Overview of geostationary and non-geostationary Meteorological Satellite (MetSat) Systems

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Overview (1)

- Meteorological satellites (MetSats) – What for?
- Societal Benefits from Metsats
- Contribution to the WMO Global Observing System (GOS)
- General MetSat system concept
- Overview of the architecture of MetSat systems
- ITU Definition of Meteorological satellites (MetSats)
- MetSat frequency allocations
- Types of MetSat RF transmissions

Overview (2)

- Frequency bands used by current and future systems
- Current global MetSat constellation
- Examples of NGSO MetSat Joint-Ventures
- Day-to-day applications of GSO and NGSO Metsat data
- A little bit of MetSat history

Meteorological satellites (MetSats) – What for? (1)

To assist the human forecaster in diagnosing and monitoring the development of hazardous weather systems…

For daily weather forecasting, to save human life and property…

For supporting safe and efficient aviation and maritime transportation system…

… and for climate and environmental monitoring.

Meteorological satellites (MetSats) – What for? (2)

- **GSO MetSat satellites obtain data from visible, near-infrared and infrared imagers and other sensors on board to provide:**
  - **Input to weather models, forecasts and warnings, e.g. for**
    - Analyses of cloud coverage, height and temperature
    - Winds
    - Precipitation estimates
    - Solar imagery
    - Environmental data collection
    - Search and rescue
  - **Constant monitoring e.g. of:**
    - Thunderstorms and hurricanes
    - Heavy rain,
    - Flash floods
    - Lightning (future)

Meteorological satellites (MetSats) – What for? (3)

- **NGSO MetSat systems ensure a global coverage of data from a variety of passive and active sensors observing in the visible, infrared and microwave spectral regions, providing:**
- **Input to weather models, forecasts, climate monitoring and operational oceanography**, e.g.:
  - Global Measurement of climatic variables (e.g. temperature and humidity profiles, water vapour, atmospheric ozone, cloud cover, surface temperature over sea and land, ice, snow and vegetation cover, etc.)
  - Detection of significant environmental events, such as fires, oil spills, volcanic eruptions, etc.
  - Ocean observations (e.g. sea surface temperatures, global sea surface wind vectors, global sea surface height)
  - Environmental data collection
  - Search and rescue

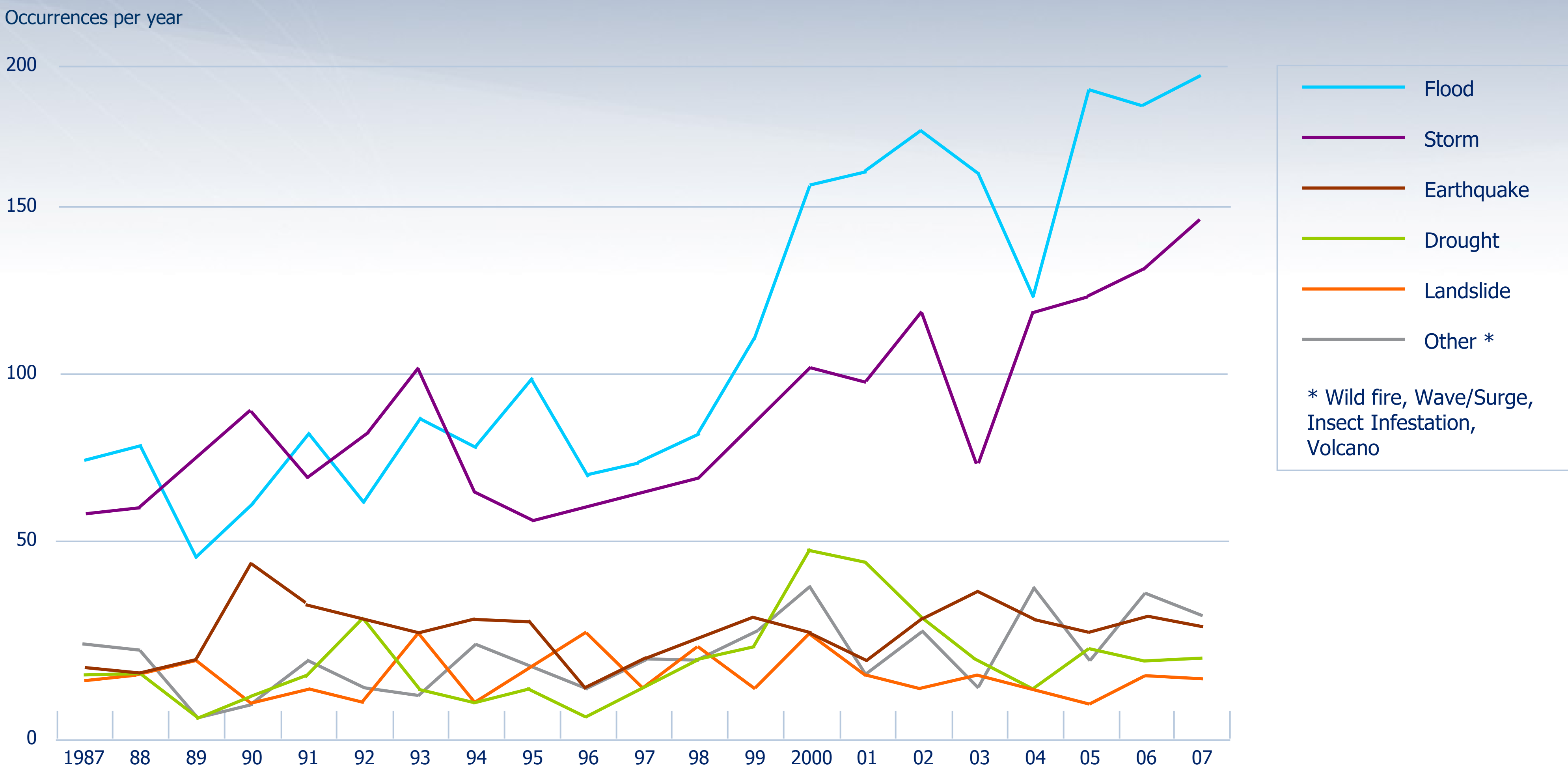
Societal Benefits from Metsats (1)

Value of weather forecasting to economy is > 20 times budget of public weather service

Contribution from satellite data > 35%

(source: Case for Space Final Report, UK Space 2006)

Societal Benefits from Metsats (2)



Source: World Bank

Societal Benefits from Metsats (3)

- Environmental and meteorological data gathered by instruments on GSO and NGSO MetSat satellites and here in particular the vast amount of additional data from sensors on the current generation of polar-orbiting satellites triggered significant improvements in the (Numerical Weather Prediction (NWP)).

- NWP is the basis of all modern global and regional weather forecasting. The data generated by the instruments carried by the latest NGSO MetSat systems can be assimilated directly into NWP models to compute forecasts ranging from a few hours up to 10 days ahead.

Societal Benefits from Metsats (4)

- Measurements from infrared and microwave radiometers and sounders on board of these NGSO MetSat systems provide NWP models with crucial information on the global atmospheric temperature and humidity structure, with a high vertical and horizontal resolution.

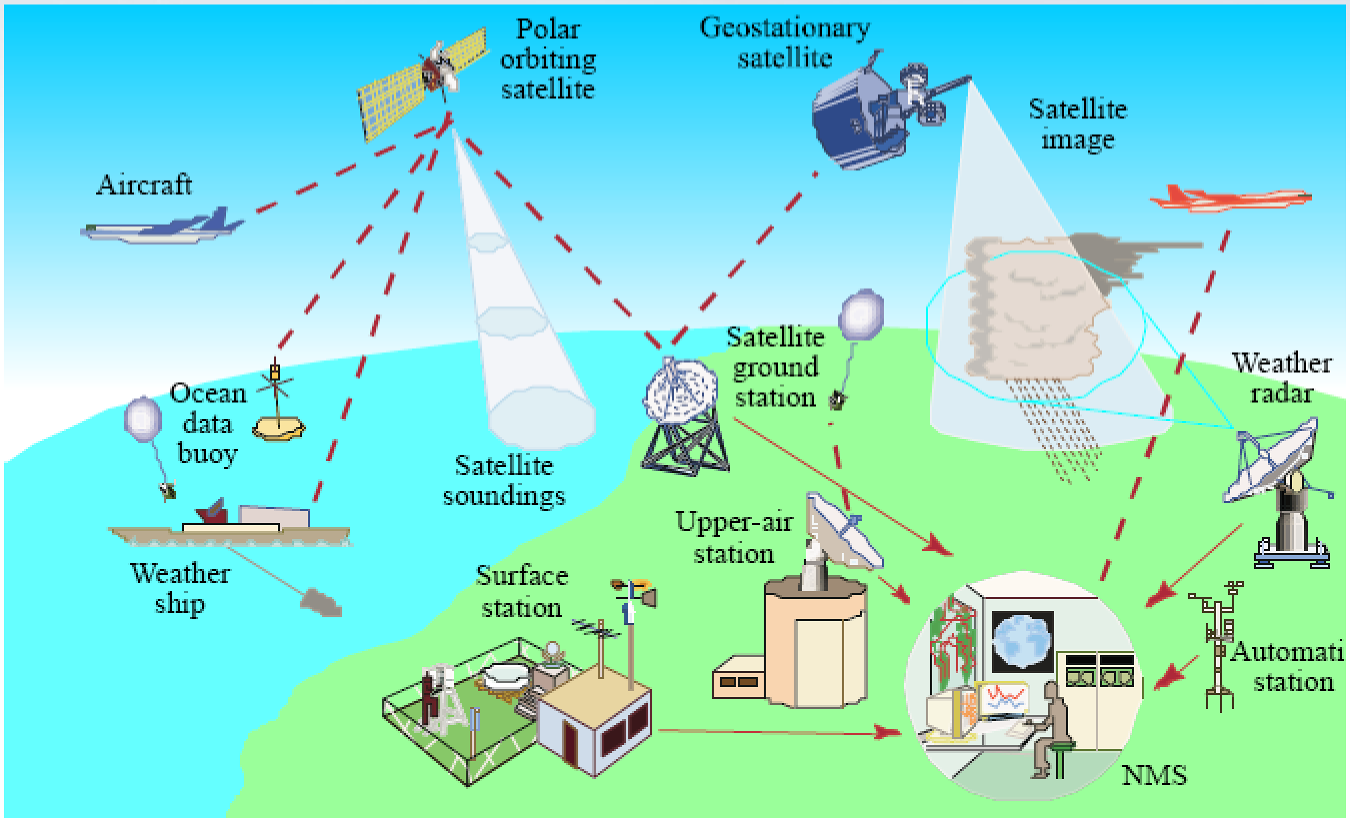
- Thus, the impressive progress made in the recent years in weather and climate analysis, monitoring and forecasts, including warnings for dangerous weather phenomena (heavy rain, storms, cyclones) that affect all populations and economies, is to a great extent attributable to spaceborne observations.

