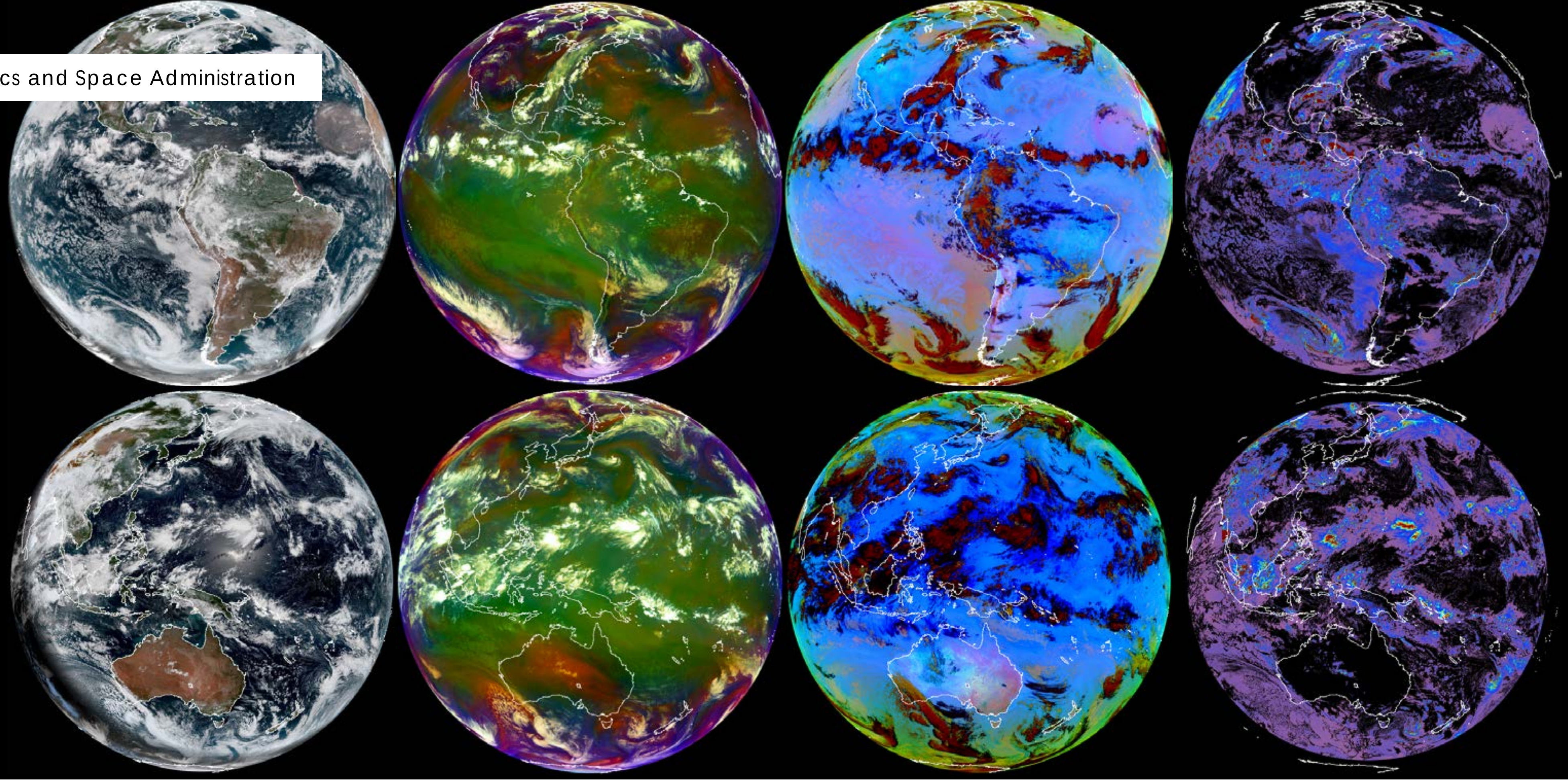
National Aeronautics and Space Administration



An Introduction to Geostationary Satellite Remote Sensing of Air Quality

Pawan Gupta, STI/USRA/NASA Marshall Space Flight Center

High Temporal Resolution Air Quality Observations from Space, September 4-25, 2018

Webinar Series Outline

Session 1

- An introduction to geostationary satellite remote sensing of air quality
- Speaker: Dr. Pawan Gupta, STI/USRA/MSFC

Session 2

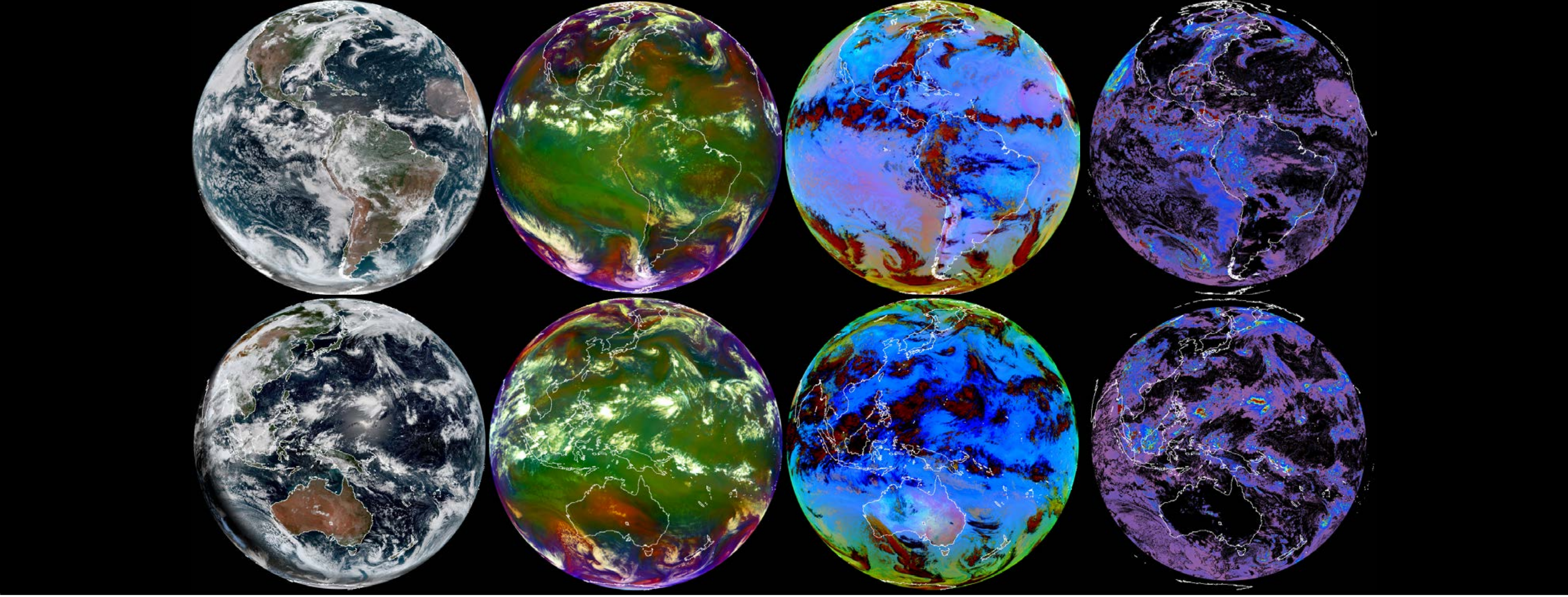
- Aerosol observations from GOES-R and GOES-S satellites over the Americas.
- Speaker: Dr. Amy K. Huff, The Pennsylvania State University/NOAA

Session 3

- Aerosol observations from the HIMAWARI, GOCI, and GEMS satellites over Asia.
- Speaker: Dr. Myungje Choi, Yonsei University, South Korea

Session 4

- Aerosol observations from the INSAT series of satellites over Asia and Africa
- Speaker: Dr. Prakash Chauhan, Indian Institute of Remote Sensing, India



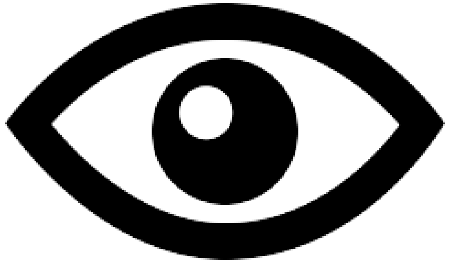
Fundamentals of Satellite Remote Sensing

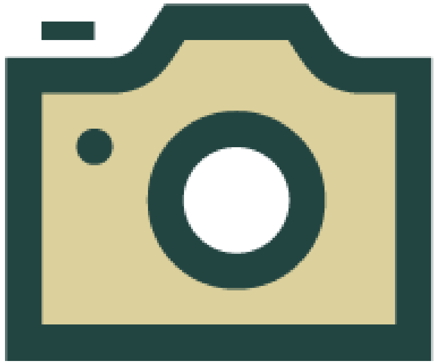
What is remote sensing?

Collecting information about an object without being in direct physical contact with it

What is remote sensing?

Collecting information about an object without being in direct physical contact with it





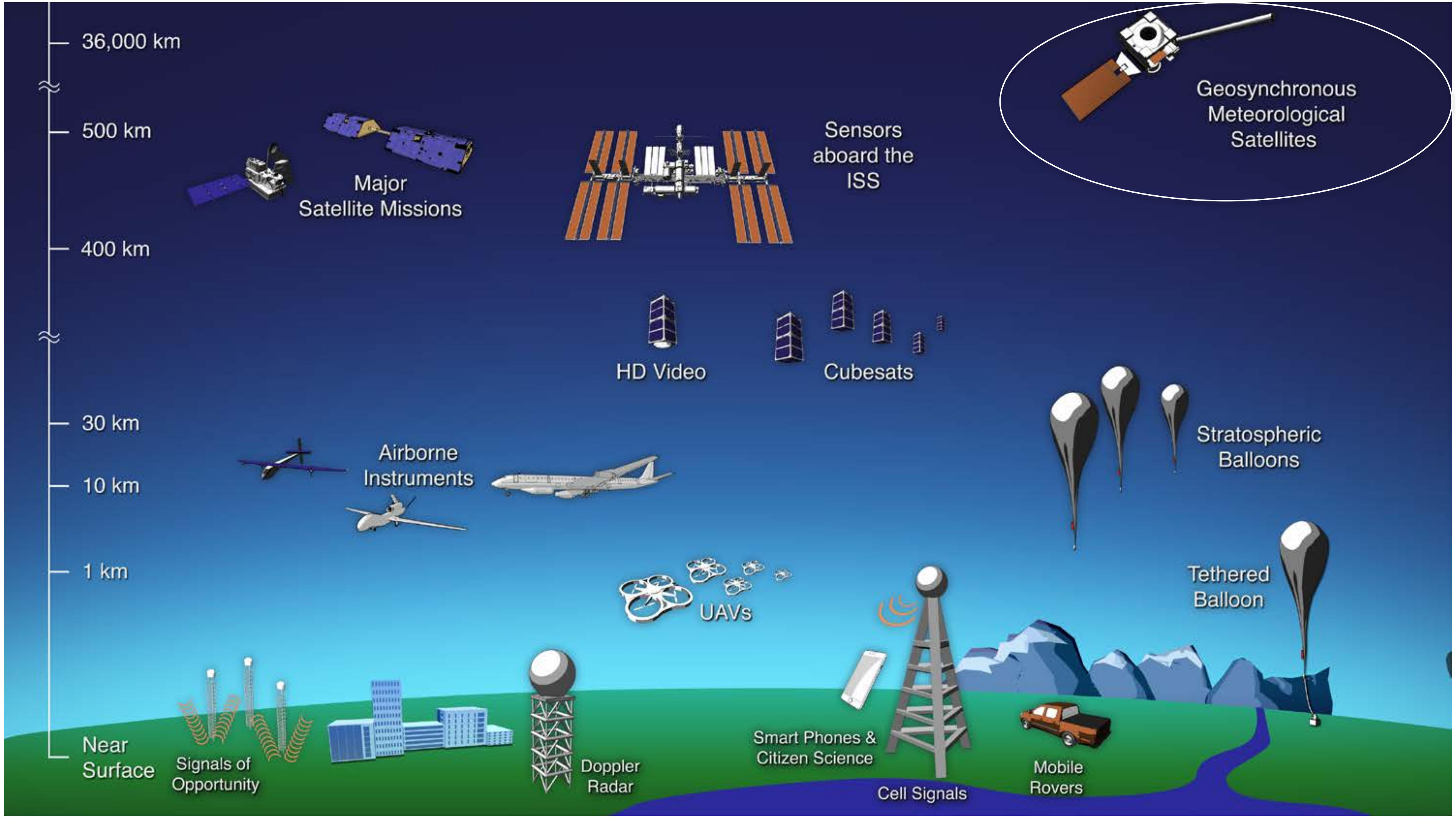
Remote Sensing: Platforms




- The platform depends on the end application
- What information do you want?
- How much detail do you need?
- What type of detail?
- How frequently do you need this data?

