Opportunities for science teaching in Climate and Earth Observation

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Outline

1. 0-D Climate models and climate principles
2. How do we know climate is changing?
3. Earth Observation from space
4. How does EO work and what is it used for?

0-D Climate model (1): Solar power

- Solar power at the mean Sun-Earth distance: $S_0 = 1370$ W m^{-2}
  - Earth disk intercepting radiation: $A_I = \pi\,(6.371\ 10^6)^2 = 1.28\ 10^{14}$ m^2
  - Earth surface: $A_T = 4\,\pi\,(6.371\ 10^6)^2 = 5.10\ 10^{14}$ m^2
- Globally average power intercepted: $S_T = S_0 / 4 = 342.5$ W m^{-2}
  - Ignoring latitude and seasons!

0-D Climate model (2): Heating

- Absorption depth: d = 10^{-3} m (soil); 10,000 m (air); 20 m (water)
- Densities: ρ = 2,000 kg m^{-3} (soil); 1.2 kg m^{-3} (air); 1,000 kg m^{-3} (water)
- Mass heat capacity: C_p = 800 J kg^{-1} K^{-1} (soil); 1,000 J kg^{-1} K^{-1} (air); 4,200 J kg^{-1} K^{-1} (water)
- Heating rates, assuming all power is absorbed in only 1 medium:

  $H = (S_T / d) / (\rho\, C_p)$ $[(J\, s^{-1}\, m^{-3}) / (kg\, m^{-3}\, J\, kg^{-1}\, K^{-1})]$

  H = 0.21 K s^{-1} (soil); 2.8 10^{-5} K s^{-1} (air); 4 10^{-6} K s^{-1} (water) or
  H = 4,466 K day^{-1} (soil); 0.595 K day^{-1} (air); 0.085 K day^{-1} (water)

0-D Climate model (3): Cooling

- Earth albedo: $\alpha = 0.3 \rightarrow$ power absorbed $(1-\alpha)\, S_T = 239.75$ W m^{-2}

- Emissivity $\varepsilon = 0.6$ (soil), 0.9 (air), 0.95 (water)

- Thermal emission loss at 15 C: $I = \varepsilon\, \sigma\, T^4$ [W m^{-2} K^{-4} K^4]
  $I = \varepsilon \times 5.67\ 10^{-8} \times (273 + 15)^4 = 234$ W m^{-2} (soil), 351 W m^{-2} (air), 370 W m^{-2} (water)

- Steady state system: $C_p\, (dT/dt) = (1-\alpha)\, S_T - \varepsilon\, \sigma\, T^4 = 0$

- Steady state T *for* $\varepsilon = 0.9$: $T_s = [(1-\alpha)\, S_T / \varepsilon\, \sigma]^{1/4} = 258$ K = -15 C

0-D Climate model: Teaching opportunities

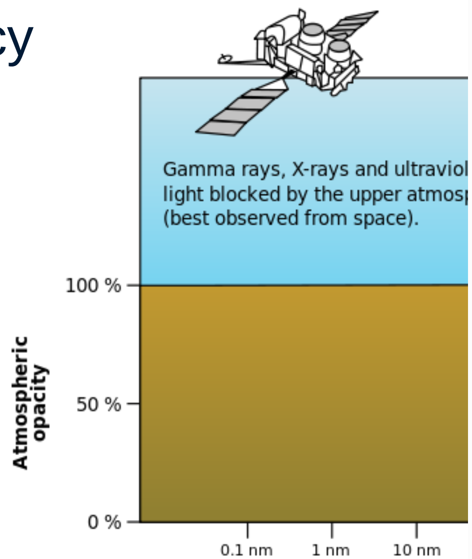
- Learn about the role of clouds, snow and ice in the climate system
- Find a place on Earth where the annual average temperature is -15 C
- Discuss the causes of the discrepancy between the steady state and the observed surface temperatures
- Study the sensitivity of these results to the values of the parameters, in particular albedo, and the various assumptions made
- Explore the roles of the atmosphere and ‘greenhouse’ gases in controlling climate
- Compare the power of the Sun to that of an electric stove, or to the electric power generation of the students’ country

