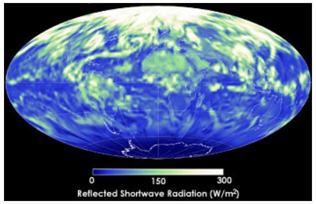
National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL



SECOND YEAR: 2604
PLANETARY REMOTE SENSING 1

INTRODUCTION

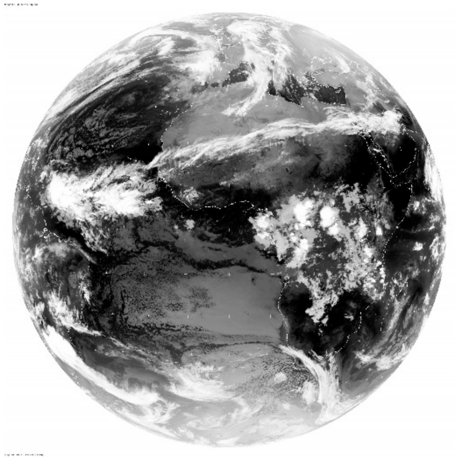
Prof. Hartmut Boesch

Earth Observation Science (EOS) Group, Michael Atiyah Building, Dept. of Physics and Astronomy, University of Leicester, U.K.

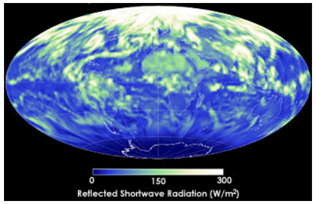
http://www2.le.ac.uk/departments/physics/research/earth-observation-science

National Centre for Earth Observation

http://www.nceo.ac.uk



THE COURSE



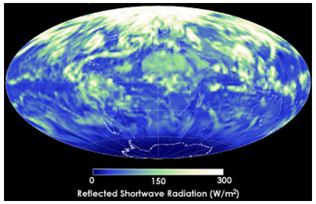
What is this course about?

- Introduction to remote sensing of the Earth from space.
- Key remote sensing techniques and instruments with examples of results.
- The emphasis will be on the Earth but techniques are transferable

Course objectives:

- To provide students with a basic understanding of remote sensing including fundamental principles, satellite instruments and applications.

THE COURSE



Recommended Resources:

- **G.W. Petty, ’A First Course in Atmospheric Radiation’, Sundog Publishing, 2006.**

  Multiple copies available in library

  36$ from http://www.sundogpublishing.com/

- **G.L. Stephens, ‘Remote sensing of the lower atmosphere’, Oxford University Press.,1994.**

  1 copy available in library

  No longer available for purchasing

- **J.T. Houghton, F.W. Taylor, and C.D Rodgers, ‘Remote Sounding of Atmospheres’, Cambridge University Press,1984.**

LECTURE PLAN

FUNDAMENTAL PRINCIPLES:

1. INTRODUCTION [HB]

2.E/M RADIATION [AB]

3.E/M RADIATION [AB]

4.E/M RADIATION [AB]

5. ATMOSPHERE: SCATTERING IN ATMOSPHERE [AB]

ACTIVE REMOTE SENSING

6. LASERS/LIDARS [HB]

7. WORKSHOP [HB+AB]

8. RADARS/OCEANS [AB]

9. RADARS/ATMOSPHERE [AB]

10. SAR [AB]

PASSIVE REMOTE SENSING

11. ATMOSPHERE: GASES [HB]

12. ATMOSPHERE: GASES [HB]

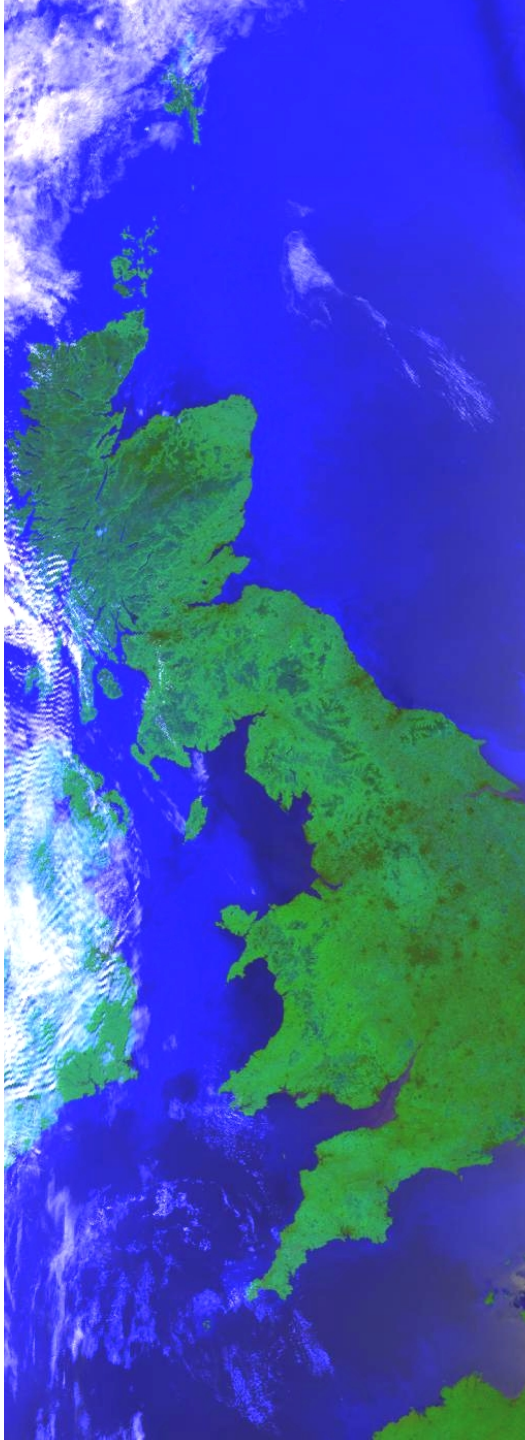
13. ATMOSPHERE: CLOUDS/AEROSOLS [HB]

14. OCEAN [HB]

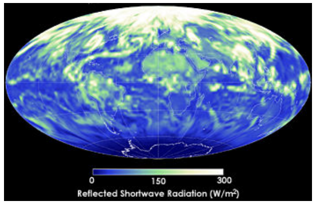
15. LAND [HB]

HB: Hartmut Boesch

AB: Alessandro Battaglia



PURPOSE OF LECTURE



Introduction to the course

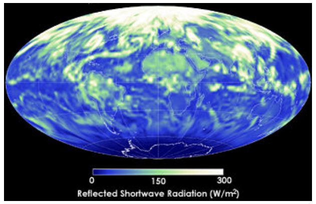
- **What is the course about?**
- **Course objectives**
- **Lecture plan**

Introduction to Remote Sensing

- **Definition of remote sensing**
- **Remote sensing applications/examples**
- **Fundamentals of remote sensing**

Course Assessment

WHAT IS REMOTE SENSING ?



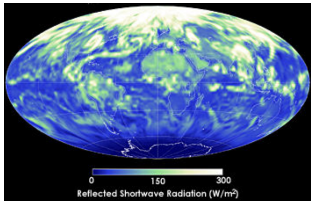
DEFINITION:

- **Remote sensing is the observation of the properties of a medium through its interaction with electromagnetic radiation.**
- **Or in other words: The acquisition of information about an object without physical contact.**

Remote sensing:

- **Commonly used to refer to spaceborne observations of the Earth/planets**
- **This course has the same bias (space and Earth).**
- **Same principles of remote sensing can be used for many other studies.**

WHAT IS REMOTE SENSING ?



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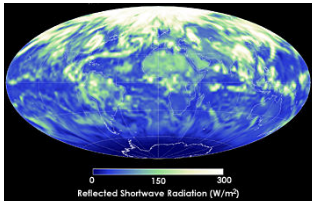
Remote sensing:

- Commonly used to refer to s the Earth/planets
- This course has the same bia
- Same principles of remote many other studies.

Remote Sensing: A New Technology?
Some early remote sensing methods
are still in use today.

An Example from the Early Days

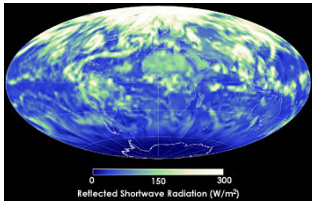


So what do we see ?

Earth surface and atmosphere ('nadir' view)

Earth's atmosphere ('limb' view)

An Example from the Early Days



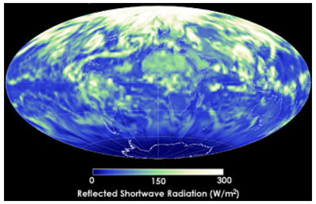
So what do we see ?

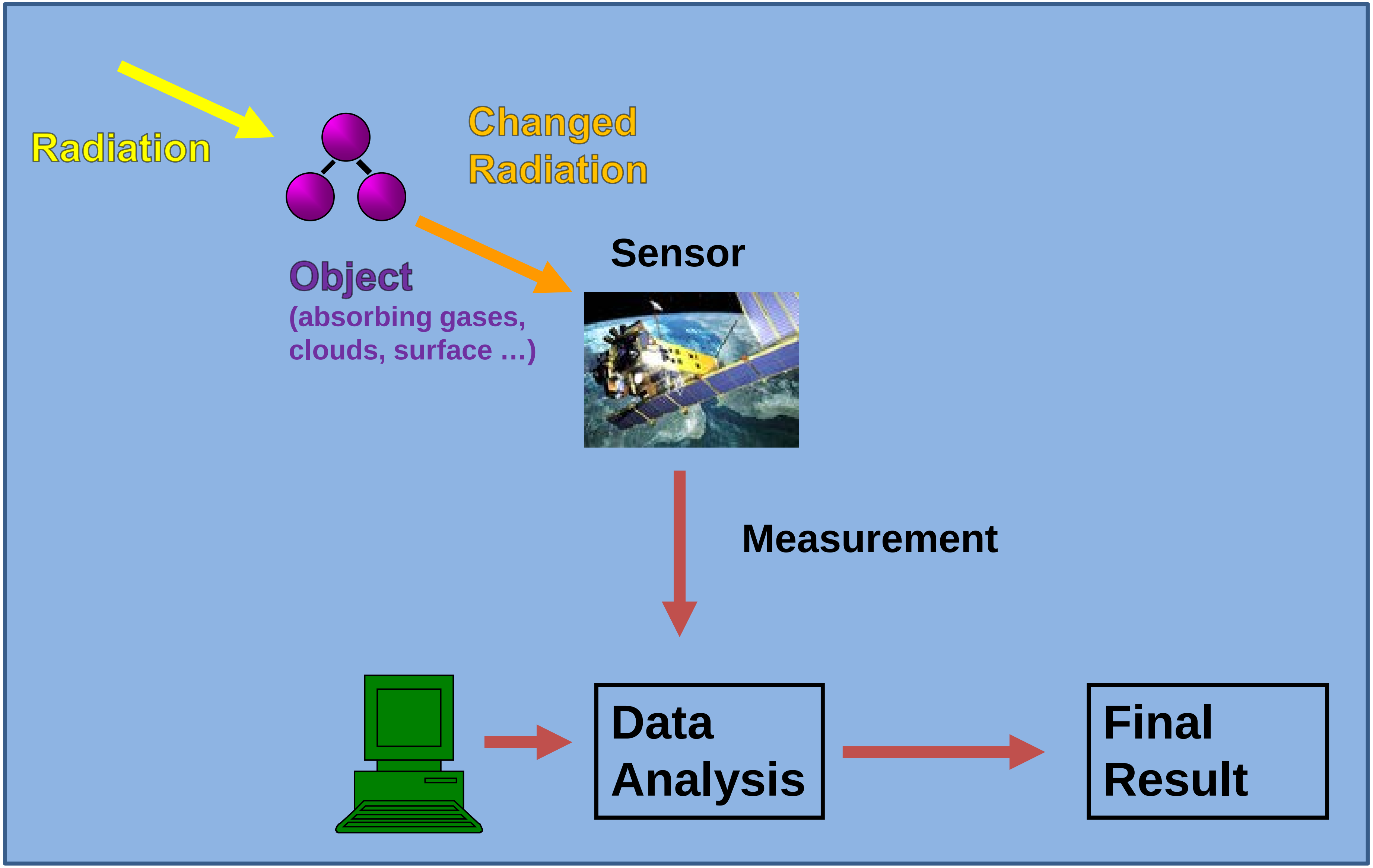
Clouds, dark and bright surfaces, scattering in the atmosphere …

Earth surface and atmosphere ('nadir' view)

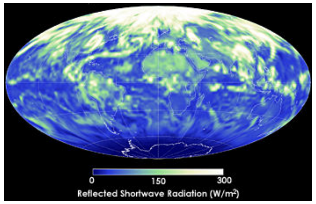
Earth's atmosphere ('limb' view)

Schematic of Remote Sensing Observation



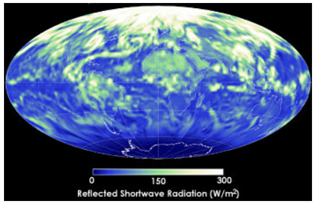


FUNDAMENTALS OF EO



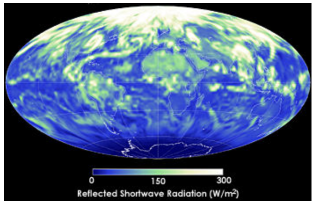
- **Sources of electromagnetic radiation:**
    - **Sun, Earth (passive)**
    - **Radar, laser beam (active)**
- **Signal information at chosen wavelength**
    - **Absorption/emission/scattering of signal**
    - **Time delay (active)**
- **View direction, path of radiation, orbit**
- **The instrument.**

PROS AND CONS OF REMOTE SENSING



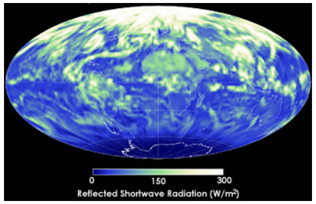
Pros	Cons

PROS AND CONS OF REMOTE SENSING



Pros	Cons
Usually all locations are accessible (atmosphere, ice, ocean)	Always indirect measurements
Provides global datasets	Signal is often affected by more parameters than just the quantity to be measured
Allows creation of long time series and extended measurement areas	Usually, assumptions and models are needed for analysis of measurements
Usually can be automated	Usually, measurement area / volume is relatively large
Often, several parameters can be measured at the same time	Validation is a major task and often not possible in a strict sense
On a per measurement basis, can be less expensive than in-situ measurements	Estimation of measurement errors is often difficult
Non-invasive	

WHY DO WE WANT TO OBSERVE THE EARTH?

