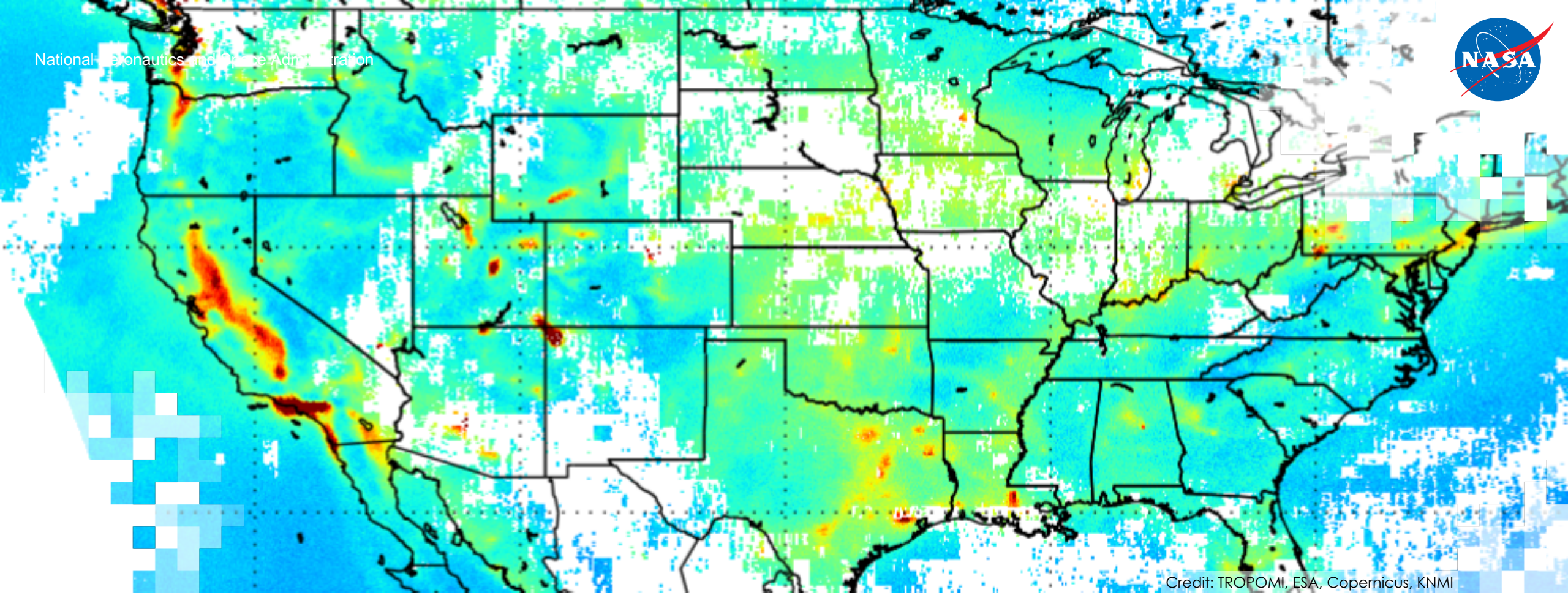


Fundamentals of Satellite Remote Sensing

Pawan Gupta, Robert Levy, and Shana Mattoo

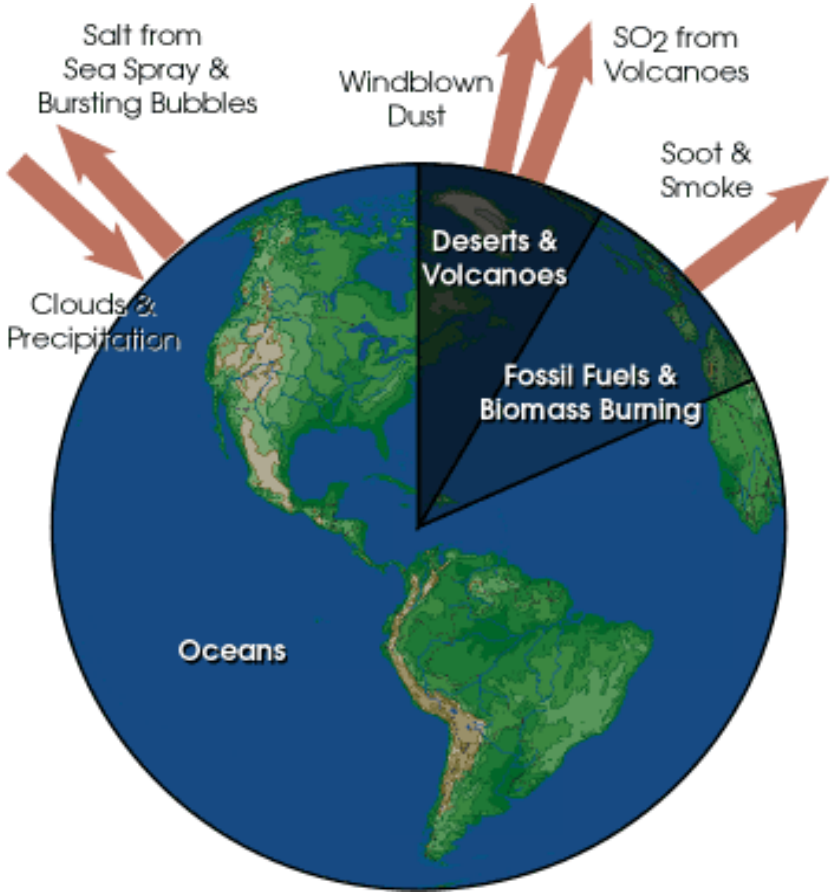
WS03 Satellite Remote Sensing of Aerosols: Data, Tools, and Air Quality

Air Pollution

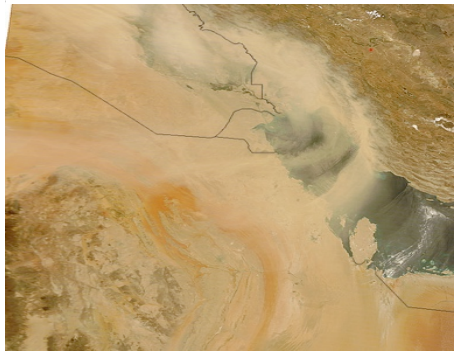
- Particles (Particulate, Aerosols)
- Gases