Contribution to the WMO GOS (1)

- The space-based component of the Global Observing System (GOS) for the measurement of environmental and meteorological data includes two constellations: operational geostationary (GSO) and operational non-geostationary (NGSO) low Earth-orbiting, mostly polar-orbiting observation satellites.
- Polar-orbiting and geostationary MetSat satellites are normally equipped with visible and infrared imagers and sounders, from which one can derive many meteorological parameters.
- Several of the polar-orbiting satellites are also equipped with microwave sounding instruments that can provide vertical profiles of temperature and humidity on a worldwide basis.

Contribution to the WMO GOS (2)

WMO Global Observing System (GOS)



MetSat System Concept (1)

Satellites commonly carry several instruments

- GSO MetSat:
  - Visible imagers
  - Infrared imagers
  - Infrared sounders (future)
  - Data Collection System
  - Search and Rescue
  - Further instruments (individual to different MetSat syste

- NGSO MetSat:
  - Visible imagers
  - Infrared imagers
  - Infrared sounders
  - Data Collection System
  - Search and Rescue
  - Active microwave sensors
  - Passive microwave sensors
  - Further instruments (individual to different MetSat systems)

MetSat System Concept (2)

1) Common to GSO and NGSO MetSat systems, raw data from instruments are transmitted to primary Earth station(s) of the operating agency of the MetSat satellite (e.g. NOAA, CMA, EUMETSAT, etc.), processed, and distributed to national meteorological centers, archives and other users.

2) Additionally, in NGSO MetSat systems raw instrument data are directly disseminated from NGSO MetSat satellites to meteorological user stations in particular to improve timeliness of the data.

MetSat System Concept (3)

3) The distribution of the processed instrument data to the user is performed either by:

- Sending back the processed instrument data to the GSO MetSat satellites for re-transmission to user stations via low and/or high rate digital signals, in frequency bands allocated to the MetSat service, or
- Distributing the processed instrument data to users through alternative dissemination means such as commercial satellite (GEONETCast), terrestrial links and/or internet.

MetSat System Concept (4)

4) Data Collection Systems (DCS) (1):

- Data collection platforms (DCPs) transmit signals to both GSO and NGSO MetSats and are relayed to the primary Earth station(s) of the operating agency of the MetSat satellite,
- DCPs are located on ground, aircraft, ships, floating buoys and animals,
- Parameters include surface temperature, wind velocity and direction, rainfall rate, stream height, atmospheric pressure and gases, ocean pollutants, sea surface currents, tracking animals and monitoring fishing fleets, etc.

MetSat System Concept (5)

4) Data Collection Systems (DCS) (2):

- DCS on GSO MetSats collect meteorological and other environmental data from Data Collection Platforms (DCPs),
- Uplinks from DCPs to MetSats are in the 401-403 MHz range in time sequential mode (time slots of typically 1 min) at transmission rates of 100 bit/s with 1.5 or 3 kHz bandwidth,
- Higher data rate DCPs (300 bit/s and 1 200 bit/s) began operation in 2003,
- For example for GOES satellites >20000 DCPs send as many as 400 000 messages per day.

MetSat System Concept (6)

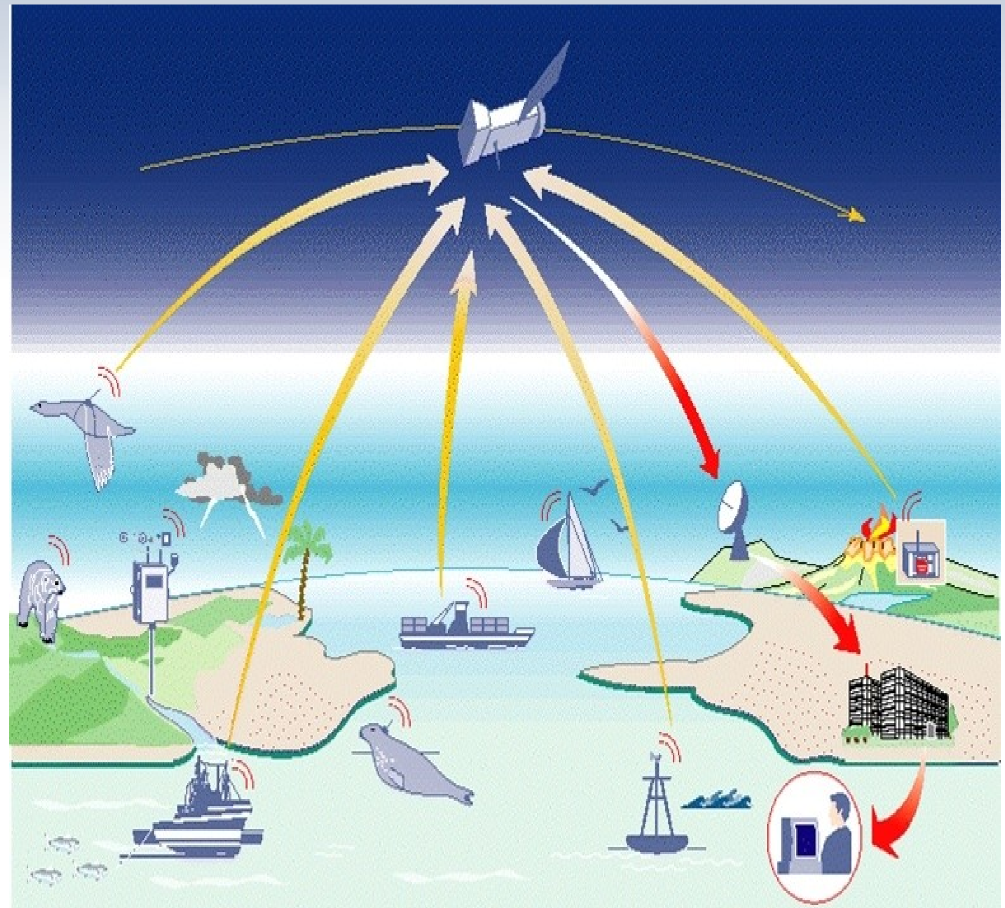
5) International Data Collection Systems (IDCS):

- In addition to the operation of so-called regional DCP channels, GSO MetSat operators also contribute to the IDCS through the operation of international channels.
- There are currently considerations among GSO MetSat operators to dedicate a number of IDCS channels for use by an emergency/disaster monitoring system.

MetSat System Concept (7)

6) DCS systems using NGSO Metsats are systems like Argos and Brazilian DCS.

- Argos-2 is flown only on the NOAA-15, -16, -17 and -18 polar-orbiting satellites.
- Argos-3, is operated on the series of Metop satellites and SARAL.
- Brazilian DCS is based on SCD and CBERS.
- Due to the compatibility between the Brazilian DCS and the Argos system as well as complementary satellite orbits, data exchange between both systems has been implemented since 2001.