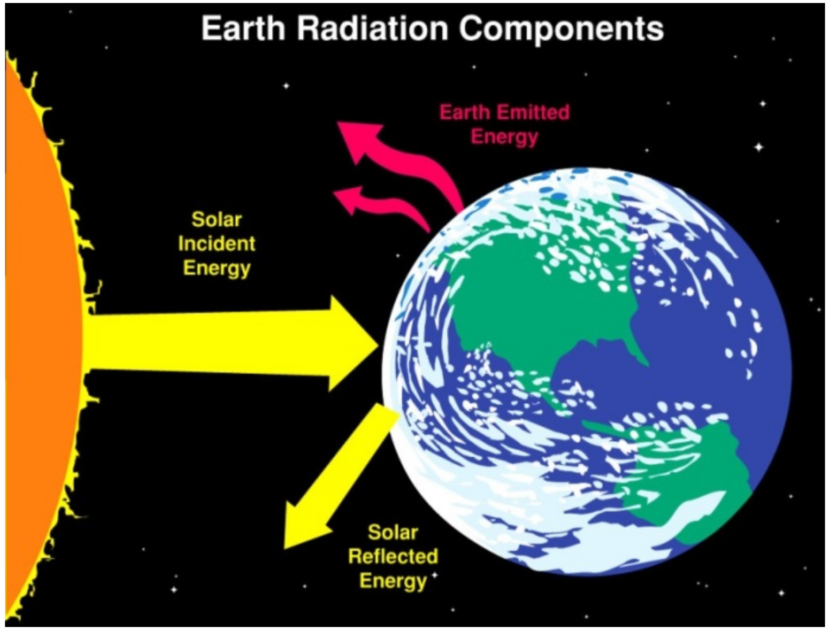
Image Credits: Natural Resources Canada

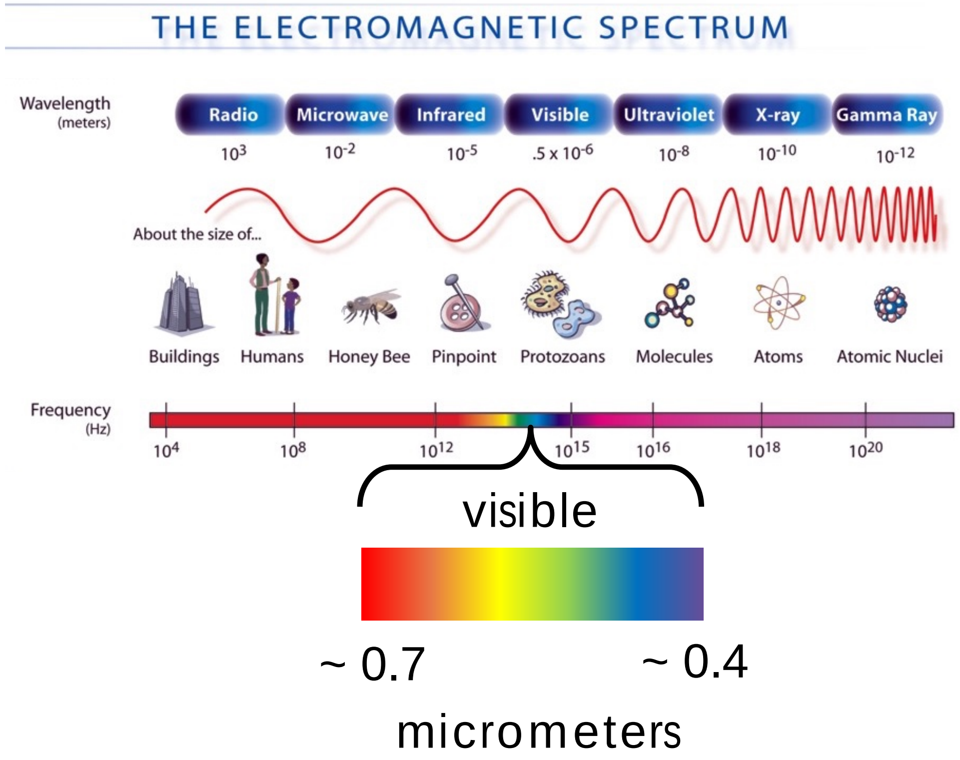
Remote Sensing of Our Planet



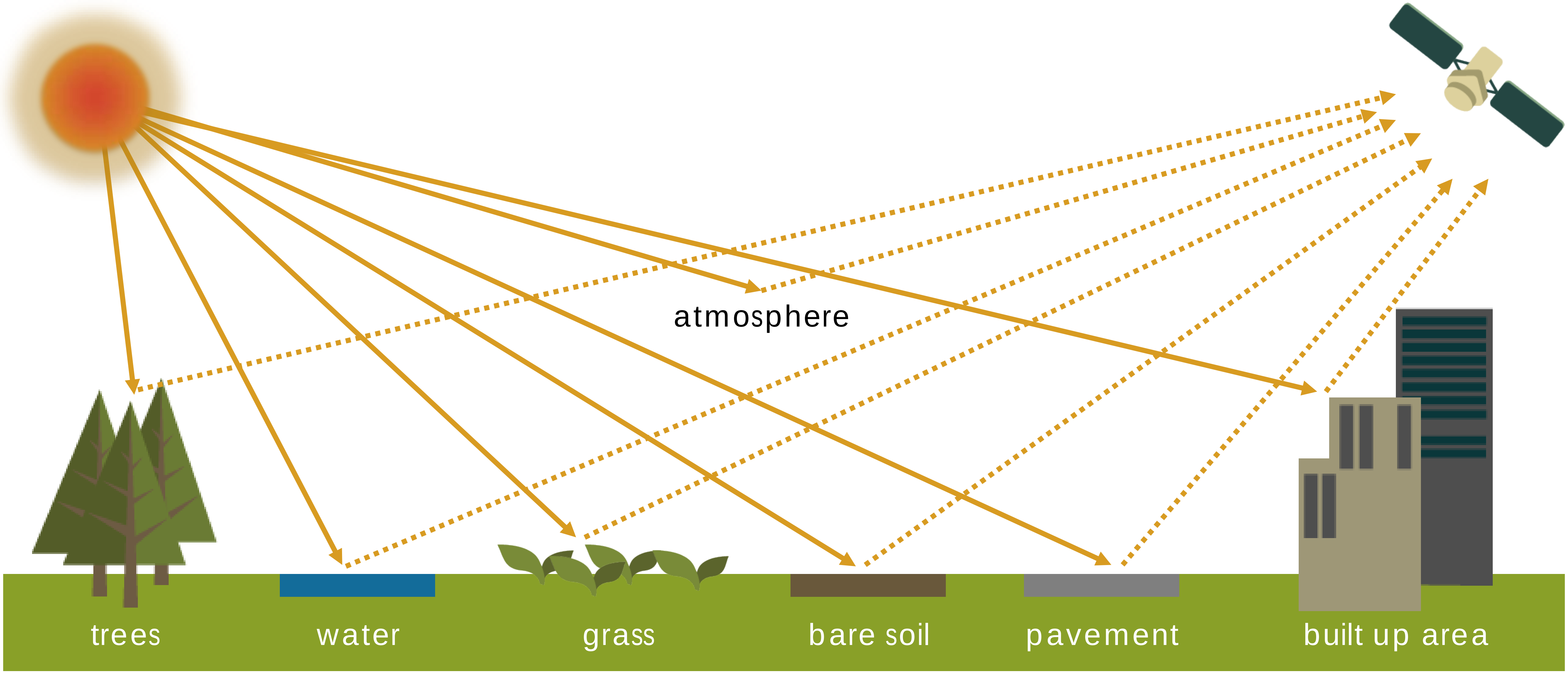
Electromagnetic Radiation

- Earth-Ocean-Land-Atmosphere System
  - Reflects solar radiation back into space
  - Emits infrared and microwave radiation into space



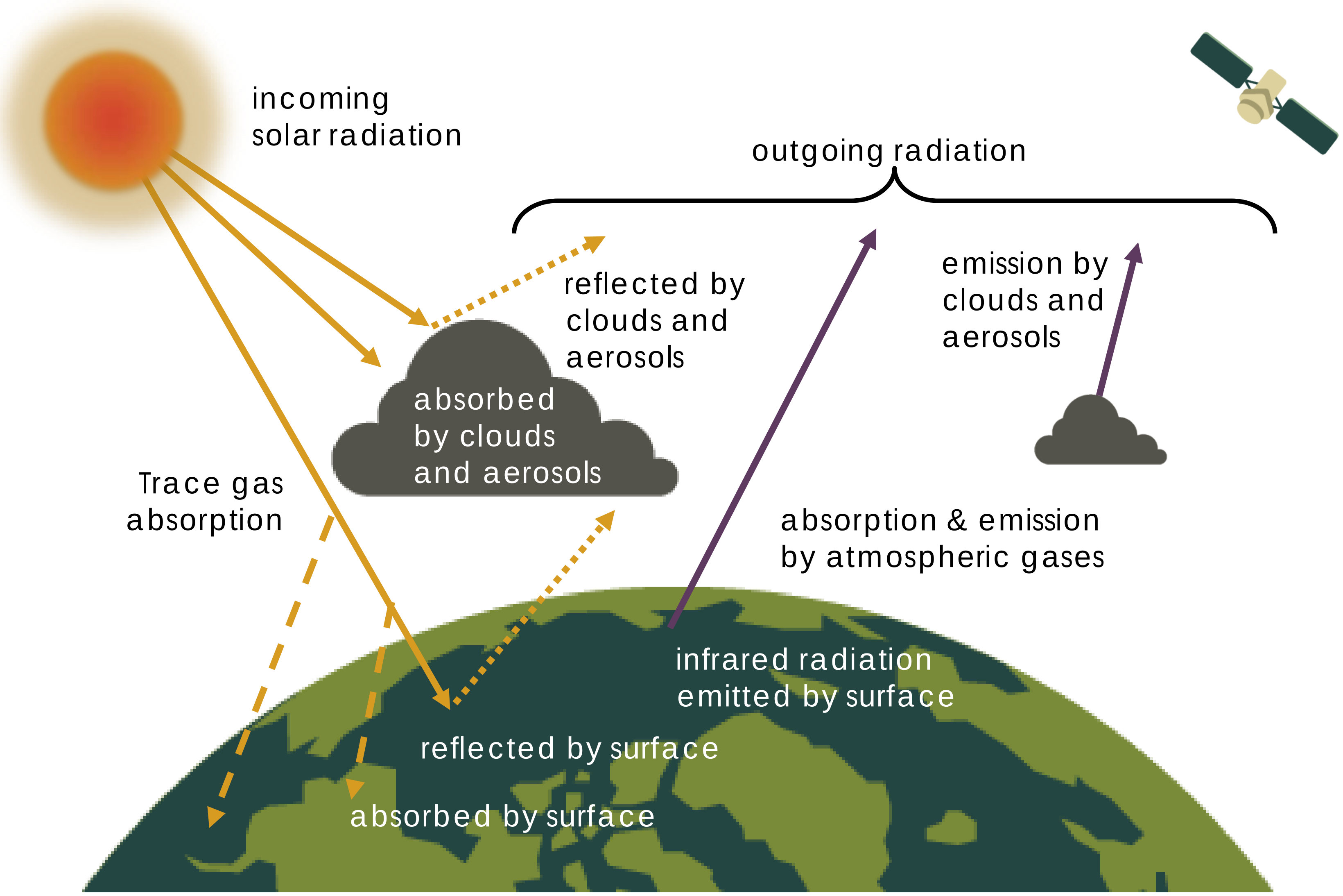


What do satellites measure ?

