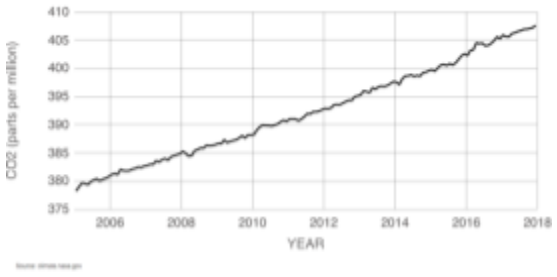
NASA A-Train:
Satellites: OCO-2, GCOM-W1, Aqua, CALIPSO, CloudSat, and Aura. On November 16, 2011, PARASOL was lowered to 9.5 km under the A-Train and on December 18, 2013 PARASOL ceased operation, fully exiting the A-Train.
At the front of the train, Aqua carries instruments that produce measurements of temperature, water vapor, and rainfall. Next in line, CloudSat, a cooperative effort between NASA and the Canadian Space Agency (CSA), and CALIPSO, a joint effort of the French space agency Centre National d'Etudes Spatiales (CNES) and NASA, have high-tech laser and radar instruments that offer three-dimensional views of clouds and airborne particles called aerosols. And the caboose, Aura, has a suite of instruments that produce high-resolution vertical maps of greenhouse gases, among many other atmospheric constituents.
The *active* sensors (i.e., CPR and CALIOP) emit pencil-thin pulses of energy that slice through the atmosphere, and strike a target. The return pulse of energy is analyzed to produce a very high-resolution view of a very small area. For CALIOP, the pulse is visible light, which is very sensitive to aerosol layers and high, thin clouds, but can't penetrate the atmosphere when thicker clouds are present. For CPR, the pulse is microwave energy, which can easily penetrate lower and thicker clouds and is sensitive to 90% of all clouds.

The *passive* sensors don't emit energy; they "see" reflected sunlight in the visible and ultraviolet wavelengths, and heat (infrared, or IR) that is both reflected and emitted from Earth's atmosphere and surface. They provide wider, more global coverage, allowing for snapshots of different layers of the atmosphere. Each instrument detects certain wavelengths of infrared, visible, ultraviolet, or microwave energy. It turns out that each of these types of radiation offers strengths and weaknesses when it comes to observing the atmosphere. IR sensors detect the heat released from whatever surface they observe, but can't penetrate thick cloud layers. (Note that HIRDLS, an IR limb sounder, looks sideways across the atmosphere and is more sensitive to very high, thin clouds.) Ultraviolet and visible sensors (e.g., MODIS) are able to probe deeper into clouds than IR sensors, but not all the way to the surface. Microwave sensors (e.g., AMSR, AMSU) can "see" the whole atmosphere—even when it's cloudy. (MLS is a bit different; it is a limb sounder that looks across the atmosphere and detects frozen water in the tops of towering clouds.)

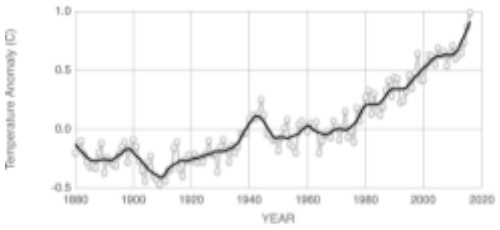
X-rays and gamma-rays are usually described in terms of energy, optical and infrared light in terms of wavelength, and radio in terms of frequency. This is a scientific convention that allows the use of the units that are the most convenient for describing whatever energy of light you are looking at. After all - there is a huge difference in energy between radio waves and gamma-rays. Here's an example. Electron-volts, or eV, are a unit of energy often used to describe light in astronomy. A radio wave can have an energy of around 4×10^{-10} eV - a gamma-ray can have an energy of 4×10^{9}eV. That's an energy difference of 10^{19} (or ten million trillion) eV!