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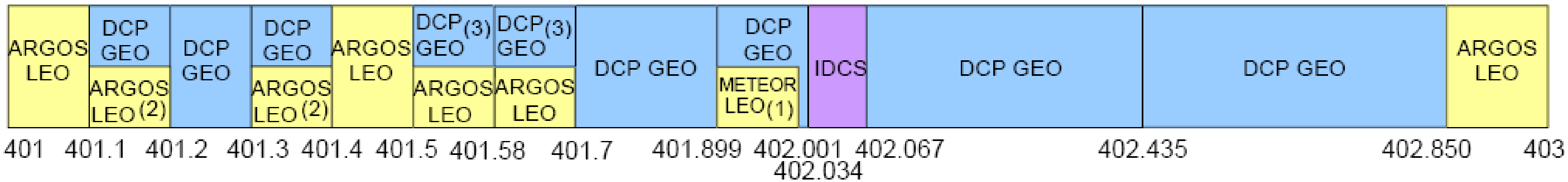
MetSat System Concept (8)

Basic general partitioning of the band 401 – 403 MHz for future long-term coordinated use of DCS systems on geostationary and non-geostationary MetSat and EESS systems



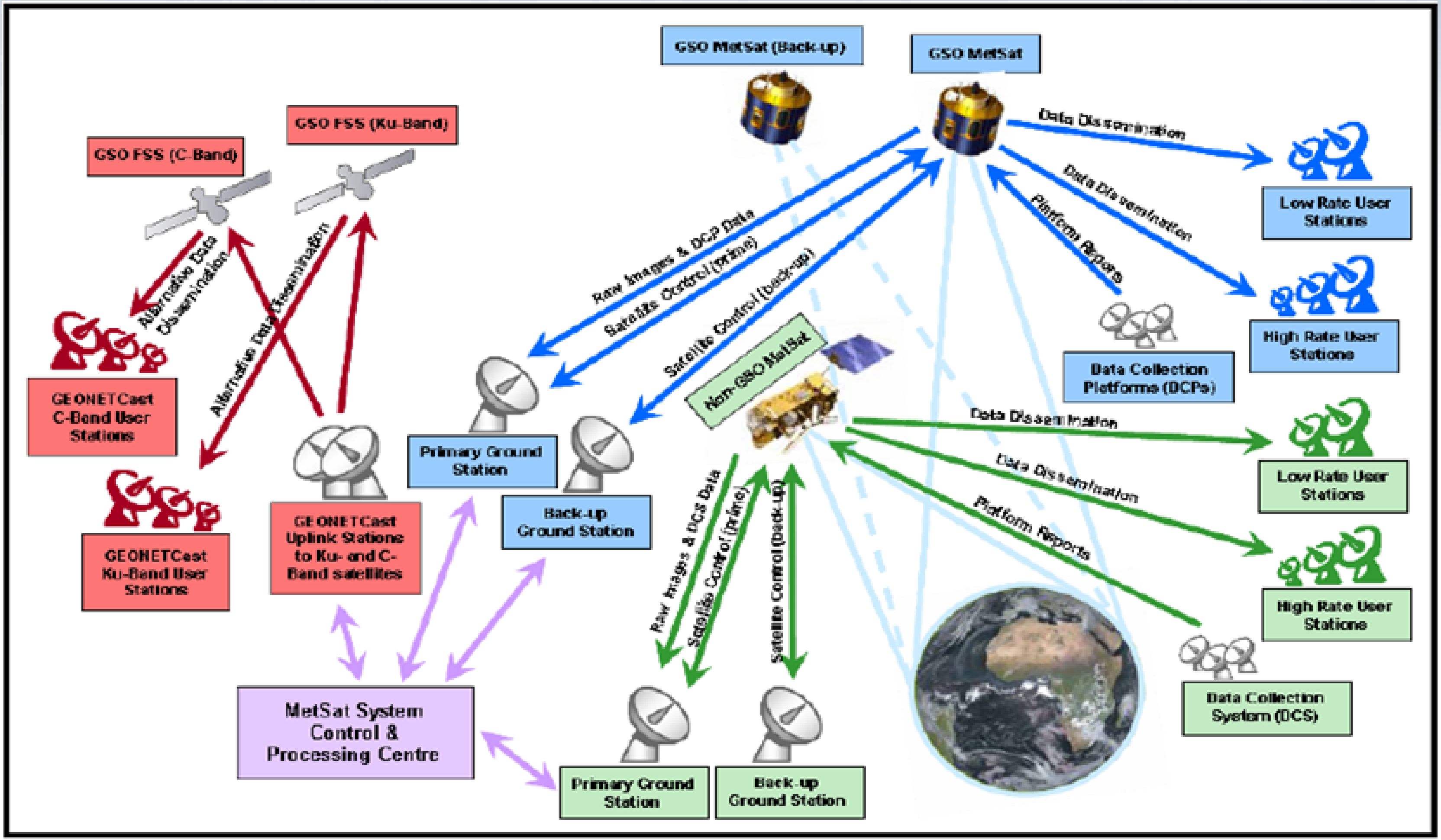
(1) The following conditions contained in Resolves 2 of Resolution SFCG 30-1 apply: In the band 401.899 – 401.998 MHz the non-geostationary MetSat system Meteor-3M will only operate over the territory of the Russian Federation.

(2) The following conditions contained in Resolves 4 of Resolution SFCG 30-1 apply for the use of the bands 401.1 - 401.2 MHz and 401.3 - 401.4 MHz by ARGOS-4 platforms:

- Maximum EIRP of -3 dBW;
- Maximum number of ARGOS-4 active platforms to be deployed in each of the two sub-bands not to exceed 1000 within the visibility circle of FY-2 and FYMETSAT-4 satellites;
- Maximum duty cycle (ratio of transmission duration over the repetition period) of each platform not to exceed 0.01 (on average 0.6 sec over 60 sec).

(3) The following conditions contained in Resolves 5 of Resolution SFCG 30-1 apply: The band 401.5 – 401.7 MHz can also be used by DCP GEO systems of the Russian Federation, noting that for the sub-band 401.58 – 401.7 MHz these systems must be limited to operation over Russian territory with a maximum EIRP of 16 dBW.

MetSat System Concept (6) – General Architecture



ITU Definition of MetSat

- Definition of Meteorological Satellite Service
  - ITU Radio Regulation 1.52: "an Earth exploration-satellite service for meteorological purposes"

- Allows radiocommunications between Earth stations and one or more space stations for:
  - Information relating to characteristics of Earth and its natural phenomena obtained from active and passive sensors on Earth satellites
  - Information collected from airborne or Earth-based platforms
  - Information distributed to earth stations

Frequency Allocations for MetSat Communications

MetSat allocations	
space-to-Earth (MHz)	Earth-to-space (MHz)
137 – 138 P	401 – 403 P
400.15 – 401 P	2025 – 2110 P[1]
460 – 470 s	8175 – 8215 P
2200 – 2290 P[1]	28500 – 30000 s[1]
7450 – 7550 P GSO	40000 – 40500 P[1]
7750 – 7900 P NGSO	
8025 – 8400 P[1]	
18000 – 18300 P GSO, ITU Regions 1 and 3	
18100 – 18400 P GSO, ITU Region 2	
25500 – 27000 P[1]	
37500 – 40500 s[1]	
65000 – 66000 P	
P = Primary, s = secondary, GSO Geostationary orbit, NGSO = Non-geostationary orbit	

[1] Since MetSat is a sub-class of the Earth exploration-satellite service, these allocations can also be used for the operation of MetSat applications.