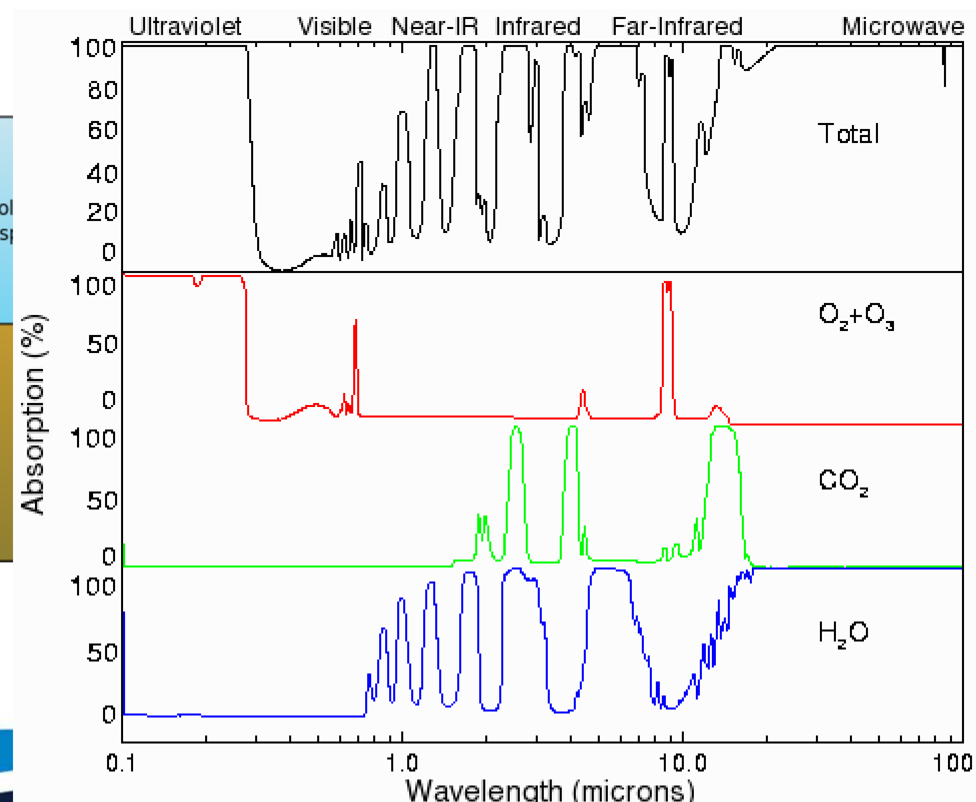
Climate principles

- The Earth is a thermal engine, heated by the Sun and cooled by thermal emission
- The bulk of the heating is occurring at the surface and in tropical areas but the cooling takes place at high altitude and everywhere
- Heat is transported vertically (convection) and from low to high latitudes (weather systems and ocean currents)
- Opportunities for teaching:
  - Describe how the solar irradiance varies with latitude and season
  - Describe how thermal cooling varies with latitude and season
  - Discuss the general circulation of the atmosphere (or of the oceans) in relation to these heating and cooling processes

Radiation transfer in the atmosphere (1)

- Atmospheric composition by volume:
  - Gases: N_2 (78%), O_2 (21%) , H_2O (0.25%), CO_2 (400 ppmv), O_3 (0.05 ppmv)
  - Particulates (aerosols): sea salt, dust, soot and ash, pollen and spores
  - Clouds and smoke plumes
- Transparency