Pollution Sources

Atmospheric aerosols are highly variable in space and time



Dust

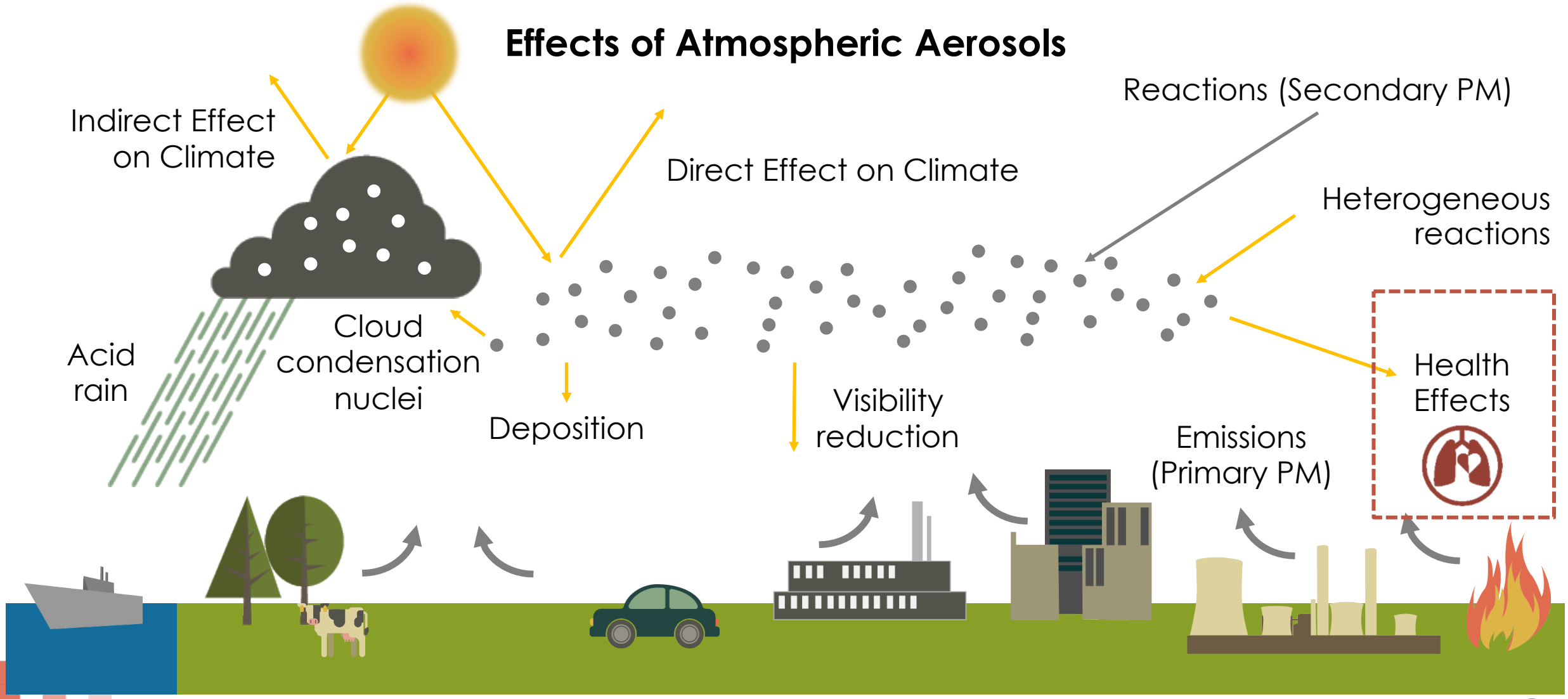


Volcanoes

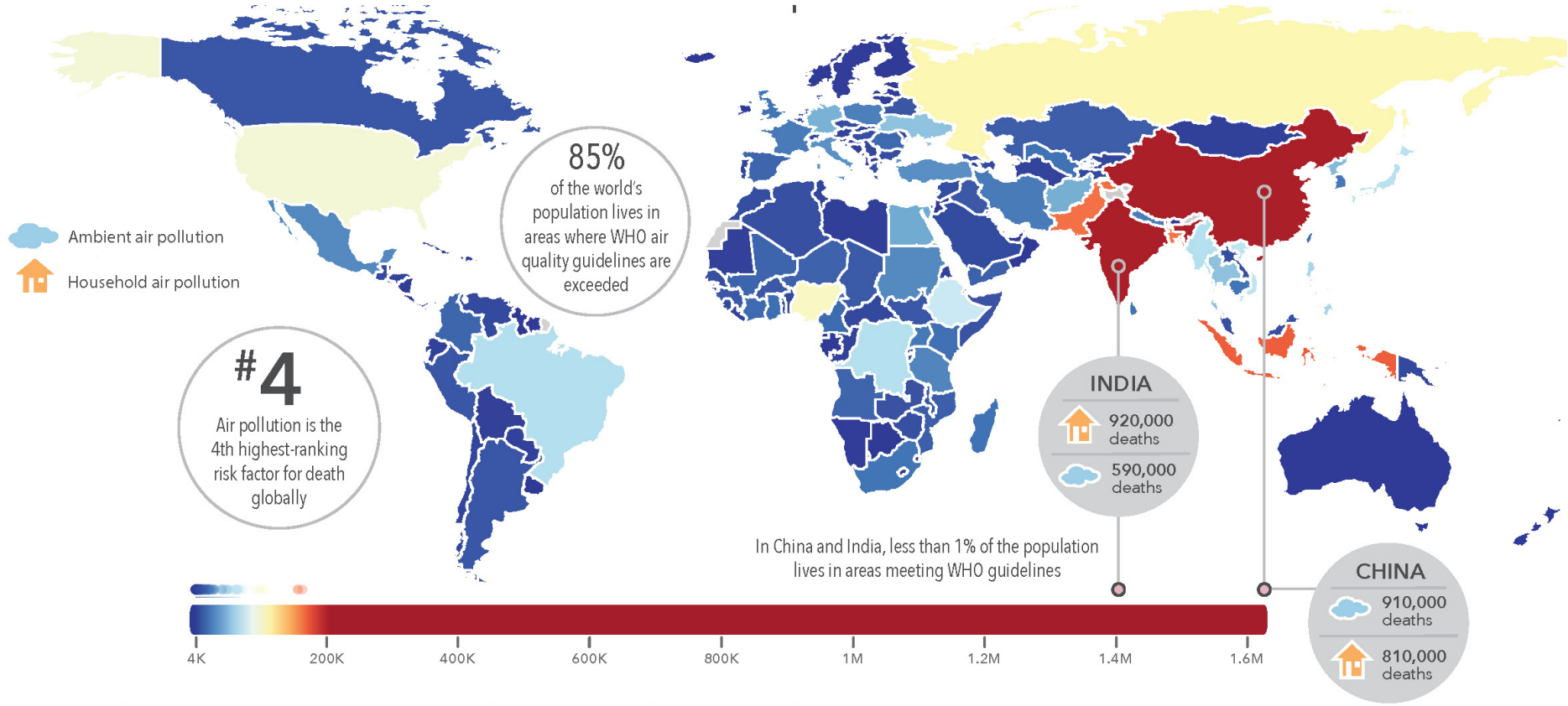
Fossil Fuels & Biomass Burning

Soot & Smoke

Motivation: Tiny, but Potent



Global Burden of Air Pollution



- Air pollution was responsible for 5.5 million deaths in 2013
- Satellite data can help quantify the impact on human health

Image Credit: The Lancet

UN Sustainable Development Goals (SDGs)

Transforming Our World: The 2030 Agenda for Sustainable Development

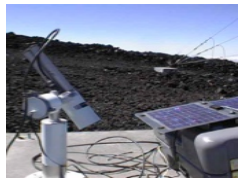
- A plan of action for people, planet, and prosperity
- All countries and all stakeholders, acting in collaborative partnership, will implement this plan
- 17 SDGs and 169 targets under this agenda
- Balance the three dimensions of sustainable development:
  – economic, social, and environmental

Text adapted from "Transforming our world: the 2030 Agenda for Sustainable Development"

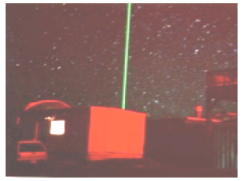
Traditional Air Quality Monitoring

Image Credits: http://aqicn.org

Air Pollution Monitoring

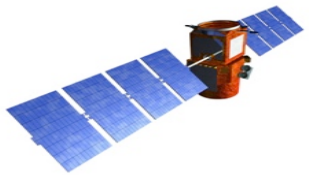



Ground Measurements

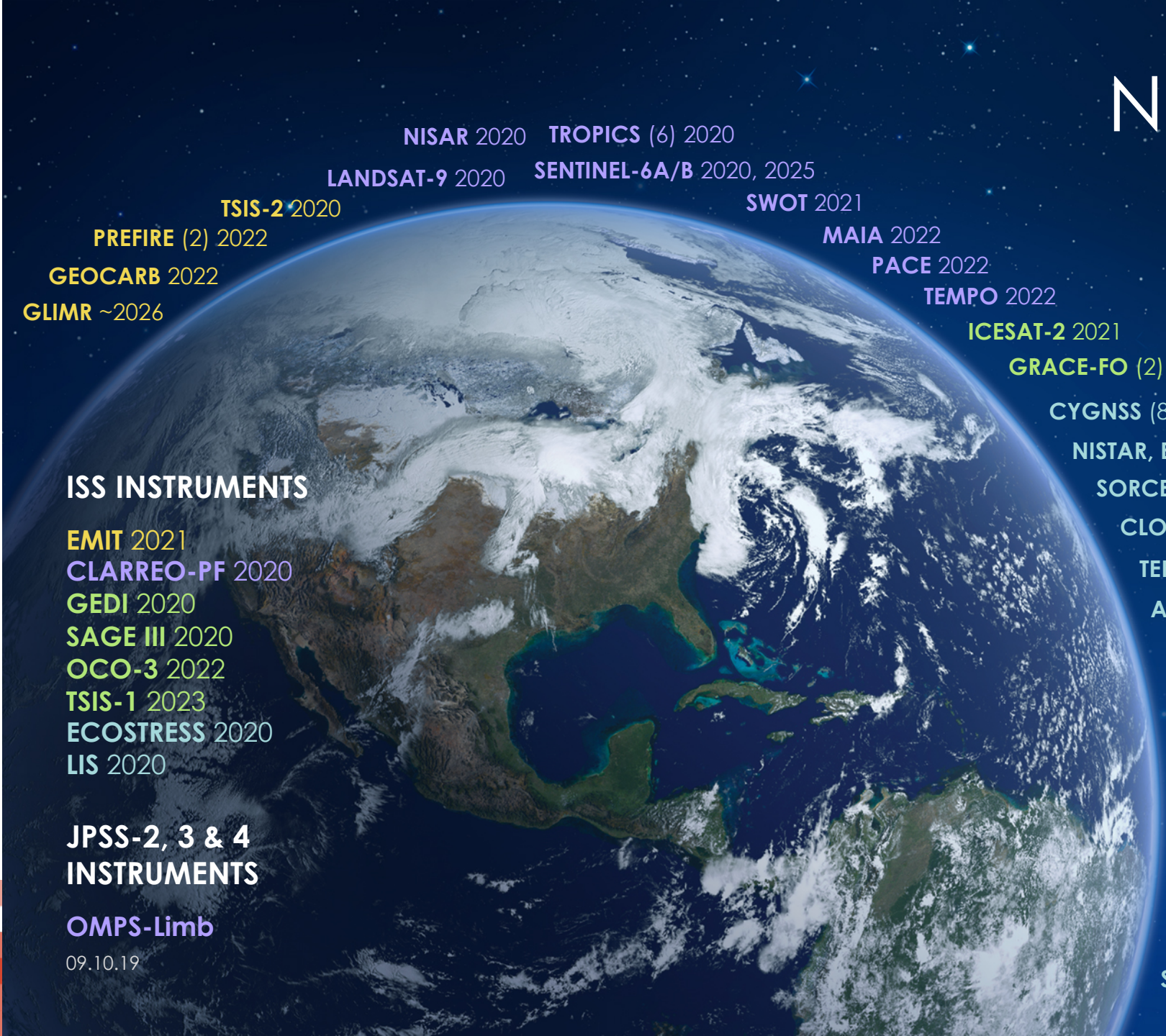
Air & Space Observations

Models



NASA EARTH FLEET

OPERATING & FUTURE THROUGH 2023



NISAR 2020
TROPICS (6) 2020
LANDSAT-9 2020
SENTINEL-6A/B 2020, 2025
TSIS-2 2020
SWOT 2021
PREFIRE (2) 2022
MAIA 2022
GEOCARB 2022
PACE 2022
GLIMR ~2026
TEMPO 2022
ICESAT-2 2021
GRACE-FO (2) 2023

