Introduction to Remote Sensing – Part 2

- Medium-resolution Sensors
  - Landsat Series
  - SPOT Series
- High-resolution Sensors
  - Ikonos
  - Quickbird
- Low(er)-resolution Sensors
  - GOES
  - AVHRR
  - MODIS

The Landsat Series of Satellites

•While early applications of remote sensing were developed for military use, those technologies are now of **benefit to society** in many other applications, including environmental research

•On **July 23, 1972**, the first remote sensing satellite designed to collect satellite imagery throughout the globe for research purposes -- the Earth Resource Satellite -- was launched. This satellite was later renamed **Landsat**. The Landsat series of satellites continues to be used today (now up to Landsat 7)

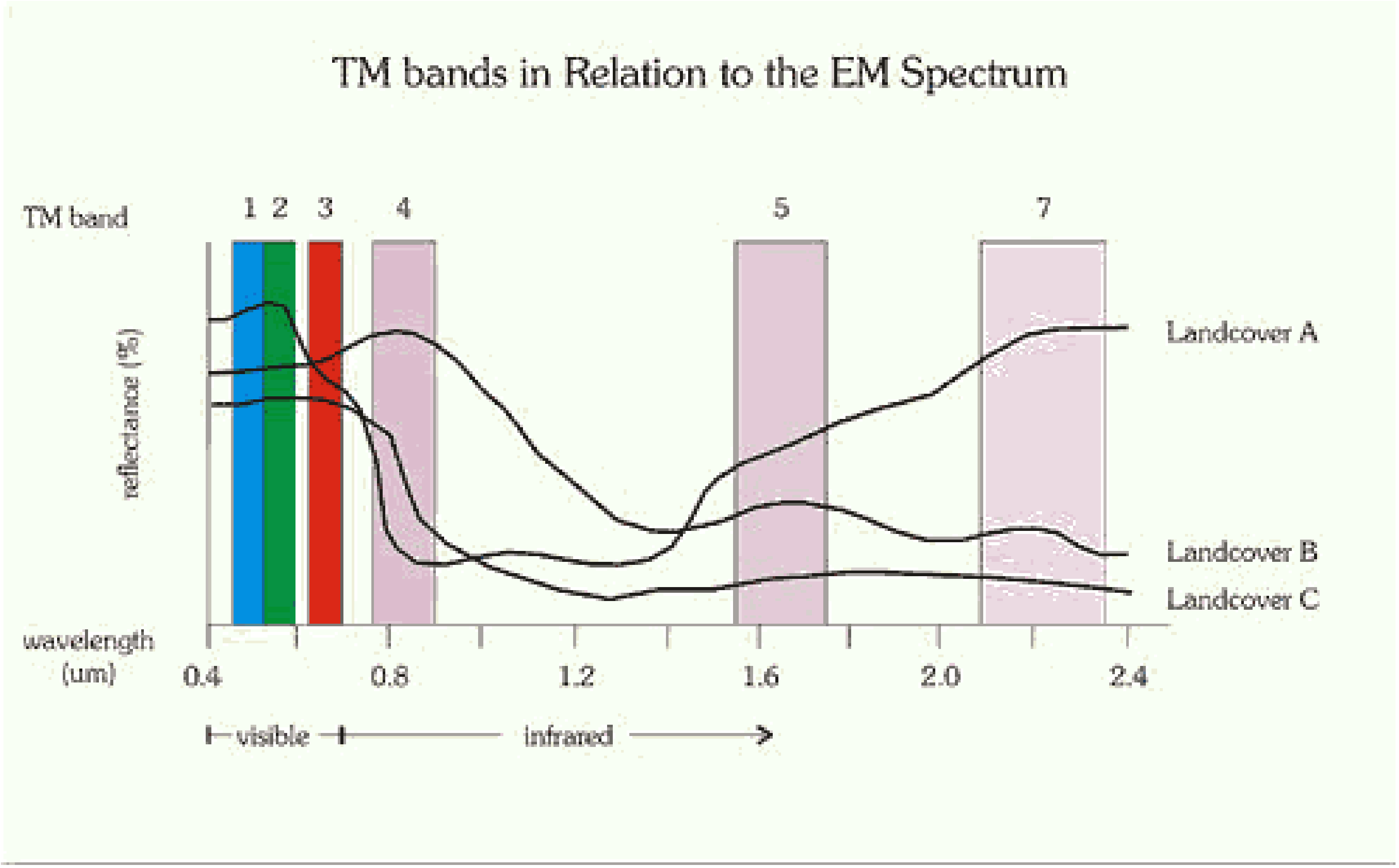
•While successive satellites in the series had more **advanced sensors** aboard, an effort was made to maintain some **continuity** in both the sensors' characteristics (e.g. their spatial, spectral, temporal, and radiometric resolutions) so that data collected from sensors aboard new **platforms** could be compared reasonably to older data

Landsat Platforms and their Sensors

Satellite	Launched	Decom.	RBV	MSS	TM	Orbit Info.
Landsat-1	23 Jul 1972	6 Jan 1978	1-3	4-7	none	18d/900km
Landsat-2	22 Jan 1975	25 Feb 1982	1-3	4-7	none	18d/900km
Landsat-3	5 Mar 1978	31 Mar 1983	A-D	4-8	none	18d/900km
Landsat-4	16 Jul 1982	--	none	1-4	1-7	16d/705km
Landsat-5	2 Mar 1984	--	none	1-4	1-7	16d/705km
Landsat-6	5 Oct 1993	Launch Failure	none	none	ETM	16d/705km
Landsat-7	15 Apr 1999	--	none	none	ETM+	16d/705km

RBV: Return Beam Vidicon {Blue, Green, Red}@~40m
MSS: Multi-spectral Scanner {Green, Red, NIR1, NIR2)@~80m
TM: Thematic Mapper {Blue, Green, Red, NIR, IR1, IR2}@~30m, TIR@120m
ETM: Thematic Mapper {Blue, Green, Red, NIR, IR1, IR2}@~30m, TIR@60m

Thematic Mapper Bands



Spectral Bands of Landsat Thematic Mapper Sensors
http://www.satelliteimpressions.com/landsat.html

Landsat 1, 2, and 3

Aronoff, S. 1989. Geographic Information Systems: A Management Perspective. WDL Publications, Ottawa, Ontario, Canada, p. 78.

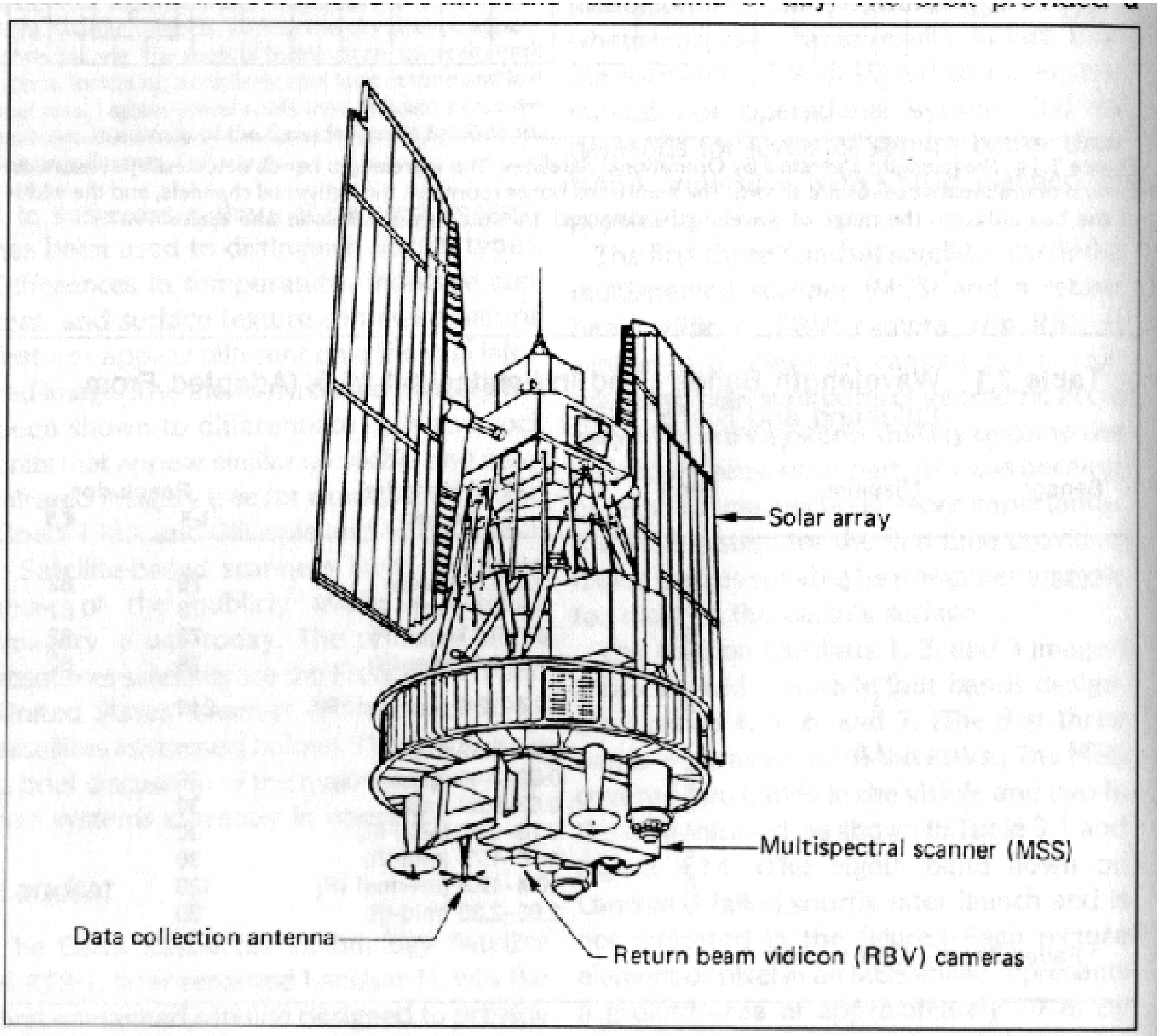


Figure 3.15 The Satellite Platform Used for Landsats 1, 2, and 3. (From *Remote Sensing and Image Interpretation* by Lillesand and Kiefer 1987, published by John Wiley and Sons.)

RBV

Return Beam Vidicon

~40m pixels

MSS

Multi-Spectral Scanner

~80m pixels

Landsat 4 and 5

Aronoff, S. 1989. Geographic Information Systems: A Management Perspective. WDL Publications, Ottawa, Ontario, Canada, p. 79.

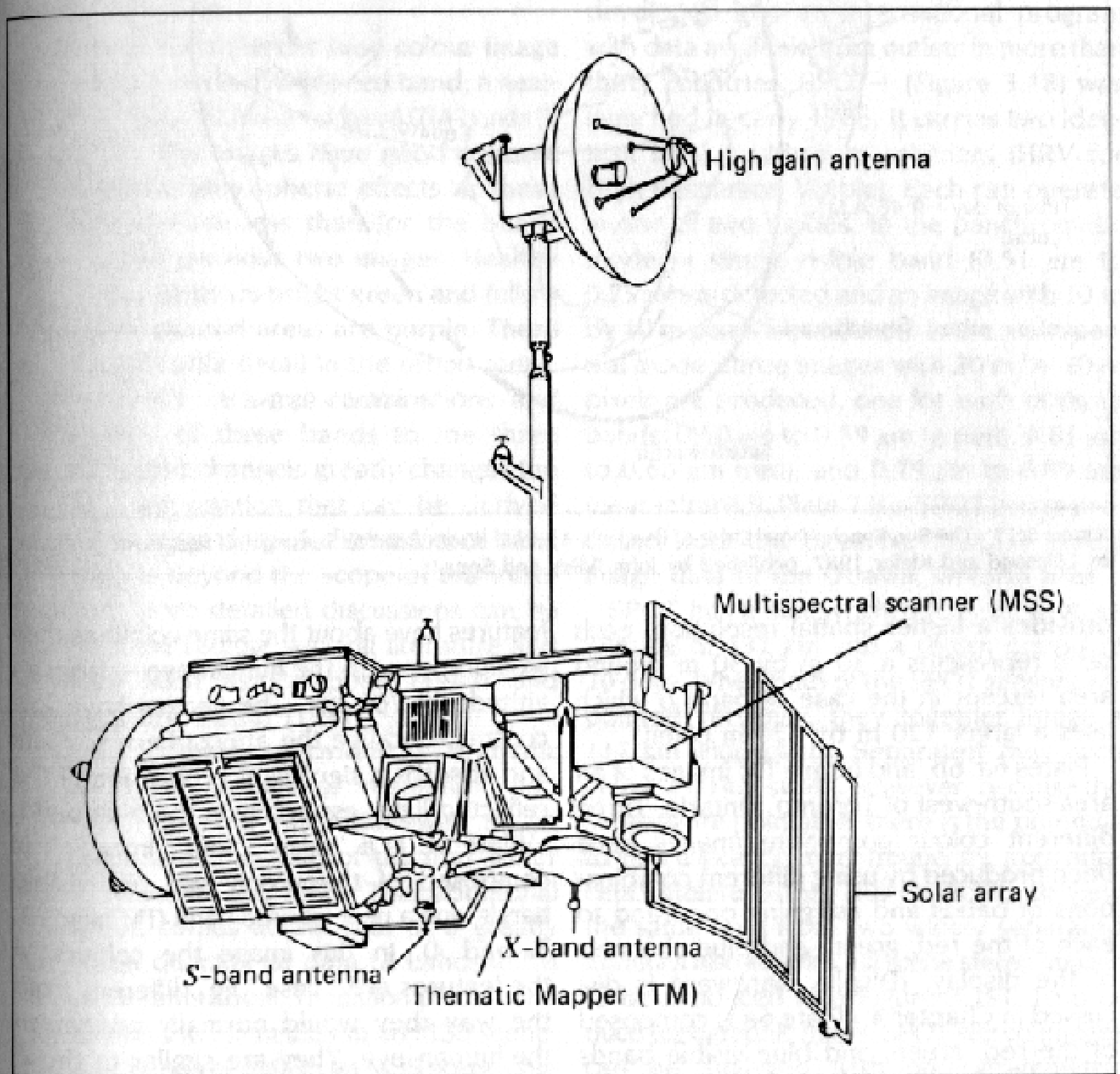


Figure 3.16 The Satellite Platform Used for Landsats 4 and 5. (From *Remote Sensing and Image Interpretation* by Lillesand and Kiefer 1987, published by John Wiley and Sons.)