- Which is the major overall gas responsible for the greenhouse gas effect (water vapor)
- Which is the major anthropogenic emitted gas responsible for the greenhouse gas effect (carbon dioxide)
- which gases absorb IR energy- water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide
- (N_2O), all act as effective global insulators
- N_2 is a major atmospheric gas BUT it is not a greenhouse gas (doesn't absorb much infrared energy

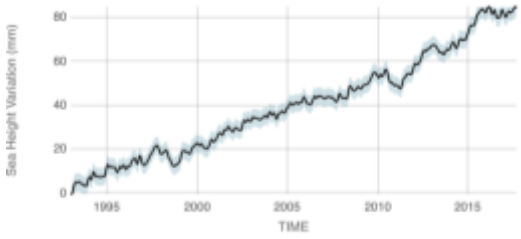
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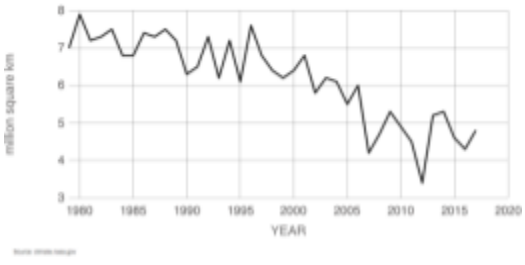
CO2 concentration in the atmosphere



