# Optical Remote Sensing: Basics, Data Processing, Applications

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# 1. Basics

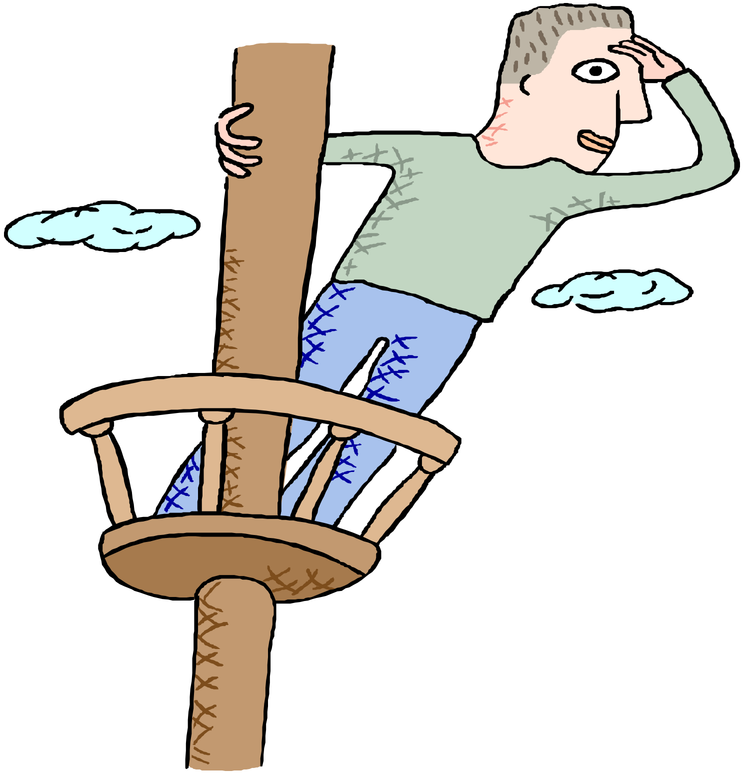
# 1.1 Formal Definitions of RS

- Measurement of spatially distributed data/information on some properties (spectral; spatial; physical) of an array of target points (pixels) within the sensed scene

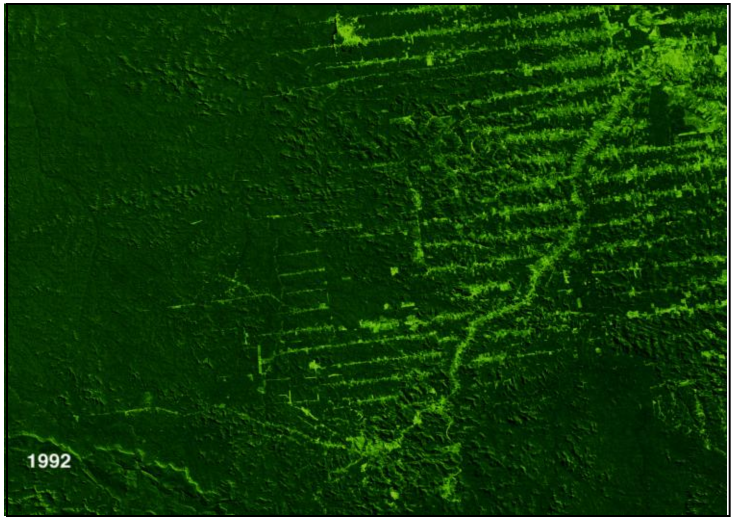
- Applying recording devices not in physical, intimate contact with the items under surveillance - but at a finite distance from the observed target (i.e. the spatial arrangement is preserved)

# Alternative Definition of RS

- Seeing what can’t be seen, then convincing someone that you’re right

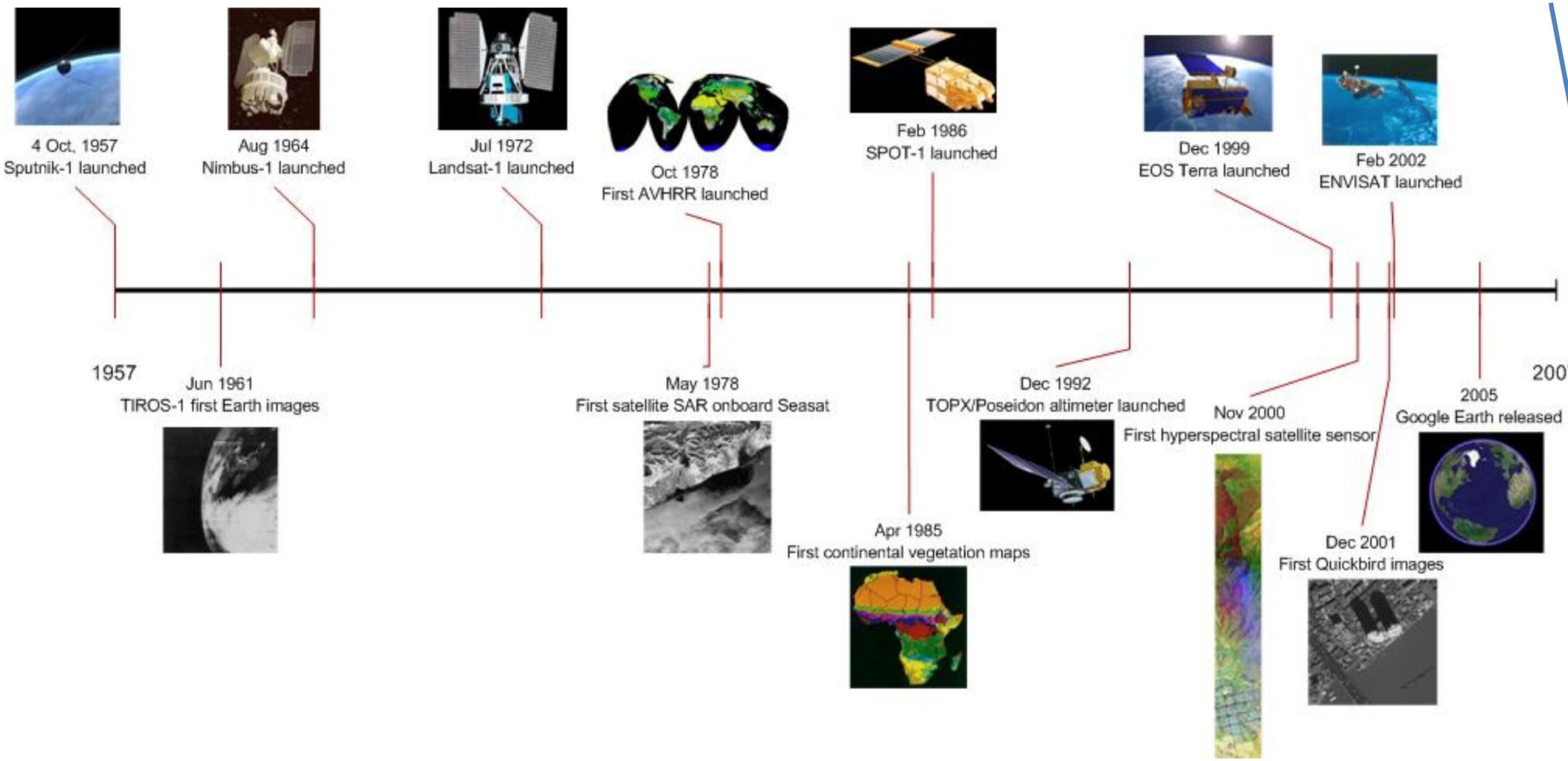


# Remote and Hostile Areas



# 1.2 Milestones of the Earth's Remote Sensing

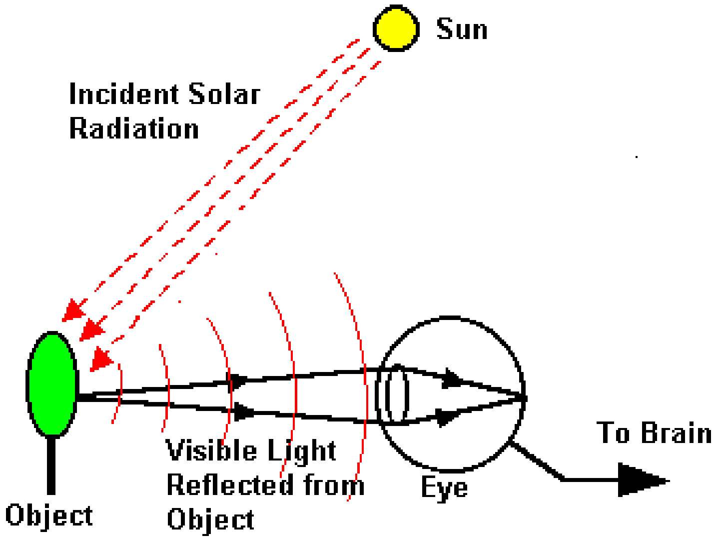
Landsat data is free 2009

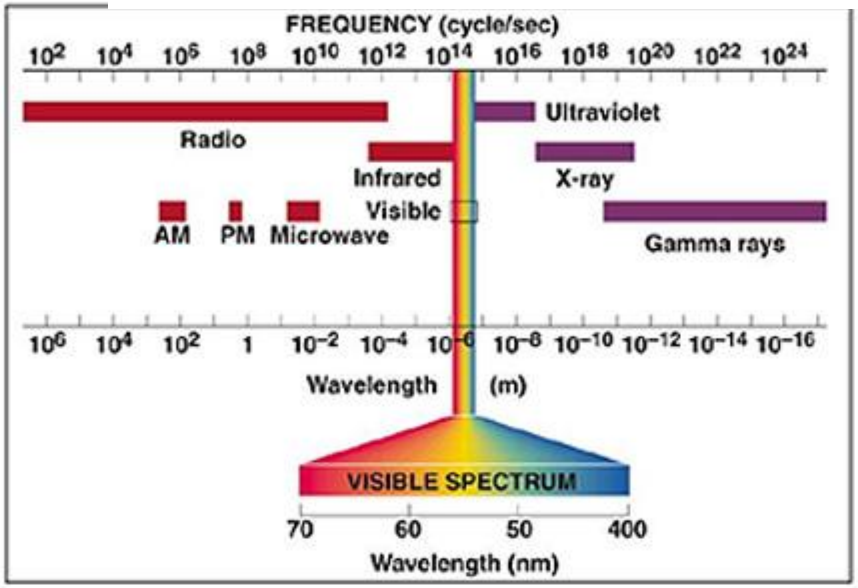


# NASA Operating Missions

# 1.3 Concept of Remote Sensing

- Human senses
  - Reflected  or issued visible light
  - sound waves
  - heat waves
  - chemical signals (smell)
- Electromagnetic Radiation
  - Solar spectrum
    - Visible
    - Infrared
    - Ultraviolet
  - Microwave

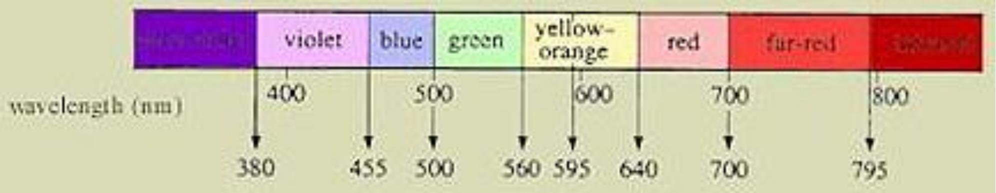


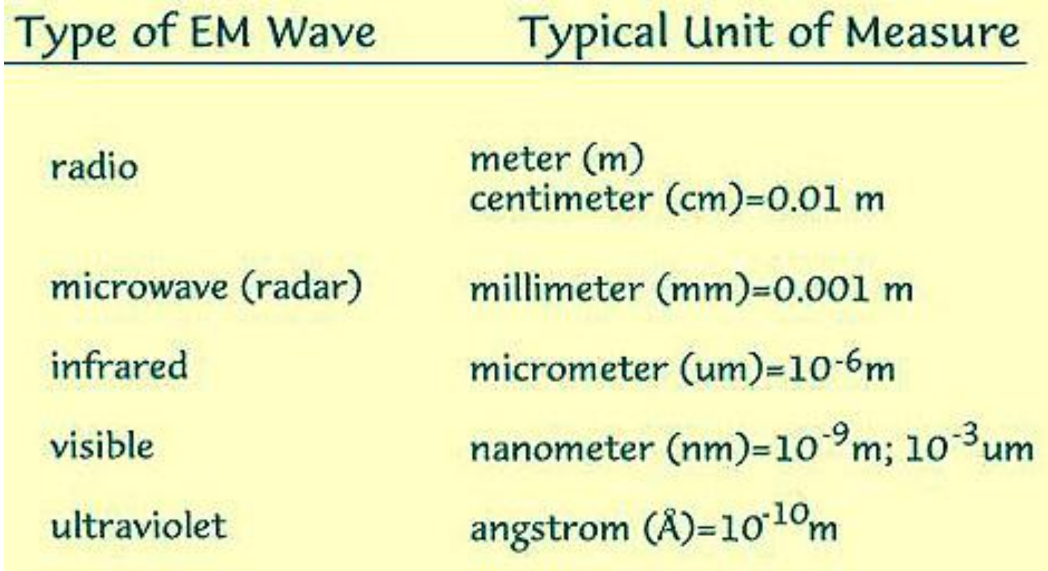


# Wave Ranges

- The human eye is said to be able to distinguish thousands of slightly different colors ~ at distinguishable 20000 color tints!
- Optical
  - Visible 0.4 - 0.7 µm