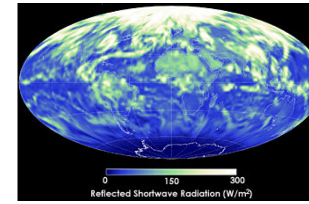


There are a myriad of invaluable uses for remote sensing data of the Environment:

- **Local physical environment, e.g., surveying pollution.**
- **Regional characteristics such as surface vegetation, mineralogy, water resources.**
- **Global environmental (climate) change, e.g., changes in land use, effects of greenhouse gases, ozone depletion.**

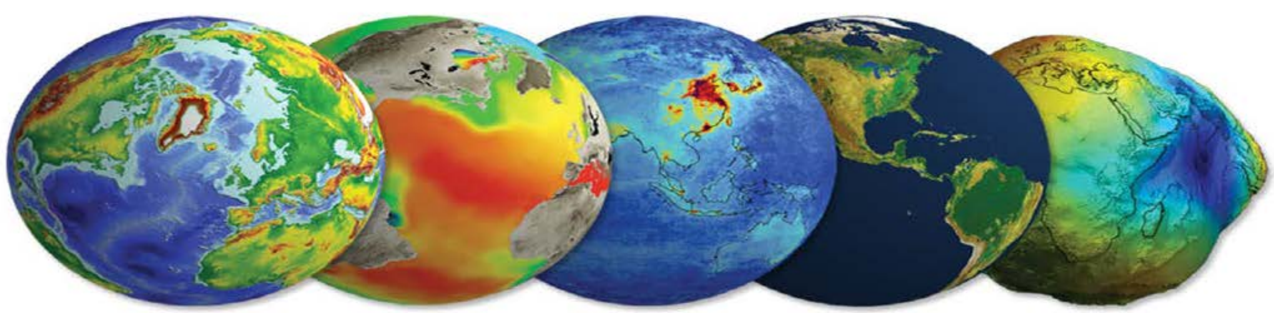
"Environment": **both the natural behaviour of the Earth system and the influence of human existence/activities (the *anthropogenic* influence).**

Which Quantities can be Measured ?



- What are we are interested in are:

Surface	Meteorology/Dynamics	Atmospheric Composition
height	pressure	aerosol burden
albedo	temperature	aerosol type
vegetation index and type	cloud cover/top height/type	Liquid/ice water content
surface (water) temperature	lightning frequency	Cloud height
fires	…	trace gas concentrations
surface roughness		…
wind speed		
chlorophyll concentrations		
ice cover/type		
Energy fluxes		
…		



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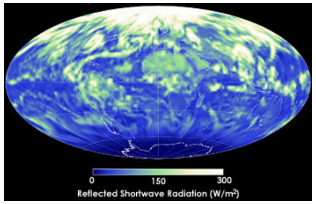
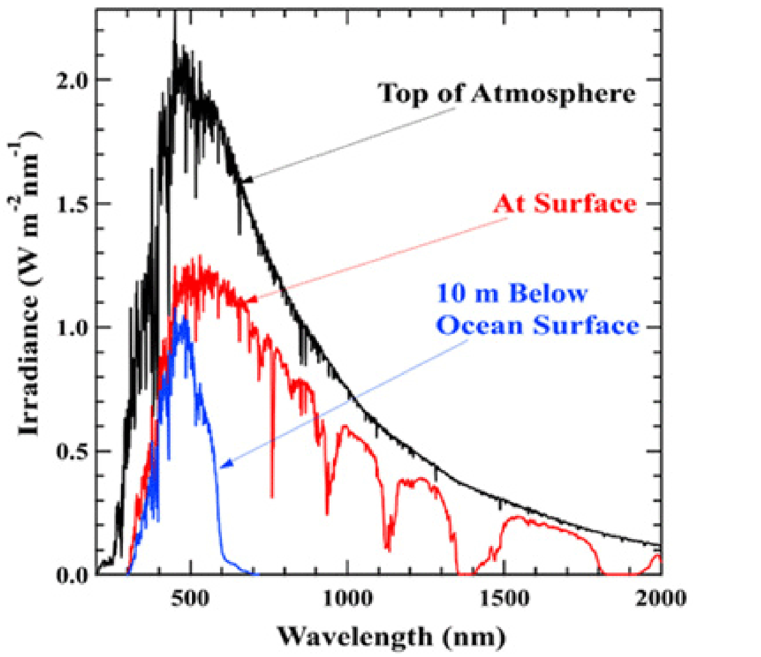


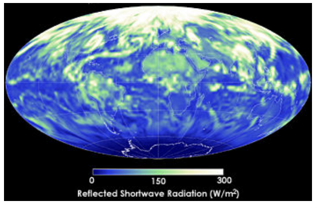
- What are we are interested in are:

Surface	Meteorology/Dynamics	Atmospheric Composition
height albedo vegetation index and type surface (water) temperature fires surface roughness wind speed chlorophyll concentrations ice cover/type Energy fluxes …	pressure temperature cloud cover/top height/type lightning frequency …	aerosol burden aerosol type Liquid/ice water content Cloud height trace gas concentrations …

- What can we measure with a satellite:
  - Absolute or relative intensities
  - Ratio of intensities
  - Spectral variations of intensities
  - Degree of polarisation
  - Time delay



Which Quantities can be Measured ?



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We need to understand the physical links

EOS Applications

Weather & Climate
-Changing Climates/Seasons
-Extreme weather events
-Changing weather patterns
-Depression tracks
-Jet Stream
-El Niño/La Niña
-Chancing precipitation patters

Land
-Land surface temperature
-Land use and land use change
-Coastal zones
-Rivers and lakes – water cycle
-Wetlands
-Deserts
-Evaporation rates
-Carbon sources/sinks
-Albedo
-Snow cover

Military
-Surveying
-Surveillance

Disasters
-Volcanic eruptions
-Hurricanes
-Fire
-Flooding
-Drought

Oceans
-Sea level rise
-Sea surface temperature
-Polar ice loss
-Ocean acidification
-Glacier evolution
-Ocean circulation
-Algal blooms
-Carbon sources/sinks
-Thermohaline circulation
-Ocean colour

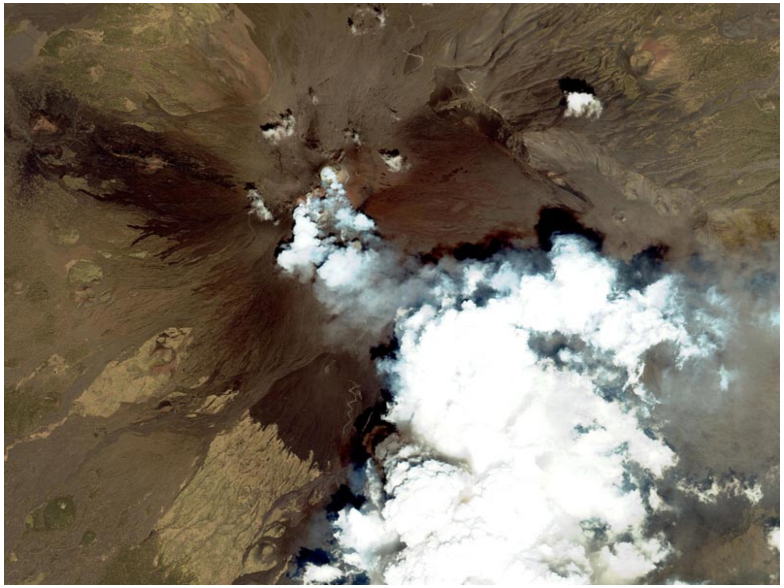
Management & Sustainability
-Mapping
-Monitoring
-Decision making

Atmosphere
-Greenhouse gases
-Ozone
-Aerosols
-Clouds
-Water vapour

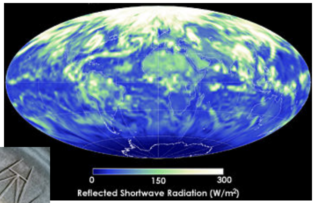
Health
-Disease invasion/migration
-Heat stroke
-Respiratory problems

Ecosystems
-Deforestation
-Desertification
-Species migration/extinction
-Photosynthesis rates
-Insect invasion
-Carbon sources/sinks
-Coral Reefs

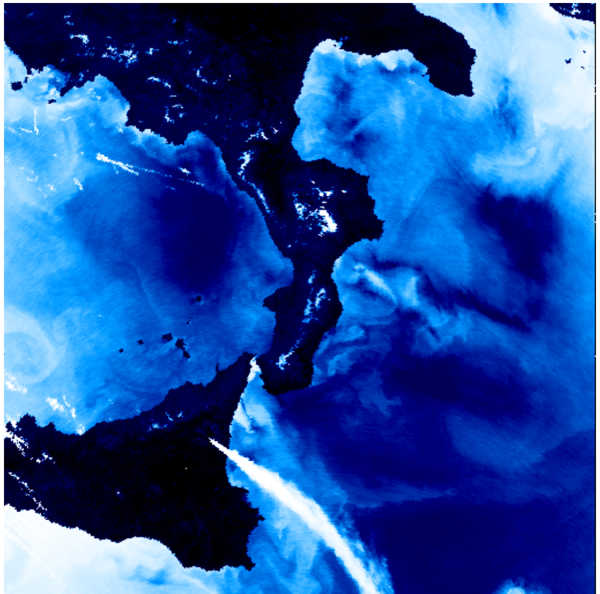
IKONOS VIEW of MT. ETNA 31/07/2001 (4 m resolution)

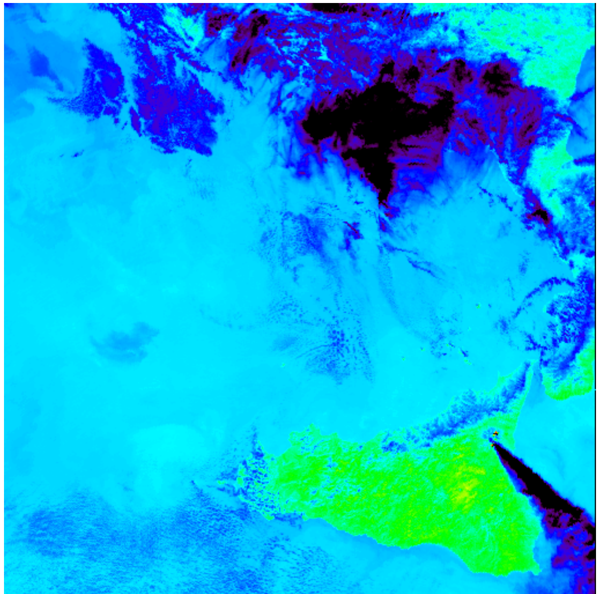


WV-3, Australian Mine (40 cm)

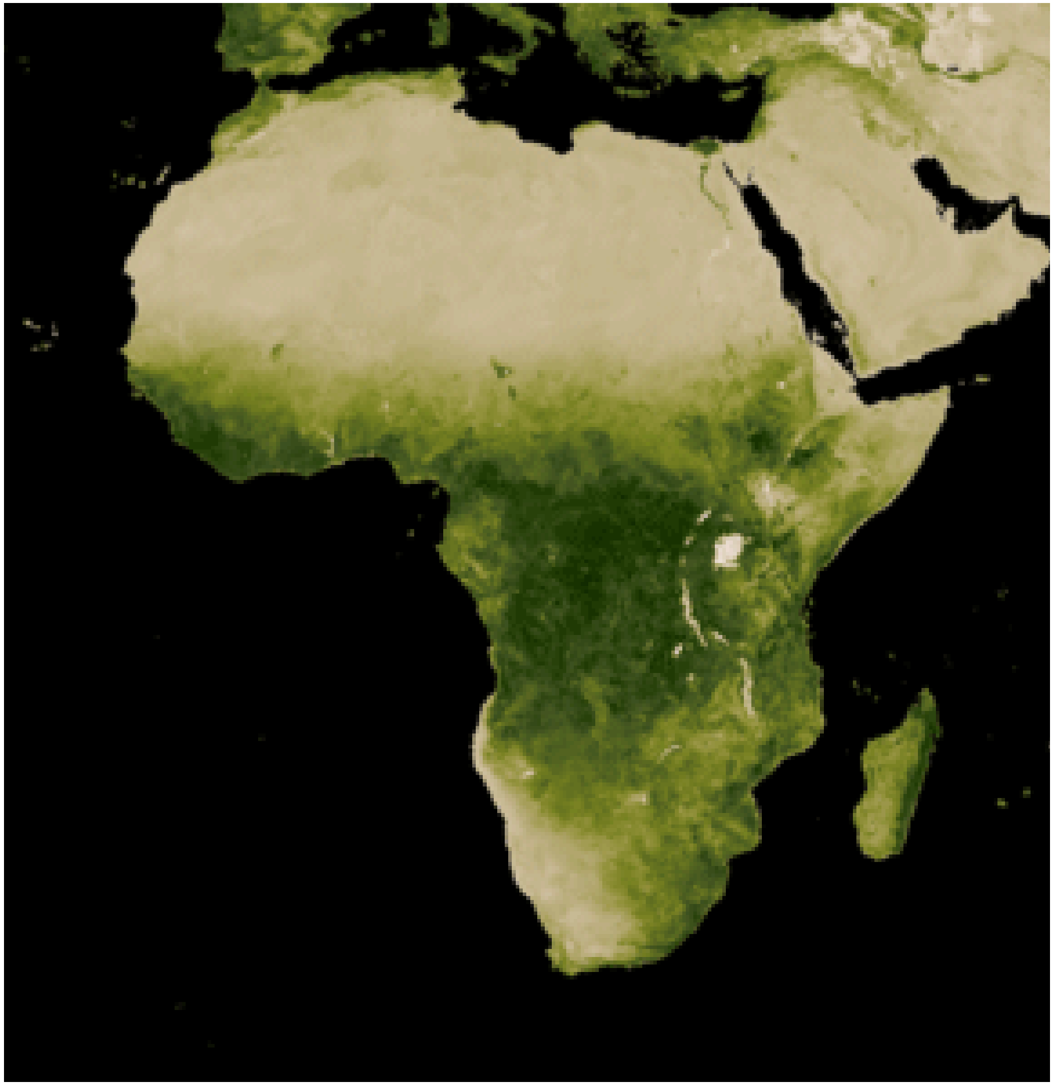


LEFT: ATSR-2 08/2001; RIGHT AATSR 28/10/2002 (1 km resolution)