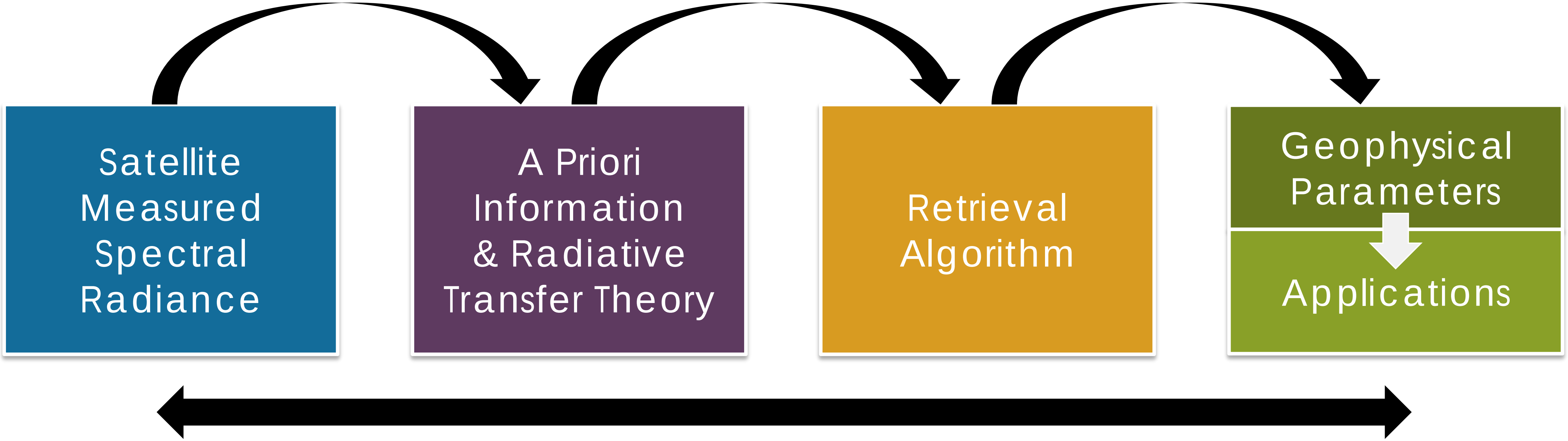


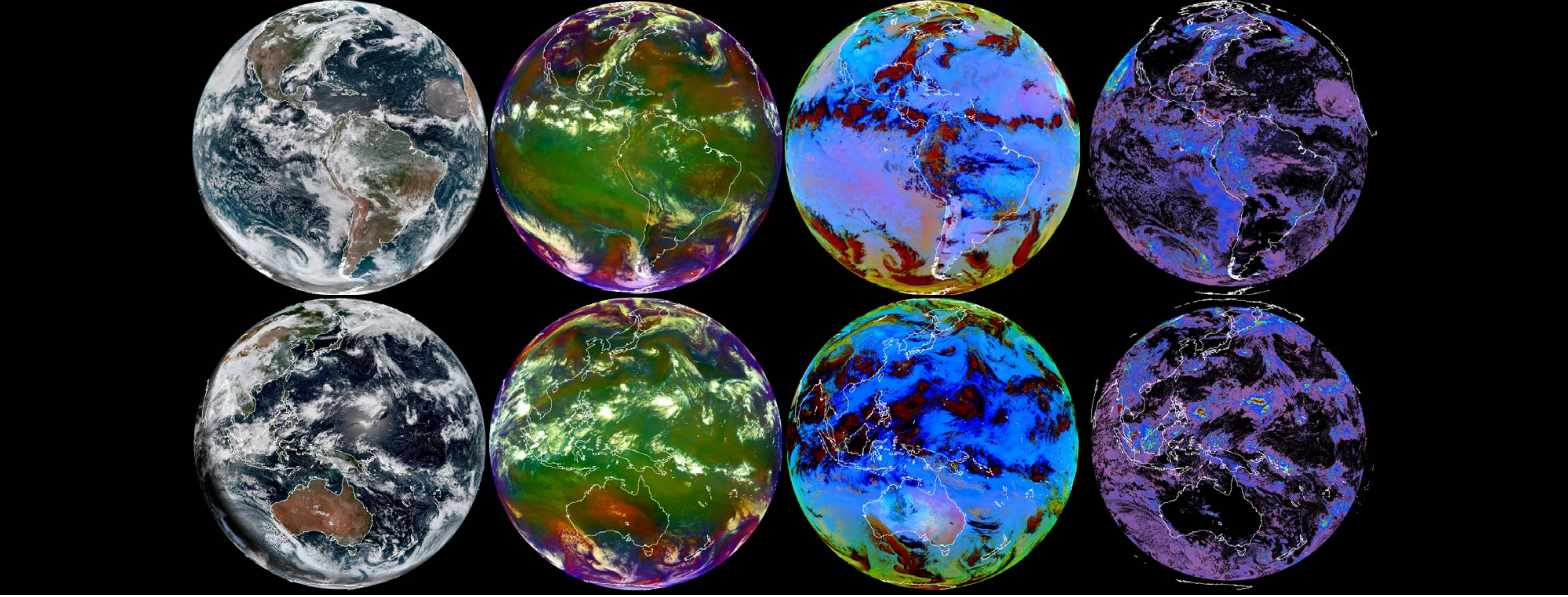
Measuring Properties of the Earth-Atmosphere System from Space

- The intensity of reflected and emitted radiation to space is influenced by the surface and atmospheric conditions
- Satellite measurements contain information about the surface and atmospheric conditions



The Remote Sensing Process





Satellites, Sensors, and Orbits

Satellites vs. Sensors

Earth observing satellite remote sensing instruments are named according to

1. the satellite (platform)
2. the instrument (sensor)

Naming Convention

- Before Launch: GOES-R & GOES-S
- After Launch: GOES-16 & GOES-17
- Operational in final orbit/position: GOES-East & GOES-West

GOES-R Spacecraft

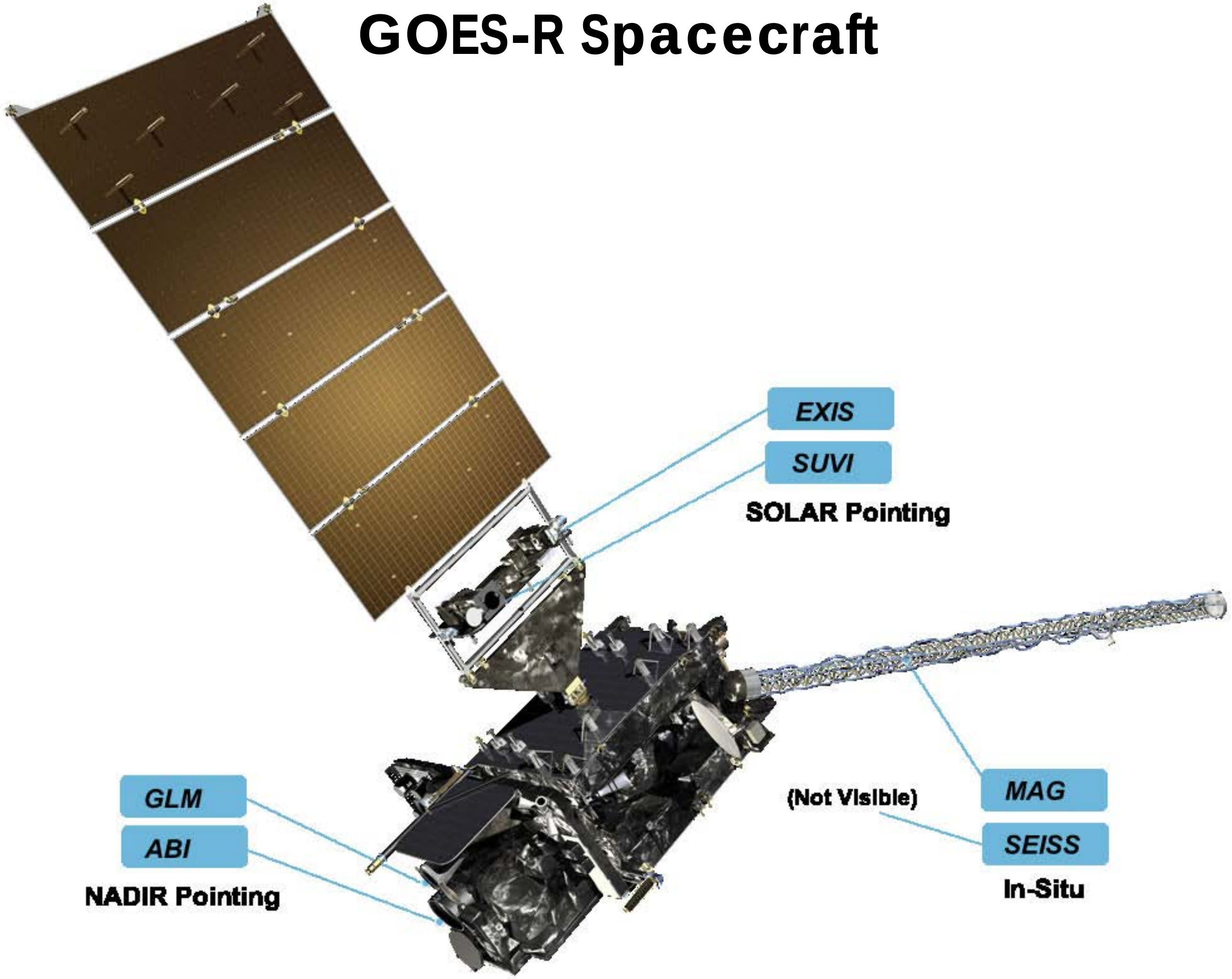
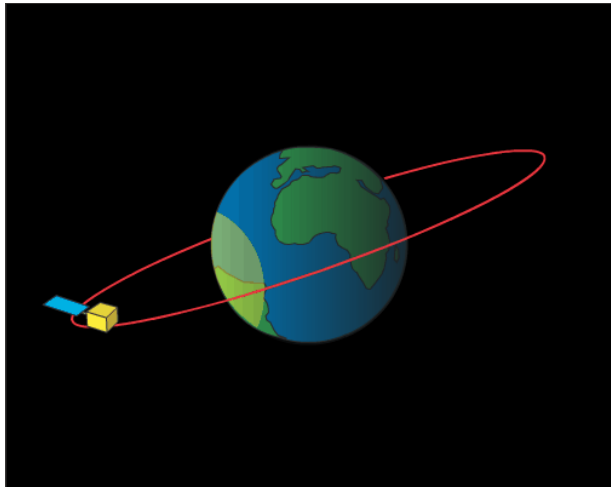


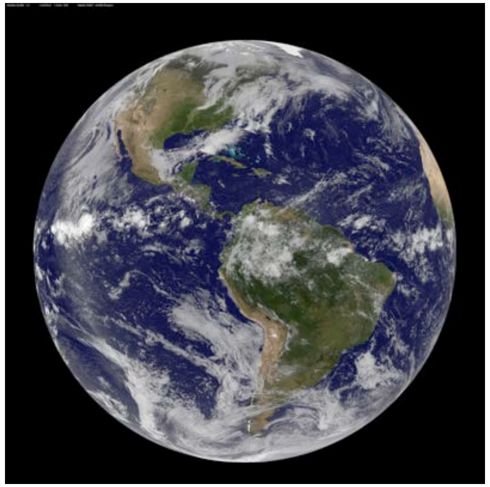
Image Credit: NASA/NOAA

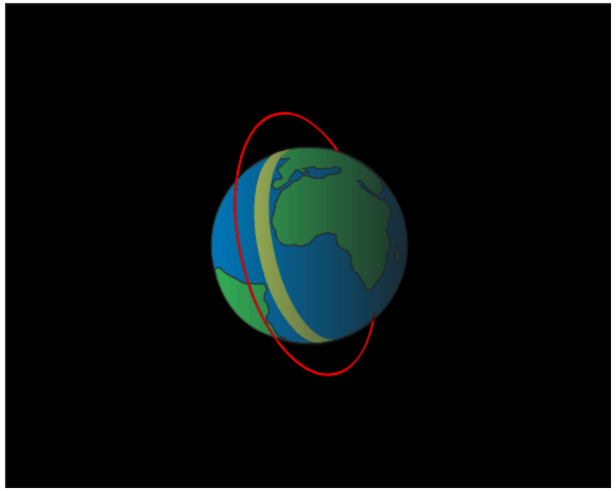
Characterizing Satellites and Sensors

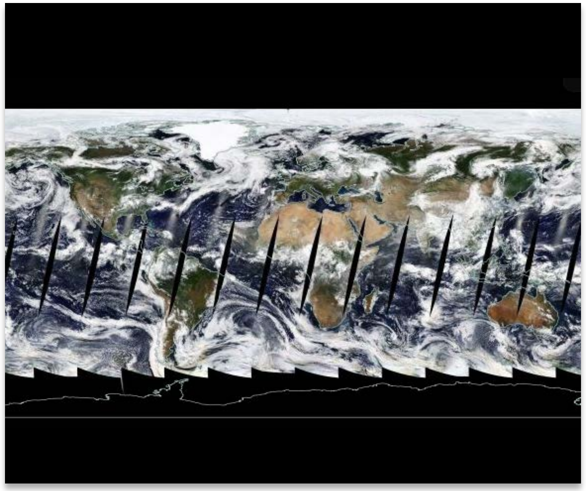
- **Orbits**
  - Polar vs. Geostationary
- **Energy Sources**
  - Passive vs. Active
- **Solar and Terrestrial Spectra**
  - Visible, UV, IR, Microwave…
- **Measurement Techniques**
  - Scanning, Non-Scanning, Imager, Sounders…
- **Resolution (Spatial, Temporal, Spectral, Radiometric)**
  - Low vs. High
- **Applications**
  - Weather, Land Mapping, Atmospheric Physics, Atmospheric Chemistry, Air Quality, Radiation Budget…

Common Orbit Types









Geostationary Orbit (GEO)

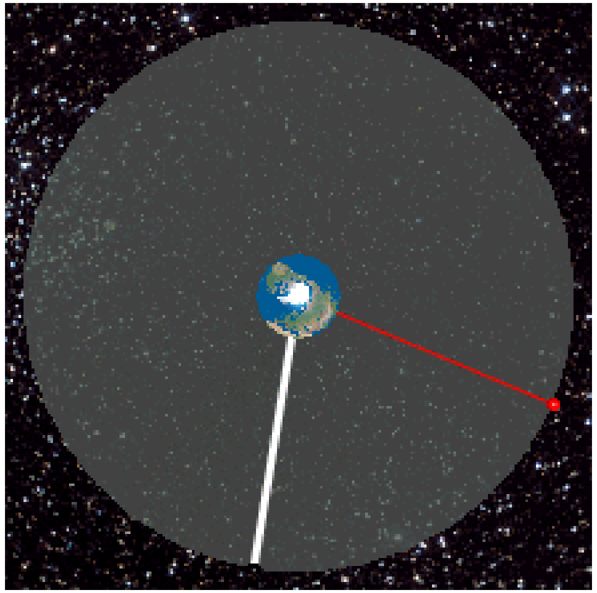
- Has the same rotational period as Earth
- Appears ‘fixed’ above Earth
- Orbits ~36,000 km above the equator

Polar Orbit (LEO)

- Fixed, circular orbit above Earth
- Sun synchronous orbit ~600-1,000 km above Earth with orbital passes are at about the same **local solar time** each day