    (400 to 700 nm)
  - Infrared 0.7 - 1000 µm (or 1 mm),
    - reflected IR (0.7 - 4.0 µm)
    - photographic IR (0.7 - 0.9 µm)
    - thermal band
      - 3 - 5 µm
      - 8 - 14 µm
- Microwave 0.1 to 100 cm





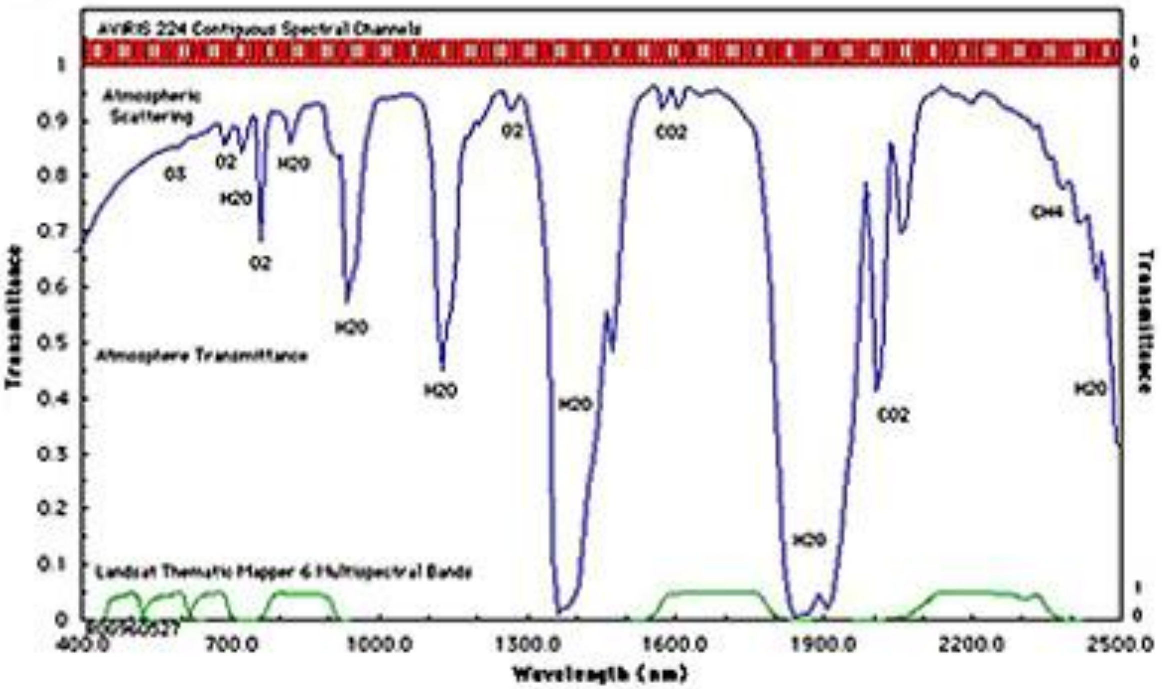
| Type of EM Wave | Typical Unit of Measure |
|---|---|
| radio | meter (m)<br>centimeter (cm)=0.01 m |
| microwave (radar) | millimeter (mm)=0.001 m |
| infrared | micrometer (um)=$10^{-6}$m |
| visible | nanometer (nm)=$10^{-9}$m; $10^{-3}$um |
| ultraviolet | angstrom (Å)=$10^{-10}$m |

# 1.4 Resolutions

- Spectral
- Radiometric
- Spatial
- Temporal

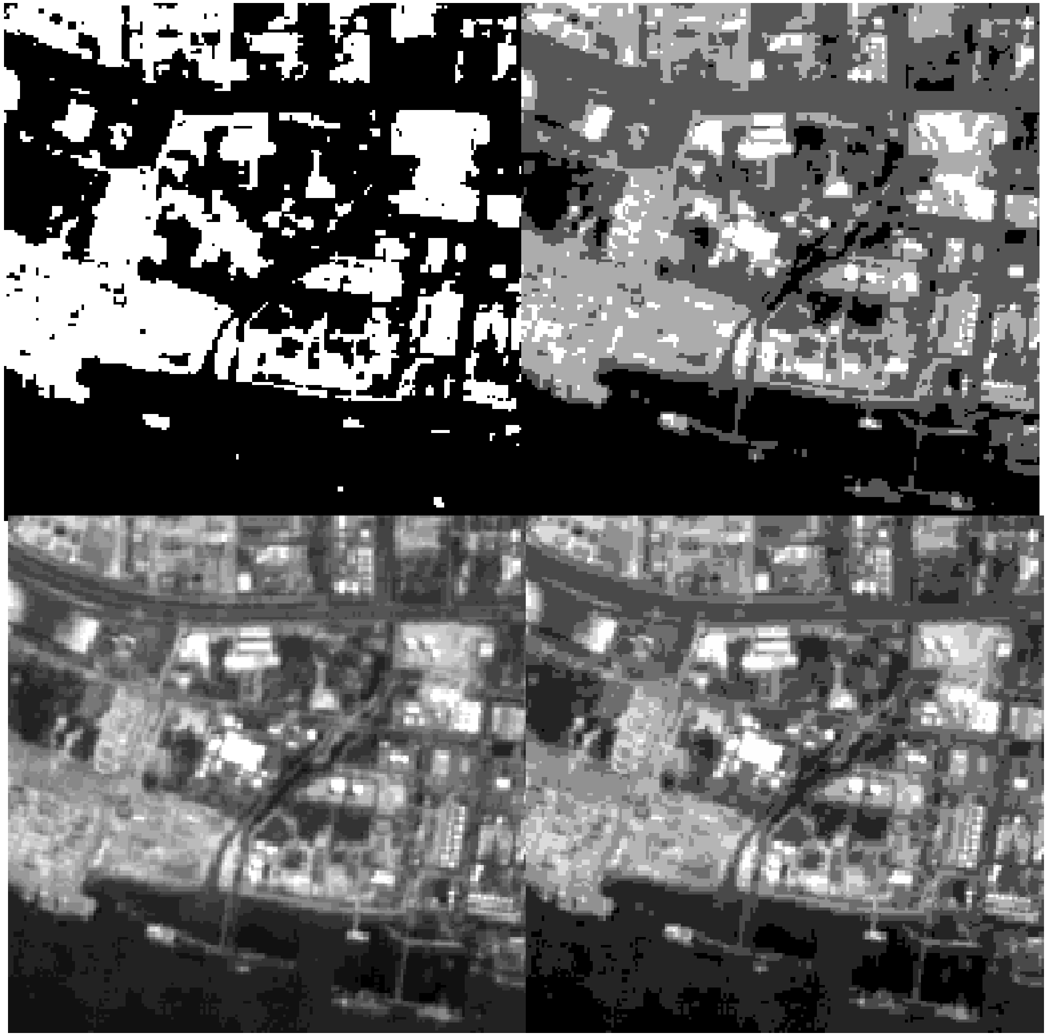
# 1.4.1 Spectral Resolution

- Number of wave bands
  - Multispectral
    - AVHRR, SPOT,MISR Landsat (4-7 bands)
  - Superspectral
    - MODIS (36 bands)
  - Hyperspectral
    - Hyperion (242 bands)



# 1.4.2 Radiometric Resolution

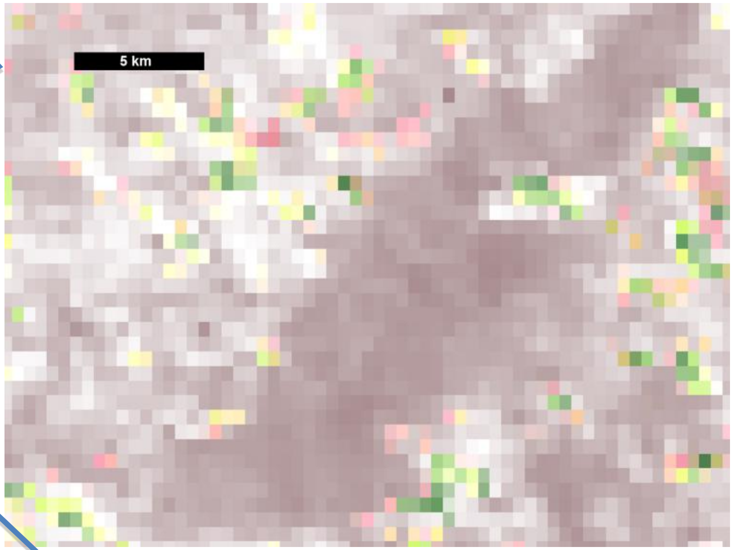
- $2^1$, $2^2$, $2^3$, and $2^4$, that is, 2(upper left), 4, 8, and 16 (lower right) gray levels, or quantized radiometric values
- Number of bits – sharpness
  - 8 bits 0-255
  - 10 bits 0-1023
  - 11 bits 0-2047



# 1.4.3 Spatial Resolution

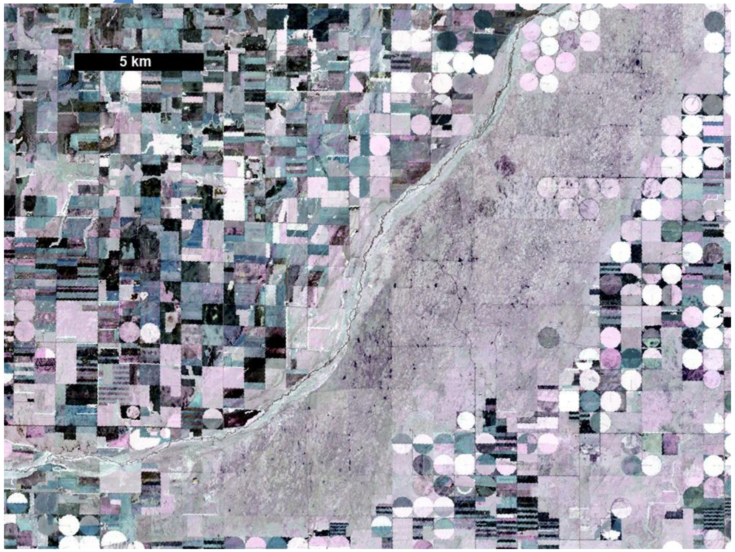
- Coarse (hundreds m)
- Moderate (tens m)
- High (m)

MODIS



Ikonos

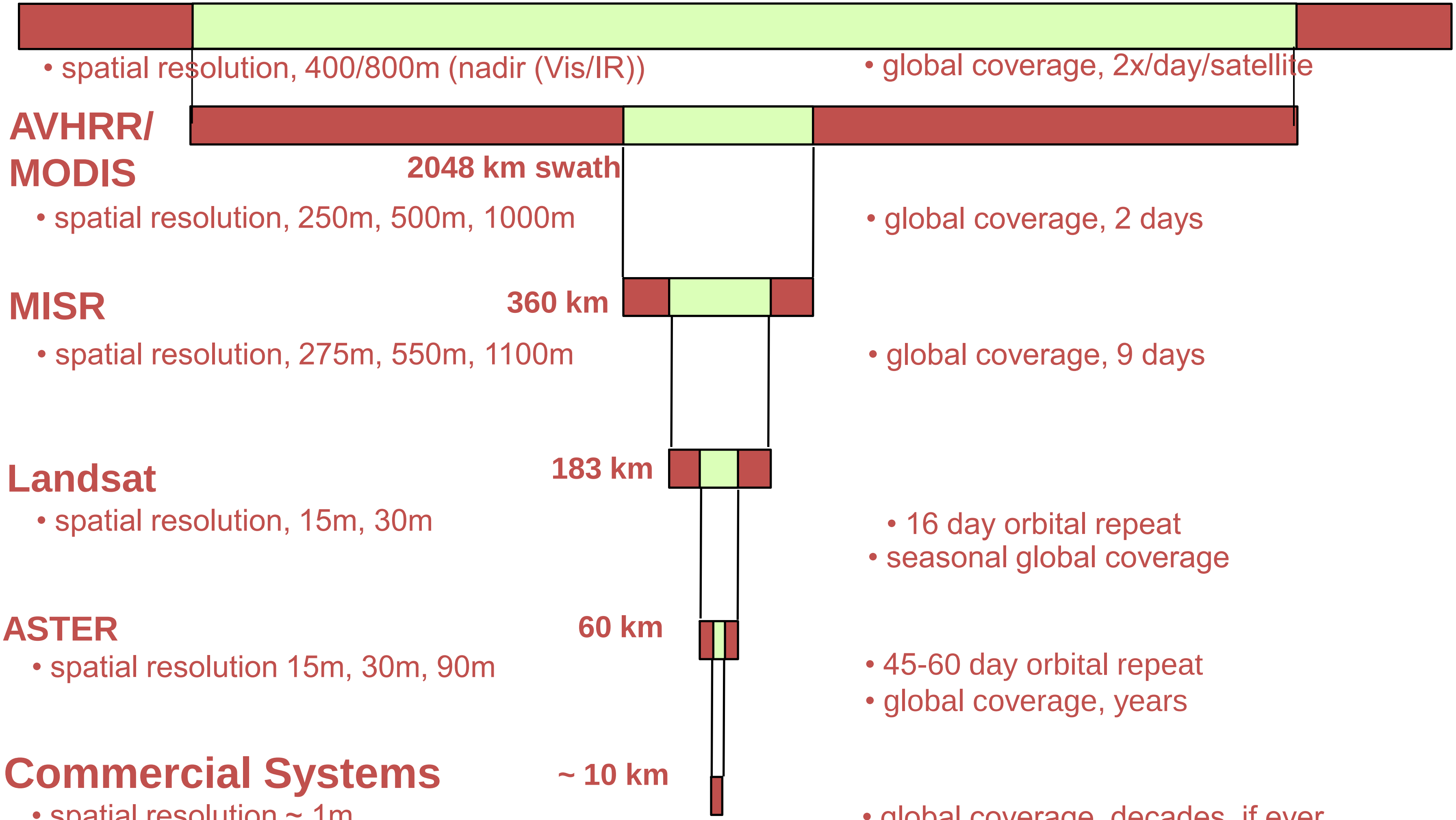
Landsat



# 1.4.4 Temporal Resolution

- Hourly (once or more times an hour)
  - Geostationary observations
- Daily (one or more orbits a day)
  - Observations from polar orbiters
- Bi-monthly (or more frequently)
  - Landsat-class observations
  - Revisit time depends on the altitude, swath, etc.
- Commonly, there is a tradeoff between temporal and spatial resolution