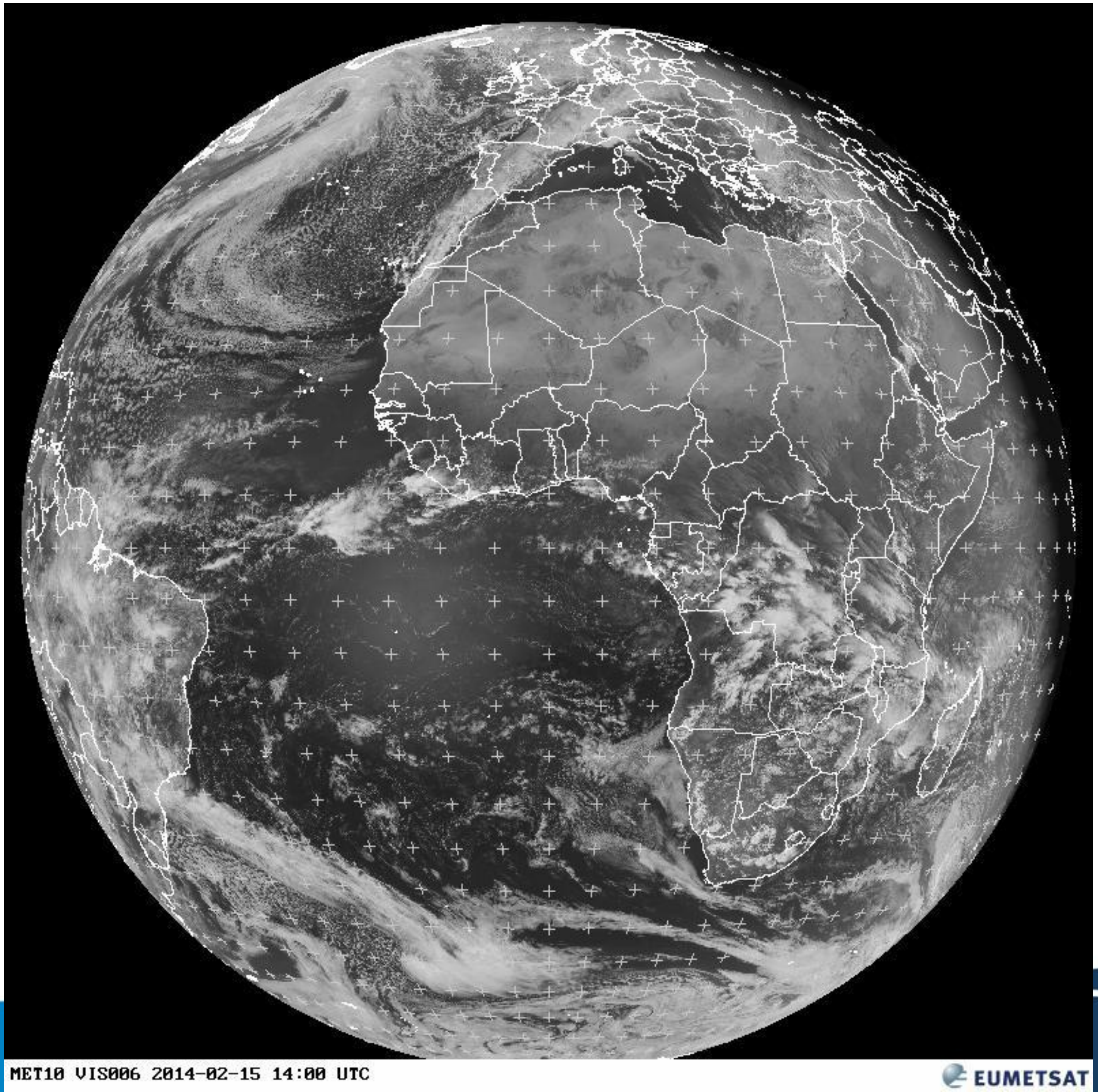


Source: Wikipedia, NASA

Source: http://randombio.com/co2.html

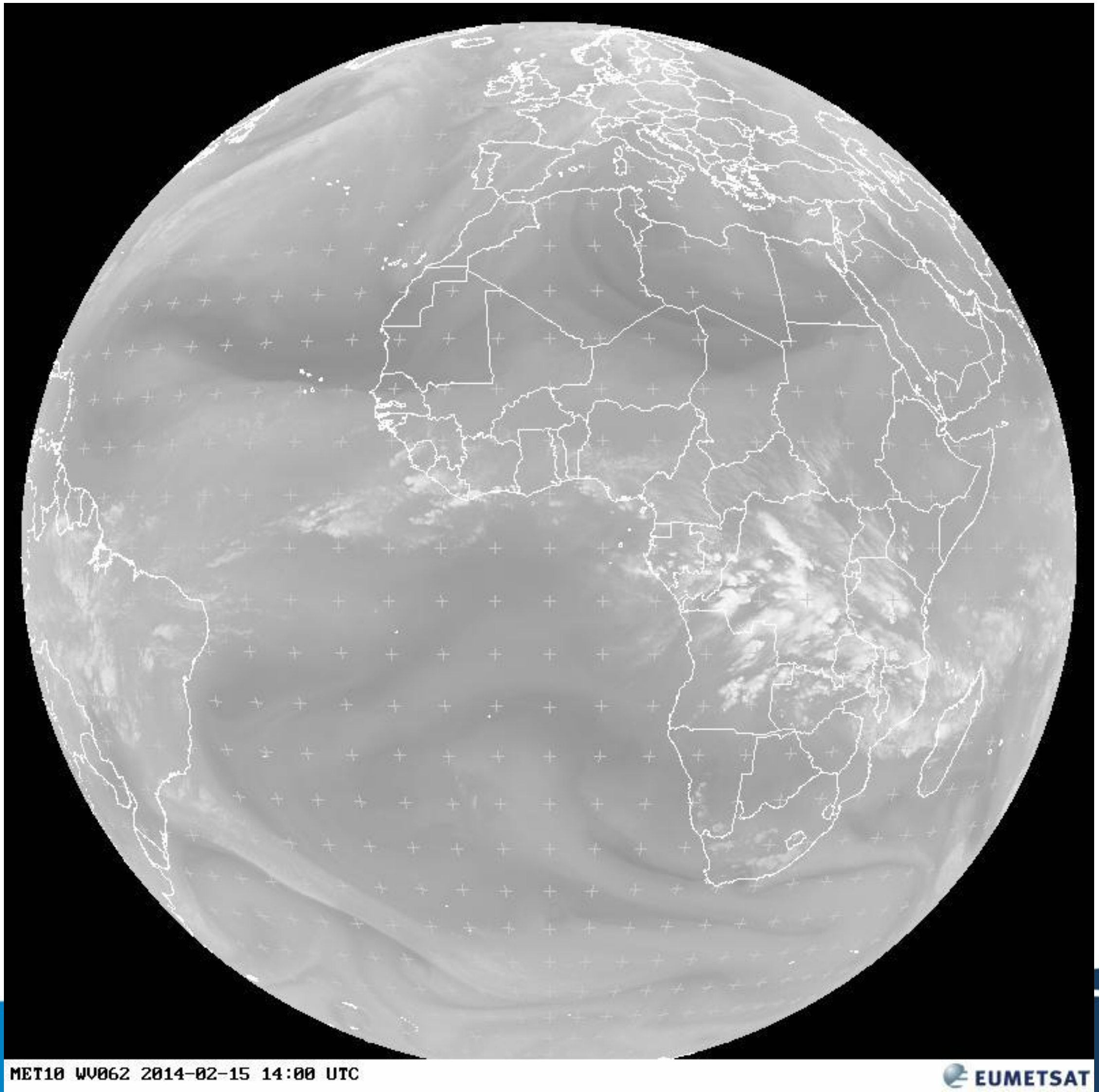
Radiation transfer in the atmosphere (2)

- The Earth observed from space at 0.6 µm:



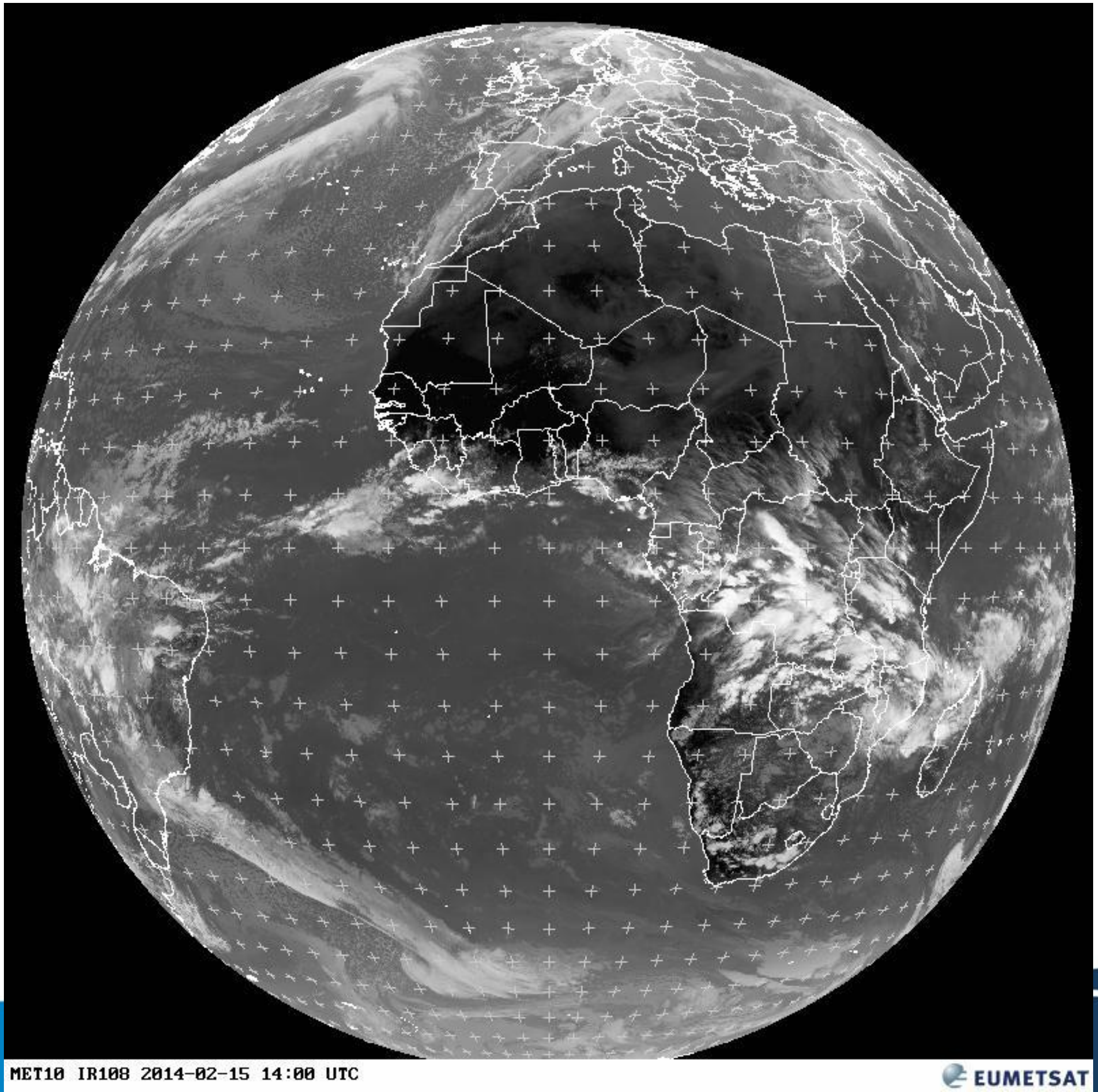
Radiation transfer in the atmosphere (3)

- The Earth observed from space at 6.2 µm:



Radiation transfer in the atmosphere (4)

- The Earth observed from space at 10.8 µm:



Radiation transfer: Teaching opportunities

- Why is clear sky blue at mid-day and orange to red at sunrise or sunset? Why is an overcast sky grey or whitish when cloudy?
- Investigate atmospheric optics phenomena like rainbow, glory, etc.
- What factors affect the transparency of the atmosphere?
- What would happen in the absence of atmospheric CO_2, or with twice as much of it?
- On a hazy day, how does the luminosity of the atmosphere change with azimuth?
- An absorbing layer is characterized by an optical depth (density) and optical properties (such as the single scattering albedo): discuss the feasibility of and constraints on retrieving these properties

How do we know climate is changing? (1)

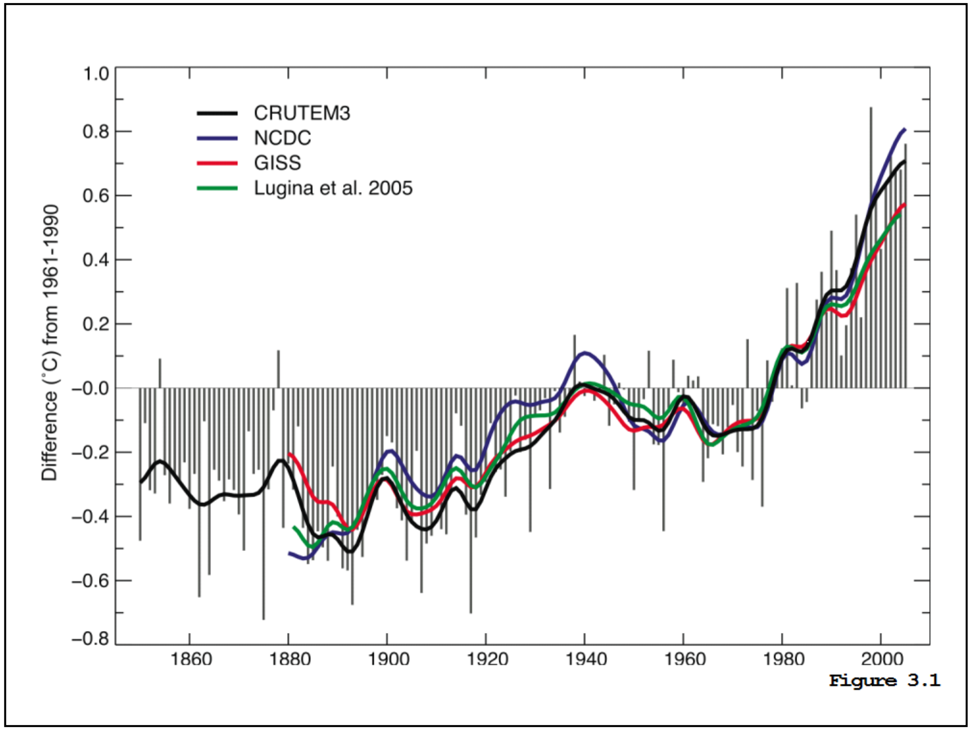
- Pre-instrumental period (up to 19^{th} century)
  - Artwork and historical accounts of earlier conditions
  - Paleoclimate methods (tree rings, varves, ^{14}C dating, etc.)