MSS

Multi-Spectral Scanner

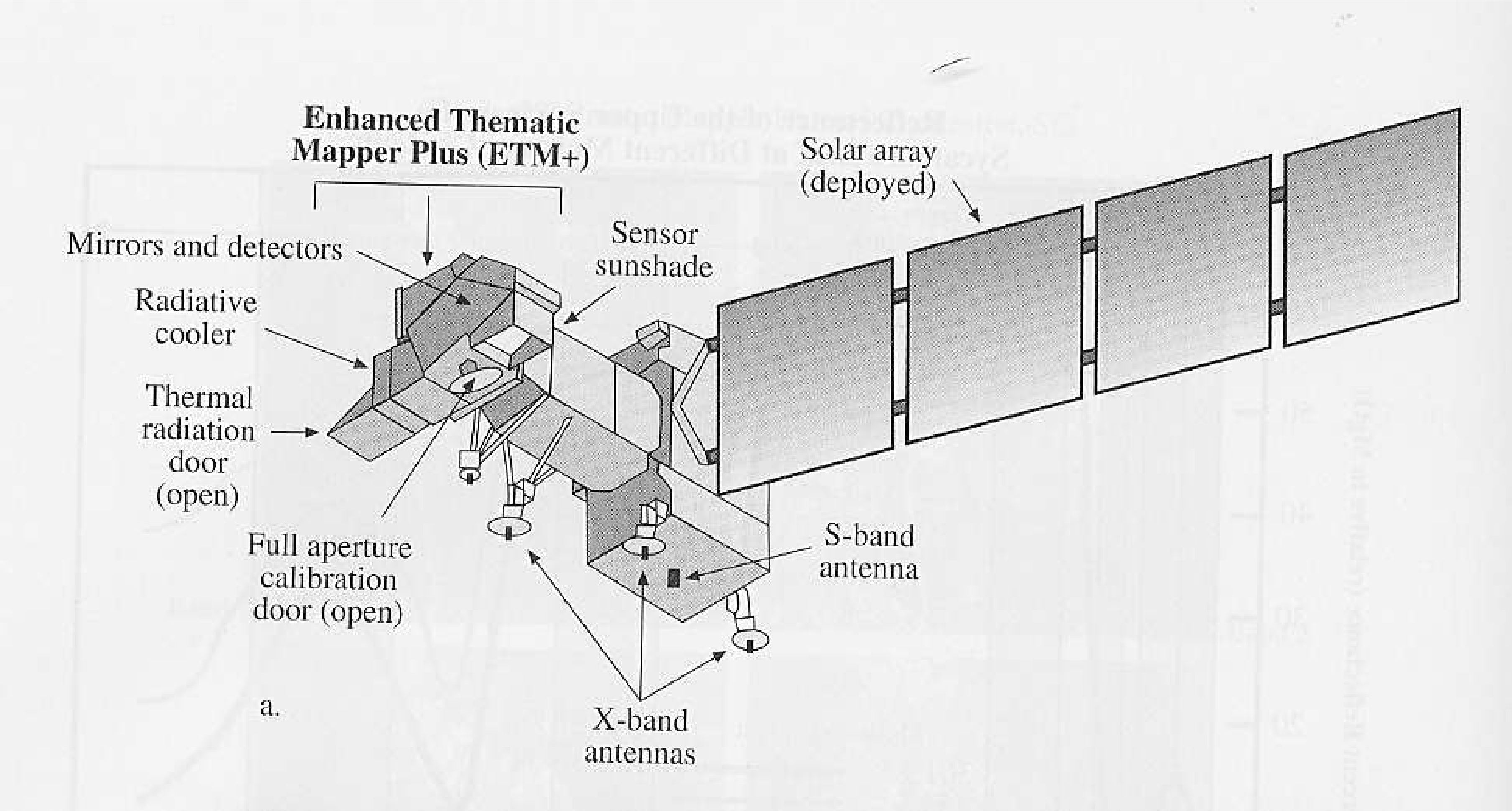
~80m pixels

TM

Thematic Mapper

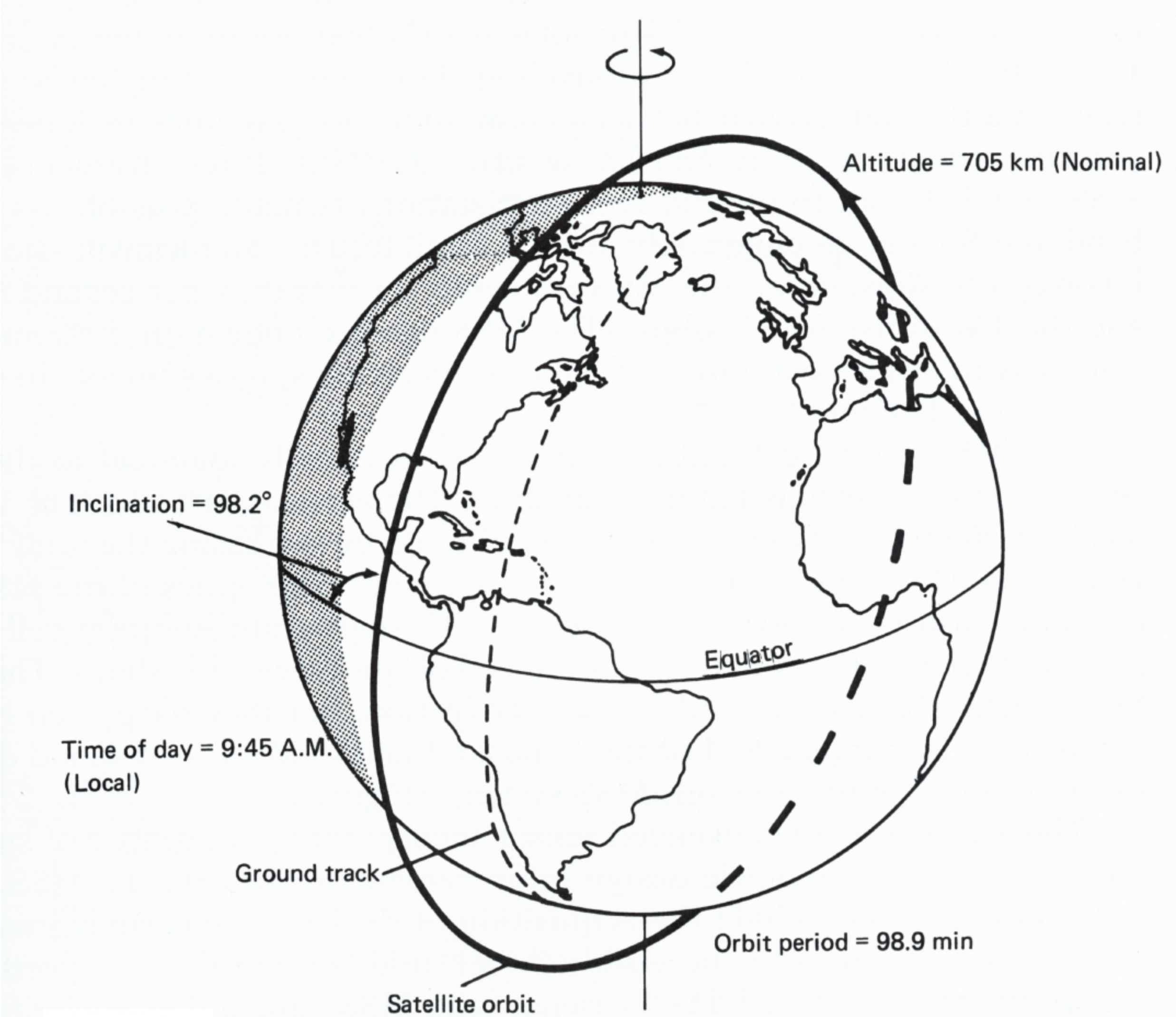
~30m pixels

Landsat (6 and) 7



ETM+ Enhanced Thematic Mapper Plus ~30m pixels

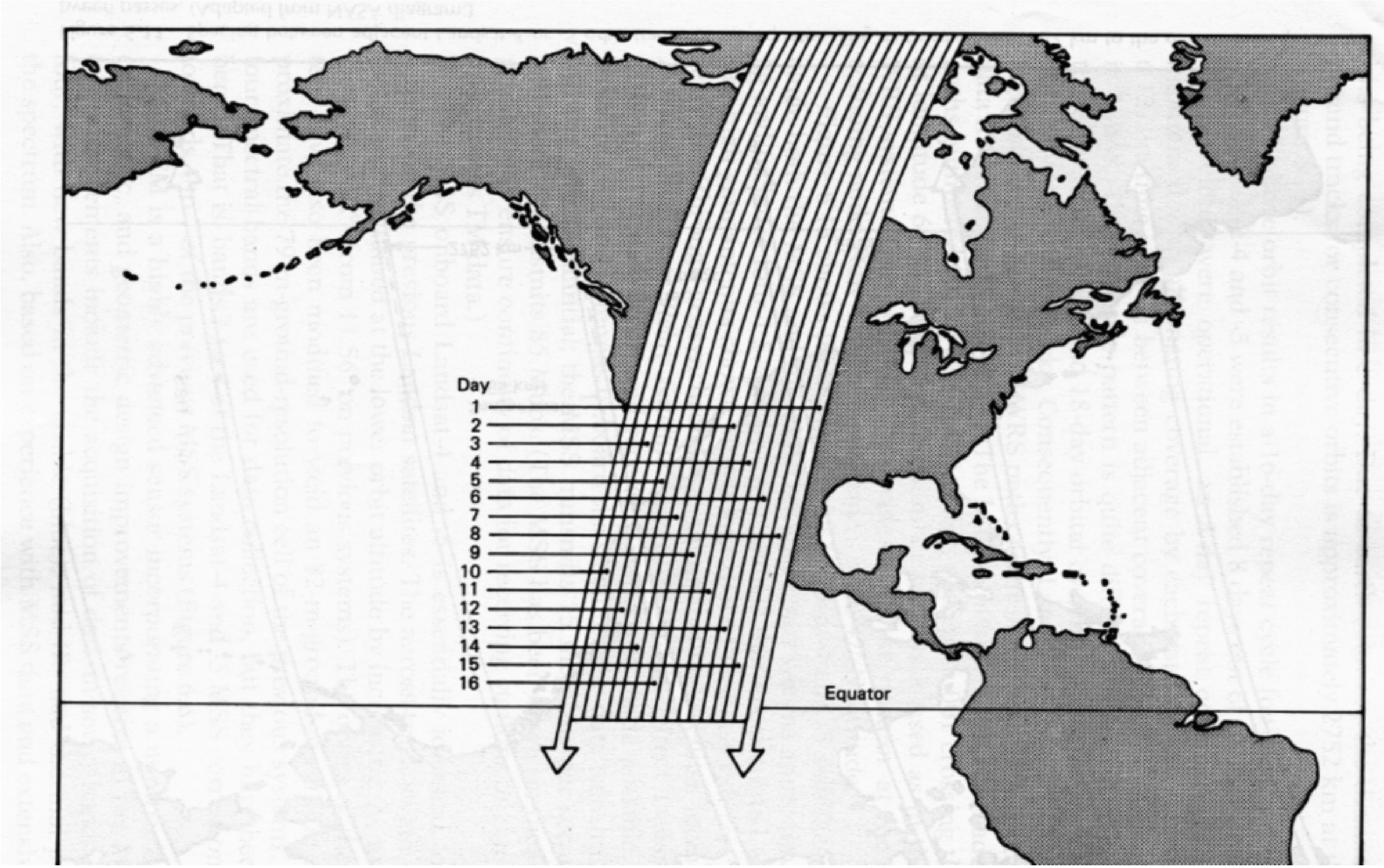
Landsat Orbits



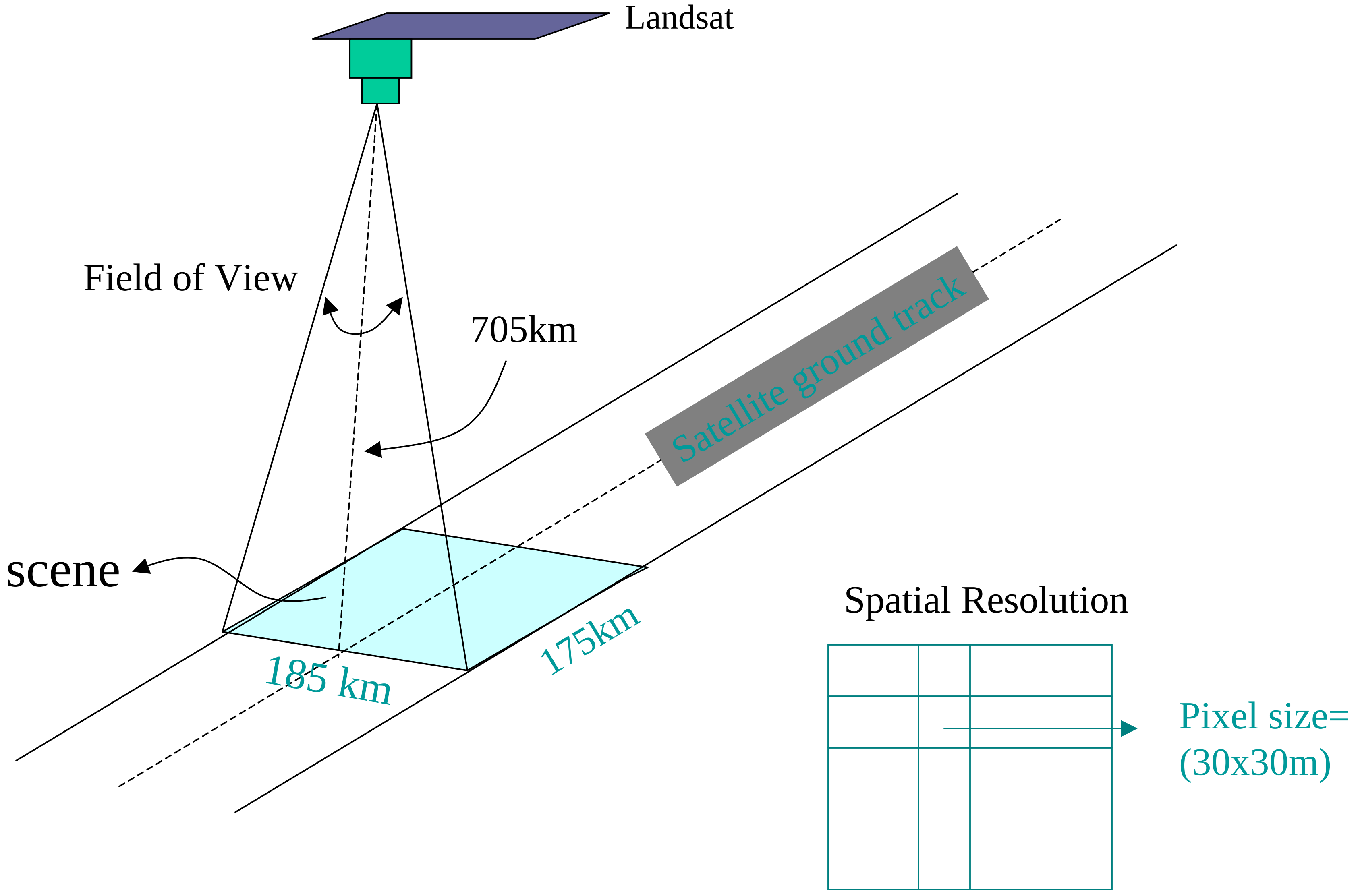
Sun-synchronous orbit of Landsat-4 and -5. (Adapted from NASA diagram.)

- Landsat satellites' orbits are designed to be **sun-synchronous orbits**, meaning that the satellites always cross the Equator at precisely the same local time (~10:00 am)
- In this way, images collected of different parts of the globe are collected under as **similar illumination conditions** as possible

Landsat Temporal Resolution



Landsat TM Swath Width



‘Wiskbroom’ Sensors

Aronoff, S. 1989. Geographic Information Systems: A Management Perspective. WDL Publications, Ottawa, Ontario, Canada, p. 72.

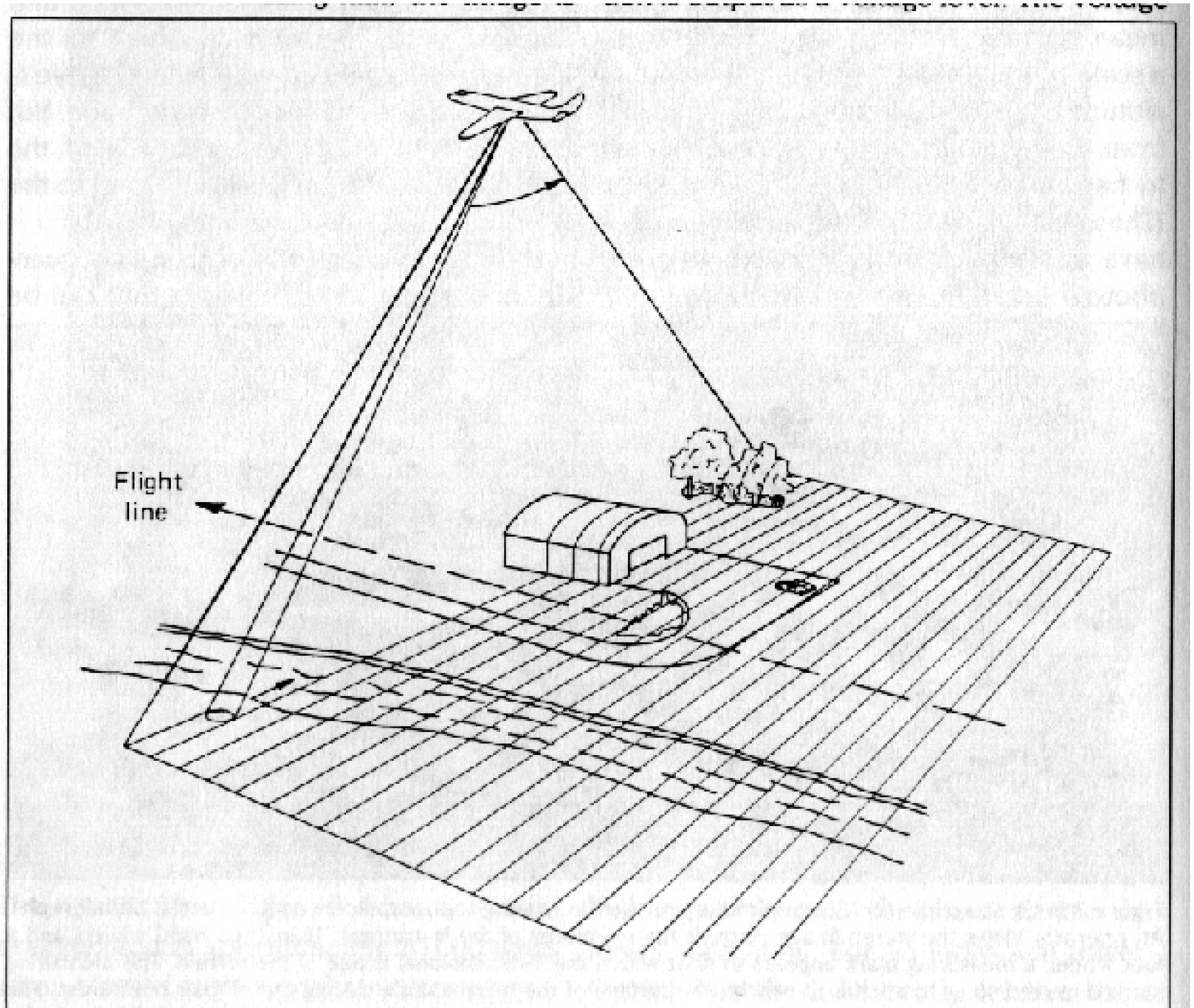
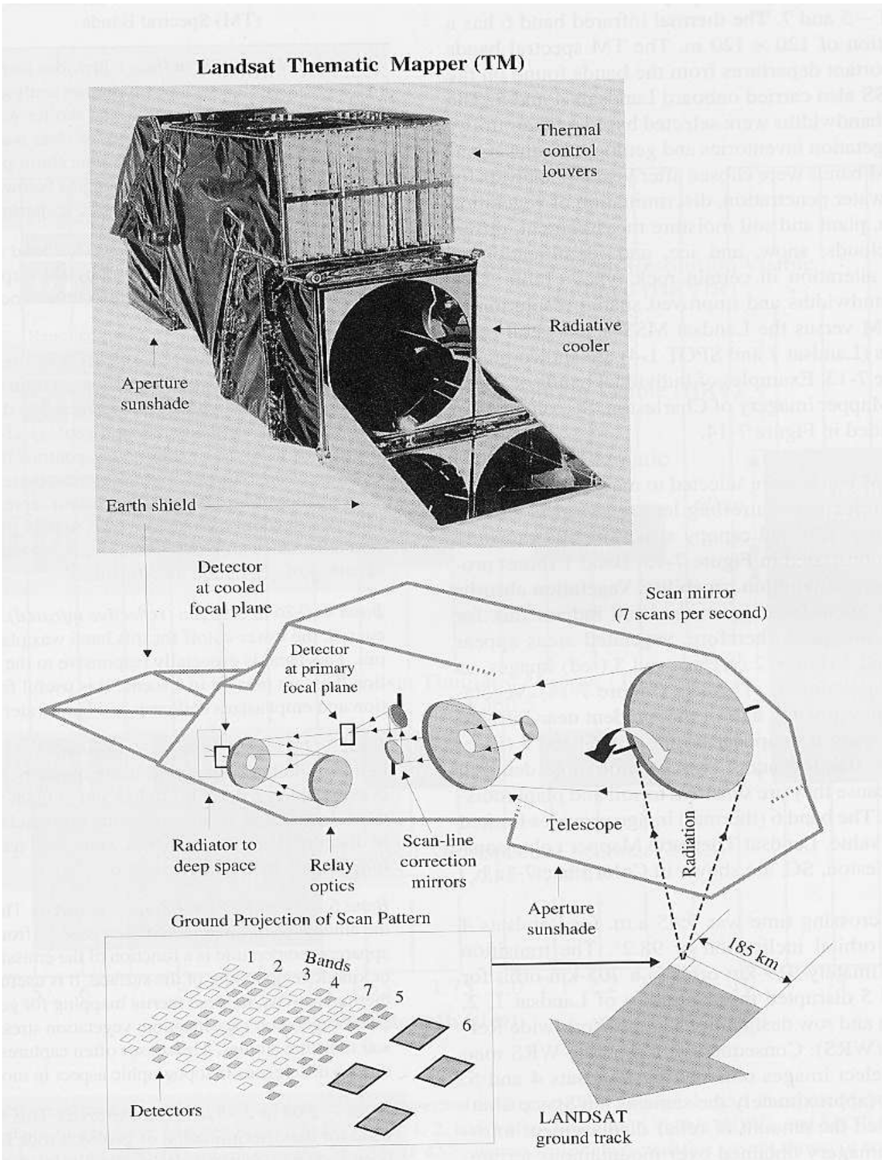
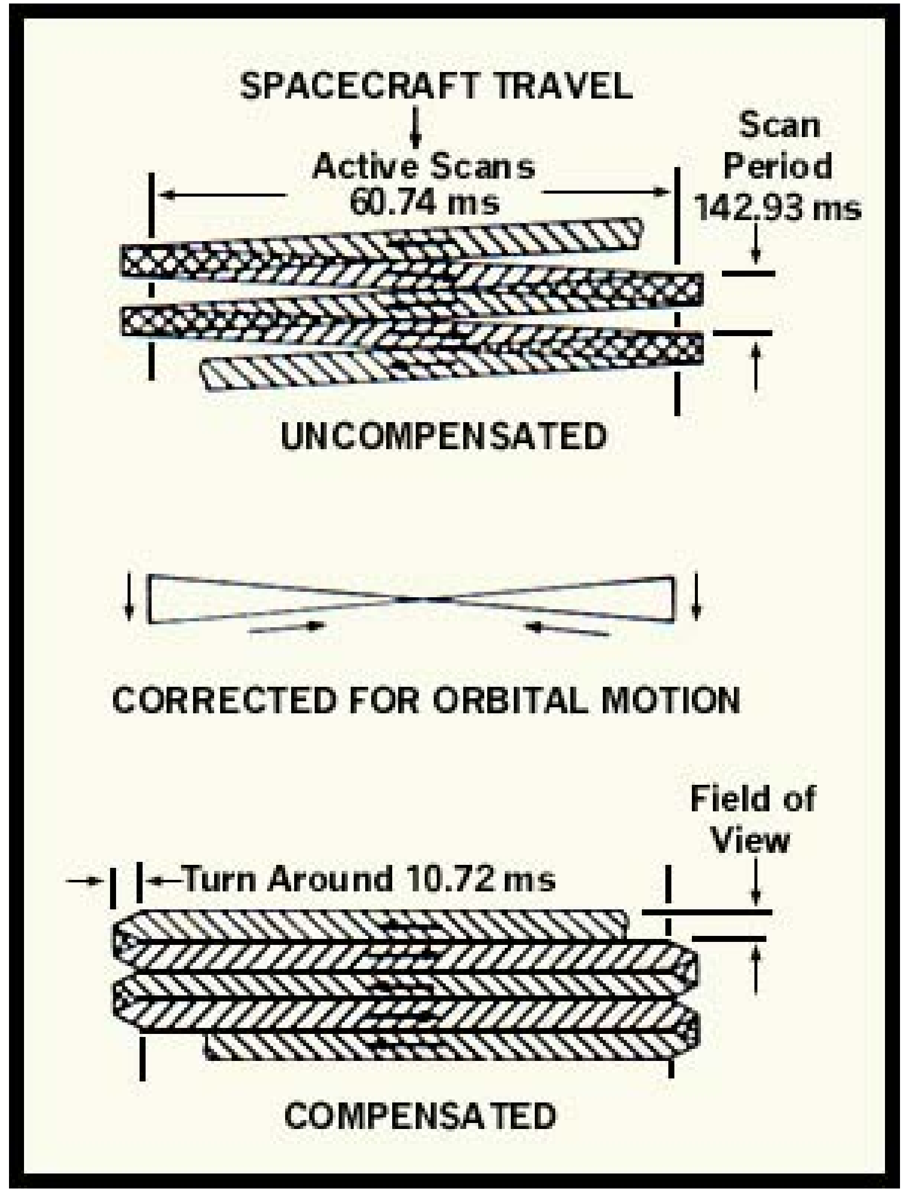


Figure 3.10 An Electro-Optical Scanner in Operation. (From *Remote Sensing and Image Interpretation* by Lillesand and Kiefer 1987, published by John Wiley and Sons.)

