik
File Pictures Movie Window Help
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Subformat Time and Date Sat Channels Source
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INDIANOC 22:00:21 - 11.10.2009 NOAA 19 1-2-3-4-5 HRPT
OMAN-LEO 22:00:21 - 11.10.2009 NOAA 19 1-2-3-4-5 HRPT
OMAN 22:00:21 - 11.10.2009 NOAA 19 1-2-3-4-5 HRPT
ARABIAN 16:53:24 - 11.10.2009 NOAA 17 1-2-3-4-5 HRPT
INDIANOC 16:53:24 - 11.10.2009 NOAA 17 1-2-3-4-5 HRPT
OMAN-LEO 16:53:24 - 11.10.2009 NOAA 17 1-2-3-4-5 HRPT
OMAN 16:53:24 - 11.10.2009 NOAA 17 1-2-3-4-5 HRPT
OMAN-LEO 14:31:10 - 11.10.2009 NOAA 16 1-2-3-4-5 HRPT
OMAN 14:31:10 - 11.10.2009 NOAA 16 1-2-3-4-5 HRPT
ARABIAN 13:25:14 - 11.10.2009 NOAA 15 1-2-3-4-5 HRPT
OMAN-LEO 13:25:14 - 11.10.2009 NOAA 15 1-2-3-4-5 HRPT
ARABIAN 12:16:28 - 11.10.2009 FY-1D 1-2-3-4-5-6-7-8-9-10 HRPT
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OMAN-LEO 12:16:28 - 11.10.2009 FY-1D 1-2-3-4-5-6-7-8-9-10 HRPT
OMAN 12:16:28 - 11.10.2009 FY-1D 1-2-3-4-5-6-7-8-9-10 HRPT
INDIANOC 11:44:38 - 11.10.2009 NOAA 15 1-2-3-4-5 HRPT
OMAN-LEO 11:44:38 - 11.10.2009 NOAA 15 1-2-3-4-5 HRPT
OMAN 11:44:38 - 11.10.2009 NOAA 15 1-2-3-4-5 HRPT
ARABIAN 9:27:59 - 11.10.2009 NOAA 19 1-2-3-4-5 HRPT
INDIANOC 9:27:59 - 11.10.2009 NOAA 19 1-2-3-4-5 HRPT
OMAN-LEO 9:27:59 - 11.10.2009 NOAA 19 1-2-3-4-5 HRPT
OMAN 9:27:59 - 11.10.2009 NOAA 19 1-2-3-4-5 HRPT
OMAN-LEO 9:23:31 - 11.10.2009 NOAA 18 1-2-3-4-5 HRPT
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INDIANOC 5:42:13 - 11.10.2009 NOAA 17 1-2-3-4-5 HRPT
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HRPT
Subformat:
ALL
Default channel:
1-2-3-4-5-6-7-8-9-10
OK
Cancel
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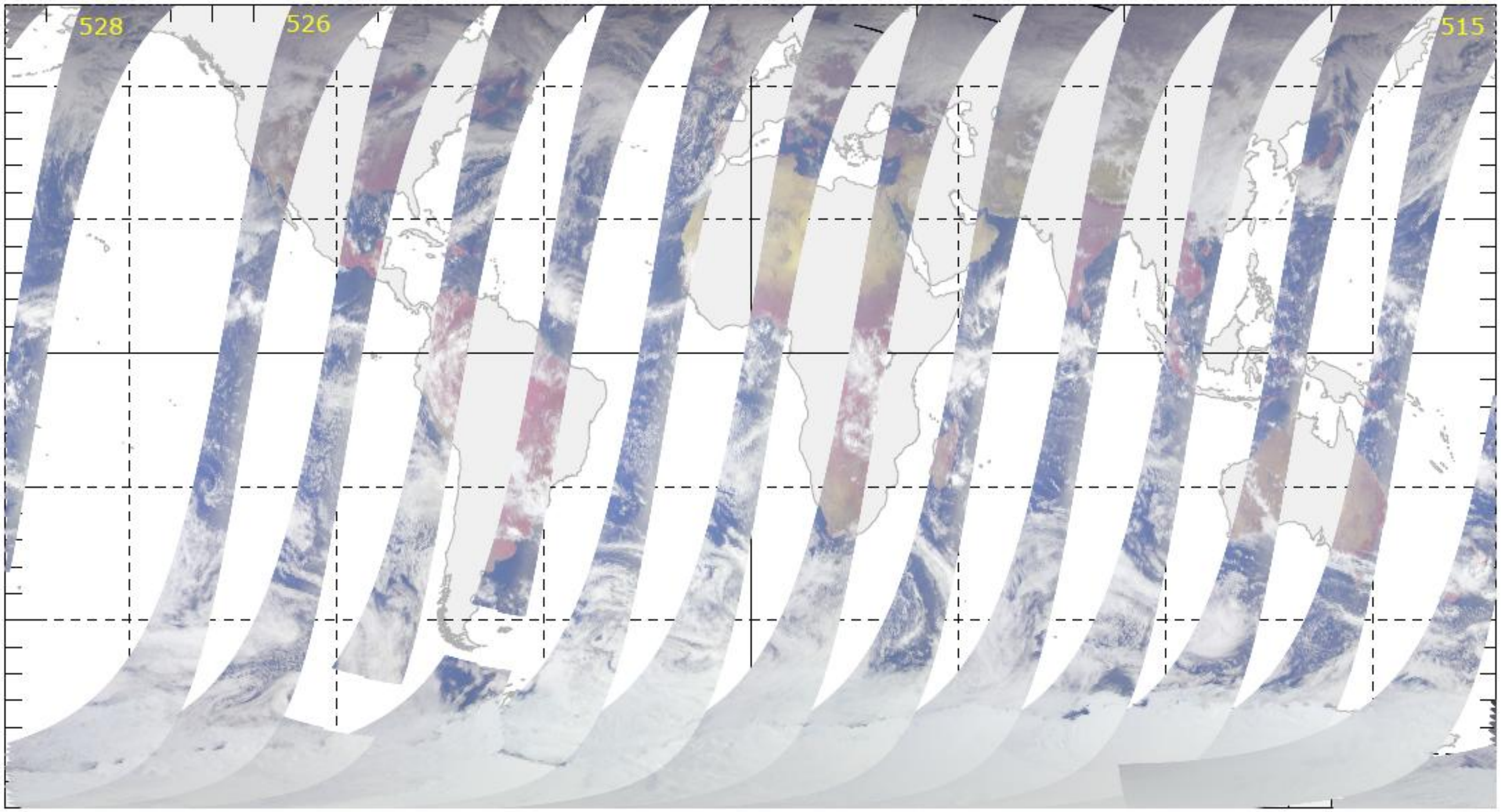
02-Feb-10

Polar Satellites

GOME-2 PMD p+s RGB 24/25 Nov 2006 (960 km swath)



Geo Synchronized VS Polar Orbital satellites

Geo Synchronized Orbit Advantages:

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

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

- Only one ground station needed for satellite monitoring.

Geostationary VS Polar Orbital

Geo Synchronized 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.

Geostationary VS Polar Orbital

Polar Orbit Advantages:

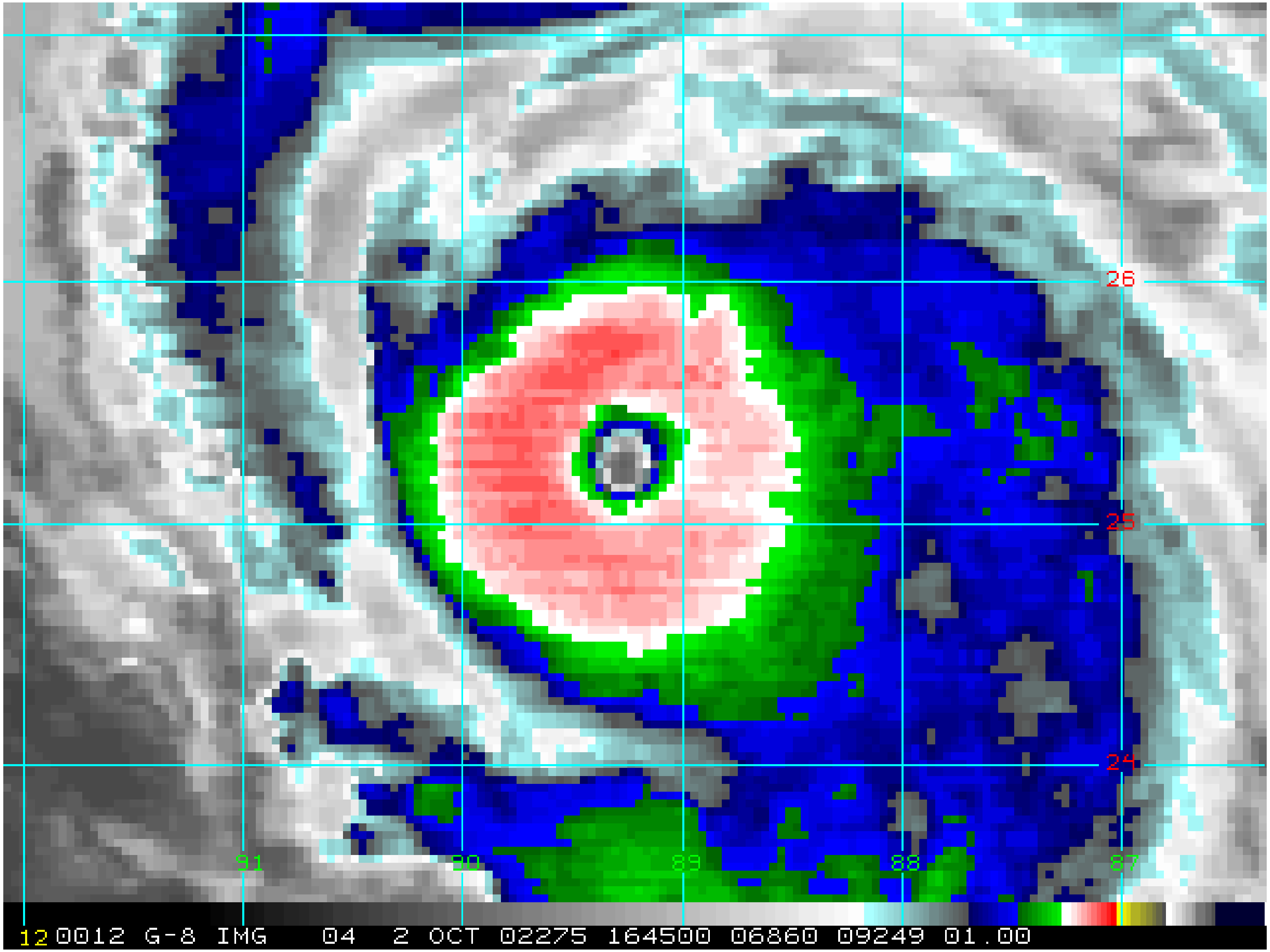
- Global coverage.
- Good ground resolution because of low orbit.
- Sun-synchronism produces consistent illumination conditions for observed surfaces, with only seasonal changes.
- A solar energy supply is ensured by sun-synchronism, although the supply changes around the orbit.

Geostationary VS Polar Orbital

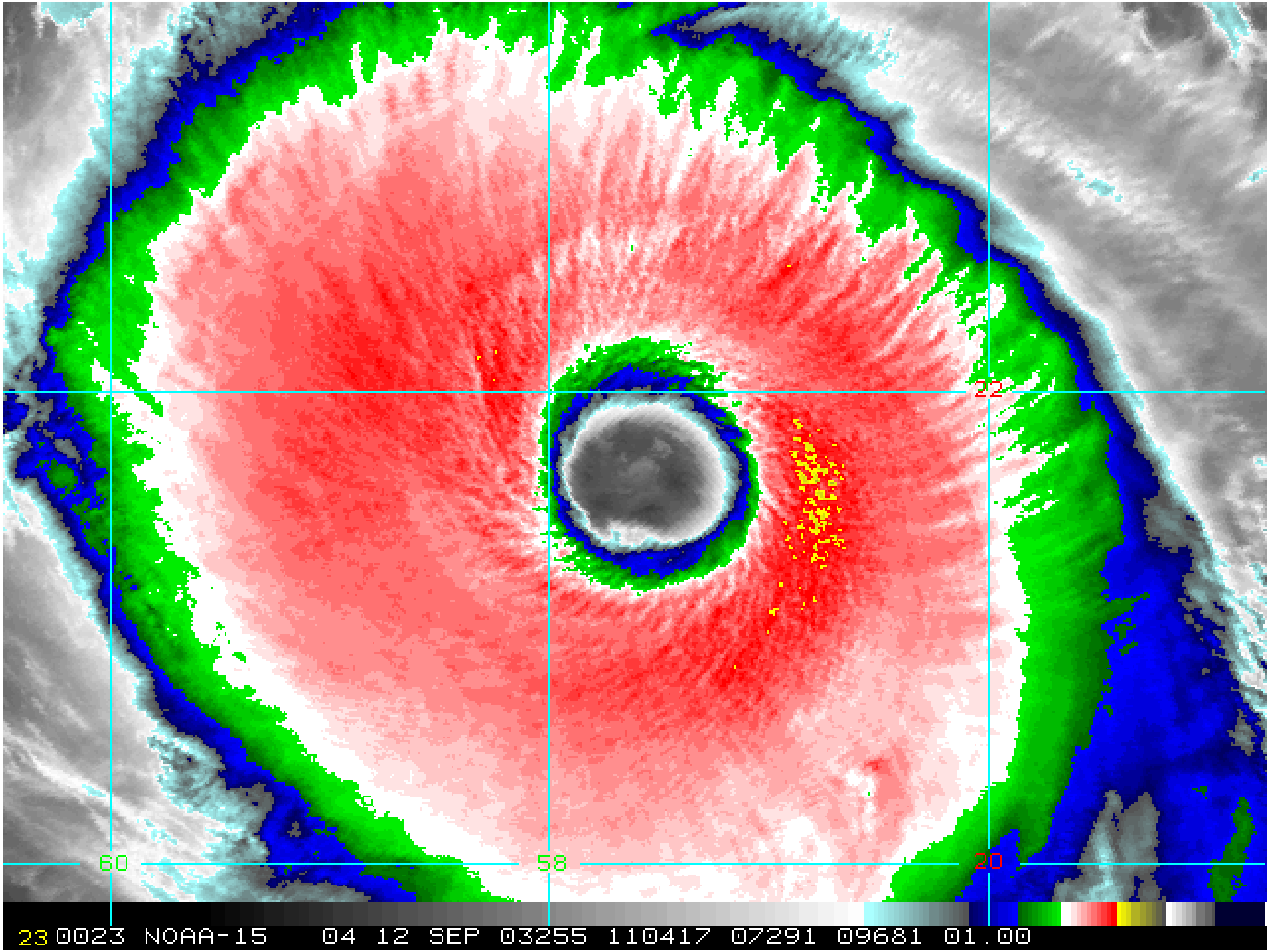
Polar Orbit Disadvantages:

- Continuous observation of every point by one satellite is not possible. Each point on Earth's surface is observed at best every orbit (100 minutes) for polar regions, at worst twice per day for equatorial regions. Multi-satellite systems solve this problem.

- Continuous satellite monitoring would require several ground stations.



26
25
24
91
90
89
88
87
12 0012 G-8 IMG 04 2 OCT 02275 164500 06860 09249 01.00

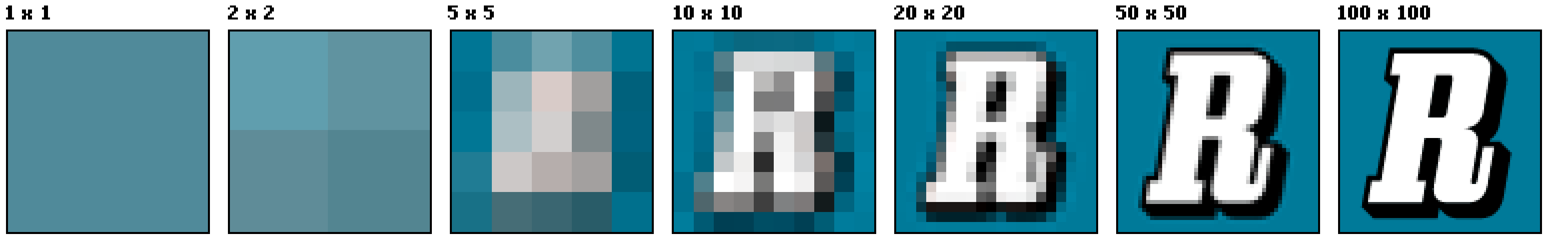


22
60
58
20
23 0023 NOAA-15 04 12 SEP 03255 110417 07291 09681 01.00

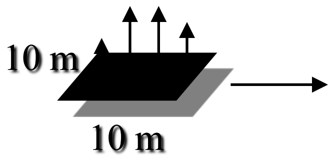
Satellites resolutions

Digital Image resolution

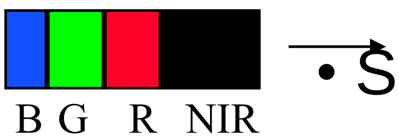
number of Pixels



Satellite Resolutions – Definitions

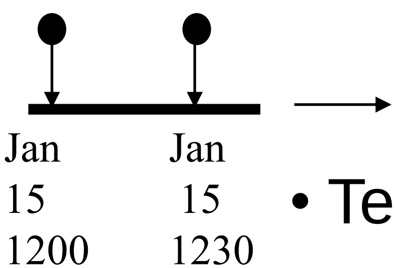


•Spatial - the size of pixel represented in the field-of-view, e.g. 10 x 10 m.