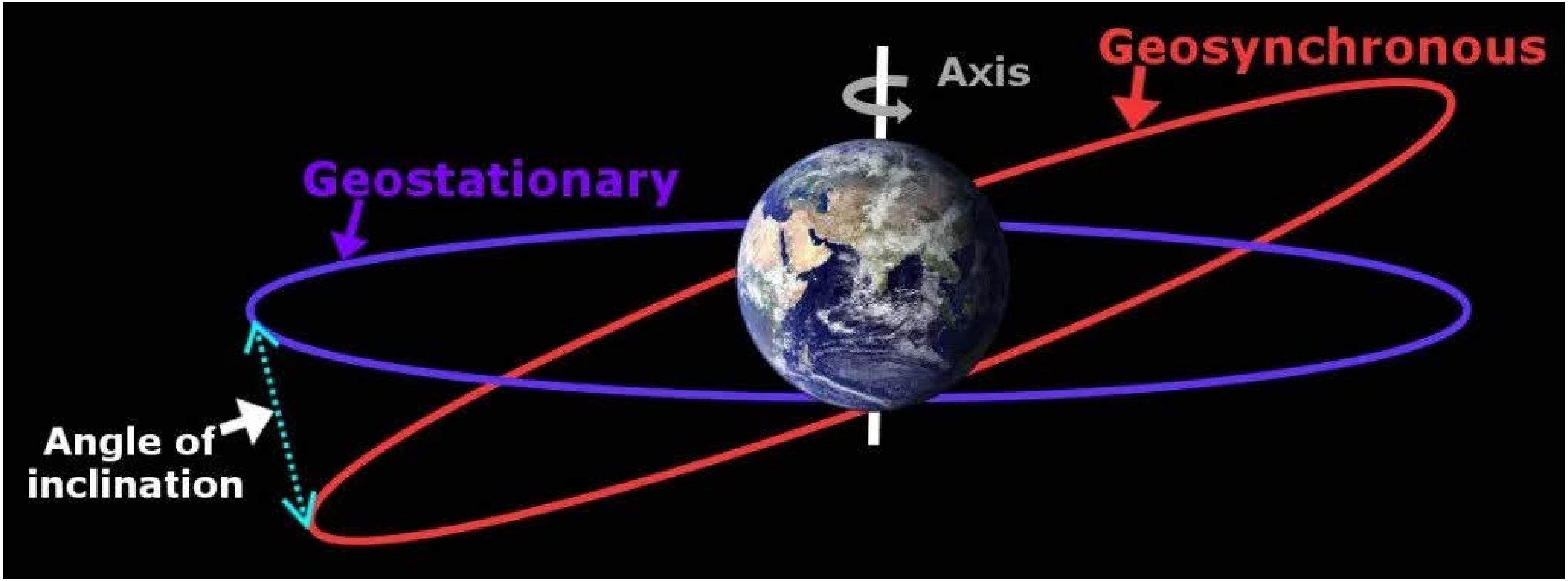
Some Facts About Geostationary Orbit

- Above the Earth's Surface - 35,786 km (or 22,236 mi)
- The orbital velocity of 3.07 km/s (1.91 mi/s)
- Circular orbit at 0 degree inclination with Equator
- This allows satellite to match the Earth's rotation period.



Source: [Wikipedia]

Geostationary vs. Geosynchronous



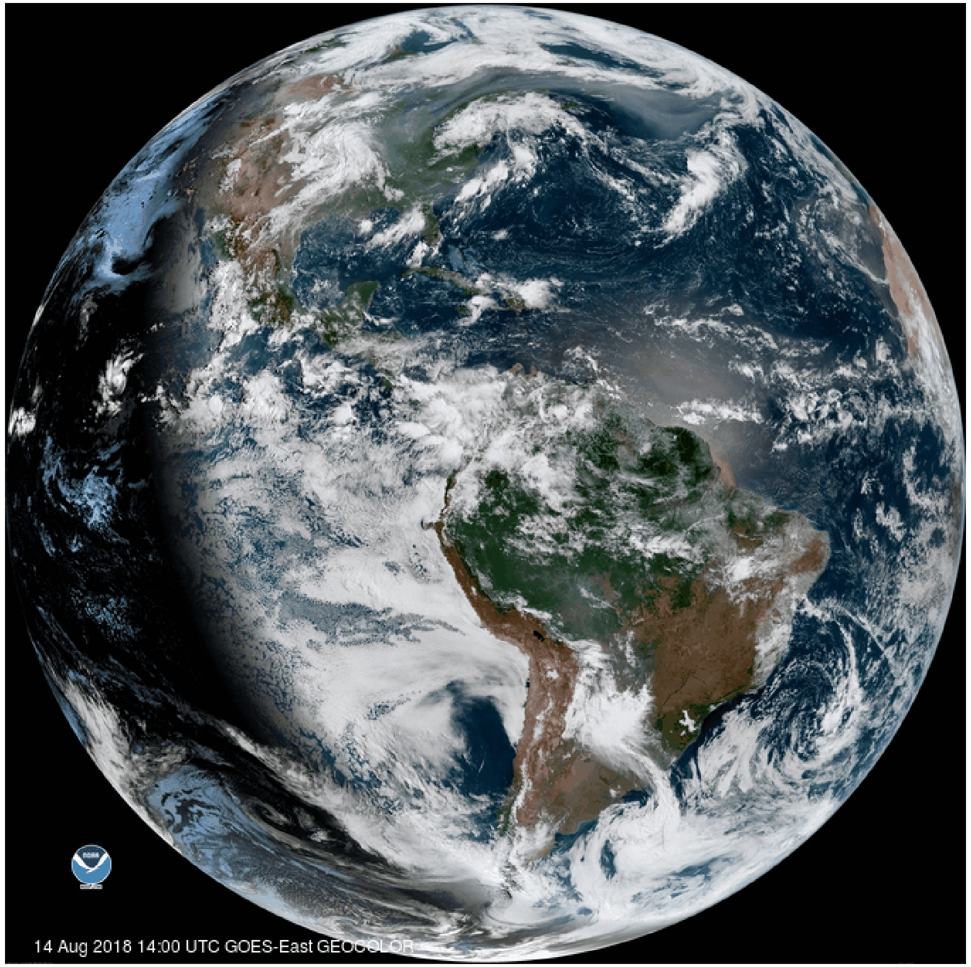
Geostationary orbit is a special type of geosynchronous satellite at the equator