Earth temperature change (difference from long average) over time



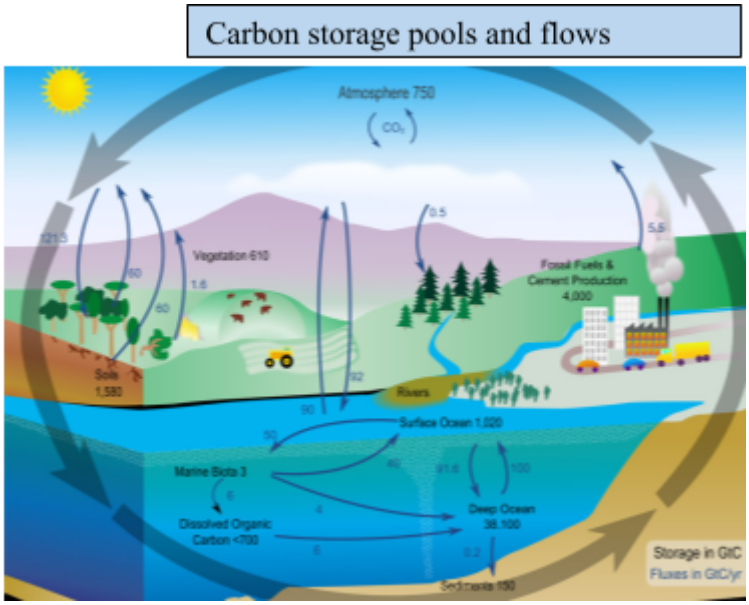
Sea level height change over time

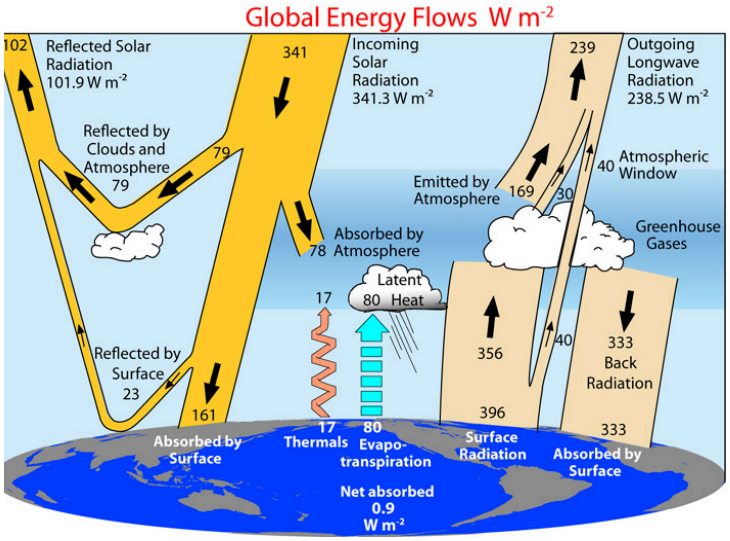


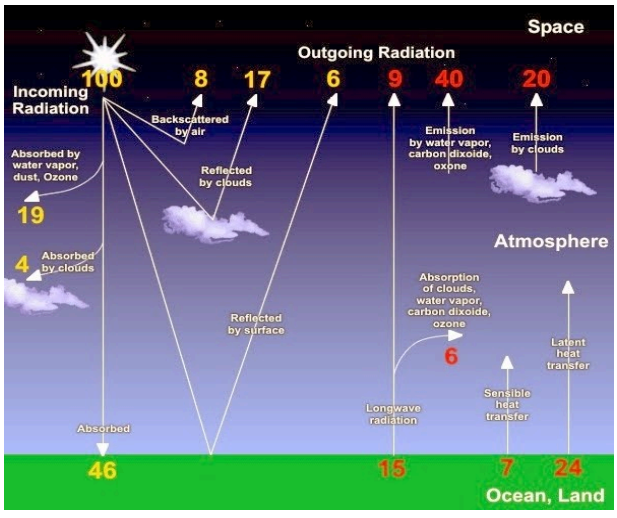
Sea Ice change over time

Satellite	Summary of Measurements	Instruments	Orbit, altitude	Launch Date	Responsible Organization *French ^European
Aqua	A synergistic instrument package measuring at visible, infrared, and microwave frequencies allows comprehensive studies of water in the Earth/atmosphere system, including its solid, liquid and gaseous forms, plus studies of vegetation, both on the land and in the ocean.	AMSR-E, AIRS, AMSU-A, HSB, CERES, MODIS	LEO, sun-sync, 702 km (436 mi)	May 4, 2002	NASA/GSFC
Aura	Observations from limb sounding and nadir imaging allow studies of the horizontal and vertical distribution of key atmospheric pollutants and greenhouse gases and how these distributions evolve and change with time.	HDRLS, MLS, TES, OMI	LEO, sun-sync, 708 km (440 mi)	July 15, 2004	NASA/GSFC
CALIPSO	Observations from space-borne lidar, combined with passive imagery, will lead to improved understanding of the role aerosols and clouds play in regulating the Earth's climate.	CALLIOP, IIR, WFC	LEO, sun-sync, 701 km (437 mi)	April 28, 2006>	NASA/GSFC, NASA/LaRC, CNES*
CloudSat	Cloud Profiling Radar will allow for the most detailed study of clouds to date and should better characterize the role clouds play in regulating the Earth's climate.	CPR	LEO, sun-sync, 708 km (440 mi)	April 28, 2006	NASA/GSFC, NASA/JPL
GOES-16	Geostationary. provides advanced imagery and atmospheric measurements of Earth's Western Hemisphere, real-time mapping of lightning activity, and improved monitoring of solar activity and space weather. fire detection and intensity estimation. detection of low cloud/fog, tropical cyclone track and intensity forecasts, monitoring of atmospheric river events that can cause flooding and mudslides. monitoring of smoke and dust. air quality warnings and alerts	ABI, GLM, EXIS, SUVI	Geo, Long: 75.2° West, 35,788km (22,237 mi)	November 19, 2016	NOAA
OCO-2	Three grating spectrometers will make global, space-based observations of the column-integrated concentration of CO2, a critical greenhouse gas.	Three grating spectrometers	LEO, sun-sync, 824 km (512 mi)	July 2, 2014	NASA/GSFC NASA/JPL
NPP (or Suomi NPP)	Climate change -- contribute to long-term records of global environmental data critical for understanding the dynamics of climate change Health of the ozone layer -- daily measurements of the atmospheric ozone layer that will determine whether the ozone layer is recovering as expected Natural disasters -- monitor wildfires, volcanic eruptions, snowstorms, droughts, floods, hurricanes and dust plumes Weather predictions -- a sounding instrument will collect information about cloud cover, atmospheric temperatures, humidity and other variables critical to accurate weather prediction Vegetation -- map global land vegetation and quantify changes in plant productivity to understand the global carbon cycle and monitor agricultural processes to predict and respond to food shortages and famines Global ice cover -- monitor changes to Earth's sea ice, land ice and glaciers to track the pace of climate change Air pollution -- monitor the spread of health-sapping pollutants such as soot, particulate matter, nitrogen dioxide and sulfur dioxide Temperatures -- maintain a global record of atmospheric, land surface and sea surface temperatures critical to	ATMS, CrIS, OMPS, VIIRS, CERES	LEO, sun-sync, 708 km (440 mi)	October 28, 2011	NASA/NOAA