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

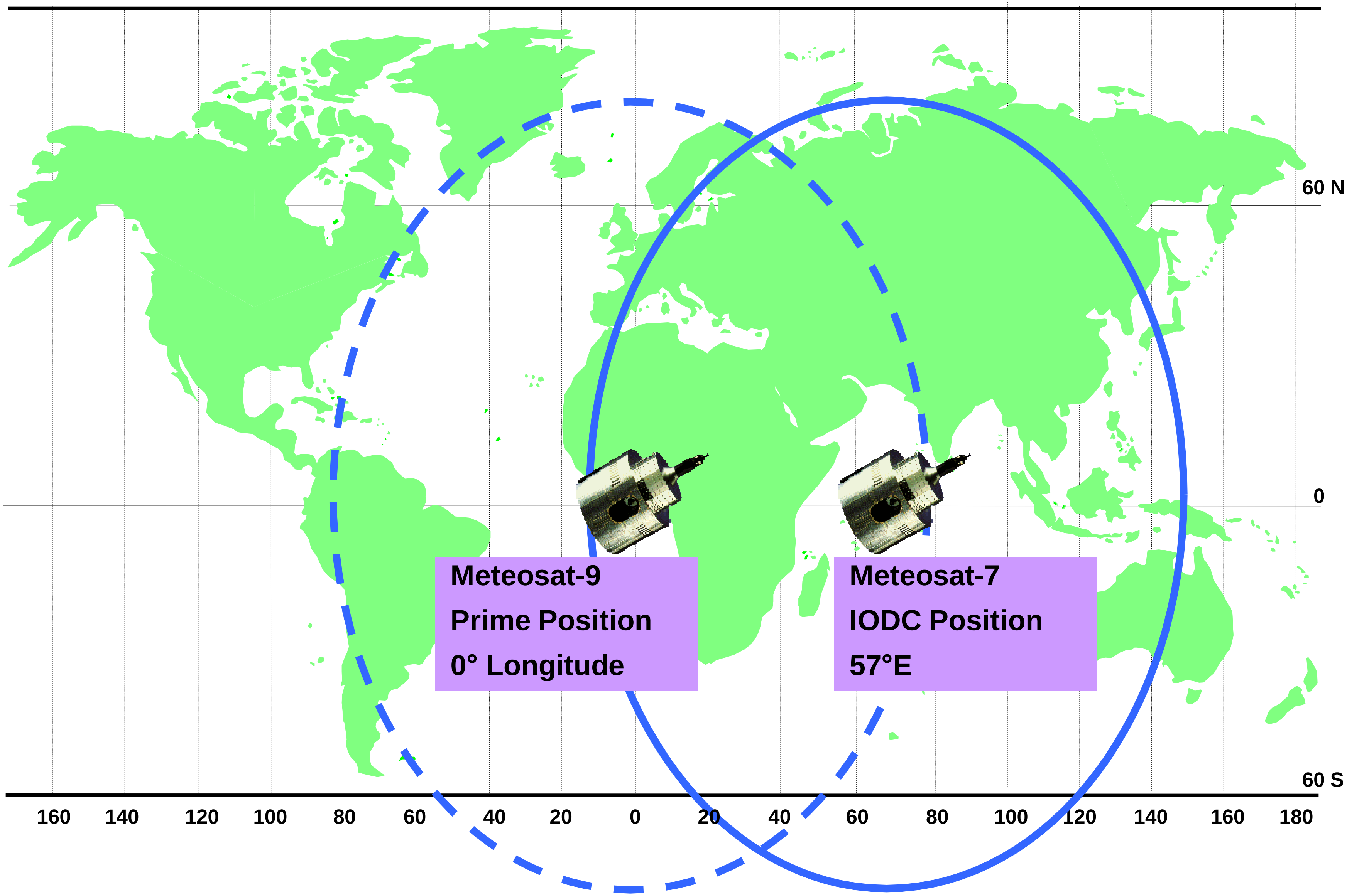
• Radiometric - the sensitivity of detectors to small differences in electromagnetic energy.



• Temporal - how often the sensor acquires data, e.g. every 30 minutes.

Meteosat Series

Meteosat Series



EUMETSAT

Meteosat Series

- Operational history Meteosat First Generation:
- Meteosat-1 1977-October 1979 *
- Meteosat-2 1981-1991
- Meteosat-3 1988-1995
- Meteosat-4 1989-1995
- Meteosat-5 1991-2007
- Meteosat-6 1993-2006
- Meteosat-7 1997-2013

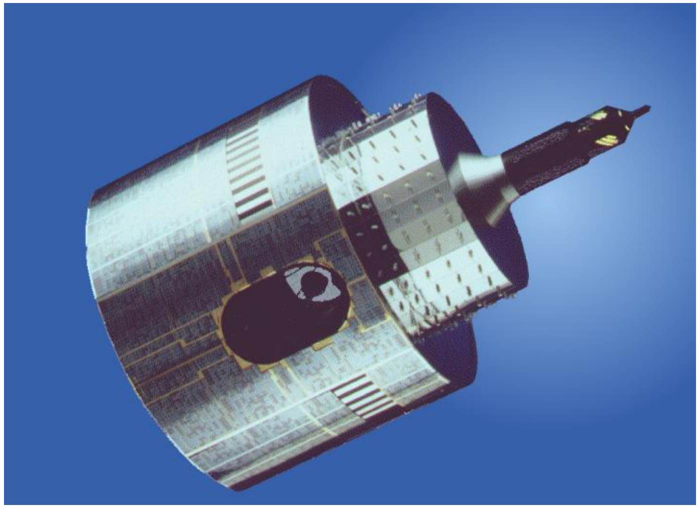
* Due to a radiometer problem the imaging stopped and the satellite was only used for data dissemination

Meteosat Series

Operational history of Meteosat Second Generation :

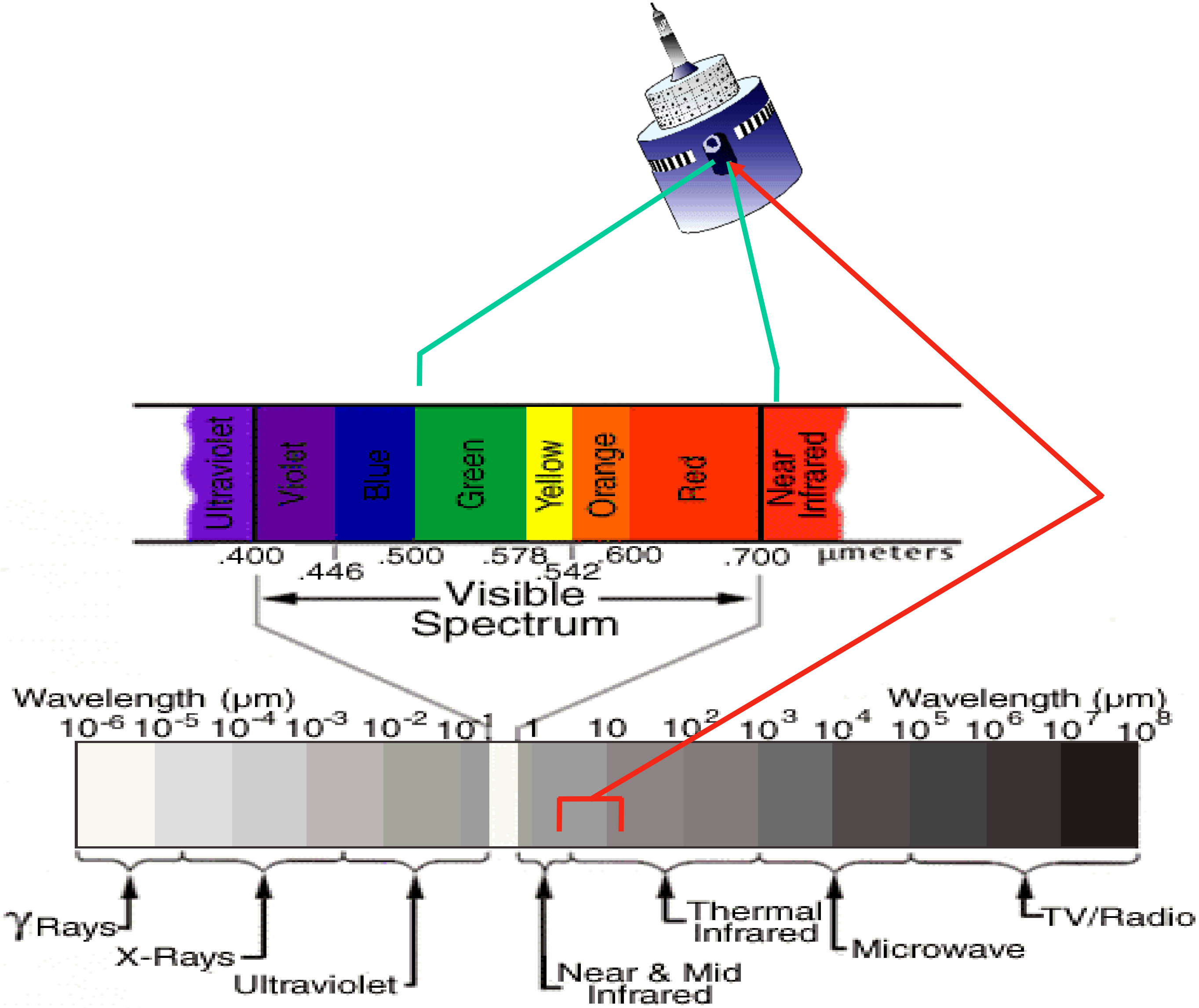
- Meteosat-8 2003-2006   (MSG-1)
- Meteosat-9 2006- 2014 (MSG-2)

METEOSAT-1 to 7
Meteosat First Generation (MFG)

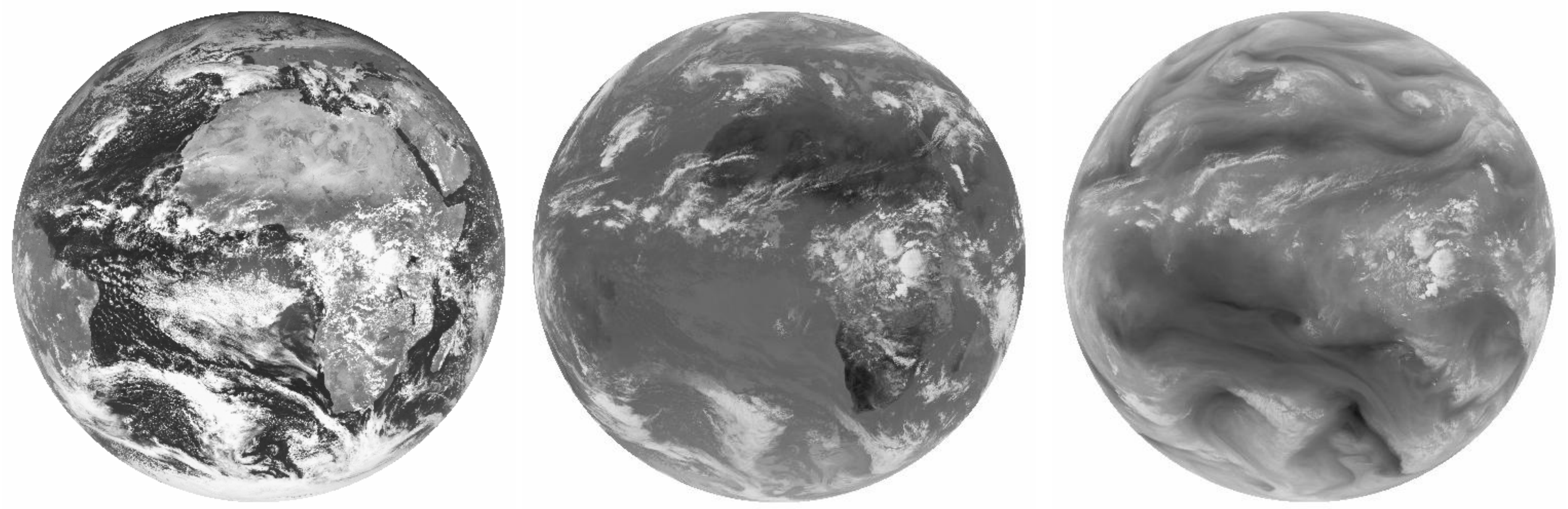


- Vis & IR Imager
- 3 Spectral Channels
- Images every 30 Minutes
- 5 km horizontal ‘Sampling Distance’
- VIS-Channel 2.5 km

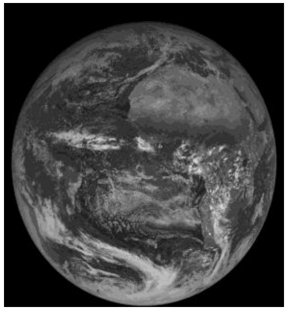
Channels of First Generation METEOSAT



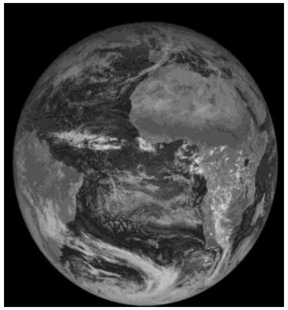
VIS, IR & WV channels
of Meteosat First Generation



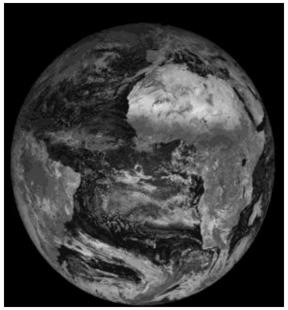
Met-8 First Image on 28 November 2002



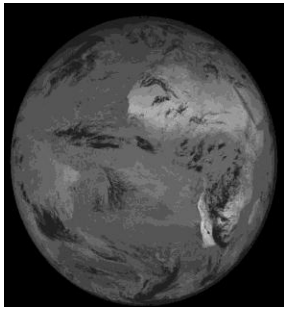
VIS 0.6



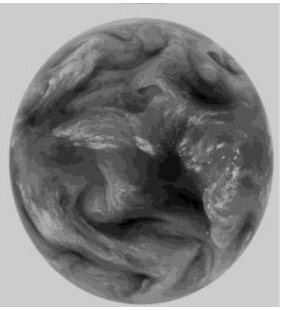
VIS 0.8



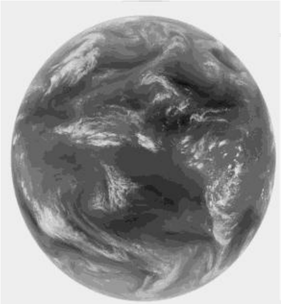
NIR 1.6



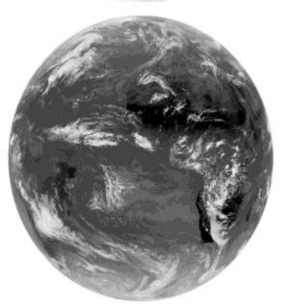
NIR 3.9



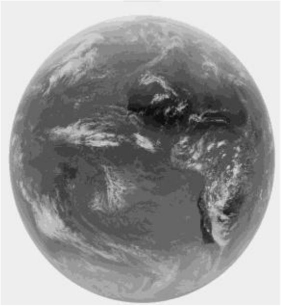
WV 6.2



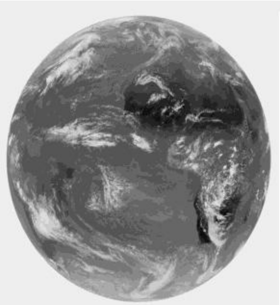
WV 7.3



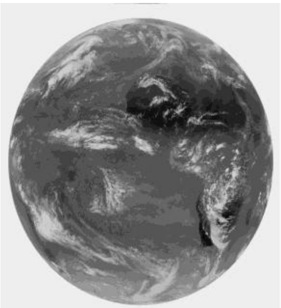
IR 8.7



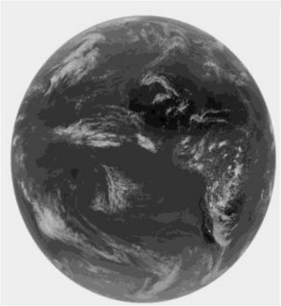
IR 9.7



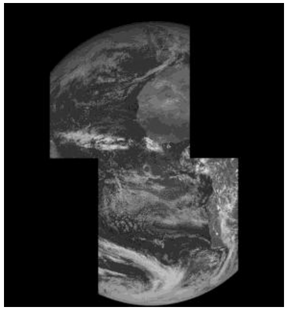
IR 10.8



IR 12.0



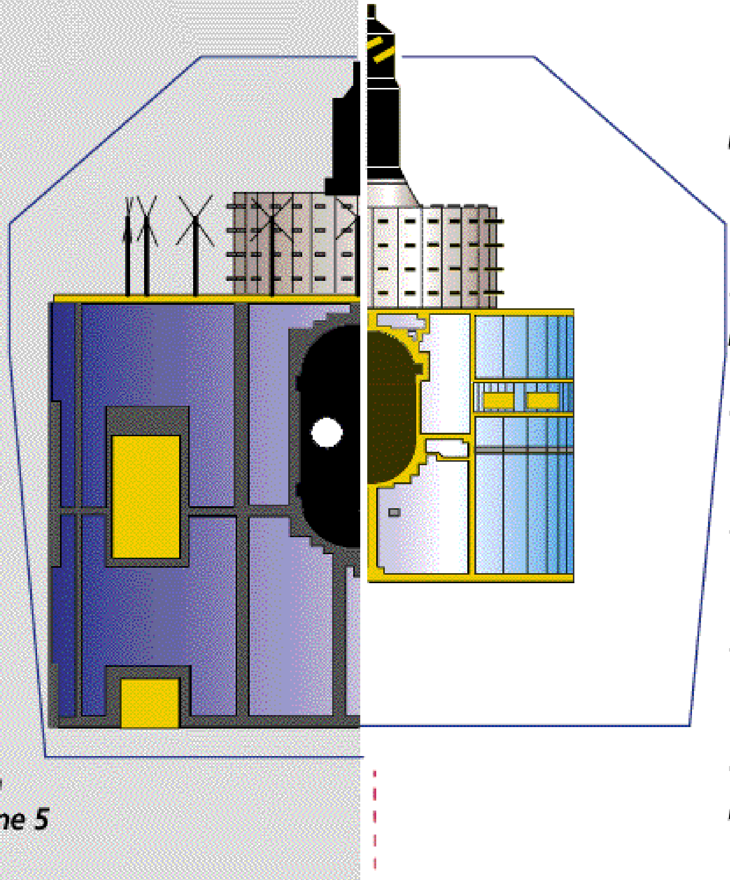
IR 13.4



HRVIS

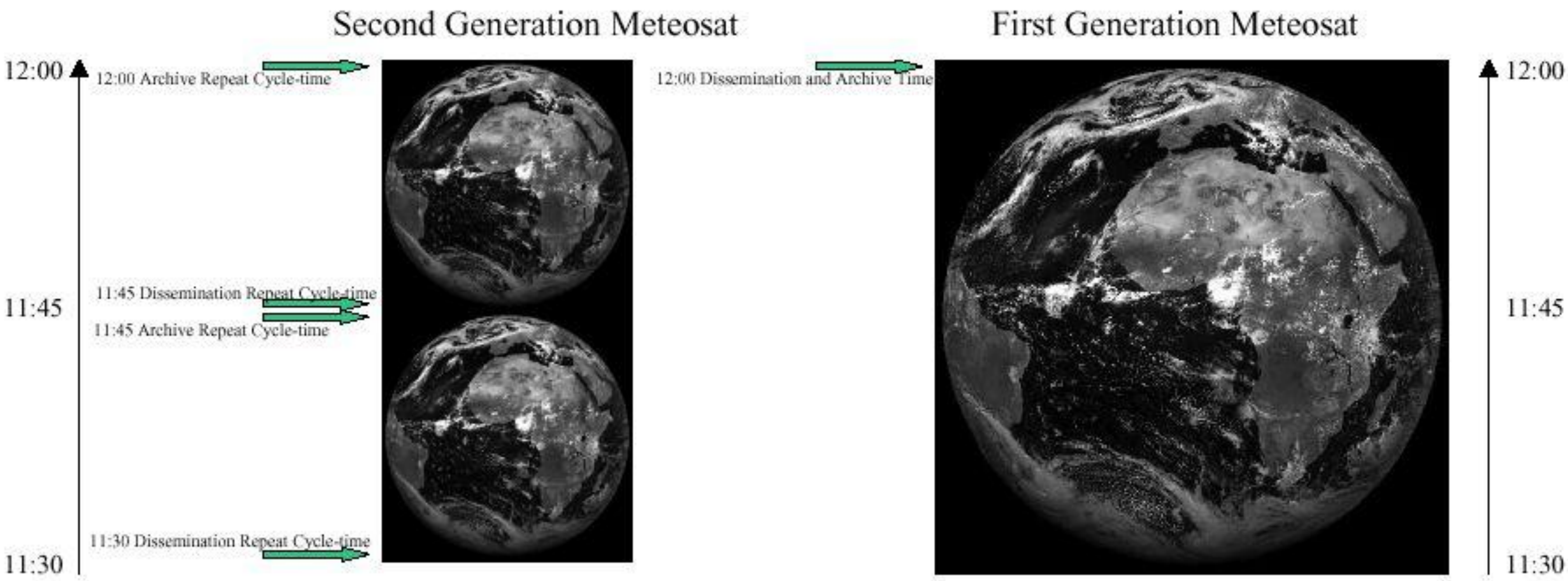
Comparison: MSG - MFG

- 12 channels enhanced imaging and pseudo sounding radiometer.
- 100 rpm spin stabilized body
- Bi-propellant unified propulsion system
- 500W power demand
- 2000kg in GTO
- Design compatibility with Ariane 4 (spelda 10) & Ariane 5