# Synergistic Use of Optical Remote Sensing



**VIIRS** 3300 km swath

- spatial resolution, 400/800m (nadir (Vis/IR))
- global coverage, 2x/day/satellite

**AVHRR/ MODIS** 2048 km swath

- spatial resolution, 250m, 500m, 1000m
- global coverage, 2 days

**MISR** 360 km

- spatial resolution, 275m, 550m, 1100m
- global coverage, 9 days

**Landsat** 183 km

- spatial resolution, 15m, 30m
- 16 day orbital repeat
- seasonal global coverage

**ASTER** 60 km

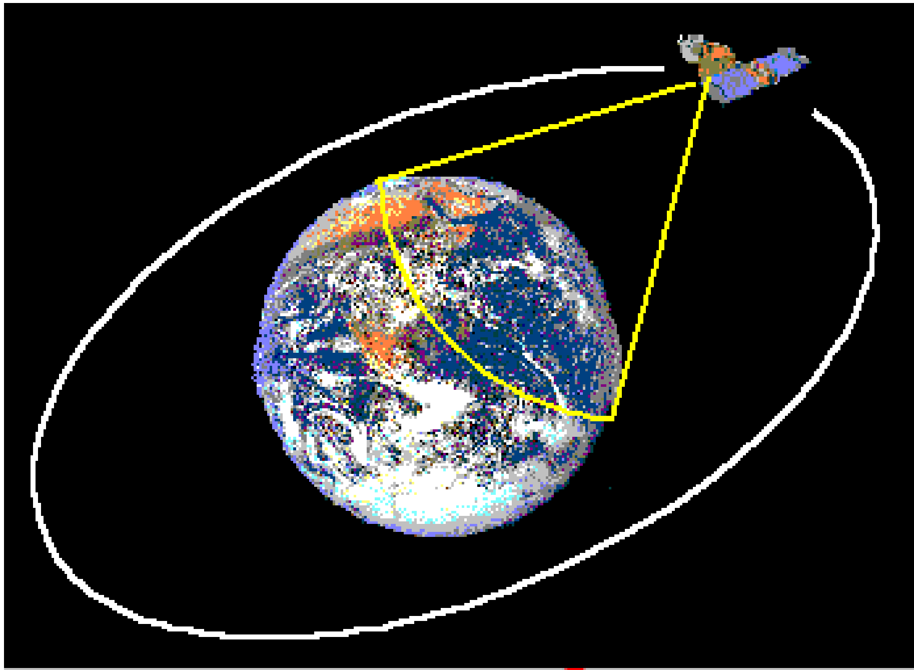
- spatial resolution 15m, 30m, 90m
- 45-60 day orbital repeat
- global coverage, years

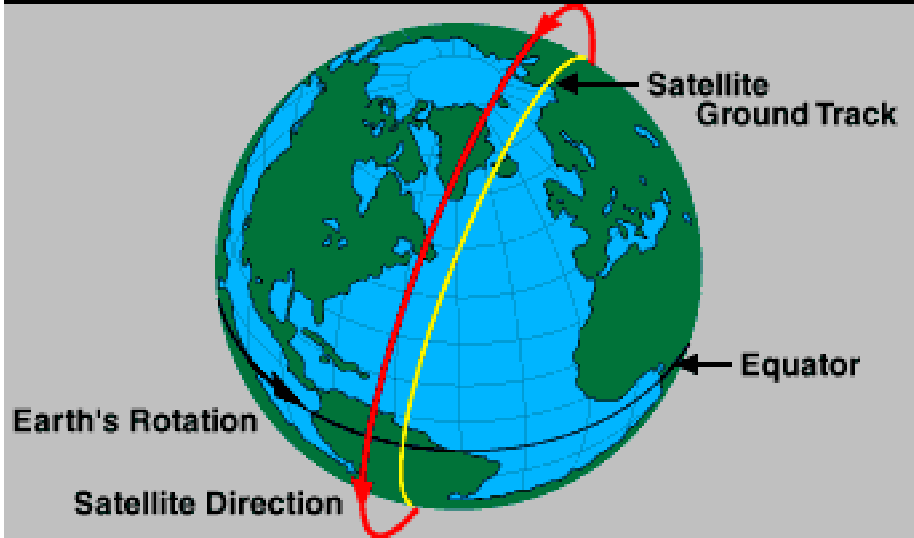
**Commercial Systems** ~ 10 km

- spatial resolution ~ 1m
- global coverage, decades, if ever

# 1.5 Satellite Orbits

- Geostationary Earth orbit (GEO)
  - appear stationary with respect to the earth surface
  - view the same area on the earth
  - located at a high altitude of 36,000 km
  - used by meteorological satellites
  - Coarse spatial resolution
- Low Earth Orbit (LEO) (Polar-orbiting, sun synchronous)
  - near-polar orbit, 700-800km altitude
  - always pass over a location at a given latitude at the same local solar time
  - the same solar illumination condition (except for seasonal variation)
  - Coarse to moderate to high spatial res.



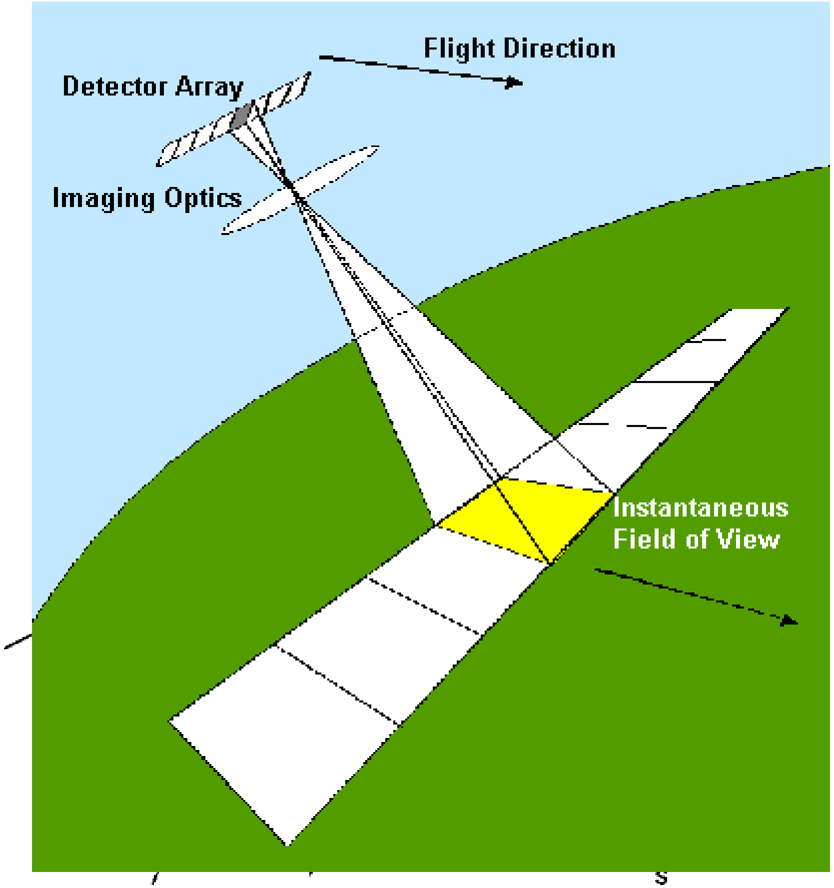


# Satellite Orbital Terms: Field of View, Swath, Footprint, Repeat Cycle

- A satellite follows a generally elliptical orbit around the earth. The time taken to complete one revolution of the orbit is called the orbital period.
- The satellite traces out a path on the earth surface - the ground track. As the earth below is rotating, the satellite traces out a different path on the ground in each subsequent cycle.
- The field of view controls the swath width of a satellite image. That width, in turn, depends on the optics of the observing telescope, on electronic sampling limits inherent to the sensor, and on the altitude of the sensor.
- The higher the satellite's orbit, the wider the swath width and the lower the spatial resolution.
- Both altitude and swath width determine the "footprint" of the sensed scene, i.e., its across track dimensions and the frequency of repeat coverage.
- Remote sensing satellites are often launched into special orbits such that the satellite repeats its path after a fixed time interval. This time interval is called the repeat cycle of the satellite.

# 1.6 Radiometers:
# Whisk Broom versus Pushbroom

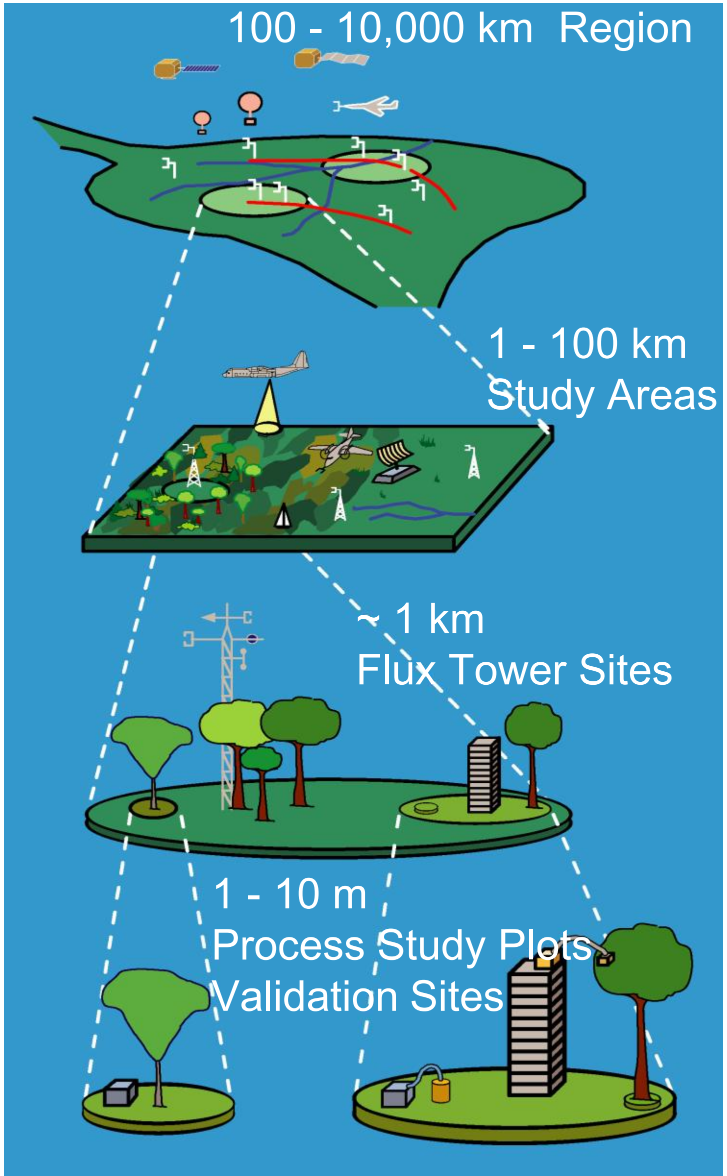
- The Landsat and AVHRR sensors are built in a “whisk broom” (across track) configuration. In a whisk broom sensor, a mirror scans across the satellite’s path, reflecting light into a single detector which collects data one pixel at a time. A whiskbroom has fewer detectors, so calibration is easier, and pixel-pixel radiometric uniformity is less complicated
- A “pushbroom” (along track) sensor (e.g. next Landsat - LDCM OLI, SPOT, Sentinel-2) consists of a line of sensors arranged perpendicular to the flight direction of the spacecraft. Different areas of the surface are imaged as the spacecraft flies forward.