ISS INSTRUMENTS

EMIT 2021
CLARREO-PF 2020
GEDI 2020
SAGE III 2020
OCO-3 2022
TSIS-1 2023
ECOSTRESS 2020
LIS 2020

JPSS-2, 3 & 4 INSTRUMENTS

OMPS-Limb

09.10.19

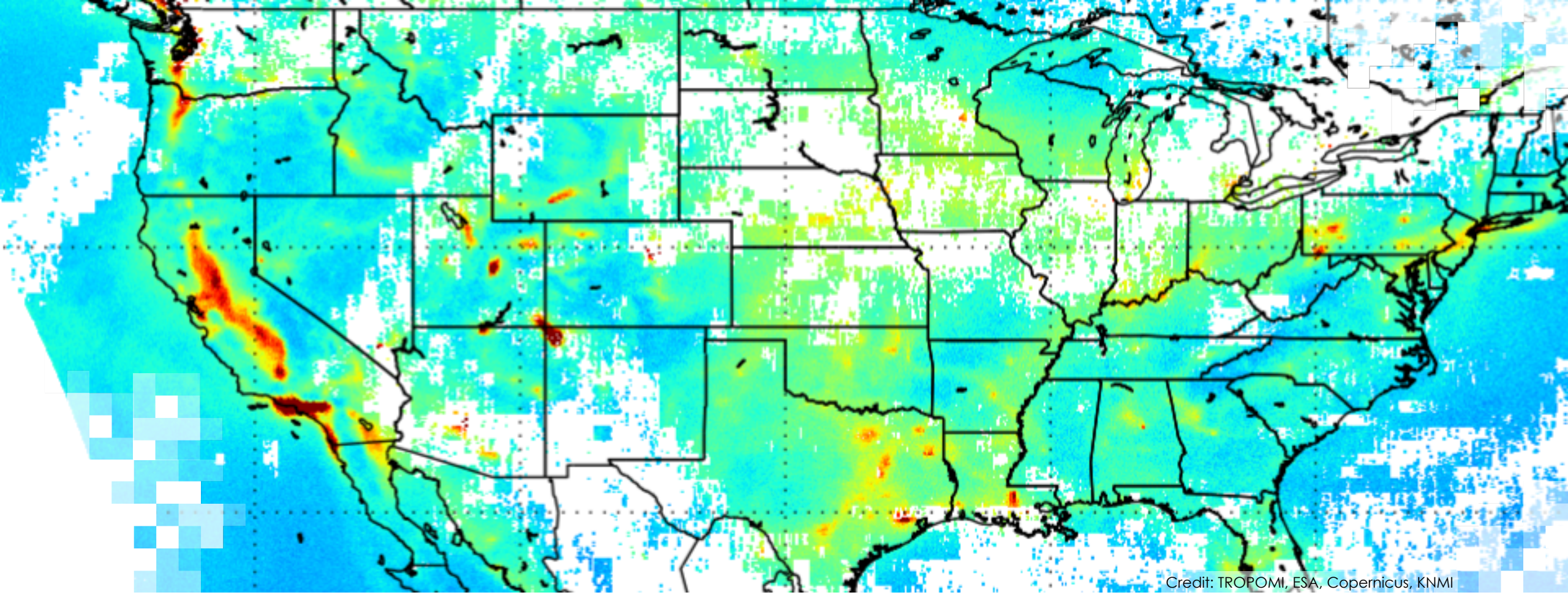
CYGNSS (8) 2020
NISTAR, EPIC (DSCOVR/NOAA) 2020
SORCE 2020
CLOUDSAT 2021
TERRA >2021
AQUA >2022
AURA >2022
CALIPSO >2022
GPM >2022
LANDSAT 7 (USGS) ~2022
LANDSAT 8 (USGS) >2022
OCO-2 >2022
OSTM/JASON 2 (NOAA) >2022
SMAP >2022
SUOMI NPP (NOAA) >2022

INVEST/CUBESATS

RAVAN 2016
RainCube 2018
CSIM 2018
CubeRRT 2018
TEMPEST-D 2018
CIRiS 2019
HARP 2019
CTIM*
HyTI*
SNoOPI*
NACHOS*

** Launch date TBD*

(PRE) FORMULATION
IMPLEMENTATON
PRIMARY OPS
EXTENDED OPS



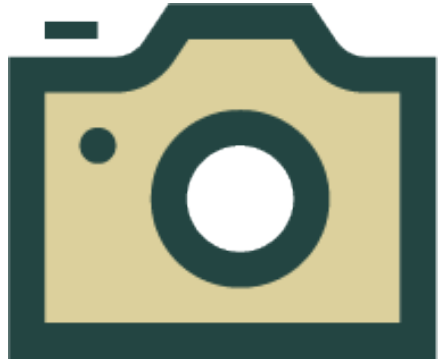
Why use satellite data?

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?