MetSat RF Transmission Types

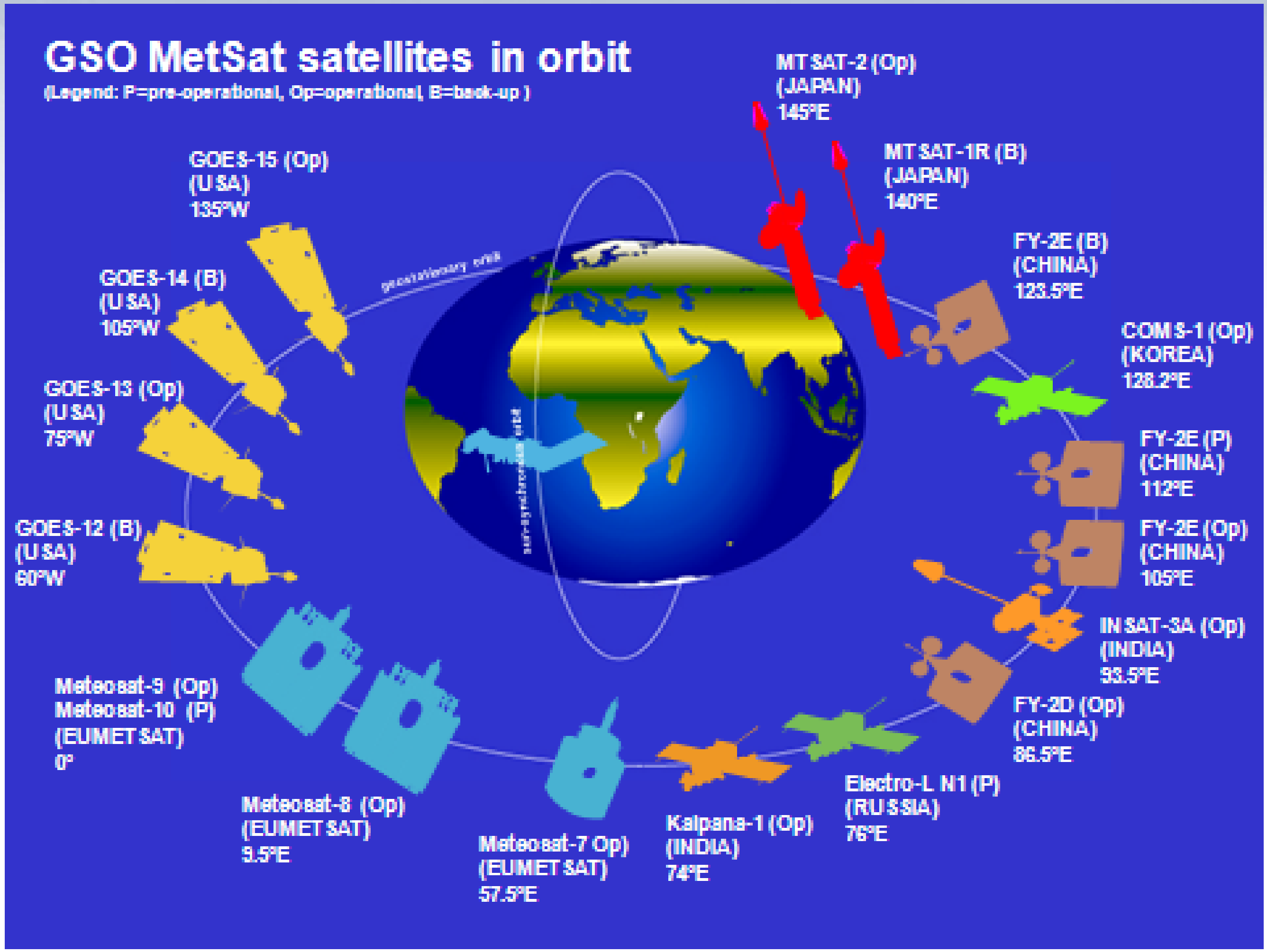
- Telemetry, Telecommand and Ranging of the spacecraft,
- Transmissions of observation data to main reception stations of the MetSat system,
- Relay of signals from Data Collection Platforms and Search and Rescue transmitters,
- Re-transmissions of pre-processed data through the GSO MetSat satellite to meteorological user stations,
- Direct transmissions of un-processed observation data from the NGSO MetSat satellite to meteorological user stations,
- Alternative data dissemination of pre-processed data to users (not in MetSat or EESS bands).

Frequency bands used

The following table provides an overview of the frequency bands most commonly used:

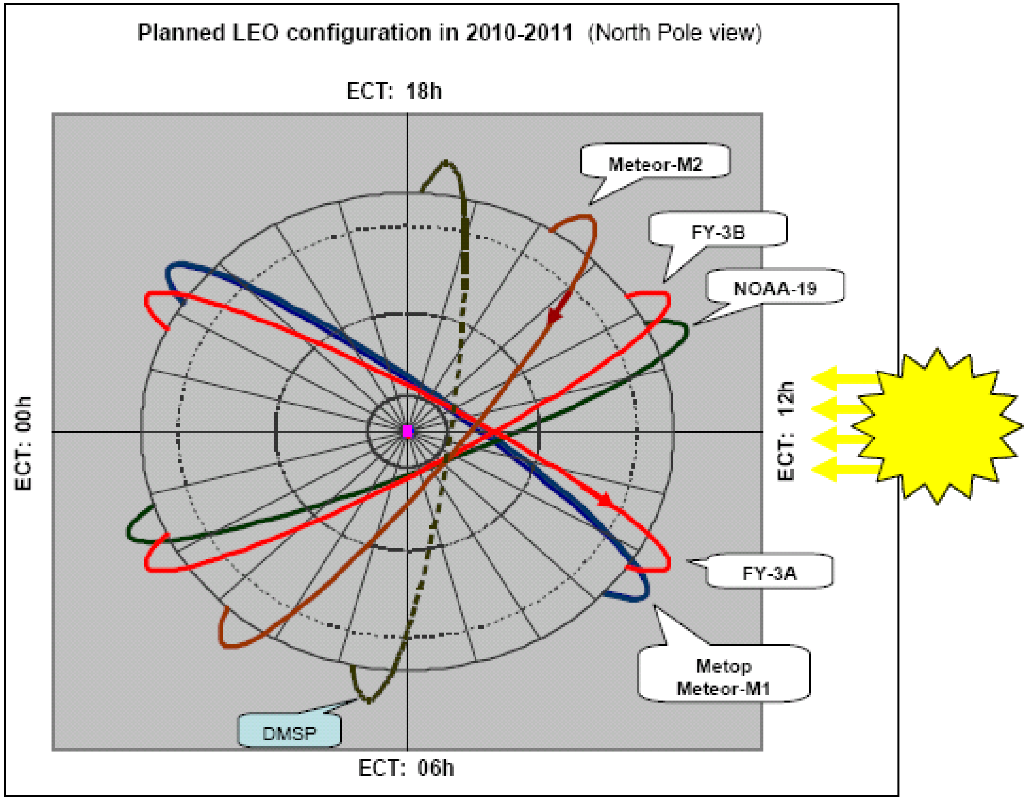
Telemetry/Telecommand and Ranging	GSO/NGSO GSO/NGSO	current/future current/future	2025 – 2110 MHz 2200 – 2290 MHz
Instrument raw data downlink	GSO NGSO GSO/NGSO GSO GSO/NGSO	current/future current/future current/future future future	1675 – 1710 MHz 7750 – 7900 MHz 8025 – 8400 MHz 18.0 – 18.3 GHz (R1, R3) 25.5 – 27 GHz
Low rate direct dissemination to user stations	NGSO GSO	current/future current/future	137 – 138 MHz 1675 – 1710 MHz
High rate direct dissemination to user stations	GSO/NGSO NGSO NGSO	current/future current/future future	1675 – 1710 MHz 7750 – 7900 MHz 25.5 – 27 GHz
Data Collection Systems	GSO/NGSO NGSO	current/future current/future	401 – 403 MHz 400.15 – 401 MHz, 460 – 470 MHz
Search and Rescue	GSO/NGSO GSO/NGSO	current/future current/future	406 – 406.1 MHz 1544 – 1545 MHz

Current global constellation of GSO MetSats



Current global constellation of NGSO MetSats

- The continuous and long-term collection of observations from the non-geostationary orbit will be ensured through current and future satellites operated by a number of national and regional meteorological organizations throughout the world.
- NGSO MetSat contingency planning is carried out in the framework of the Coordination Group for Meteorological Satellites (CGMS), see adjacent figure.



NGSO MetSat Joint Ventures (1)

- EUMETSAT and NOAA teamed together to provide synergistic enhancement of NGSO MetSat capabilities in the so-called Initial Joint Polar-Orbiting Operational Satellite System (IJPS),
- IJPS comprises a Metop satellite from Europe and a NOAA satellite from USA. The satellites fly in complementary orbits designed to ensure global data coverage at intervals of no more than 6 hours.
- IJPS data lead to improved short-term forecasts and long-term climatologic assessment of the effect of weather on the Earth's environment,
- This joint venture between NOAA and EUMETSAT will continue for the next generation NGSO MetSat systems of these two organisations in form of the Joint Polar System (JPS).

NOAA provides satellites for afternoon flight

EUMETSAT provides satellites for mid-morning flight

Satellites carry common core of instruments

- Advanced Very High Resolution Radiometer (AVHRR/3)
- High Resolution Infrared Radiation Sounders (HIRS/4)
- Advanced Microwave Sounding Unit (AMSU-A)
- Data Collection System (DCS)
- Search and Rescue Satellite-Aided Tracking (SARSAT)
- Space Environmental Monitor (SEM)
- Microwave Humidity Sounder (MHS)