Image Credit: ScienceABC

Low Earth Orbit (LEO) & Geostationary Satellites Orbiting the Earth

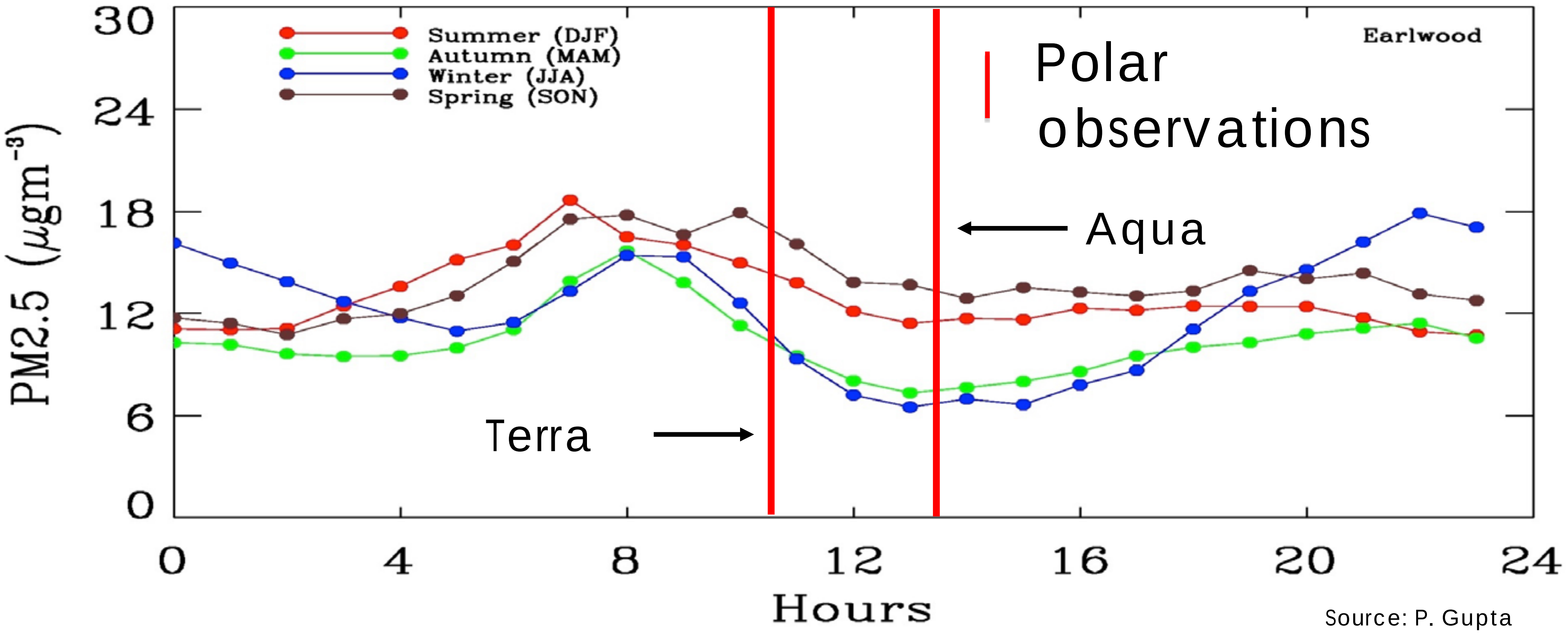
LEO Orbit

GEO Orbit



Observation Frequency

Polar Orbiting Satellites: 1-3 observations per day, per sensor

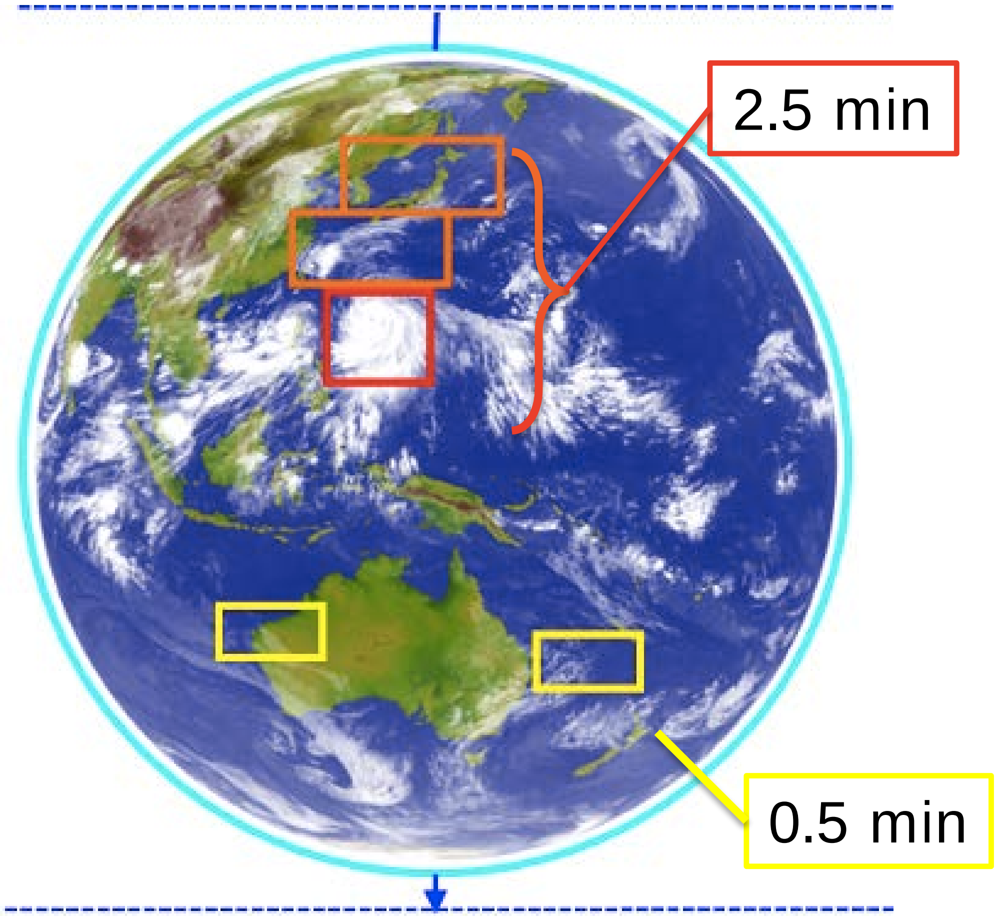


Source: P. Gupta

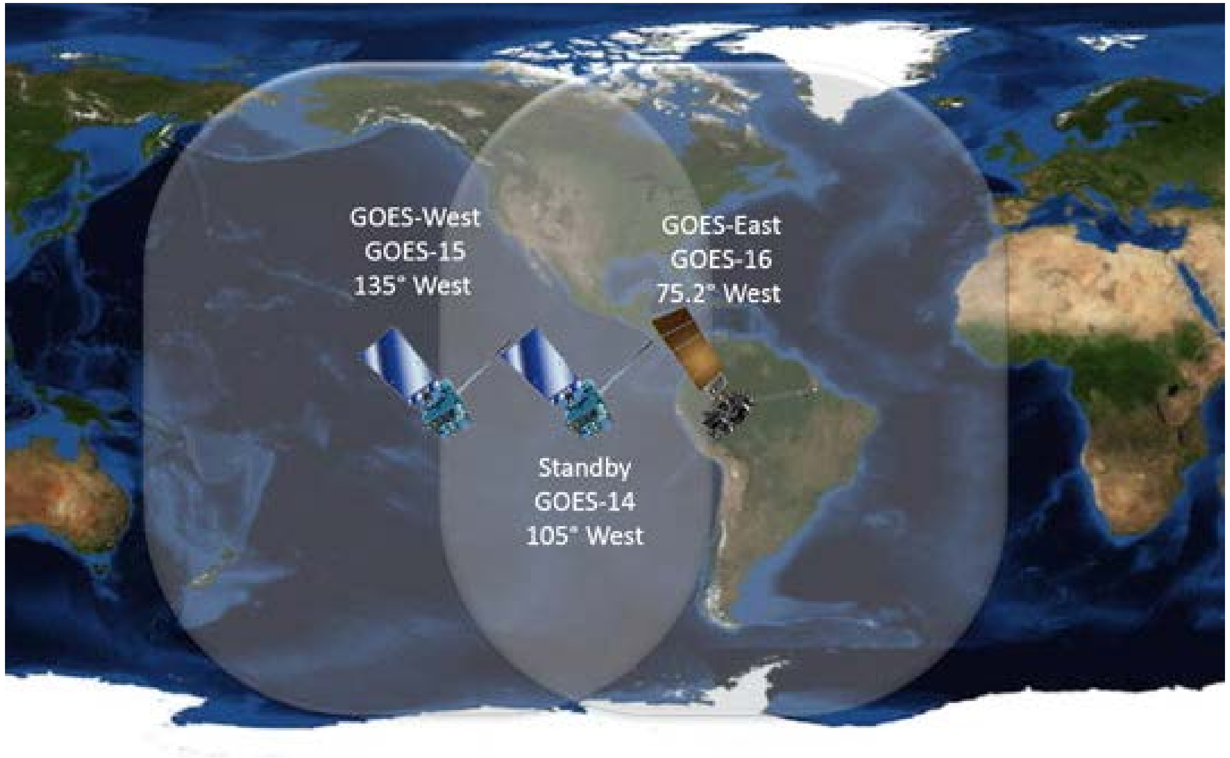
Geostationary Satellites: Every 30 sec. to 15 min.

Future Geo satellites: TEMPO, GEMS, Sentinel-4

Advanced Himawari Imager (AHI) & Advanced Baseline Imager (ABI): Spatial Coverage and Temporal Resolution

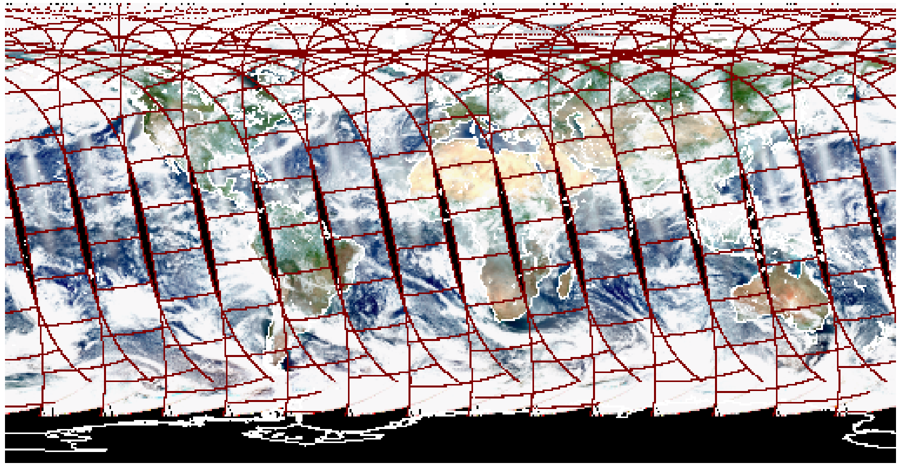


Full Disk: Every 10 min

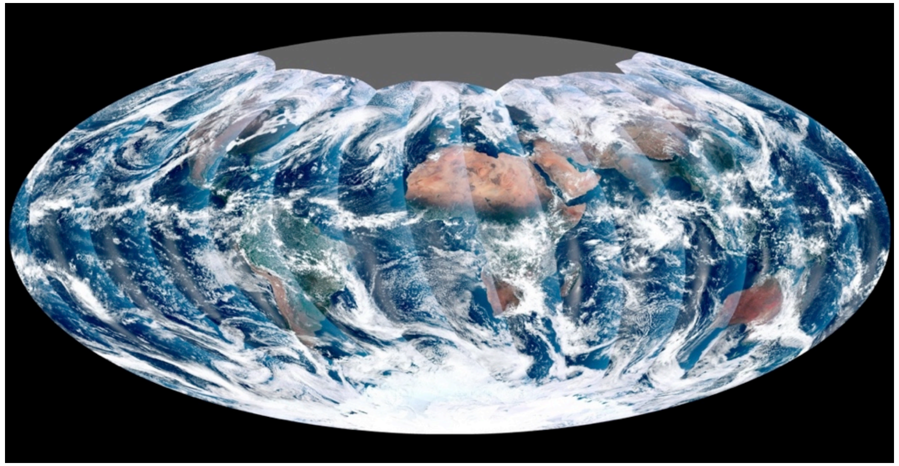


Full Disk: Every 15 min
CONUS: Every 5 min
Mesoscale: Every 0.5 min

Global (LEO) vs Regional Coverage (GEO)



MODIS



VIIRS

GOES-16

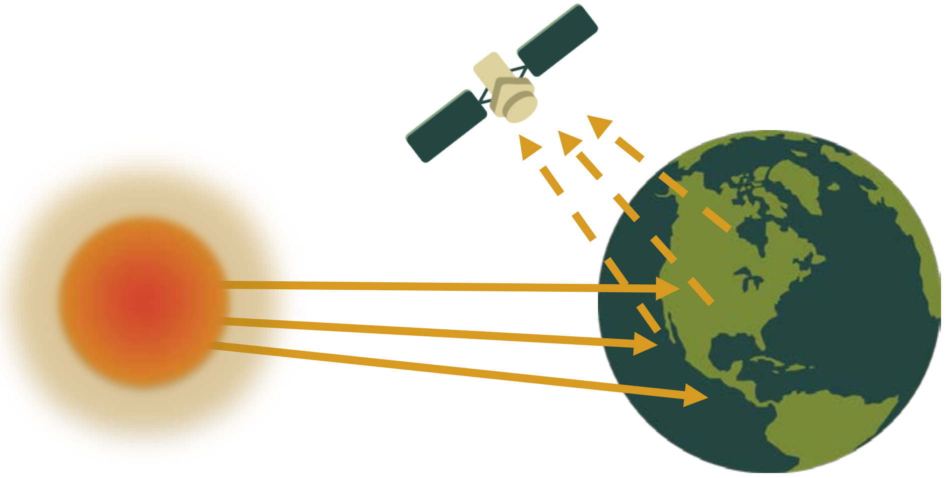
METEOSAT-8

HIMAWARI-9

Image source: NOAA

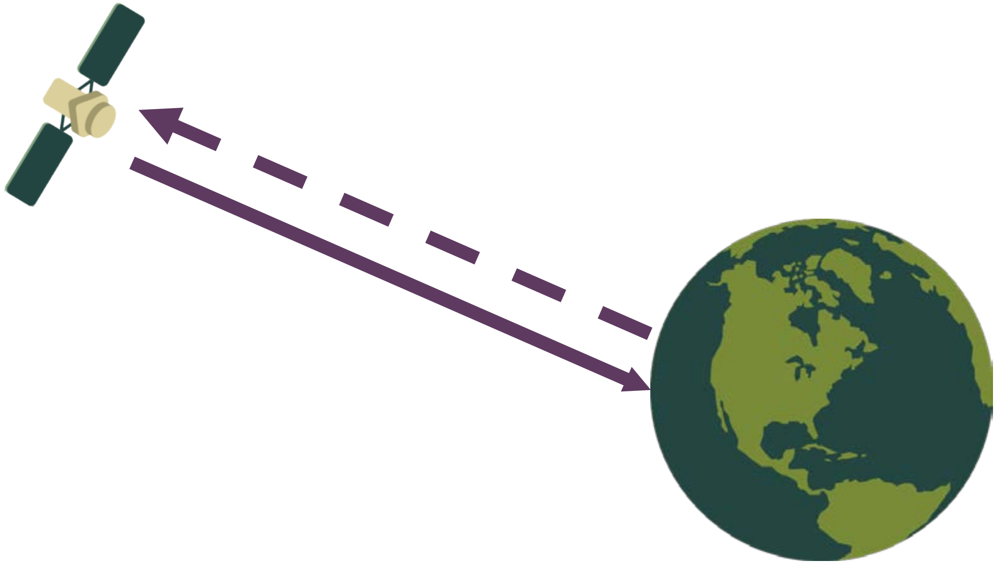
Active & Passive Sensors

Passive Sensors



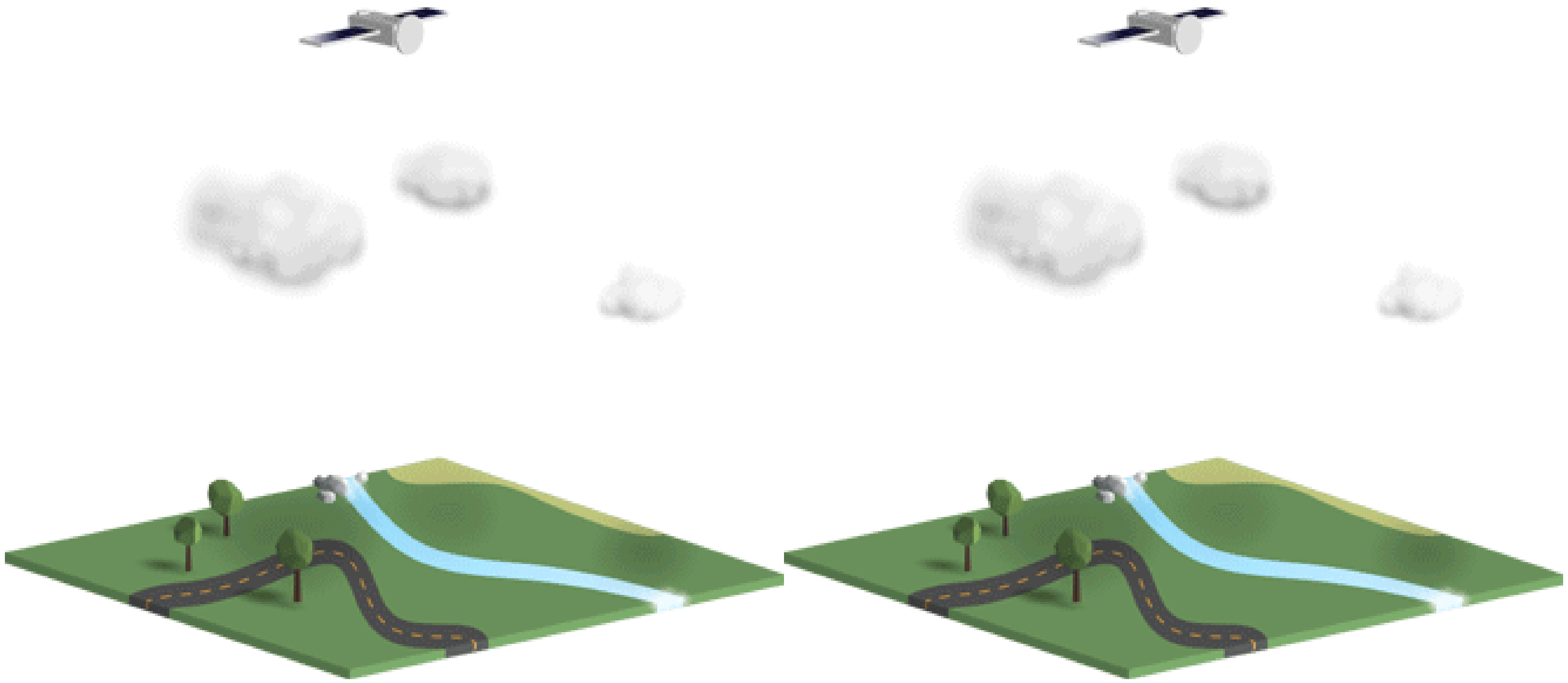
- Detect only what is emitted from the landscape, or reflected from another source (e.g., light reflected from the sun)
- Examples: (**MODIS, VIIRS, ABI, AHI**)