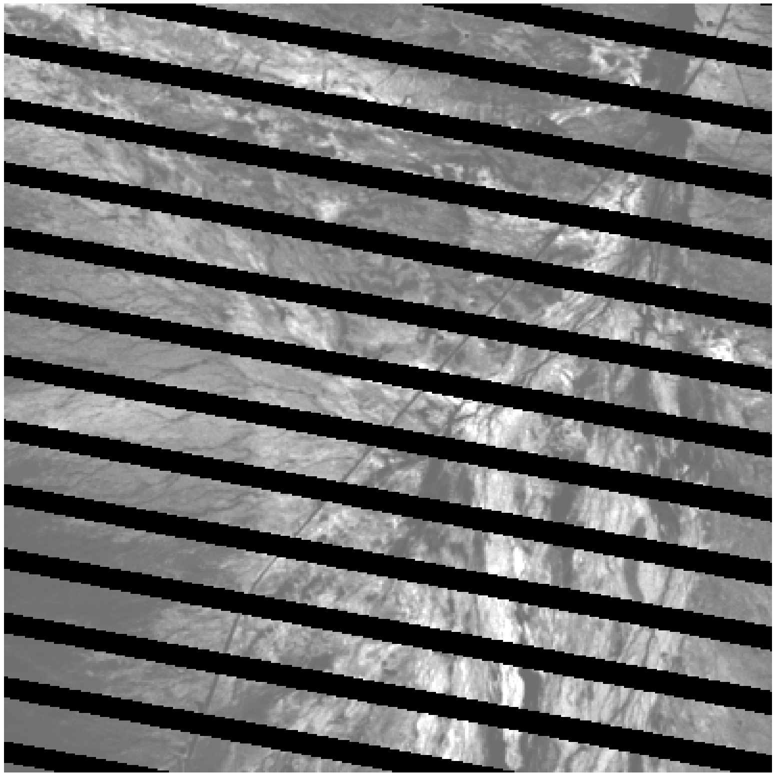
The Thematic Mapper Sensor

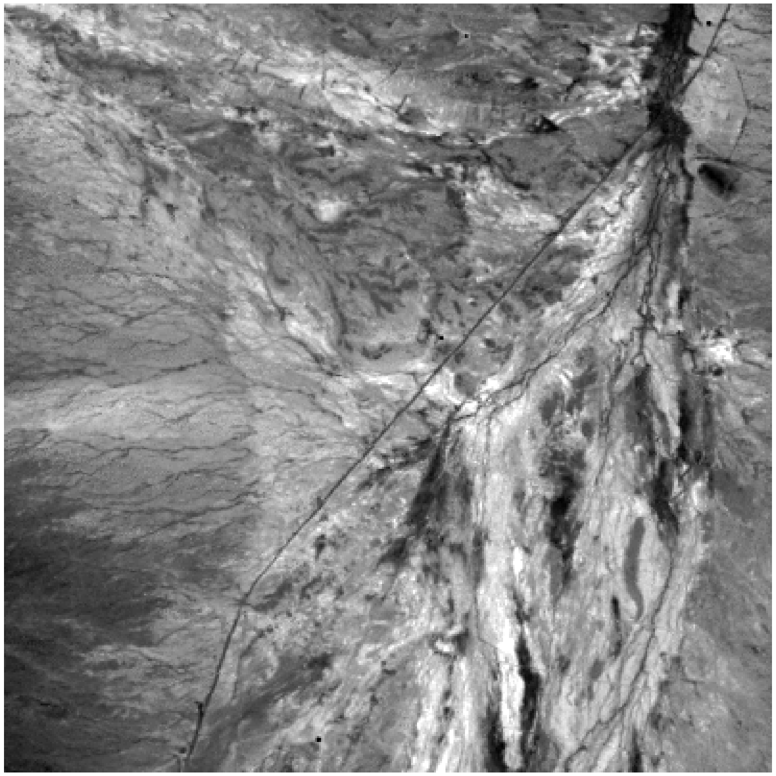




http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter13/htmls/slc.html ^

Scan Line Corrector Failure aboard Landsat 7

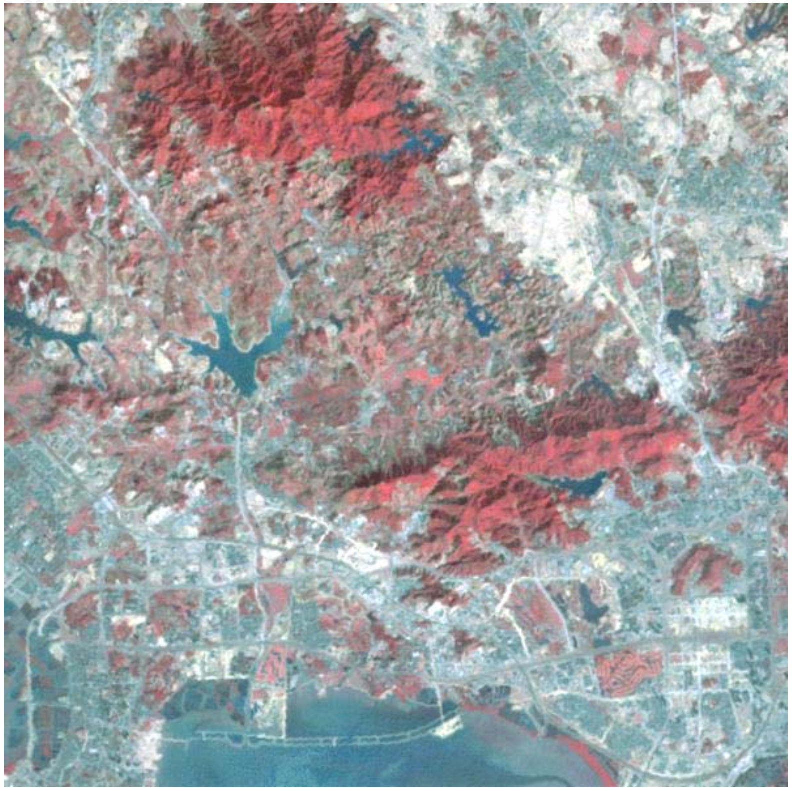




•On May 31, 2003, the scan line corrector in the Enhanced Thematic Mapper plus sensor **failed**

Using Landsat to Study Land Use Change

Landsat 5 TM image on Dec 10, 1988 of the Shenzhen Special Econ. Zone, China (RGB=432)



Landsat 5 TM image on Dec 30, 1995 of the Shenzhen Special Econ. Zone, China (RGB=432)

The SPOT Series of Satellites

•The United States' work with the Landsat series of satellites is **not the sole example** of a series of space-based satellite platforms that were developed to house multi-spectral scanning sensors designed to image the whole of the globe

•While the Landsat satellites in the 1970's were certainly the pioneering effort of this type, France soon followed suit with its **SPOT** (Systeme Pour L'Observation de la Terre - translation: System for Earth Observation) program

•SPOT 1 was launched in early 1986, and used some slightly different approaches to achieve **higher spatial resolutions** and **flexibility in image targeting** which the Landsat program did not achieve

SPOT Characteristics

Launch Dates

SPOT 1: February 22, 1986
SPOT 2: January 22, 1990
SPOT 3: September 26, 1993
SPOT 4: March 24, 1998
SPOT 5: May 3, 2002

Temporal resolution = 26 days
Radiometric resolution = 8-bit

HRV imaging instruments: SPOT 1, 2 and 3

Spectral bands:	Spatial resolution	swath width
0.5-0.59 (green)	20x20 m	60km
0.61-0.68 (red)	20x20 m	60km
0.79-0.89 (NIR)	20x20 m	60km
0.51-0.73 (panchromatic)	10x10 m	60km

HRVIR imaging instruments: SPOT 4

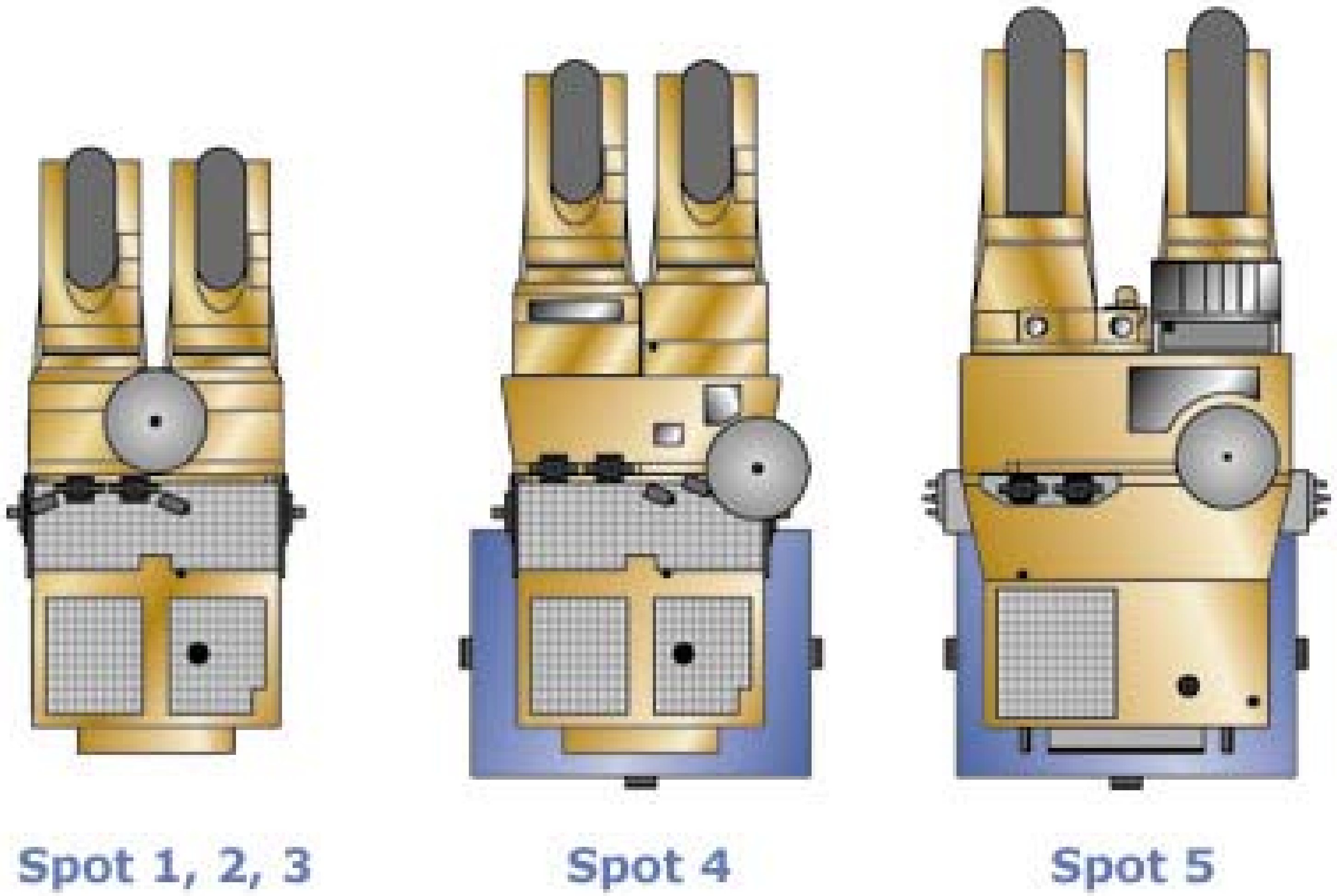
Spectral bands:	Spatial resolution	swath width
1.58-1.75 (SWIR)	20x20 m	60km

HRG imaging instruments: SPOT 5

Higher spatial resolution: 5m panchromatic, 10m visible/NIR bands, 20m SWIR

These are the primary sensors, each platform carries other …

SPOT Platforms



http://spot5.cnes.fr/gb/programme/programme.htm

‘Pushbroom’ Sensors

Aronoff, S. 1989. Geographic Information Systems: A Management Perspective. WDL Publications, Ottawa, Ontario, Canada, p. 74.

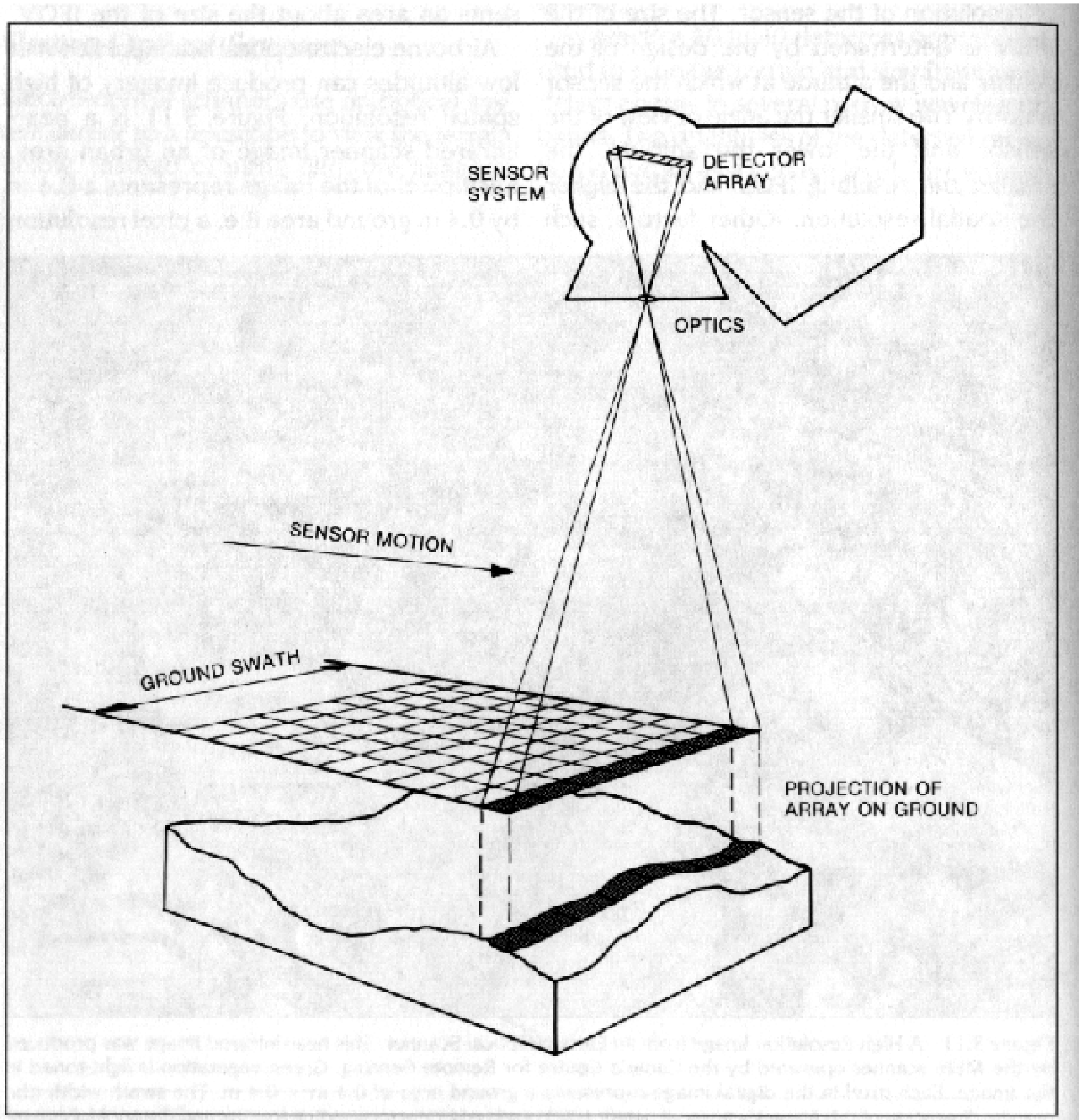
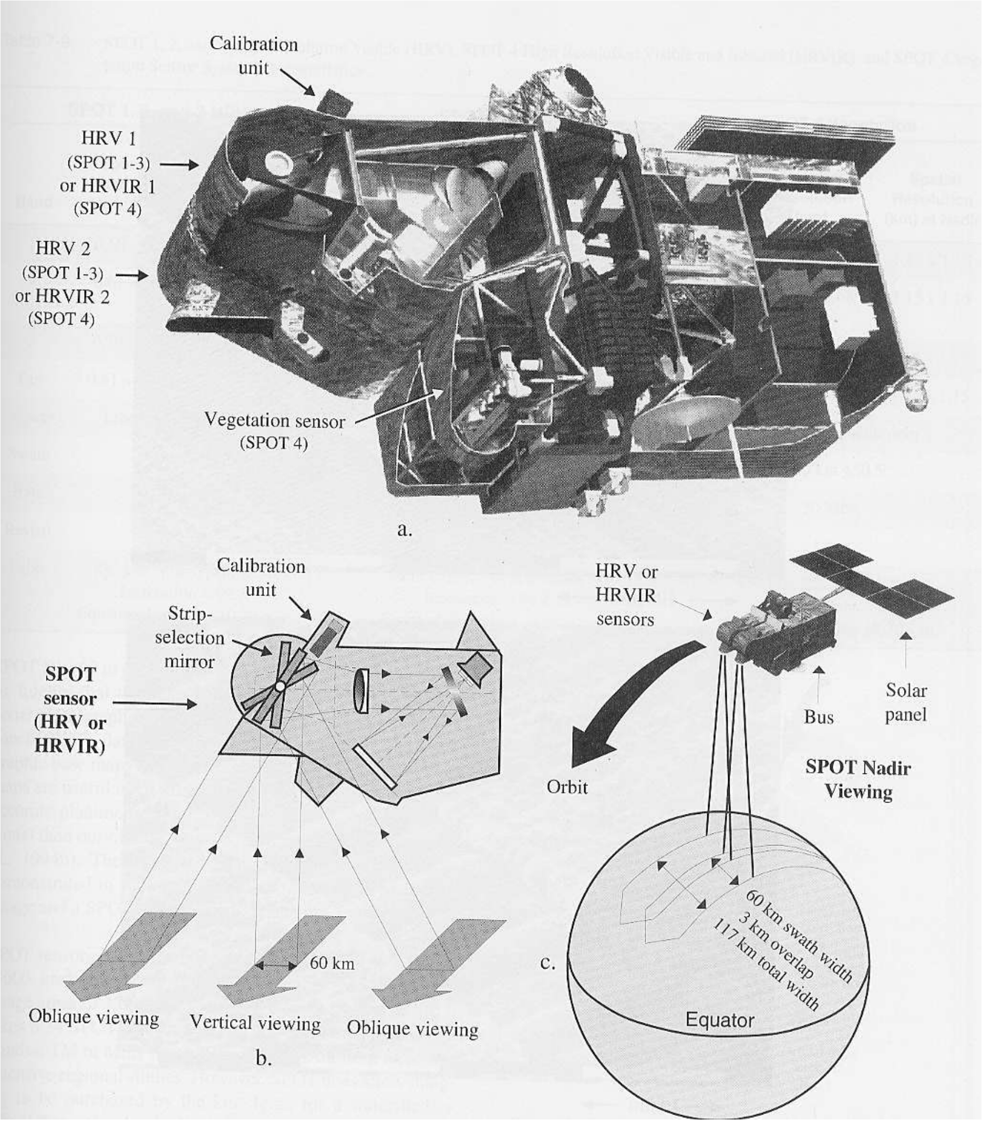


Figure 3.12 The Principle of Pushbroom Scanning.

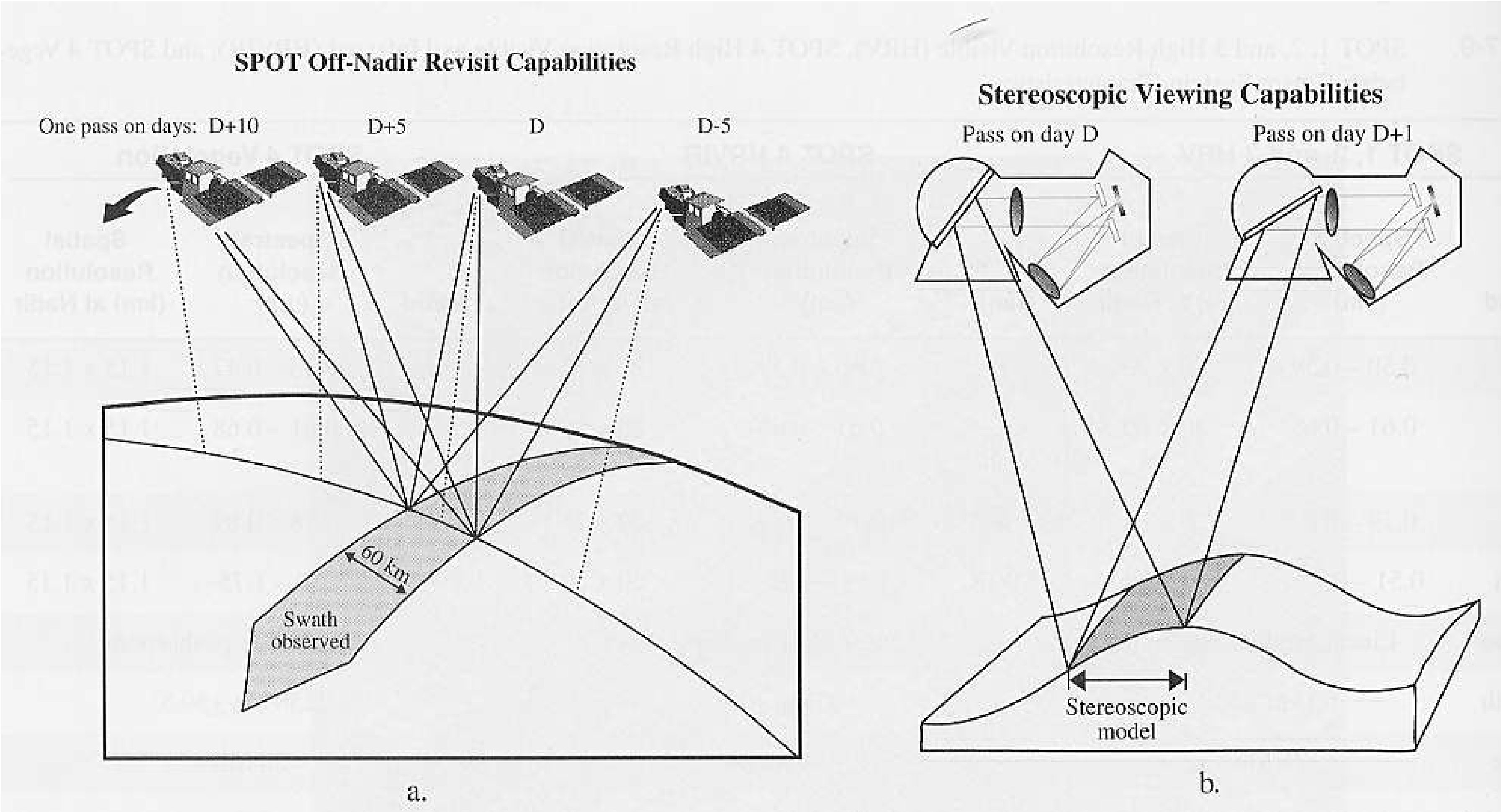
SPOT Sensor Characteristics

1. SPOT uses an **along track** scanning system (a.k.a. a pushbroom system): There is no scanning mirror (like in the wiskbroom scanner system used by TM)
   - Advantage: This allows longer dwell time for each pixel, thus **higher spatial resolution**
   - Disadvantage: **Sensor calibration is a challenge**, all adjacent sensors need to have equal sensitivity to radiance
2. The sensors are **pointable**, allowing repeat coverage of the same location from different angles
   - This increases the potential **frequency of coverage** of areas where cloud cover is a problem
   - This can provide samples for BRDF studies and other efforts where **multi-angle information** is useful
3. Two identical sensors give the ability to collect **stereoscopic imagery**