Images: Natural Resources Canada

Remote Sensing of Our Planet

36,000 km

500 km

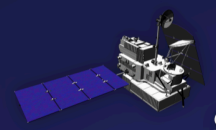
400 km

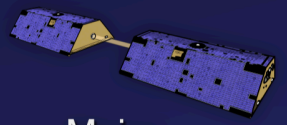
30 km

10 km

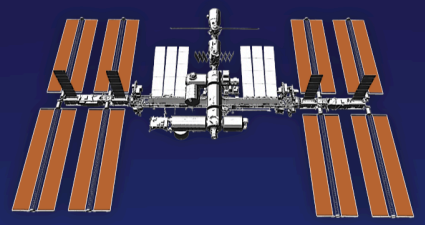
1 km

Near Surface





Major Satellite Missions



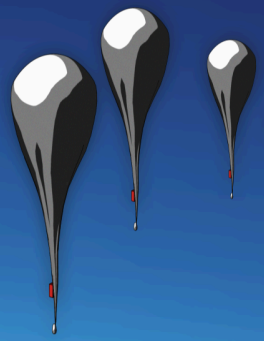
Sensors aboard the ISS

Geosynchronous Meteorological Satellites

HD Video

Cubesats

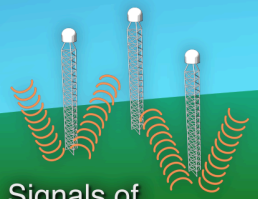
Airborne Instruments



Stratospheric Balloons

UAVs

Tethered Balloon



Signals of Opportunity

Doppler Radar

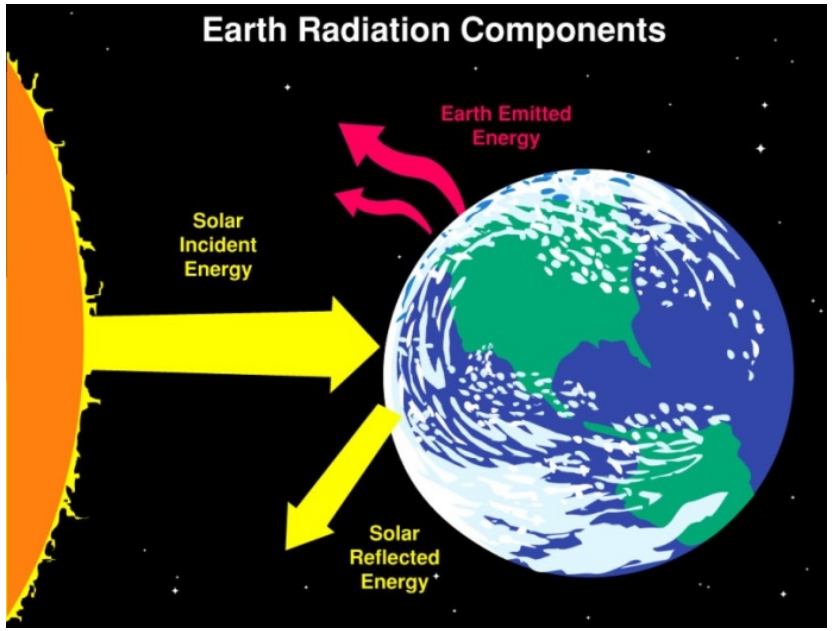
Smart Phones & Citizen Science

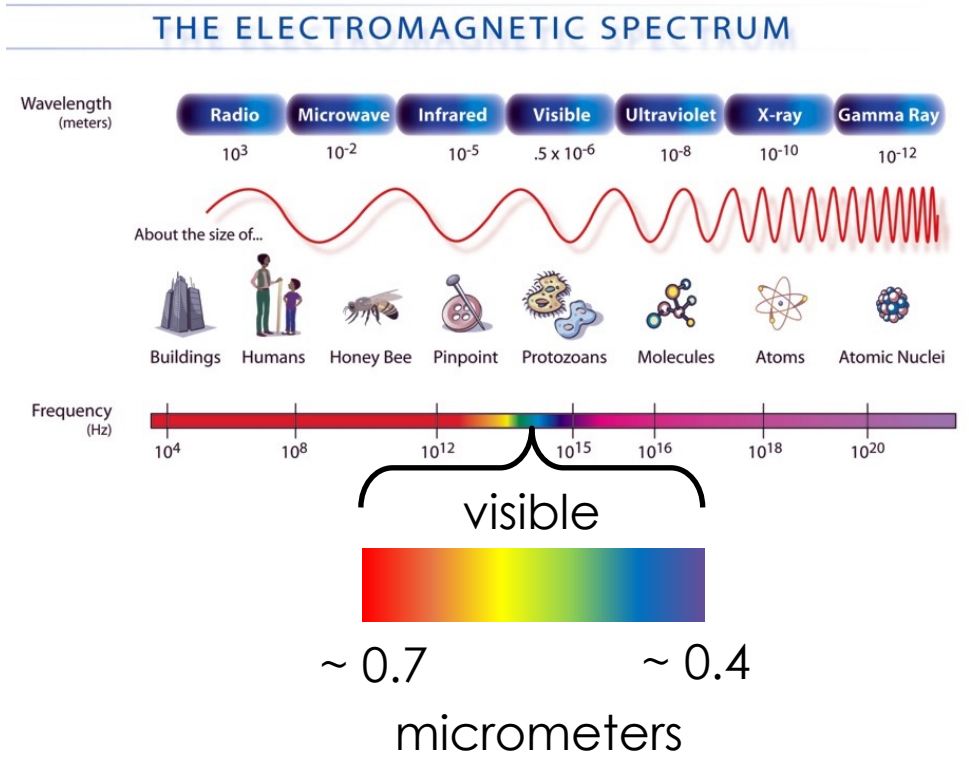
Cell Signals

Mobile Rovers

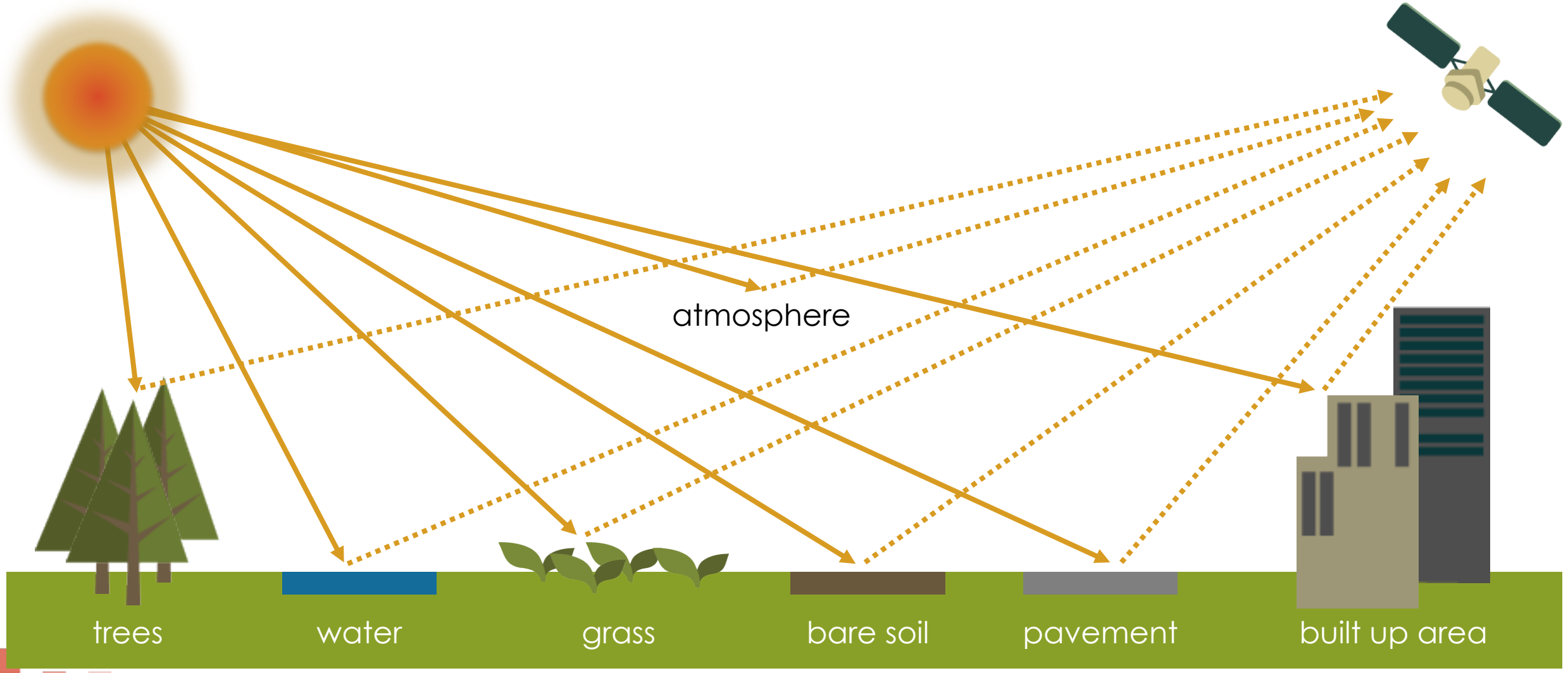
Electromagnetic Radiation

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



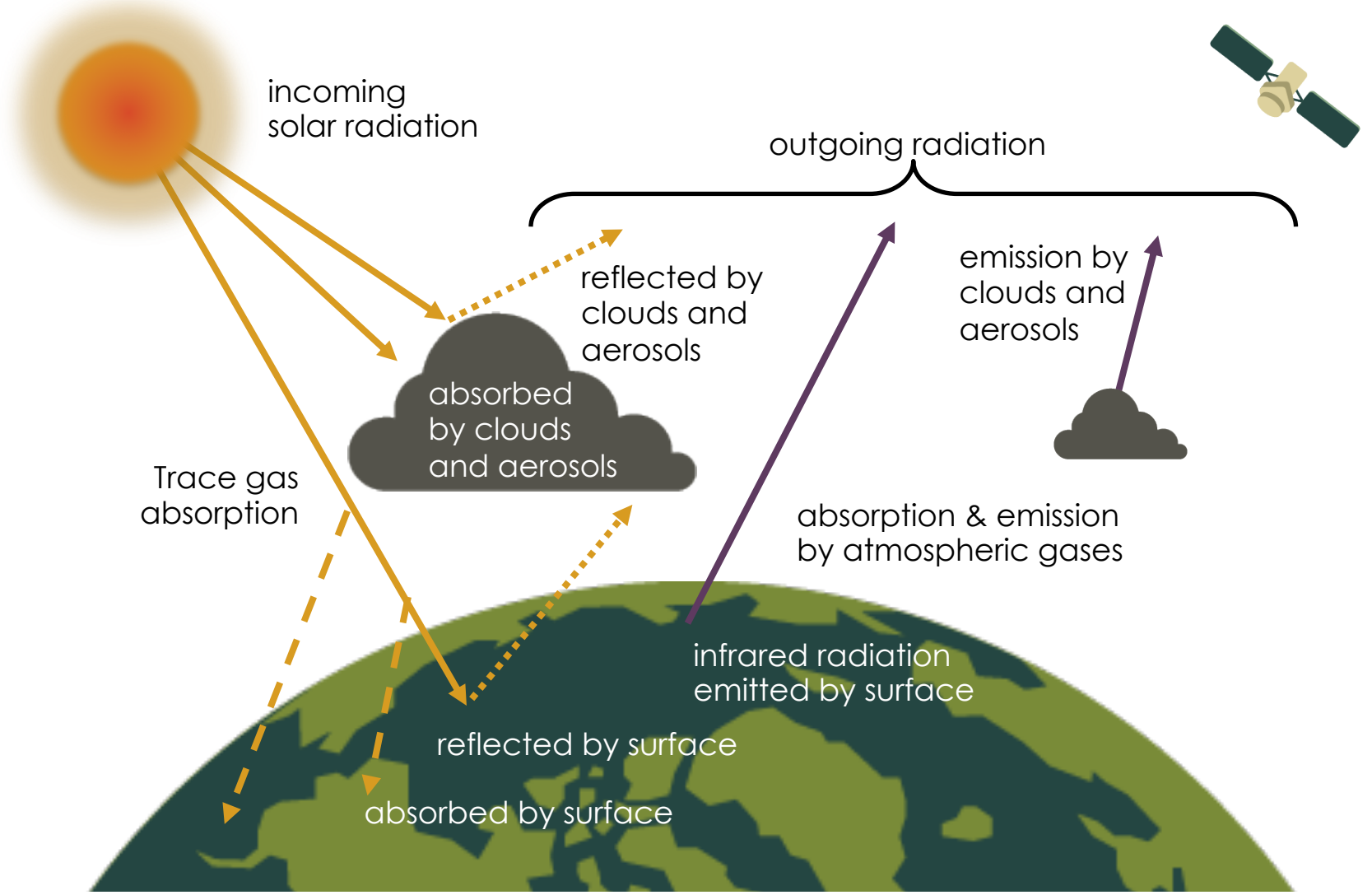


What do satellites measure ?

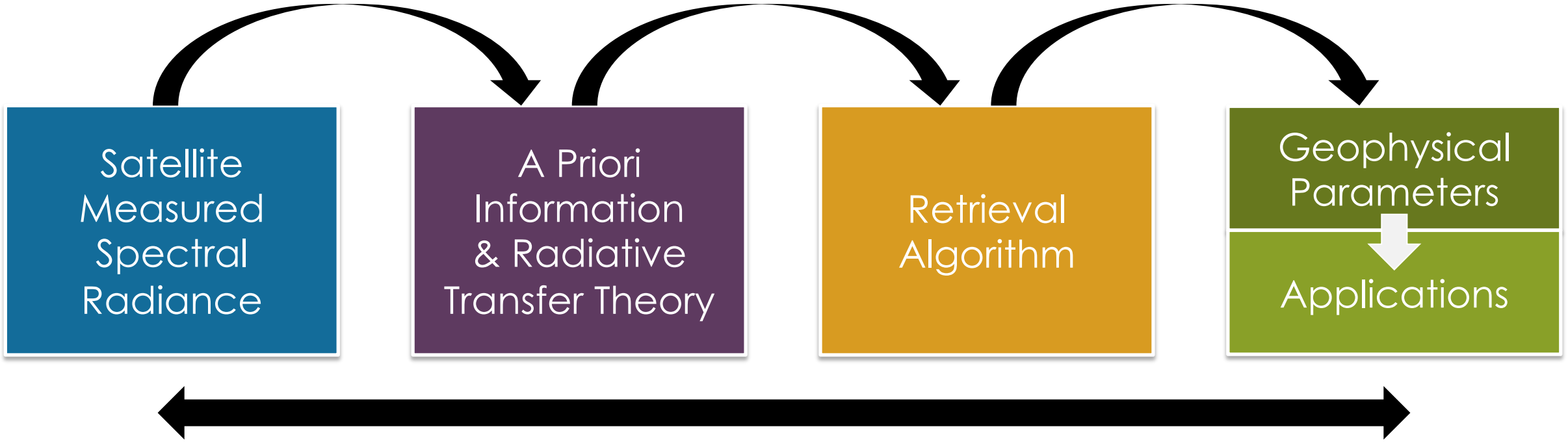


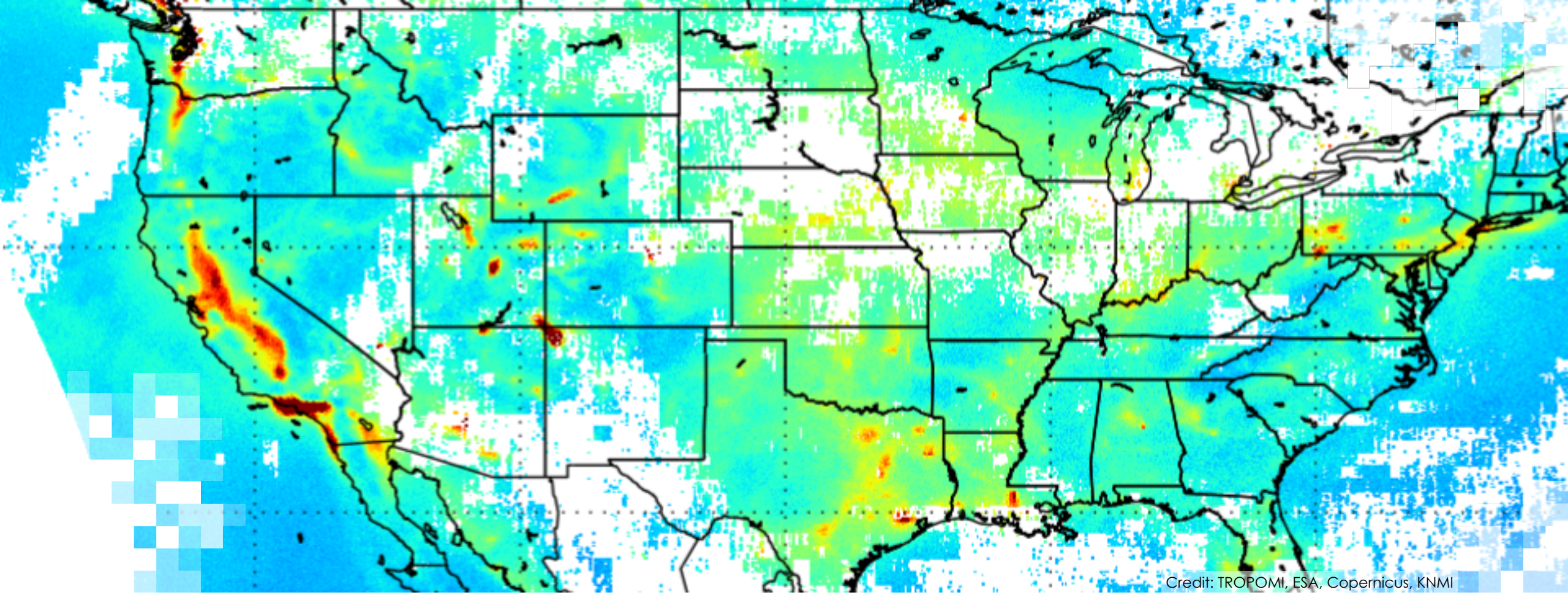
Measuring Properties of the Earth-Atmosphere System from Space