Active Sensors



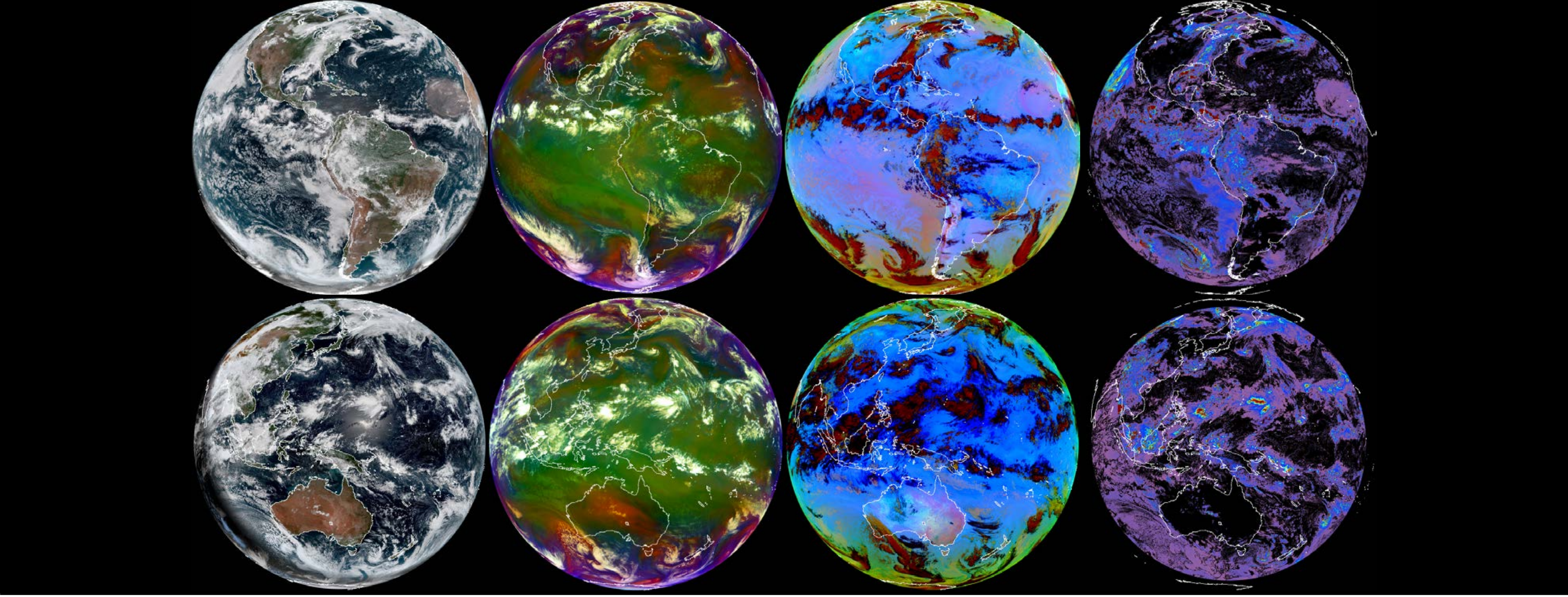
- Instruments emit their own signal and the sensor measures what is reflected back (e.g. sonar and radar)
- Example: **CALIPSO,**

Active & Passive Sensors



Passive | Sensors detect only what is emitted from the landscape, or reflected from another source (e.g., light reflected from the sun).

Active | Instruments emit their own signal and the sensor measures what is reflected back. Sonar and radar are examples of active sensors.



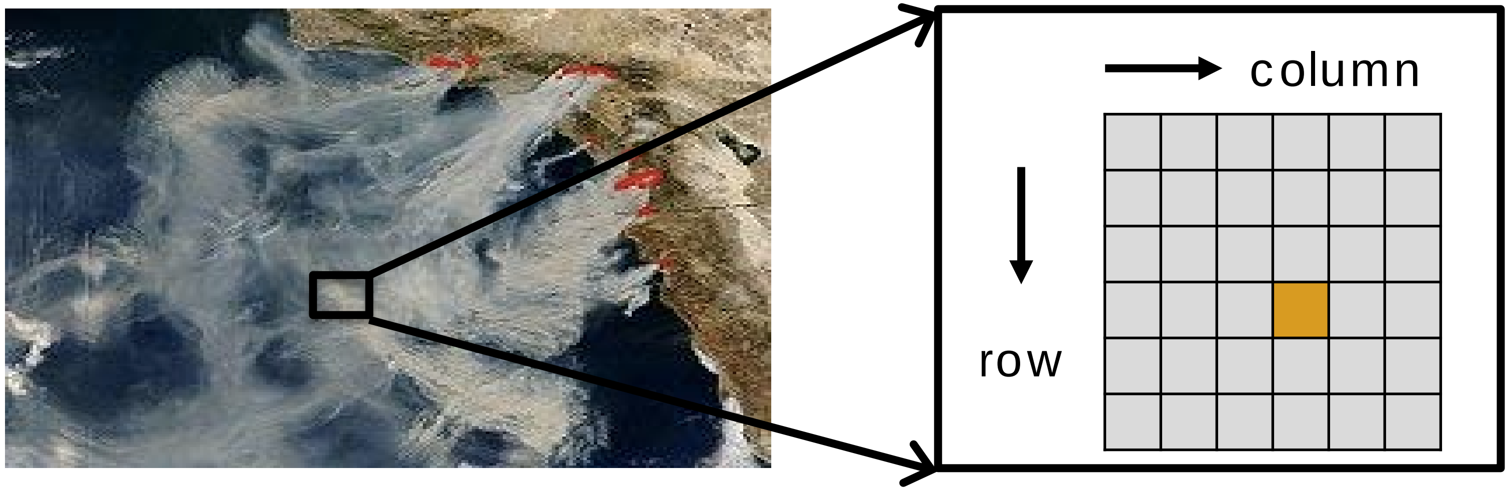
Resolution

Remote Sensing – Types of Resolution

- **Spatial Resolution**
  - Smallest spatial measurement
- **Temporal Resolution**
  - Frequency of measurement
- **Spectral Resolution**
  - Number of independent channels
- **Radiometric Resolution**
  - Sensitivity of the detectors

Each resolution depends on the satellite orbit configuration and sensor design.
Resolutions are different for different sensors.

Pixel – the Smallest Unit of an Image



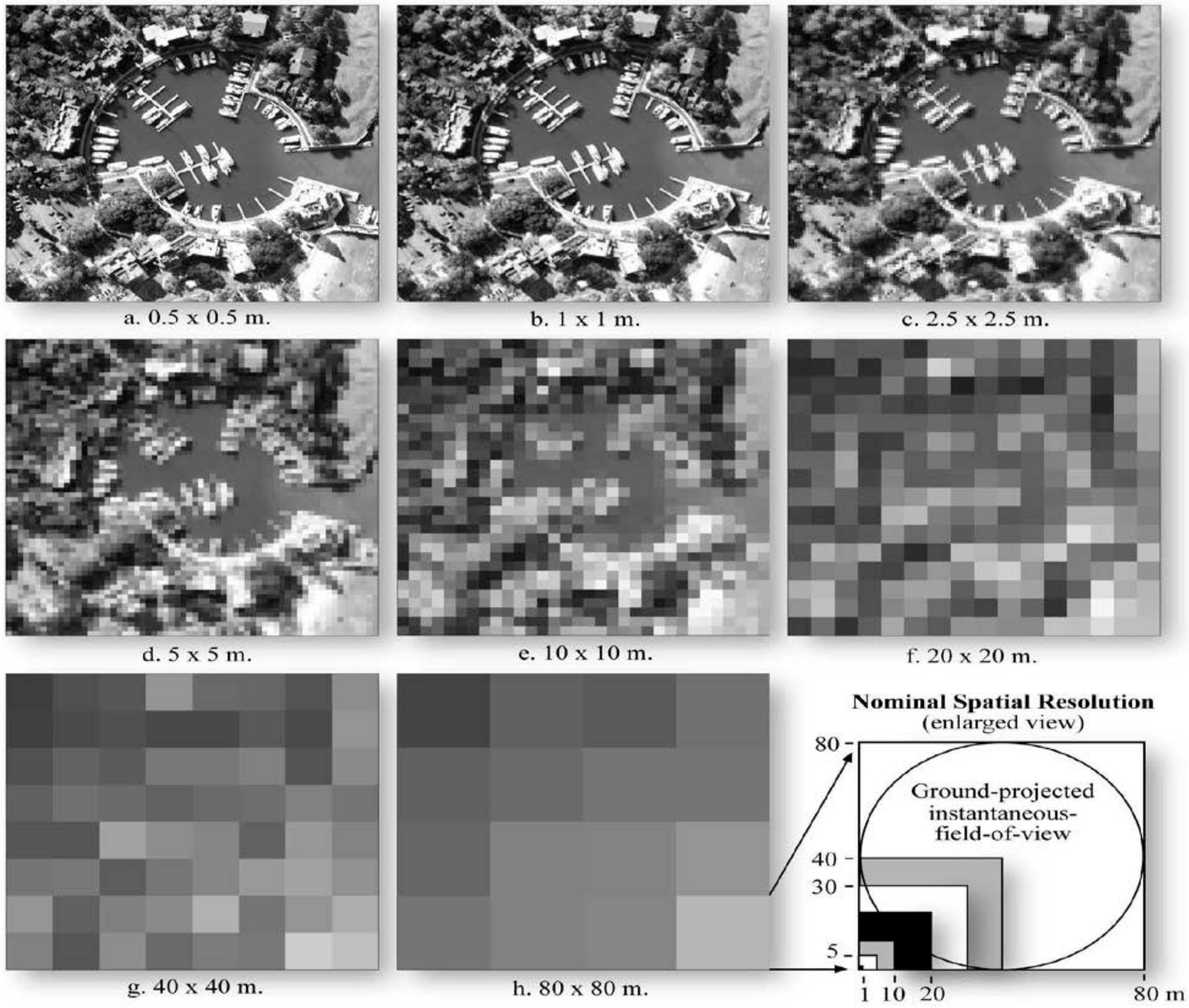
- A digital image is composed of a two-dimensional array of individual picture elements – called pixels – arranged in columns and in rows
- Each pixel represents an area on the Earth's surface
- A pixel has an intensity value and a location address in the 2D image
- Spatial resolution is defined by the size of a pixel

*Text Source: Center for Remote Imaging, Sensing & Processing

Why is spatial resolution important?

- ABI & AHI (GEO)
  – 500 m – 2 km
- MODIS (LEO)
  – 250 m – 1 km
- VIIRS (LEO)
  – 375 m

Imagery of Harbor Town in Hilton Head, SC, at Various Nominal Spatial Resolutions



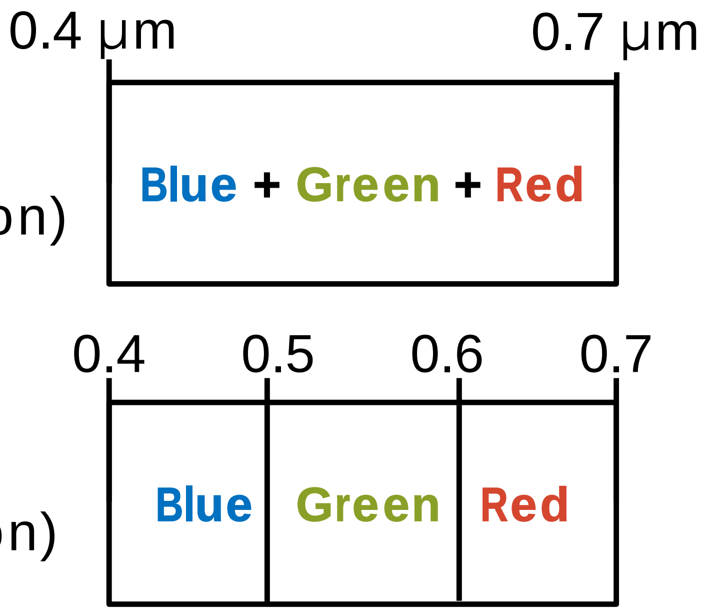
Source: Introductory Digital Image Processing, 3rd edition, Jensen, 2004

Spectral Resolution

- Spectral resolution describes a sensor's ability to define fine wavelength intervals
- The finer the spectral resolution, the narrower the wavelength range for a particular channel or band
- **Multispectral Sensors**
  - MODIS, ABI, AHI
  - moderate spectral resolution
  - Particles pollution
- **Hyperspectral Sensors**
  - OMI, AIRS
  - High spectral resolution
  - Future GEMS, TEMPO
  - Gases pollution

Black & White Film
(Low Spectral Resolution)

Color Film
(High Spectral Resolution)



AHI & ABI: Spectral Coverage

AHI

Band	Wavelength (μm)	Spatial Resolution (km)
1	0.46	1
2	→ 0.51	1
3	0.64	0.5
4	0.86	0.5
5	1.6	2
6	2.3	2
7	3.9	2
8	6.2	2
9	7.0	2
10	7.3	2
11	8.6	2
12	9.6	2
13	10.4	2
14	11.2	2
15	12.3	2
16	13.3	2

ABI

Future GOES Imager (ABI) band	Central Wavelength (μm)	Nominal Subsatellite IGFOV (km)
1	0.47	1
2	0.64	0.5
3	0.865	1
4	→ 1.378	2
5	1.61	1
6	2.25	2
7	3.90	2
8	6.19	2
9	6.95	2
10	7.34	2
11	8.5	2
12	9.61	2
13	10.35	2
14	11.2	2
15	12.3	2
16	13.3	2

Source: http://www.data.jma.go.jp/

Radiometric Resolution

- Imagery data are represented by positive digital numbers that vary from 0 to (one less than) a selected power of 2
- The maximum number of brightness levels available depends on the number of bits (represents radiometric resolution) used in representing the energy recorded
- The larger this number, the higher the radiometric resolution