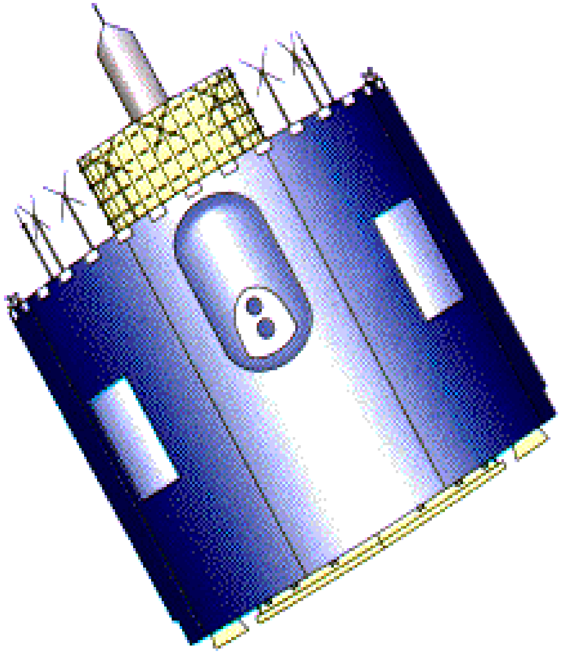
- 3 channels imaging radiometer
- 100 rpm spin stabilized body
- Solid apogee boost motor
- 200W power demand
- 720 kg in GTO
- Flight qualified with Delta 2914, Ariane 1-3-4

Comparison: Time Stamping of MFG and MSG Image Data



Differences in the time stamping between first and second generation Meteosat satellite data

Meteosat Second Generation (MSG)



- Spinning Enhanced VIS & IR Imager
- 12 spectral Channels
- Images every 15 minutes
- 11 channels with

  3 km horizontal ‘sampling distance’ at Sub-Satellite Point (SSP)
- High-resolution VIS-Channel

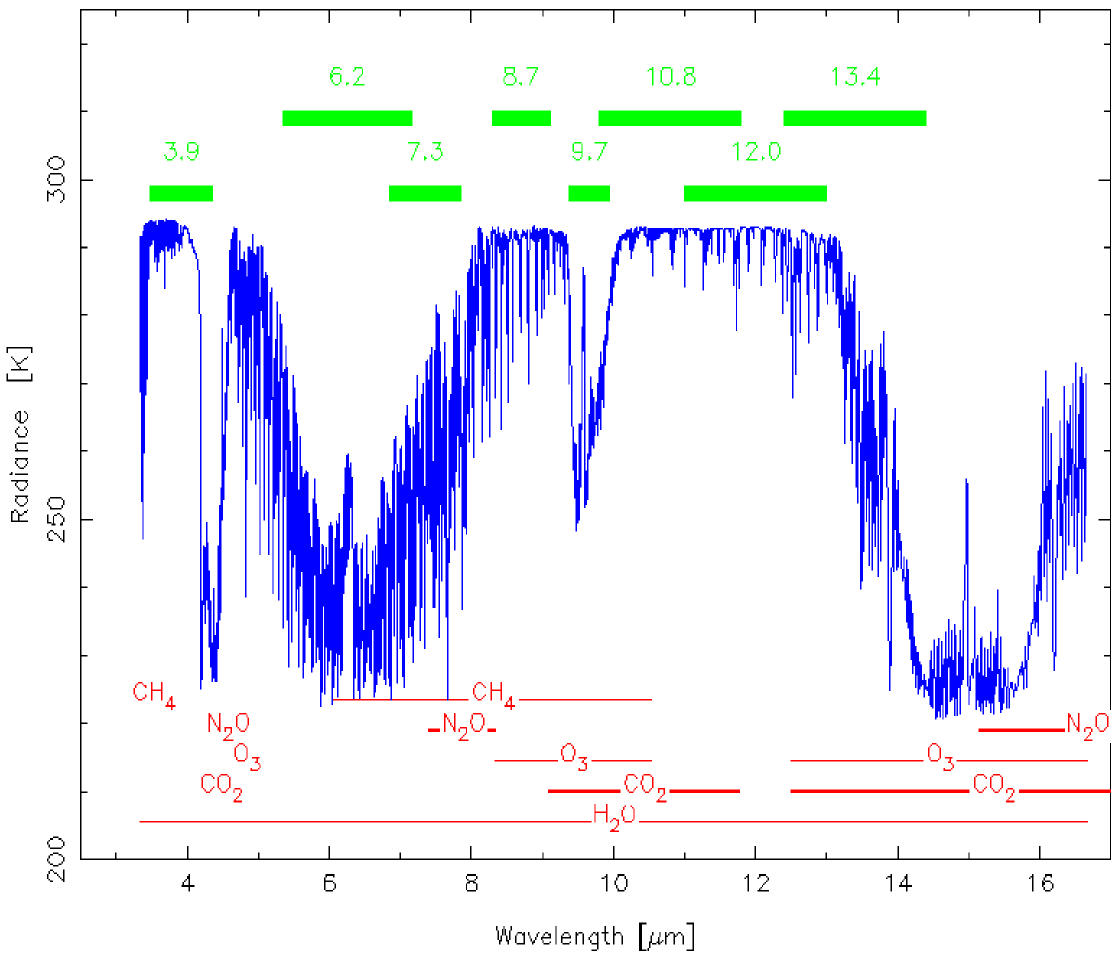
  1 km sampling distance (SSP)

MSG SEVIRI CHANNELS

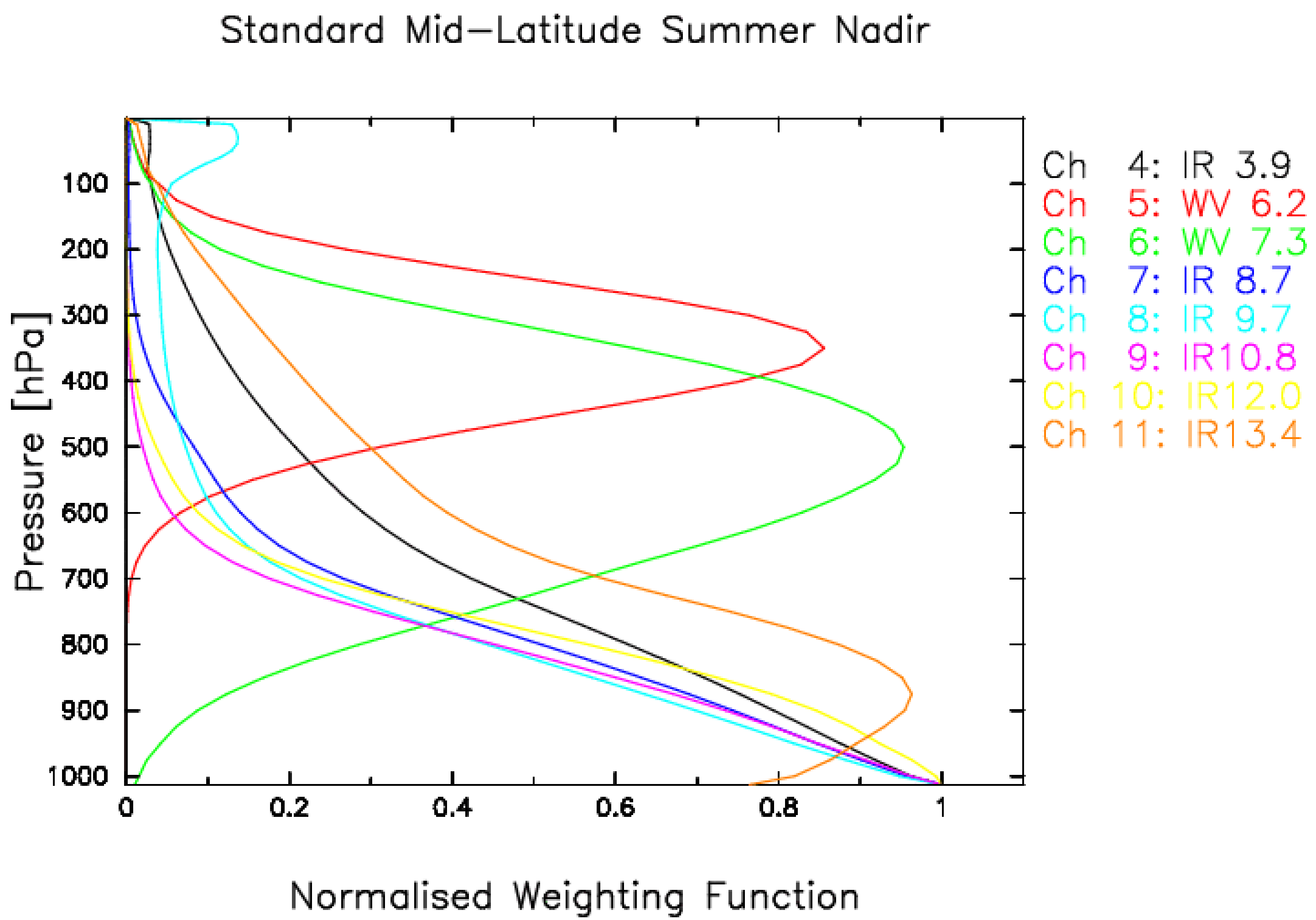
Basic + Airmass + High-resolution VIS Missions

Window	Band (µm)	Absorption	Band (µm)
VIS 0.6	0.56 - 0.71	H_2O 6.2	5.35 - 7.15
VIS 0.8	0.74 - 0.88	H_2O 7.3	6.85 - 7.85
IR 1.6	1.50 - 1.78	O_3 9.7	9.38 - 9.94
IR 3.9	3.48 - 4.36	CO_2 13.4	12.40 - 14.40
IR 8.7	8.30 - 9.10		
IR 10.8	9.80 - 11.80	High Res VIS	1km Sampling
IR 12.0	11.00 - 13.00	HRV	0.4 - 1.1

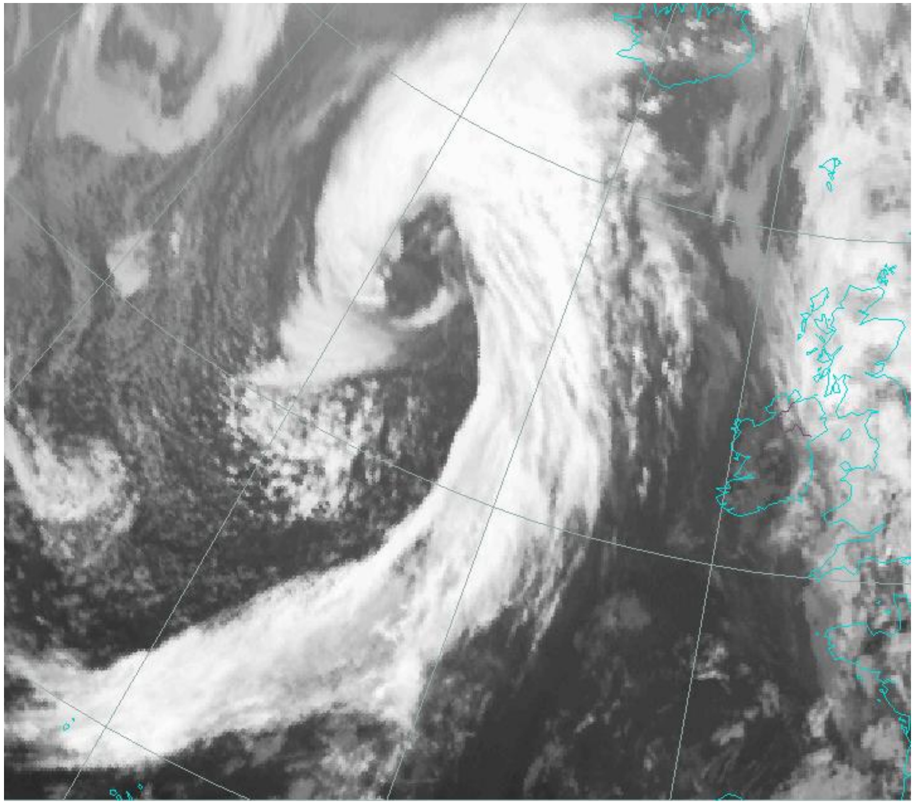
SEVIRI IR Channels



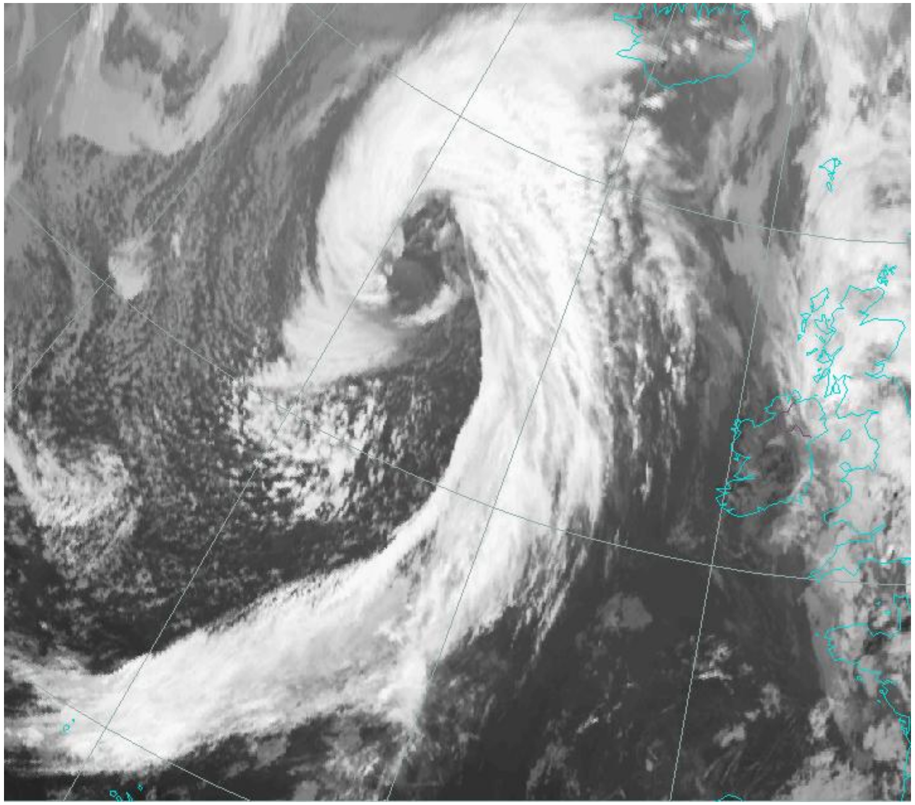
Contribution Functions



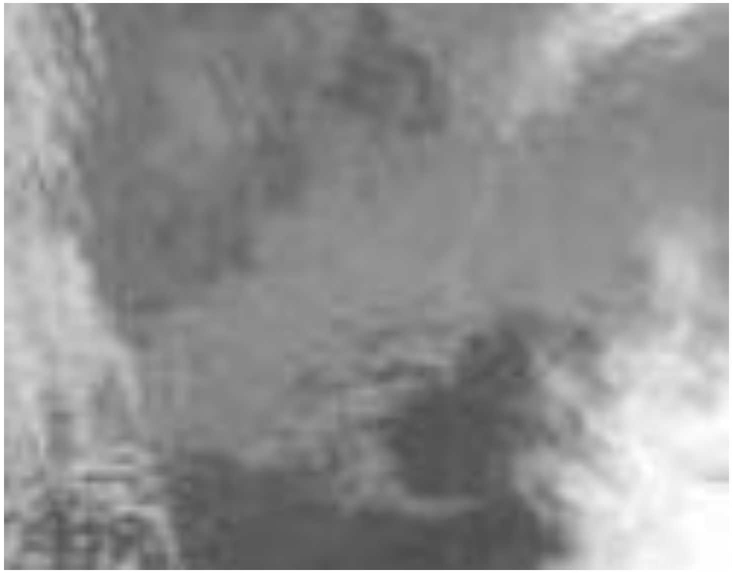
MSG: IMPROVED SPATIAL SAMPLING
(Example: 13 October 2003, 12:15 UTC)