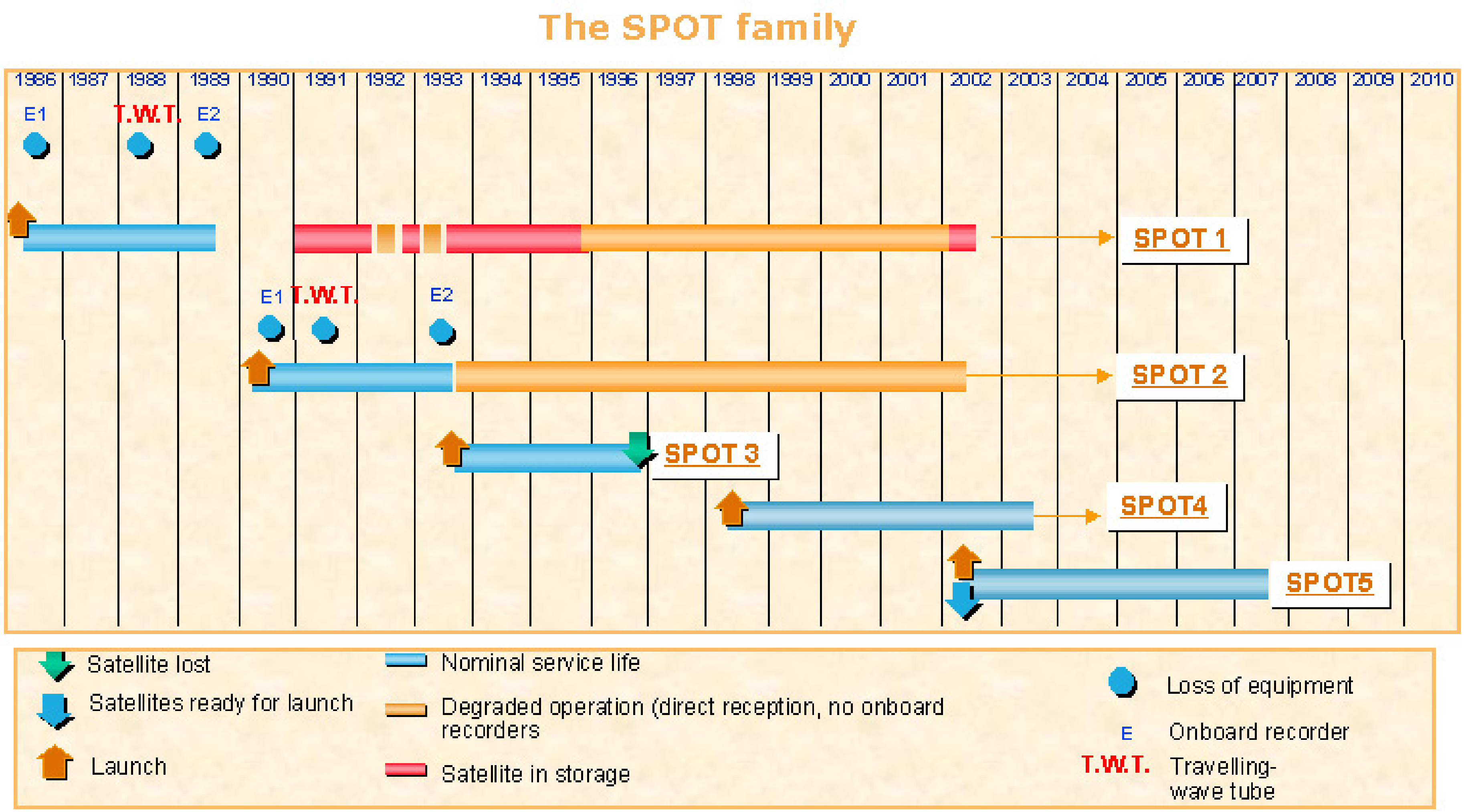
SPOT Satellite



Pointable SPOT Sensors



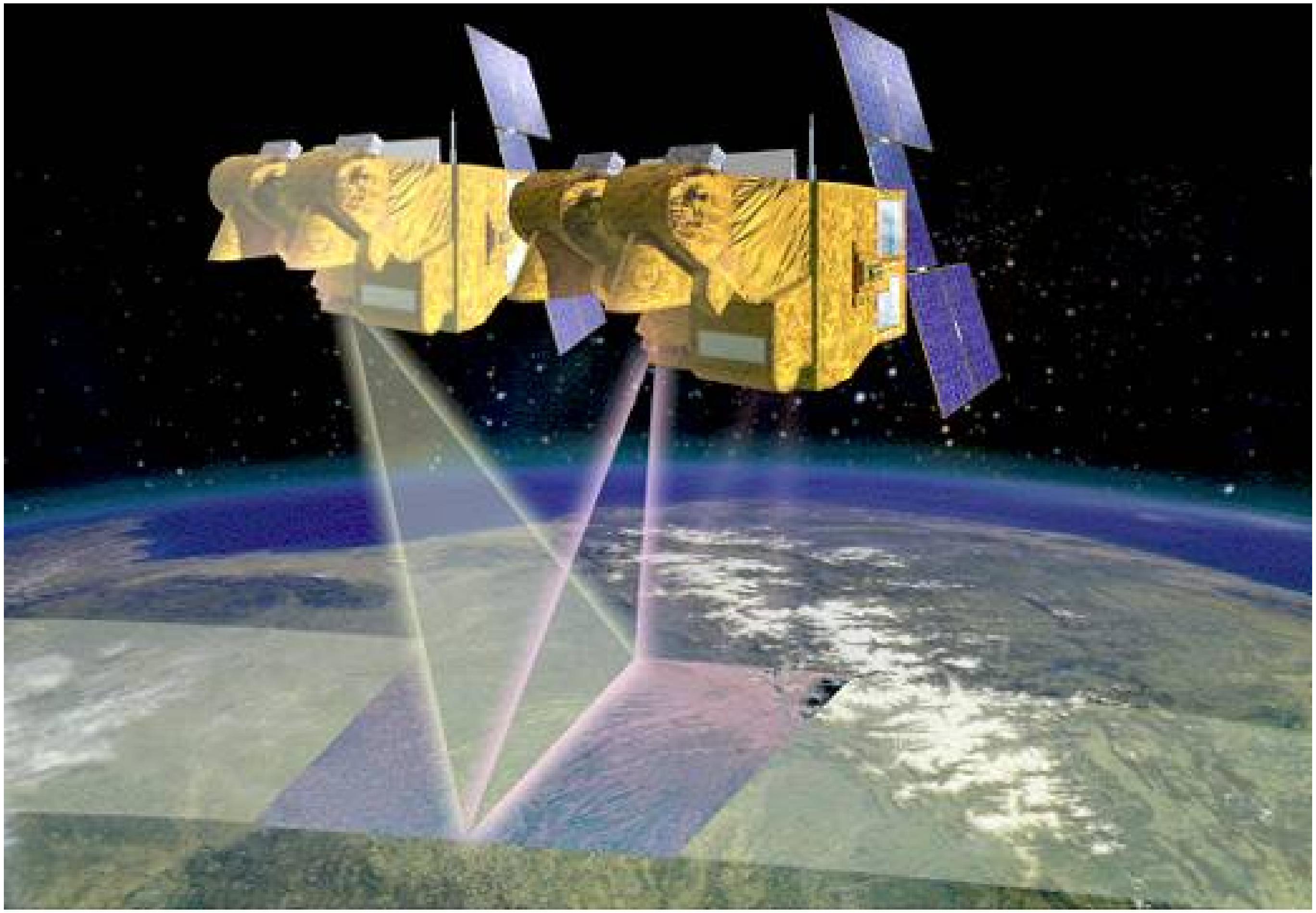
SPOT Operational Capability



http--spot5.cnes.fr-gb-images-112gb_1.jpg

SPOT 5 HRS Sensor

•SPOT 5 has an additional panchromatic sensor called the HRS that can be pointed either 20 degrees forward or aft, and is used to generate **stereopair imagery** using images taken in rapid succession



http://spot5.cnes.fr/gb/satellite/satellite.htm

SPOT 5 HRS Sensor

•Stereopairs can be used to generate **digital elevation models,** along with co-registered **panchromatic imagery** that can be used to produce flythrough movies, like this one of Naples and Mount Vesuvius from data collected shortly after SPOT-5 became operational:

http://spot5.cnes.fr/video/ves_low.mpg

Ikonos

Owner: Space Imaging (a **commercial** concern)

Launched: September 1999

Temporal resolution: 11 days (1-3 days considering oblique views)

Radiometric resolution: 11-bit (**8x better** than TM or SPOT)

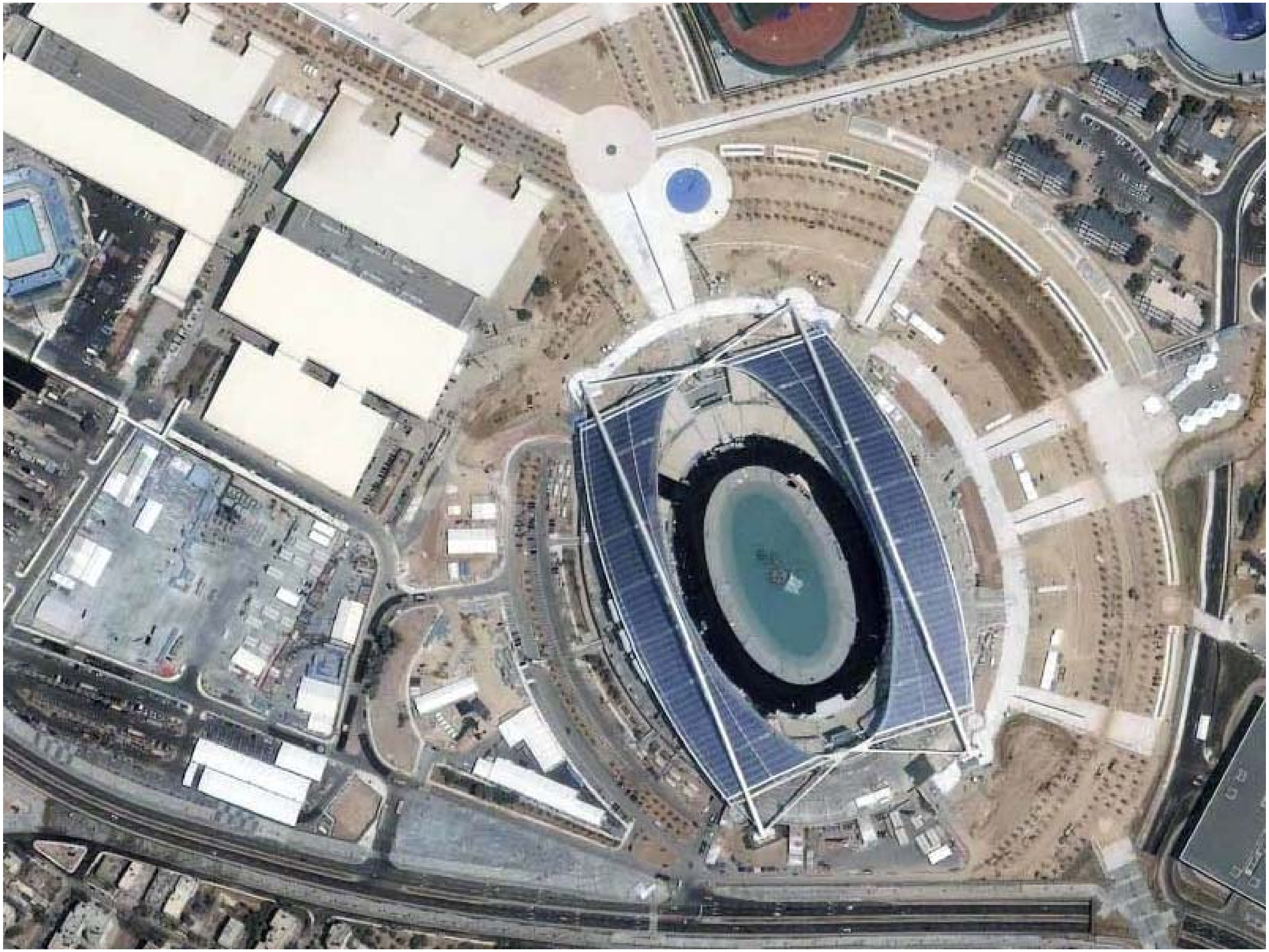
Spectral bands	spatial resolution
0.45-0.52 (blue)	4m
0.51-0.60 (green)	4m
0.63-0.70 (red)	4m
0.76-0.85 (NIR)	4m
0.45-0.90 (Panchromatic)	1m

Swath width: 11km

Sensor systems: pushbroom system, **pointable** both along track and across track.

Orbit: 682km sun-synchronous having an equatorial crossing time of 10:30am

Ikonos Image - Athens Olympic Sports Complex



July 24, 2004

Quickbird

Owner: Digital Globe (another **commercial** concern, the competition!)

Launched: October 18, 2001

Temporal resolution: 1-5 days (considering oblique views)

Radiometric resolution: 11-bit (**8x better** than TM or SPOT)

Spectral bands	spatial resolution
0.45-0.52 (blue)	2.5m
0.52-0.60 (green)	2.5m
0.63-0.69 (red)	2.5m
0.76-0.90 (NIR)	2.5m
0.45-0.90 (Panchromatic)	60cm

Swath width: 16.5km

Sensor systems: pushbroom system, **pointable** both along track and across track.

Orbit: 450km sun-synchronous having an equatorial crossing time of 10:30am

Quickbird Image - Athens Olympic Sports Complex

August 23, 2004

The GOES Program

- The **GOES (Geostationary Orbiting Environmental Satellite)** program is a joint venture between the National Aeronautical and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA)
- NASA's primary responsibility was to **engineer the launch** of the satellites and place them in orbit
- NOAA is concerned with the **science associated with the collected data**; the GOES satellites are primarily applied to atmospheric research (collecting meteorological and climatological data, producing energy budgets and atmospheric gas composition assays, predicting severe weather, tracking sea surface temperatures etc.)

The Early GOES Satellites

- The complete details of every GOES satellite would be tedious to list here … the GOES program started around the same time as the Landsat program, having grown out of the **Synchronous Meteorological Satellite (SMS)** program that began in the late 1960’s (SMS-1 launched May 17, 1974)
- SMS-1, SMS-2, GOES-1, GOES-2, and GOES-3 were all essentially the same, carrying the **Visible Infrared Spin-Scan Radiometer (VISSR),** which effectively was a camera that could provide visible and infrared photographs of cloud conditions over a ‘full disk’ view of half of the Earth
- The **geostationary orbit** of this series of satellites meant that their effective spatial and temporal resolutions are very different from those we have seen so far

Geostationary Orbit

•Instead of revolving around the Earth every 90-100 minutes in a sun-synchronous orbit like the other satellites we have discussed, these satellites were placed into an orbit that **maintains a fixed relationship** with the Earth

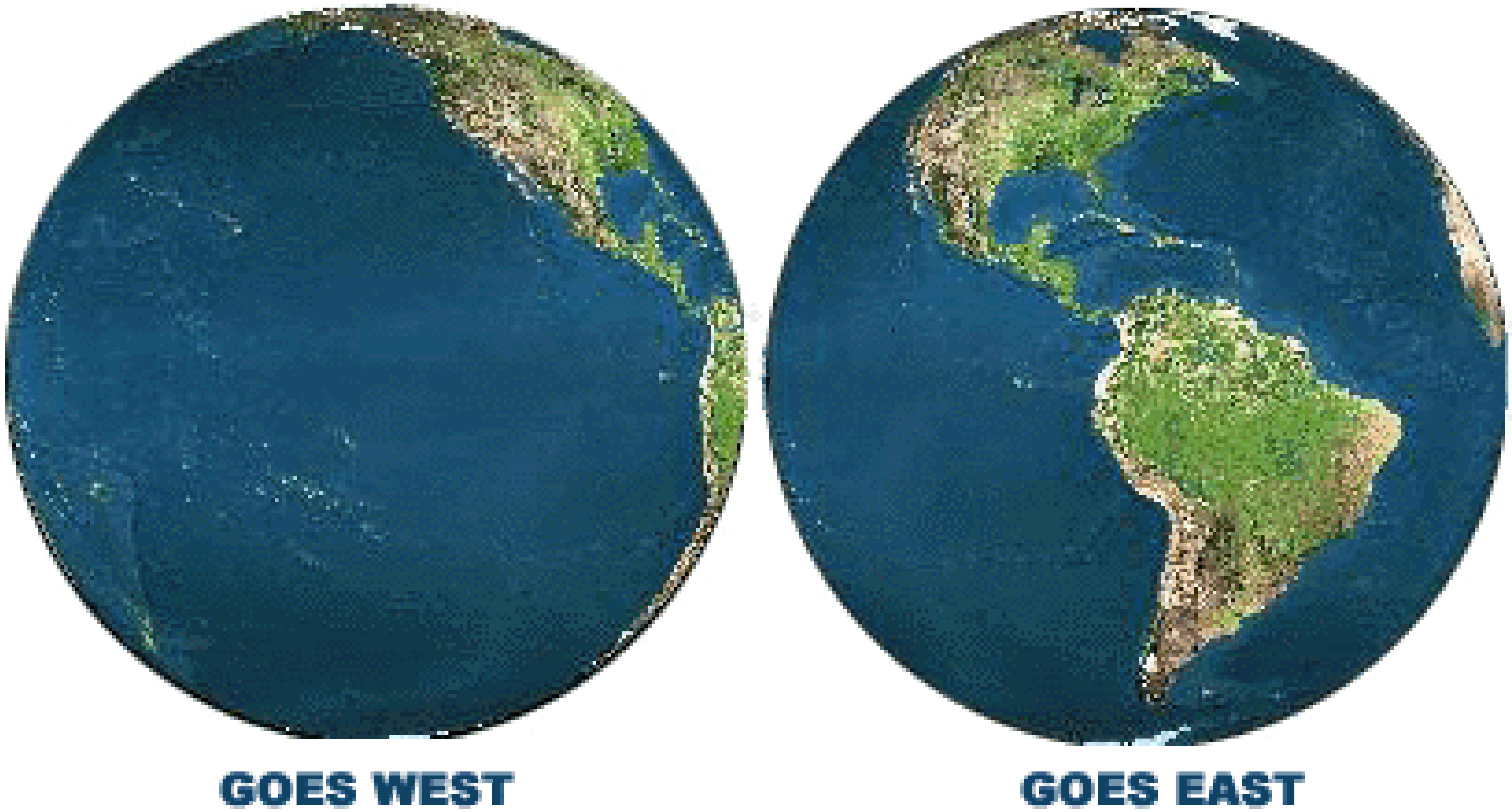
•These orbits are **very high** (~35,800 km above the surface of the Earth), and the combination of this high orbit with a **broad field of view** means that sensors on these platforms can image a **'full-disk'** or half the planet at one time

•Because this orbit is geostationary, these satellites can image that half of the planet within their view **continuously** such that information can be gathered over the full diurnal night-day cycle, although spatial resolution is sacrificed in this approach (much bigger pixels!)

The Later GOES Satellites

- A total of **12 GOES Satellites** have been launched through the course of the program, and at present, there are 4 that remain potentially operational:
  - GOES-9 is being used by the Japanese Meteorological Agency to replace a satellite they lost
  - GOES-10 is currently designated **GOES-EAST** and is imaging the Americas and the Atlantic Ocean
  - GOES-11 is in orbit and dormant, waiting to be used to replace another satellite when it fails (**in storage**)
  - GOES-12 is currently designated **GOES-WEST** and is imaging the Pacific Ocean

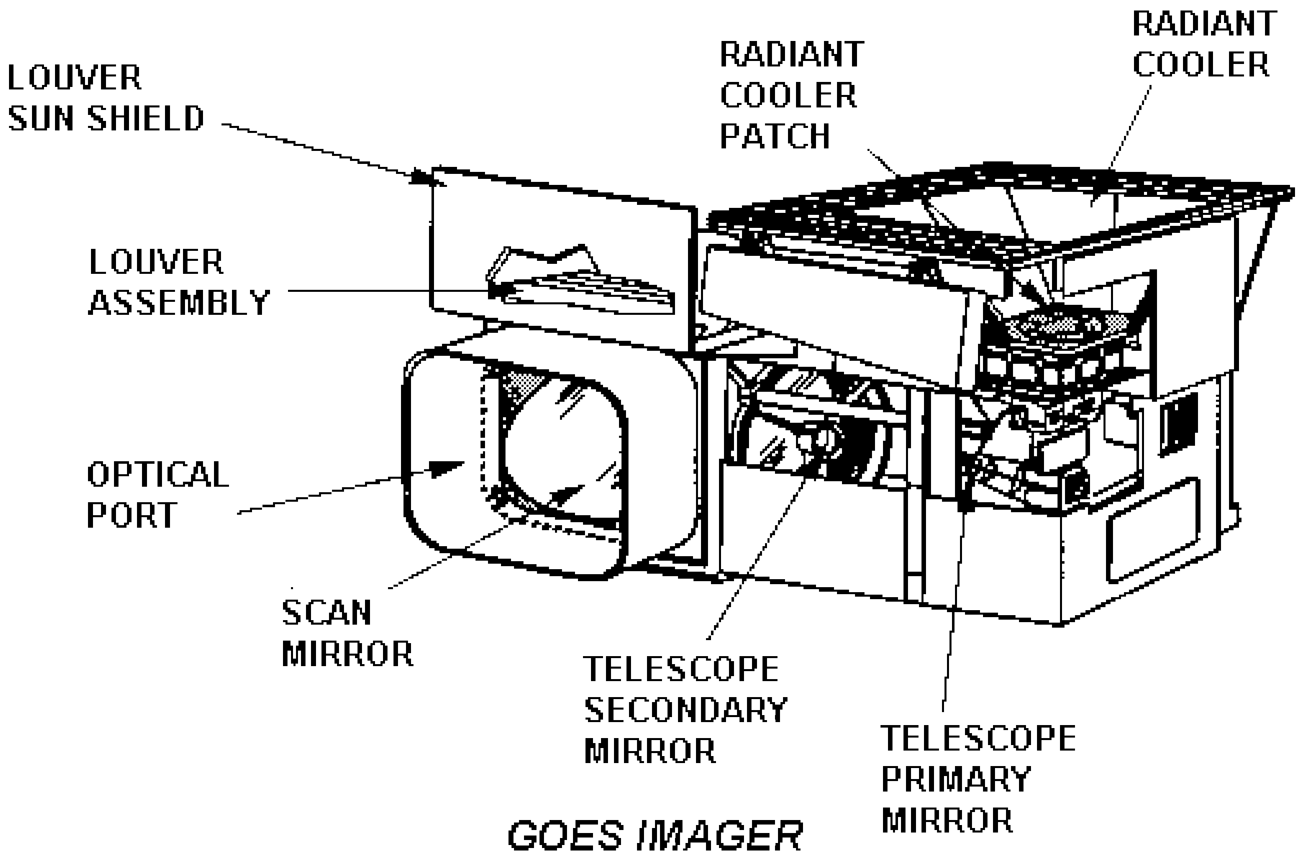
GOES-East and GOES-West



http://noaasis.noaa.gov/NOAASIS/ml/genlsatl.html

The GOES Imager

•The current GOES satellites carry multiple sensors, but the one we are chiefly interested in is simply called the **Imager**