- 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





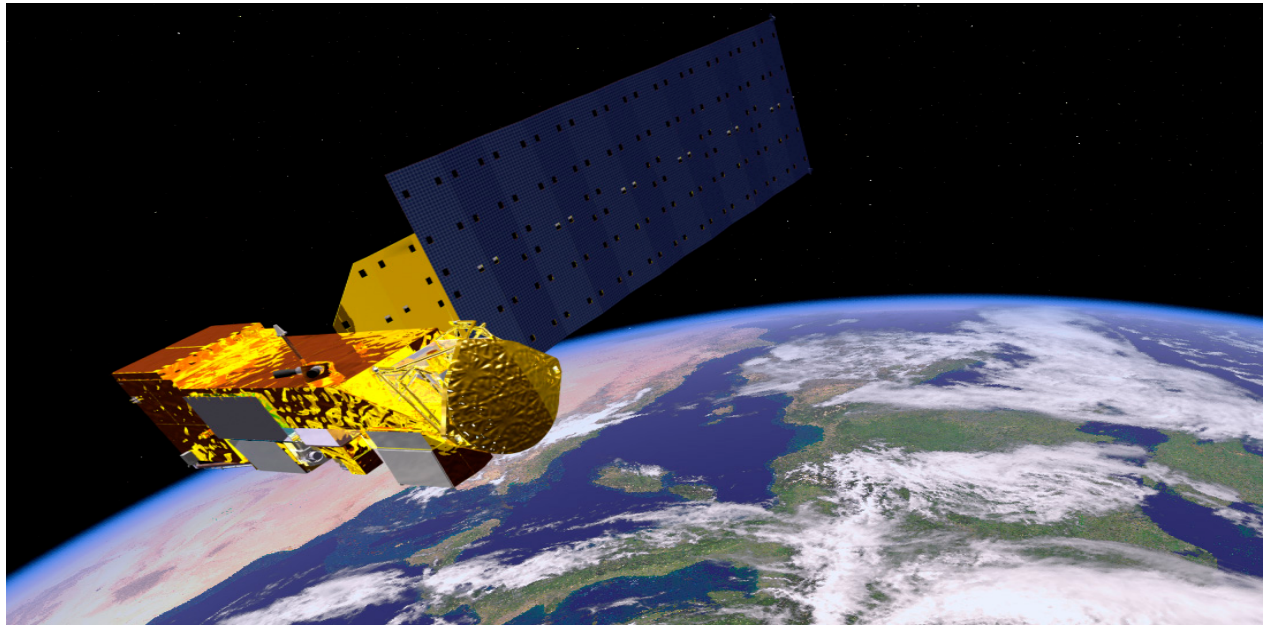
Satellites, Sensors, and Orbits

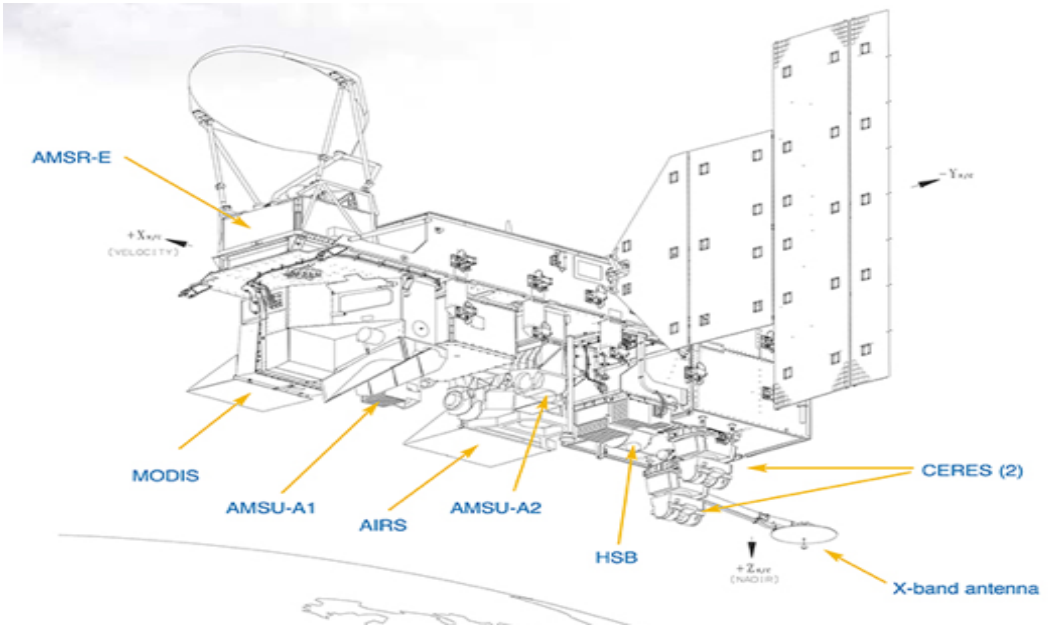
Satellites vs. Sensors

Earth-observing satellite remote sensing instruments are named according to:

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

Aqua Satellite

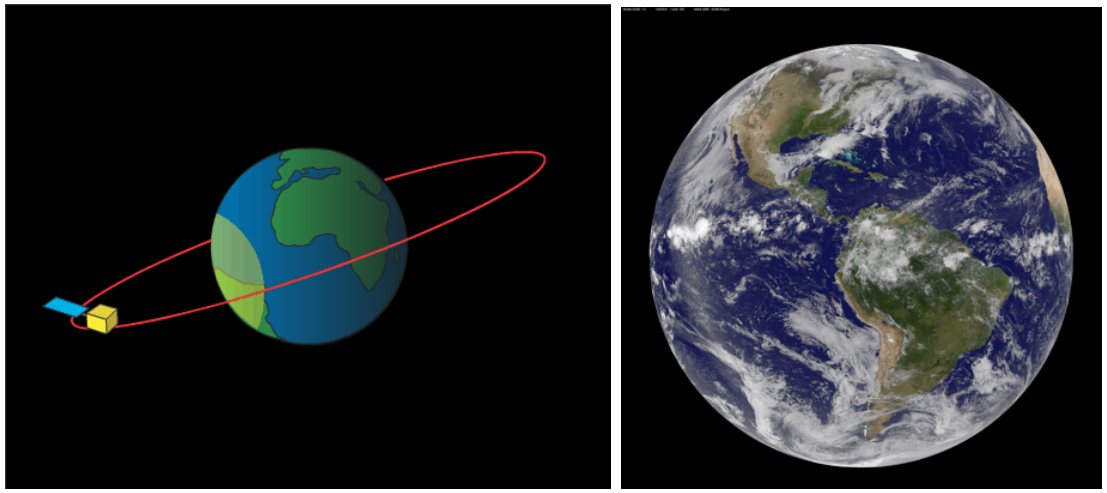




Characterizing Satellites and Sensors

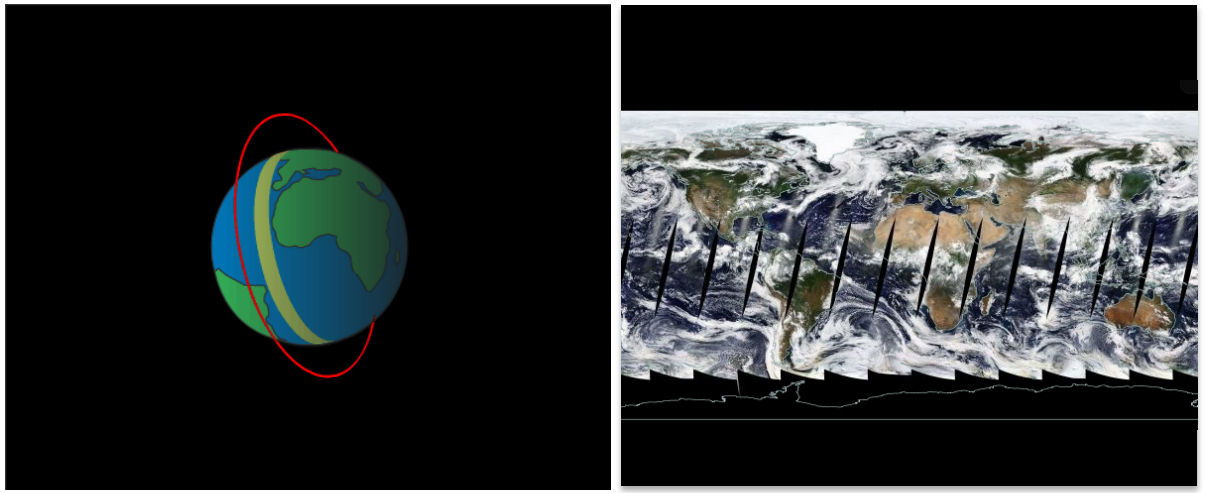
- **Orbits**
  - Polar vs. Geostationary
- **Energy Sources**
  - Passive vs. Active
- **Solar and Terrestrial Spectra**
  - Visible, UV, IR, Microwave…
- **Measurement Techniques**
  - Scanning, Non-Scanning, Imager, Sounders…
- **Resolution (Spatial, Temporal, Spectral, Radiometric)**
  - Low vs. High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