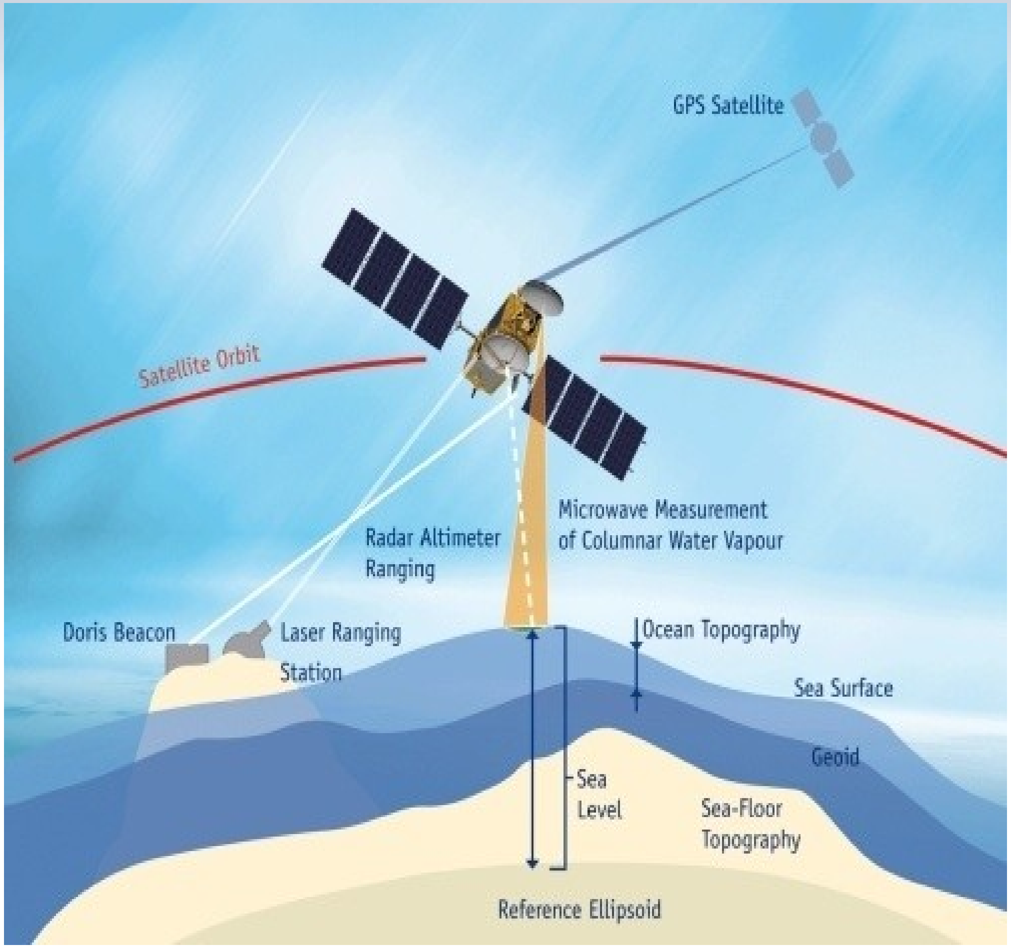
Unique Instruments

NOAA: Solar Backscatter Ultraviolet (SBUV) Radiometer

EUMETSAT: Infrared Interferometer Sounder (IASI), scatterometer, ozone instrument, and GPS occultation sounder

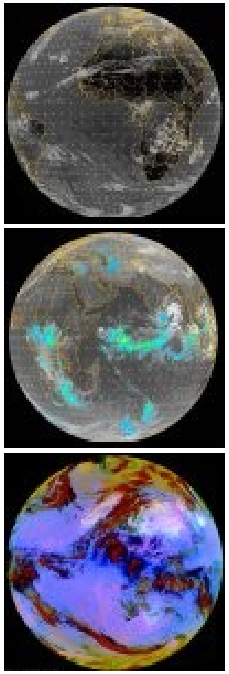
NGSO MetSat Joint Ventures (2)

- **The Ocean Surface Topography Mission (OSTM), is a successful cooperation between the US and Europe linking** two operational and two research agencies (EUMETSAT, NOAA, CNES and NASA) whose goal is to collect global ocean surface data on a continuous basis for several decades.
- The Jason-1, -2 and -3 (to be launched in 2014) satellites measure the global sea surface height to an accuracy of a few centimetres every 10 days which enables the determination of ocean circulations and mean sea level trends in support of weather forecasting, climate monitoring and operational oceanography.



Applications of Metsat data (1)

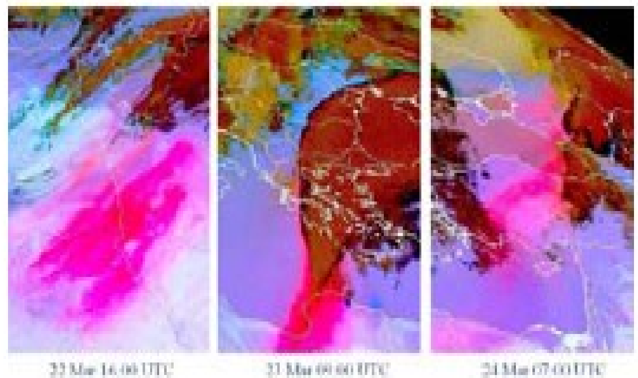
- The 'real-time' images are a comprehensive compilation of satellite products developed from different instrument data reproduced in graphical form, incorporating satellite image-data loops; visualised products derived from satellite data, and a selection of RGB composite images.
- Near-real time imagery is available as direct observations from the spectral channels of GSO MetSat satellites, and specific instruments on board of NGSO MetSat satellite.
- Visualised products from GSO MetSats, e.g. Fire, Global Instability Index, Atmospheric Motion Vectors and Multi-sensor Precipitation Estimate.
- RGB composite products offerings the possibility of compressing multi-spectral information content for optimum visualisation.



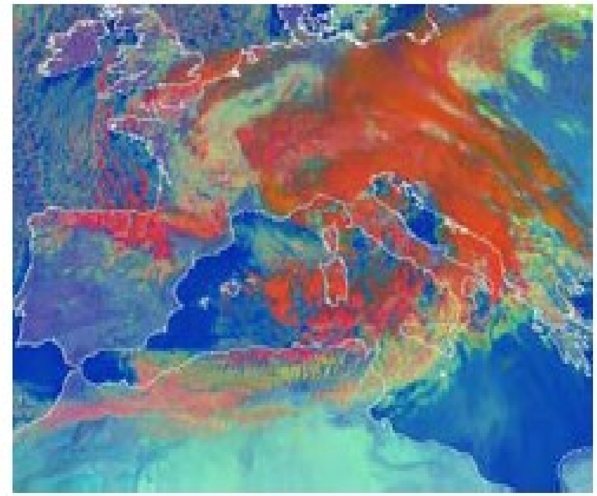
Applications of Metsat data (2)

Image of processed data from a GSO meteorological satellite

Cyclonic storm over the North Atlantic (Meteosat-9 Airmass RGB, 19/05/08 12:00 UTC)



Major dust outbreak from Northern Africa towards Greece, Turkey, Russia and Kazakhstan (Meteosat-9, Dust RGB, 22/03/08 - 24/03/08)



Meteo-02-2

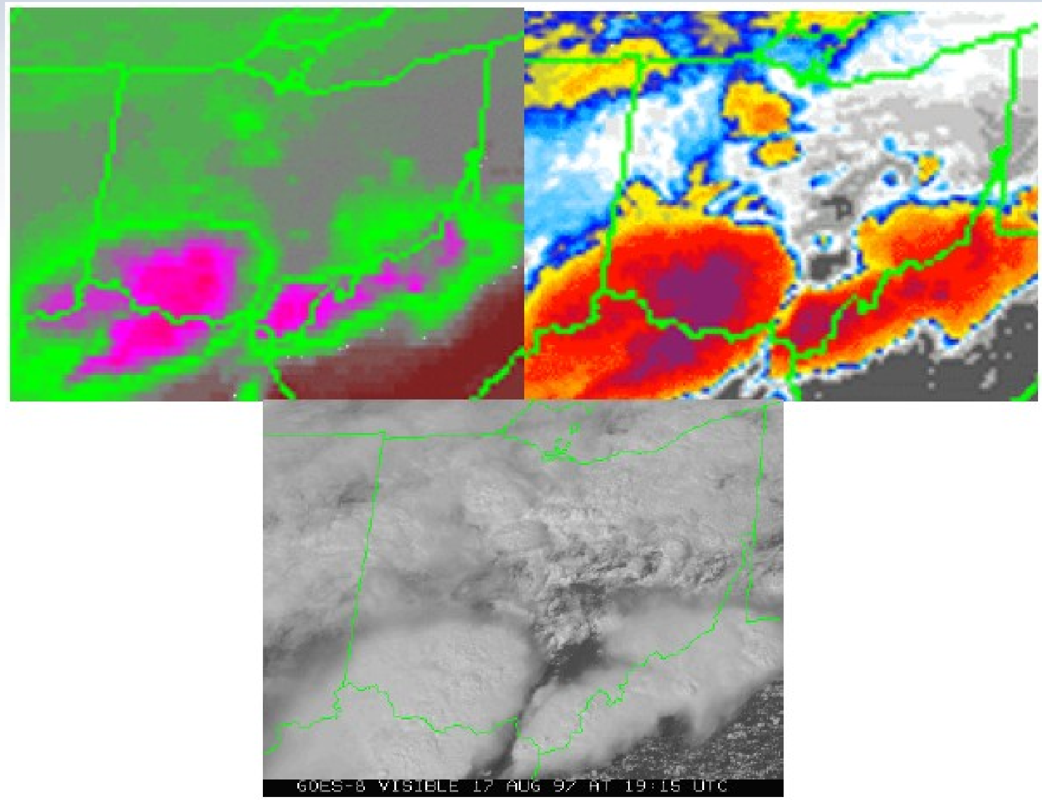
Strong mistral and Genoa cyclone with heavy precipitation over southern Alps (Meteosat-8 RGB: VIS0.8, IR3.9r, IR10.8, 20/03/07 09:00 UTC

Applications of Metsat data (3)

GOES 1-km visible image of Hurricane Katrina a day before the 29 August 2005 landfall just east of New Orleans