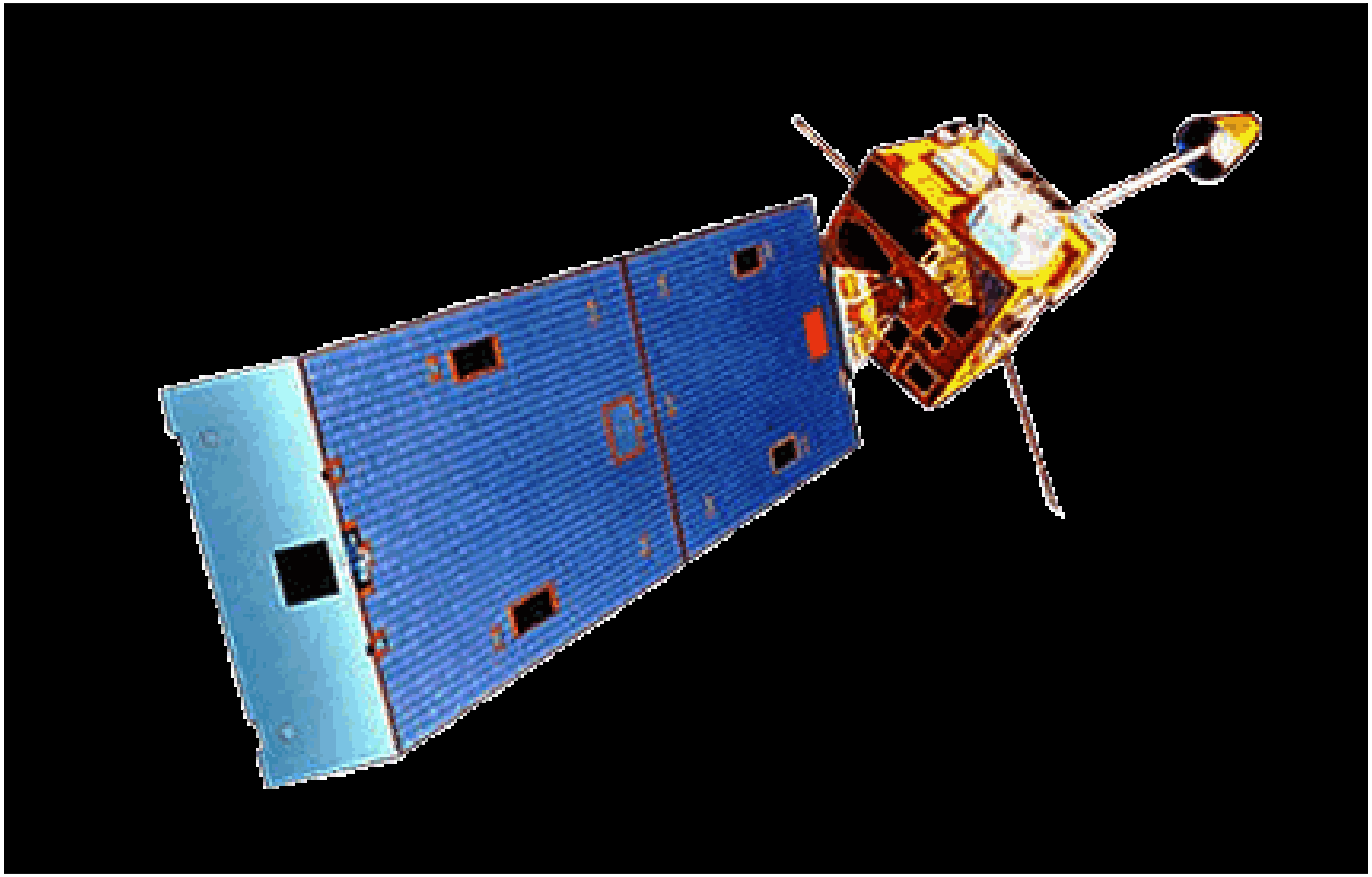
http://noaasis.noaa.gov/NOAASIS/ml/imager.html

The GOES Imager

- The GOES Imager is a **five channel (one visible, four infrared)** imaging radiometer designed to sense radiant and solar reflected energy from sampled areas of the earth
- Like the Thematic Mapper, the Imager is a 'wiskbroom' scanner that sweeps back and forth using a **mirror scanning system** that can instantaneously image an **8km square pixel** in its lowest resolution band (at nadir; when pointed at a part of the Earth that if further from the point directly below the satellite, the shape and size of a pixel become distorted)
- The Imager can scan a 3000 by 3000 km (1864 by 1864 miles) extent centered over the United States in less than a minute, although it is often used to produce "full-disk" images of the visible hemisphere

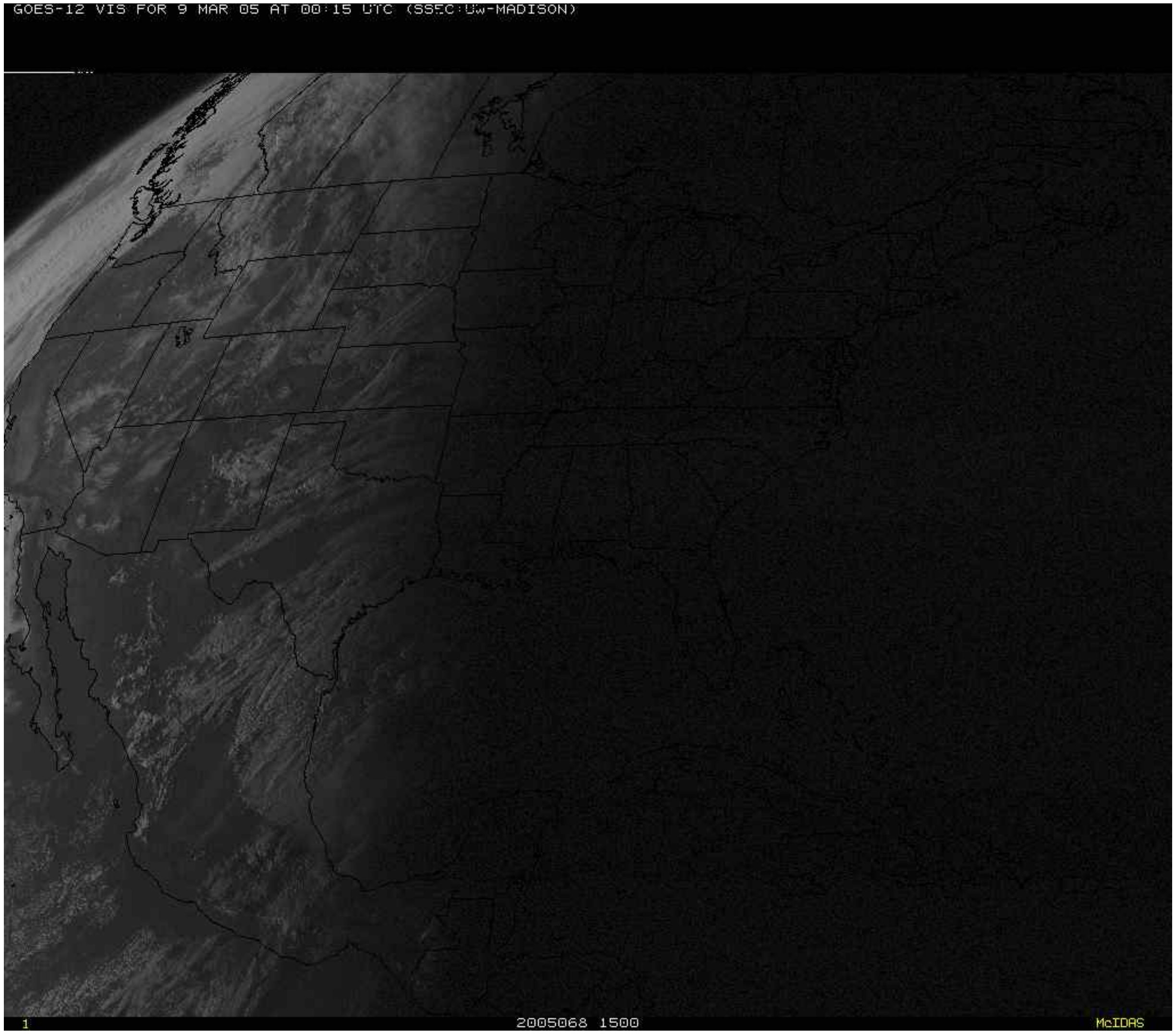
The GOES Satellite

•This is an artist's conception of **GOES platform**, with the usual solar panels, antennae, sensors, etc.



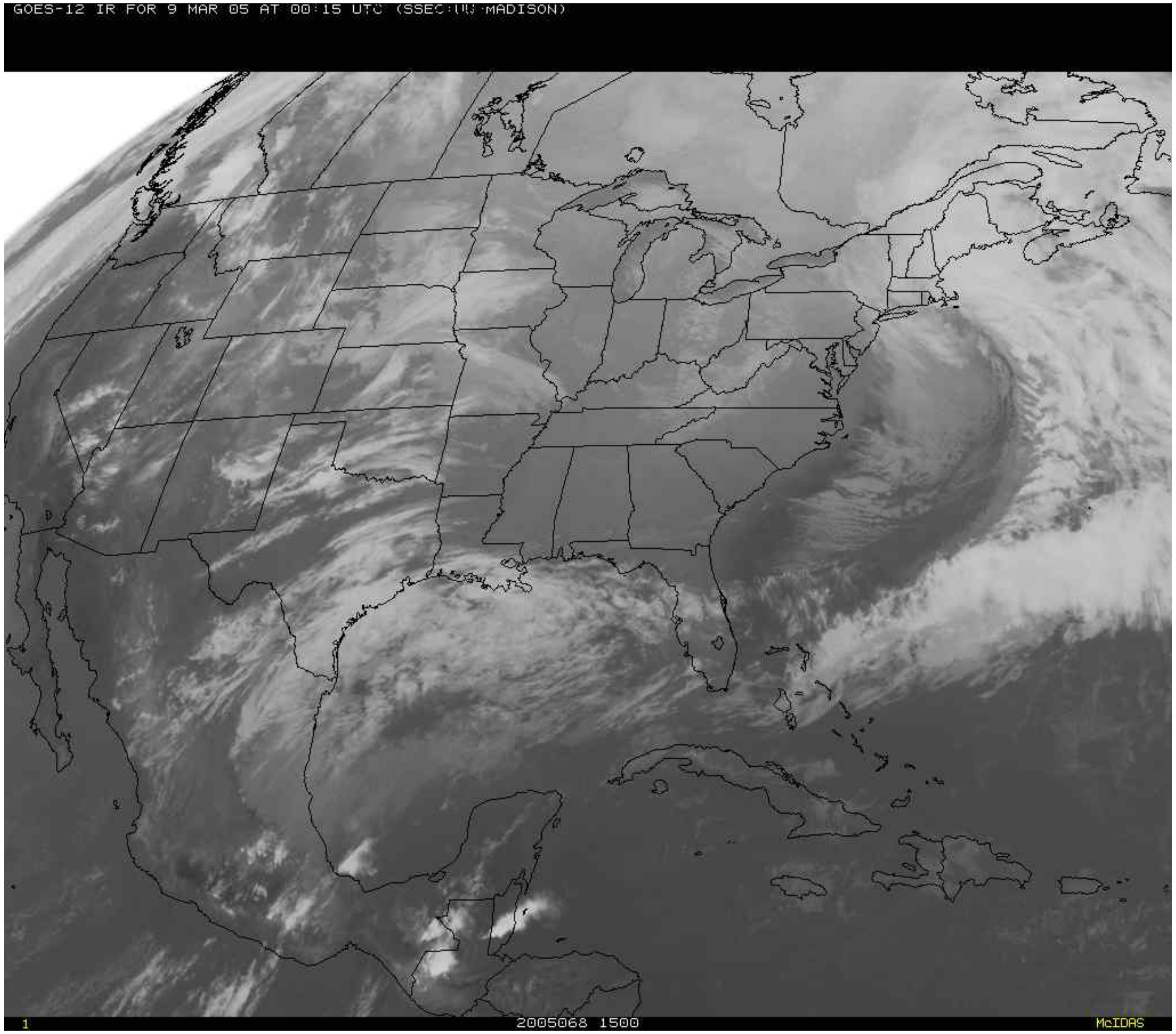
http://www.oso.noaa.gov/goesstatus/

GOES-East North America Images



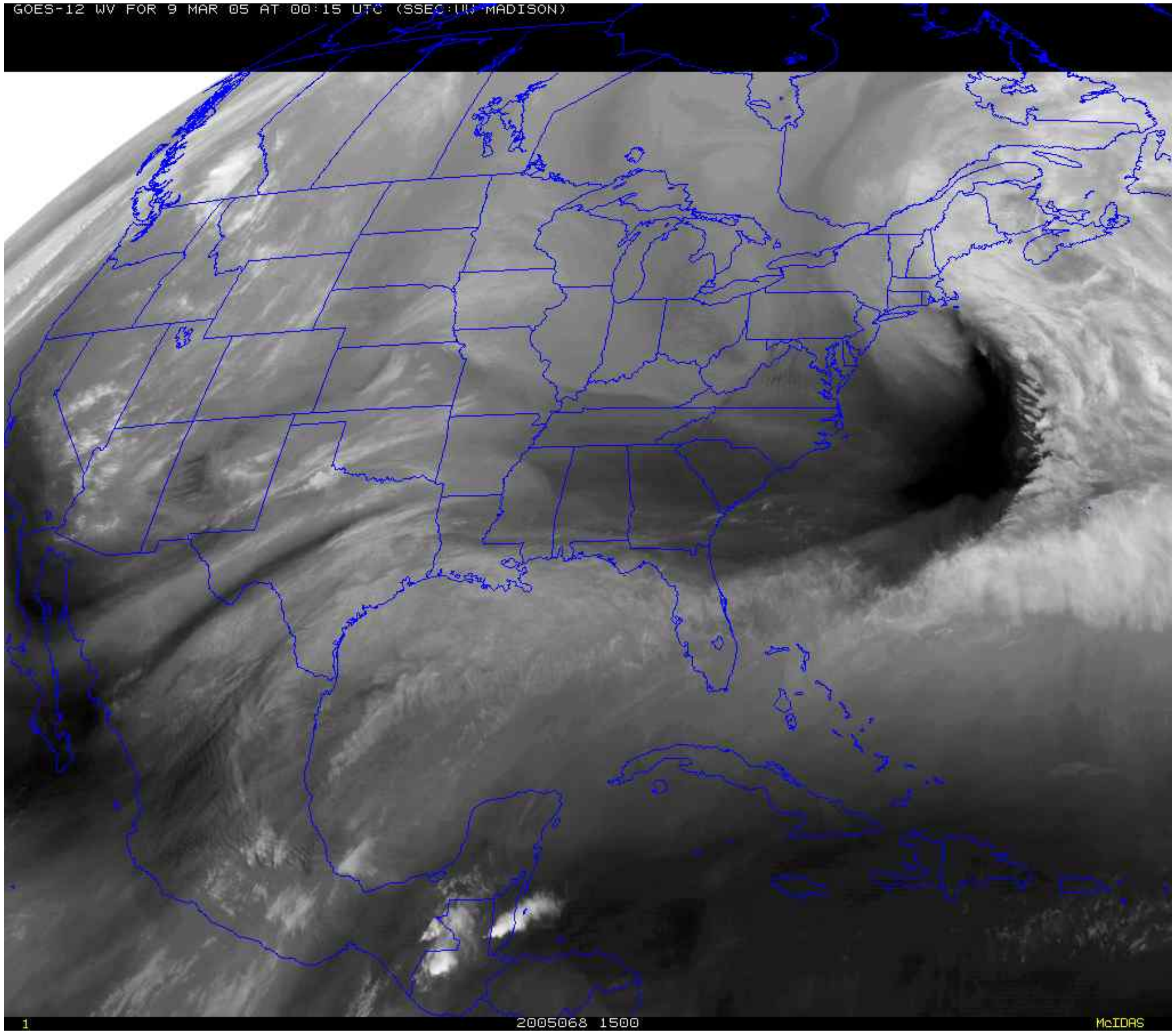
http://www.ssec.wisc.edu/data/east/latest_eastvis.jpg

GOES-East North America Images



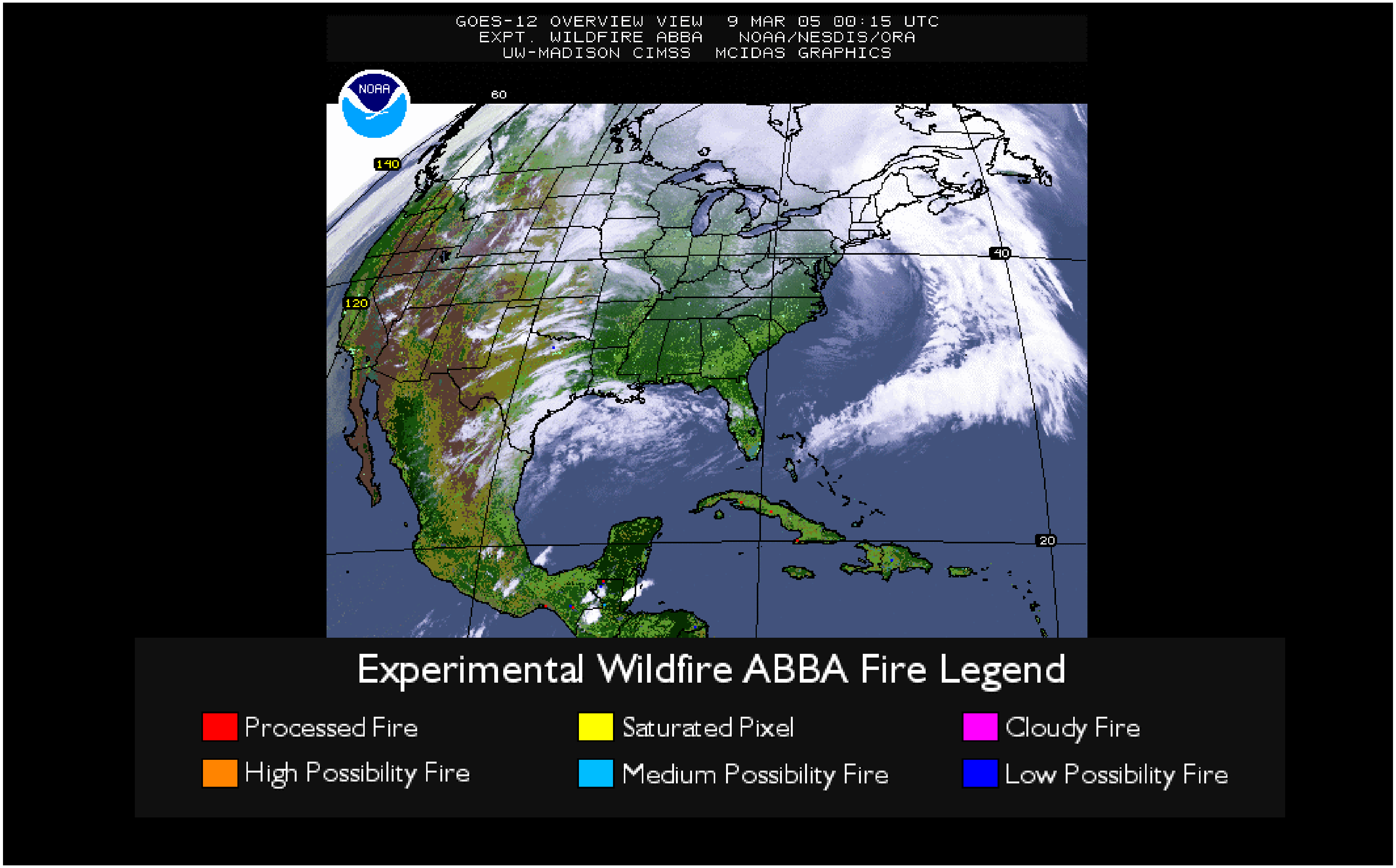
http://www.ssec.wisc.edu/data/east/latest_eastir.jpg