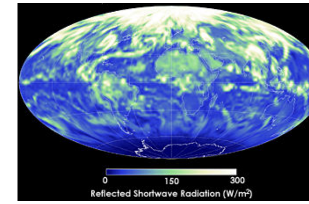


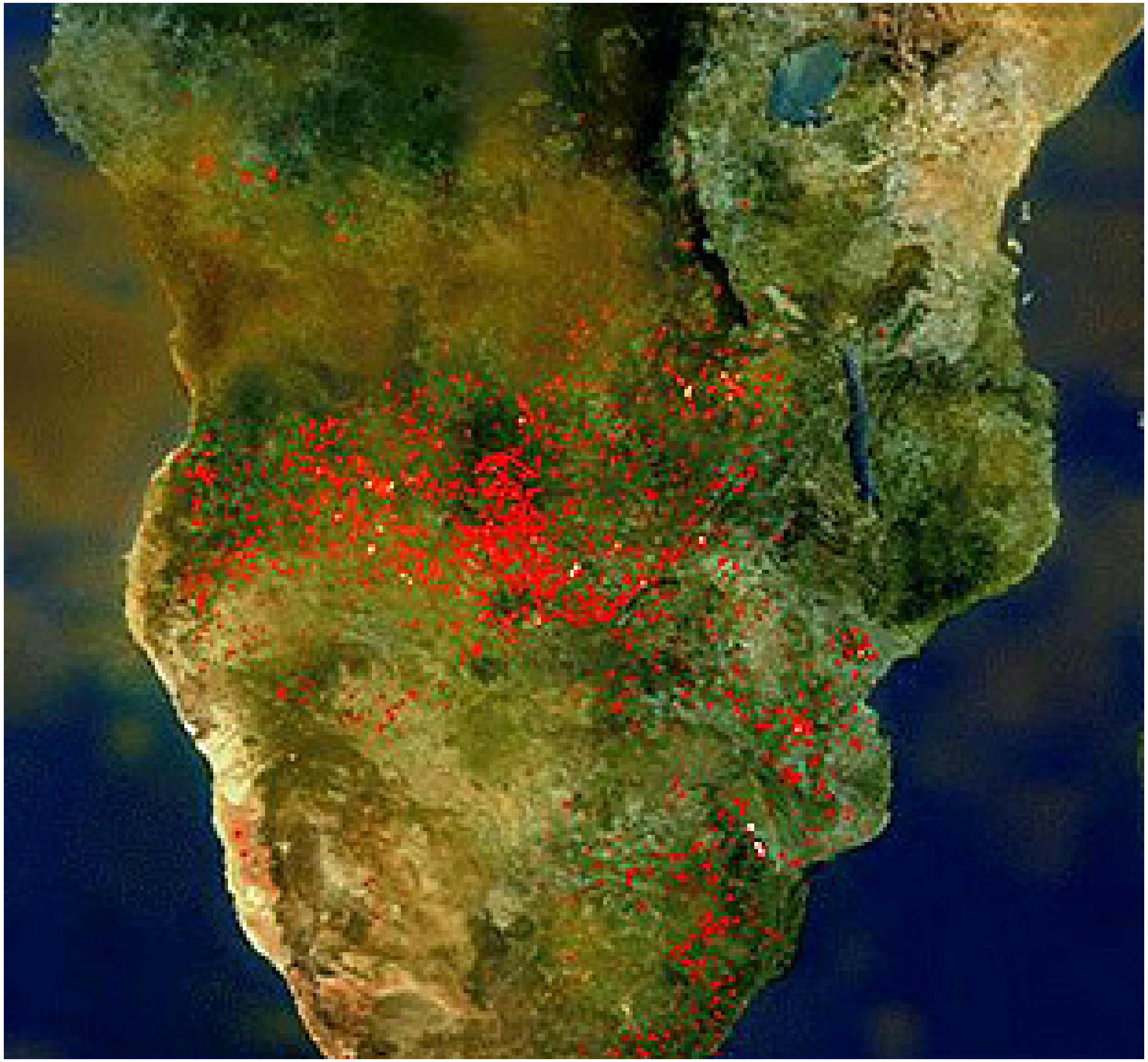


VEGETATION IN AFRICA (NDVI)



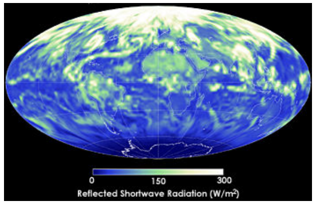
BIOMAS BURNING FIRES AND AEROSOLS





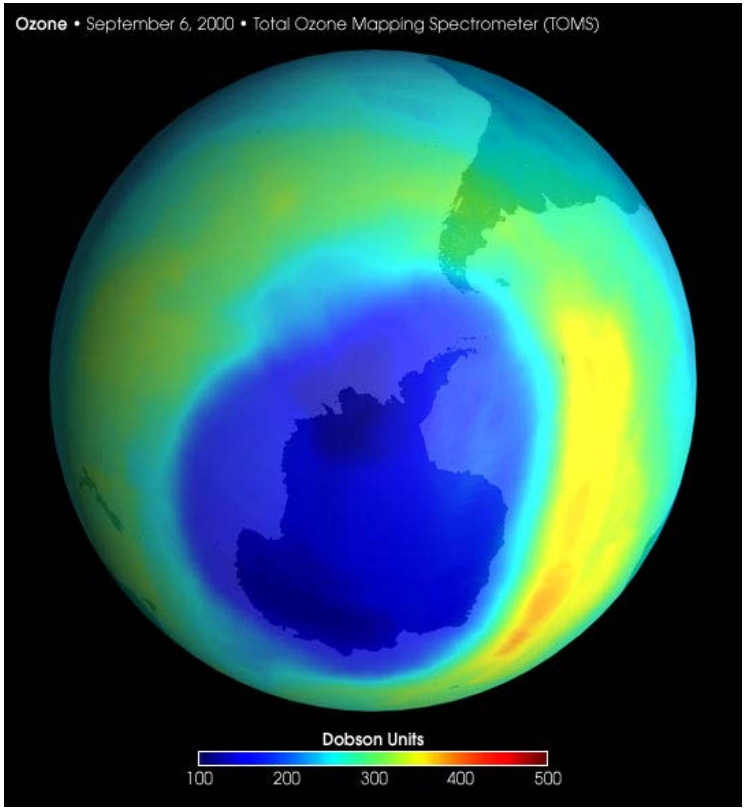
TOMS AEROSOL,AVHRR FIRES,SEPT,2000

GLOBAL OBSERVATIONS: THE OZONE HOLE

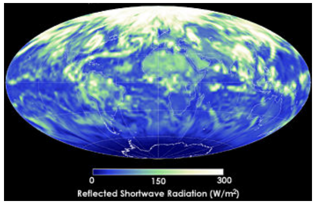


ANTARCTIC OZONE HOLE:SEPTEMBER 6 2000 (EP TOMS)

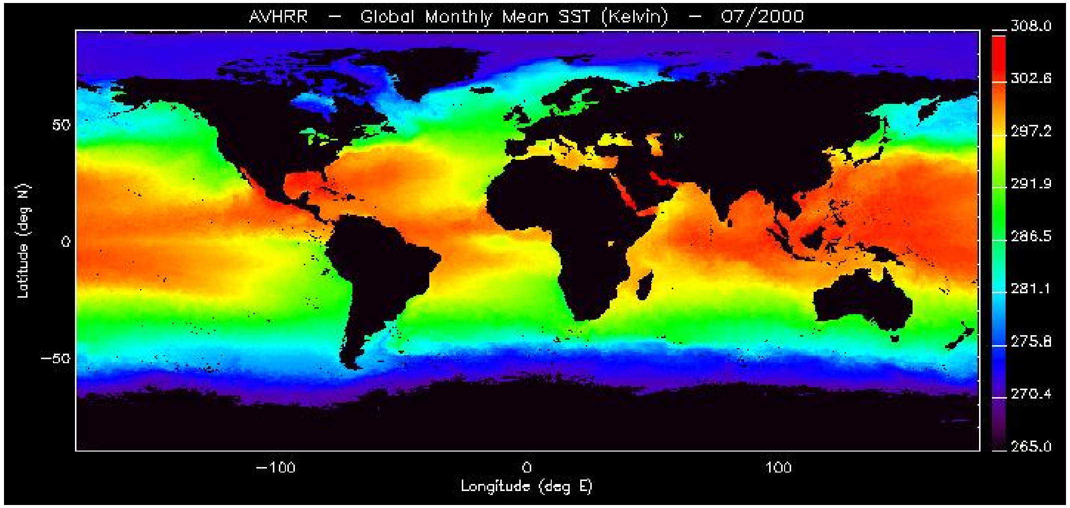
The largest ever ozone hole (area) covering 28.3 million km^2



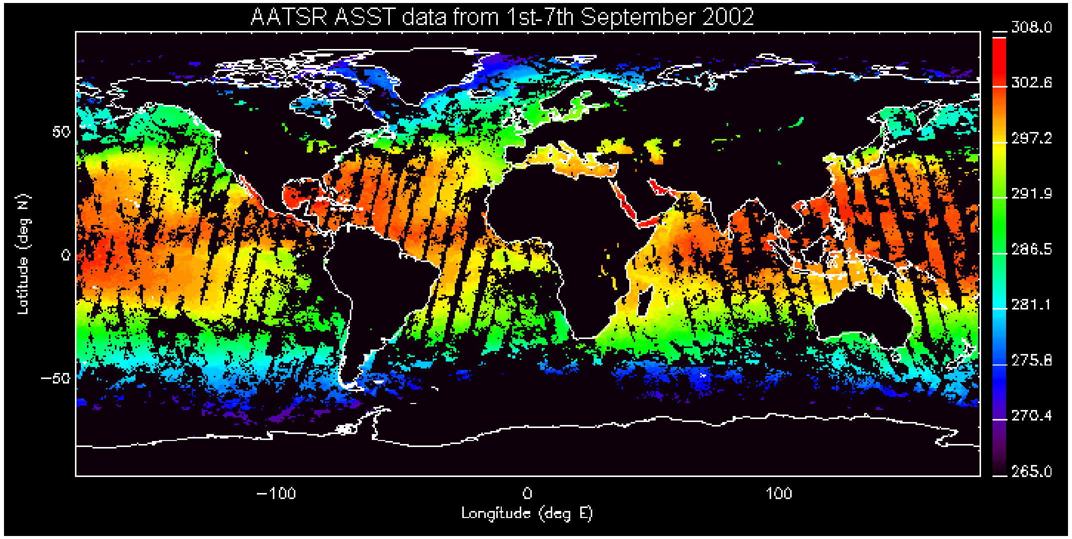
GLOBAL OBSERVATIONS: SEA SURFACE TEMPERATURE



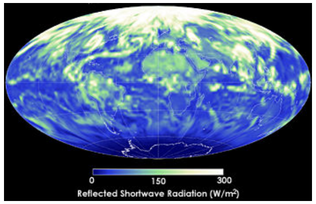
AVHRR average for month: 07/2000



AATSR AVERAGE FOR 1 WEEK: 1-7/09/2002

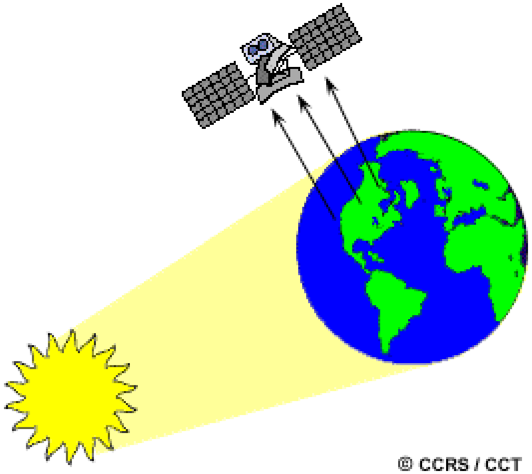


Classification: Active vs. Passive Remote Sensing



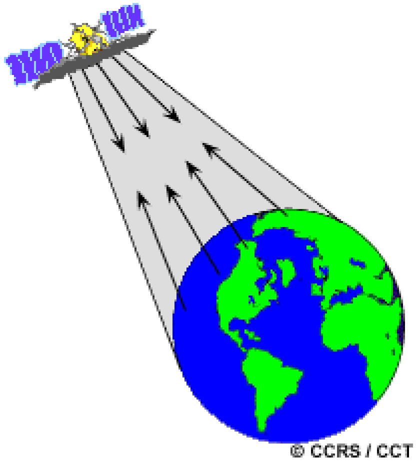
Passive Remote Sensing:

- Natural sources of radiation
- Direct attenuated, reflected, scattered, or emitted radiation is analysed

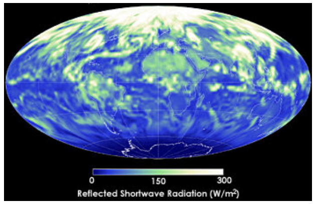


Active Remote Sensing:

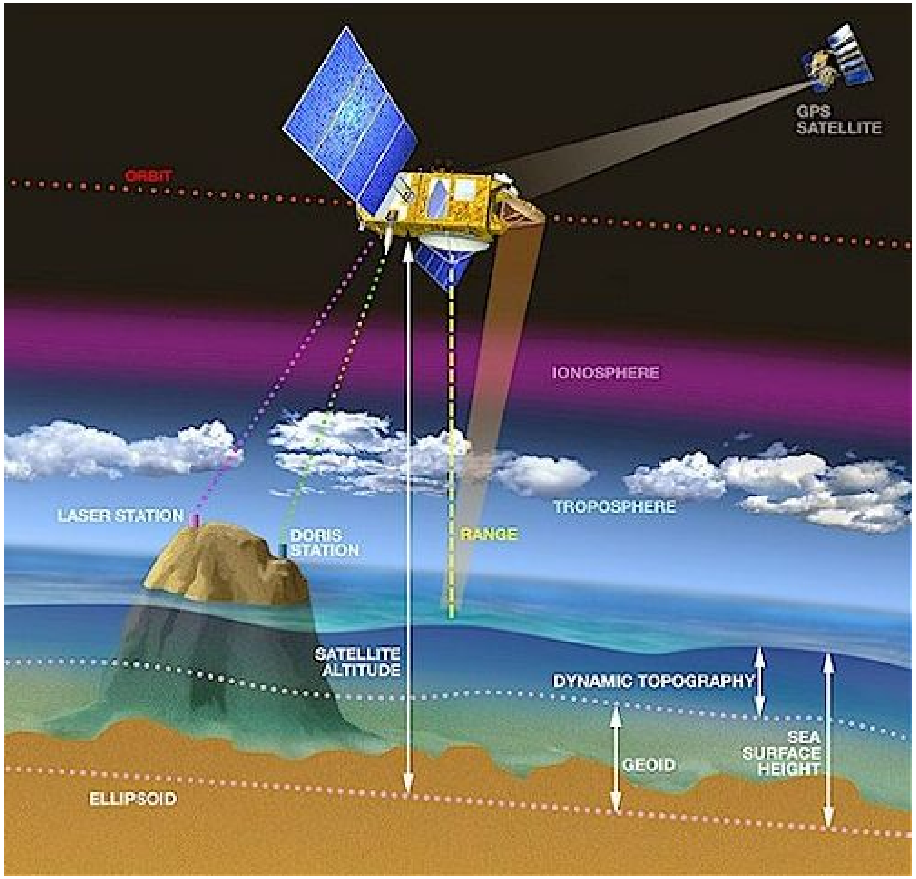
- Artificial source of radiation is used to probe a planet
- Sources tend to be very frequency specific within the same wavelength regions employed by passive sensing



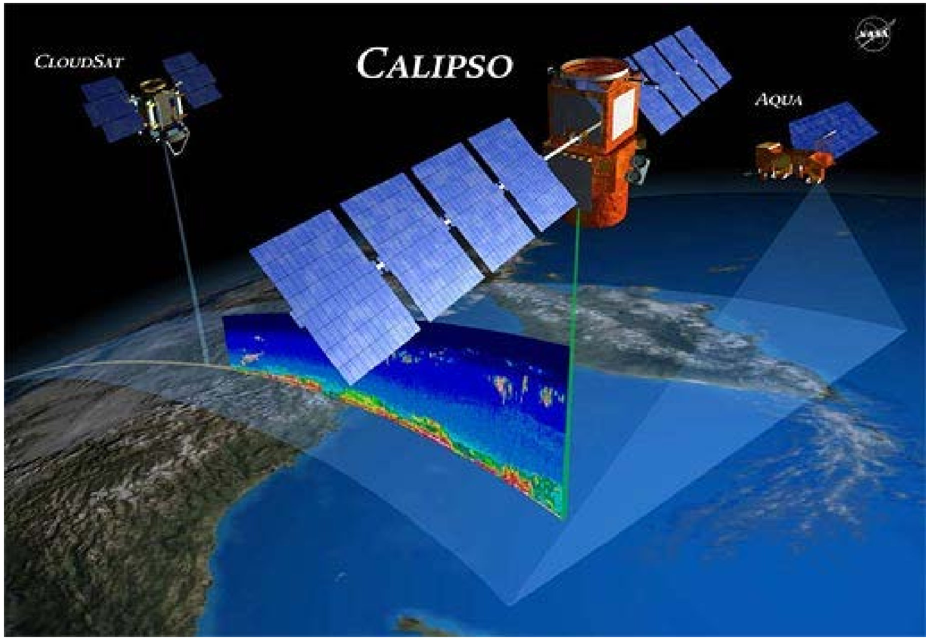
Active Remote Sensing



RADAR

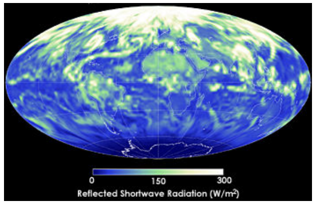


LIDAR (Laser)



Active remote sensing allows ranging !

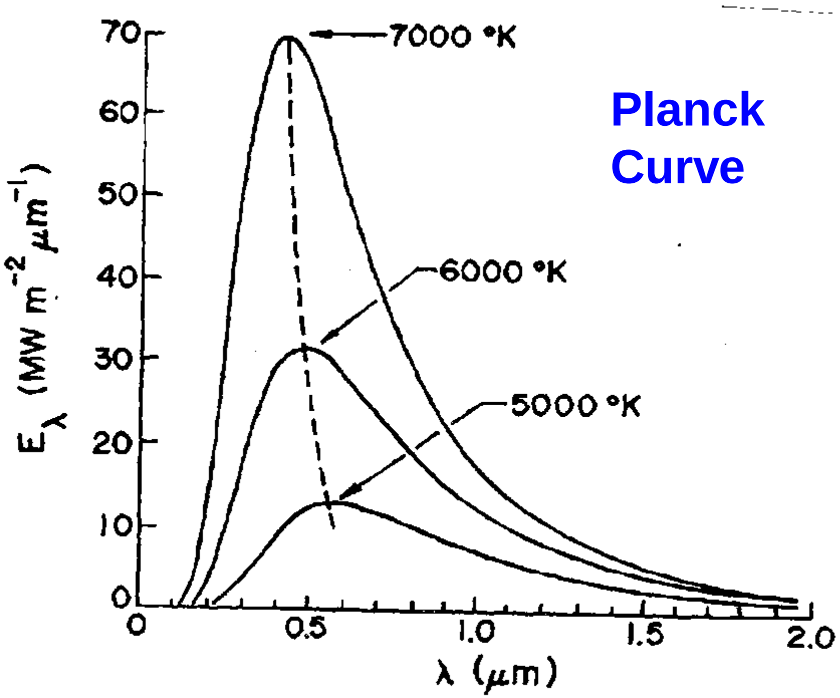
NATURAL SOURCES OF RADIATION



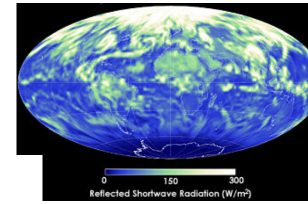
For the Earth, natural sources of radiation are provided by the emission of grey bodies (emissivity < 1.0, for black body type emitters)

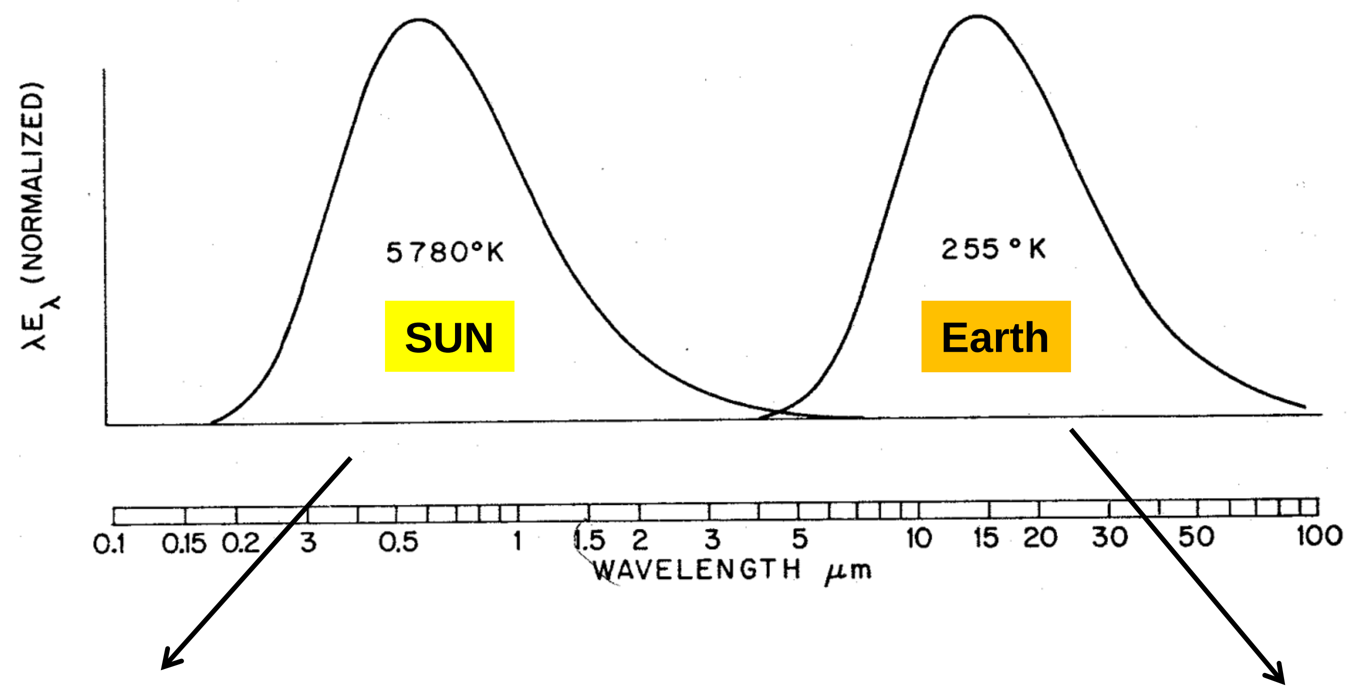
Black body is characterised by:

- **Large dependence on wavelength**
- **Total emitted power increases strongly with temperature (~T^4) - *Stefan Boltzmann Law***
- **Curves from different T's do not cross each other**
- **Well defined maximum for a given T that is at smaller λ for larger T (*Wien law*)**



Two Radiation Sources



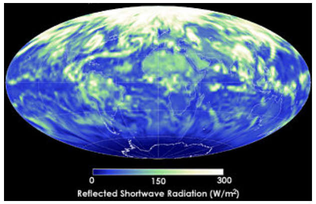


Shortwave Range:
- **Sun as a Light Source:**
- **High Intensity**

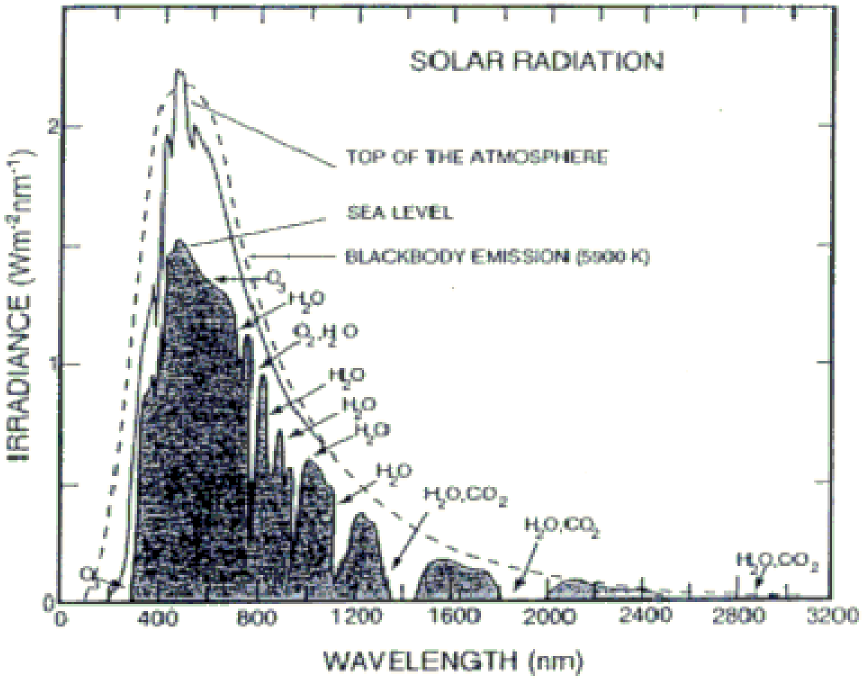
Long wave Range:
- **Thermal IR radiation:**
- **Available night and day**

- **Shortwave and longwave range are well separated**
- **Thermal emission can be (usually) neglected in the solar spectral range and vice versa**