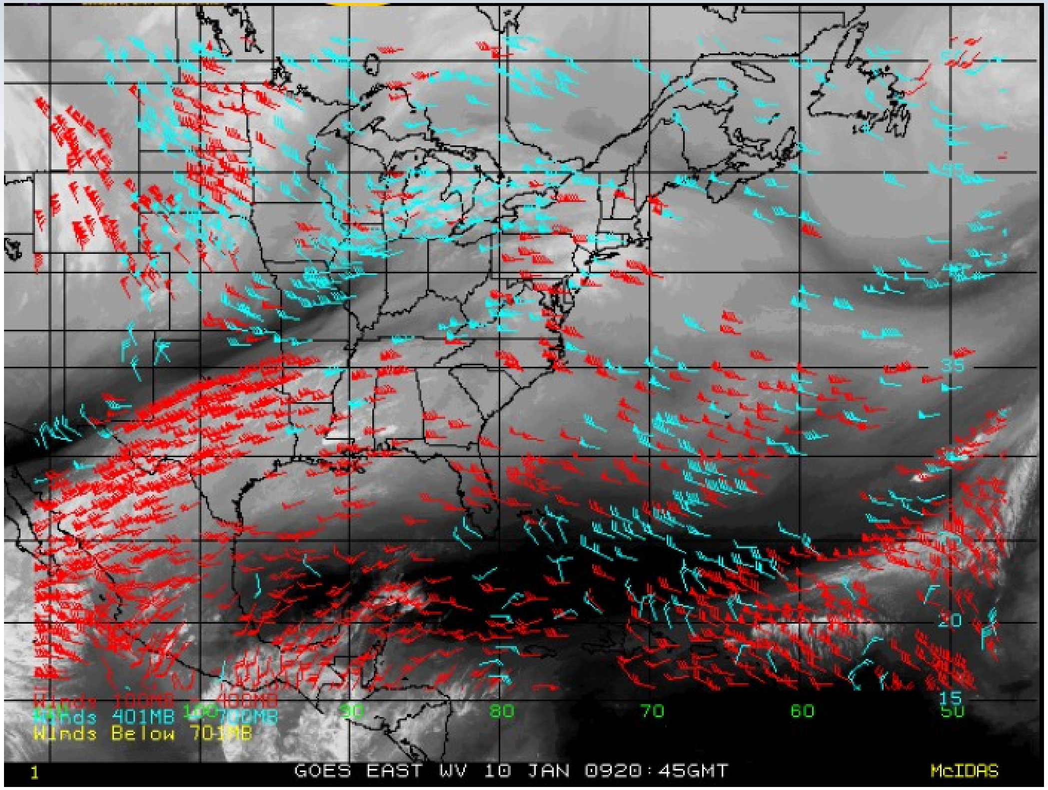
Applications of Metsat data (4)

GOES water vapour, infrared and visible images to locate and monitor severe storms



Applications of Metsat data (5)

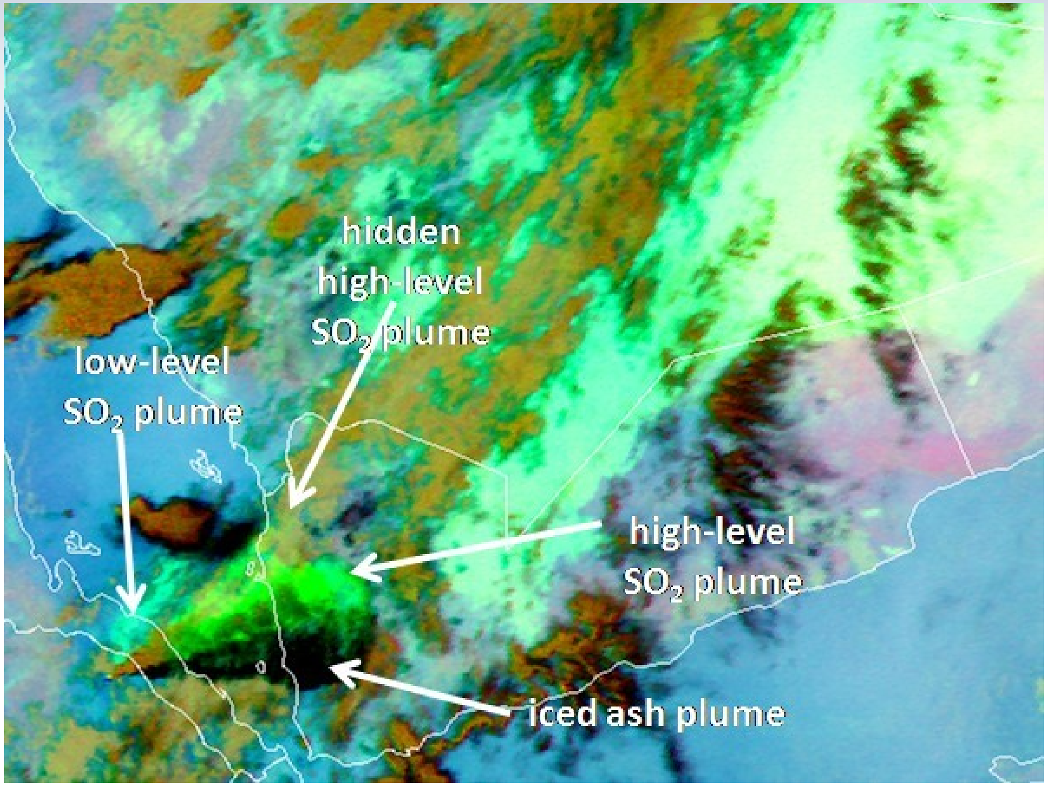
GOES Northern Hemisphere water vapour winds



Applications of Metsat data (6)

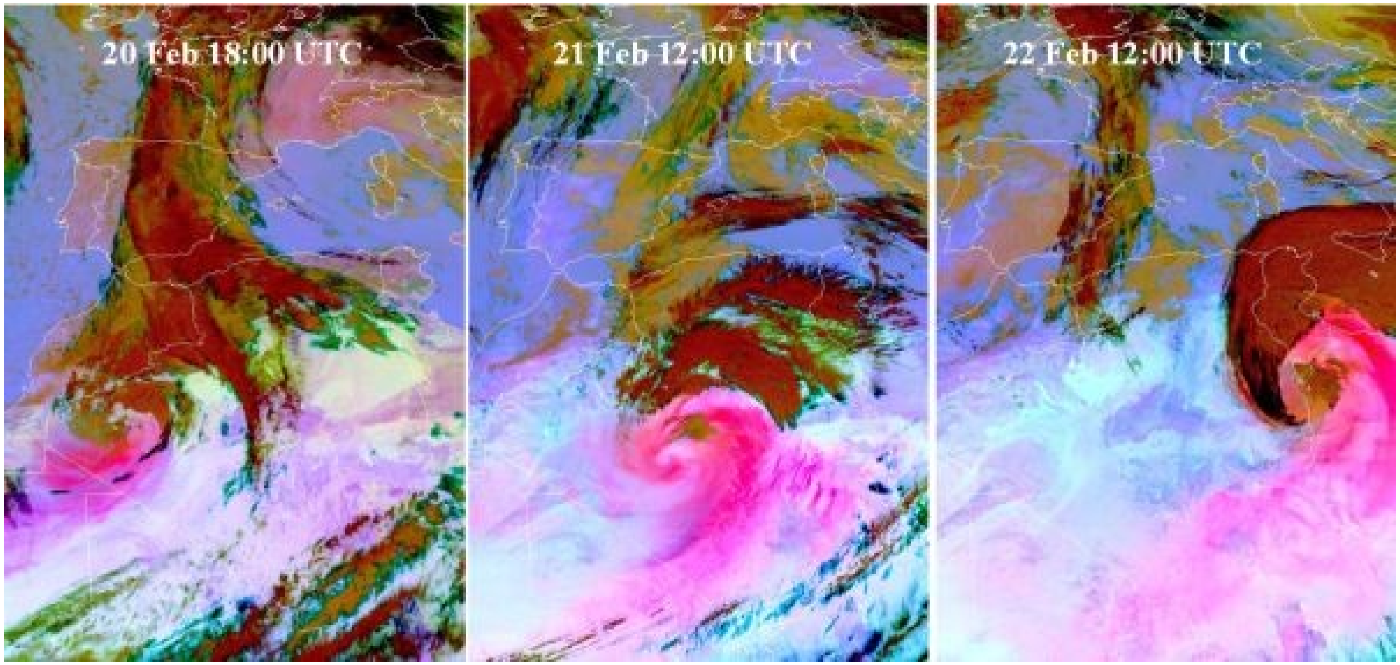
On 3 Nov 2008 a volcanic eruption was observed with Meteosat-9 using the Volcanic Ash RGB product (IR12.0-IR10.8, IR10.8-IR8.7, IR10.8).

The eruption occurred in a range of volcanoes in northern Ethiopia, called the Erta Ale range.