Source: http://www.philipcoppens.com/tassili.html

Source: http://www.edunetconnect.com/cat/timemachine/10000wa.html

How do we know climate is changing? (2)

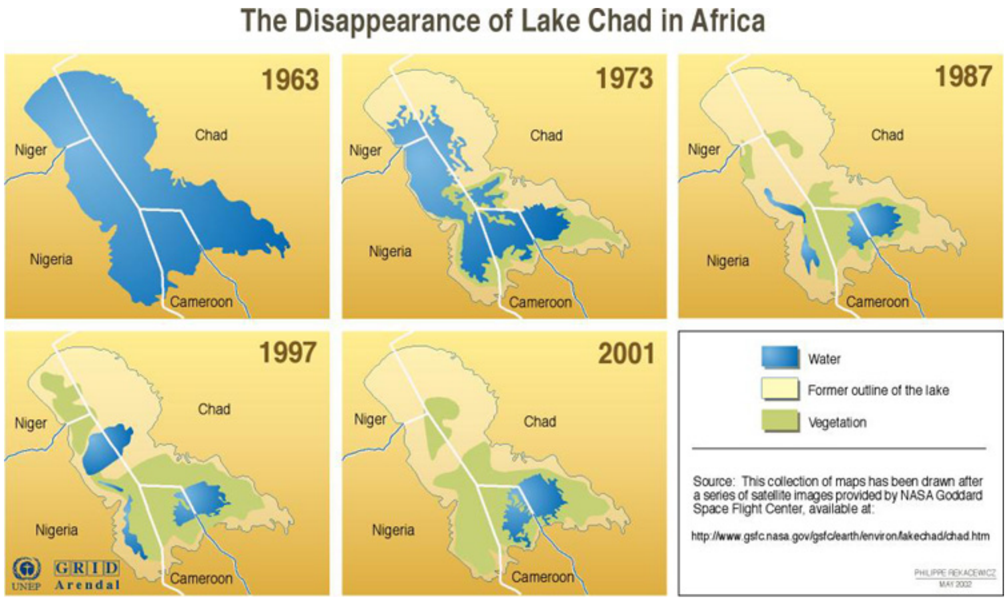
- Instrumental period (from 19th century onwards)
  - Changes in temperature, precipitation, pressure, storm occurrences, etc.
  - Changes in blooming dates, bird migrations, insect proliferation, etc.



Source: IPCC AR-4, Figure 3.1

How do we know climate is changing? (3)

- Satellite remote sensing period (from 1960 onwards)
  - TIROS (1960), NIMBUS (1964), ERTS/Landsat (1972), AVHRR (1978), and many others, especially during the last 20 years



Source: http://www.grida.no/climate/vitalafrica/english/14.htm (UNEP)

Climate change: Teaching opportunities

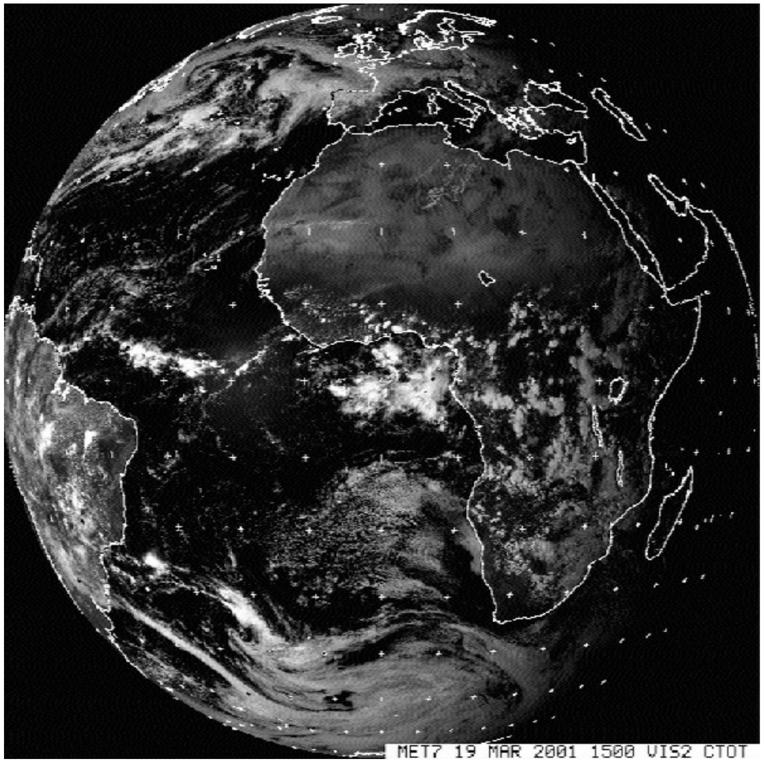
- Get, plot and analyse climatological data for your area
- Identify extreme events and find out whether their frequency is changing
- Talk with elderly people and ask about their perceptions of changes
- Compare how your own climate and its changes differ from those of other regions
- Learn about climate predictions for your area, for instance from the IPCC assessment reports
- Research the current and probable future impacts of climate changes in your area
- Discuss mitigation and adaptation strategies

What is remote sensing?