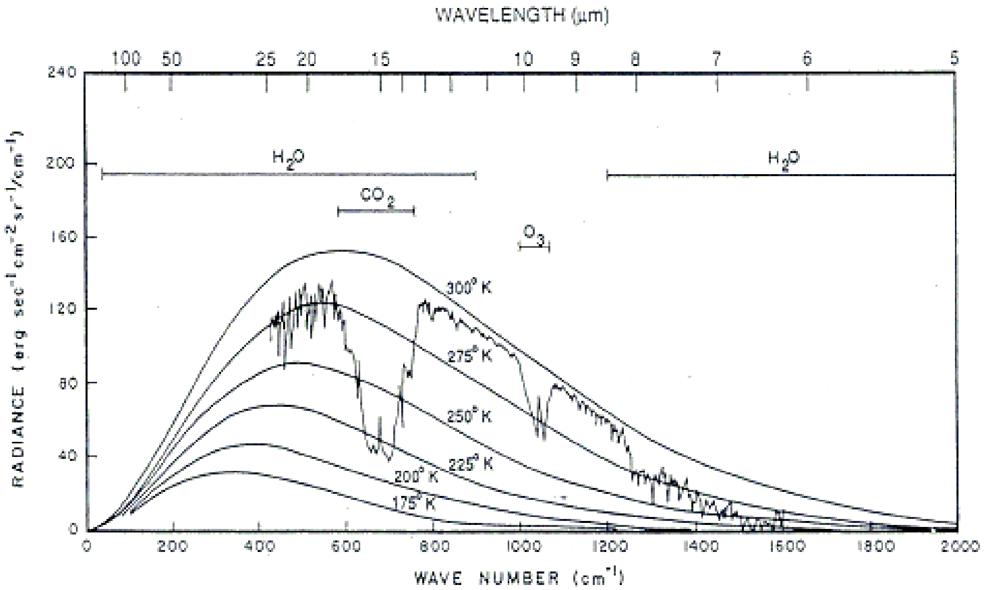
NATURAL SOURCES OF RADIATION



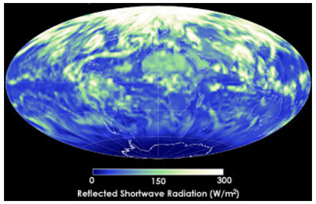
Solar radiation at Earth's surface



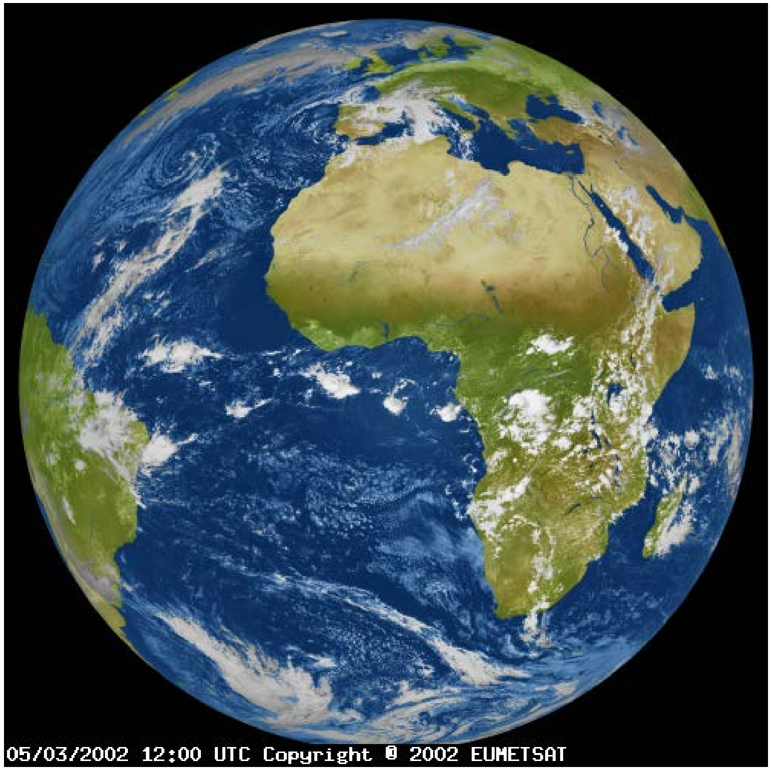
Thermal radiation at top of atmosphere



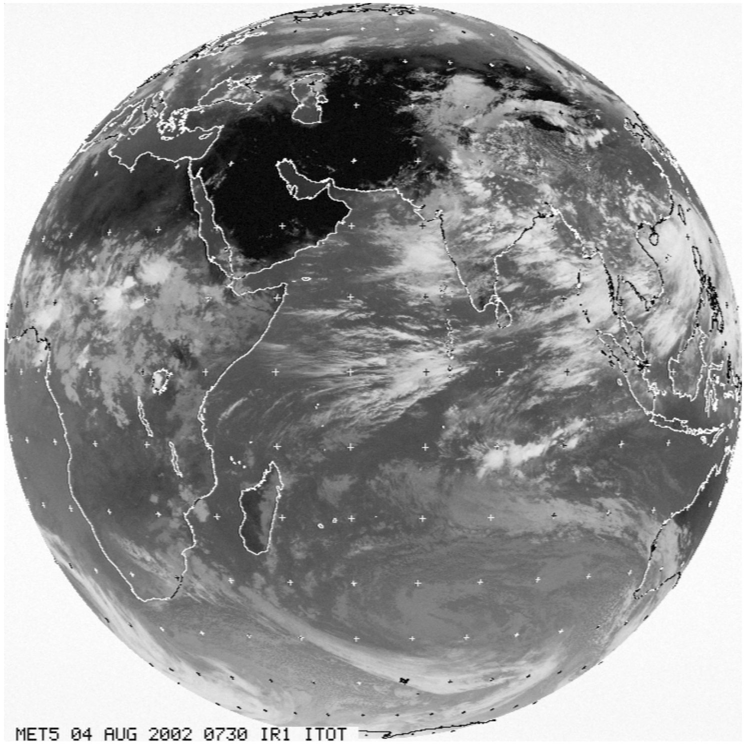
METEOSAT-7



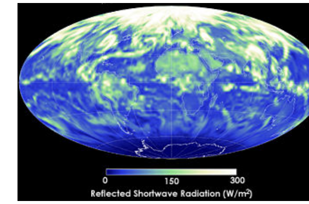
VISIBLE COLOUR

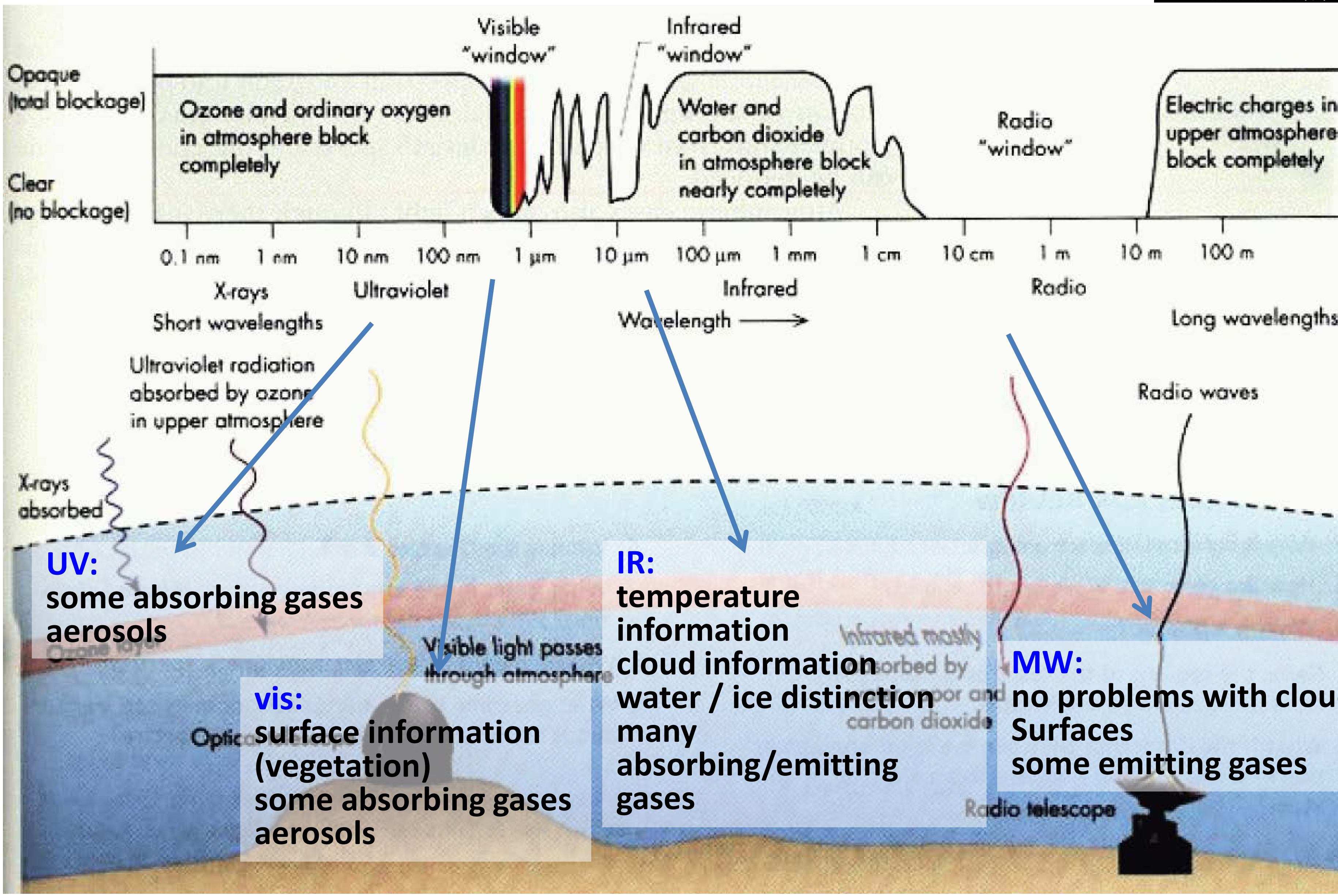


IR



Classification : Wavelength Range





UV:
some absorbing gases
aerosols

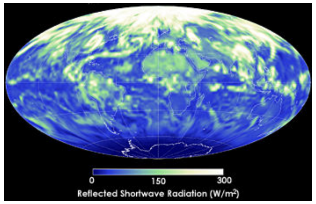
vis:
surface information (vegetation)
some absorbing gases
aerosols

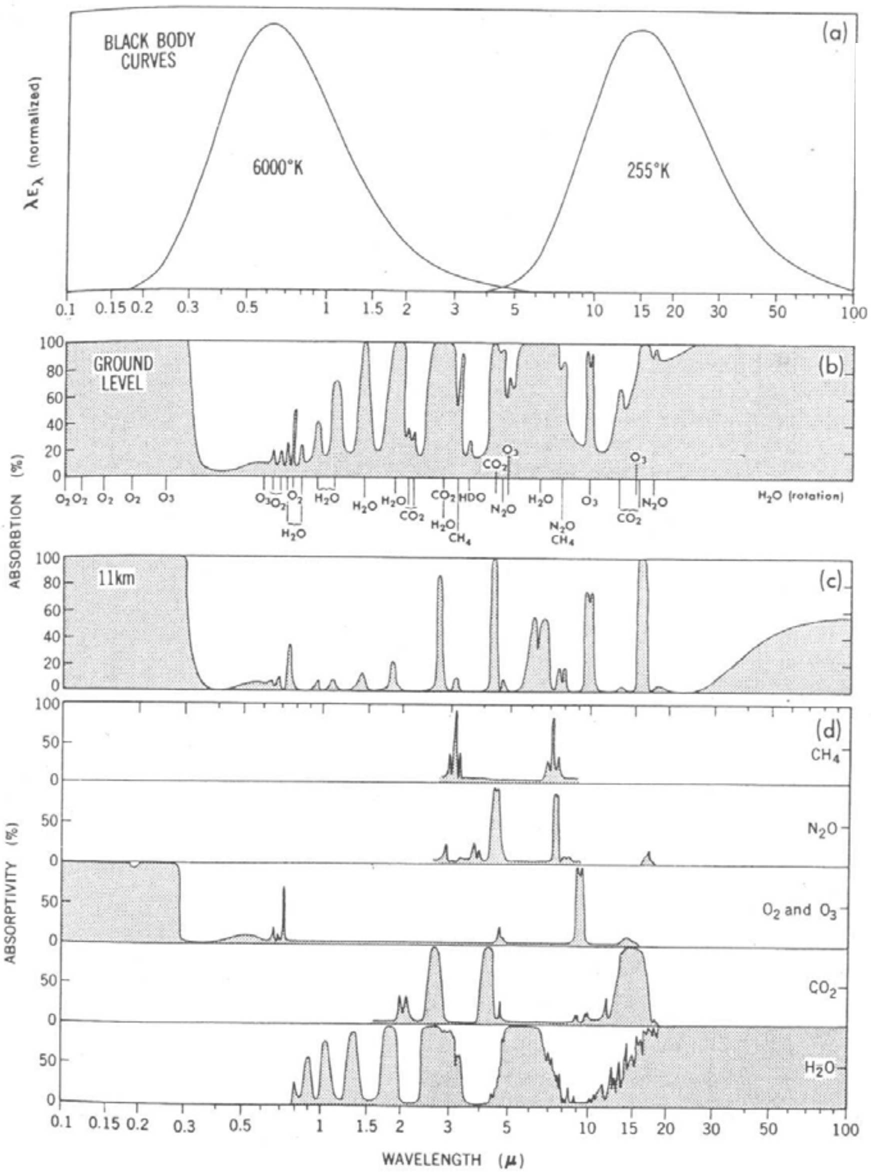
IR:
temperature information
cloud information
water / ice distinction
many absorbing/emitting gases

MW:
no problems with clouds
Surfaces
some emitting gases

SPECTROSCOPY

Absorption of light due to interaction of radiation with matter (QUANTUM MECHANICS!)