Pushbroom sensors are generally lighter and less expensive than their whisk broom counterparts, and can gather more light because they look at a particular area for a longer time => SNR (longer dwell time) and no moving parts to break down

# 1.7 Tools: Remote Sensing as Part of the Observational System

- Remote sensing (satellite and airborne)
  - Optical
    - Passive
      - Coarse resolution multispectral (300m-2000m; e.g. AVHRR, MODIS, MISR, OLS)
      - Moderate resolution multispectral or hyperspectral (Landsat; Hyperion) (10-100m)
      - High resolution multispectral (0.5-5m; IKONOS, Orbview)
    - Active: Lidars
      - GLAS
  - Microwave
    - Passive
      - SSMR, SSMI
    - Active: Radars
      - Single frequency (L-, C-, or X-band)
      - Multiple/combined frequency
      - Single polarization (VV, or HH, or HV)
      - Multiple/combined polarization
- In situ systematic observations and field campaigns
- Modeling and integrative data analysis
- Data and information systems



# 2. Data Processing

# Processing Chain

- Geo-correction/orthorectification
- Calibration
    - Satellite data records (SDR), or time series of measured radiances
- Cloud (and Cloud Shadow) Detection/Masking/Screening
- Atmospheric Correction
- Derivation of bi-directional reflectances and brightness temperatures
    - Environmental Data Records (EDR), or time series of derived parameters
- Anisotropic Correction/Normalization
- Derivation of Essential Climate Variables
    - Essential Climate Variables (ECV) defined by both the Global Climate Observing System and Global Terrestrial Observing System

# 2.1 Geocorrection

- Registration: The alignment of one image to another image of the same area.
- Rectification: The alignment of an image to a map so that the image is planimetric, just like the map. Also known as georeferencing.
- Geocoding: A special case of rectification that includes scaling to a uniform, standard pixel grid.
- Orthorectification: Correction of the image, pixel-by-pixel, for topographic distortion.

Original (Tucson, AZ)

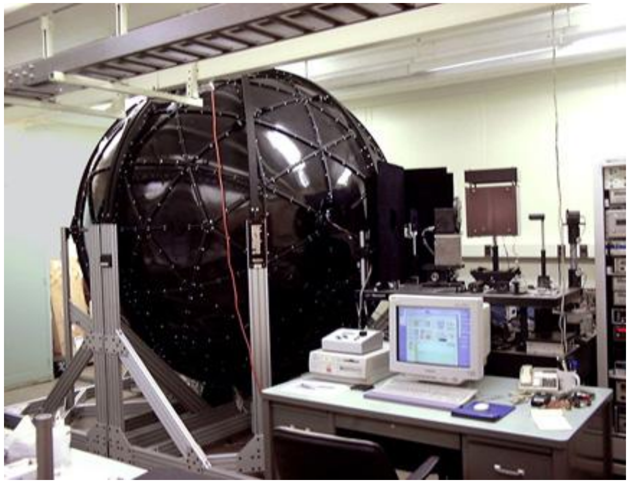
Rectified

# 2.2 Calibration

- Determine how well the response of a sensor (digital numbers DNs) representing the reflectance at a particular wavelength band conforms to the actual values of the parameters being measured.

$$L_b^s = \text{cal\_gain}_b \cdot \text{DN}_b + \text{cal\_offset}_b$$

- What is to be calibrated is essentially a system of electronics that produces a signal whose variations are usually a measure of intensity variations of incoming spectroradiance.
- Most instrument calibration is done indoors, i.e., in a laboratory setting. But most remote sensing instrument use is in the natural world, i.e. outdoors in the field.
- Calibration coefficients (to convert DNs to radiances) are supplied with data. The trouble is that often these coefficients are outdated because of sensor degradation. Then, a **post-launch correction to calibration coefficients** needs to be done.



# Normalized Difference Vegetation Index

- Ideally should be calculated from calibrated, normalized, atmospherically corrected surface reflectances (even better if they are corrected for viewing geometry)
  - Sometimes calculated from DN values
  - More often from calibrated radiances $L^s$
  - Less often from surface reflectances $\rho$
- Here we will consider top-of-atmosphere reflectances, $R_1$ is visible; $R_2$ is near-IR

$$NDVI = (R_2 - R_1)/(R_2 + R_1)$$

# Post-Launch Calibration Methods

- Invariable Targets
  - Bright
    - Bright Deserts
    - High cloud tops
    - Ice sheet
    - Glint on water
  - Dark
    - Water
    - Dark desert
- Global data
  - Averaged desert/rainforest
  - Averaged ocean (no glint)

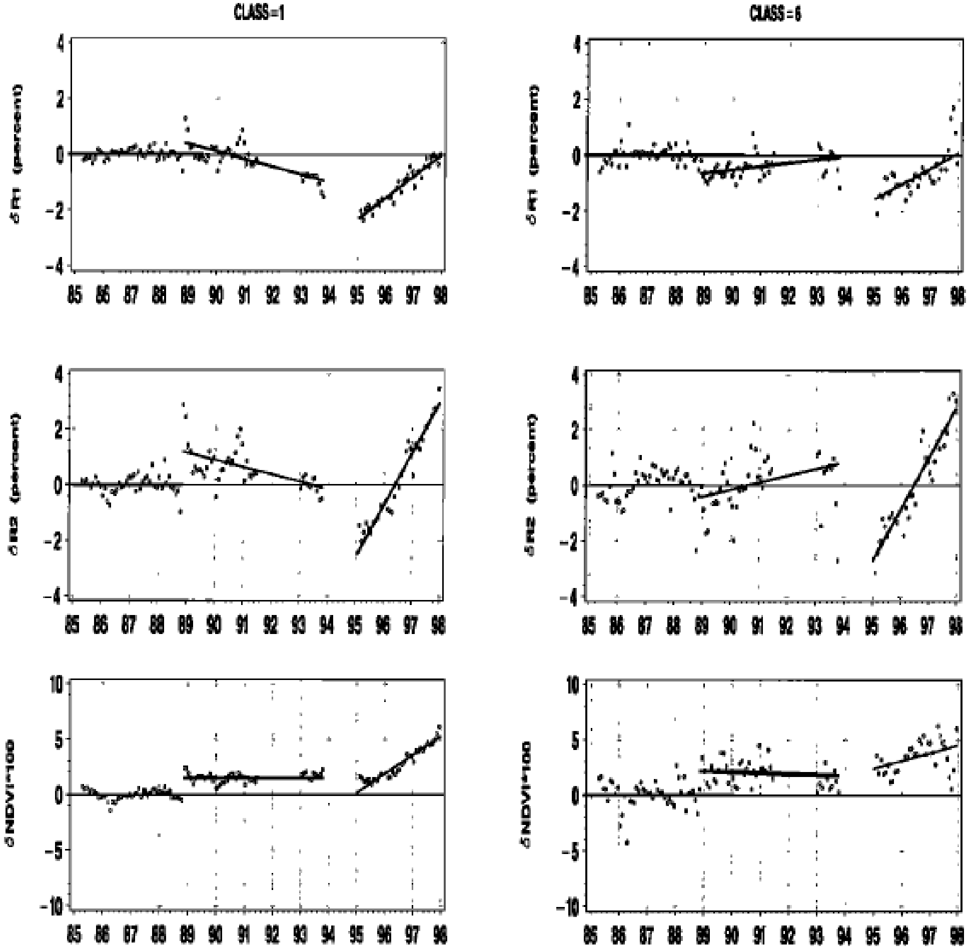
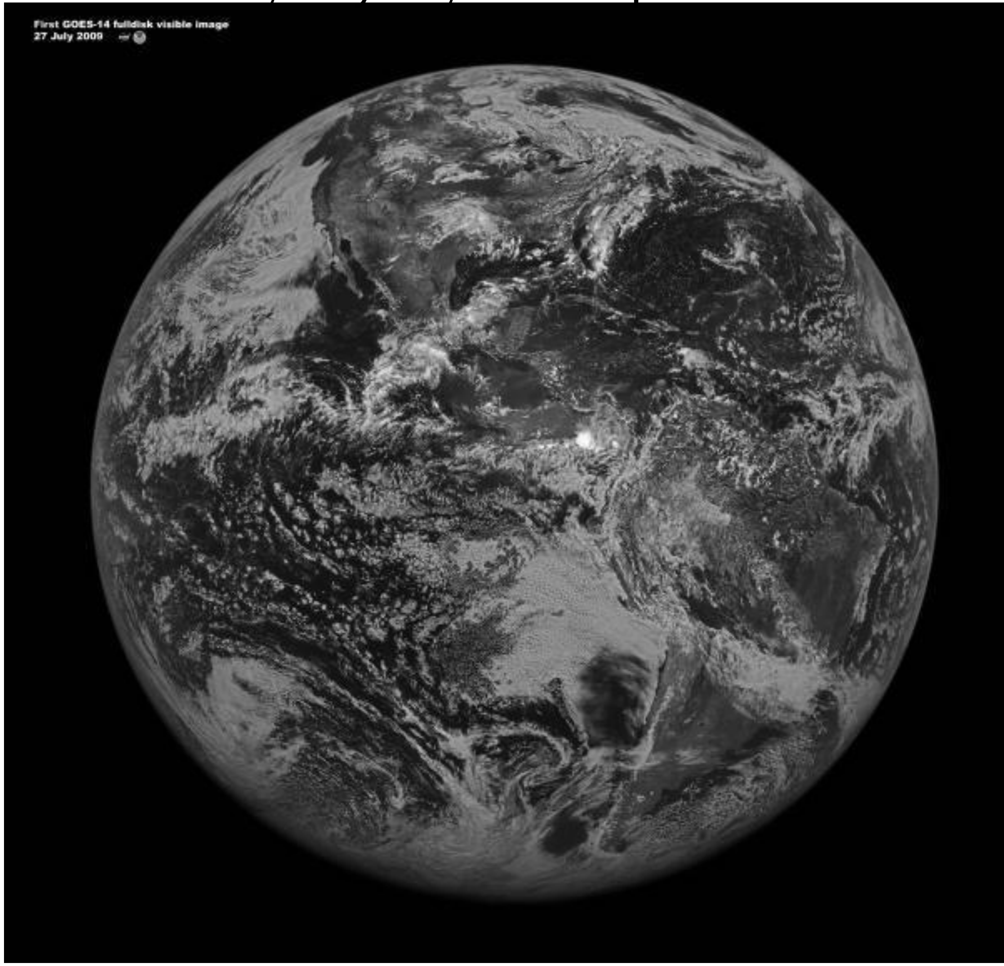


**Figure 6.** R1 (top), R2 (middle), and NDVI (bottom) anomalies (circles) corrected for SZA, with regression lines for each satellite for desert (left) and rain forest (right). Data for July 1991 to December 1992 and October 1993 to September 1994 are omitted.

# 2.3 Cloud Problem

- Cloudiness is the main obstacle for optical RS of land surface
- Cloud detection is probably THE most important (and maybe the most difficult) step in optical data processing

2009, July 27, at 2:00 p.m. EDT



GOES-14 Satellite First Full Disk Image (Visible)
1-km spatial resolution

# Cloud Detection Techniques

- Clouds are bright, cold, often non-uniform
- Spectral
  - Brightness values thresholding
  - Spectral ratios and differences thresholding
- Texture (spatial coherence)
- Continuity (temporal coherence)
- Compositing (assuming that at least one day is clear during the compositing period, e.g. a week or a month)
  - Darkest (selecting min visible reflectance)
  - Warmest (selecting max temperature)
  - Greenest (selecting max vegetation index) – most popular
- Compositing is a “quick and dirty” cloud screening and atmospheric correction but no control of the final result