Common Orbit Types



Geostationary Orbit

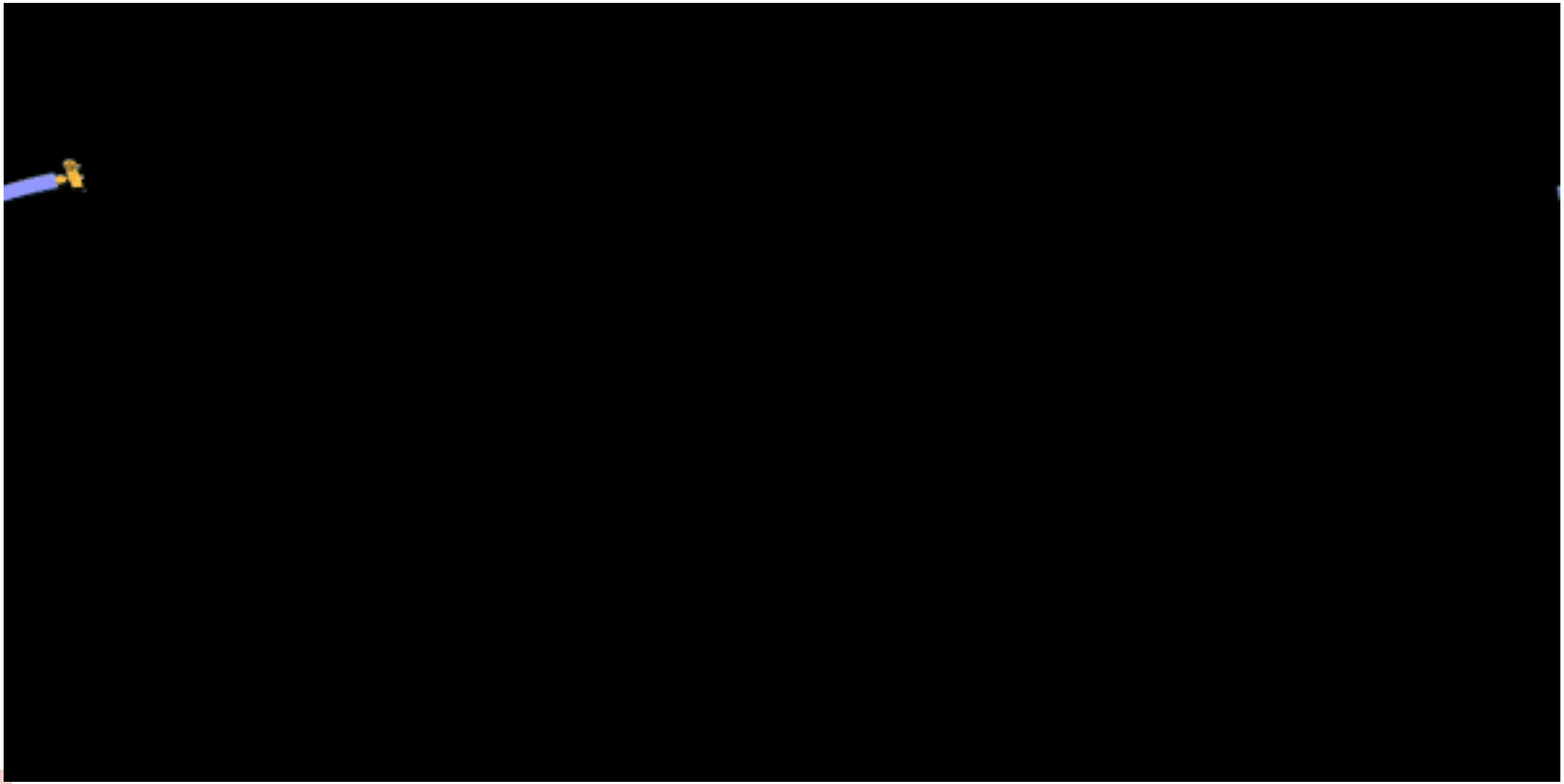
- Has the same rotational period as Earth
- Appears ‘fixed’ above Earth
- Orbits ~36,000 km above the equator



Polar Orbit

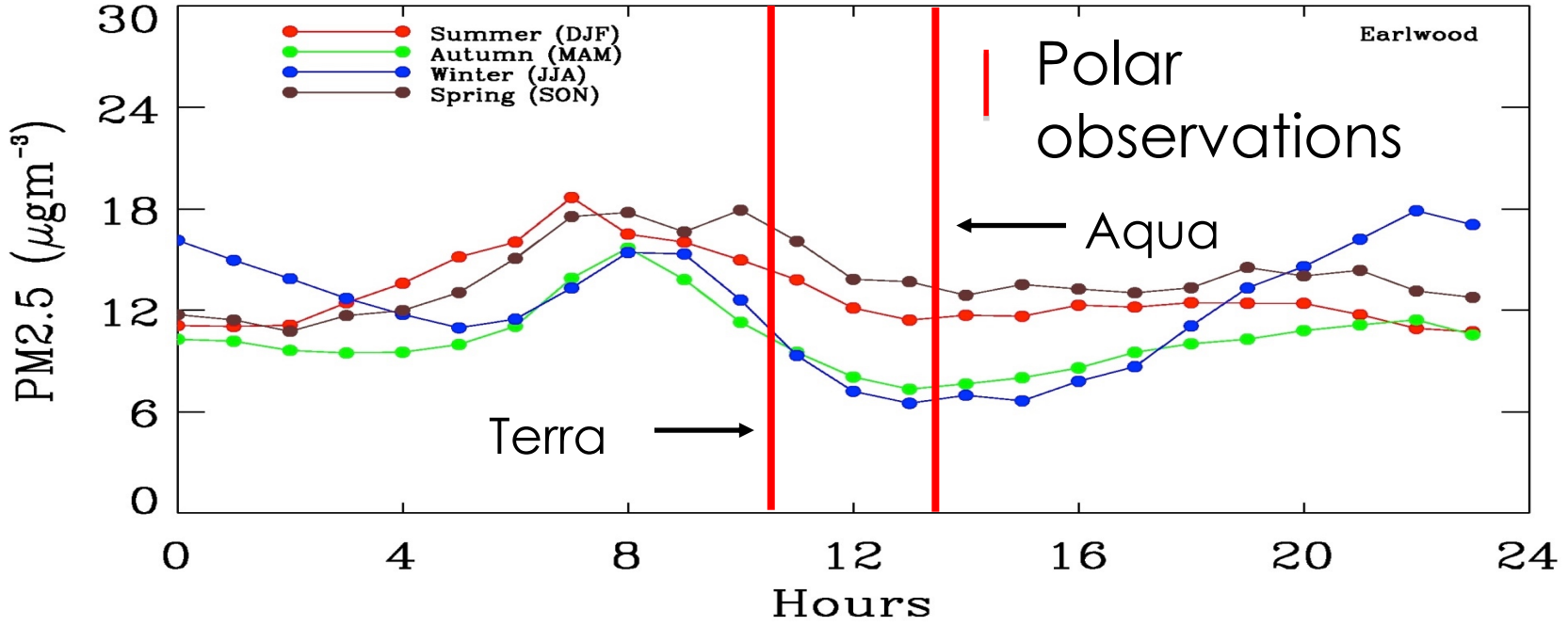
- Fixed, circular orbit above Earth
- Sun synchronous orbit ~600-1,000 km above Earth with orbital passes are at about the same **local solar time** each day

Aqua Satellite Orbiting the Earth



Observation Frequency

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

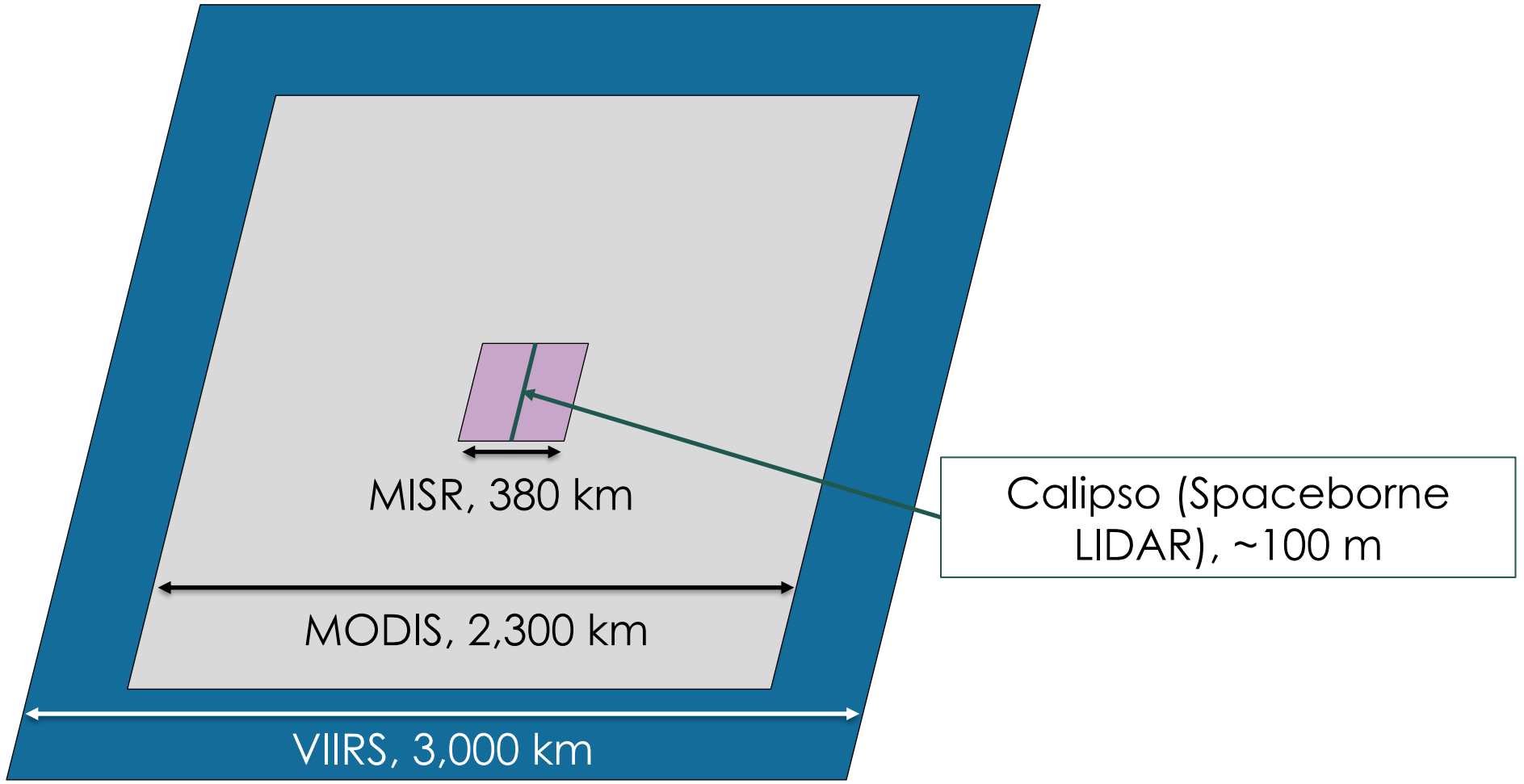


Geostationary Satellites: Every 30 sec. to 15 min.