Applications of Metsat data (7)

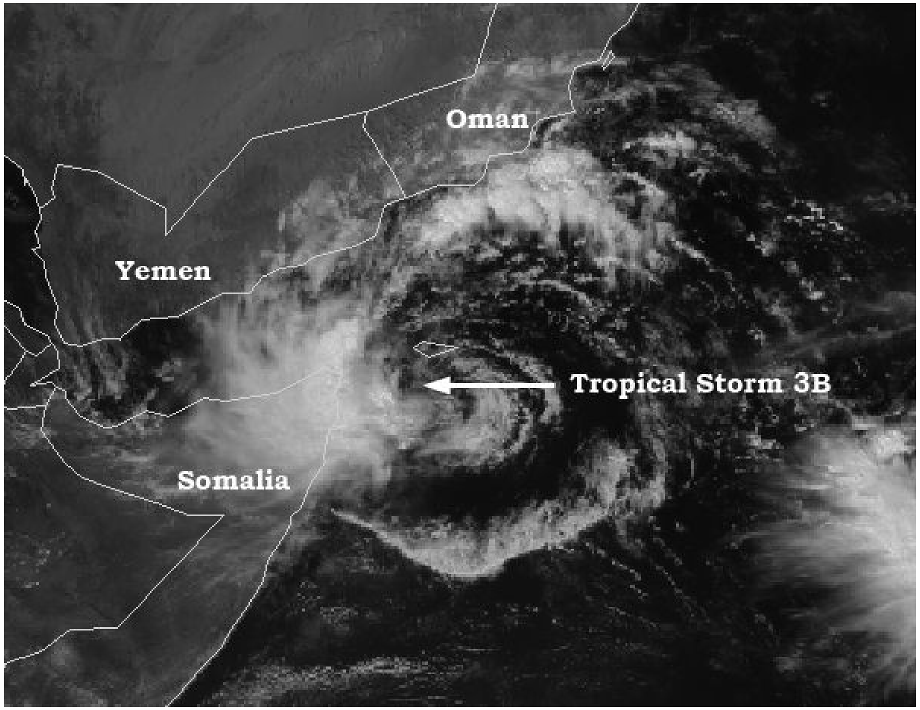
The images from Meteosat-8 (RGB Composite IR12.0-IR10.8, IR10.8-IR8.7, IR10.8) show a large-scale dust cloud over Northern Africa caused by a cold air outbreak.

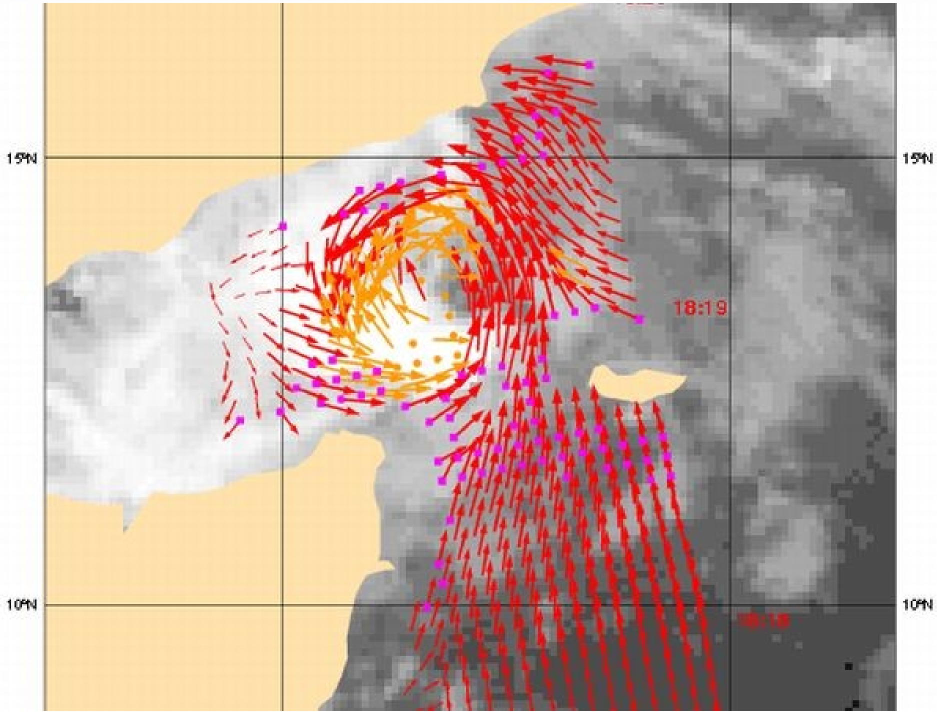


Applications of Metsat data (8)

Meteosat-7 (VIS Channel) captured the tropical storm as it was skirting the Horn of Africa on 21 Oct 2008.

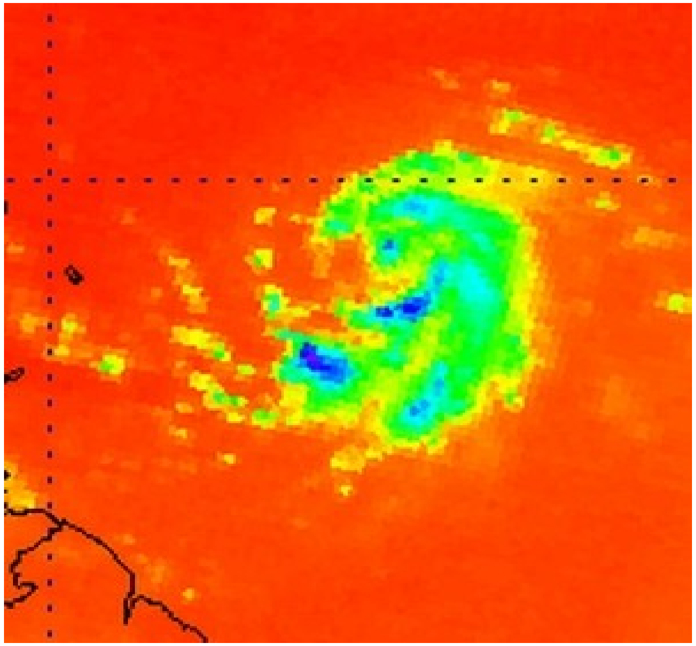
As of 22 Oct 2008, the tropical depression steered northwest over the eastern Gulf of Aden bound for southern Arabia (see Metop-A ASCAT wind product below).



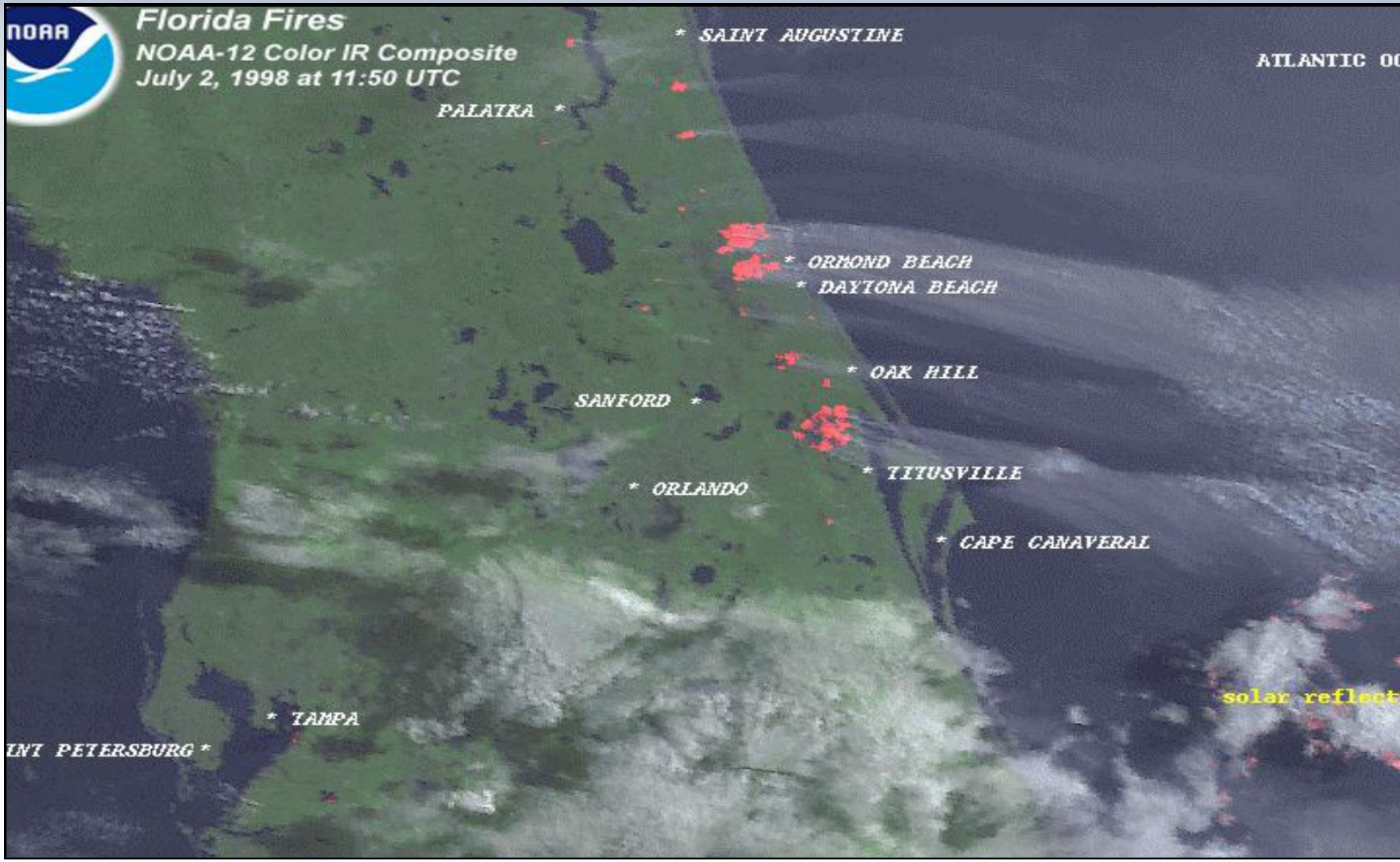


Applications of Metsat data (9)

The left image shows an Metop-A AVHRR RGB composite where white areas indicate colder cloud tops and likely precipitation, but it is difficult to determine exactly where the precipitation is falling beneath these cloud tops and to determine the rain rate. The image on the right shows, for approximately the same area, a Metop-A MHS (Microwave Humidity Sounder) band 2 (157 GHz) image. In this image one can see right through the Cirrus clouds to precipitation signatures caused by ice scattering. Thus, while infrared sensors detect only cloud top temperatures, using the high-frequency scattering channels from MHS allows one to observe precipitation cell signatures directly and to derive more precise quantitative rain rates.