- Principles:
  - A signal is emitted or reflected by the target of interest
  - The signal must be influenced by the target in understandable ways, and preferably by properties of interest
  - The signal is transmitted but not modified by other processes
  - The signal is received (absorbed) by an instrument
  - A model of signal generation and transport must be available
  - A mathematical procedure must be available to invert this model against observations
- For satellite remote sensing
  - Signals are electromagnetic waves
  - Information is retrieved from spatial, temporal, spectral, directional or polarimetric variations

Spatial variability

12,600 km



EUMETSAT

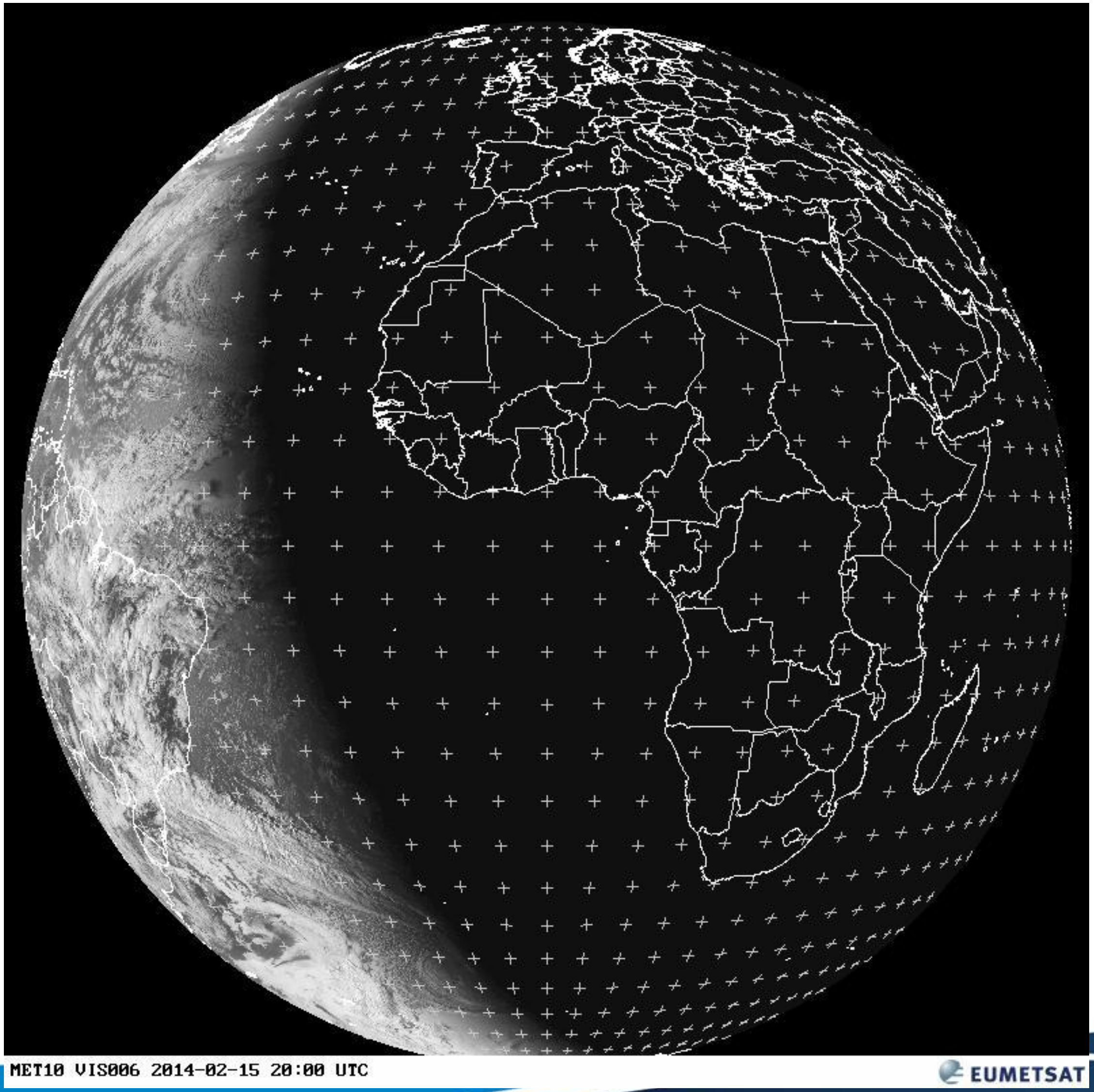
Meteosat 7
19 April 2001
λ: 0.4–1.0 µm
Resolution: 5 km