GOES-East North America Images

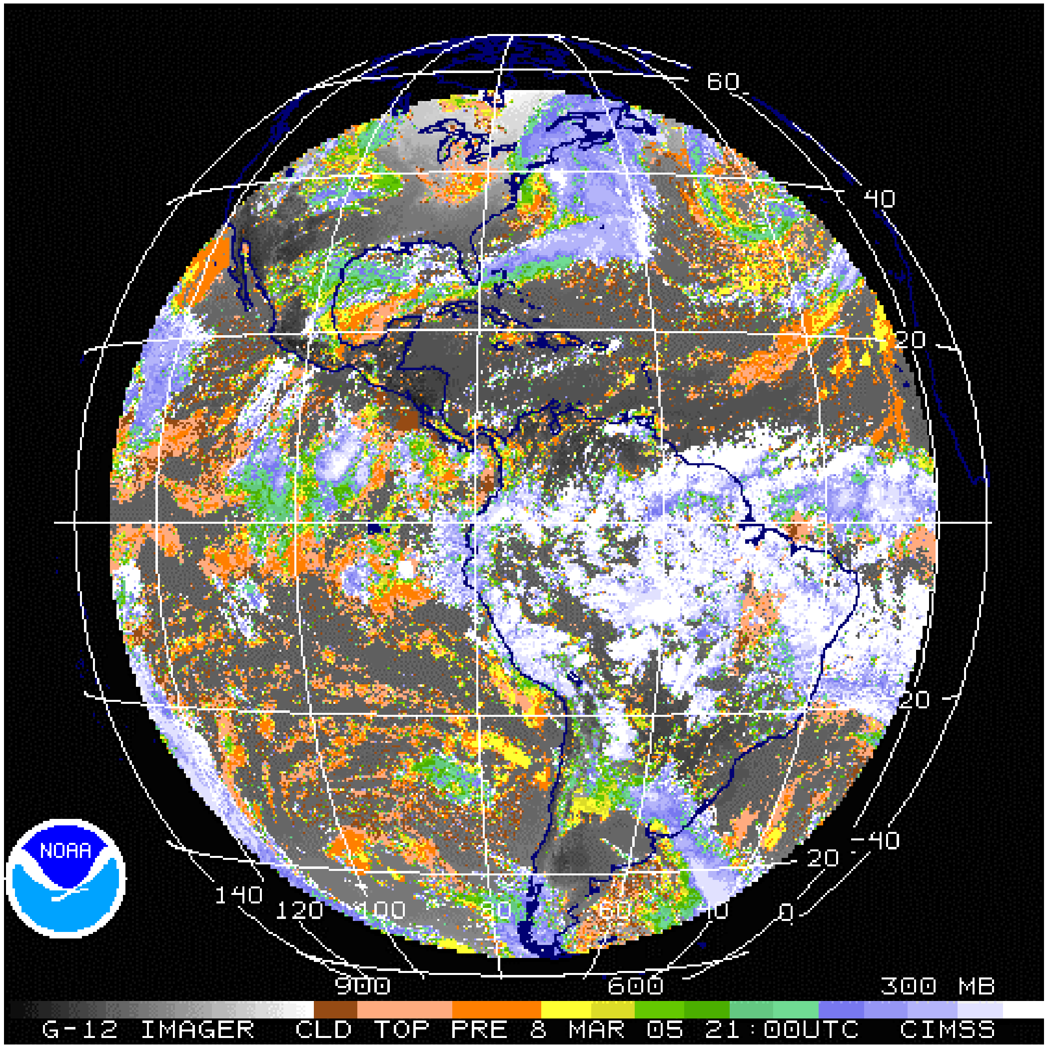


http://www.ssec.wisc.edu/data/east/latest_eastwv.jpg

GOES Derived Products - Fire

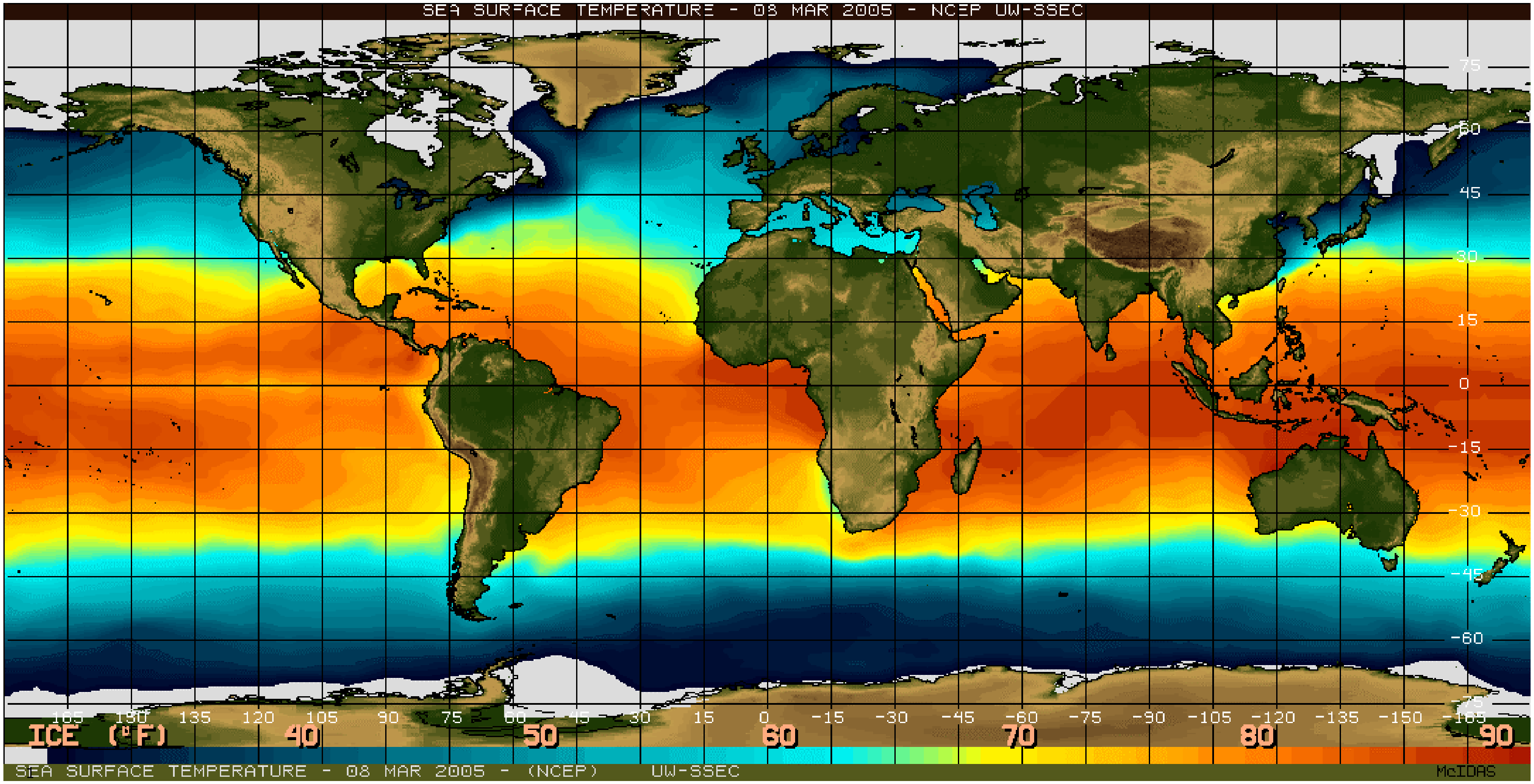


GOES Derived Products - Clouds



http://cimss.ssec.wisc.edu/goes/realtime/ctpimgg12.05067.2100.gif

GOES Derived Products - SST



http://www.ssec.wisc.edu/data/sst/latest_sst.gif

AVHRR

•**AVHRR (Advanced Very High Resolution Radio-meter)** is also a joint venture between NASA and NOAA, and this sensor has been present on many platforms

•AVHRR was designed to address many of the same applications as GOES, imaging **water vapor** in the atmosphere and **surface temperatures**, but it does so at much higher spatial resolution than GOES (1.1 km pixels at nadir), and uses a sun-synchronous orbit that has these satellites image the entire surface of the Earth every 12 hours

•Because AVHRR has **red and near infrared bands**, along with short-wave infrared and thermal infrared bands, it can be used for **vegetation studies** in addition to the applications described above

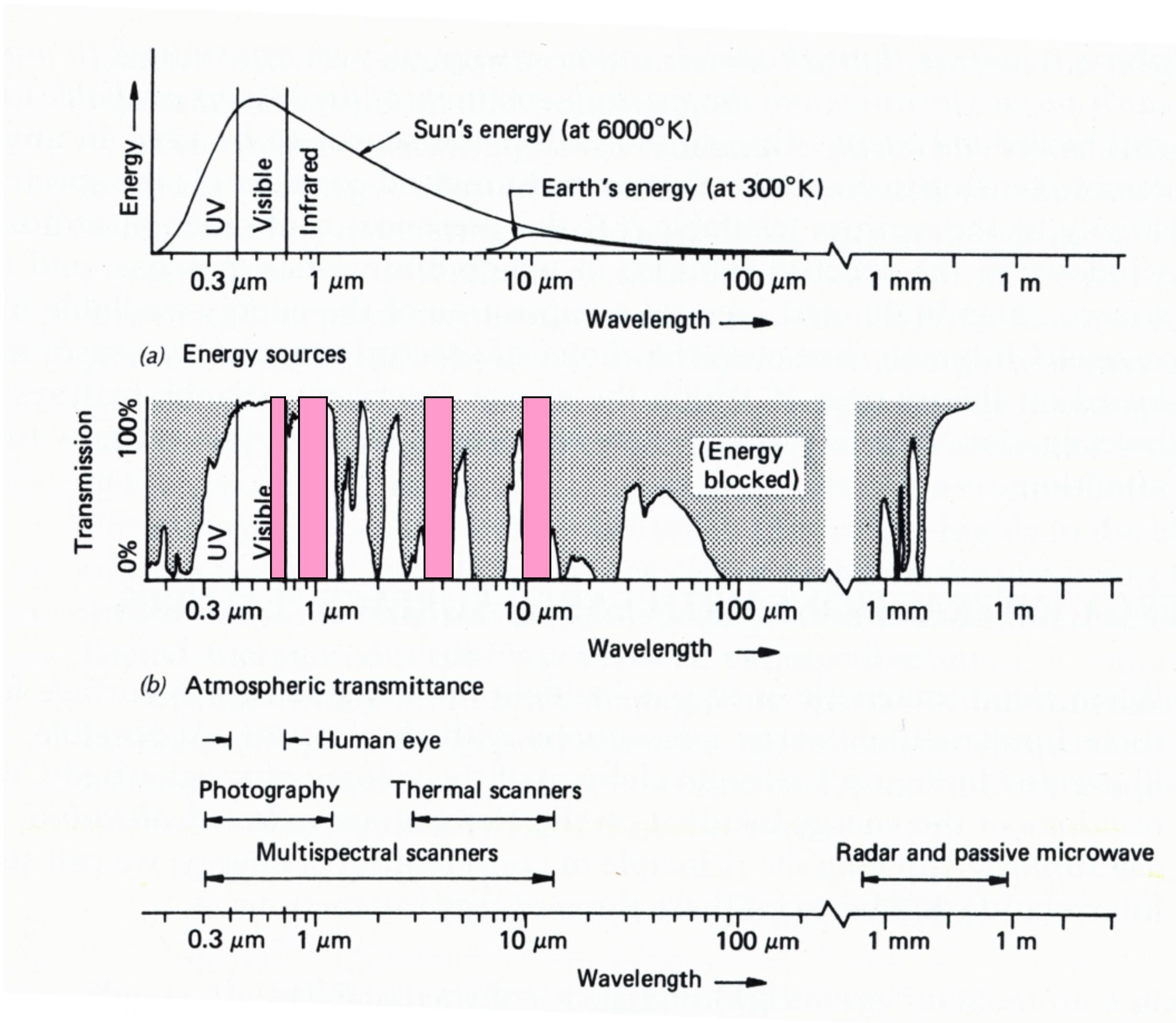
AVHRR Characteristics

TABLE 6.9 Characteristics of NOAA-6 to -15 Missions

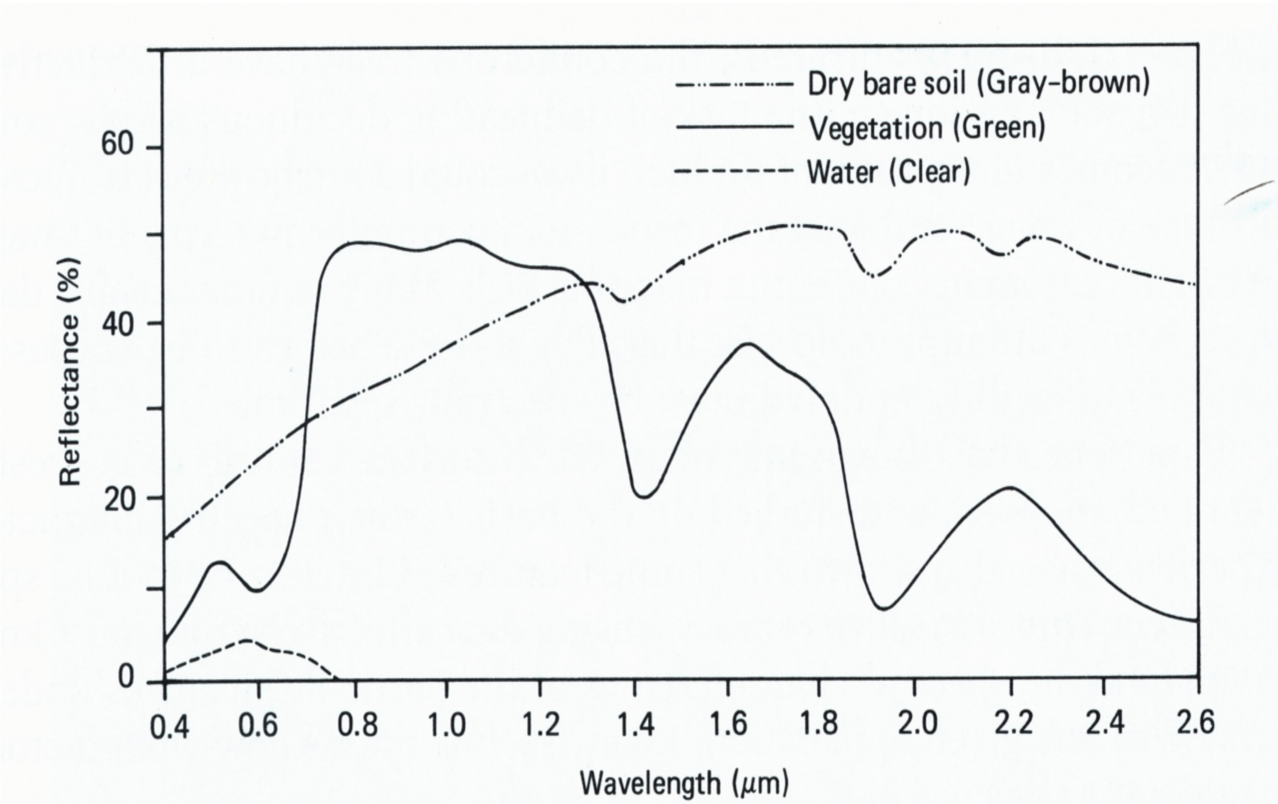
Parameter	NOAA-6, -8, -10, -12, and 15	NOAA-7, -9, -11, and -14[a]
Launch	6/27/79, 3/28/83, 9/17/86, 5/14/91, 5/13/98	6/23/81, 12/12/84, 9/24/88, 12/30/94
Altitude, km	833	870
Period of orbit, min	101	102
Orbit inclination	98.7°	98.9°
Orbits per day	14.2	14.1
Distance between orbits	25.6°	25.6°
Day-to-day orbital shift[b]	5.5° E	3.0° E
Orbit repeat period (days)[c]	4–5	8–9
Scan angle from nadir	±55.4°	±55.4°
Optical field of view, mrad	1.3	1.3
IFOV at nadir, km	1.1	1.1
IFOV off-nadir maximum, km		
Along track	2.4	2.4
Across track	6.9	6.9
Swath width	2400 km	2400 km
Coverage	Every 12 hr	Every 12 hr
Northbound equatorial crossing (P.M.)	7:30	1:30–2:30
Southbound equatorial crossing (A.M.)	7:30	1:30–2:30
AVHRR spectral channels, μm		
1	0.58–0.68	0.58–0.68
2	0.72–1.10	0.72–1.10
3	3.55–3.93[d]	3.55–3.93
4	10.5–11.50	10.3–11.30
5	Channel 4 repeat[e]	11.5–12.50

[a]NOAA-13 failed due to a short circuit in its solar array.
[b]Satellite differences due to differing orbital alignments.
[c]Caused by orbits per day not being integers.
[d]NOAA-15 includes two separate channels: 3A (1.58–1.64 μm) and 3B (3.55–3.93 μm).
[e]NOAA-12 and -15 include a separate channel 5.

AVHRR Bands


Energy
UV
Visible
Infrared
Sun's energy (at 6000°K)
Earth's energy (at 300°K)
0.3 μm
1 μm
10 μm
100 μm
1 mm
1 m
Wavelength
(a) Energy sources
Transmission
100%
0%
UV
Visible
(Energy blocked)
0.3 μm
1 μm
10 μm
100 μm
1 mm
1 m
Wavelength
(b) Atmospheric transmittance
Human eye
Photography
Thermal scanners
Multispectral scanners
Radar and passive microwave
0.3 μm
1 μm
10 μm
100 μm
1 mm
1 m
Wavelength

Normalized Difference Vegetation Index



$$NDVI = \frac{(NIR - R)}{(NIR + R)}$$

NDVI [-1,1]

•Vegetation has a **strong contrast in reflectance** between red and near infrared EMR, and NDVI takes advantage of this to **sense the presence/density of vegetation**