GREY SHADE = REGIONS WHERE GASES ABSORB RADIATION

Absorption at ground level

Absorption at 11 km height

CH_4

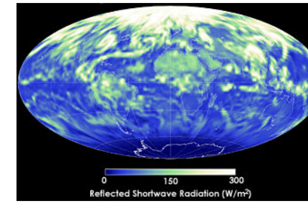
N_2O

O_3/O_2

CO_2

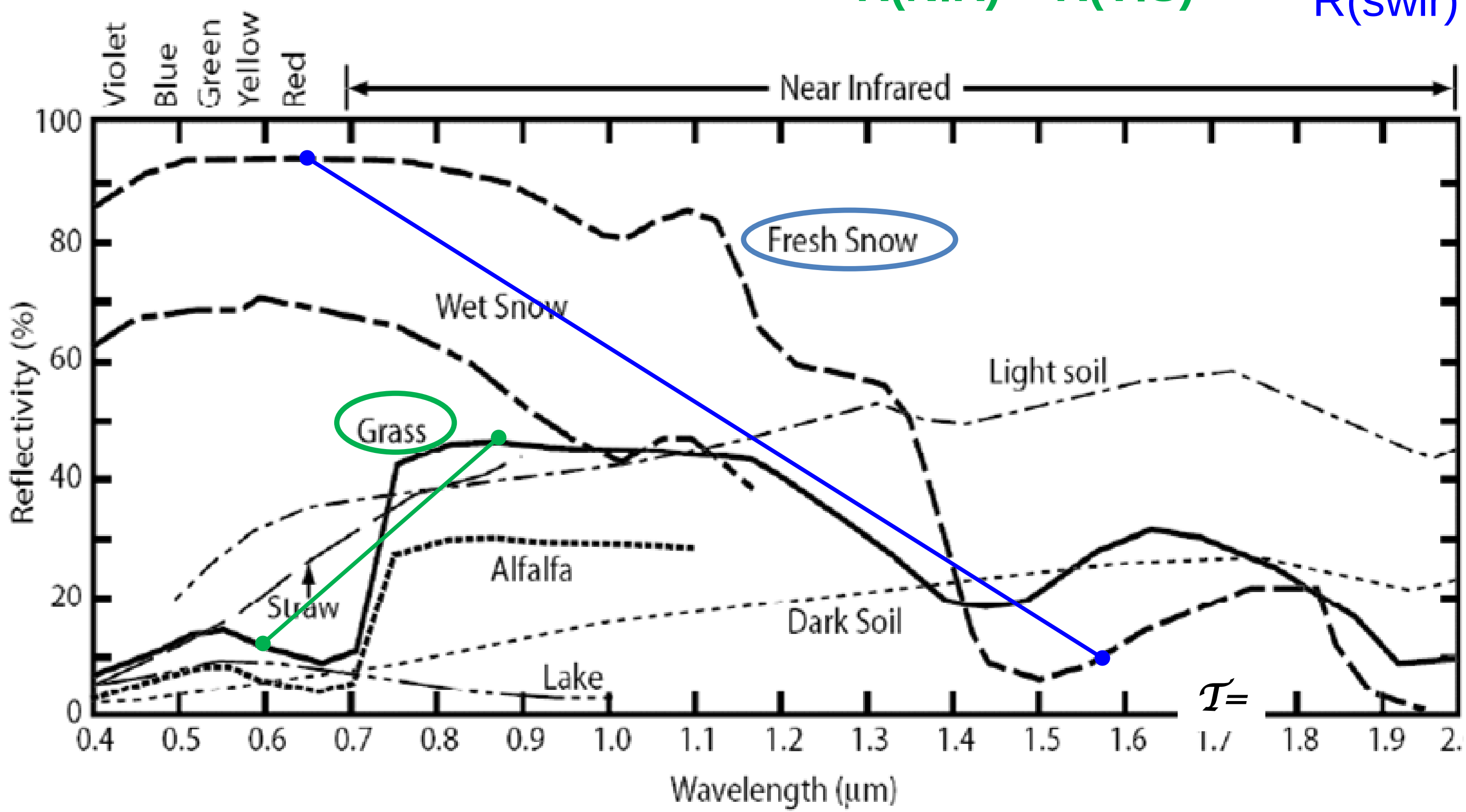
H_2O

Information on Surface



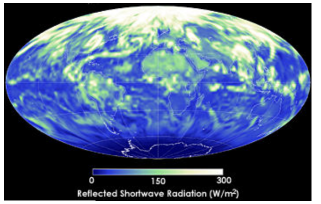
Characterizing snow via Normalized Difference Snow Index (NDSI) = $\frac{R(vis) - R(swir)}{R(swir) - R(vis)}$

Characterizing Vegetation via NDVI = $\frac{R(NIR) - R(VIS)}{R(NIR) + R(VIS)}$

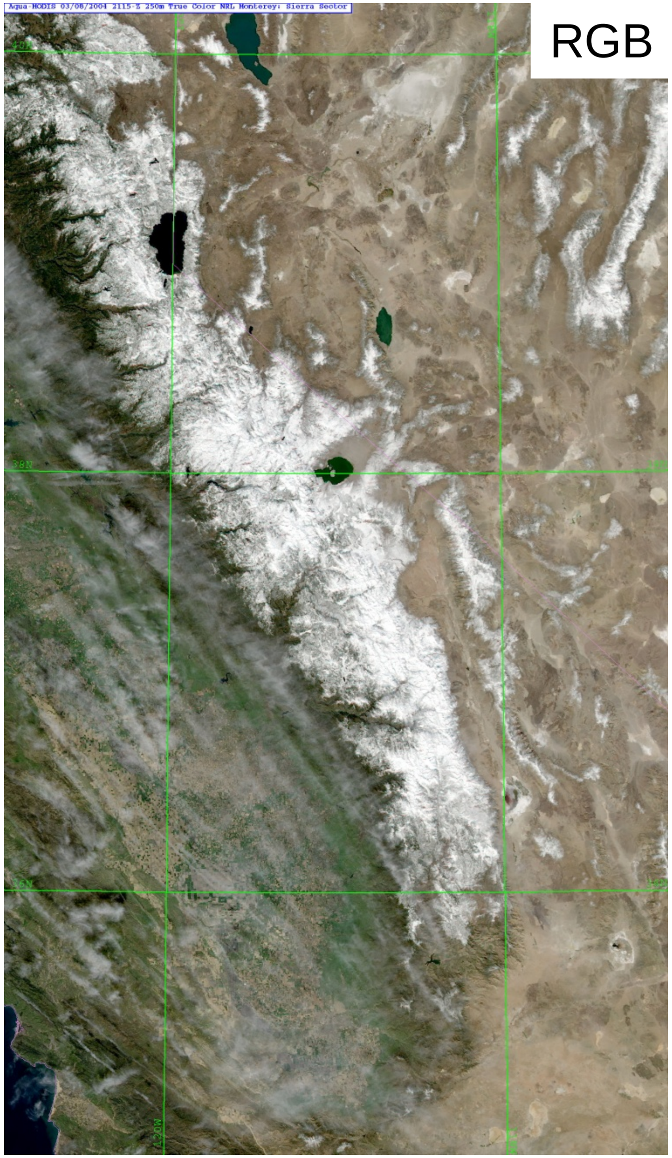


Ratios (indices) provide a simple and powerful way of characterizing surface (the need for atmospheric correction is in first order removed)