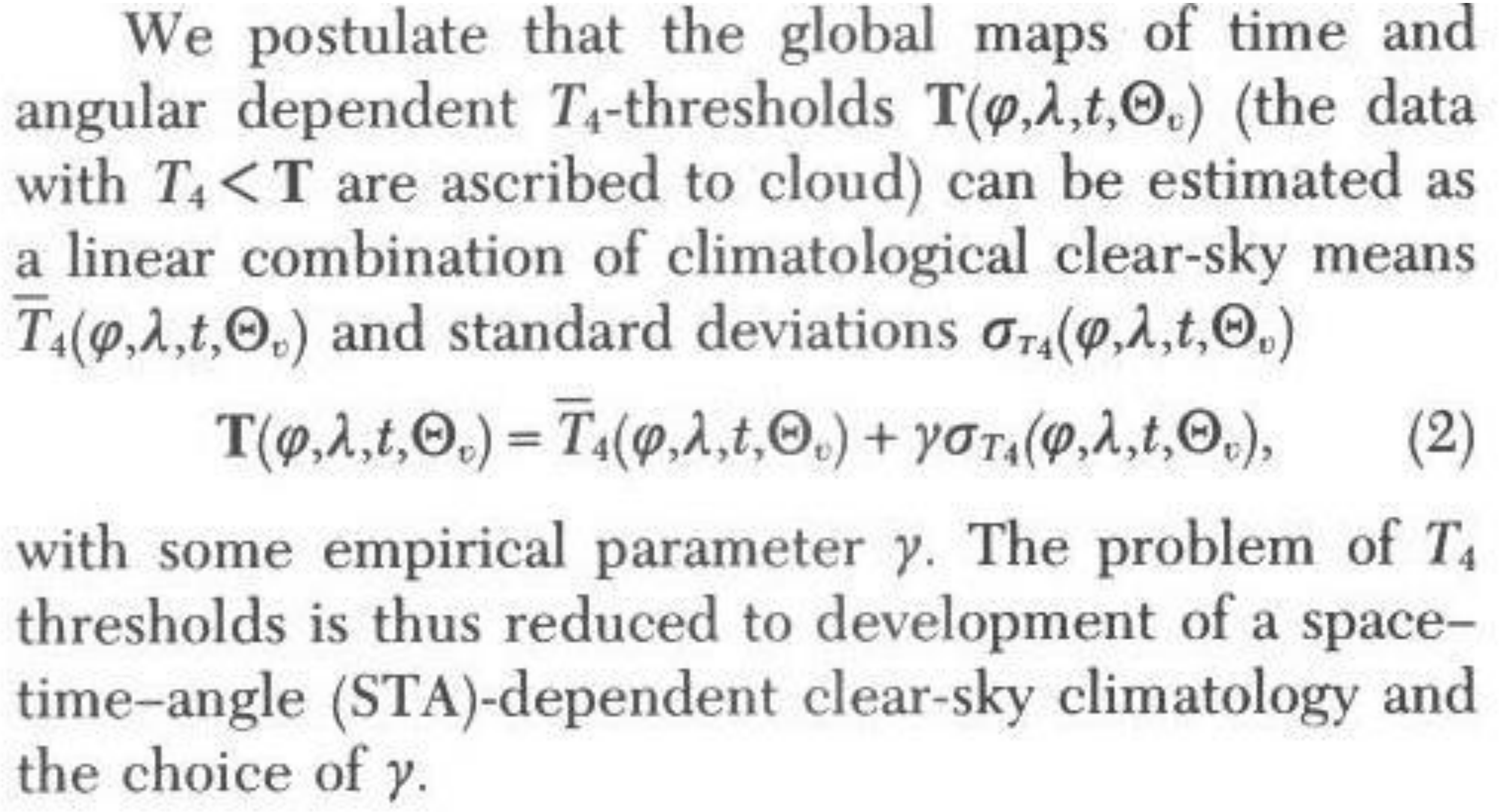
# Weekly Composites in the NOAA Global Vegetation Index Dataset collected operationally at NOAA/NESDIS

Good for agricultural monitoring

- Many areas in NDVI images are still cloudy
- How to check? Hint: look at the thermal image

# On the Importance of Using Thermal Data in NDVI Studies

## Developing Thermal Thresholds for Detecting Residual Cloud



We postulate that the global maps of time and angular dependent $T_4$-thresholds $\mathbf{T}(\varphi,\lambda,t,\Theta_v)$ (the data with $T_4 < \mathbf{T}$ are ascribed to cloud) can be estimated as a linear combination of climatological clear-sky means $\overline{T}_4(\varphi,\lambda,t,\Theta_v)$ and standard deviations $\sigma_{T4}(\varphi,\lambda,t,\Theta_v)$

$$\mathbf{T}(\varphi,\lambda,t,\Theta_v) = \overline{T}_4(\varphi,\lambda,t,\Theta_v) + \gamma\sigma_{T4}(\varphi,\lambda,t,\Theta_v), \qquad (2)$$

with some empirical parameter $\gamma$. The problem of $T_4$ thresholds is thus reduced to development of a space–time–angle (STA)-dependent clear-sky climatology and the choice of $\gamma$.

Gutman, G., A. Ignatov and S. Olson, 1994: Towards better quality of AVHRR composite images over land: Reduction of cloud contamination. Remote Sens. Environment, 50, 134-148.

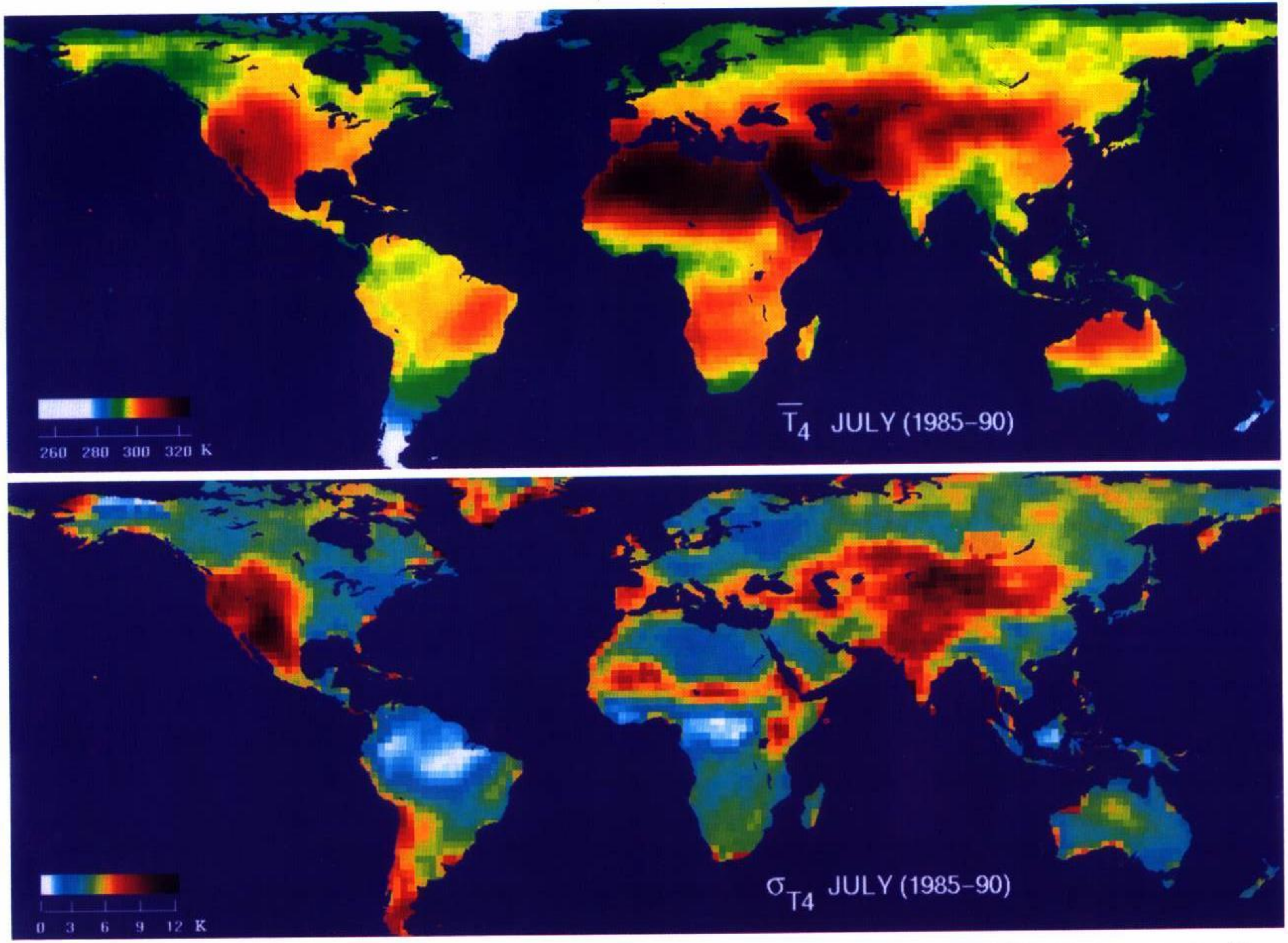
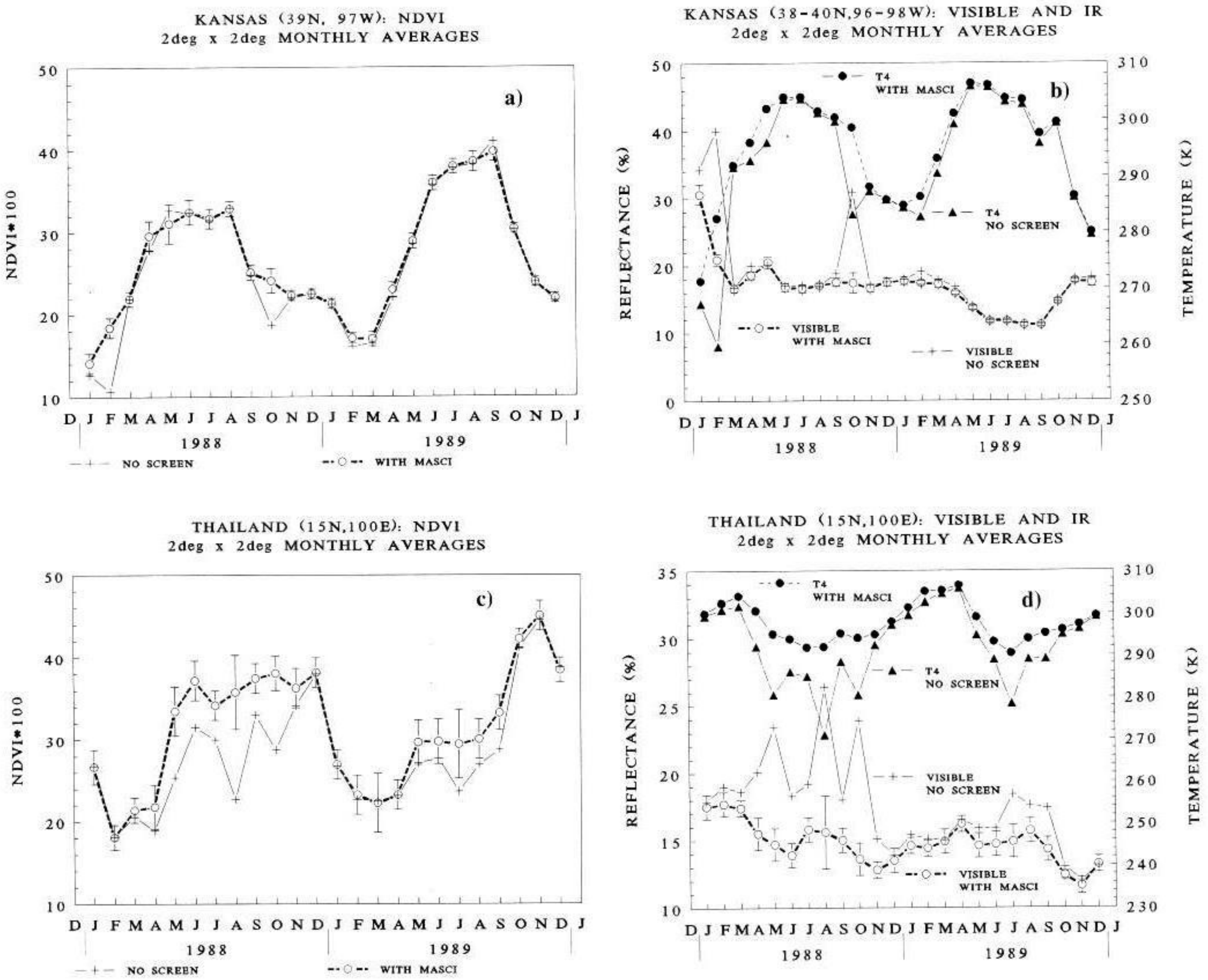


*Figure 5.* Global July maps of clear-sky background of $\overline{T}_4$ (top) and $\sigma_{T4}$ (bottom) for nadir viewing bin based on 6-year (1985–1990) time series of weekly composite images for each 2° × 2° land surface areas. $\sigma_{T4}$ accounts for spatiotemporal (intramonthly and interannual) variability within each 2° × 2° area.


KANSAS (39N, 97W): NDVI
2deg x 2deg MONTHLY AVERAGES

KANSAS (38-40N,96-98W): VISIBLE AND IR
2deg x 2deg MONTHLY AVERAGES

THAILAND (15N,100E): NDVI
2deg x 2deg MONTHLY AVERAGES

THAILAND (15N,100E): VISIBLE AND IR
2deg x 2deg MONTHLY AVERAGES

*Figure 7.* Monthly mean NDVI, visible reflectances, and brightness temperatures derived from the data in the backscatter viewing bin for Kansas and Thailand with (circles) and without (crosses) MASCI application.