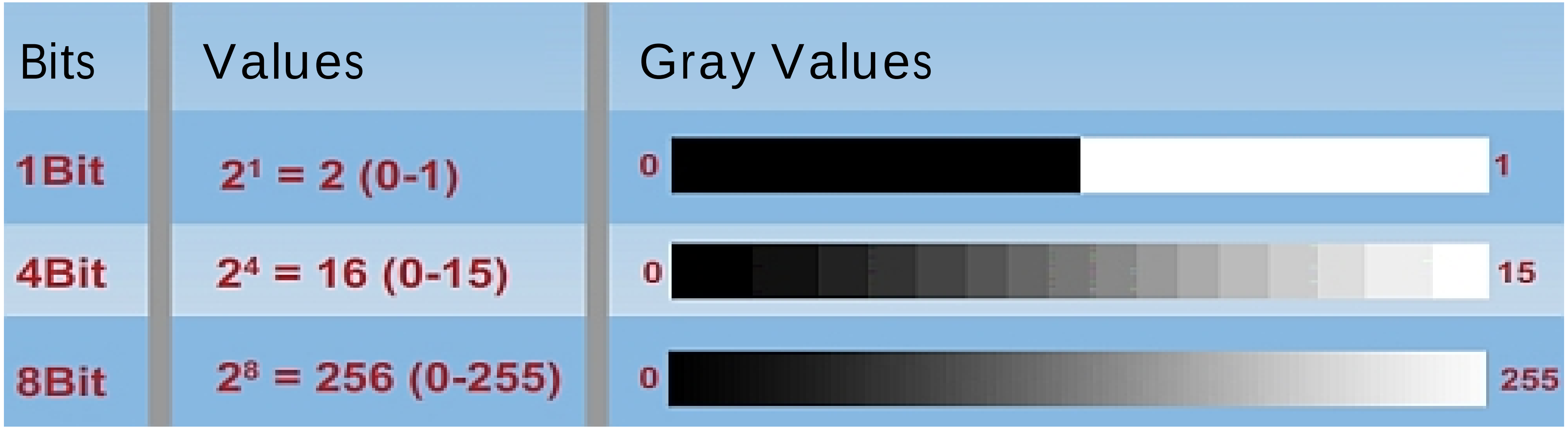


Image Source: FIS ; *Text Source: Natural Resources Canada

Radiometric Resolution

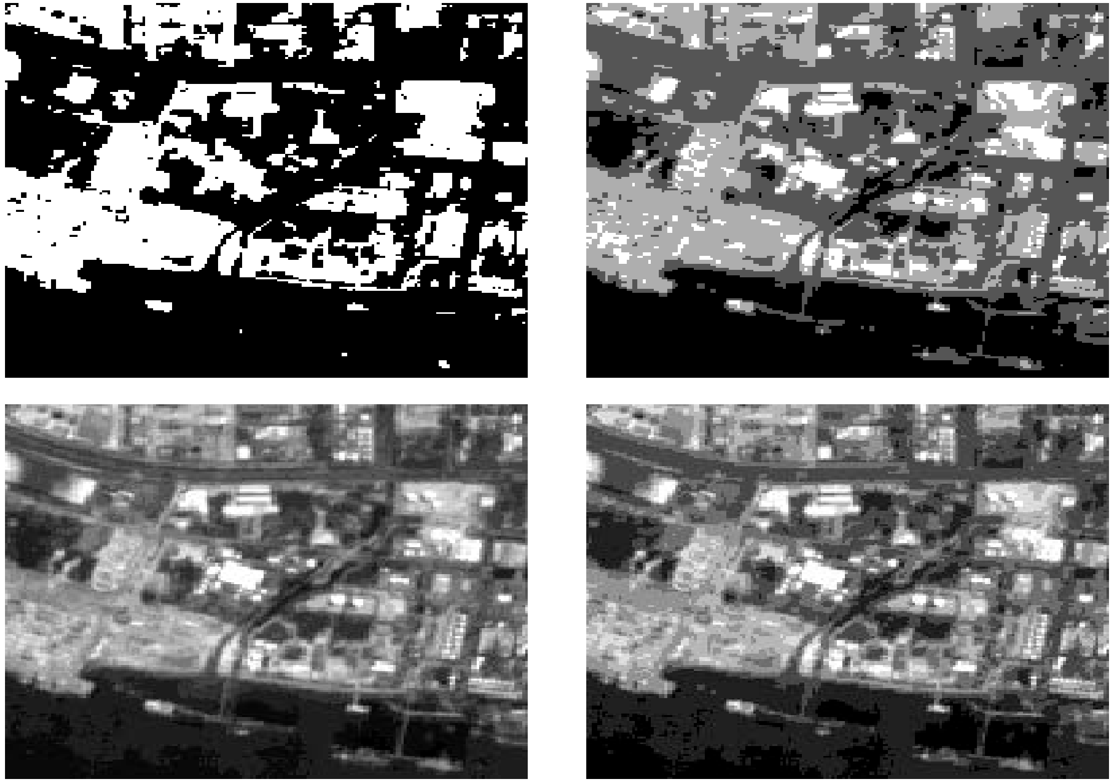
- Detects the difference in brightness levels
- The more sensitive the sensor - the higher the radiometric resolution
- If radiometric precision is high, an image will be sharp
- Expressed in bits
- NASA Satellite Sensor Examples:
  – 12 bit sensor (MODIS, MISR, Landsat-8 TM/MSS): 2^{12} or 4,096 levels
  – 10 bit sensor (AVHRR): 2^{10} or 1,024 levels
  – 8 bit sensor (Landsat-7 TM): 2^{8} or 256 levels (0-255)
  – 6 bit sensor (Landsat-7 MSS): 2^{6} or 64 levels (0-63)

ABI (GOES-R & S) – 12 (most band) and 14 bits (3.9 µm)

Radiometric Resolution

2 - levels

4 - levels



8 - levels

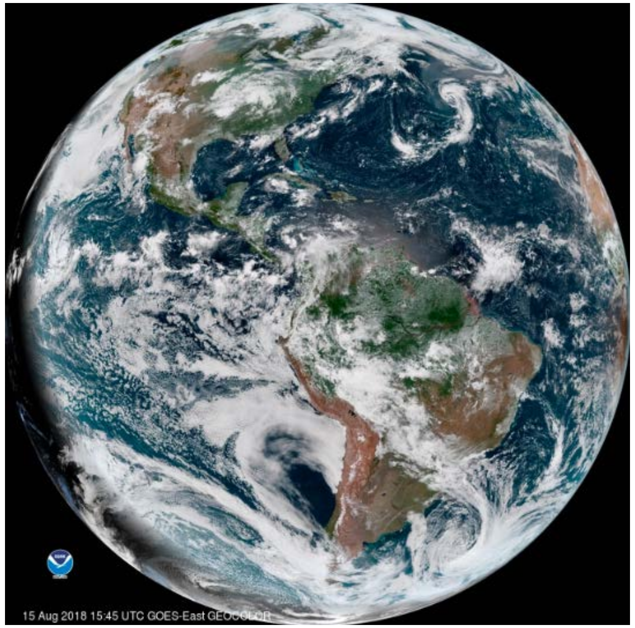
16 - levels

In classifying a scene, different classes are more precisely identified if radiometric resolution is high

GOES-R (ABI) has 4,096 levels

Temporal Resolution

- How frequently a satellite can provide observation of the same area on the earth
  - It mostly depends on the swath width of the satellite – the larger the swath – the higher the temporal resolution



Global coverage in….
- MODIS
  - 1-2 days
- OMI
  - 1 day
- MISR
  - 6-8 days
- VIIRS
  - 1 day

- Geostationary (only regional coverage)
  - 30 sec – 1 hr

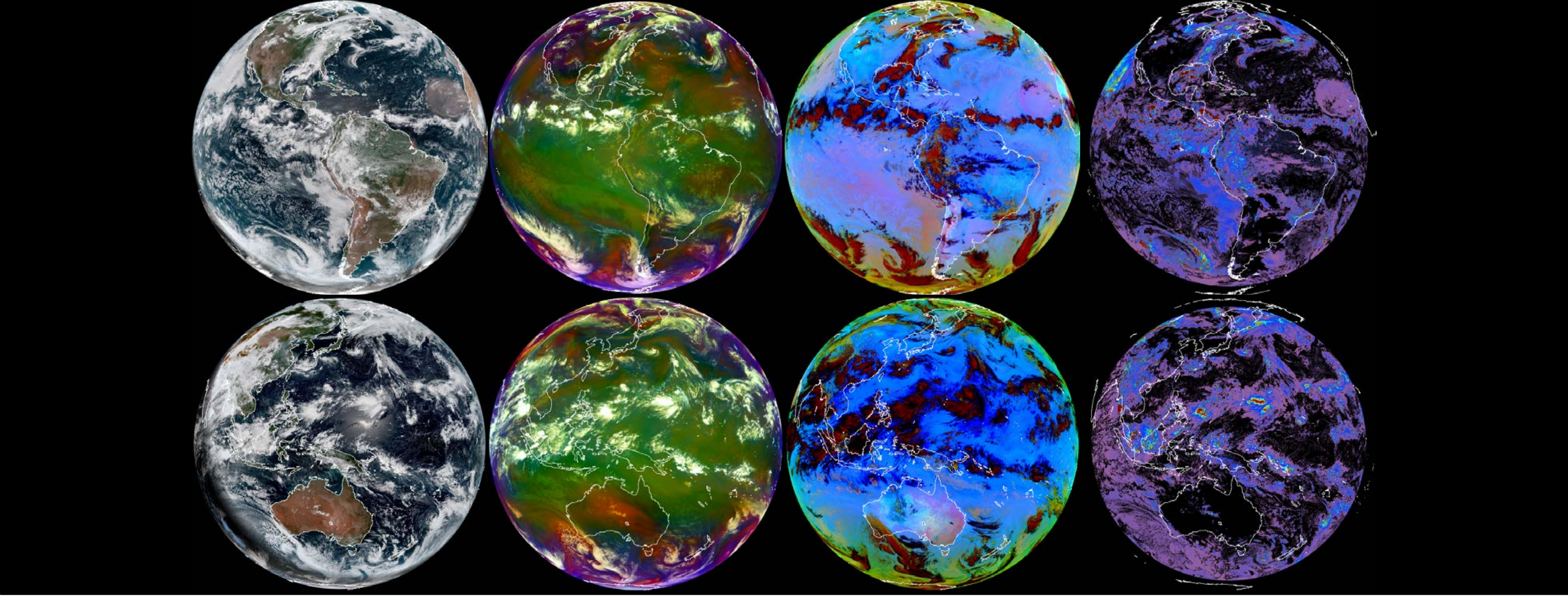
GOES-R Image Source: https://www.star.nesdis.noaa.gov/GOES/GOES16_FullDisk_Band.php?band=GEOCOLOR&length=24

Remote Sensing Tradeoff

It is **very difficult** to obtain extremely high spectral, spatial, temporal, **AND** radiometric resolutions, all at the same time

References and Further Reading

- Natural Resources Canada: http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/educational-resources/9309
- Center for Remote Imaging, Sensing, and Processing: http://www.crisp.nus.edu.sg/~research/tutorial/image.htm
- NASA Earth Observatory: http://earthobservatory.nasa.gov/Features/RemoteSensing/remote_06.php
- EOS-Goddard: http://fas.org/irp/imint/docs/rst/Front/tofc.html
- Spectral Resolution: http://web.pdx.edu/~jduh/courses/Archive/geog481w07/Students/Cody_SpectralResolution.pdf



Online Tools

Global Geostationary Meteorological Satellites

- GOES – United States of America
- Meteosat – European Space Agency
- Himawari – Japan
- Fengyun – China
- INSAT - India

Name of Satellite, Alternate Names	Longitude (degrees)	Launched (year)
GOCI/COMS-1 (Communication, Ocean, and Meteorological Satellite; Cheollian)	128	2010
Electro-L1 (GOMS 2 [Geostationary Operational Meteorological Satellite 2]	76	2011
Electro-L2	77.8	2015
Fengyun 2D (FY-2D)	86.51	2006
Fengyun 2E (FY-2E)	123.59	2008
Fengyun 2F (FY-2F)	105	2012
Fengyun 2G (FY 2G)	0	2014
Gaofen 4	105.5	2015
GOES 13 (Geostationary Operational Environmental Satellite, GOES-N)	−75	2006
GOES 14 (Geostationary Operational Environmental Satellite, GOES-O)	−104.41	2009
GOES 15 (Geostationary Operational Environmental Satellite, GOES-P)	−135	2010
GOES 16 (Geostationary Operational Environmental Satellite GOES-R)	−75	2016
Himawari 8	140	2014
Himawari 9	140	2016
INSAT 3A (Indian National Satellite)	93.53	2003
INSAT 3D (Indian National Satellite)	82	2013
INSAT 3DR (Indian National Satellite)	74	2016
Kalpana-1 (Metsat-1)	74.07	2002
SEVIRI/Meteosat 10 (MSGalaxy-3,MSG 3)	0	2012
SEVIRI/Meteosat 11 (MSG 4)	0	2015
SEVIRI/Meteosat 8 (MSGalaxy-1, MSG-1)	41.5	2002
SEVIRI/Meteosat 9 (MSGalaxy-2, MSG 2)	−0.02	2005
MTSAT-2 (Multi-Functional Transport Satellite)	145.06	2006

M. Sowden et al. 2018, AE, https://ww.sciencedirect.com/science/article/pii/S1352231018302516

Reference Paper

A CLOSER LOOK AT THE ABI ON THE GOES-R SERIES

TIMOTHY J. SCHMIT, PAUL GRIFFITH, MATHEW M. GUNSHOR, JAIME M. DANIELS, STEVEN J. GOODMAN, AND WILLIAM J. LEBAIR

The ABI on the GOES-R series is America's next-generation geostationary advanced imager and will dramatically improve the monitoring of many phenomena at improved time and space scales.