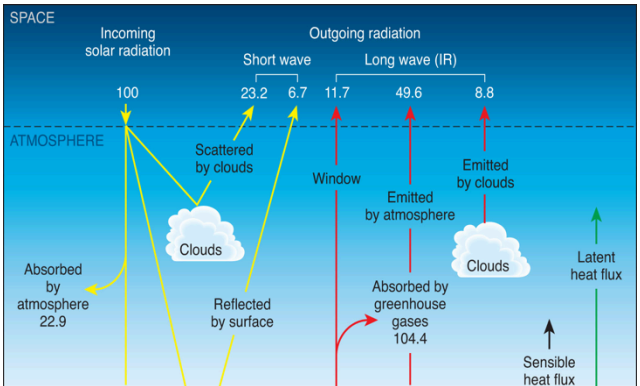
	understanding the long-term dynamics of climate change Earth's energy budget -- make measurements to determine how much energy is entering and exiting Earth's atmosphere				
Topex-Poseidon, Jason-1 Jason-3	Radar altimeters used for sea surface height (SSH) and sea waves. The primary instrument is radar altimeter. The altimeter will measure sea-level variations over the global ocean with very high accuracy (as 1.3 inches or 3.3 centimeters),Continual, long-term, reliable data of changes in ocean surface topography	Poseidon (Altimeter),DORIS, AMR-2, GPSP,LRA	LEO, non-polar 1,331 km (827 mi)	1992, 2001, 2016	NASA,NOAA, CNES*, EUMETSAT^







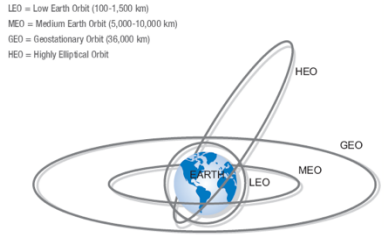


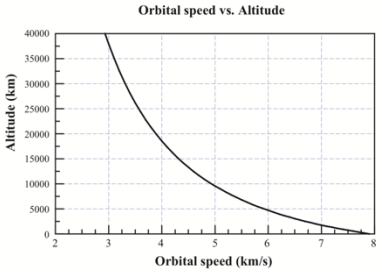


VIIRS Bands

VIIRS Band	Spectral Range (um)	Nadir HSR (m)	MODIS Band(s)	Range	HSR
DNB	0.500 - 0.900				
M1	0.402 - 0.422	750	8	0.405 - 0.420	1000
M2	0.436 - 0.454	750	9	0.438 - 0.448	1000
M3	0.478 - 0.498	750	3 10	0.459 - 0.479 0.483 - 0.493	500 1000
M4	0.545 - 0.565	750	4 or 12	0.545 - 0.565 0.546 - 0.556	500 1000
I1	0.600 - 0.680	375	1	0.620 - 0.670	250
M5	0.662 - 0.682	750	13 or 14	0.662 - 0.672 0.673 - 0.683	1000 1000
M6	0.739 - 0.754	750	15	0.743 - 0.753	1000
I2	0.846 - 0.885	375	2	0.841 - 0.876	250
M7	0.846 - 0.885	750	16 or 2	0.862 - 0.877 0.841 - 0.876	1000 250
M8	1.230 - 1.250	750	5	SAME	500
M9	1.371 - 1.386	750	26	1.360 - 1.390	1000
I3	1.580 - 1.640	375	6	1.628 - 1.652	500
M10	1.580 - 1.640	750	6	1.628 - 1.652	500
M11	2.225 - 2.275	750	7	2.105 - 2.155	500
I4	3.550 - 3.930	375	20	3.660 - 3.840	1000
M12	3.660 - 3.840	750	20	SAME	1000
M13	3.973 - 4.128	750	21 or 22	3.929 - 3.989 3.929 - 3.989	1000 1000
M14	8.400 - 8.700	750	29	SAME	1000
M15	10.263 - 11.263	750	31	10.780 - 11.280	1000
I5	10.500 - 12.400	375	31 or 32	10.780 - 11.280 11.770 - 12.270	1000 1000
M16	11.538 - 12.488	750	32	11.770 - 12.270	1000