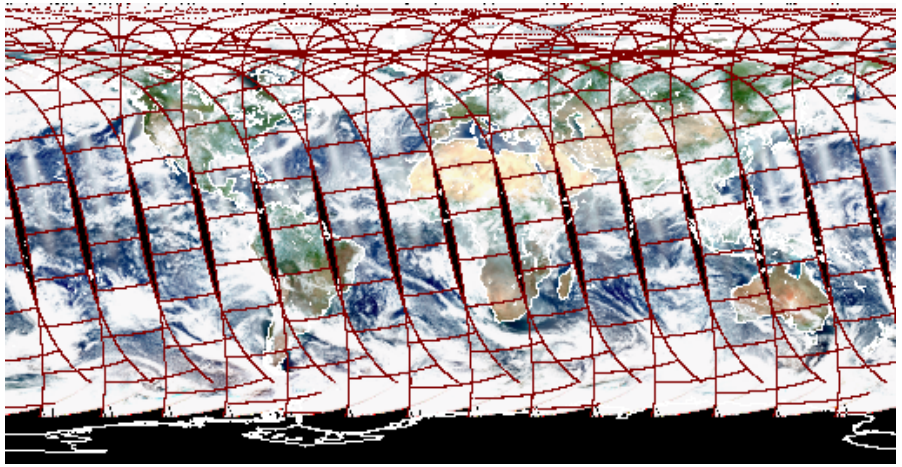
Future Geo satellites: TEMPO, GEMS, Sentinel-4