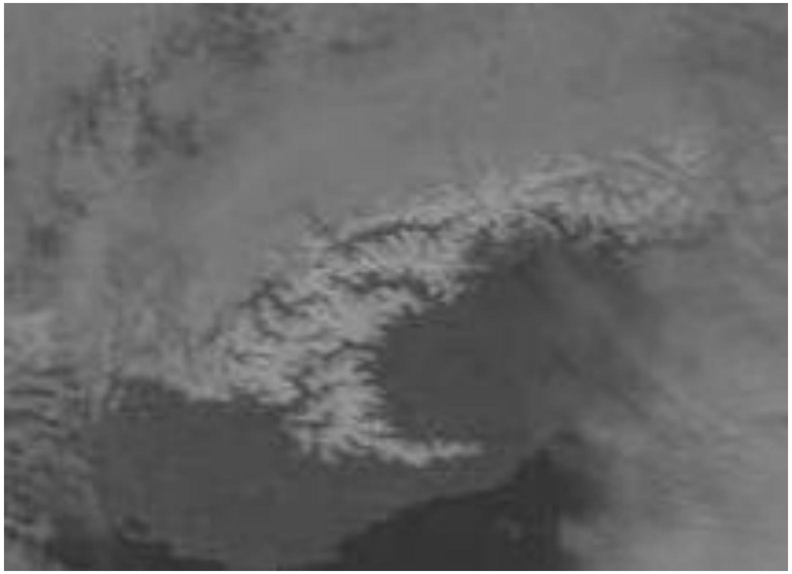
MFG IR Channel 5 km



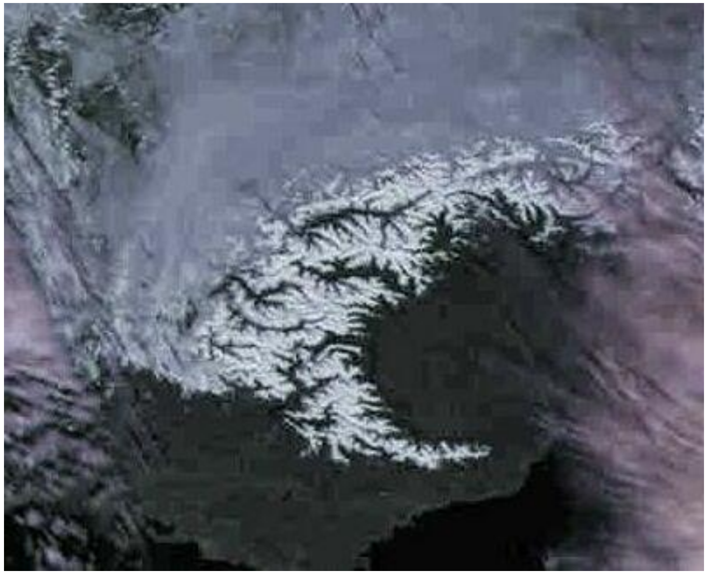
MSG IR10.8 Channel 3 km



MFG IR Channel ~ 5 km



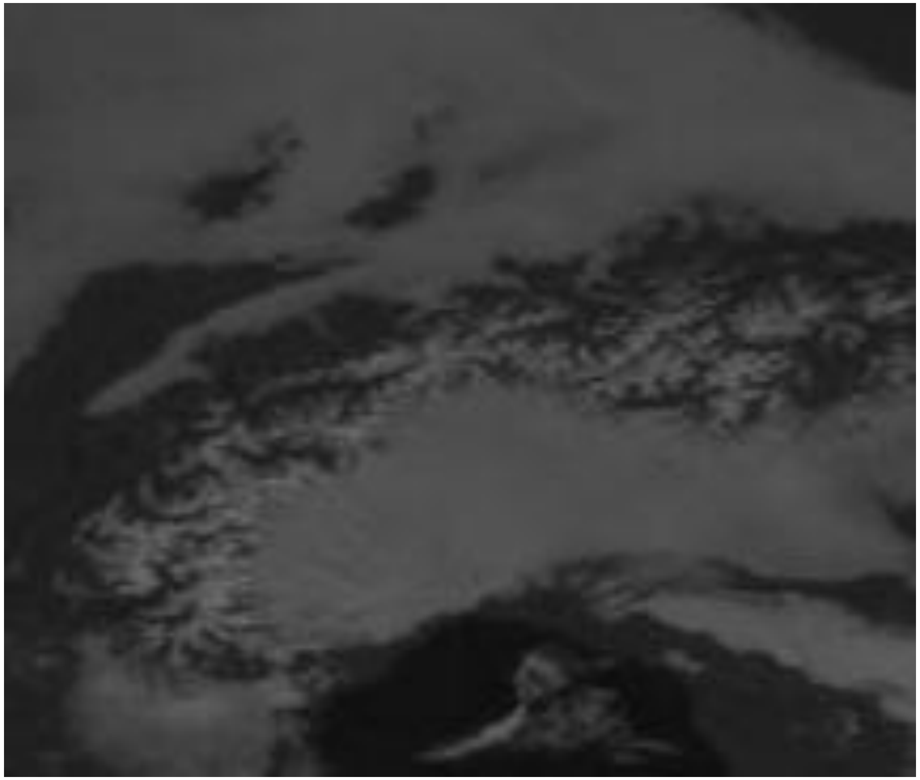
MFG VIS Channel ~ 2.5 km



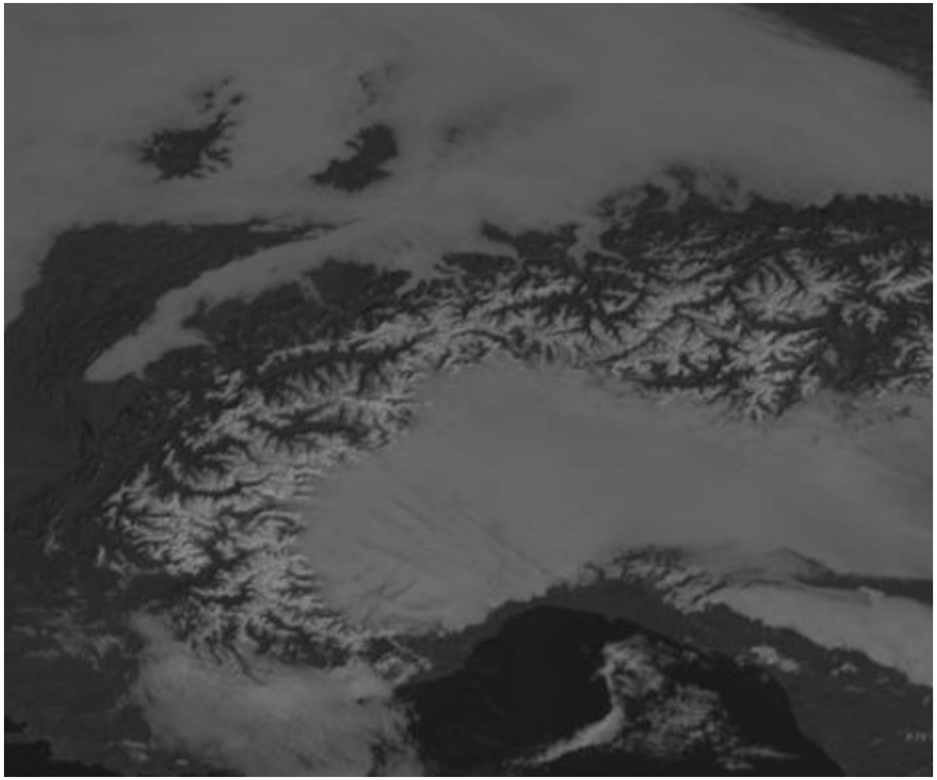
MSG HRV channel ~ 1 km

MSG: IMPROVED SPATIAL SAMPLING
(Example: 4 December 2002, 12:30 UTC)

MSG: IMPROVED SPATIAL SAMPLING
(Example: 11 November 2003, 11:00 UTC)

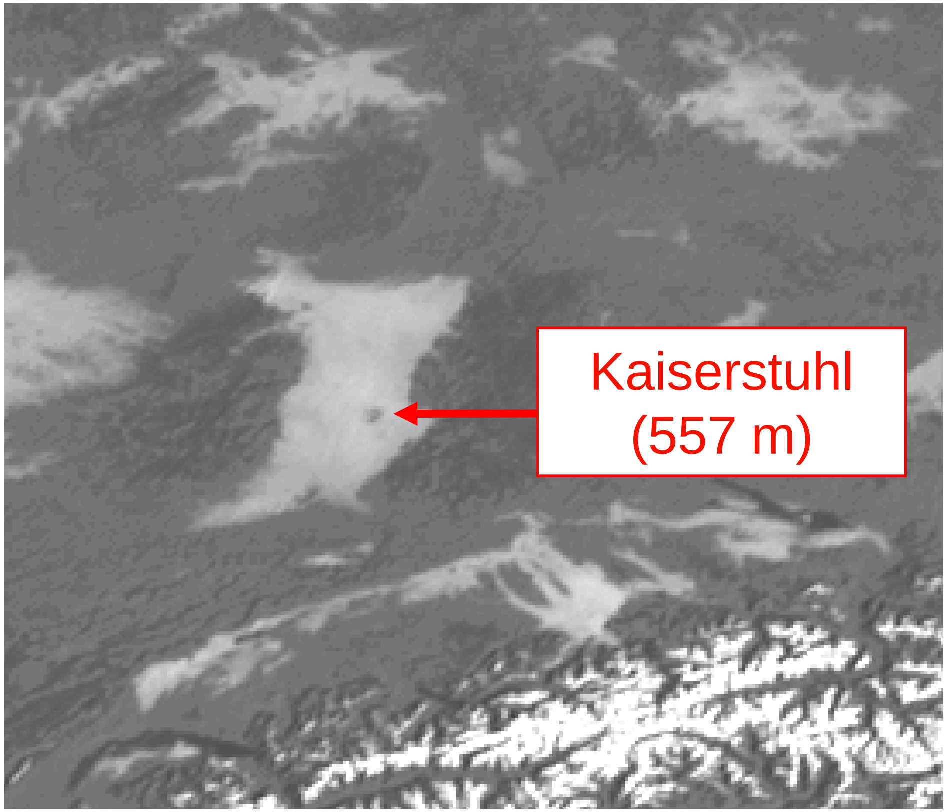


MFG VIS Channel 2.5 km



MSG HRVIS Channel 1 km

MSG: IMPROVED SPATIAL SAMPLING
(Example: 5 November 2003)



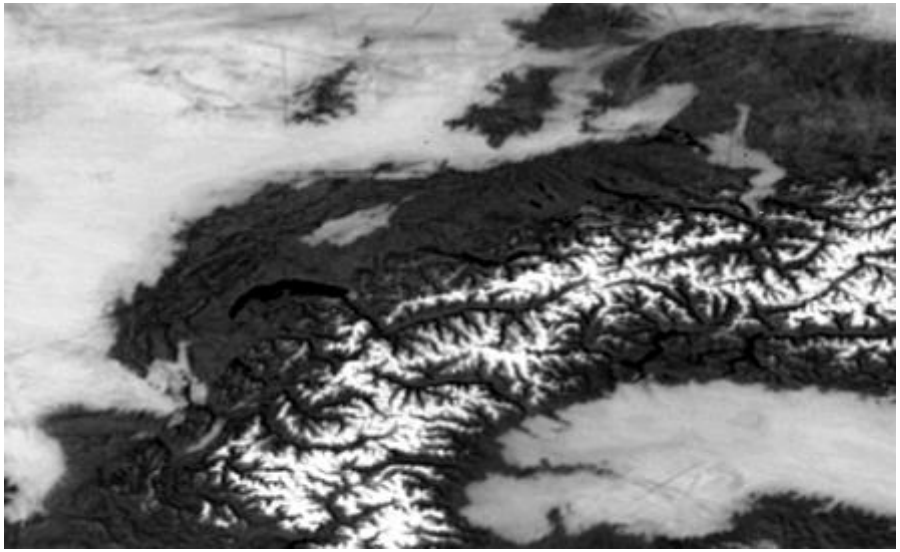
MFG VIS Channel 2.5 km

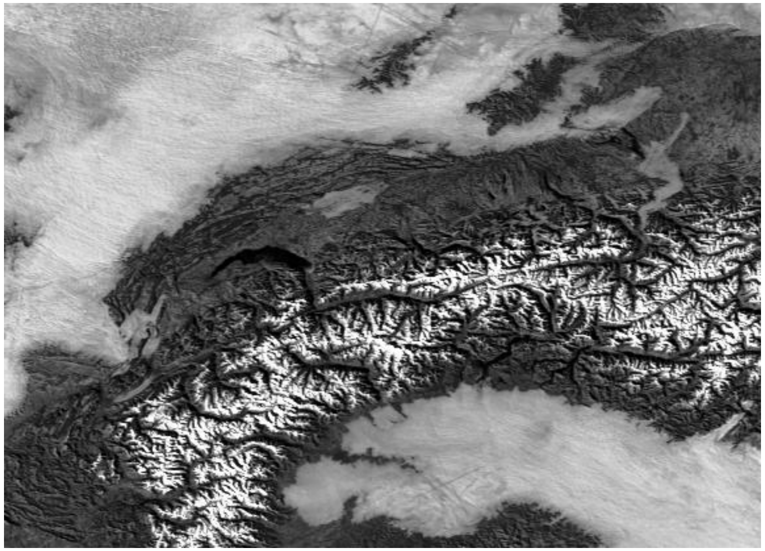
MSG HRVIS Channel 1 km

08:00 UTC

08:45 UTC

IMPROVED SPATIAL SAMPLING
- MSG-1 HRVIS vs NOAA-16 AVHRR CH2 -
(Example: 19 November 2003)

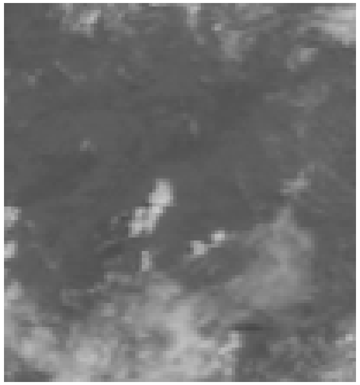




MSG HRVIS Channel, 13:00 UTC

AVHRR Channel 2, 13:02 UTC

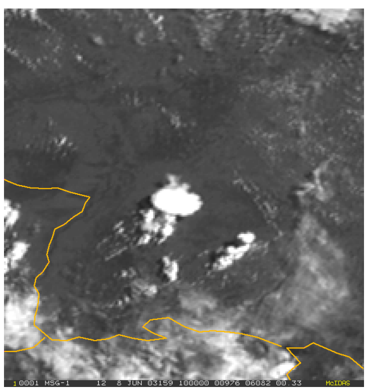
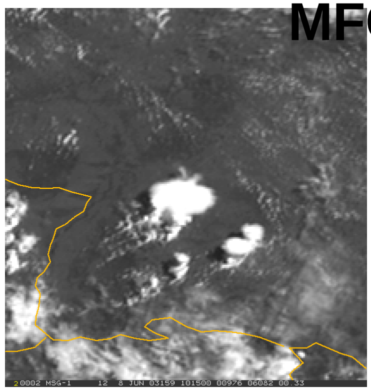
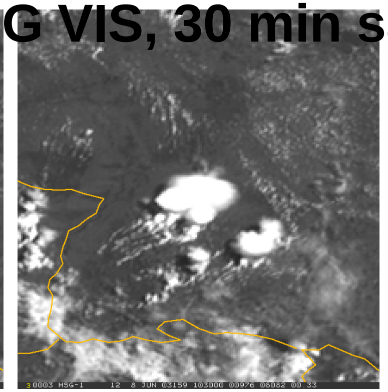
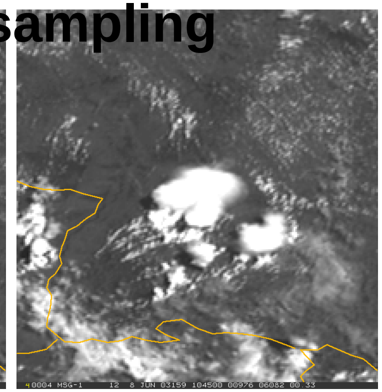
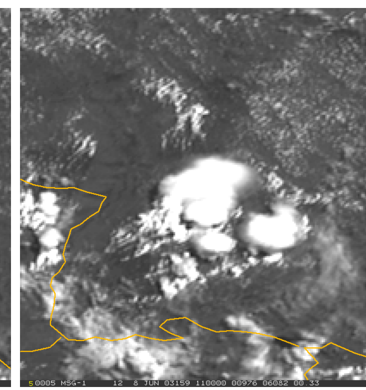
MSG: IMPROVED TIME SAMPLING
(Example: 8 June 2003)



10:00 **10:30**

11:00

MFG VIS, 30 min sampling

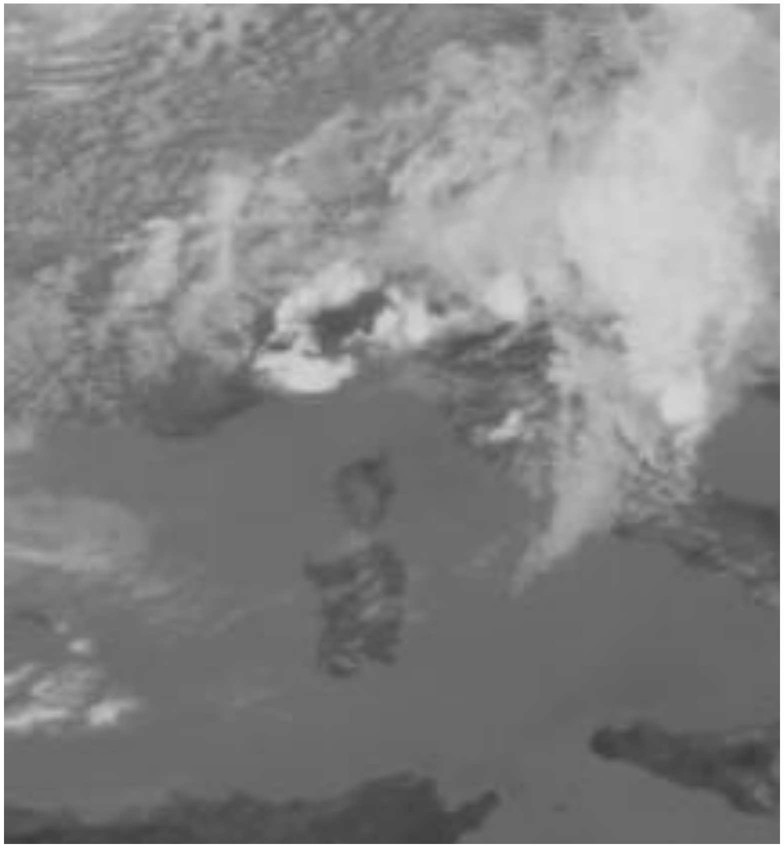






10:00 **10:15** **10:30** **10:45**

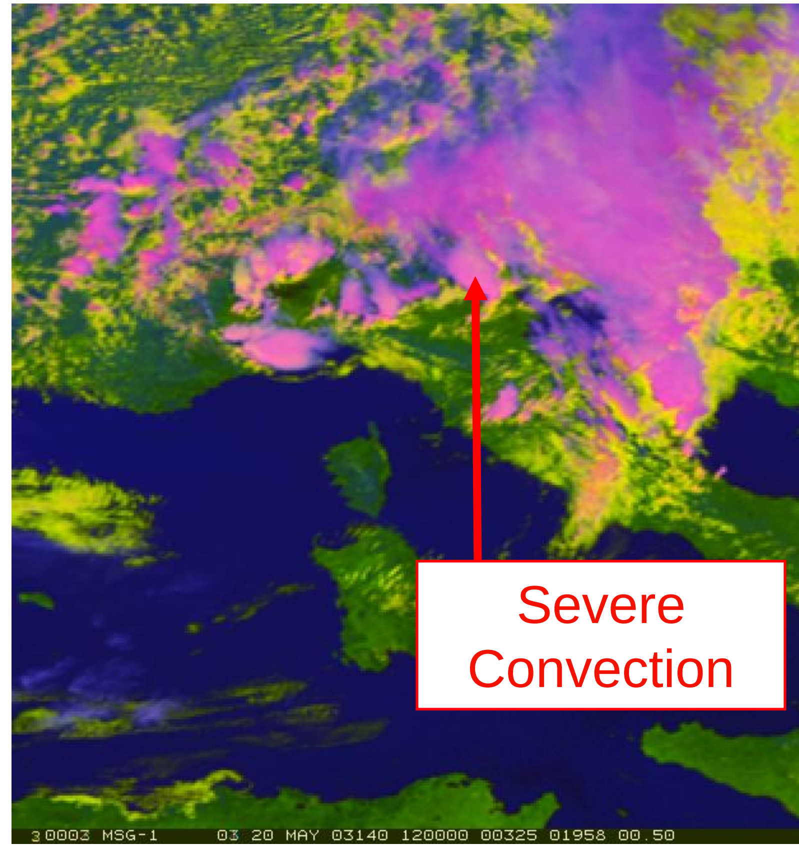
11:00

MSG HRVIS, 15 min sampling

MSG: IMPROVED SPECTRAL SAMPLING
(Example: 20 May 2003, 12:00 UTC)