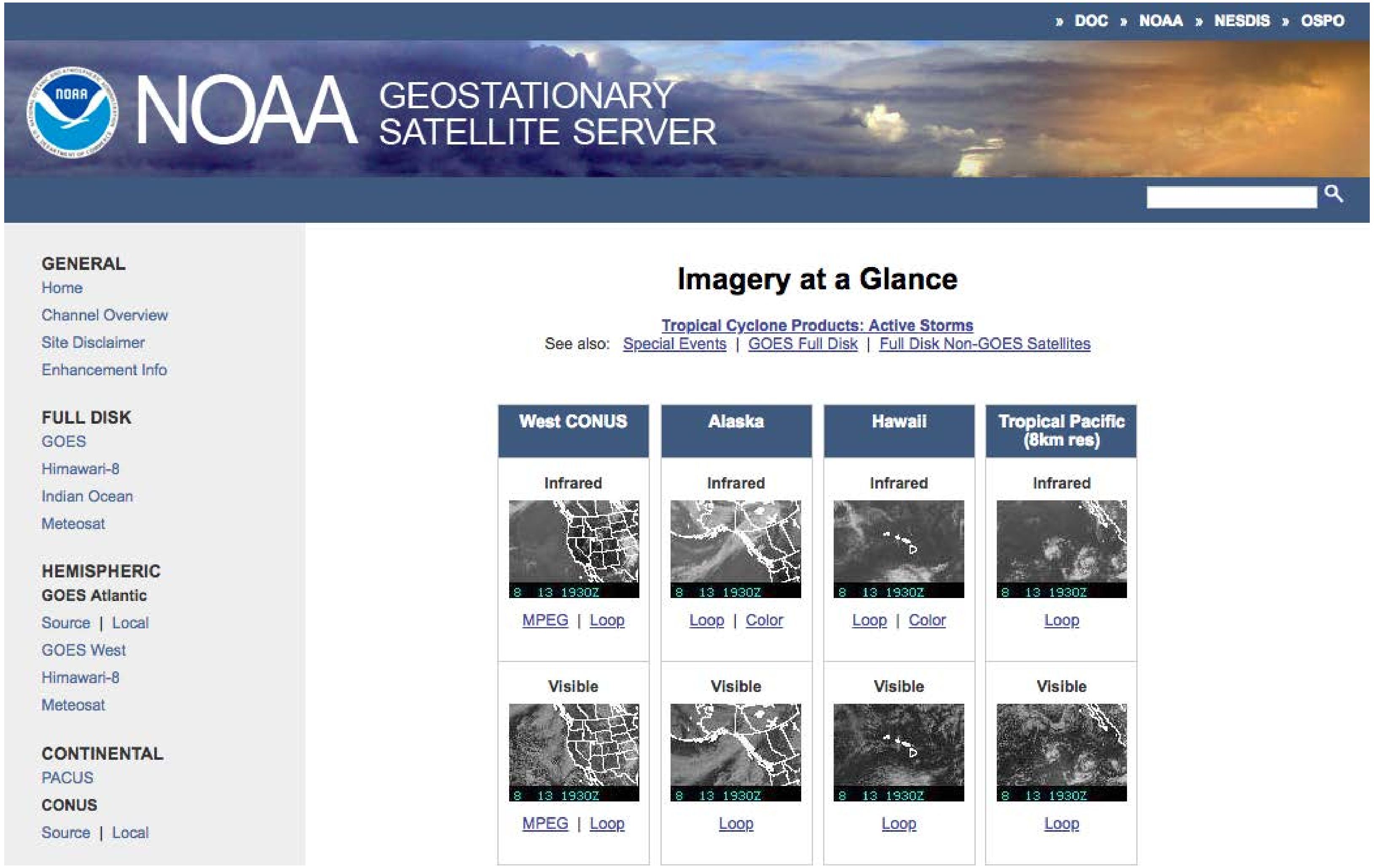
The era of imaging the Earth from the geostationary perspective began on 6 December 1966 with the launch of an experimental sensor (Spin-Scan Cloudcover Camera) on board *Application Technology Satellite-1* (*ATS-1*; Suomi and Parent 1968). The first operational follow-on satellite was the *Geostationary Operational Environmental Satellite-1* (*GOES-1*), launched in October 1975 (Davis 2007). *ATS-1* had only visible sensors, while *GOES-1* had both visible and infrared (IR) sensors, allowing for monitoring clouds at night. Subsequent generations of sensors improved the spectral coverage, added an operational sounder, and many other improvements (Menzel and Purdom 1994). The Advanced Baseline Imager (ABI) on the GOES-R series continues this coverage, with a greatly improved sensor. The mission of the ABI is to measure Earth's radiant and reflective solar energy at moderate spatial and spectral resolution and high temporal and radiometric resolution. The first satellite in the GOES-R series was launched on 19 November 2016. The ABI is a state-of-the-art 16-band radiometer, with spectral bands covering the visible, near-infrared, and IR portions of the electromagnetic spectrum (Table 1). Many attributes

AFFILIATIONS: SCHMIT—NOAA/NESDIS/Center for Satellite Applications and Research/Advanced Satellite Products Branch, Madison, Wisconsin; GRIFFITH—Space and Intelligence Systems, Harris Corporation, Fort Wayne, Indiana; GUNSHOR—Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin–Madison, Madison, Wisconsin; DANIELS—NOAA/NESDIS/Center for Satellite Applications and Research, Operational Products Development Branch, College Park, Maryland;

https://journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-15-00230.1

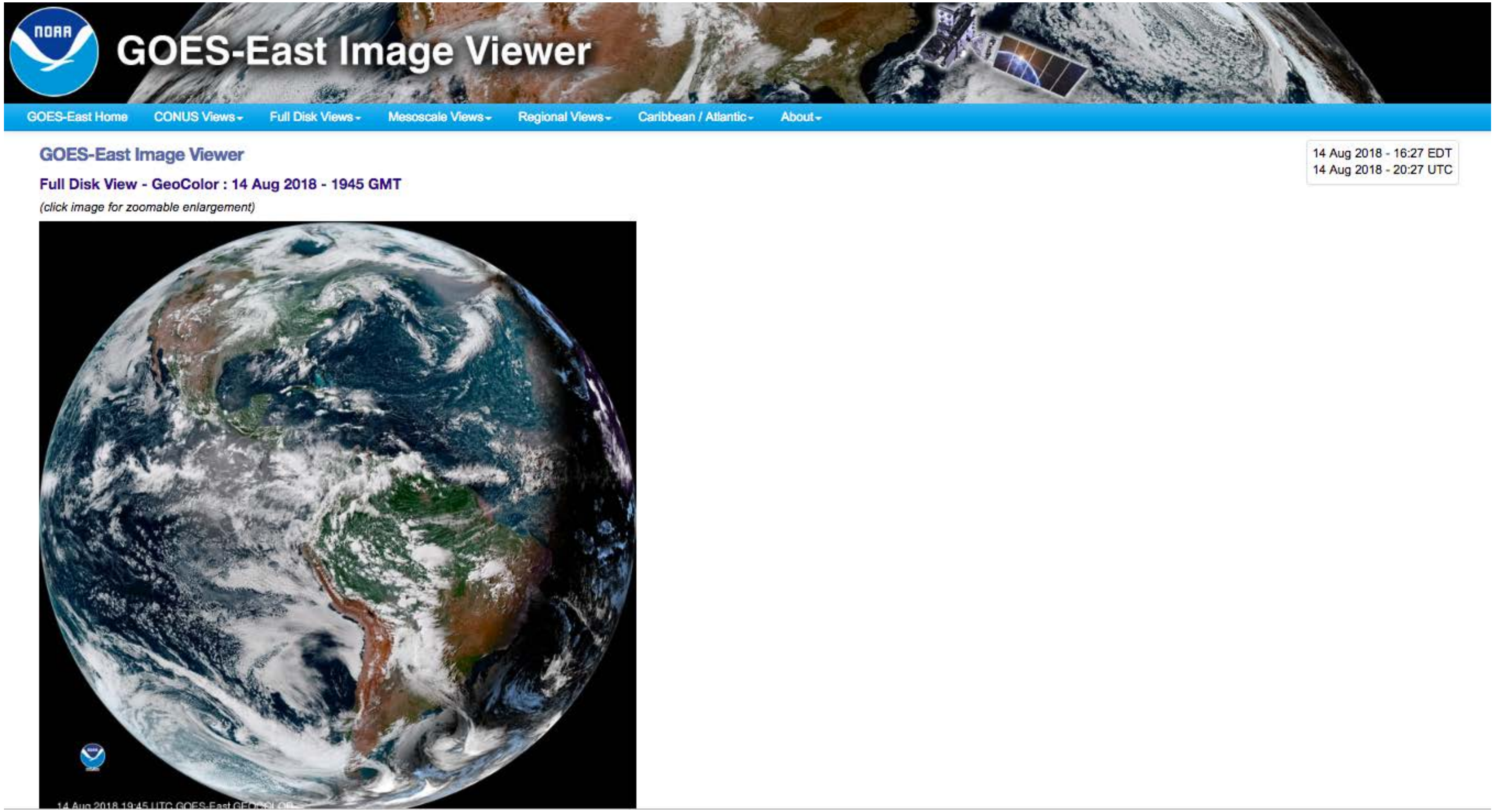
NOAA Geostationary Satellite Server

http://www.goes.noaa.gov/



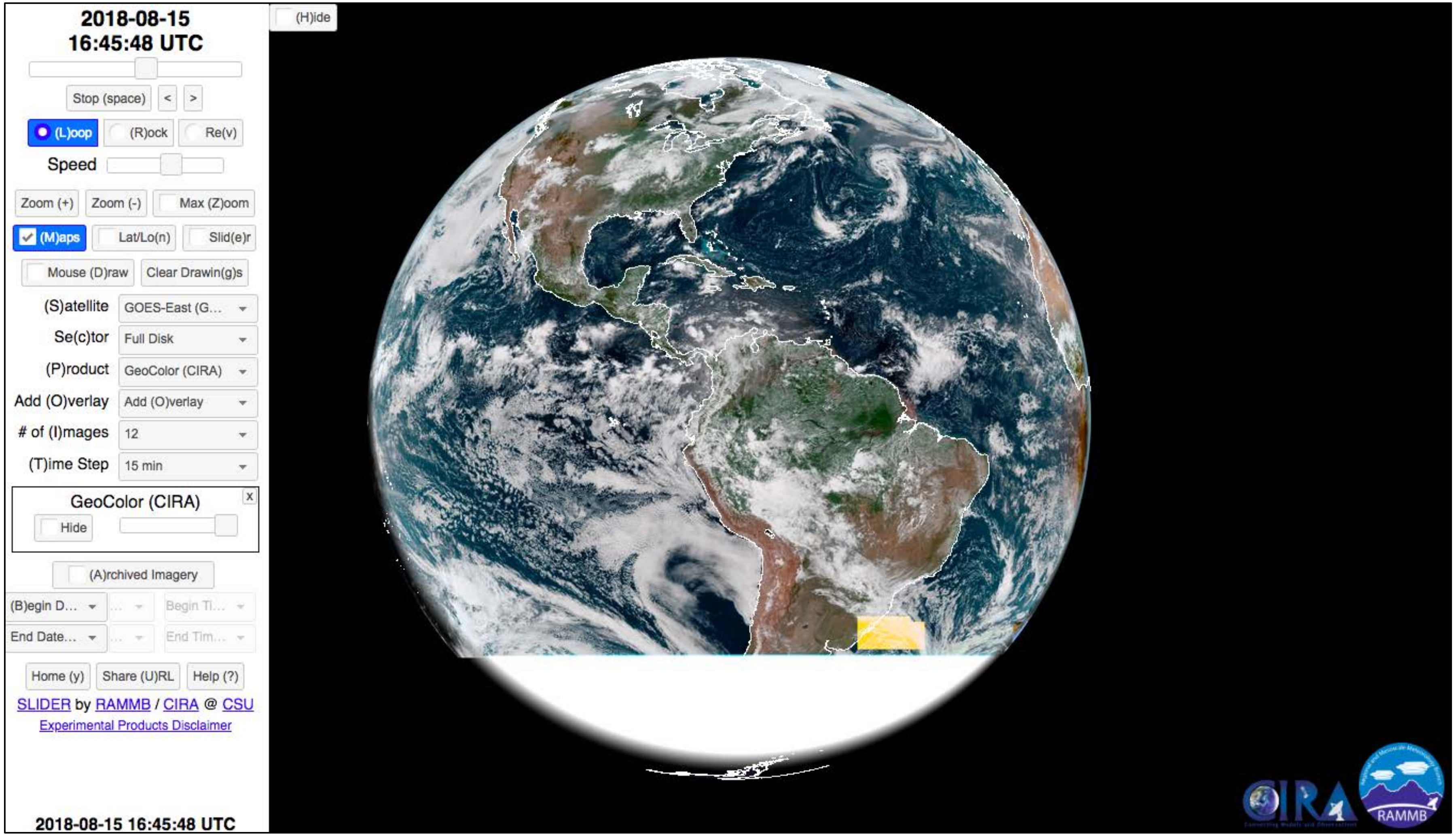
GOES-East Viewer

https://www.star.nesdis.noaa.gov/GOES/GOES16_FullDisk_Band.php?band=GEOCOLOR&length=24



ABI & AHI Sliders

http://rammb-slider.cira.colostate.edu/



AHI Viewer – P-Tree

http://www.eorc.jaxa.jp/ptree/