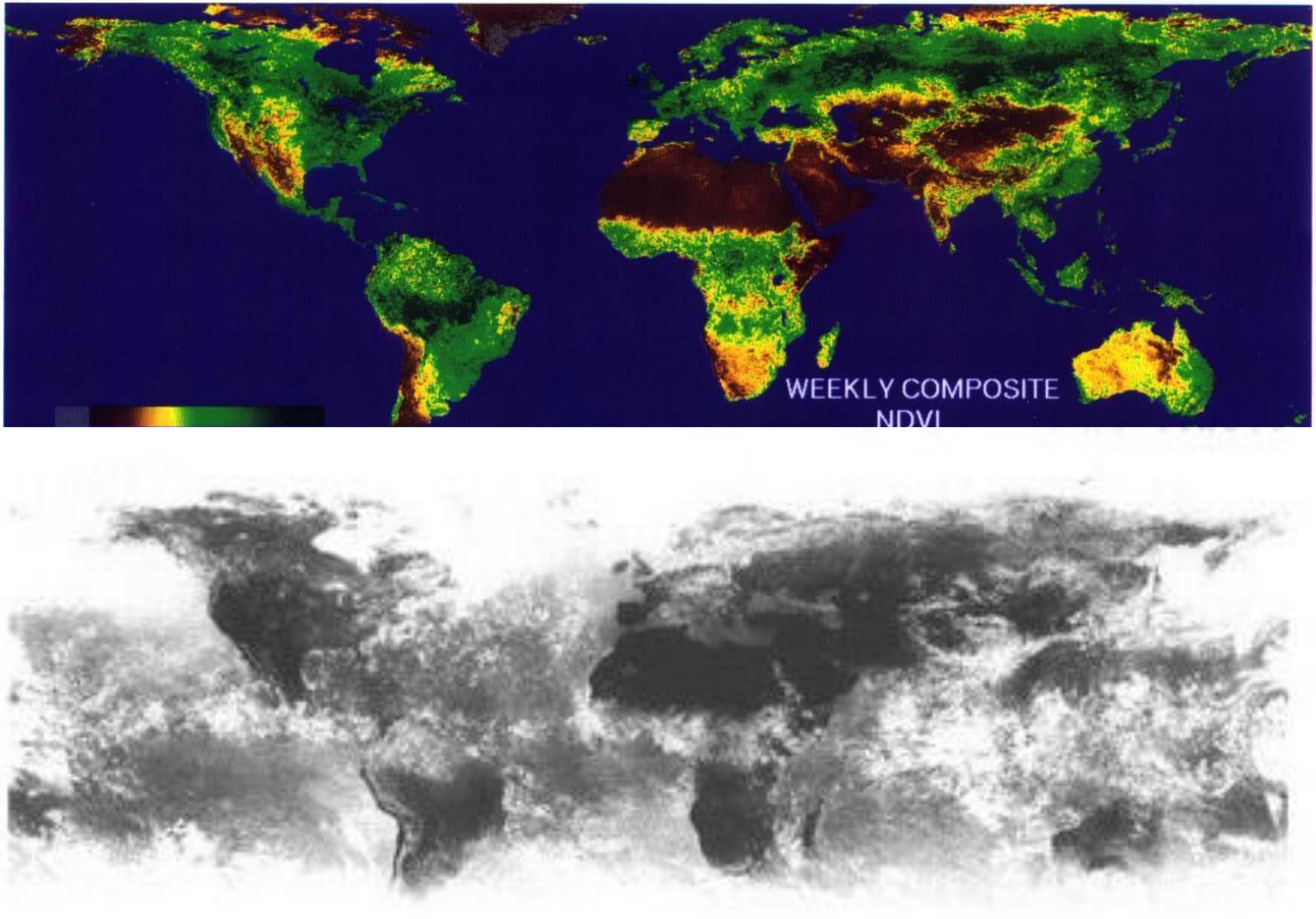
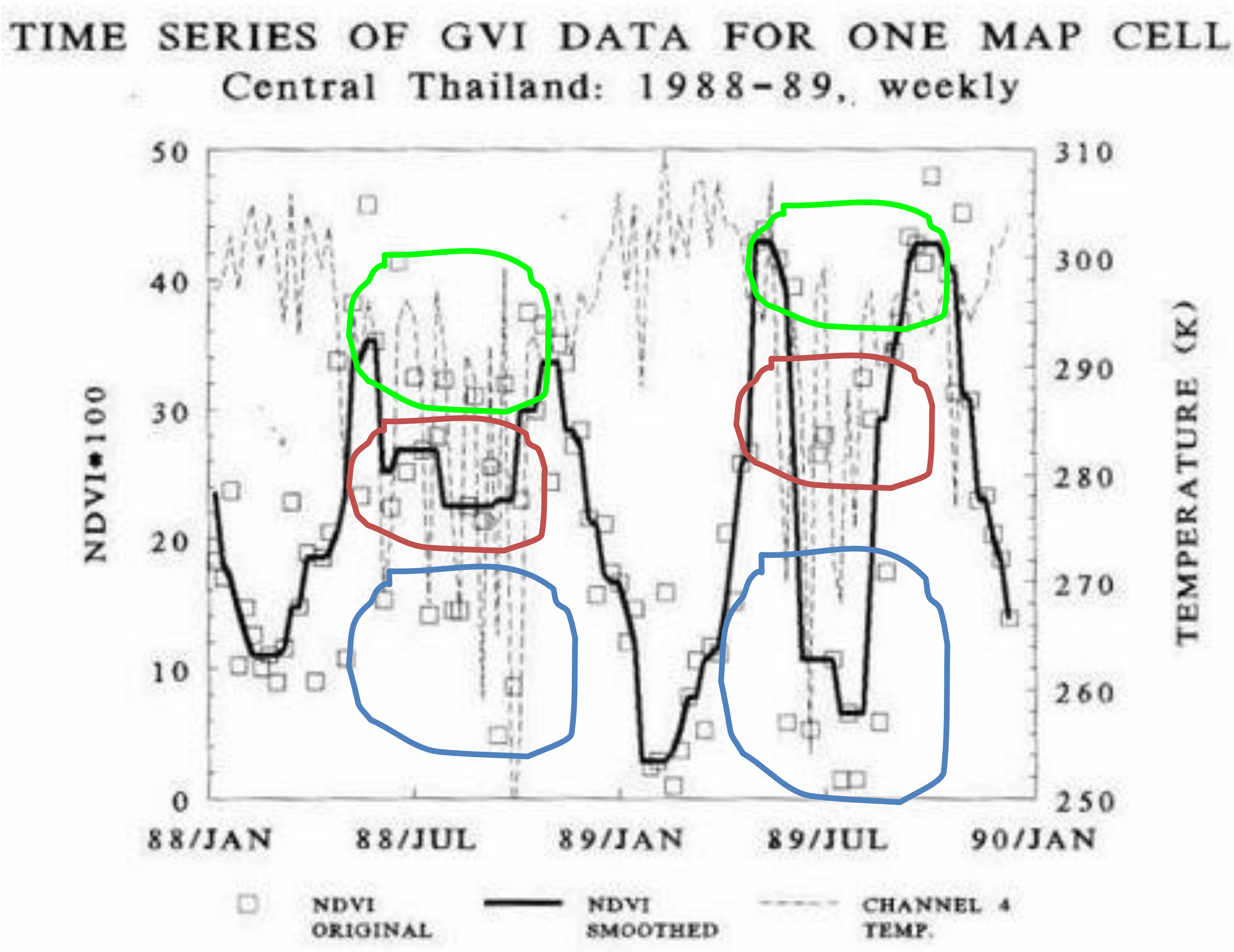


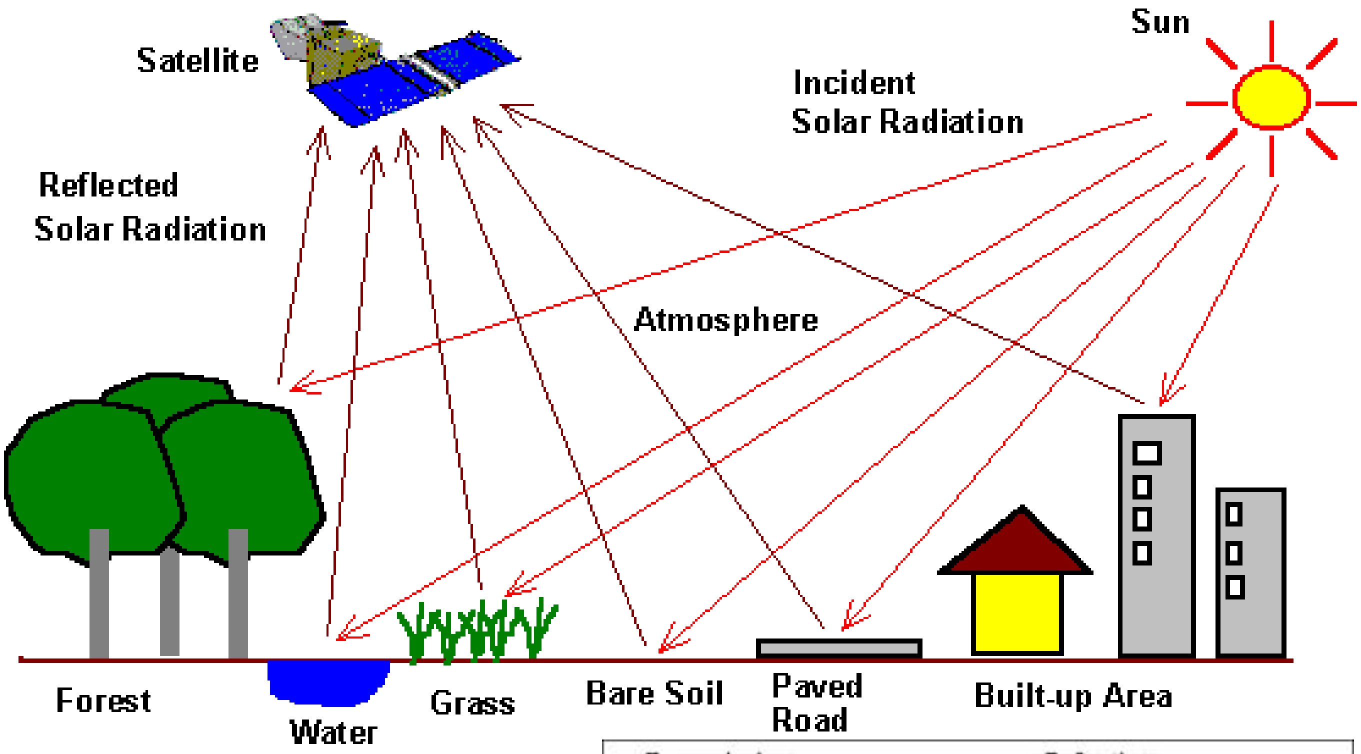
*Figure 8.* Weekly composite NDVI for 10–16 July 1989 with and without cloud mask (MASCI-generated overlay in white). The corresponding $T_4$ image is shown in Figure 1.

# On the Danger of Smoothing the Unscreened Data:

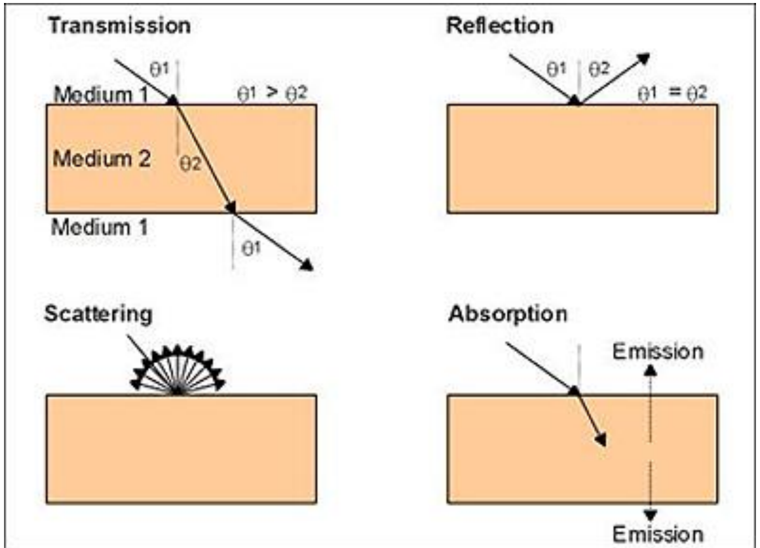
## Example on weekly composite NDVI (NOAA GVI dataset)



# 2.4 Atmospheric Correction



Correction needed for
- Aerosols
- Water vapor
- Molecular (Rayleigh)
- Ozone
- Other gases ($O_2$,$N_2O$, etc.)