NDVI from AVHRR

Feb 27-Mar 12

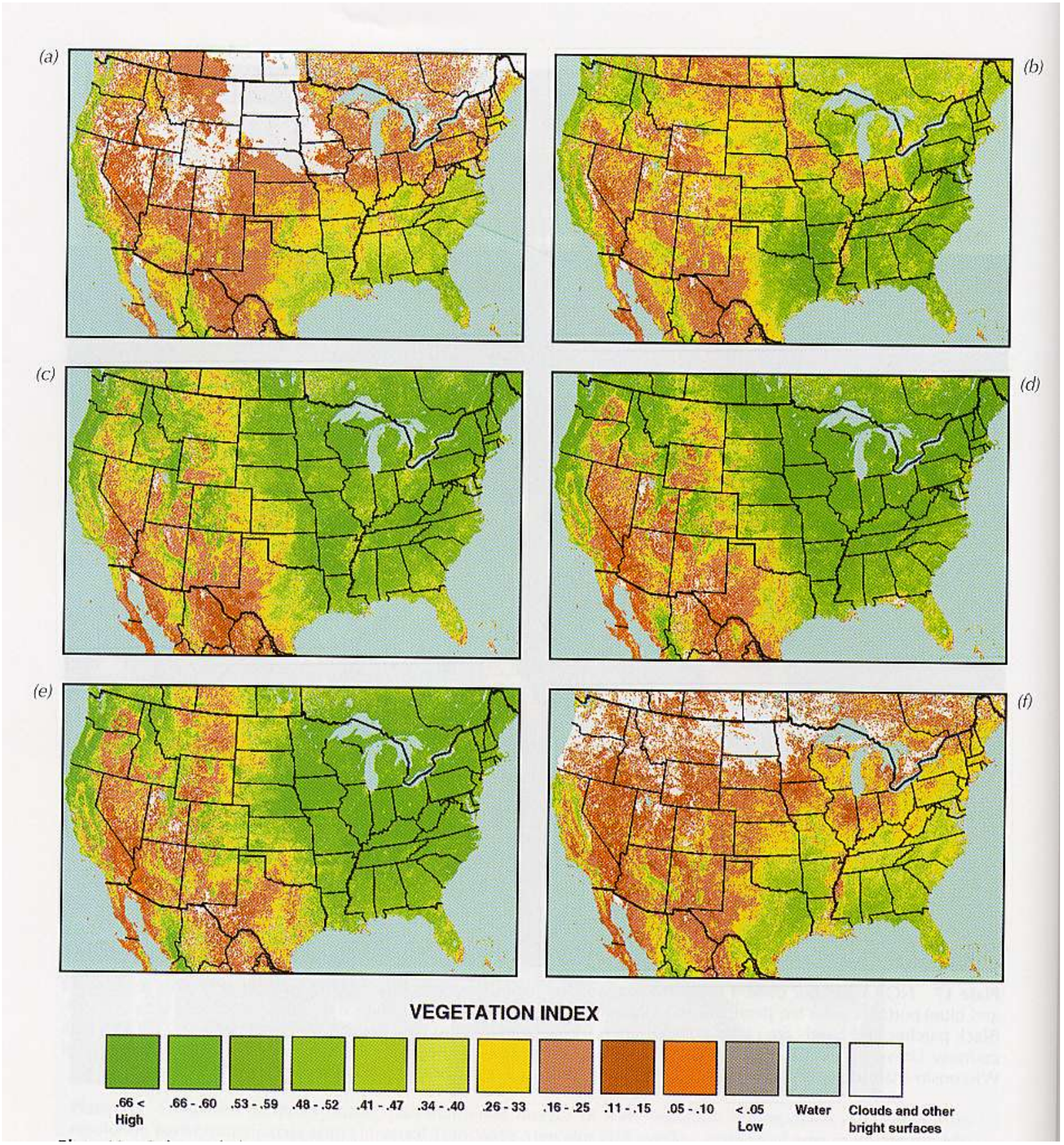
Apr 24-May 7

Jun 19-Jul 2

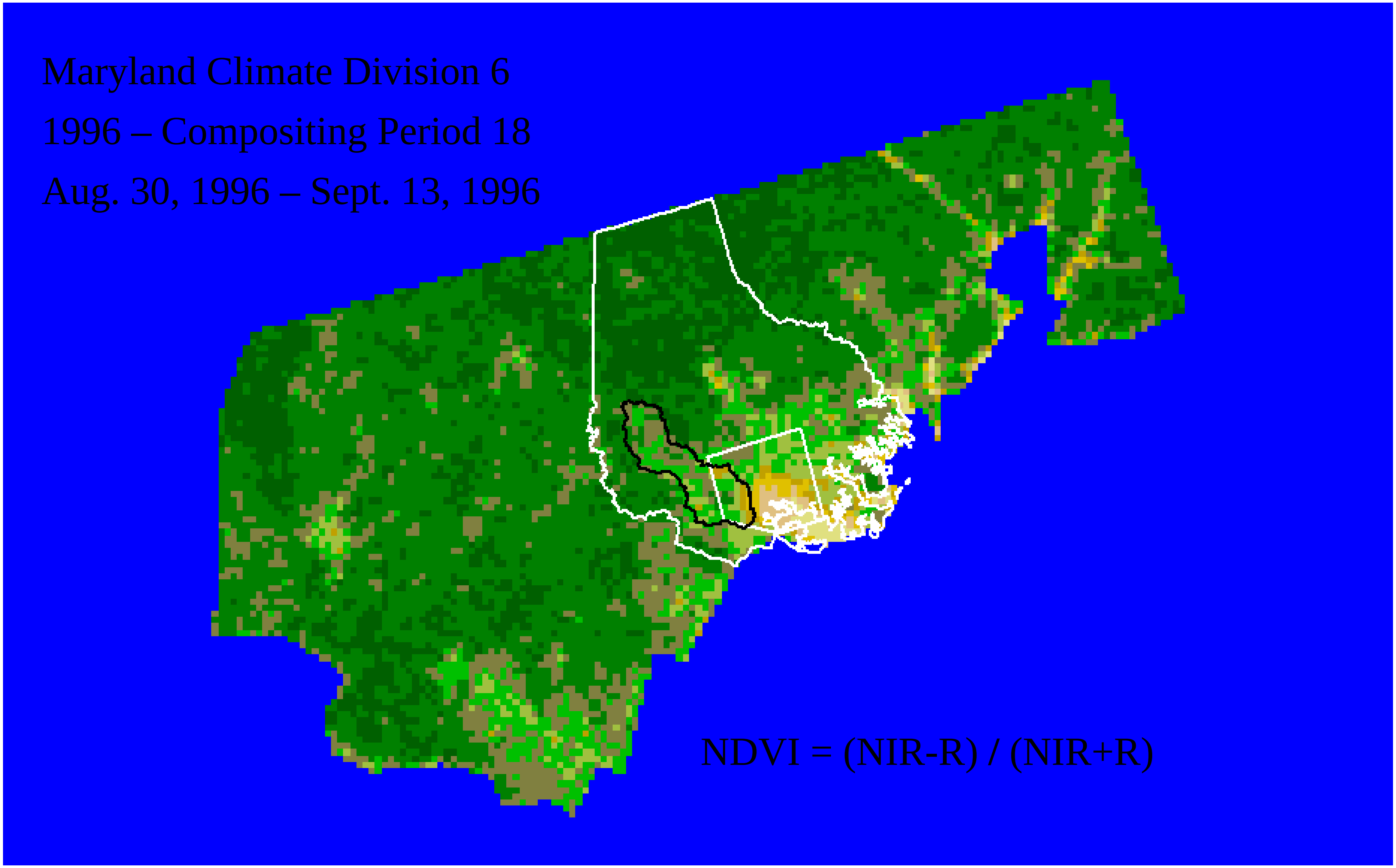
Jul 17-Jul 30

Aug 14-Aug 27

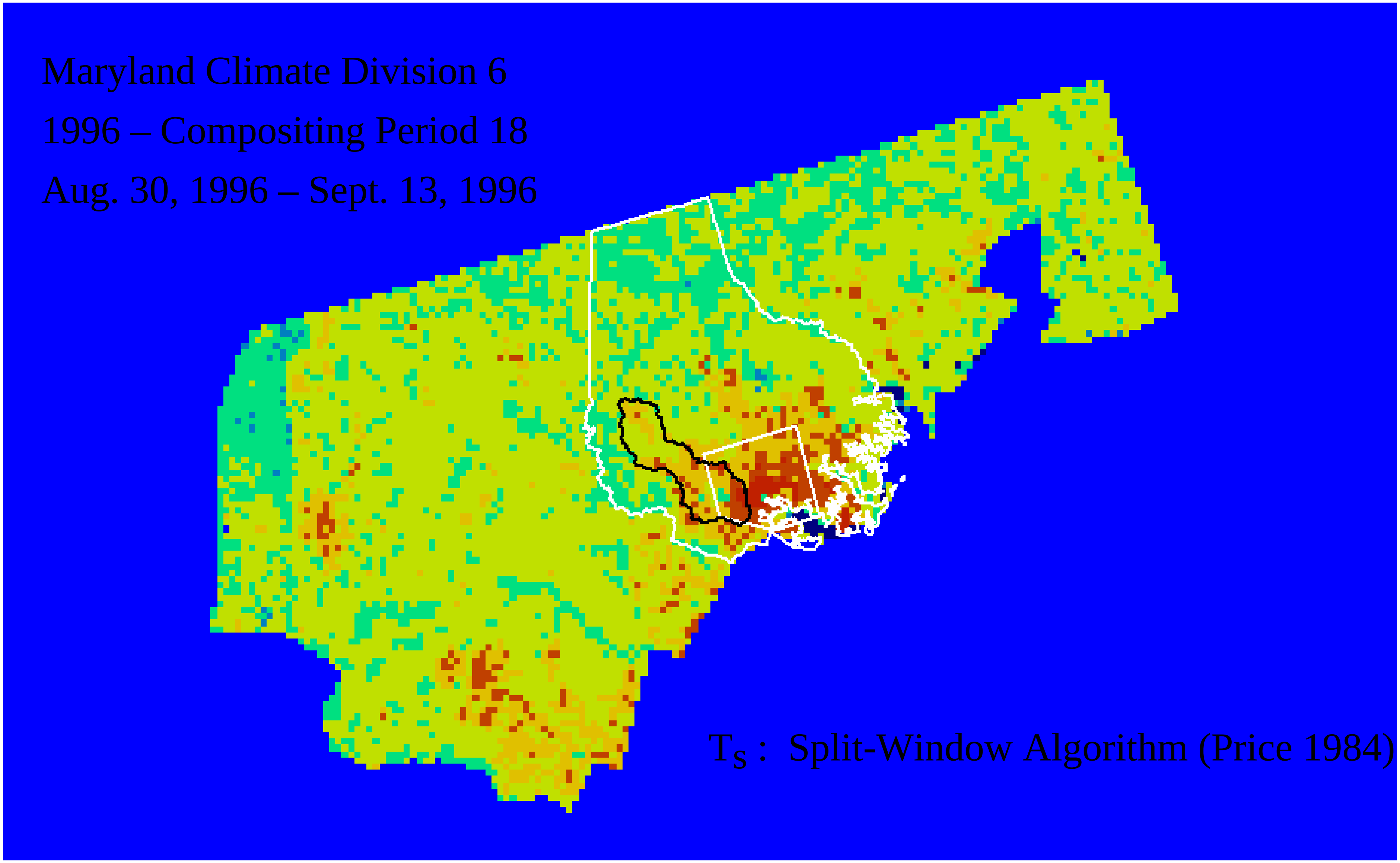
Nov 6- Nov19



AVHRR Satellite Imagery - NDVI



AVHRR Satellite Imagery - T_s



MODIS

- AVHRR has been superceded by **MODIS (Moderate Resolution Imaging Spectrometer)** which is a project being run by NASA, in partnership with the USGS (US Geological Survey)
- The MODIS sensors are the ‘centerpiece’ sensors on two new satellites that have been called Earth Observing Systems (EOS-AM and EOS-PM), codenamed **Terra and Aqua**
- **Terra** was designed to focus on land-based applications and has an equatorial **overpass time of about 10:30 AM**, while **Aqua** was designed for more sea-oriented applications and has an equatorial **overpass time of about 2:30 PM**, and the MODIS sensors on them are known as MODIS-AM and MODIS-PM

MODIS Characteristics

Orbit: 705 km,

Time to cross equator: 10:30 a.m. descending node (Terra), 2:30 pm descending node (Aqua)

sun-synchronous, near-polar, circular

Sensor Systems: Across Track Scanning (‘Wiskbroom’)

Radiometric resolution: 12 bits

Temporal resolution: 1-2 days

Spatial Resolution:

250 m (bands 1-2)

500 m (bands 3-7)

1000 m (bands 8-36)

Design Life: 6 years

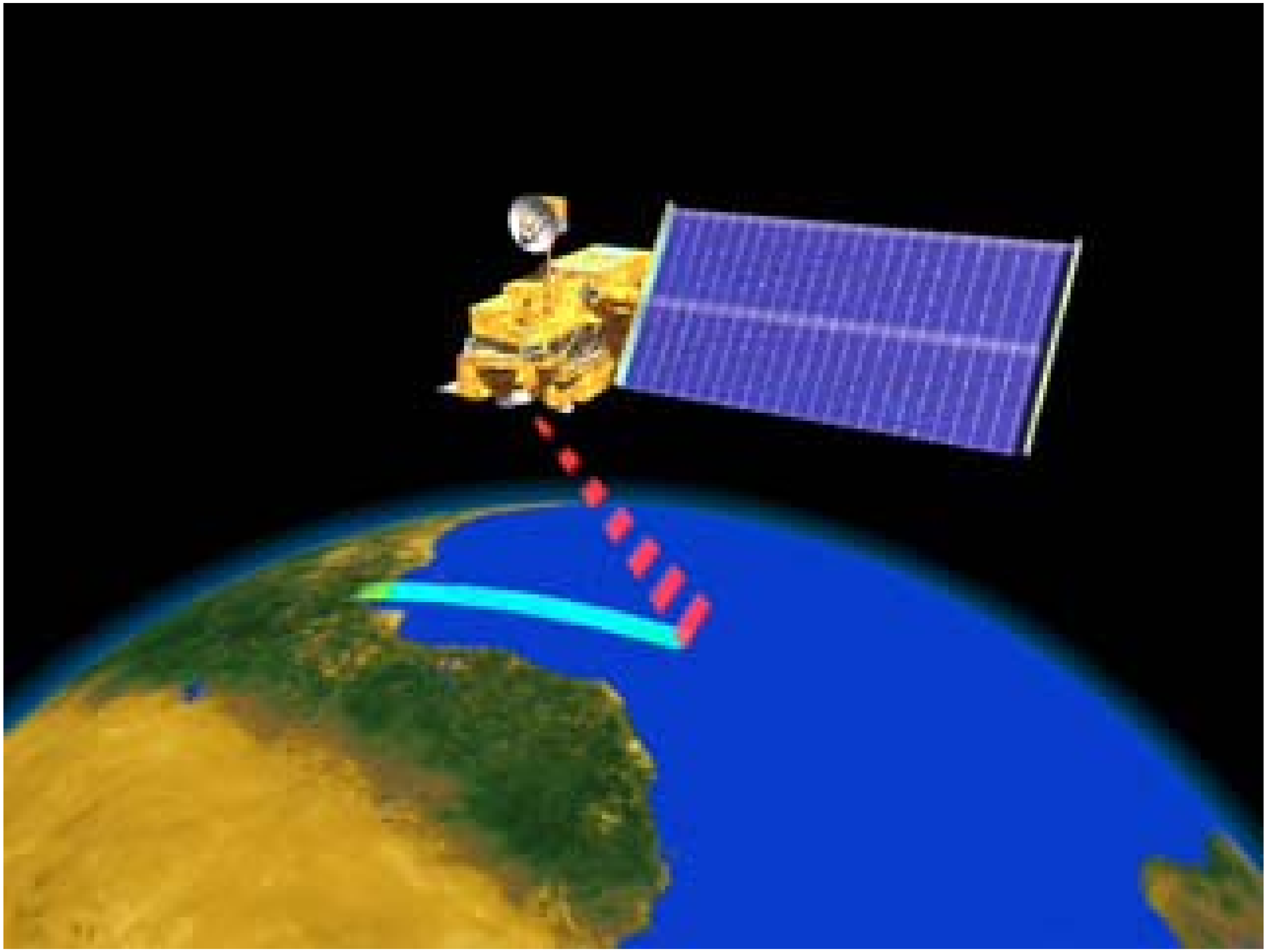
MODIS Bands

TABLE 6.14 MODIS Spectral Bands

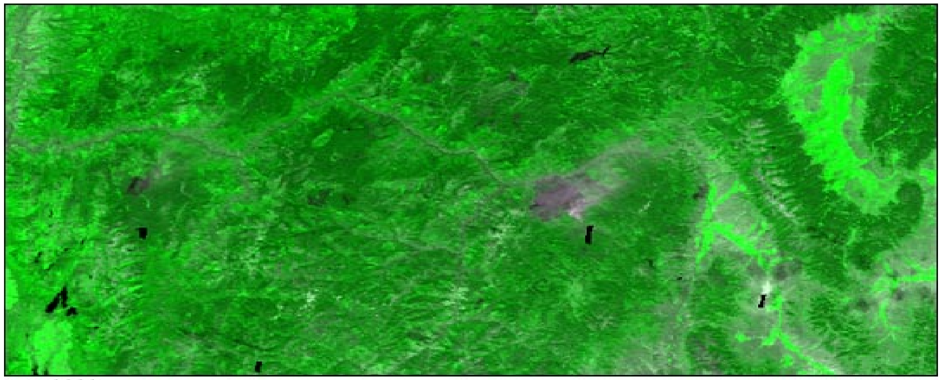
Primary Use	Band	Bandwidth	Resolution (m)
Land/cloud boundaries	1	620–670 nm	250
	2	841–876 nm	250
Land/cloud properties	3	459–479 nm	500
	4	545–565 nm	500
	5	1230–1250 nm	500
	6	1628–1652 nm	500
	7	2105–2155 nm	500
Ocean color/ phytoplankton/ biogeochemistry	8	405–420 nm	1000
	9	438–448 nm	1000
	10	483–493 nm	1000
	11	526–536 nm	1000
	12	546–556 nm	1000
	13	662–672 nm	1000
	14	673–683 nm	1000
	15	743–753 nm	1000
	16	862–877 nm	1000
Atmospheric water vapor	17	890–920 nm	1000
	18	931–941 nm	1000
	19	915–965 nm	1000
Surface/cloud temperature	20	3.660–3.840 μm	1000
	21[a]	3.929–3.989 μm	1000
	22	3.929–3.989 μm	1000
	23	4.020–4.080 μm	1000
Atmospheric temperature	24	4.433–4.498 μm	1000
	25	4.482–4.549 μm	1000
Cirrus clouds	26[b]	1.360–1.390 μm	1000
Water vapor	27	6.538–6.895 μm	1000
	28	7.175–7.475 μm	1000
	29	8.400–8.700 μm	1000
Ozone	30	9.580–9.880 μm	1000
Surface/cloud temperature	31	10.780–11.280 μm	1000
	32	11.770–12.270 μm	1000
Cloud top altitude	33	13.185–13.485 μm	1000
	34	13.485–13.758 μm	1000
	35	13.785–14.085 μm	1000
	36	14.085–14.385 μm	1000

[a]Band 21 and 22 are similar, but band 21 saturates at 500 K versus 328 K.
[b]Wavelength out of sequence due to change in sensor design.