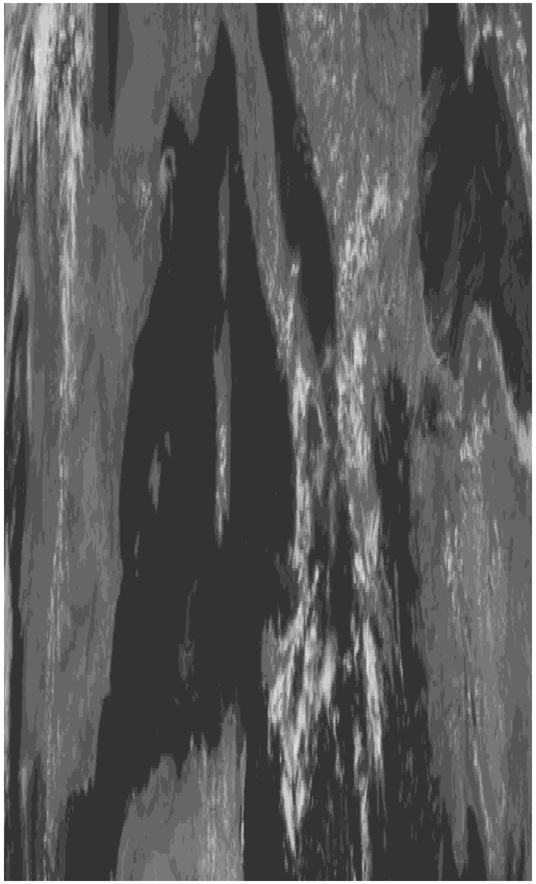


MFG IR Channel



MSG RGB Composite (R=01, G=03, B=04i)

MSG: IMPROVED SPECTRAL SAMPLING
(Example: 3 August 2003, 12:00 UTC)

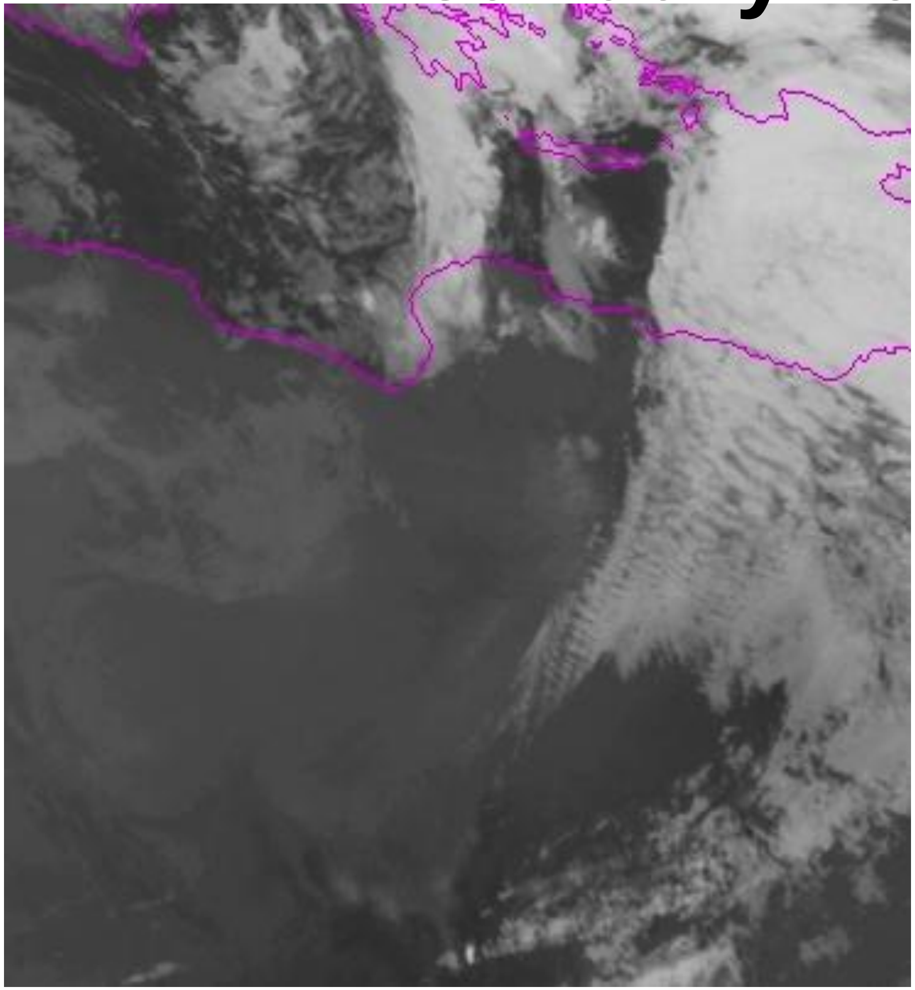


MFG VIS Channel

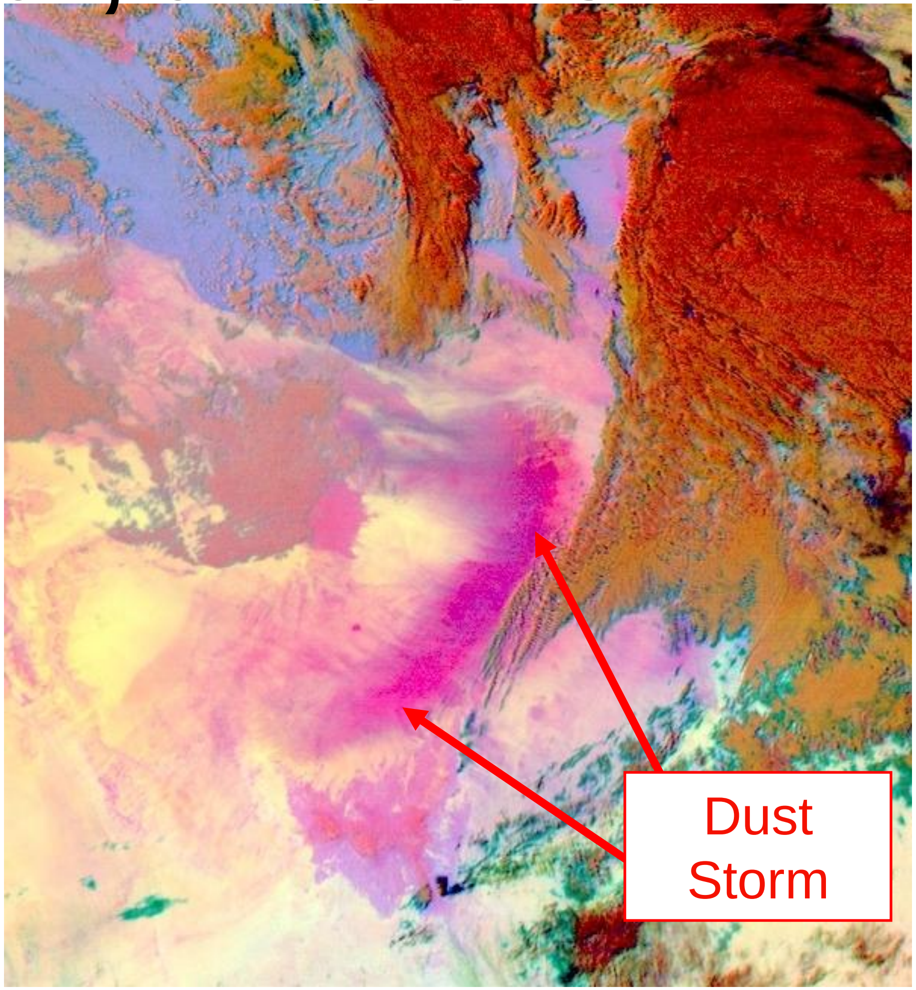
MSG RGB Composite (R=03, G=02, B=01)

Dust Storm, Egypt

22 January 2004, 02:00 UTC



MFG IR Channel i



MSG RGB Composite
IR12.0-IR10.8, IR10.8-IR8.7,

The Following Slides ….

- … will show full disk views of each channel, providing a general overview

MSG Channel VIS0.6

Land Surface

sun glint

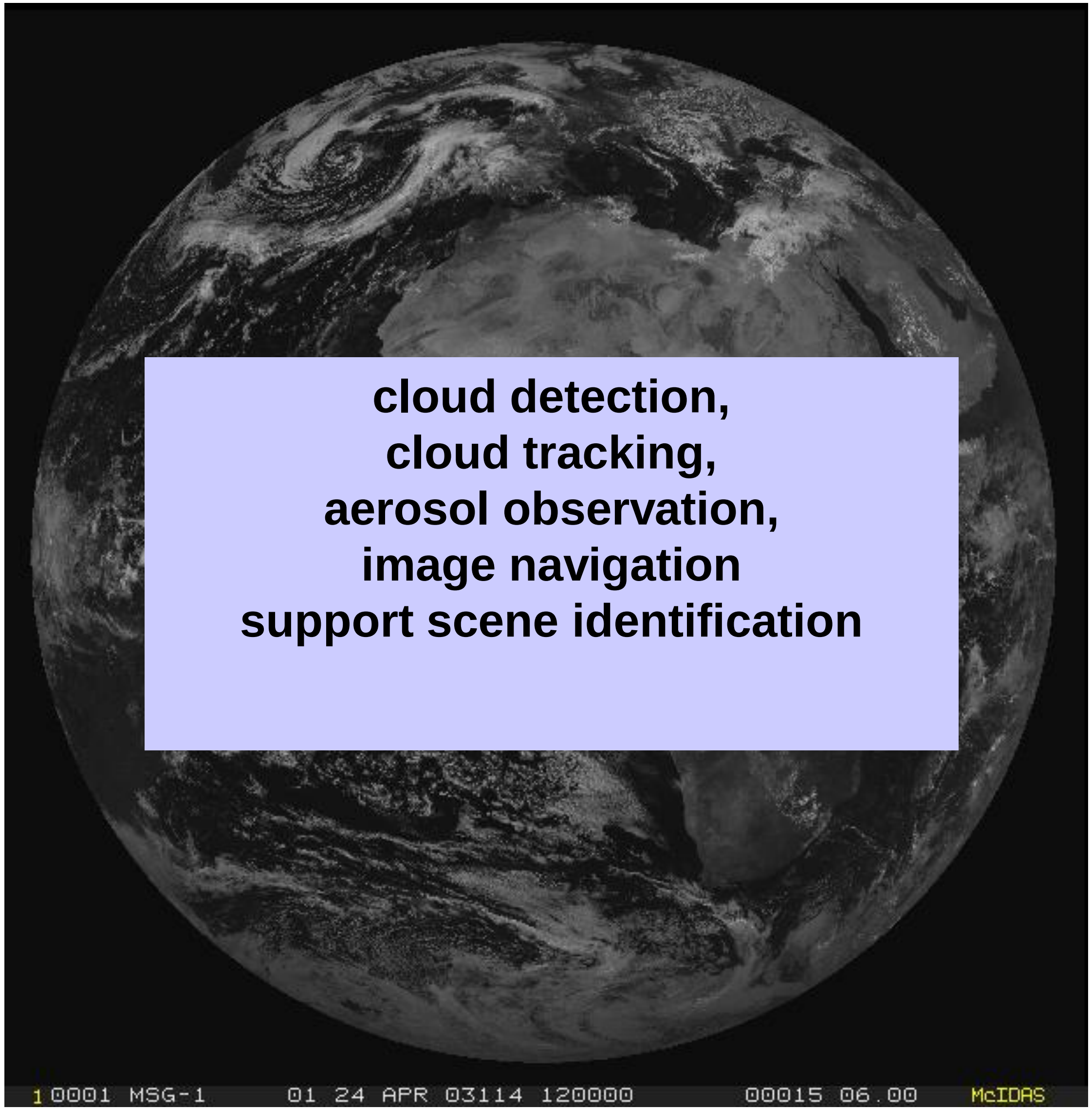
snow

desert

bare soil

forest

sea



cloud detection,
cloud tracking,
aerosol observation,
image navigation
support scene identification

Clouds

high reflectance

thick clouds

thin clouds over land

thin clouds over sea

low reflectance

MSG Channel VIS0.8

Land Surface

sun glint

snow

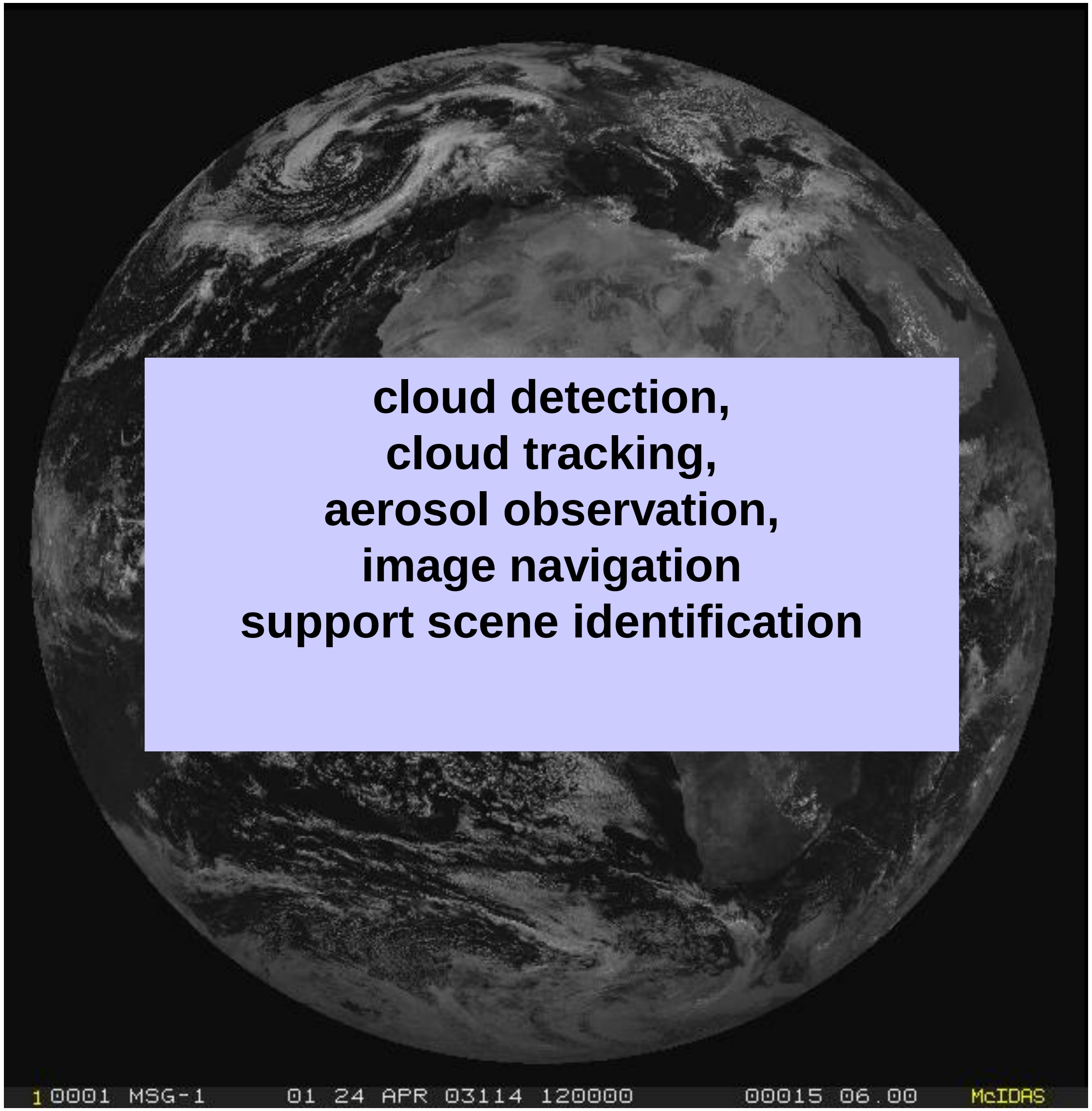
desert

grass etc.

forest

bare soil

sea



cloud detection,
cloud tracking,
aerosol observation,
image navigation
support scene identification

Clouds

high reflectance

thick clouds

thin clouds over land

thin clouds over sea

low reflectance

MSG Channel NIR1.6

Land Surface

sun glint

desert

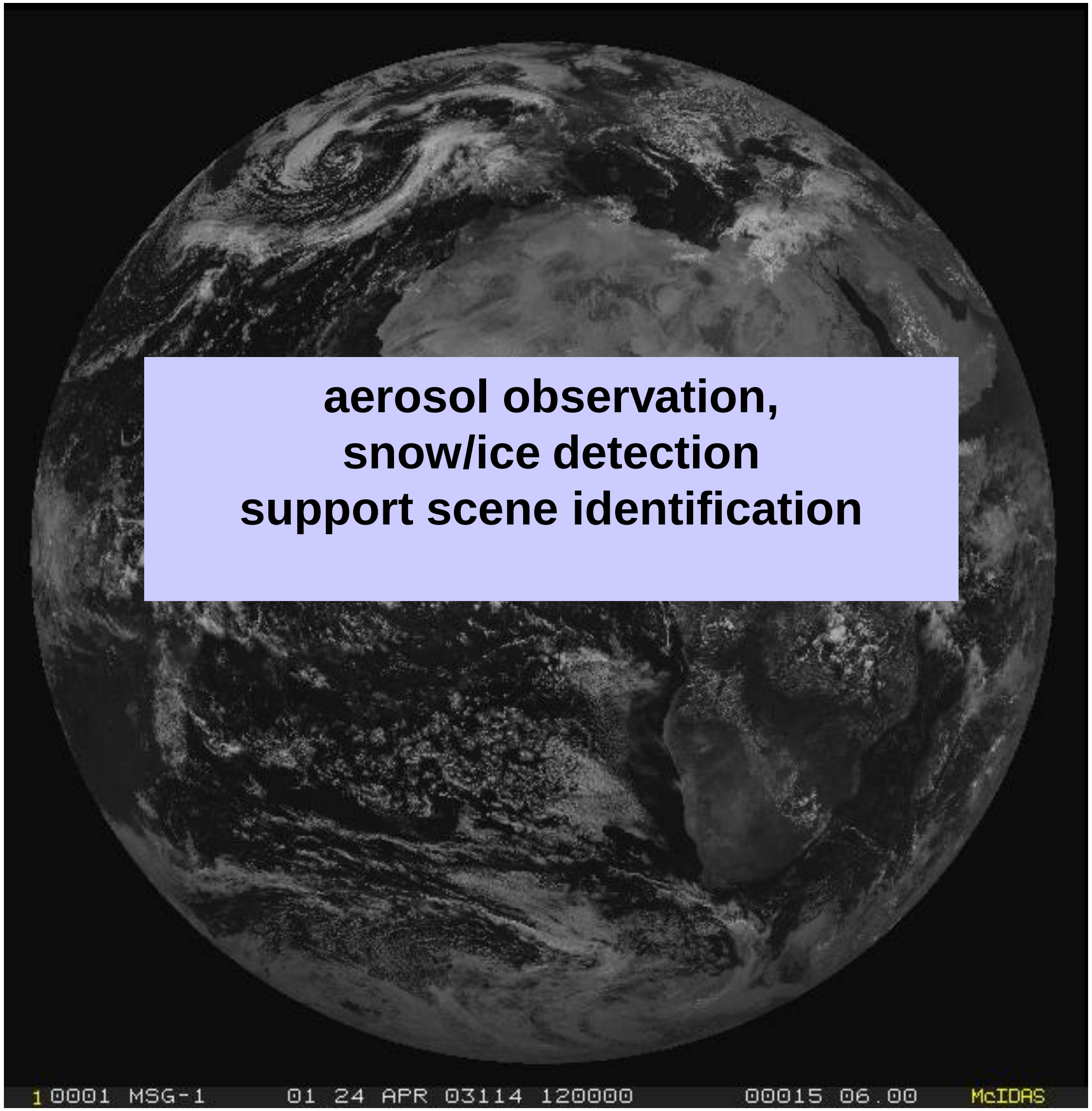
grass etc.