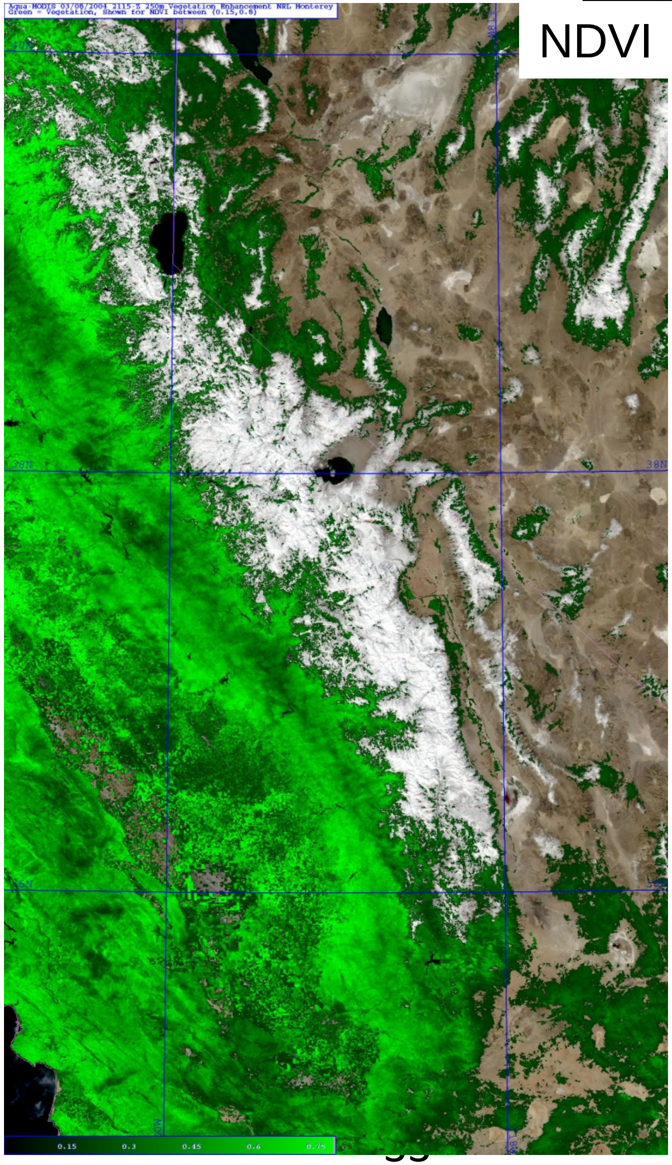
NDVI Measurement from MODIS



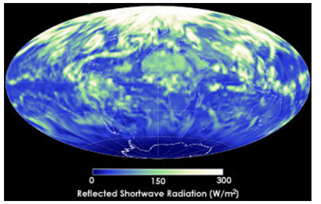
RGB

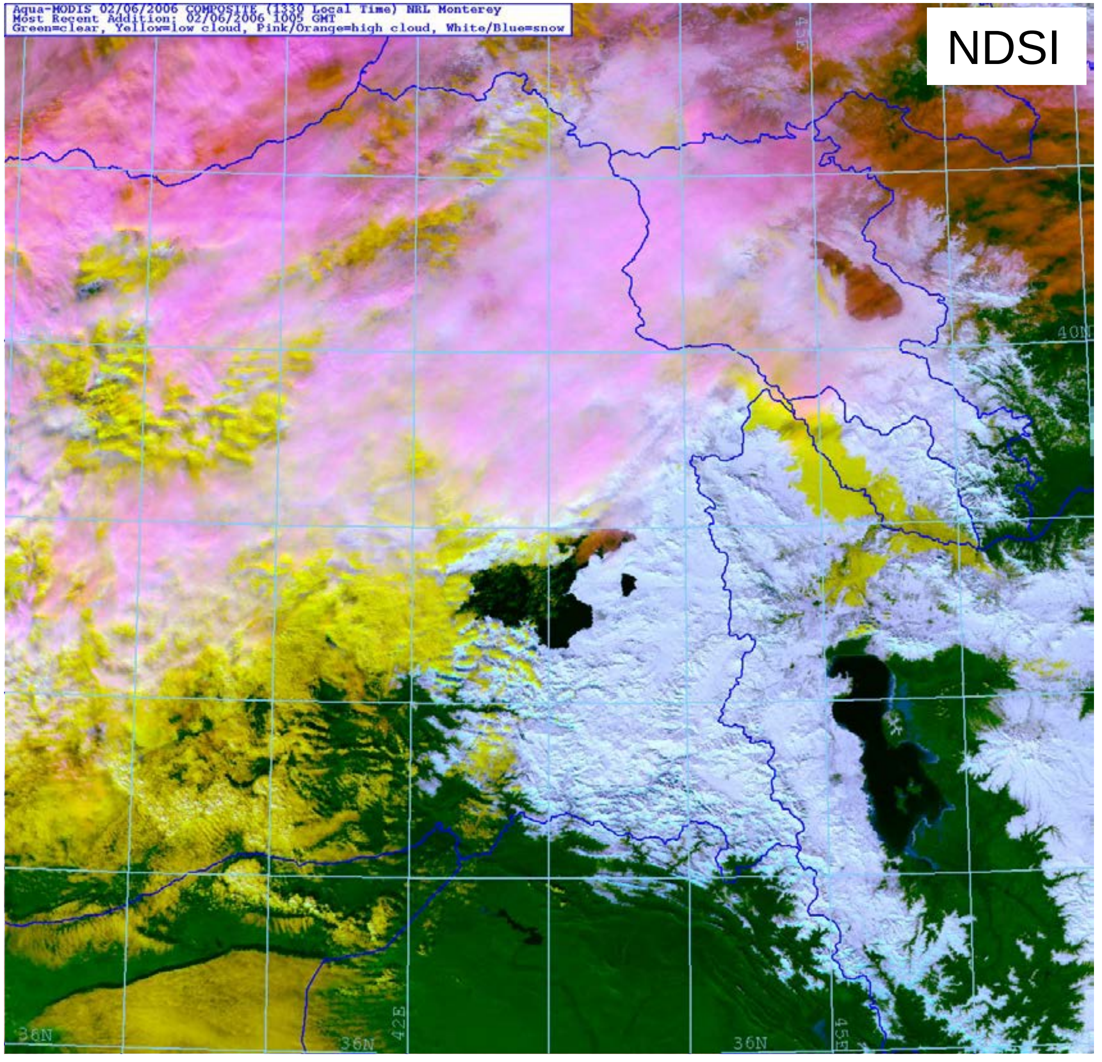


NDVI



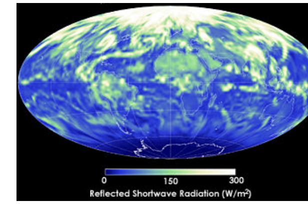
Snow Detection from MODIS

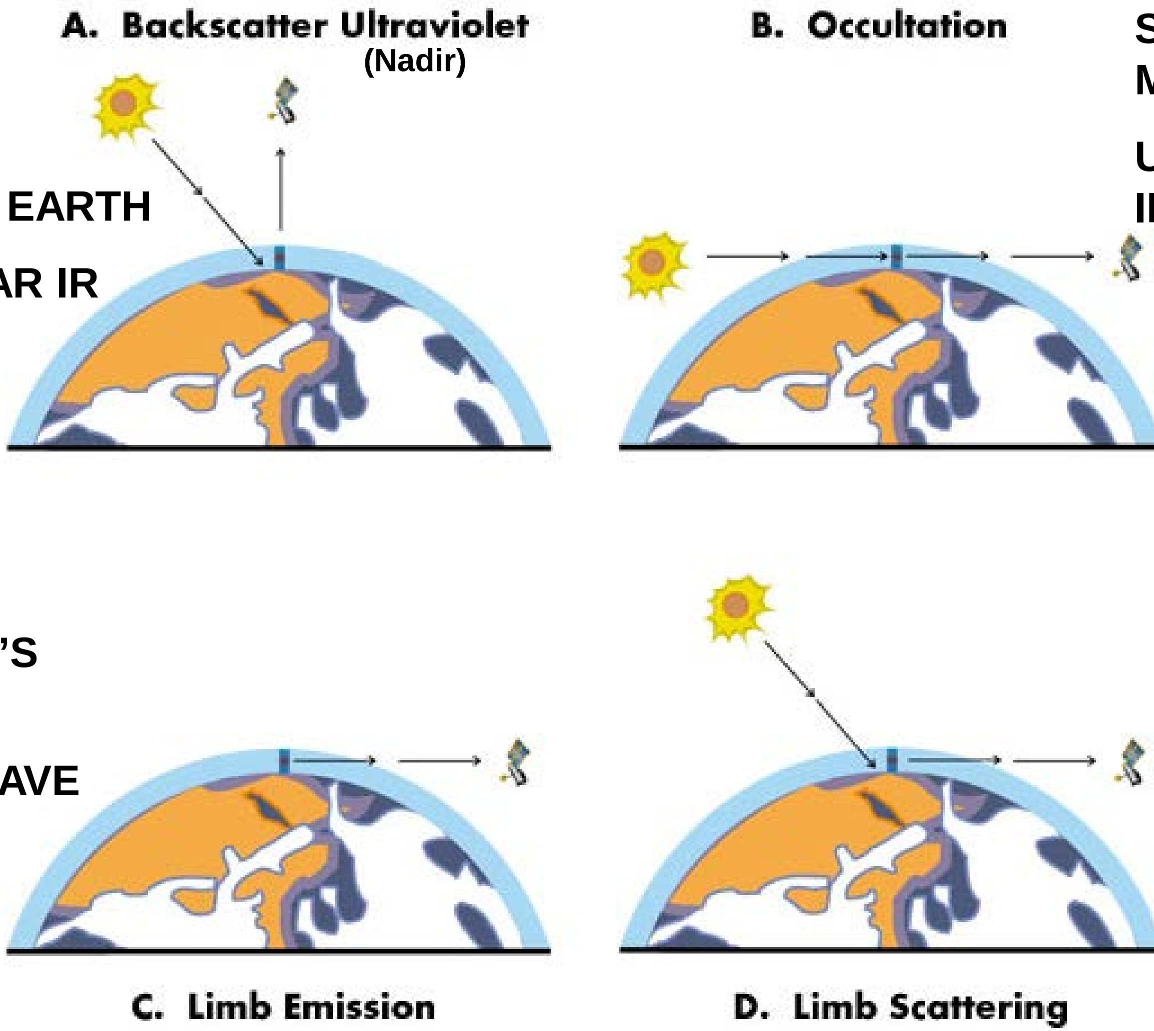




Snow and clouds appear white in RGB image

Classification: VIEW DIRECTIONS (PASSIVE INSTRUMENTS)





SOURCE=SUN or EARTH

U/V, VISIBLE, NEAR IR

or IR (emission)

SOURCE=SUN, MOON OR STAR

U/V, VISIBLE, NEAR IR, MID-IR

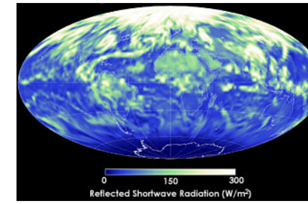
SOURCE=EARTH'S ATMOSPHERE

MID-IR, MICROWAVE

SOURCE=SUN

U/V, VISIBLE

VIEW DIRECTIONS (PASSIVE INSTRUMENTS)



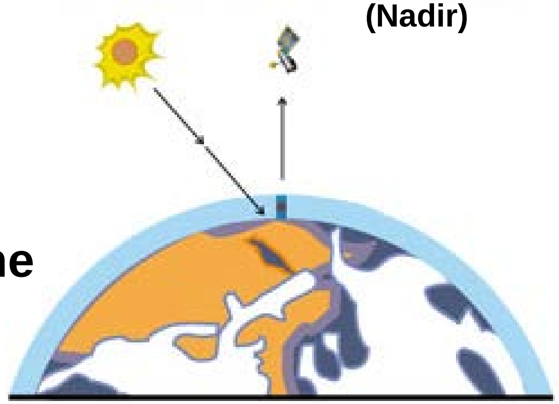
View normal to the planet's surface

High spatial resolution at the surface.

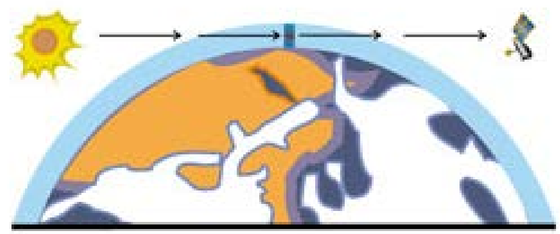
Off-nadir to increase spatial coverage

A. Backscatter Ultraviolet

(Nadir)

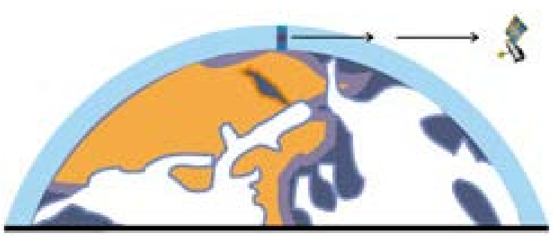


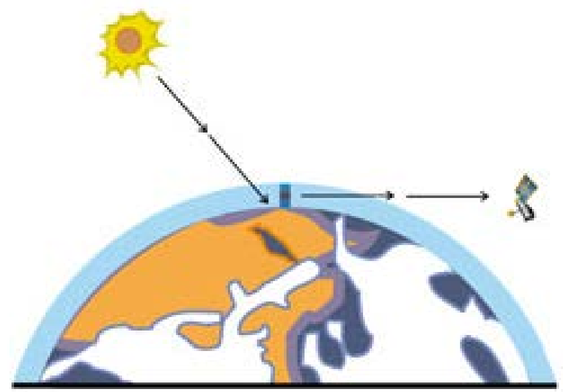
B. Occultation



View at raising or setting Sun

Very high vertical resolution in the atmosphere



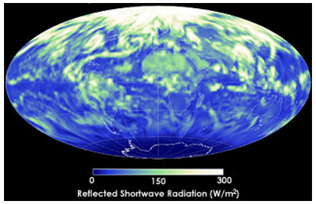


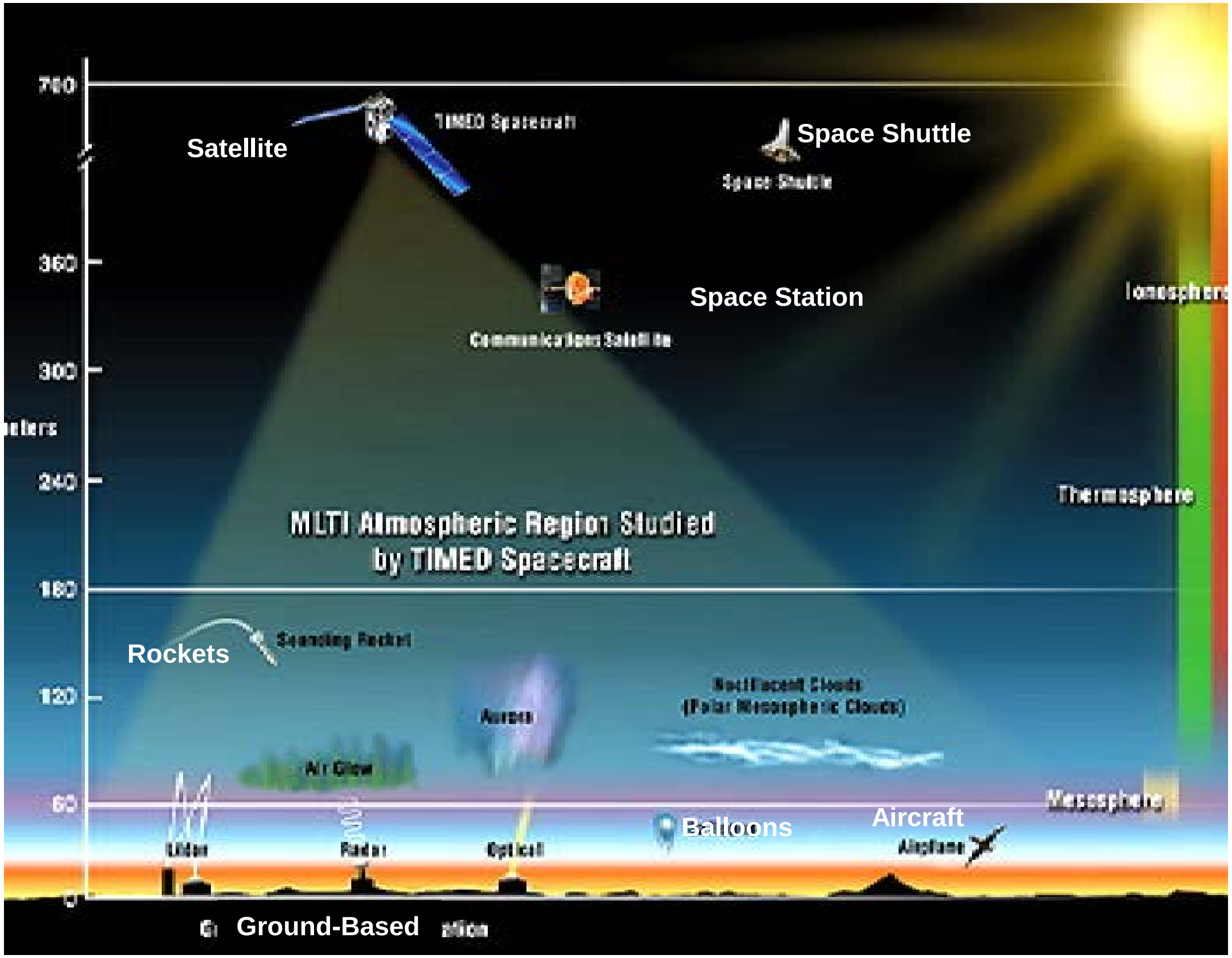
C. Limb Emission

D. Limb Scattering

View tangential to the planet's atmosphere
Vertical resolution in the atmosphere.

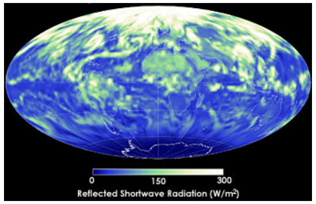
Classification: Platforms





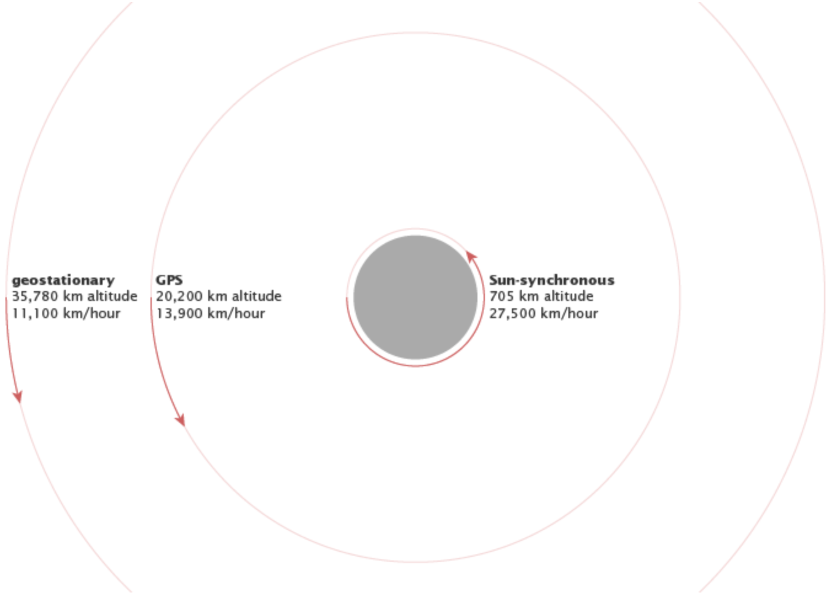
- **Satellite**
  - \+ global coverage
  - \- poor accessibility
  - \- expensive
- **Space Shuttle/Space Station**
  - \+ global coverage
  - \+ good accessibility
  - \- limited time coverage
- **Rockets** (up to 80 km)
  - \+ very high altitude
  - \- expensive, sporadic
- **Sonde/balloon/High Altitude Plattform** (up to 30 km)
  - \+ high altitude
  - \- logistically difficult
  - \- often expensive
- **Air-borne** (up to 15 km)
  - \+ fast moving, long distance
  - \- expensive, sporadic
- **Ground-based**
  - \+ continuous, high accuracy, easy accessibility
  - \- local measurement

Classification: ORBITS

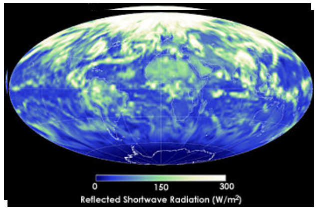


Different Earth orbits give satellites varying perspectives, each valuable for different reasons

Three types of Earth orbits: high Earth orbit, medium Earth orbit, and low Earth orbit (LEO)

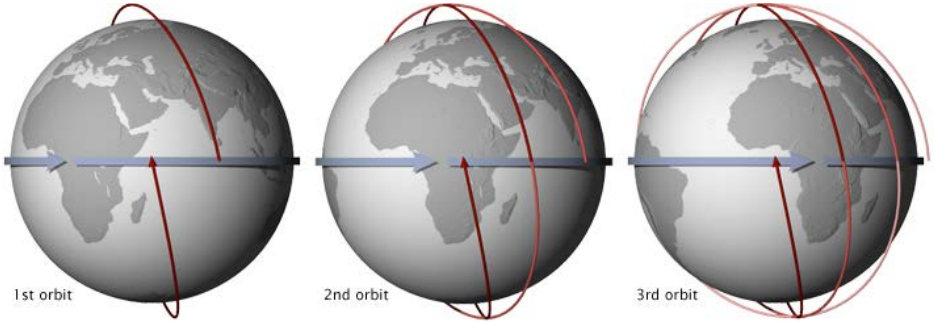


- **LEO: most science satellites (*Space shuttle or NASA A-train)***
- **Mid: navigation satellites**
- **High: weather and communication**