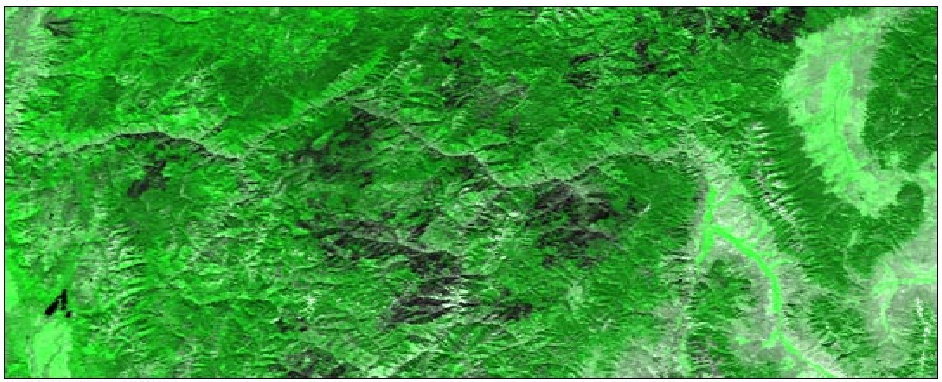
MODIS Orbit



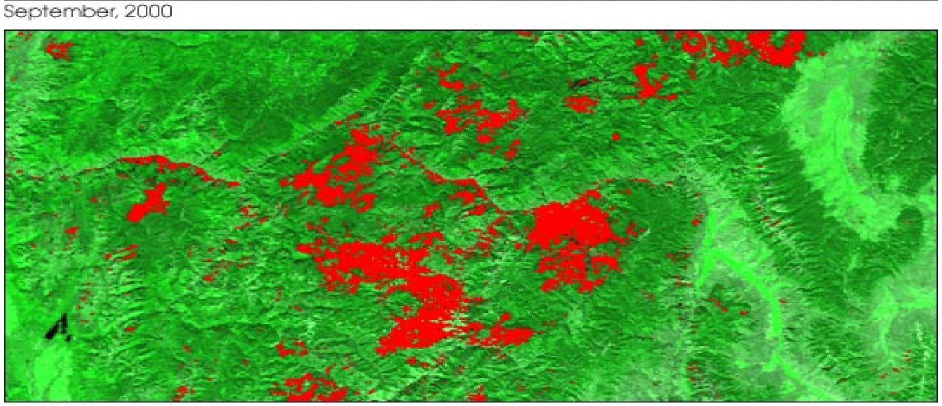
MODIS Applications - Fire Damage


July, 2000

Pre-forest fire


September, 2000

Post-forest fire

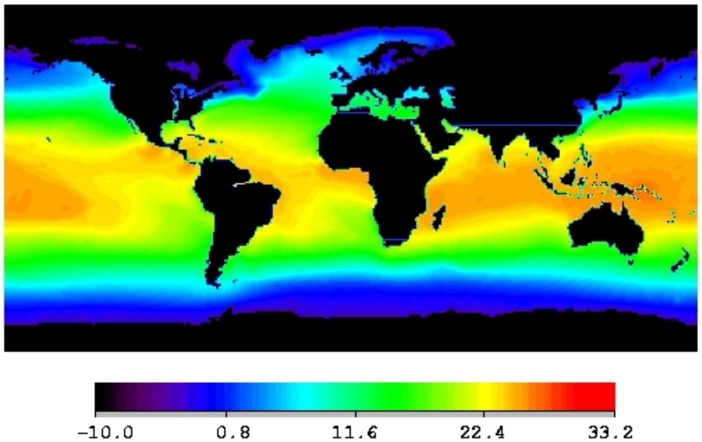

Burned Area

Scale (km)
0 25

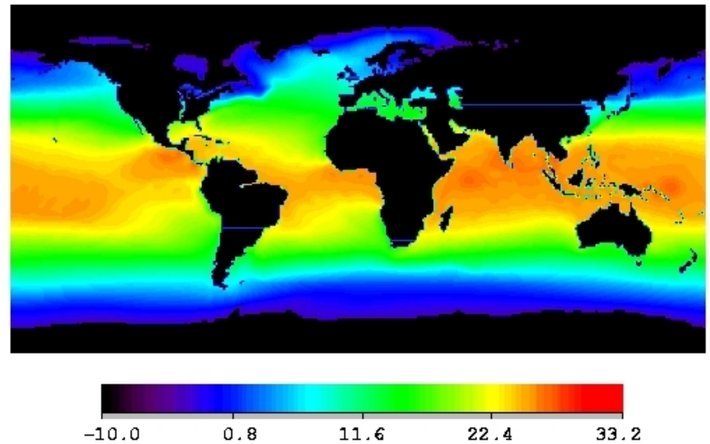
Burnt area identified from space

MODIS Applications - SST

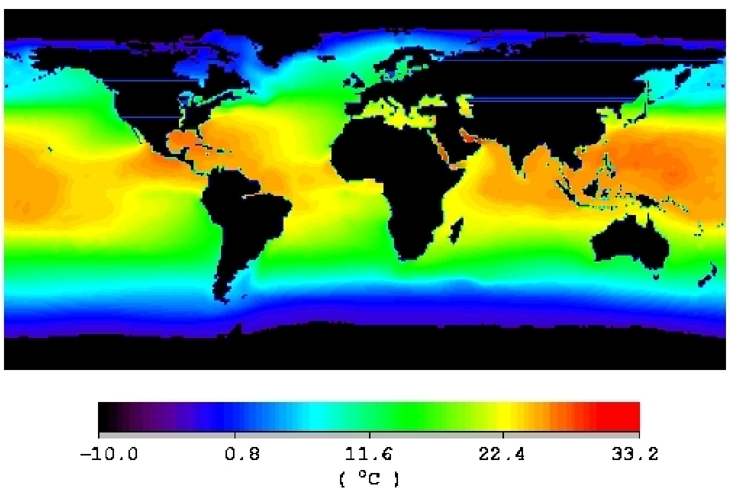
January



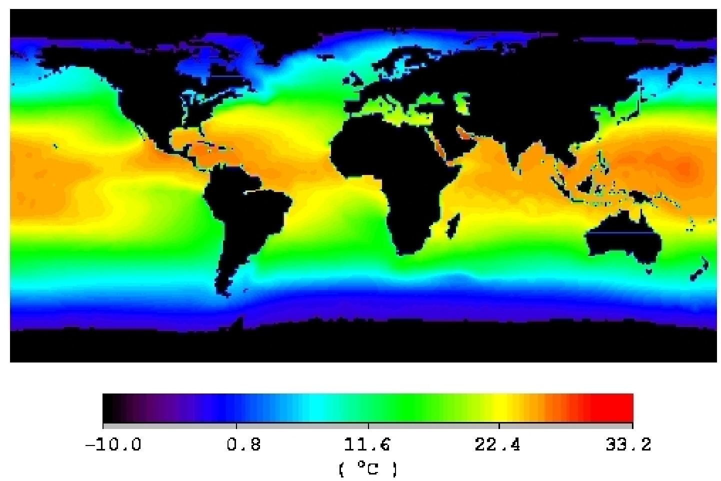
April



July

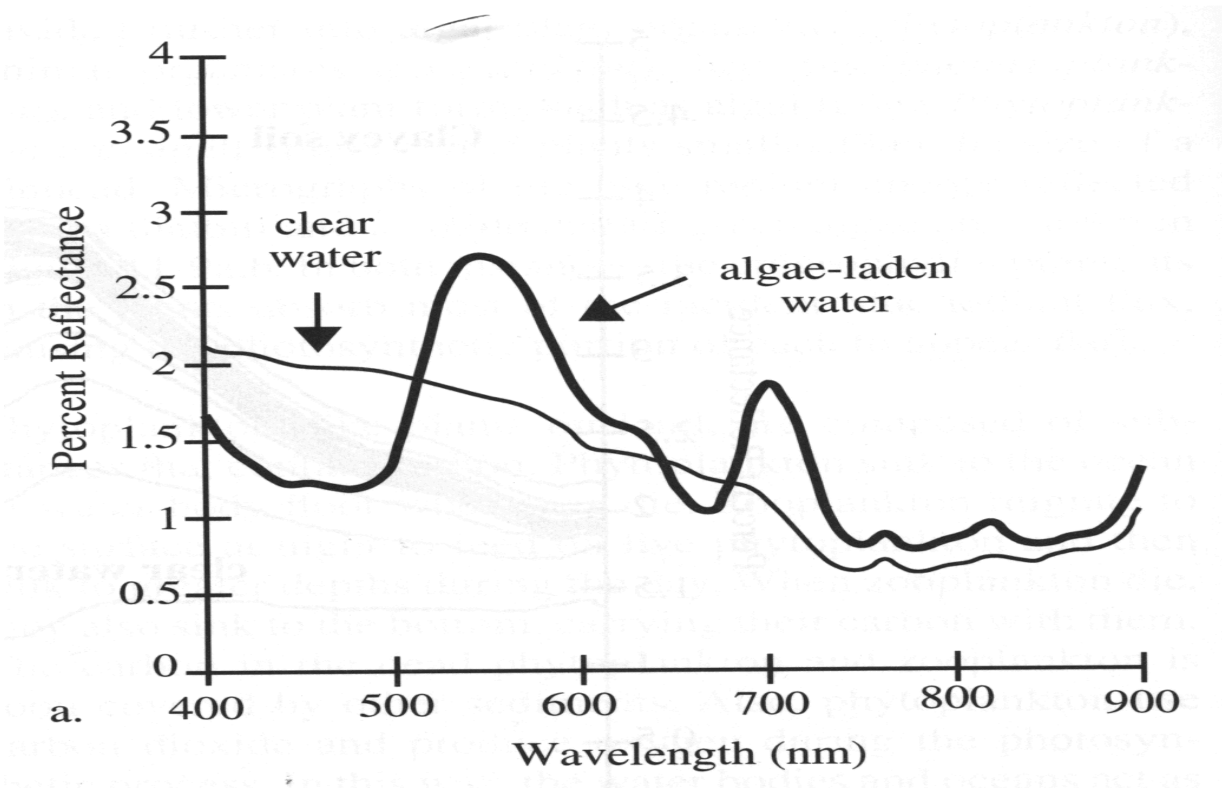


October



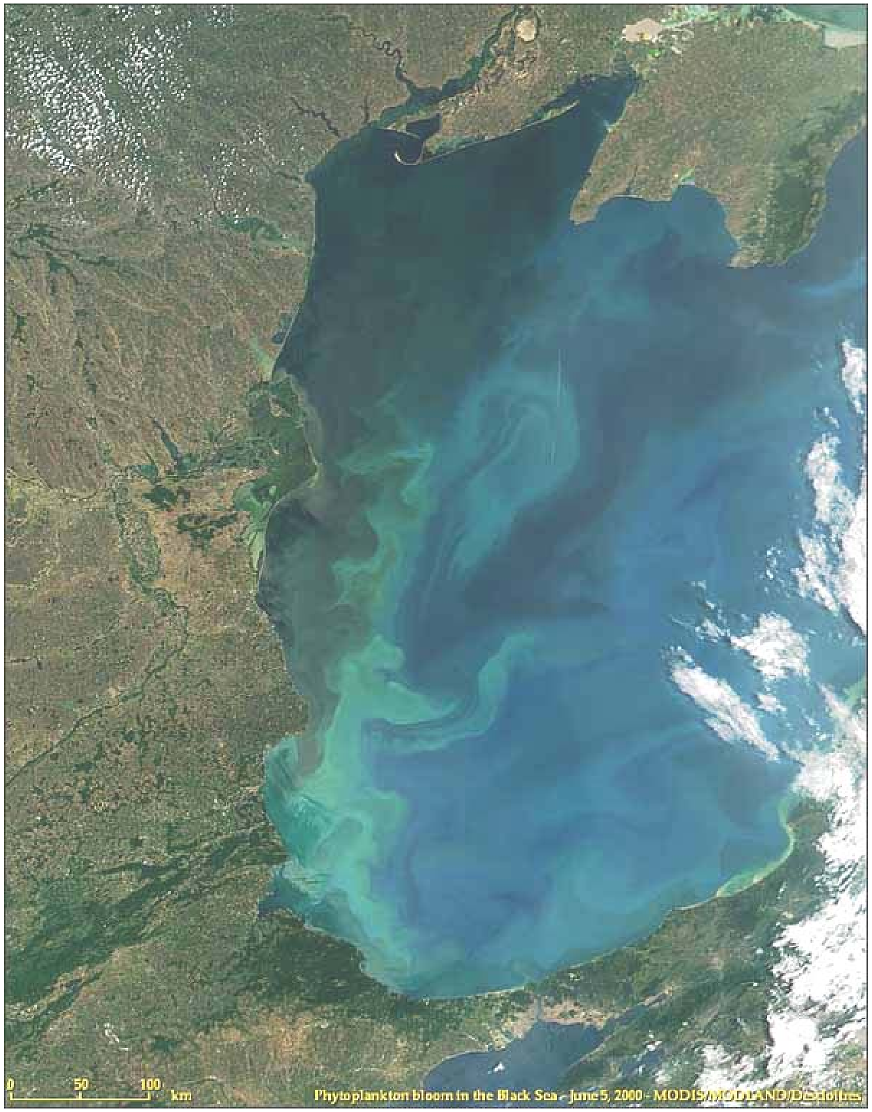
MODIS Applications - Algae

Spectral Properties of Water with Algae

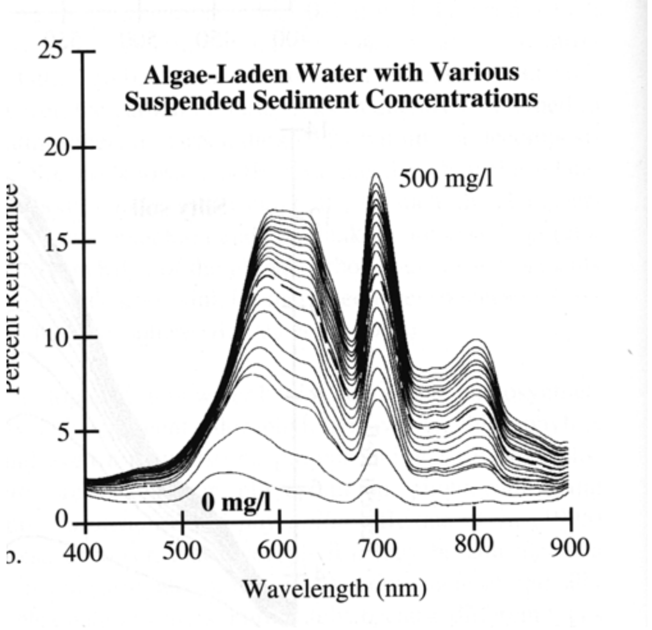


Algae **absorbs** a significant amount of **CO_2**, and its presence / absence / abundance is important to understanding the ocean. It is useful to track the spatial and temporal dynamics of algae blooms

MODIS Applications - Algae

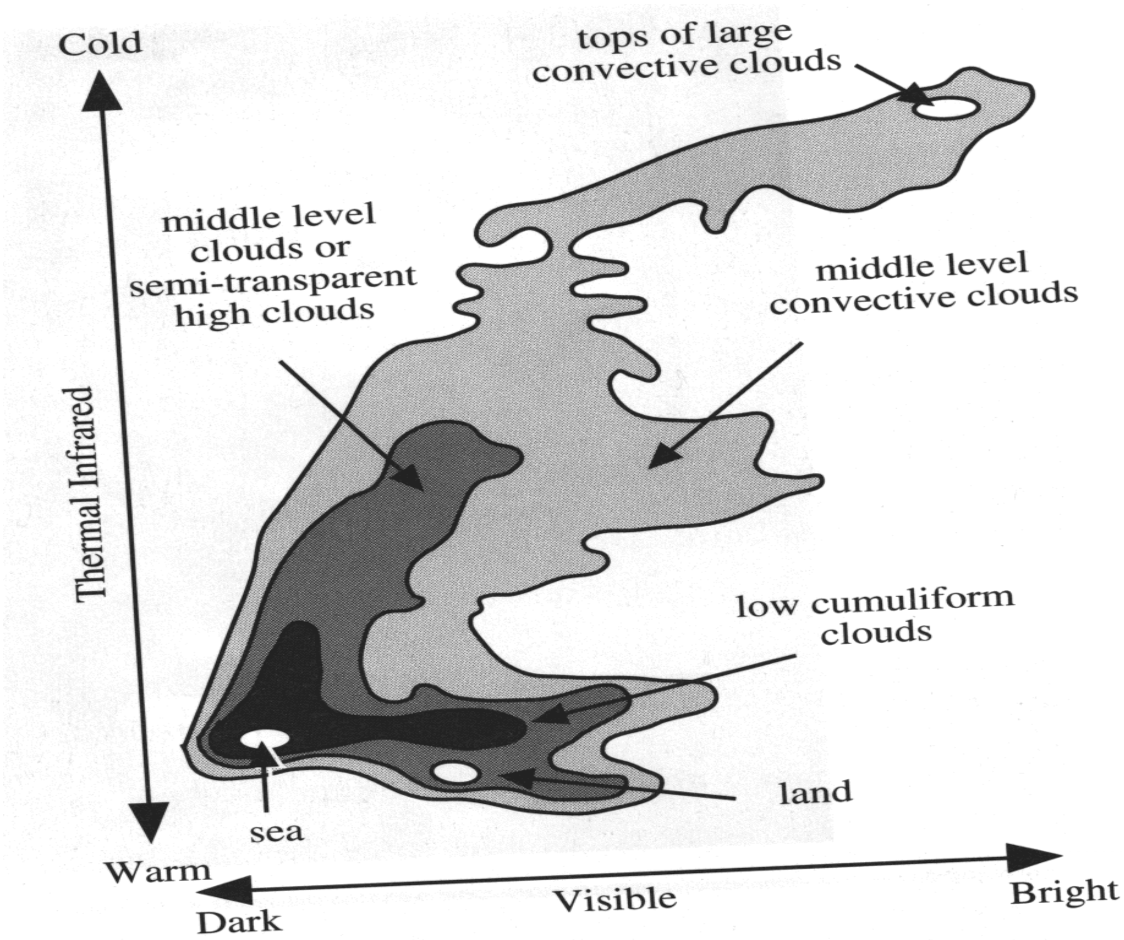


Phytoplankton bloom in the Black Sea. MODIS band 1 (red), 4 (green) and 3 (blue)

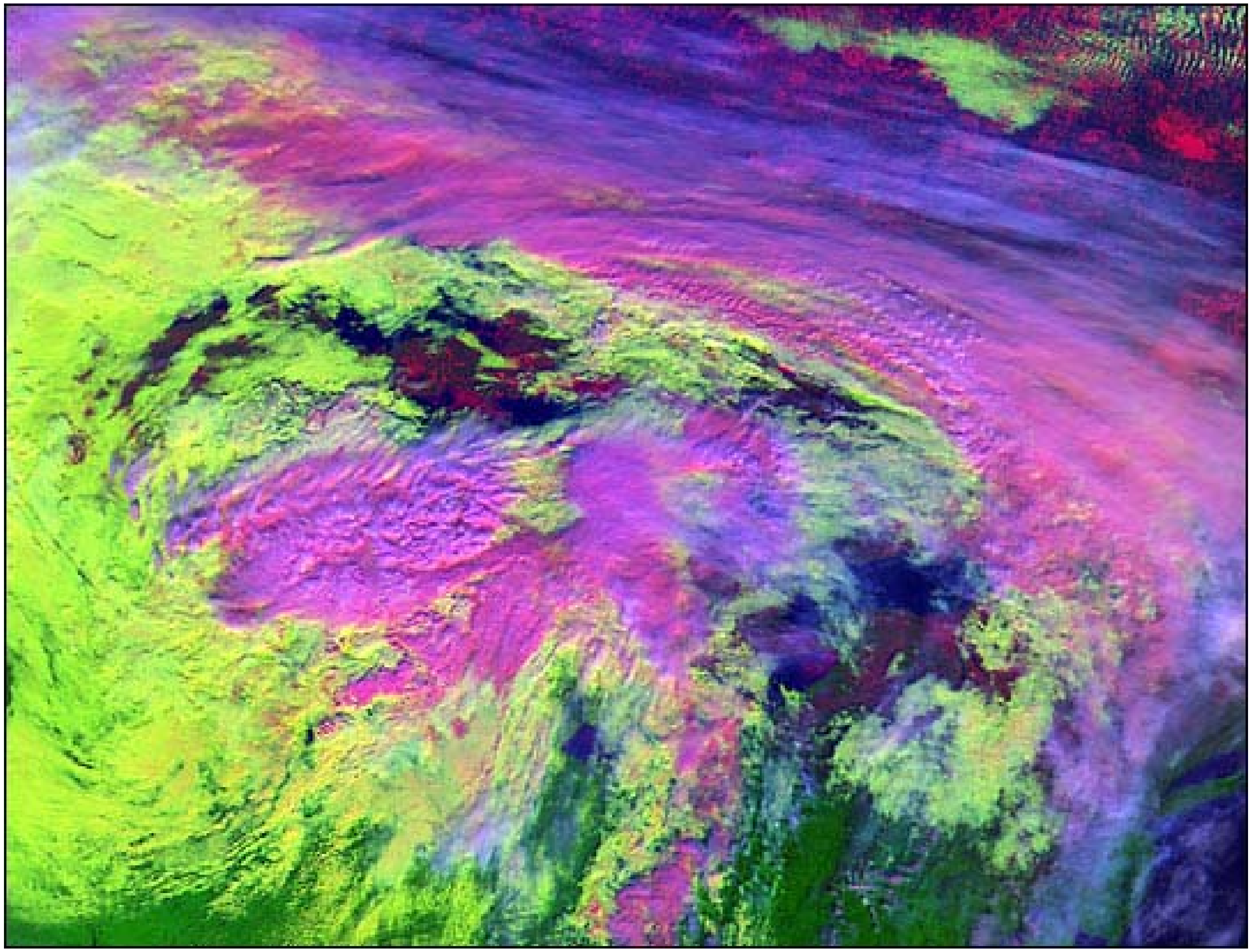


MODIS Applications - Clouds

Cloud Spectral Properties



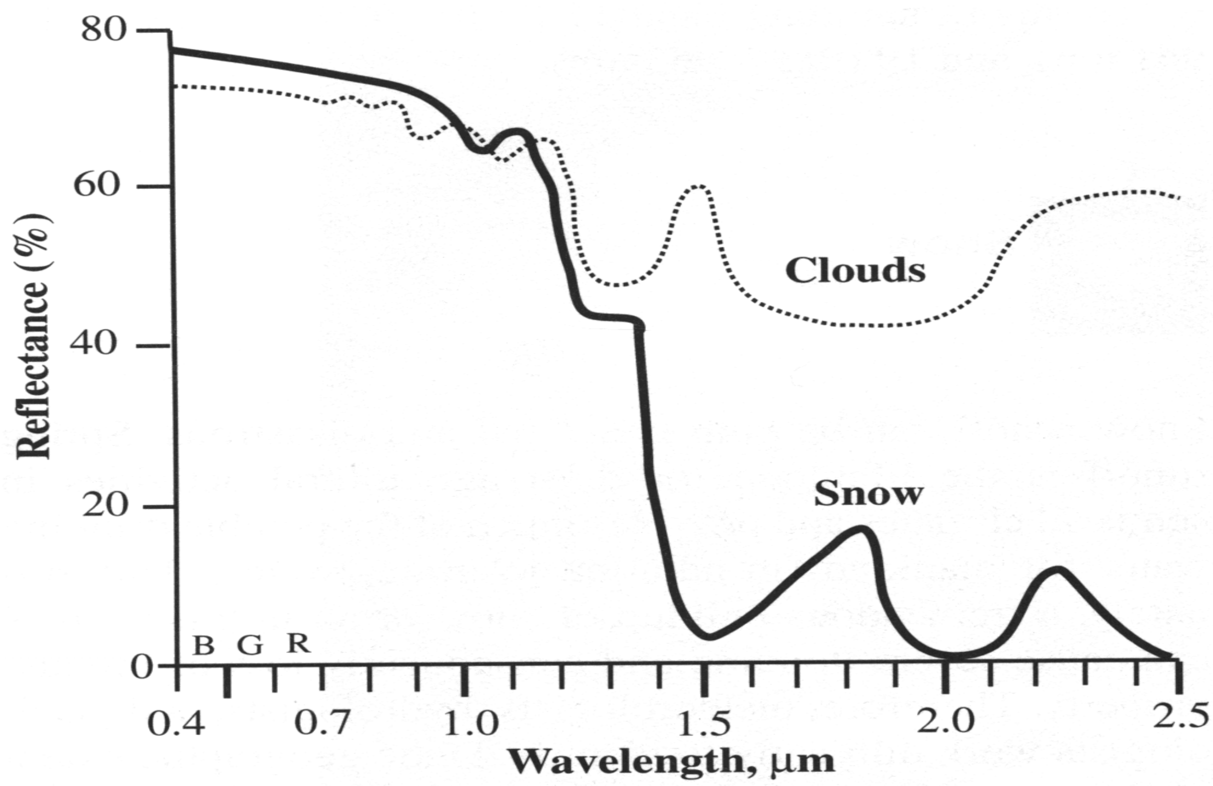
MODIS Applications - Clouds



Cloud types from MODIS: pink - cold high level snow and ice clouds; neon green - low level water clouds. These two cloud types reflect and emit radiant energy differently

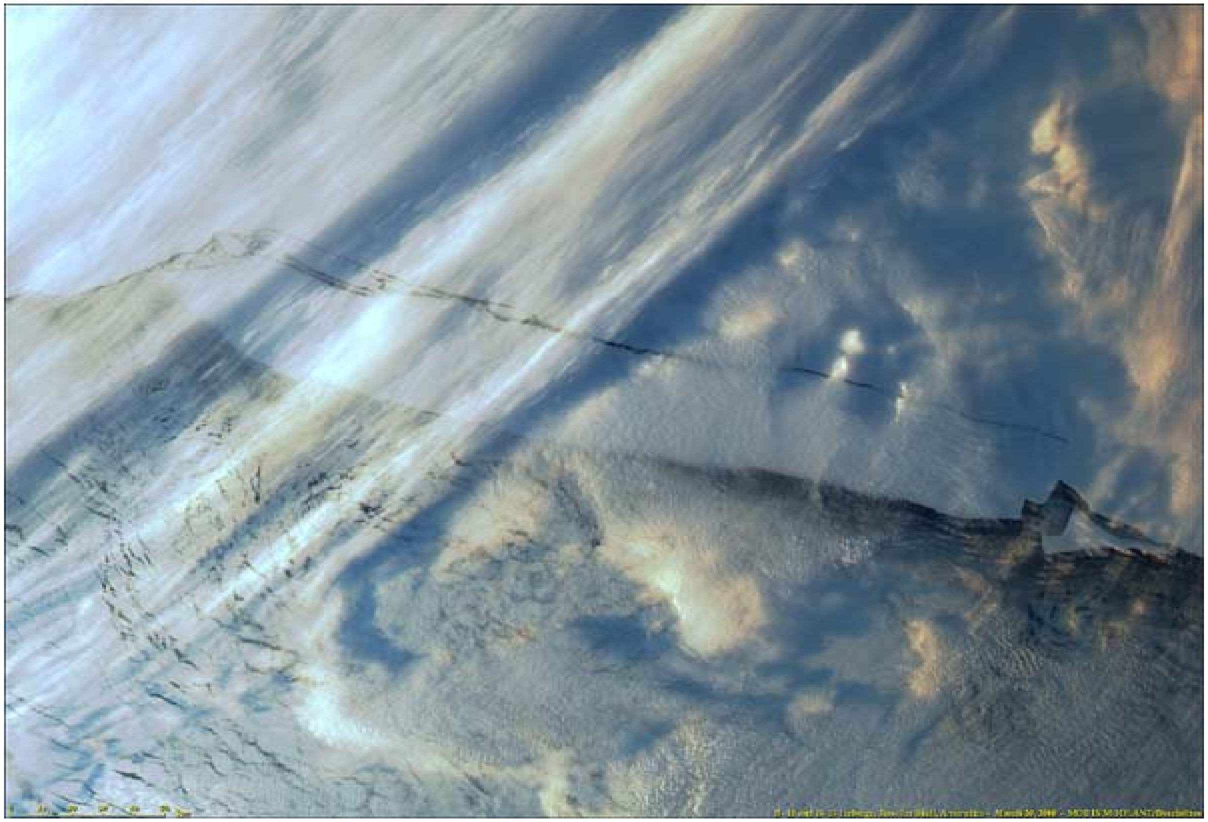
MODIS Applications - Snow

Spectral Properties of Clouds and Snow



In the **visible spectrum** clouds and snow look **very similar**. Thus, it is difficult to separate them with human eyes. But they are **very different in the mid-infrared**

MODIS Applications - Snow



A **massive iceberg**, one of the largest ever observed, broke off the Ross Ice Shelf near Roosevelt Island in Antarctica in mid-March 2000. This iceberg is about 40 miles wide and 300 miles long. The breaking off of such a big iceberg may be related to global climate change

Introduction to Remote Sensing – Part 2

- Medium-resolution Sensors
  - Landsat Series
  - SPOT Series
- High-resolution Sensors
  - Ikonos
  - Quickbird
- Low(er)-resolution Sensors
  - GOES
  - AVHRR
  - MODIS