forest

bare soil

snow

sea



aerosol observation,
snow/ice detection
support scene identification

Clouds

high reflectance

water clouds with small droplets

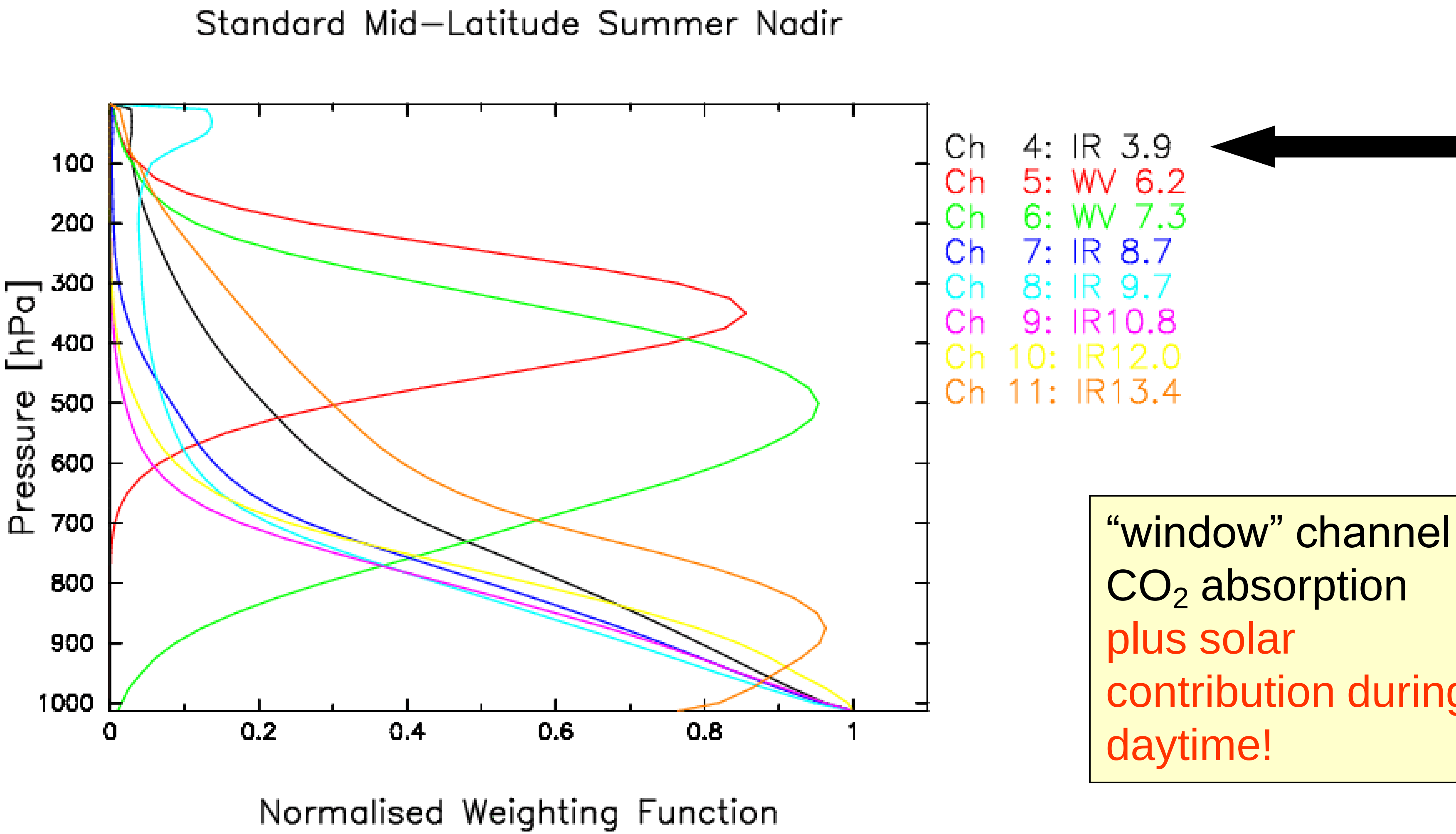
water clouds with large droplets

ice clouds with small particles

ice clouds with large particles

low reflectance

Contribution Function



"window" channel
CO_2 absorption
plus solar contribution during daytime!

MSG Channel IR3.9 Day

Land Surface

snow

sea

cold land

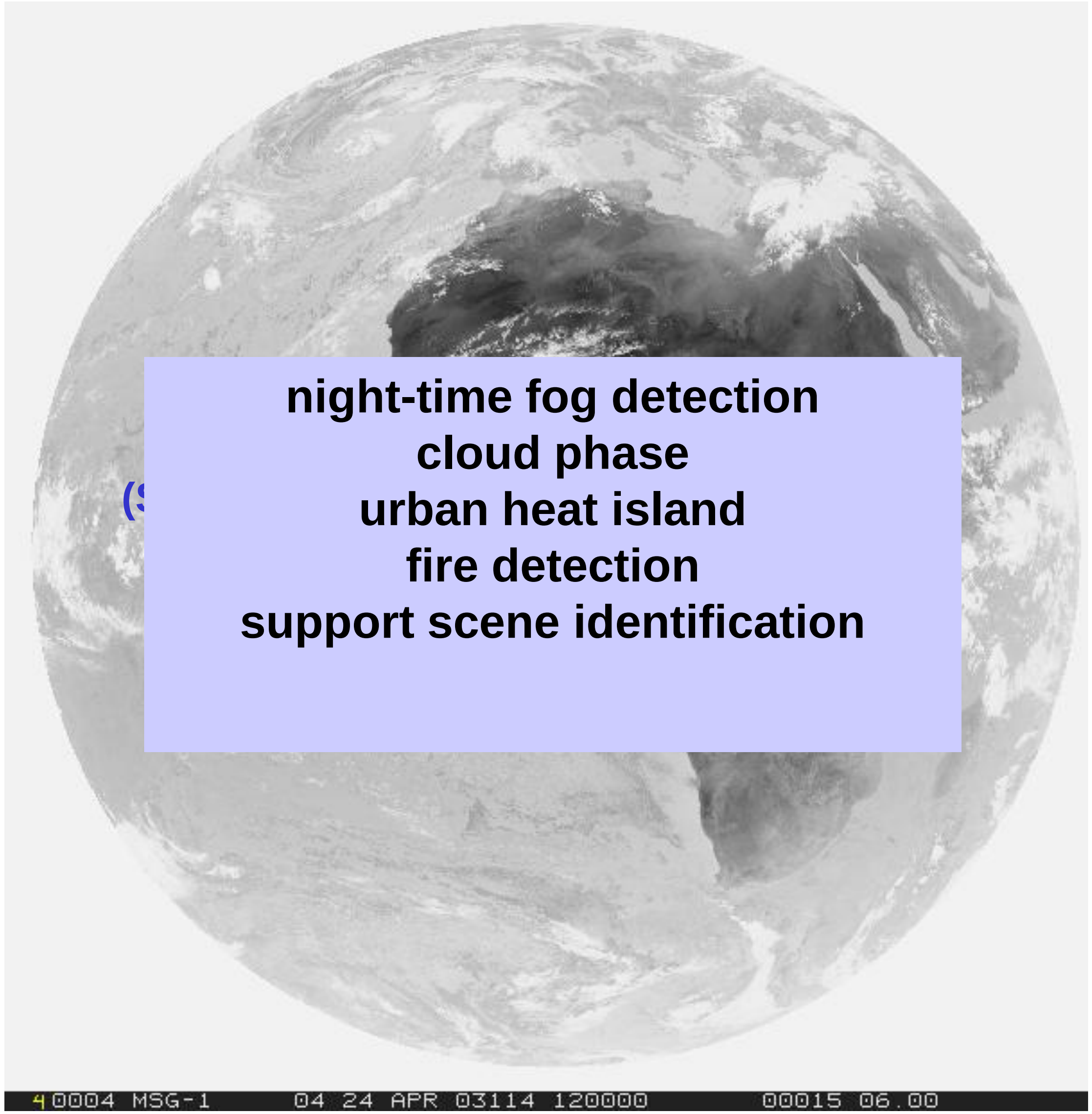
warm tropical areas

forest

hot desert

fires

sun glint



night-time fog detection
cloud phase
urban heat island
fire detection
support scene identification

Clouds

low reflectance/ cold

cold ice clouds

ice clouds with small particles

water clouds over sea

water clouds over land

high reflectance/ warm

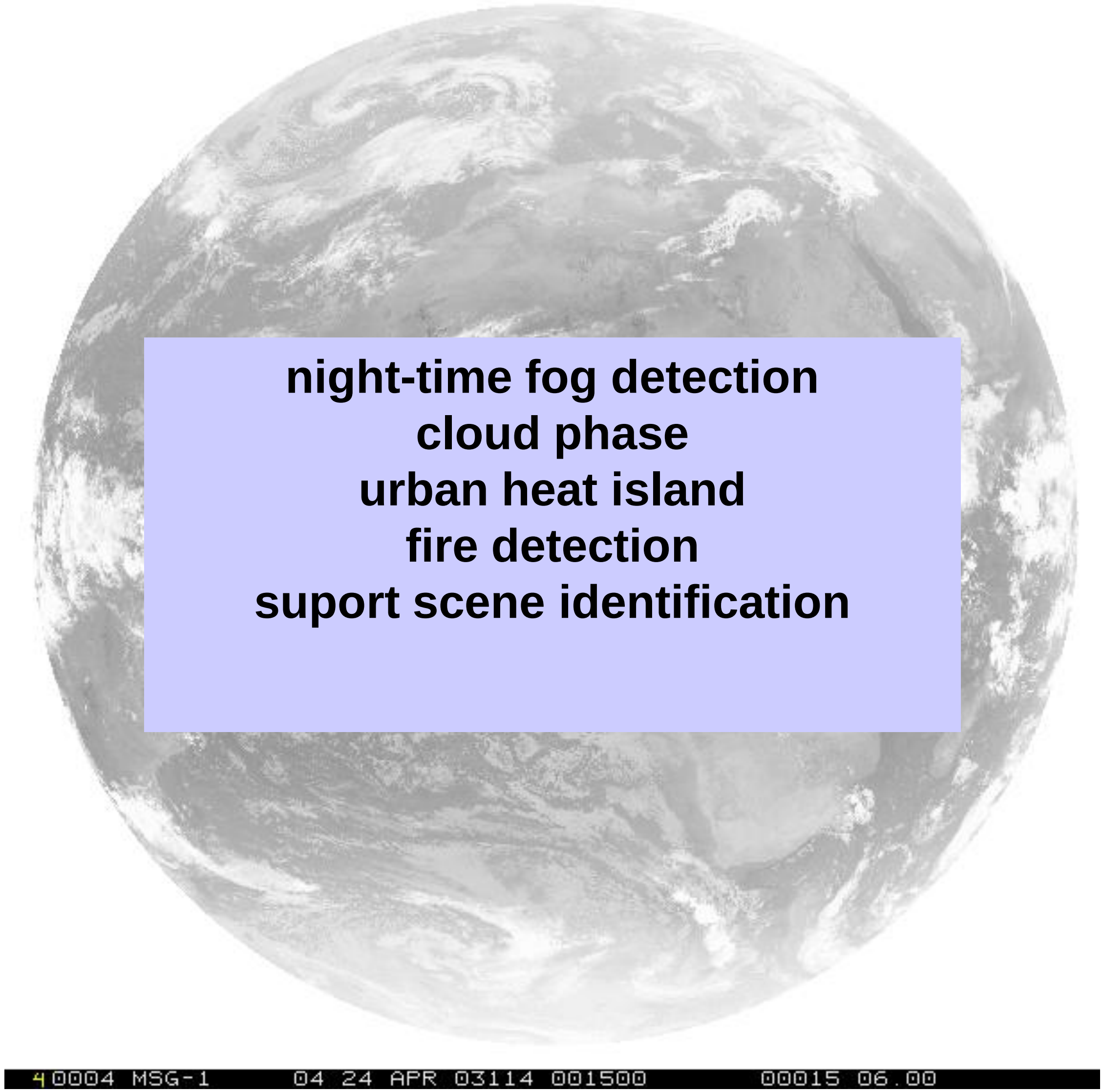
MSG Channel IR3.9 Night

Land Surface

cold surfaces

warm surfaces (trop. oceans, lakes)

fire
s



night-time fog detection
cloud phase
urban heat island
fire detection
suport scene identification

Clouds

cold

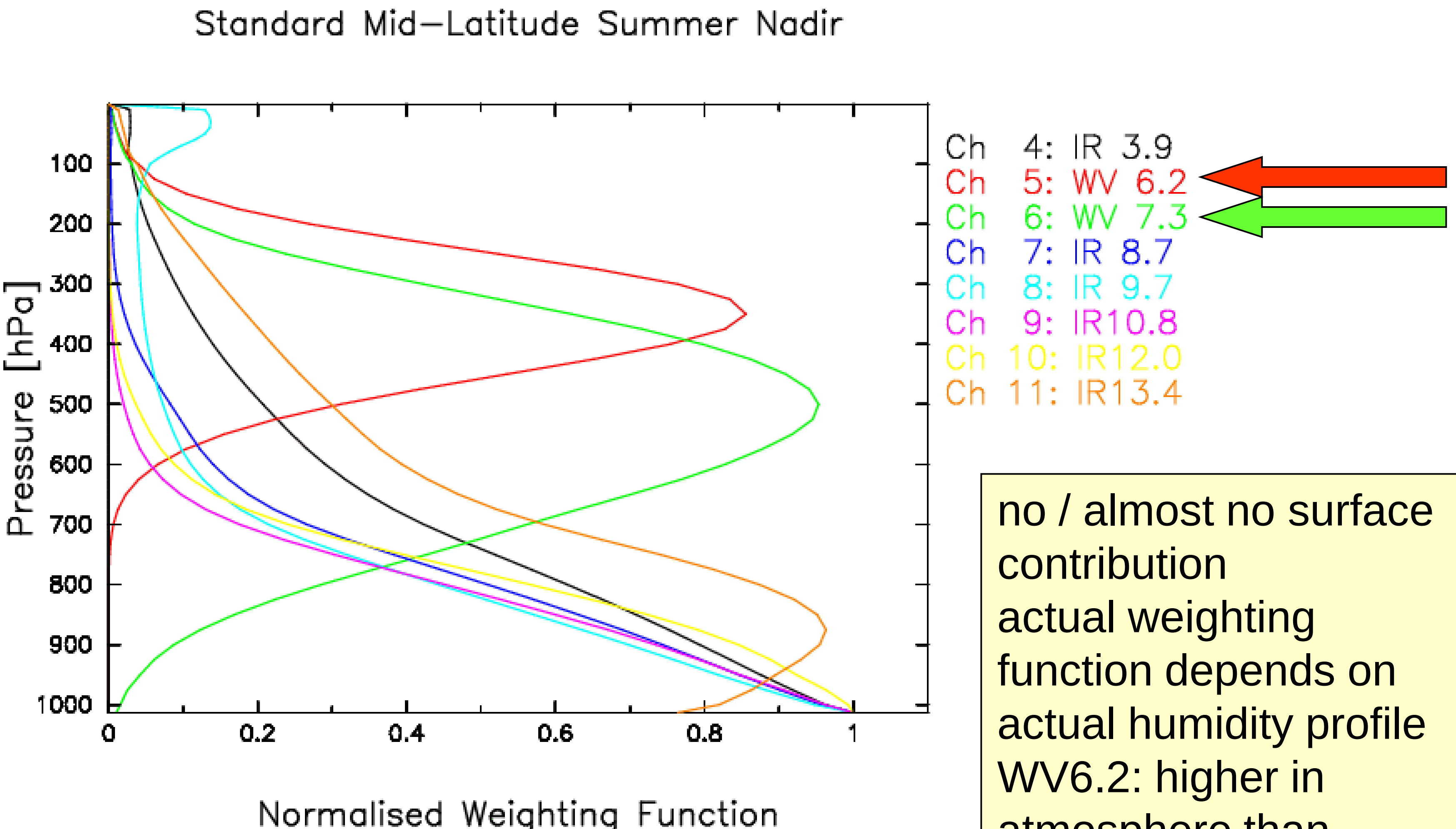
high-level clouds

mid-level clouds

low-level clouds

warm

Contribution Function



no / almost no surface contribution
actual weighting function depends on actual humidity profile
WV6.2: higher in atmosphere than WV7.3

MSG Channel WV6.2

Land Surface

high humidity in upper troposphere

low humidity in upper troposphere

water vapour information
wind tracking
support scene identification
support GII retrieval

Clouds

cold

high-level clouds

warm

MSG Channel WV7.3

Land Surface

high humidity in mid troposphere

low humidity in mid troposphere

high level warm surface

water vapour information
wind tracking
support scene identification
support GII retrieval