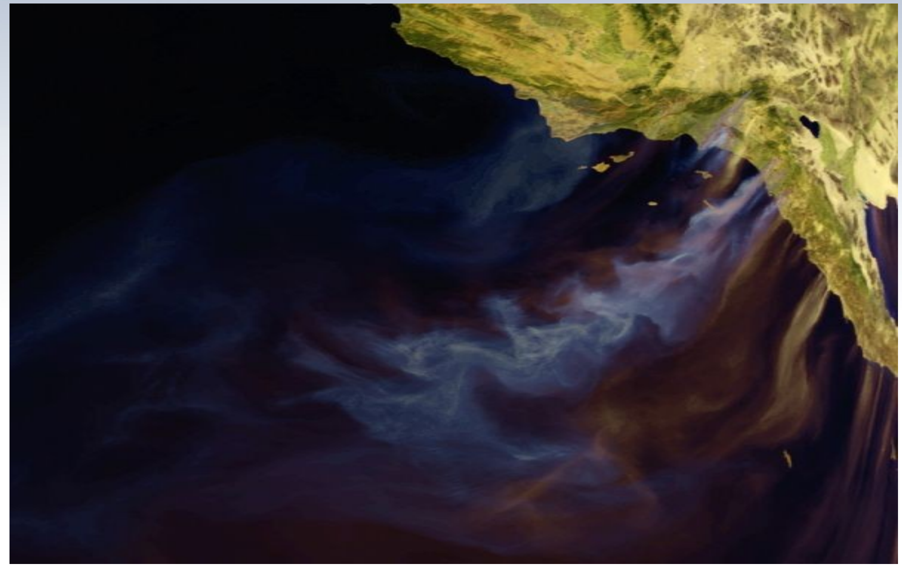


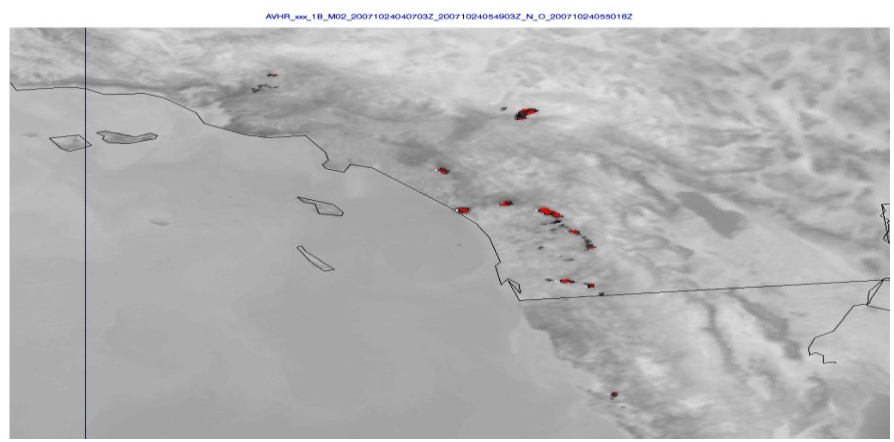
Applications of Metsat data (10)



Applications of Metsat data (11)

The Metop-A AVHRR image (RGB Composite NIR1.6, VIS0.8, VIS0.6) on the right shows fires in California on 22 Oct 2007 when large smoke plumes were visible over the Pacific Ocean.





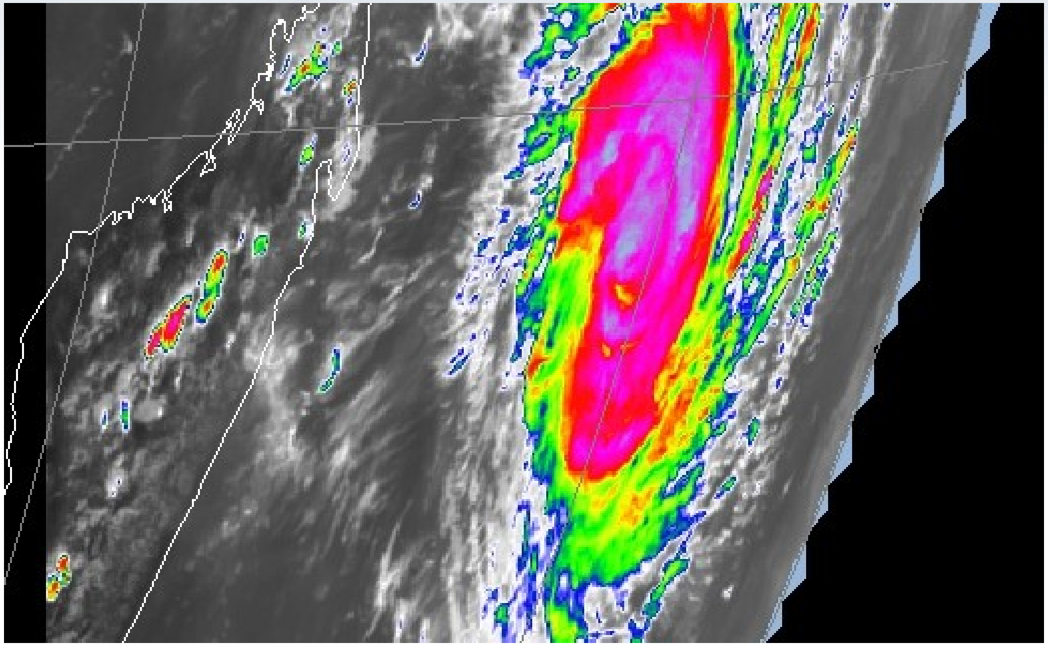
Smoke cloud seen from ground.

Applications of Metsat data (12)

Meteosat-9 (IR10.8 Channel) captured the Tropical Cyclone Giovanna on 11 February 2012 which had a well developed eye near the coast of Madagascar.

Cyclones of this intensity (Category 3 to 4) often cause severe damage.

In this image the coloured areas represent higher, colder clouds, with the strongest winds in the pink/lilac areas.



Historical Overview (1)

- Concept for meteorological satellites traces their origin to the rocket, sensor, and satellite development projects beginning after World War II,
- Measurements recovered from salvaged recorders or from radio transmissions were the basis for meteorological satellites research,
- Still cameras became part of the payload and recovered film depicted images of the Earth's surface and cloud cover from space.

Historical Overview (2)

First weather satellite launched from Cape Canaveral, FL

- Satellite Weight: 122 kg
- Payload: Two TV cameras, two video recorders, and the power, communications, and other systems needed

First view of cloud formations as they developed and moved across the continent

Historical Overview (3)

- Success of TIROS-1 led to approval of an operational weather satellite program in May 1961
  - Provision of day/night observations of global cloud cover
  - Open broadcasts of such data available from any ground station in view of satellite
- First Automatic Picture Transmission capability on TIROS-8, beginning December 1963

Historical Overview (4)

- On 6 Dec 1966 NASA launched the first Applications Technology Satellite (ATS-1) demonstrating the value of geostationary orbit to continuously monitor the same portion of the Earth,
- Success of ATS-1 led to development of NASA's Synchronous Meteorological Satellites (SMS-1 and -2) and then to first GOES.

1960-70's: NASA's Synchronous Meteorological Satellites (SMS) 1 and 2, prototype for NOAA's GOES and GOES 1-3. *Operational: 1974 until 1982*

- Geostationary satellite experiment begun in 1966
  - spin stabilized satellite (rotating at 100 revolutions per minute) viewing the earth only about ten percent of the time
  - monitor cataclysmic weather events
- Principle on board instrument
  - Visible Infrared Spin Scan Radiometer (VISSR) providing full-disk day and night imagery of cloud conditions

Historical Overview (5)

- With the launch of the first Meteosat satellite on 23 November 1977, Europe gained the ability to gather weather data over its own territory with its own satellite.
- Meteosat began as a research programme for a single satellite by the European Space Research Organisation, a predecessor of the European Space Agency (ESA).
- Once the satellite was in orbit, the immense value of the images and data it provided led to the move from a research to an operational mission requiring a dedicated organisation to conduct it.
- In anticipation of the founding of EUMETSAT, ESA launched the Meteosat Operational Programme (MOP) in March 1983.