AIRS (Atmospheric Infrared Sounder)
AMSR-E (Advanced Microwave Scanning Radiometer for the Earth Observing System)
AMSU-A (Advanced Microwave Sounding Unit-A)
ATMS (Advanced Technology Microwave Sounder): A microwave radiometer for global moisture and temperature
CrIS (Cross-track Infrared Sounder) IR interferometer to monitor atmospheric moisture and pressure
CERES (Clouds and Earth's Radiant Energy System): a radiometer to detect thermal radiation, including reflected solar radiation and thermal radiation emitted by the Earth
EXIS (Extreme Ultraviolet and X-ray Irradiance Sensors)
HSB (Humidity Sounder for Brazil) *inoperable
MODIS (Moderate-Resolution Imaging Spectroradiometer)
HIRDLS (High-Resolution Dynamics Limb Sounder)
GLM (Geostationary Lightning Mapper)
MLS (Microwave Limb Sounder)
OMI (Ozone Monitoring Instrument)
OMPS (Ozone Mapping and Profiler Suite) imaging spectrometers to measure ozone levels, especially near the poles
SUVI (Solar Ultraviolet Imager)
TES (Tropospheric Emission Spectrometer)
VIIRS (Visible Infrared Imaging Radiometer Suite): 22-band radiometer to collect infrared and visible data
CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization)
IIR (Imaging Infrared Imager)
WFC (Wide-Field Camera)
CPR (Cloud Profiling Radar)
AMSR2 (Advanced Microwave Scanning Radiometer 2)
OCO-2 uses Three high-resolution grating spectrometers
SSH: sea surface height
SM: soil moisture
BT: brightness temperature
TOA: Top of atmosphere
Vis-TIS: visible to thermal IR
AOD: aerosol optical depth
FTIR: Fourier Transform IR
TP, Jason: Topex-Poesidon, Jason 1 &3 radar altimeters





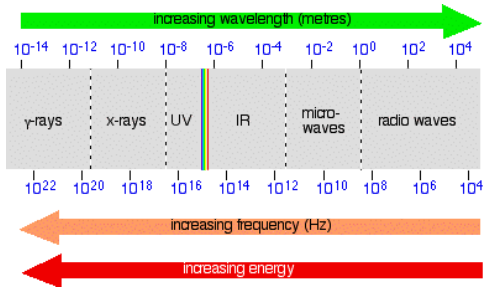


Table 4.1. Selected values for the speed and altitude of satellites in circular orbits.

Altitude (km)	Orbital Speed (km/s)
200	7.8
500	7.6
1,000	7.4
5,000	5.9
10,000	4.9
Semisynchronous: 20,200	3.9
Geosynchronous: 35,800	3.1

Orbital periods
LEO: 1.6 hours (99 min)
MEO: 3.5 hours (200 min)
GEO: 24 hours (1 day)

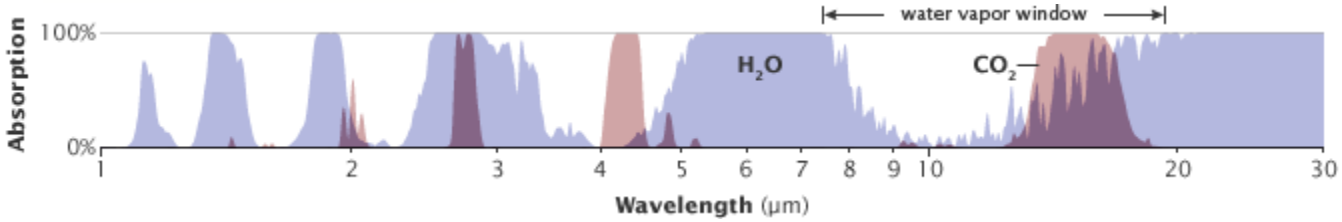
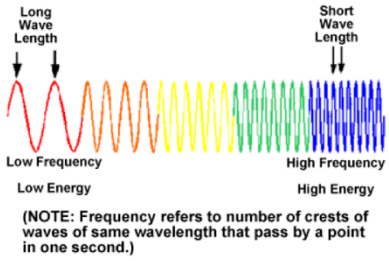
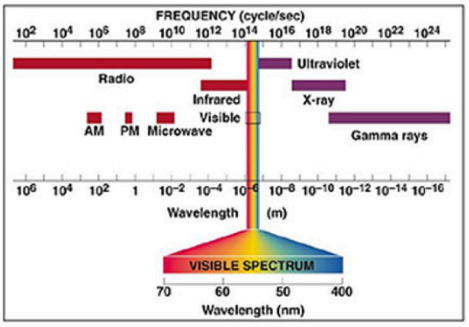


Figure 1: High absorption means the remote sensing device cannot see through the atmosphere. Regions where the absorption is low are called atmospheric windows.





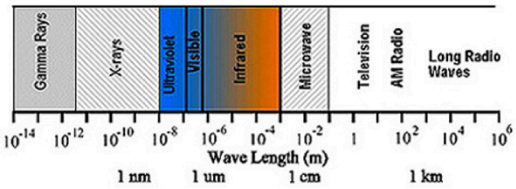




Image Type	Pixel Value	Color Levels
8-bit image	$2^8 = 256$	0-255
16-bit image	$2^{16} = 65536$	0-65535
24-bit image	$2^{24} = 16777216$	0-16777215