Clouds

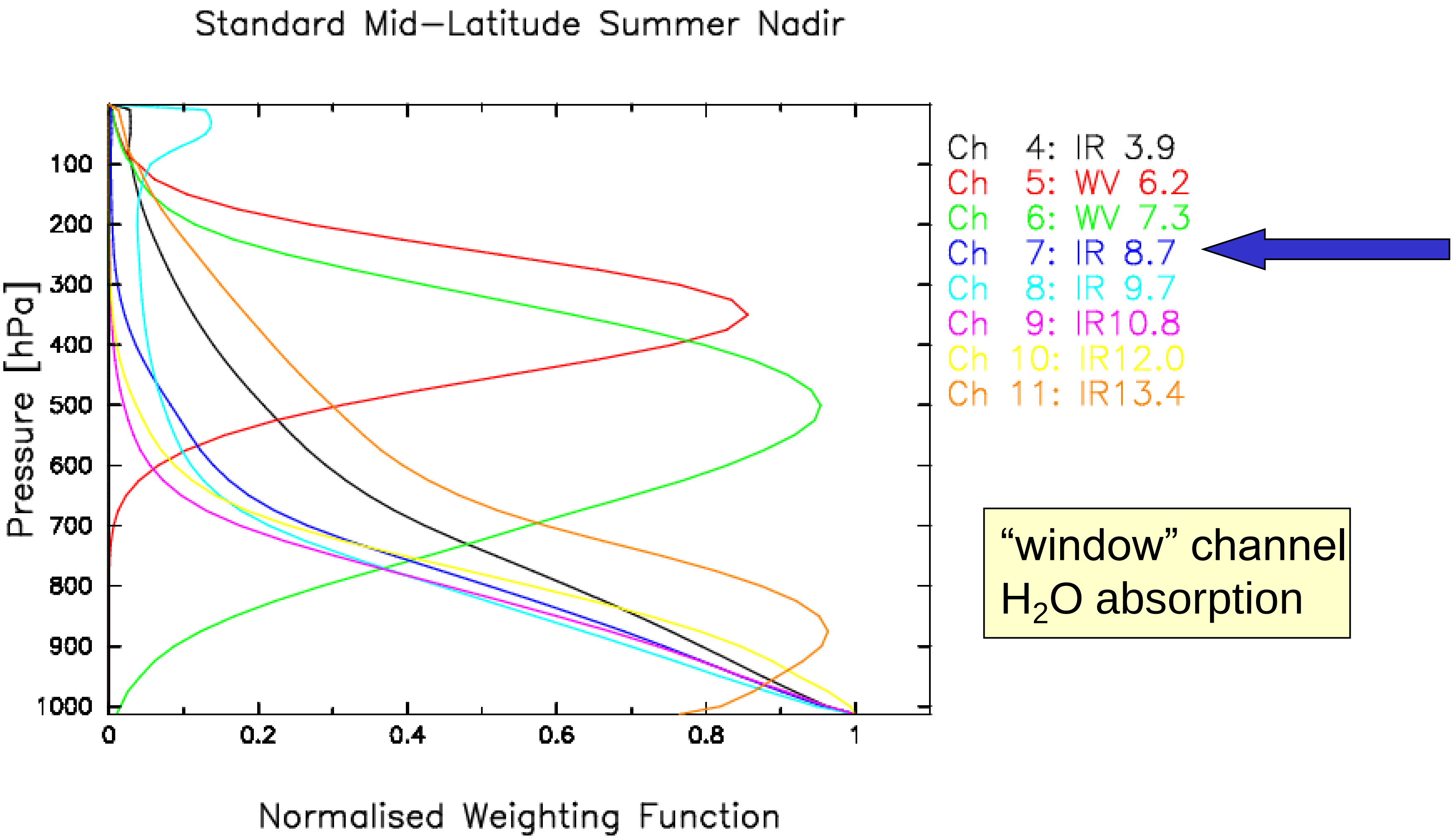
cold

high-level clouds

mid-level clouds

warm

Contribution Function



“window” channel
H_2O absorption

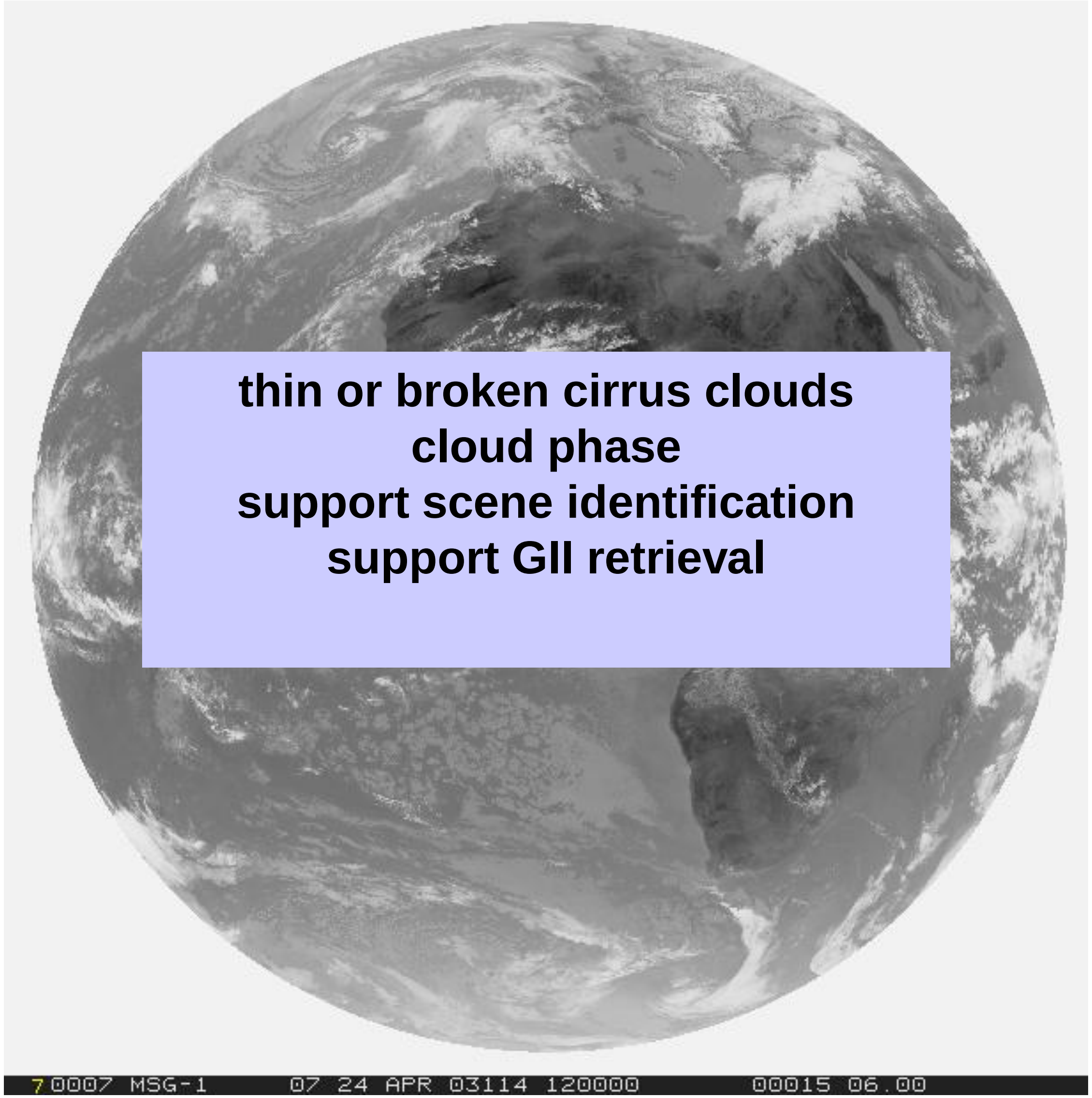
MSG Channel IR8.7

Land Surface

cold land surface

warm sea surface

hot land surface



thin or broken cirrus clouds
cloud phase
support scene identification
support GII retrieval

Clouds

cold

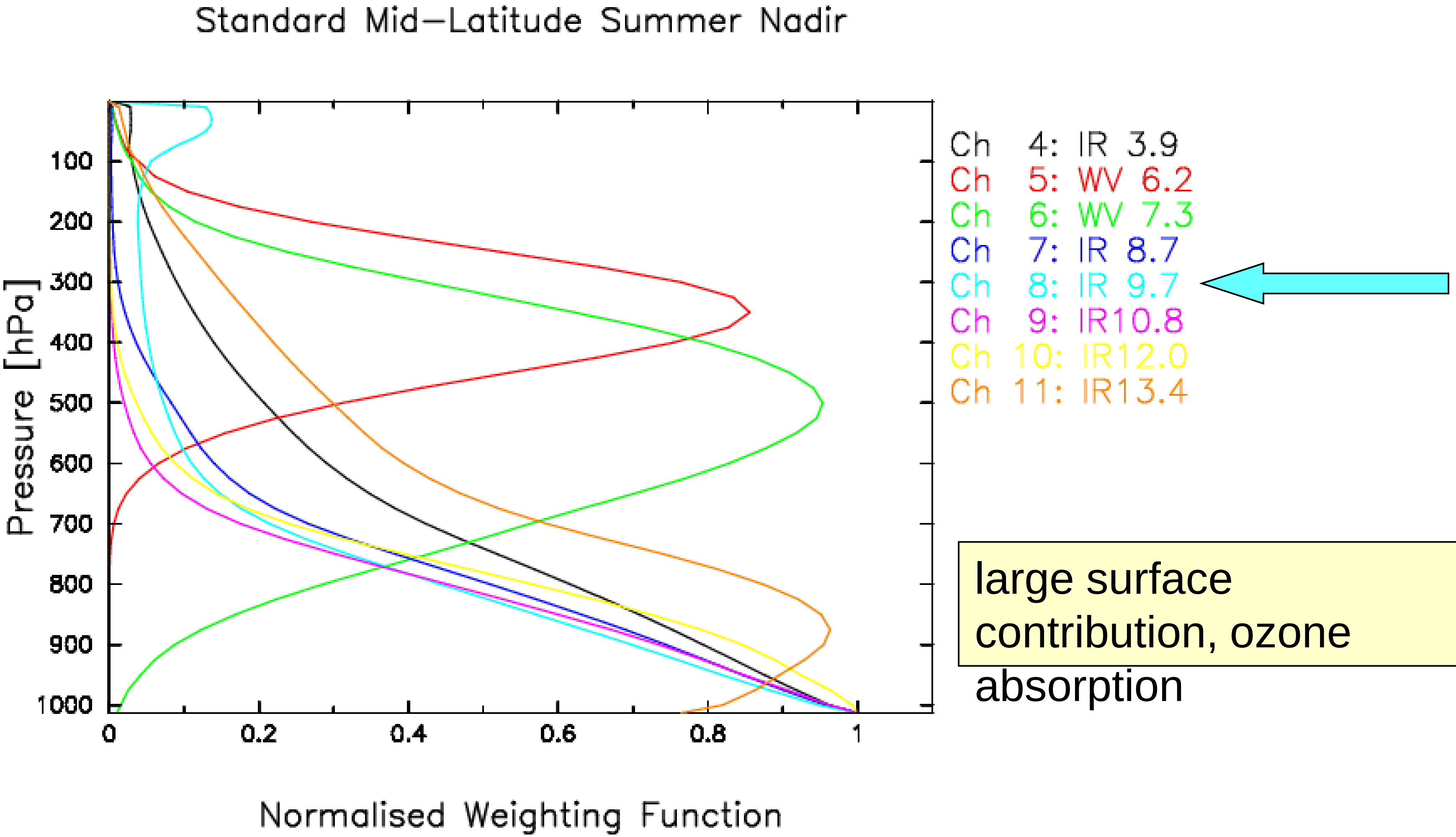
high-level clouds

mid-level clouds

low-level clouds

warm

Contribution Function



large surface contribution, ozone absorption

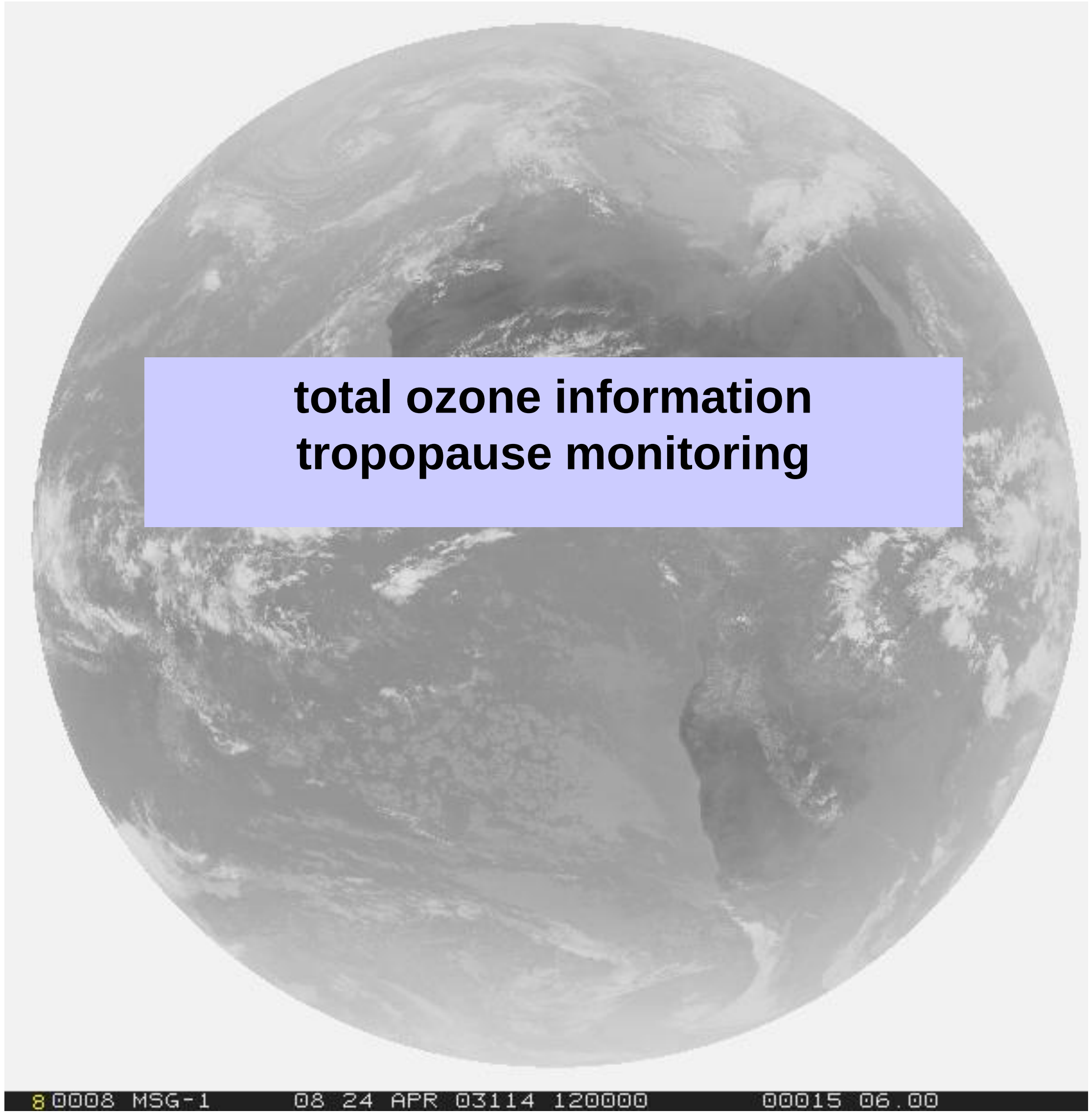
MSG Channel IR9.7

Land Surface

cold land surface

warm sea surface

hot land surface



Clouds

cold

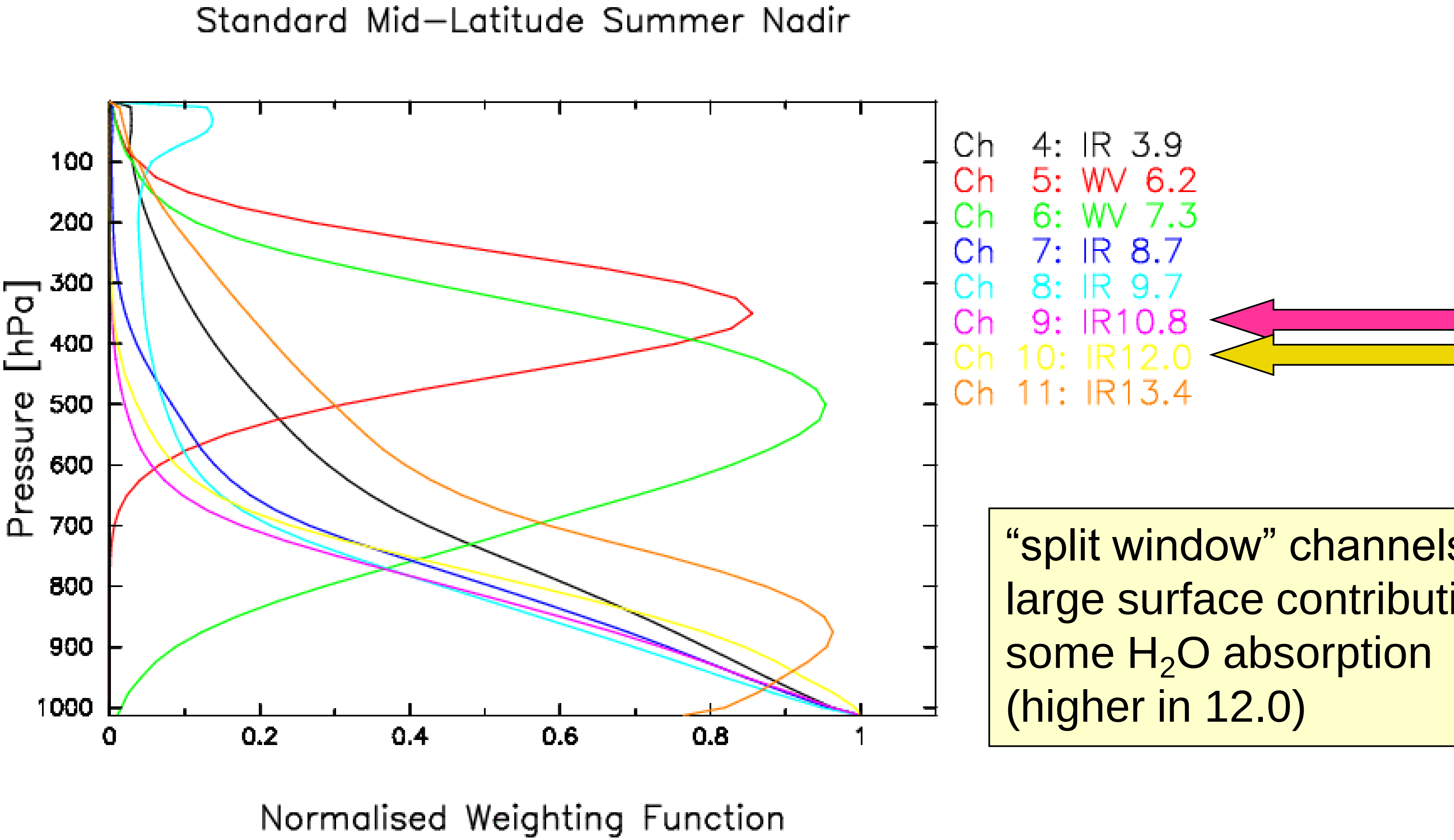
high-level clouds

mid-level clouds

low-level clouds

warm

Contribution Function



"split window" channels
large surface contribution
some H_2O absorption
(higher in 12.0)