# Atmospheric Scattering Phase Function Effects

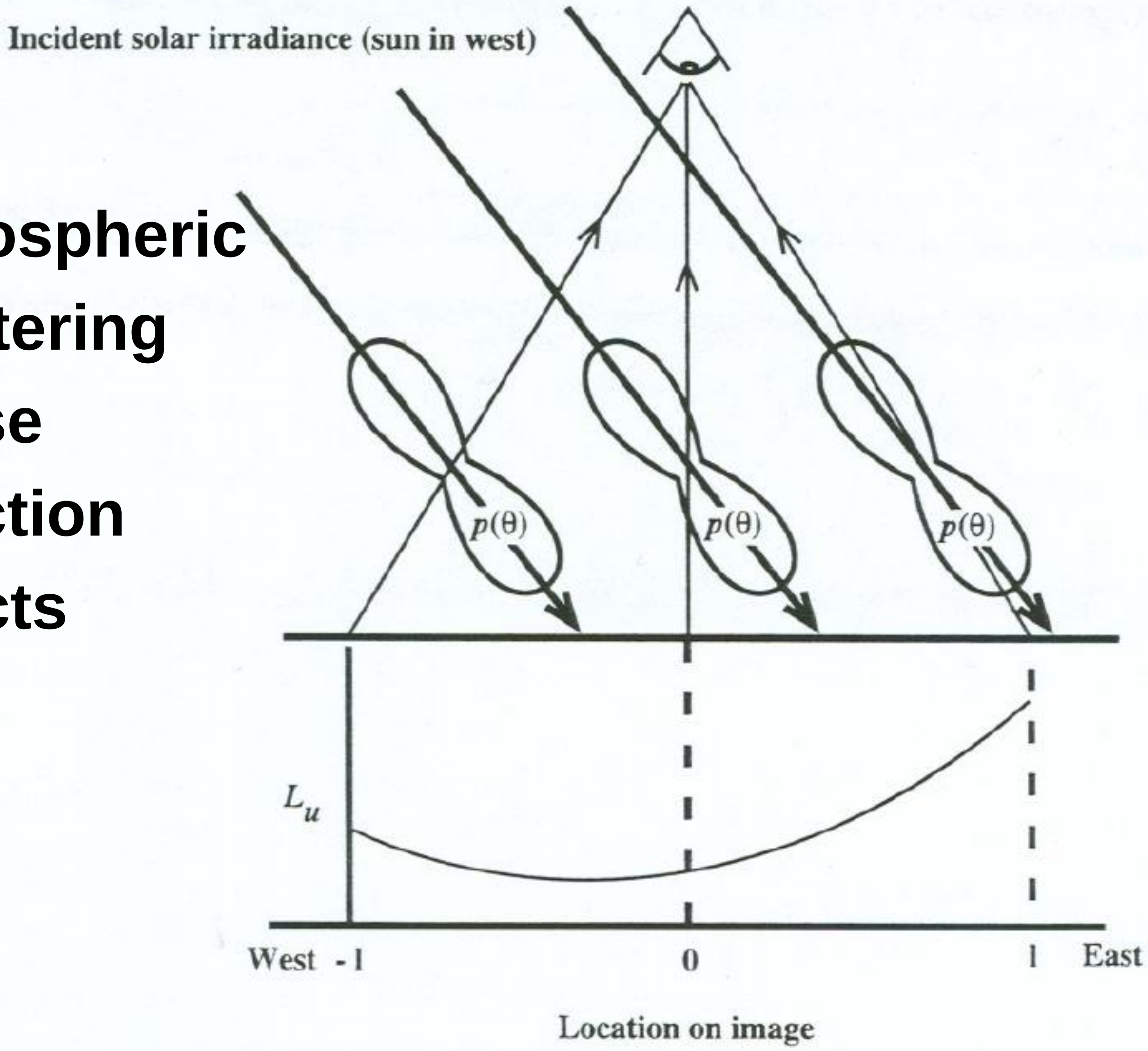
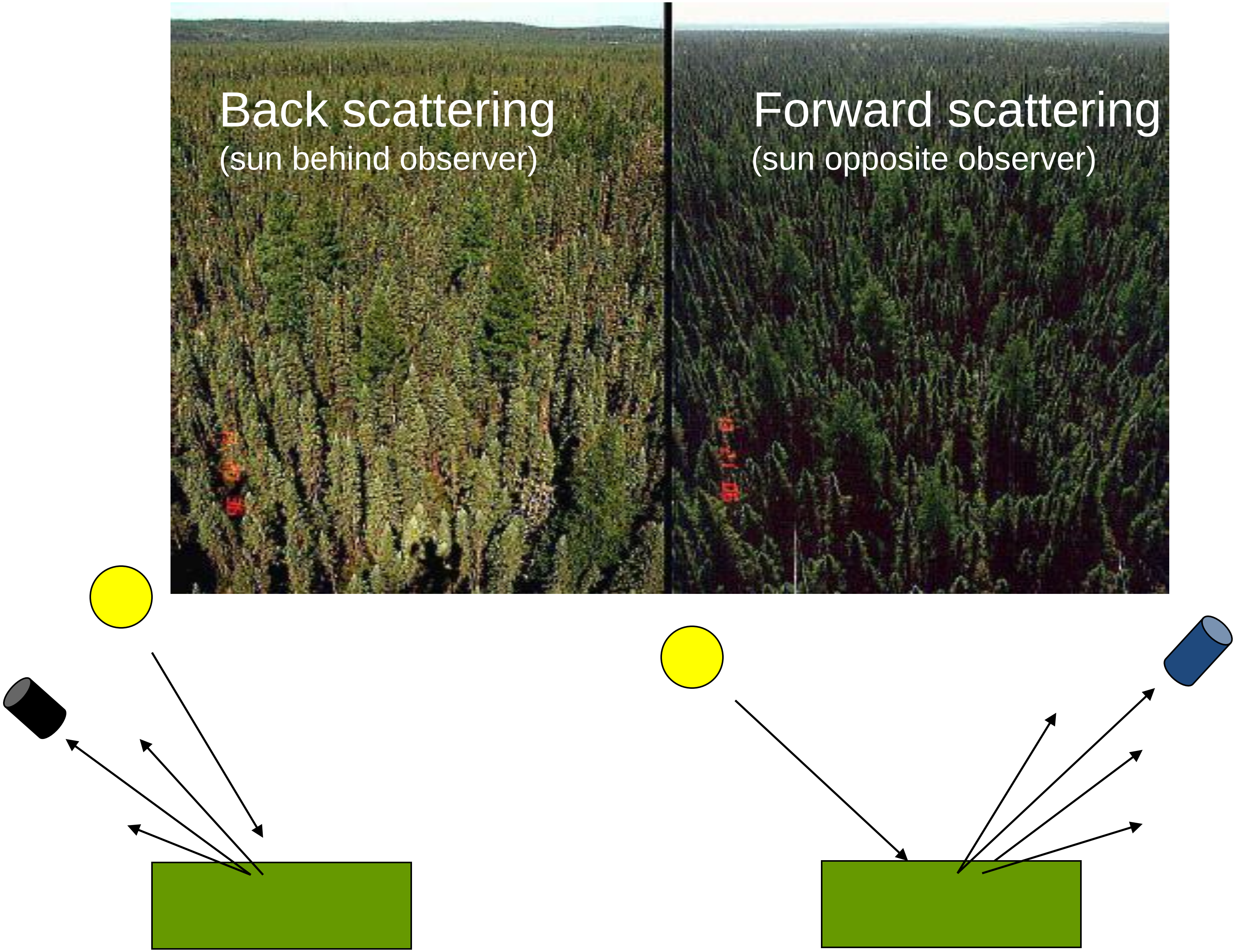


Figure 4.11 Variation in path radiance with view angle. A Rayleigh phase function is shown for refe



Back scatter direction

Forward scatter direction

# Solving for at-surface radiance

- Estimate atmospheric path radiance and viewpath transmittance to obtain at-surface radiance $L_b(x, y)$, often called surface-leaving radiance.
- At-sensor:

$$L_b^s(x,y) = \boxed{\tau_{vb}}\,\boxed{L_b(x,y)} + \boxed{L_b^{sp}}$$

- Solve for at-surface radiance

$$L_b(x,y) = \frac{L_b^s(x,y) - L_b^{sp}}{\tau_{vb}}$$

- In terms of calibrated at-sensor satellite data

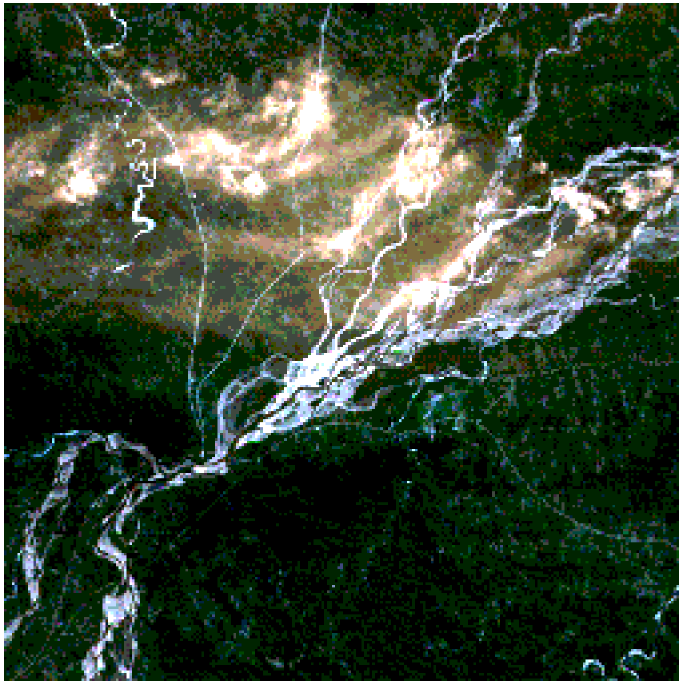
$$L_b(x,y) = \frac{\text{cal\_gain}_b \cdot \text{DN}_b + \text{cal\_offset}_b - \boxed{L_b^{sp}}}{\boxed{\tau_{vb}}}$$

modis.gsfc.nasa.gov/data/atbd/ atbd_mod08.pdf

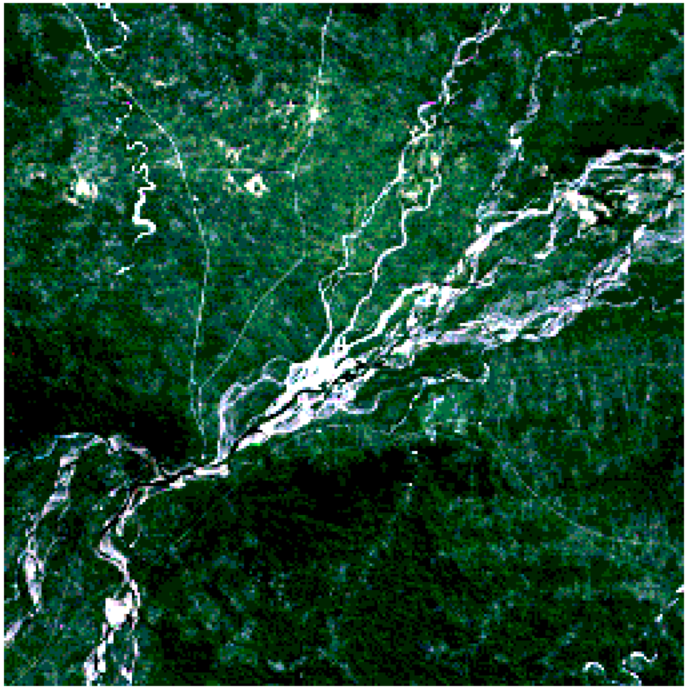
# In-Scene Method for Deriving Path Radiance

- Path radiance can be estimated with the Dark Object Subtraction (DOS) technique
- In-scene method assumes dark objects have zero reflectance, and any measured radiance is attributed to atmospheric path radiance only
- Subject to error if object has even very low reflectance
- View-path atmospheric transmittance is not corrected by DOS
- Dark Object Subtraction
  - Identify “dark object” in the scene
  - Estimate lowest DN of object, $DN_{0b}$
  - Assume $DN_{0b}=L^{sp}{}_{b}$
  - DN values (calibrated to at-sensor radiance) within the dark object assumed to be due only to atmospheric path radiance
  - Subtract, $DN_{0b}$ from all pixels in band b
- DOS can be improved by incorporating atmospheric models but then you need many parameters

# Image Atmospheric Correction



Before Correction



After Correction

# 2.5 Deriving Surface Variables: Surface Reflectance

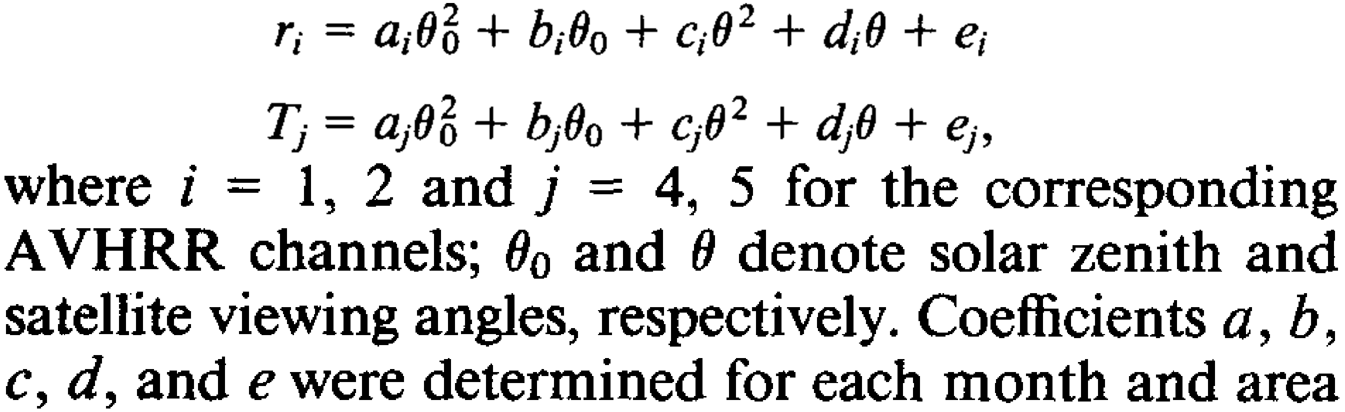
- Further conversion to reflectance requires 4 more parameters

$$\rho_b(x,y) = \frac{\pi L_b(x,y)}{\tau_{sb} E_b^0 \cos\left[\theta(x,y)\right] \zeta^2}$$

- solar path atmospheric transmittance (from model or measurements)
- exo-atmospheric solar spectral irradiance (known)
- incident angle (from DEM)
- Normalized Sun-Earth distance: **ζ** (day of the year)

# 2.6 Normalization

- Empirical polynomial description



$$r_i = a_i\theta_0^2 + b_i\theta_0 + c_i\theta^2 + d_i\theta + e_i$$

$$T_j = a_j\theta_0^2 + b_j\theta_0 + c_j\theta^2 + d_j\theta + e_j,$$

where $i = 1, 2$ and $j = 4, 5$ for the corresponding AVHRR channels; $\theta_0$ and $\theta$ denote solar zenith and satellite viewing angles, respectively. Coefficients $a$, $b$, $c$, $d$, and $e$ were determined for each month and area