Low Earth Orbit (LEO)

- **Typical orbit altitudes of 400 to 1000 km and inclined at some angle to the Equator.**
- **LEO orbits are almost circular with orbit duration of ~100min (half in daylight and half in night time)**
- **Polar orbits: inclinations of nearly 90º and are often sun synchronous (measurements at same local times at equator).**
- **Non-polar orbits: more restricted range of latitudes and local time for viewing a latitude will vary with each orbit.**

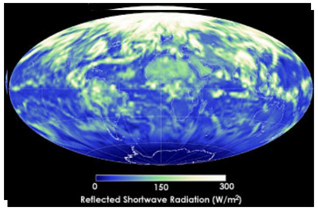


A Sun-synchronous orbit crosses over the equator at approximately the same local time each day (and night)

The inclinations of around 98º

The surface illumination angle will be nearly the same every time

Low Earth Orbit (LEO)



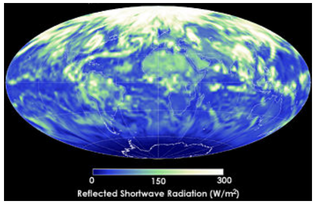
Advantages of LEO:

- **Requires low energy (cost) and allows larger payloads**
- **Good and quick accessibility**
- **Allows high latitudinal coverage and spatial resolution**
- **Limb viewing of the atmosphere possible**

Disadvantages of LEO:

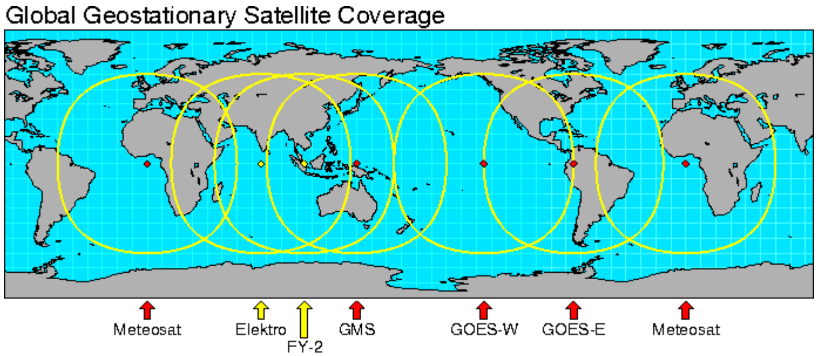
- **Still some atmospheric drag**
- **Low orbit repeat time,**
- **Satellite moves quickly wrt to surface (7-8 km/s)**
- **Larger orbit spacing at the equator.**
- **Continuous observation of a region requires constellation**

ORBITS II



Geostationary orbit (GEO)

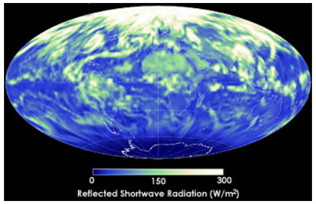
- **Orbit altitude of approx 36,000 km above the Equator (inclination angle of 0º).**
- **Satellite is "stationary" above a single point on the equator, rotating with a period of one sidereal day as for the Earth (23 hrs 56 mins 4s).**
- **Used for weather satellites such as METEOSAT, GEOS**
- **Not suited for high latitudes**



Highly elliptical and Lagrangian points

- **These offer high resolution views of particular areas and full disk views respectively. Not used very often because of launch costs and sampling limitations.**
- **Example: Molniya orbit maximises viewing time for high latitudes**

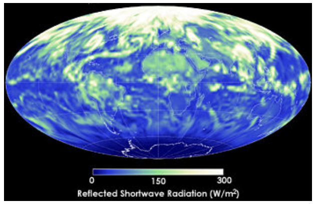
INSTRUMENTS



A generic instrument needs a

- **source of light (active or passive)**
- **collection system, a system to discriminate or select EM radiation**
- **detection system to detect EM radiation**
- **calibration system**

INSTRUMENTS



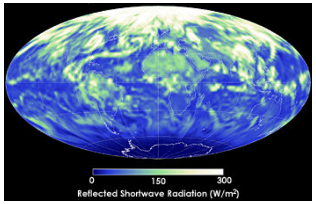
Passive instruments:

- **Spectrometers – resolve radiation from source as a function of wavelength**
- **Radiometers – integrate signal over a spectral wavelength passband (optical filter) to provide one value (rather than a spectrum)**
- **Imaging instruments: Arrays of detectors to build '2D images' of the scene e.g. the surface.**
- **Sounding instruments: Target physical properties of the atmosphere such as temperature or composition (typically vertically resolved)**

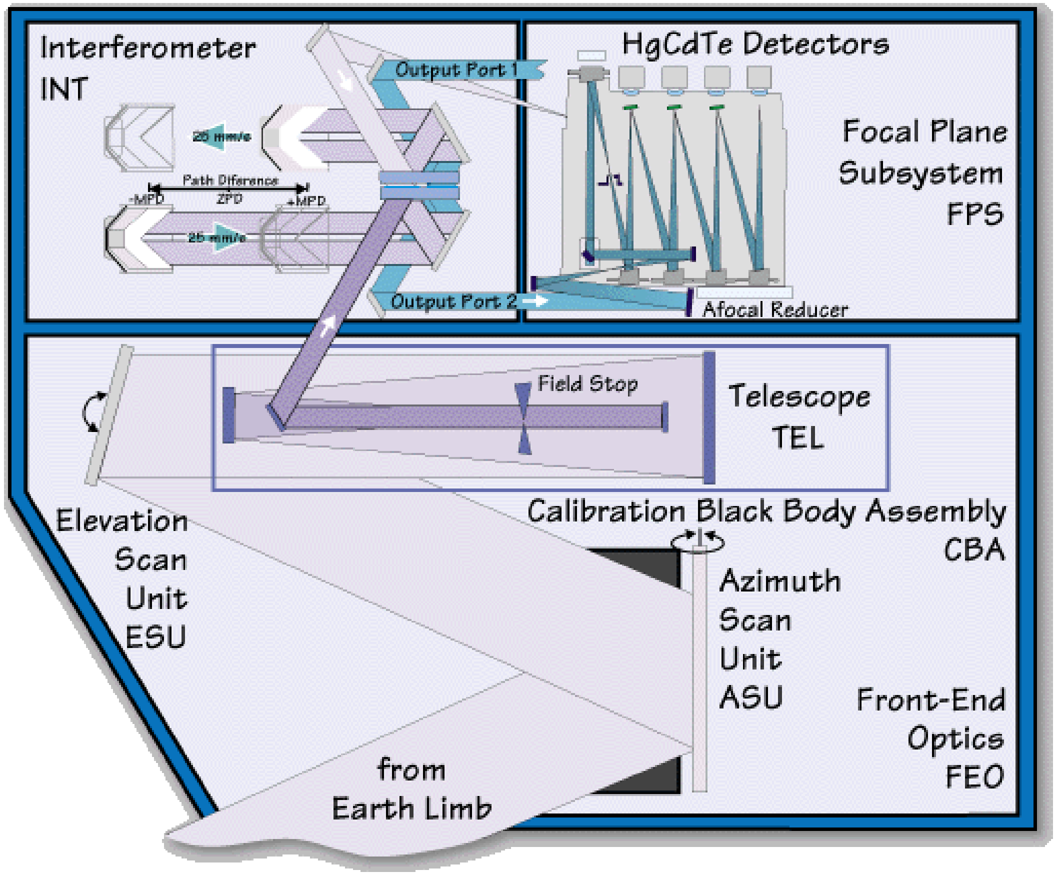
Active instruments

- **Lasers – narrow wavelength regions from infra-red to u/v.**
- **Radars/GPS – narrow wavelength regions in the microwave.**

SCHEMATIC VIEW OF THE MIPAS/ENVISAT INSTRUMENT:



MIPAS IS A FOURIER TRANSFORM SPECTROMETER – MICHELSON INTERFEROMETER



SOURCE = EARTH'S ATMOSPHERE

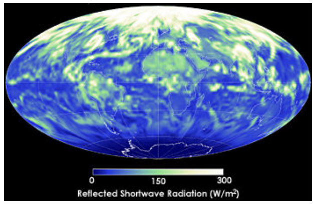
COLLECTOR = SCAN MIRROR + TELESCOPE

DISCRIMINATION = INTERFEROMETER

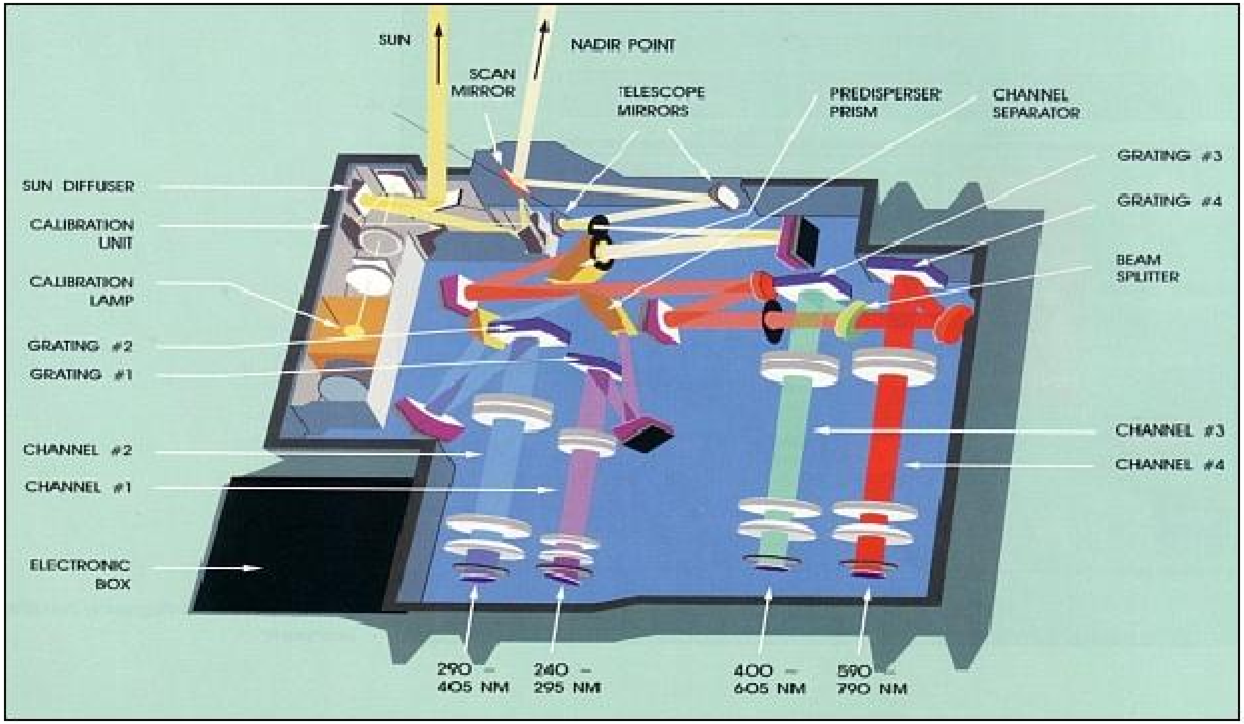
DETECTOR = COLD HgCdTe for MID-IR

CALIBRATION = ON-BOARD BLACK-BODY + COLD SPACE VIEW

SCHEMATIC VIEW OF THE GOME/ERS2 INSTRUMENT:



GOME IS A 4-CHANNEL GRATING SPECTROMETER



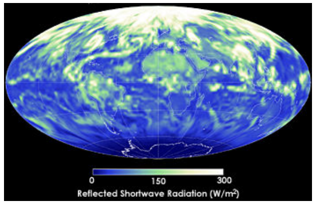
SOURCE = SUN

COLLECTOR = SCAN MIRROR + TELESCOPE

DISCRIMINATION = GRATING SPECTROMETER

DETECTOR = SI for UV/vis

CALIBRATION = LAMPS AND SUN(DIFFUSER)



PROBLEM SHEETS (50%)

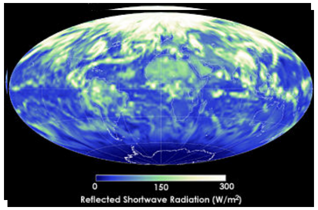
Problem sheet assessment:

- **1 Problem sheets (50%)**
- **Series of mainly mathematical questions related to the course**

- **Handed out Mid-March**
- **Deadline: 28 March**

- **Workshop: Lecture 7**

ESSAYS (50% OF FINAL MARK)



DEADLINE: 1 May (via Blackboard)

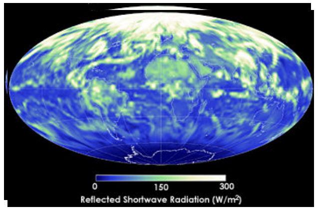
The subject of the essay (i.e. the challenge!): "To describe one remote sensing instrument in detail!"

The title of the essay: The name of the instrument.

Areas covered:

1) **An <u>introduction</u> to the instrument and its use in remote sensing**
2) **A <u>description of the remote sensing technique</u> it uses (passive r active, nadir, limb, orbit type, wavelength region, ….). Ideally with some theory or worked example, illustrating this.**
3) **A <u>description of the technical concept</u> of the instrument (e.g. optics, calibration, scanning…)**
4) **<u>Examples</u> of the measurements that the instrument has made/will make in the future.**
5) **The <u>importance of the measurements</u> (e.g. for climate change)**

ESSAYS (50% OF FINAL MARK)



Marks:

1. English.
2. Scientific content.
3. Reflection of understanding of the lectures.
4. Combination of material from a number of sources.
5. Good thinking/a real essay!

We know what's on the web. Don't simply reproduce it!

Guide length: 1500-2000 words

N.B. Introduction, Conclusions and References are required (including web references).