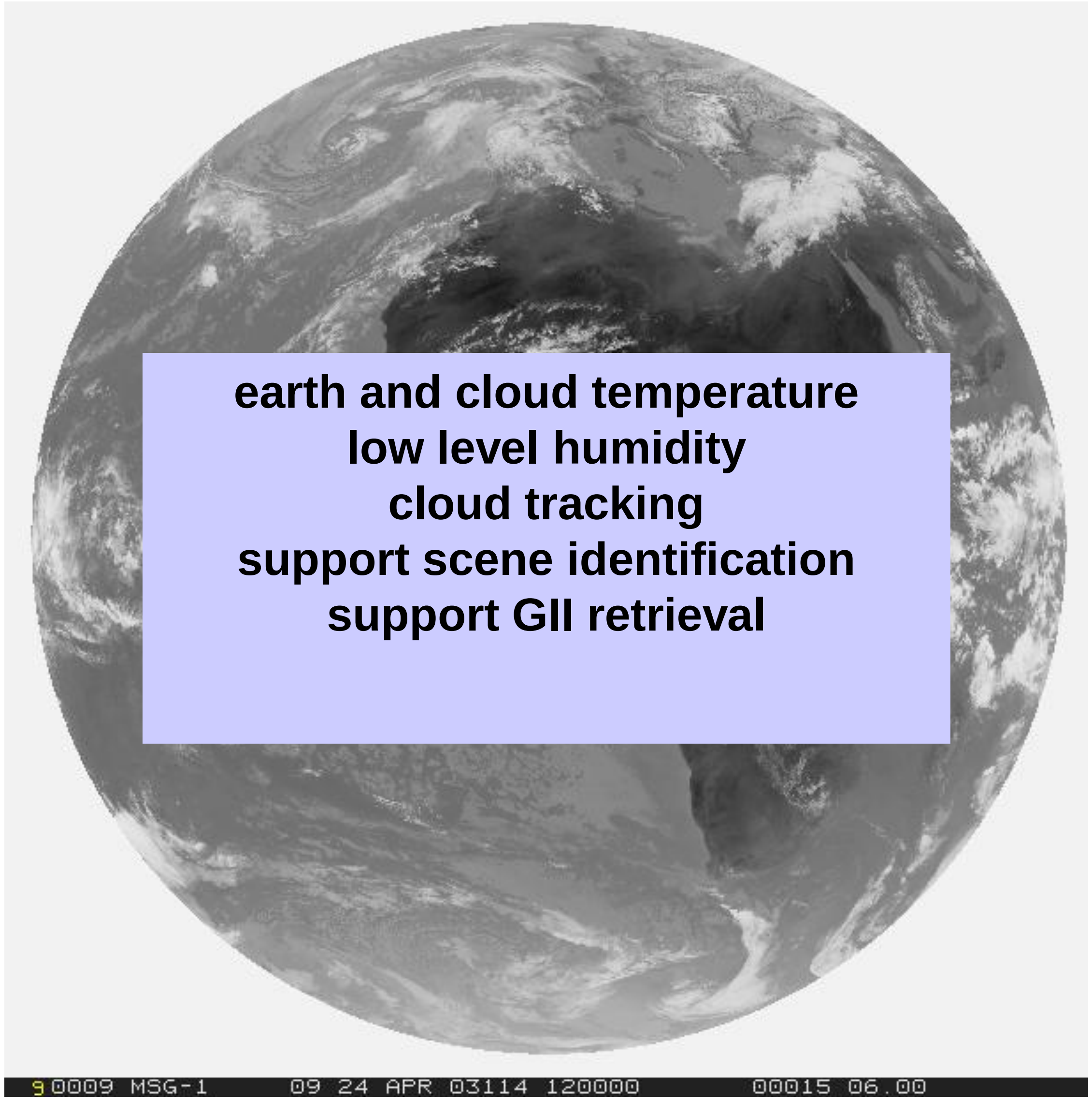
MSG Channel IR10.8

Land Surface

cold land surface

warm sea surface

hot land surface



earth and cloud temperature
low level humidity
cloud tracking
support scene identification
support GII retrieval

Clouds

cold

high-level clouds

mid-level clouds

low-level clouds

warm

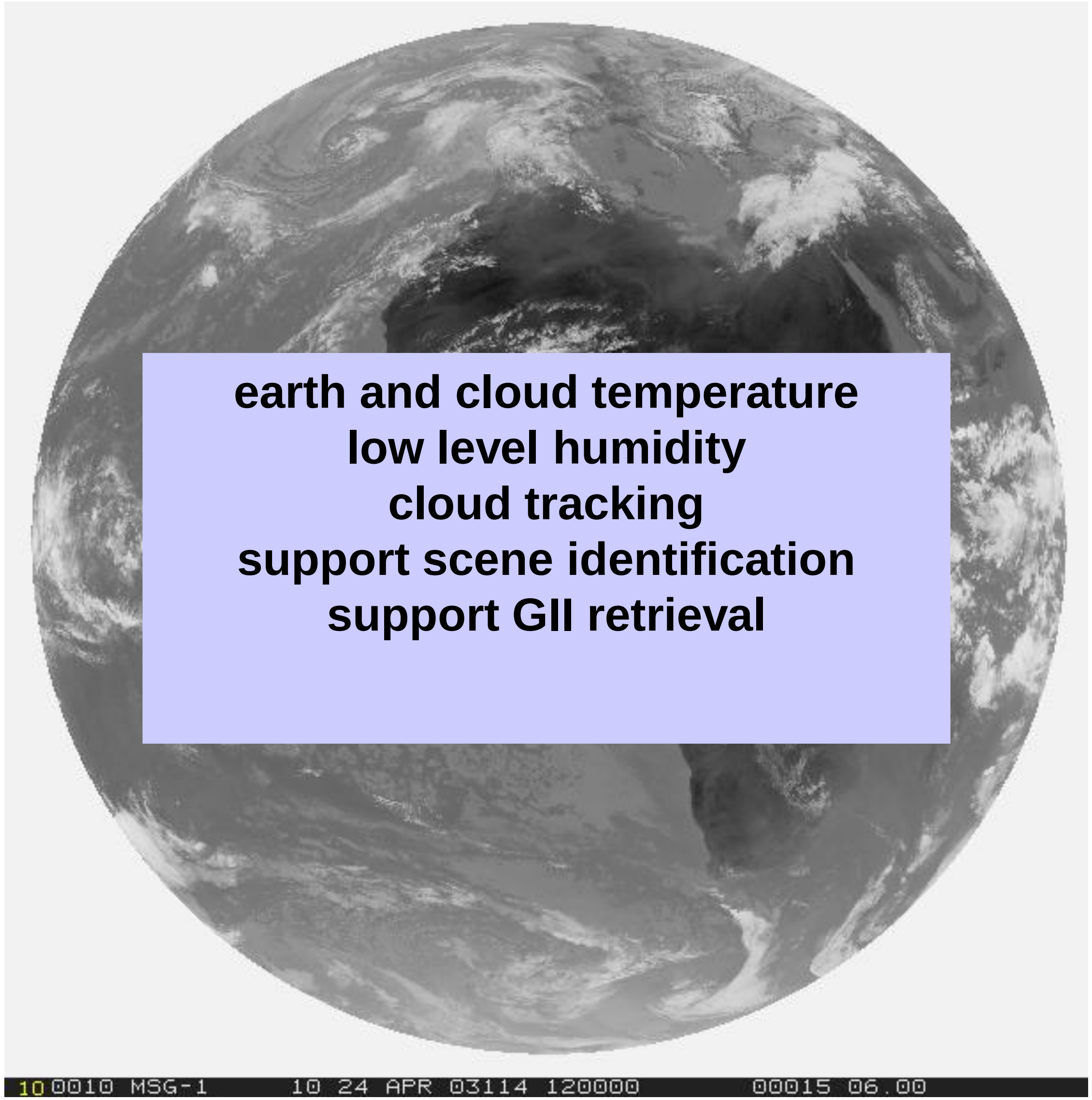
MSG Channel IR12.0

Land Surface

cold land surface

warm sea surface

hot land surface



earth and cloud temperature
low level humidity
cloud tracking
support scene identification
support GII retrieval

Clouds

cold

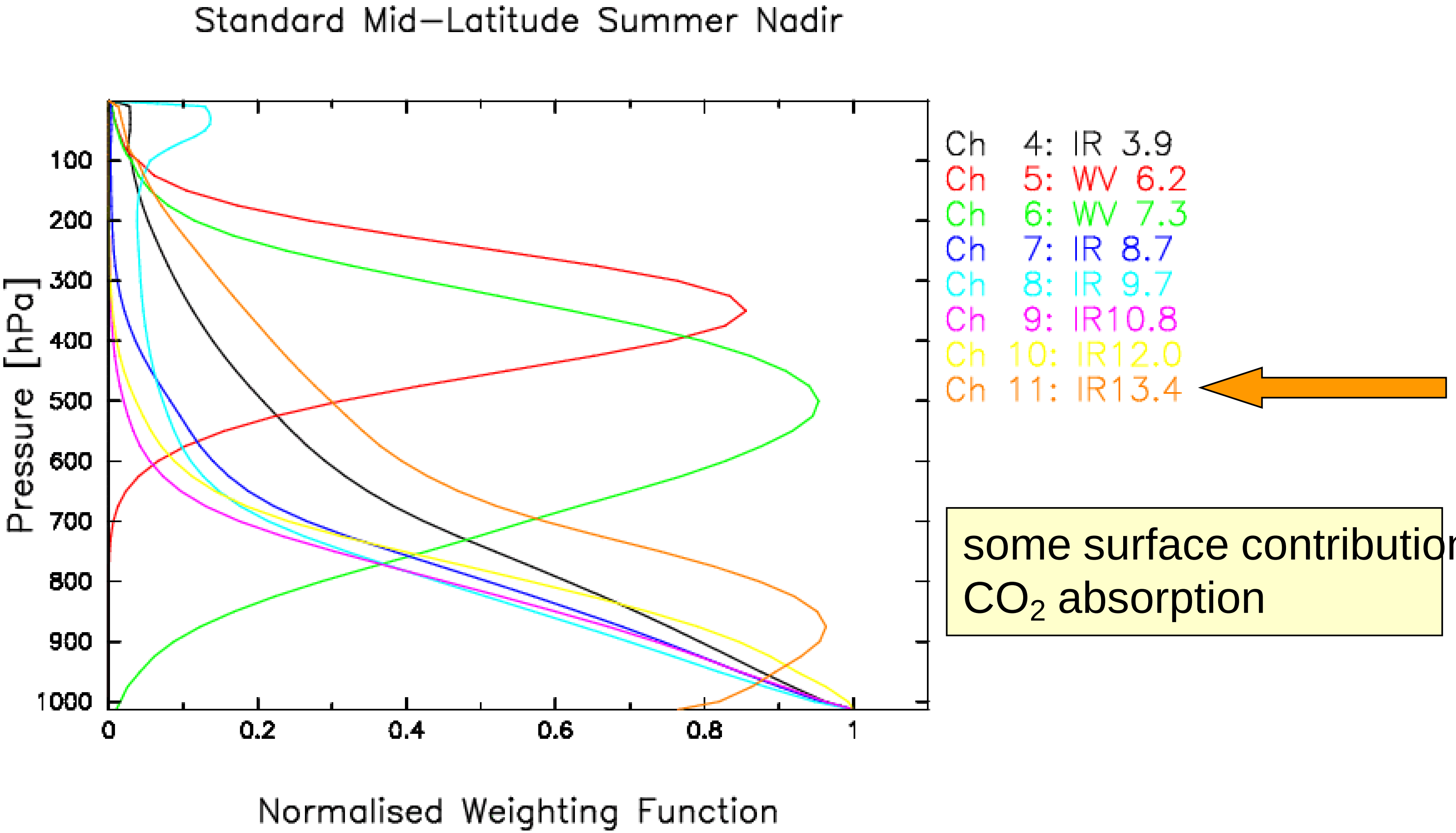
high-level clouds

mid-level clouds

low-level clouds

warm

Contribution Function



some surface contribution
CO_2 absorption

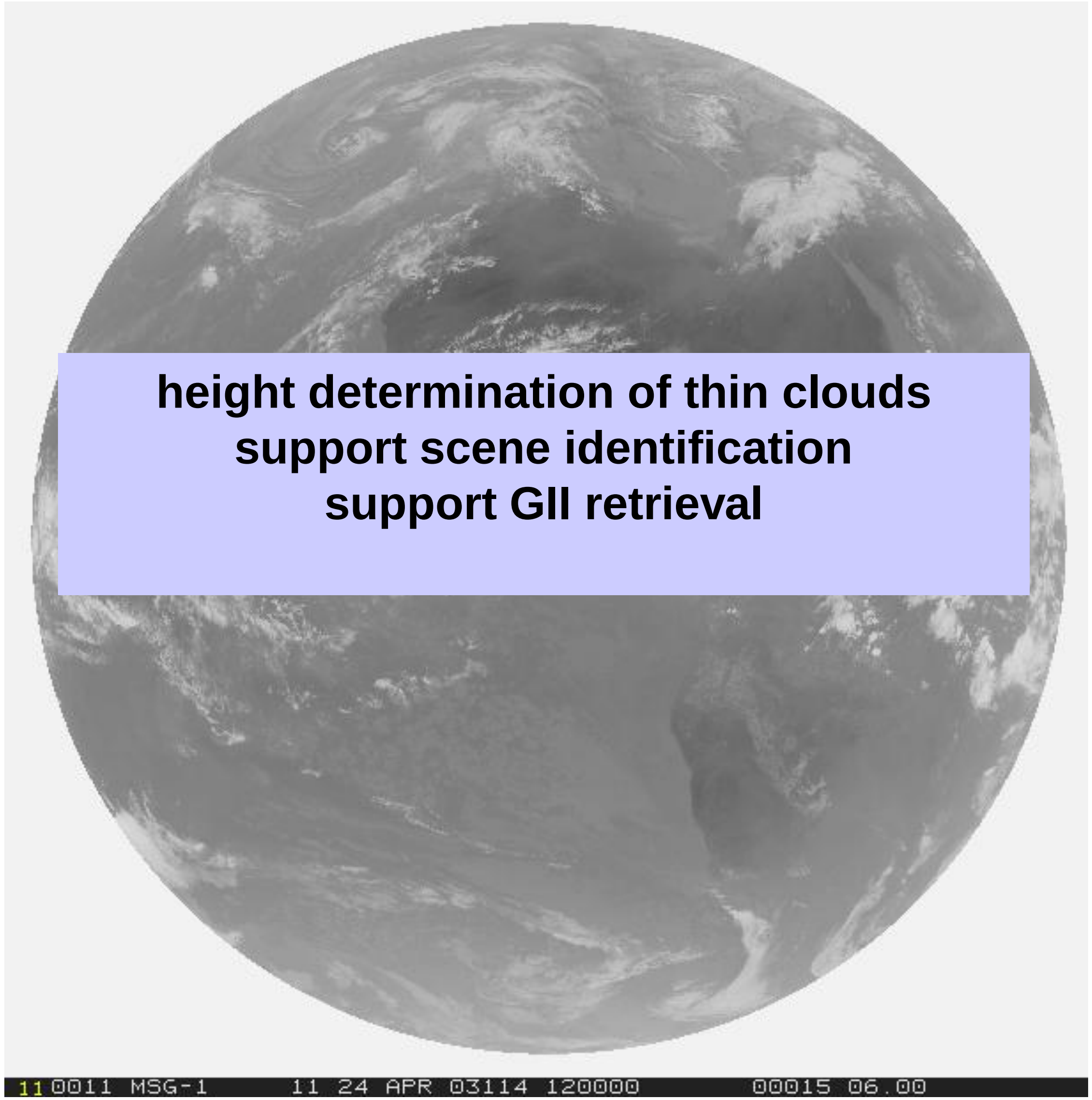
MSG Channel IR13.4

Land Surface

cold land surface

warm sea surface

hot land surface



height determination of thin clouds
support scene identification
support GII retrieval

Clouds

cold

high-level clouds

mid-level clouds

low-level clouds

warm

MSG Channel HRVIS

sun glint

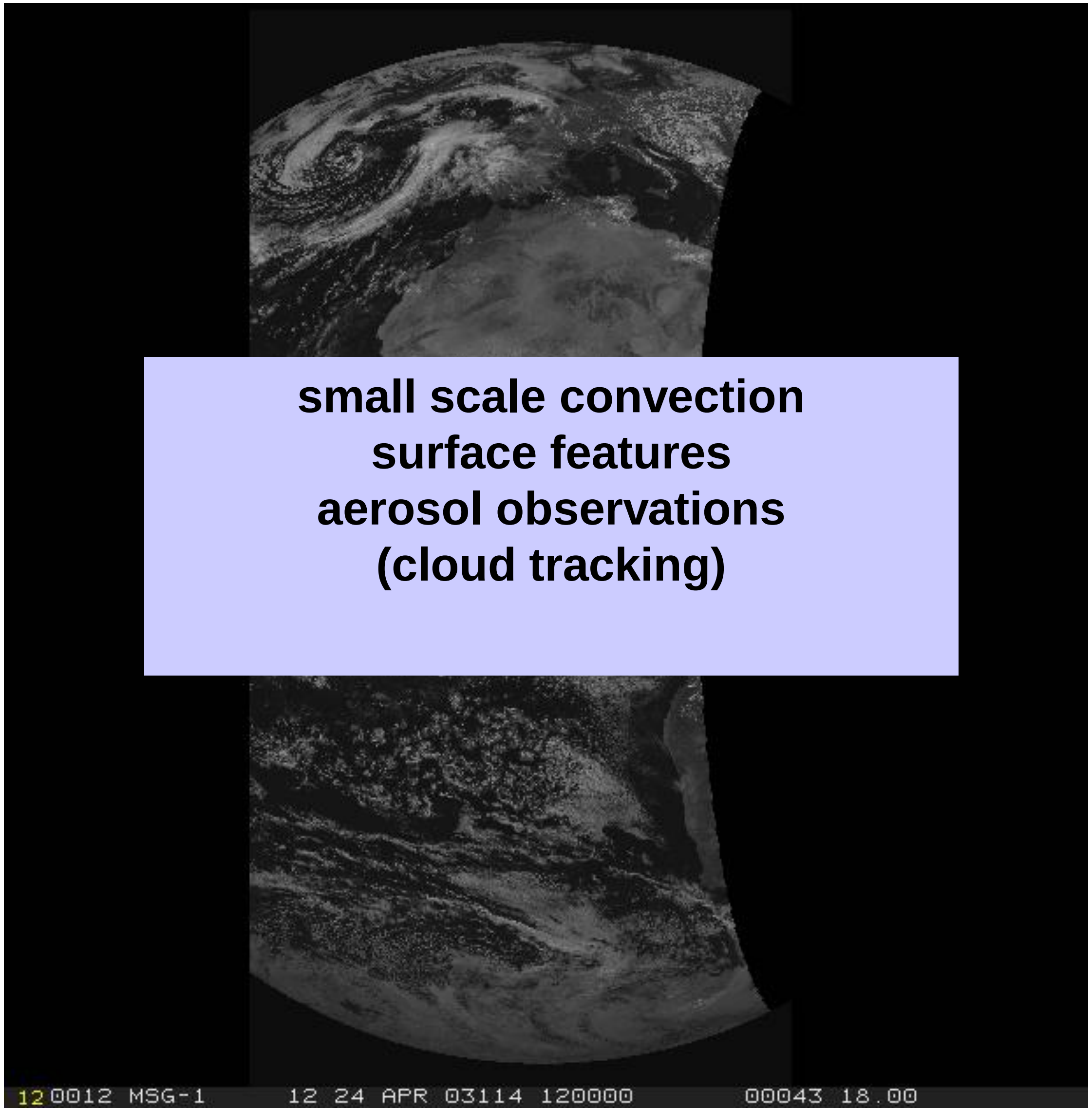
snow

desert

bare soil

forest

sea surface



small scale convection
surface features
aerosol observations
(cloud tracking)

high reflectance

very thick clouds

very thin clouds over land

very thin clouds over sea

low reflectance

Summary: Value of MSG for Nowcasting

- Higher temporal sampling (15 minutes), Improved Nowcasting (very short term forecasting)
- Higher spatial sampling (3 km IR and VIS, 1 km HRVIS)
- Higher spectral sampling (12 channels)
- Higher quality of data (e.g. 10 bits digitisation)
- Better discrimination of surfaces/clouds (window channels)
- More information on vertical structure of the atmosphere
  - Pseudo sounding and stability products
  - Water vapour at two levels (WV channels)
  - Ozone/tropopause information (IR9.7 channel)

Summary: Value of MSG for NWP

- Atmospheric Motion Vectors (AMV)
  - Better tracking (15 minutes)
  - Improved height assignment (with IR13.4 and WV channels)
  - Potential for higher resolution winds
  - Better spatial coverage near and over active weather systems
    - more layers of AMVs (2 WV channels, Ozone channel)
    - more information on cloudy and cloud-free areas
  - Automatic quality control and flags for NWP assimilation
- Clear Sky Radiances (CSR)