Source: P. Gupta

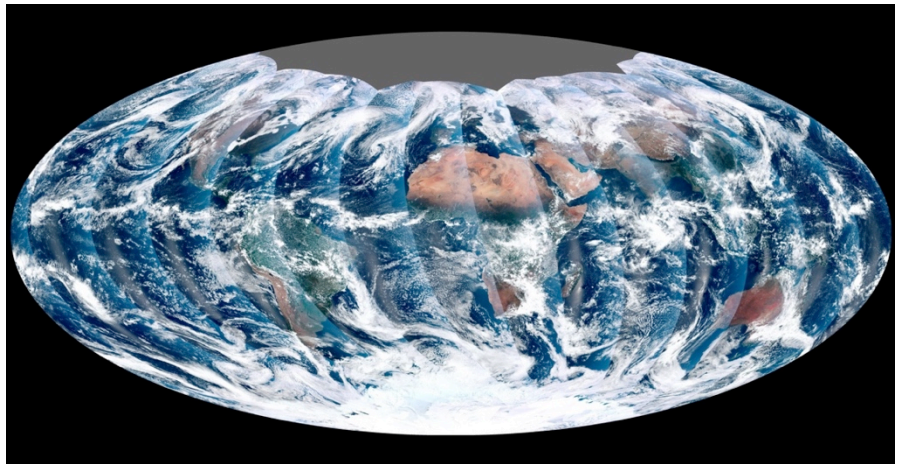
Satellite Coverage – Swath Width



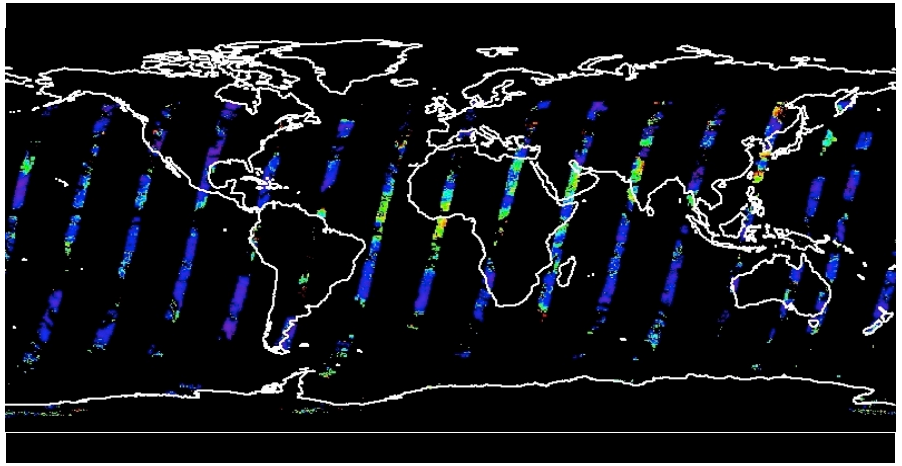
Satellite Coverage



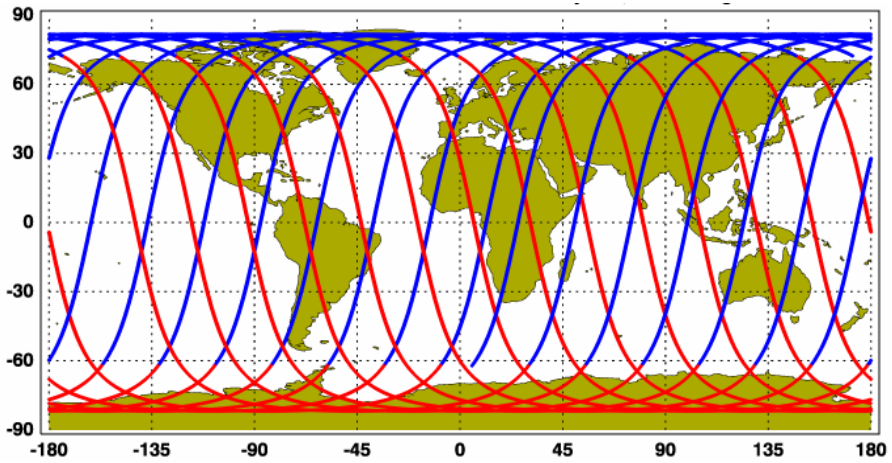
MODIS



VIIRS



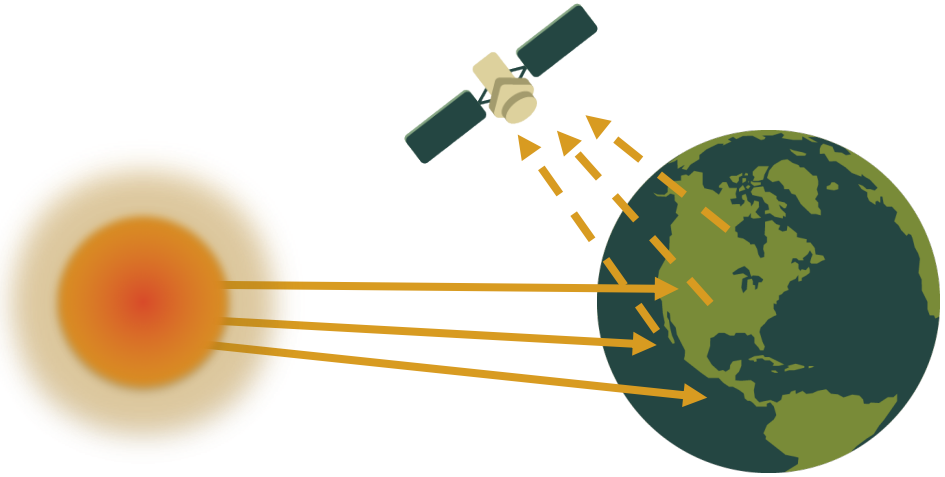
MISR



CALIPSO

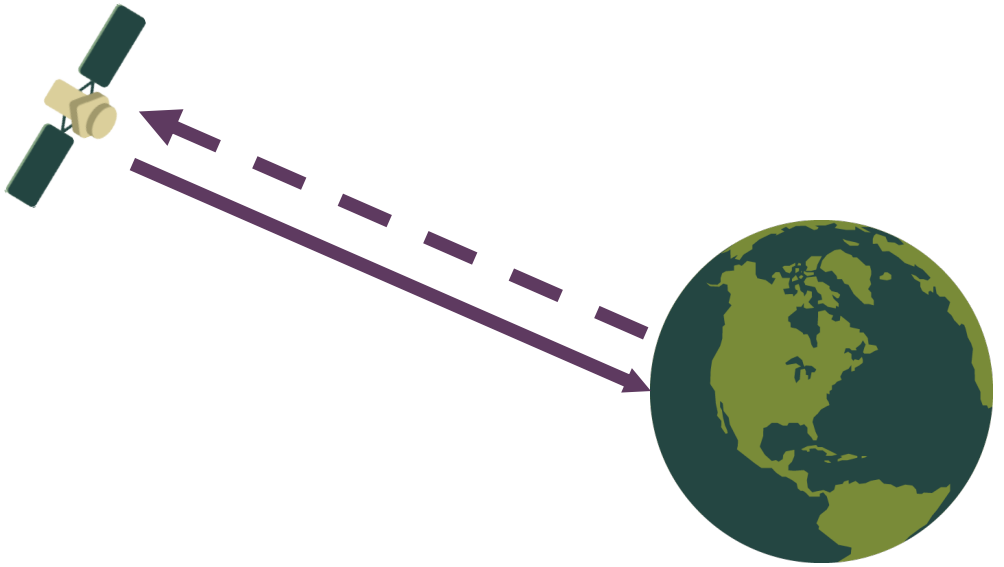
Active & Passive Sensors

Passive Sensors



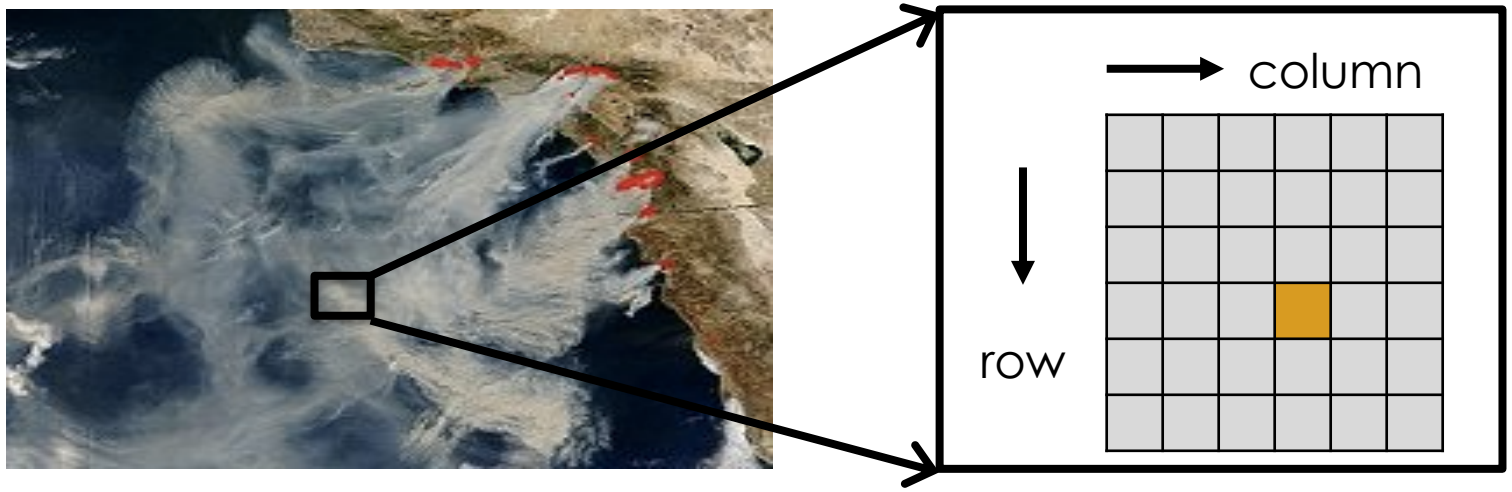
- Detect only what is emitted from the landscape, or reflected from another source (e.g., light reflected from the sun)
- Examples: (**MODIS, MISR, OMI, VIIRS**)

Active Sensors



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

Pixel – the Smallest Unit of an Image

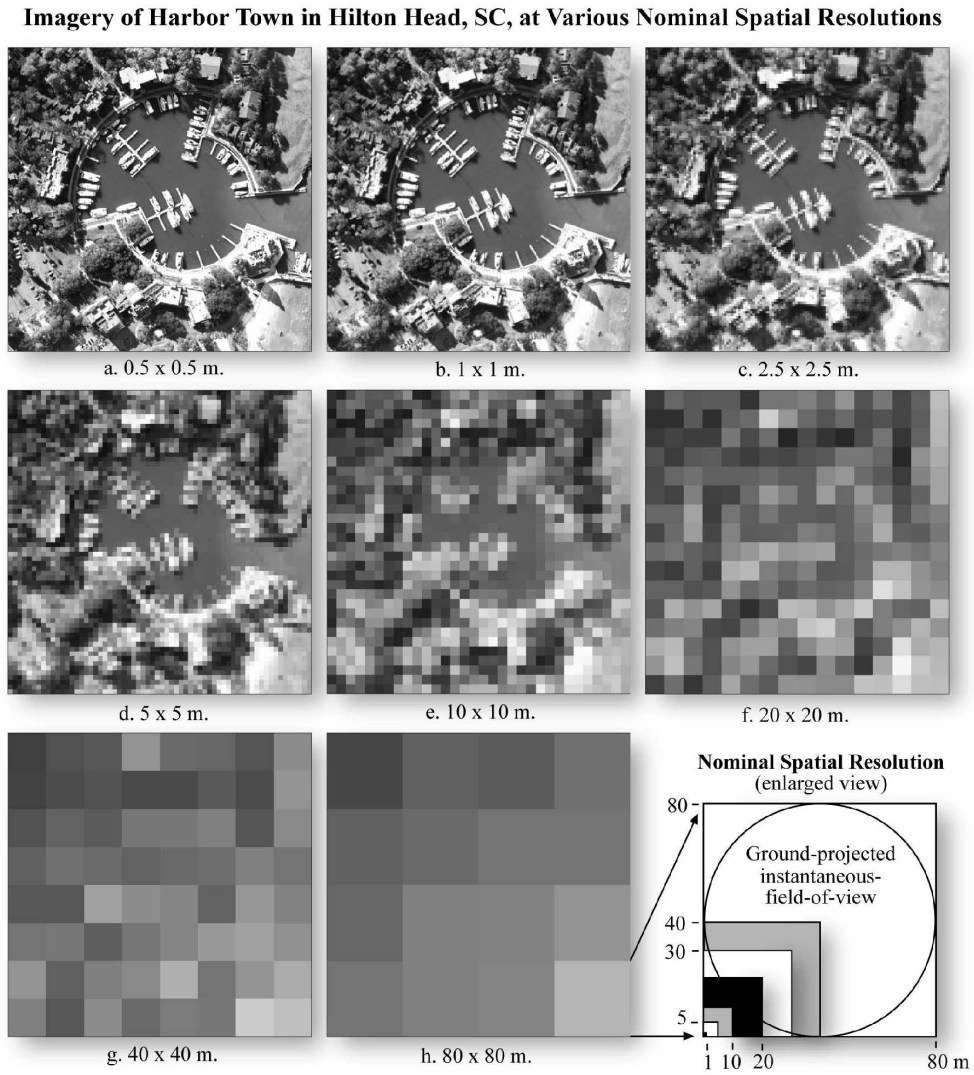


- A digital image is comprised of a two dimensional array of individual picture elements – called pixels – arranged in columns in rows
- Each pixel represents an area on the Earth's surface
- A pixel has an intensity value and a location address in the 2D image
- Spatial resolution is defined by the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

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

Why is spatial resolution important?

- MODIS
  - 250 m – 1 km
- MISR
  - 275 m – 1.1 km
- OMI
  - 13x24 km
- VIIRS
  - 375 m



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

Temporal Resolution

- How frequently a satellite can provide observation of the same area on the earth
- It mostly depends on 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
  - 30 sec – 1 hr

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.

Remote Sensing Tradeoff

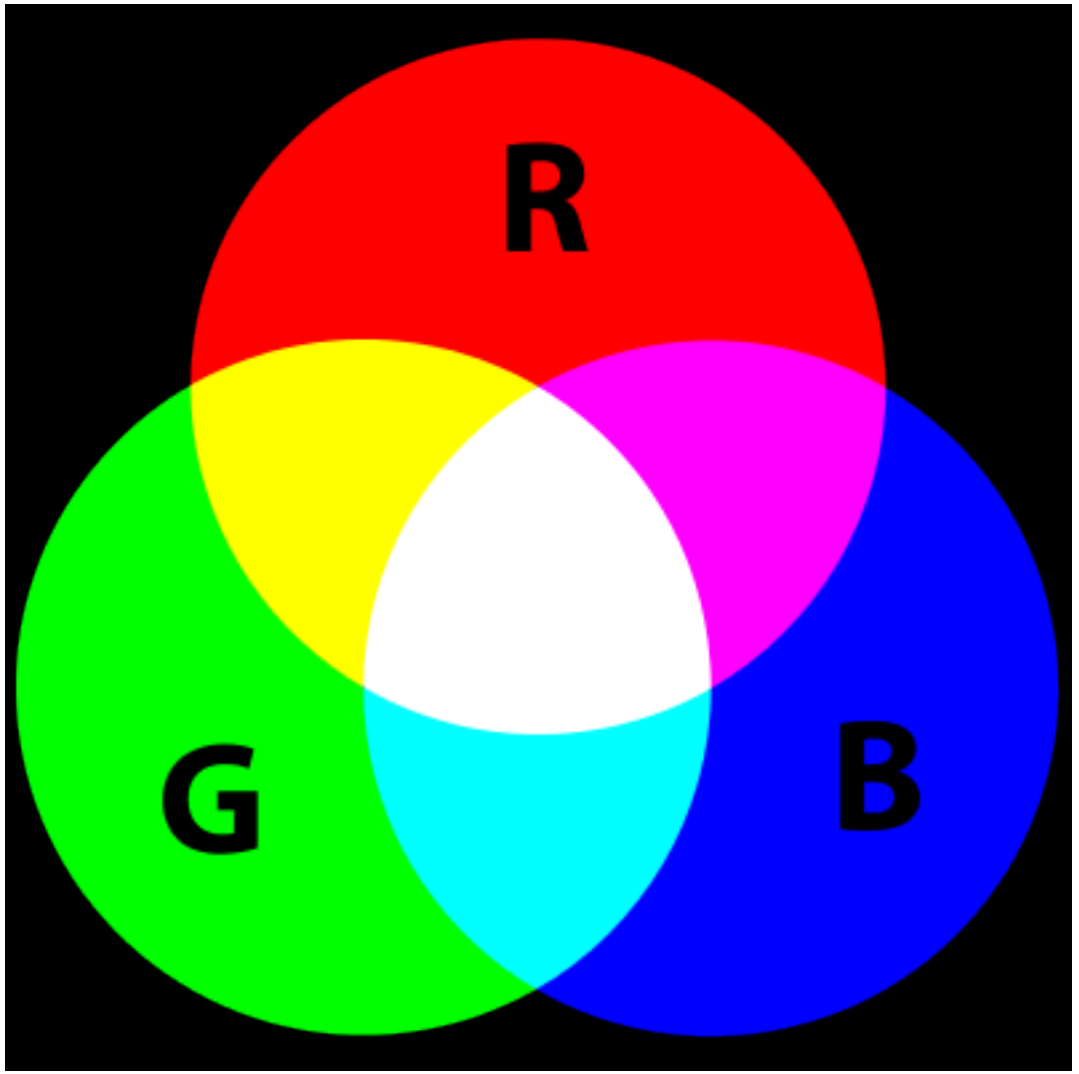
It is **very difficult** to obtain extremely high spectral, spatial, temporal, **AND** radiometric resolutions, all at the same time

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

RGB Imagery

- Create an image using any 3 bands
- Load red, green, and blue satellite bands into corresponding display channels
- Simulates what the human eye sees



True Color Image (or RGB)

A MODIS "true color image" will use MODIS visible wavelength bands 1, 4, 3

R = 0.66 µm

G = 0.55 µm

B = 0.47 µm