15 km

SPACE IMAGING

Ikonos
28 August 2004
λ: RGB composite
Resolution: 4 m

Temporal variability



Spectral variability

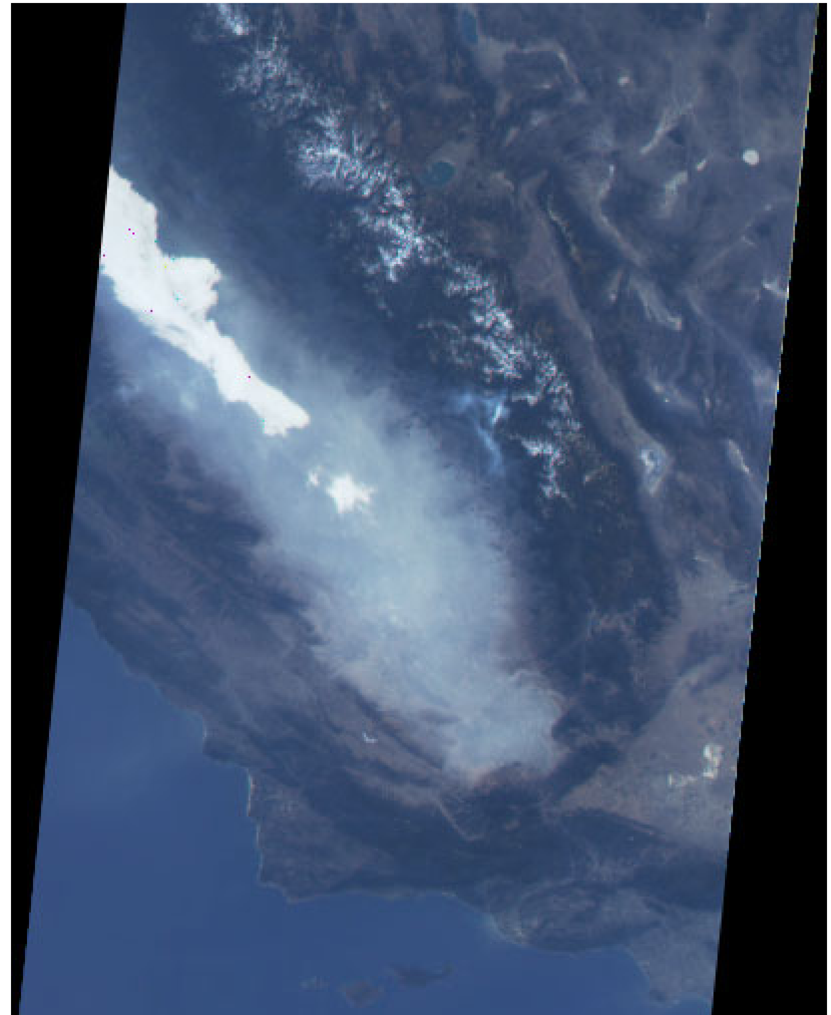
MERIS
14 July 2003
λ: RGB composite
Resolution: 300 m

Ref. figure: http://earth.esa.int/showcase/env/UK/TheChannel_MER_FR_Orbit07162_20030714.htm

Directional variability

MISR: 3 January 2001; λ: RGB composite; Resolution: 275 m, Location: San Joaquin Valley, CA

Nadir view



70° forward view

360 km

Ref. figure: http://www.spaceimaging.com/gallery/top10_2003/top10_7.htm

Satellite orbits

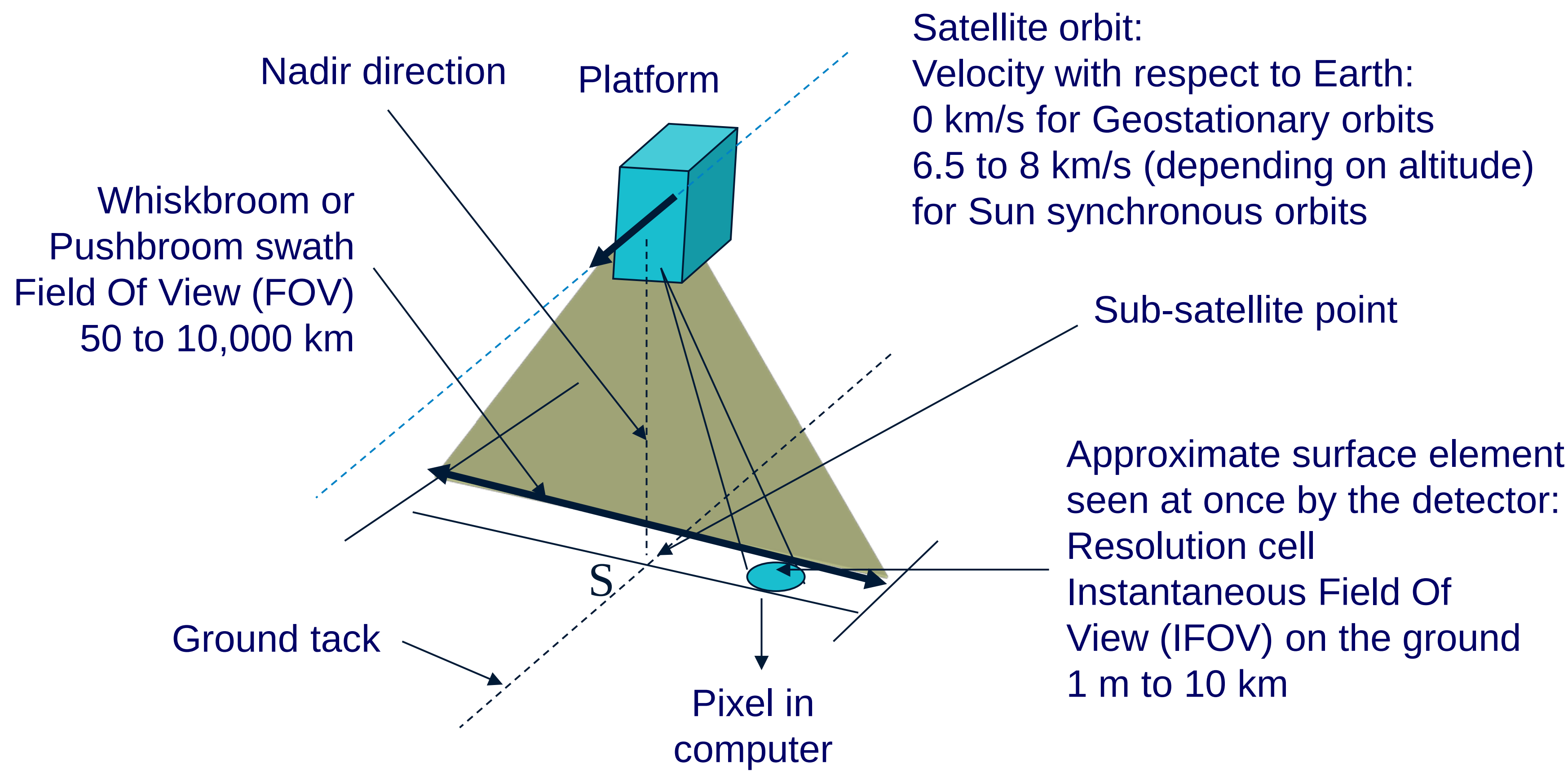
- Orbital plane is fixed with respect to stars; Earth rotates inside the orbit.
- Characteristics of circular orbits:

$$V = \sqrt{\frac{GM}{a_0 + h}} \qquad T = \frac{2\pi(a_0 + h)}{V}$$

with G = 6.67 10^{-11} m^3 kg^{-1} s^{-1}, M = 5.97219 10^{24} kg, a_0 = 6,371,000 m

- Types and altitudes *h* of orbits:
    - Low Earth Orbit (LEO, e.g., Shuttle, Space Station): *h* ~ 300 to 1,000 km
    - Polar orbit (Sun synchronous): *h* ~ 700 km, 98º inclination, *V* ~ 7 km/s
    - GPS satellites: *h* ~ 20,200 km, 55º inclination
    - Geostationary orbit: *h* ~ 36,000 km above Equator, 0º inclination, *V* ~ 3 km/s

Optical instrument terminology and operation



Instrument spatial resolution is the distance between the centers of successive measurements (ground sampling distance), not the size of the area observed.

After a slide originally prepared by François Becker (ISU)

Examples of remote sensing applications

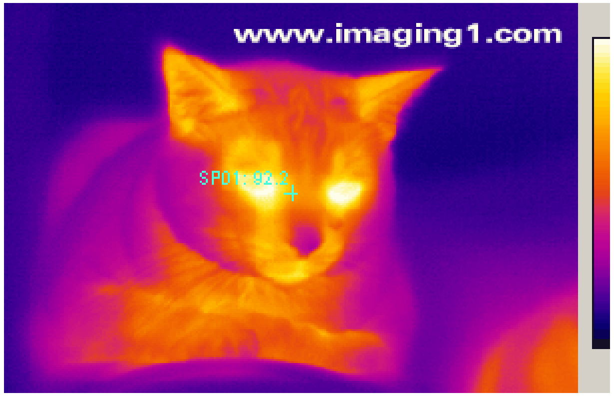
- Improving weather forecasts
- Monitoring agriculture, rangelands and forests
- Early warning for drought
- Determining land cover classes in support of planning
- Documenting urbanization and the growth of informal settlements
- Detecting algal blooms or invasive species
- Measuring air quality (pollutants, aerosols)
- Assessing damages after a disaster
- Managing fisheries, detecting oil spills

Data interpretation and model inversion (1)

- Instruments in space only measure radiation properties
- Mathematical models are setup to predict the measurements that will be acquired by the instrument as a function of the state of the target
- Addressing this *direct problem* is essential to make sure signals will carry useful information and to optimally design observing instruments
- In general, the state of the target is unknown but measurements are available: the model must be inverted against the data
- This *inverse problem* is complex because there are often many combinations of sate variables that could explain the measurements

Data interpretation and model inversion (2)

- Example: a thermal image, where each pixel corresponds to a measurement of the emission intensity in the infrared spectral domain:



- The radiation flux *I* (in W m^{-2}) is related to the temperature *T* (in K) of the target (the only state variable in this case) by the formula:

$$I = \sigma T^4$$

- If the model (*f*) is correct, the temperature of the target is given by:

$$T = [I/\sigma]^{1/4}$$

- However, if the target is not a perfect blackbody, it will emit with a spatially- and spectrally-variable emissivity *ε* and the model (*f*) becomes:

$$I = \varepsilon \sigma T^4$$

- Because the system now has two state variables (*ε* and *T*), there is an infinite number of couples of values that could satisfactorily 'explain' the measured intensity *I*: choose the *best* rather than the *true* solution

Remote sensing: Teaching opportunities

- Calculate the speed of Apollo spacecraft around the Moon (a_m = 1,737 km, h = 110 km, M = 7.3477 10^{22} kg)
- Take or get photographs in different weather conditions (e.g., sunny, cloudy, foggy, rainy) and discuss the processes that affect their quality
- For a given photograph, list objects, events or properties that
  - can unambiguously and directly be observed
  - could be deduced with a good probability
  - cannot logically be derived from it
- Hearing, smelling and tasting are other forms of remote sensing: discuss their advantages and drawbacks
- Discuss the feasibility of retrieving the ingredients and the recipe of a meal by only tasting or smelling the dish
- Mathematical analogue: the solution of an equation *y=f(x)* is given by the intersection of the graph of the function with the *x* axis *y=0*: discuss the feasibility of determining the function by only knowing the solutions

Any questions?