Normalization: use specific values for θ and $\theta_o$
For example: $\theta$=45° and $\theta_o = 0$ (nadir)

Gutman, G., 1994: Global data on land surface parameters from NOAA AVHRR for use in numerical climate models. J. Climate,7, 669-680

- Models (e.g. Roujean model or BU models)

# Landsat Reflectance Normalization Using MODIS Correction Factors

$$\hat{\rho}_{ETM+,t1}\left(\lambda_{ETM+},\Omega_{nadir},\Omega'_{solar\,noon}\right)=c\times\rho_{ETM+,t1}\left(\lambda_{ETM+},\Omega_{observed},\Omega'_{observed}\right)$$

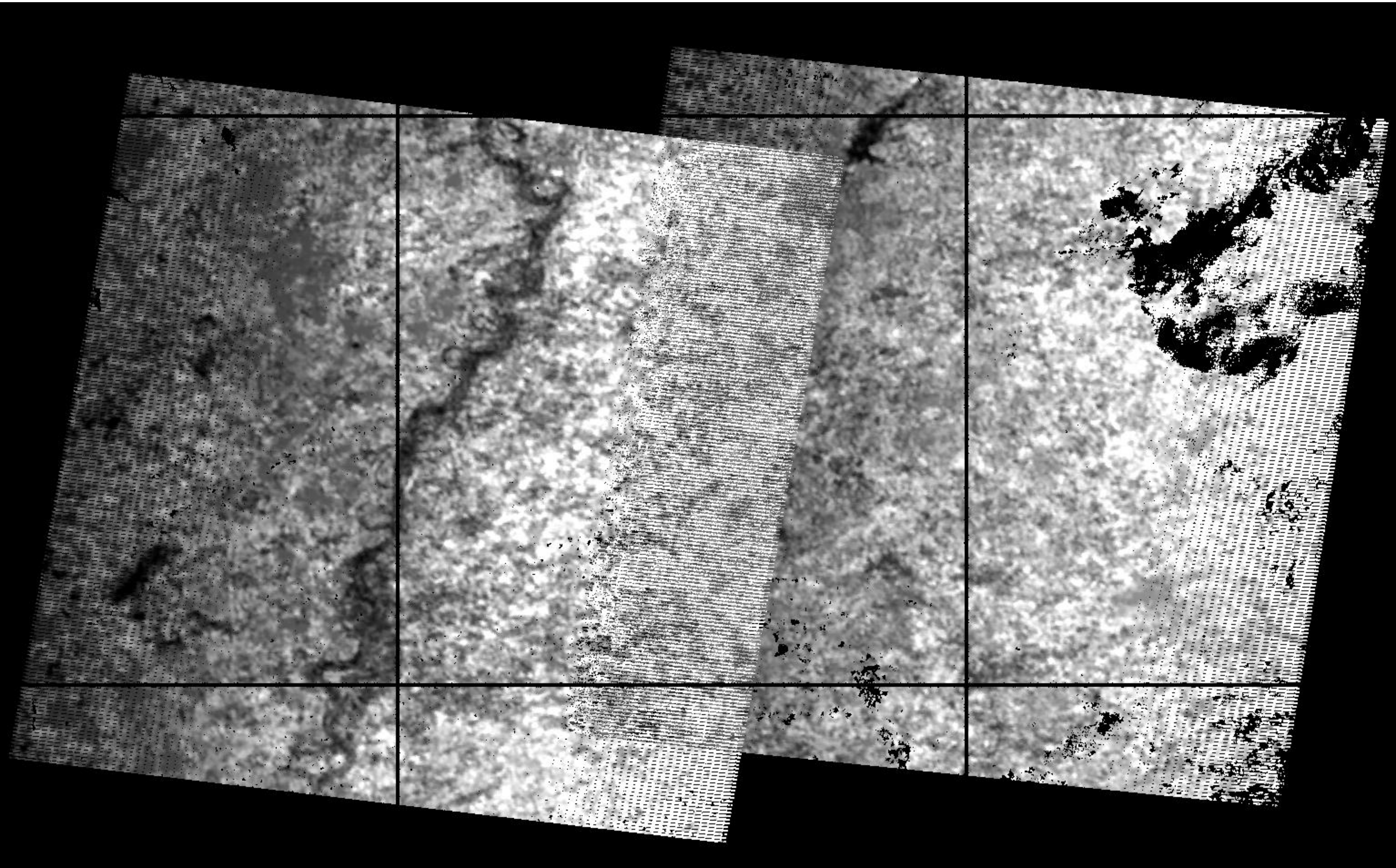
$$c=\frac{\hat{\rho}_{MODIS,t1}\left(\lambda_{MODIS},\Omega_{nadir},\Omega'_{solar\,noon}\right)}{\hat{\rho}_{MODIS,t1}\left(\lambda_{MODIS},\Omega_{observed},\Omega'_{observed}\right)}$$

$\hat{\rho}_{MODIS}$ computed from MODIS 16-day 500-m BRDF/Albedo product spectral BRDF model parameters

Thus, Landsat 30-m reflectance may be normalized to some desired geometry, e.g., nadir view zenith and local solar noon, for each 500-m MODIS pixel.

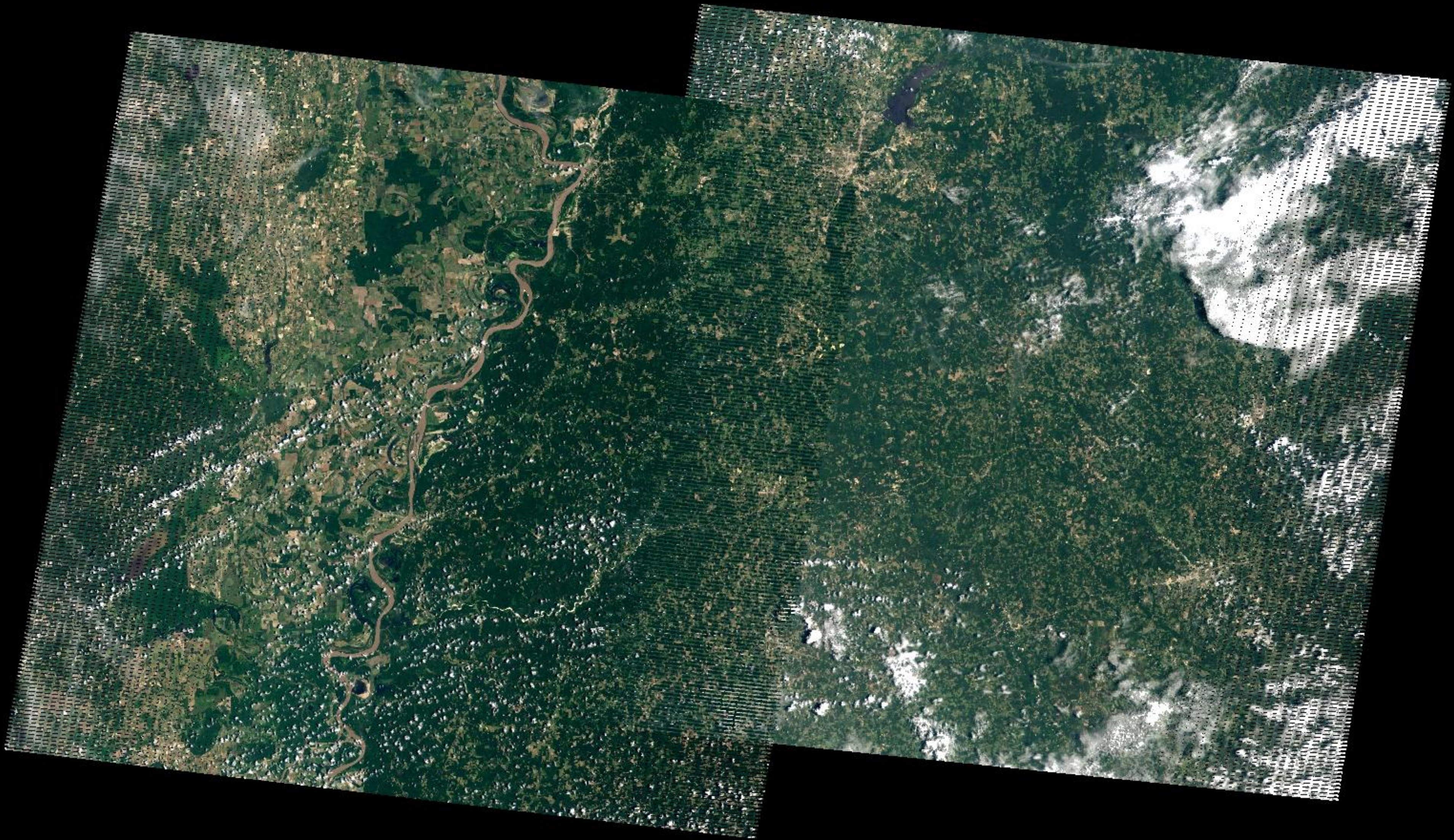
David Roy, South Dakota State University

# Band 3 (red, 0.63-0.69 μm)
# MODIS derived scaling factors ( range: 0.97-1.43 )

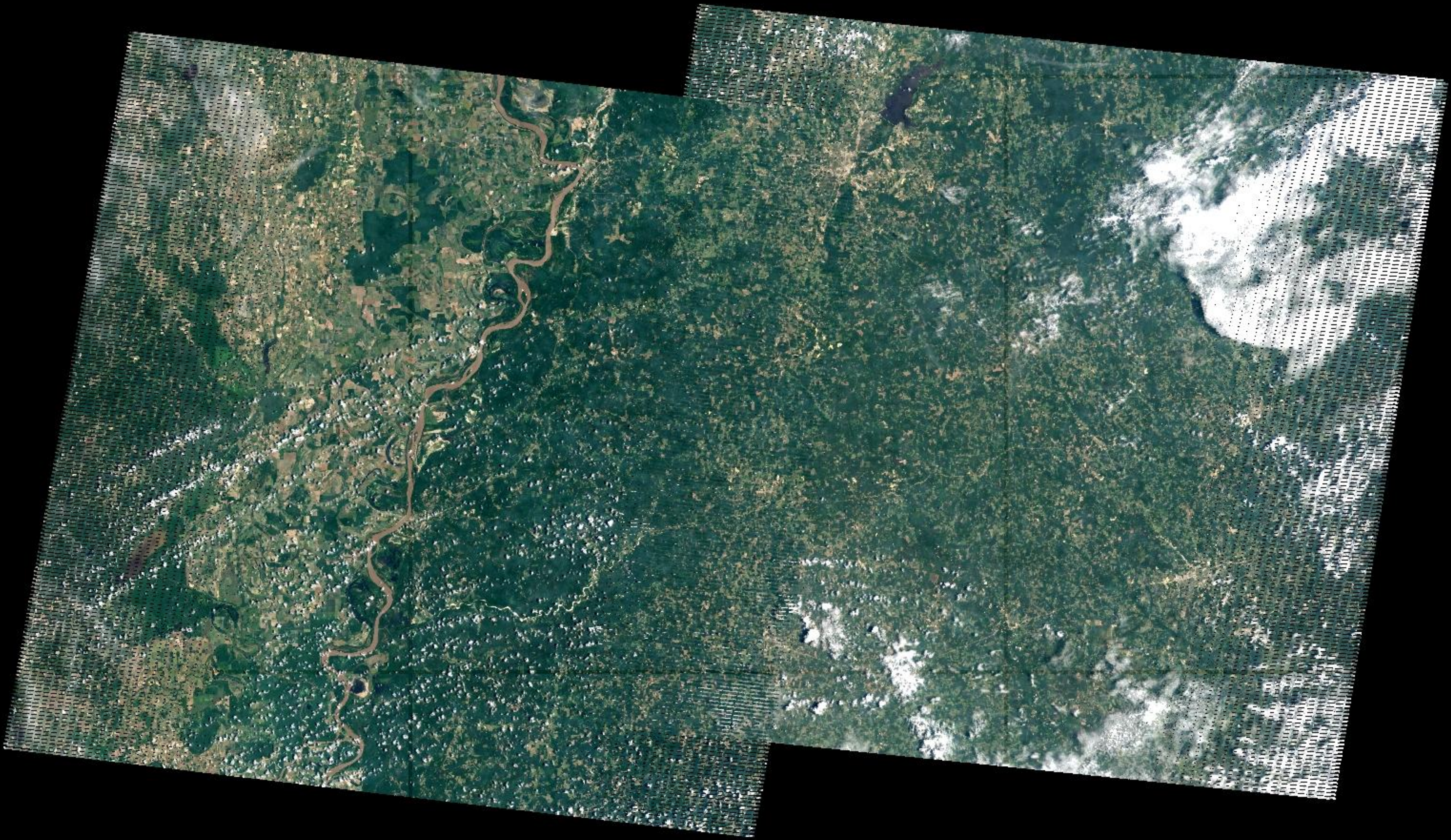


# Path 23 Row 38, July 12 & Path 22 Row 38, July 5, 2008
Band 3, 2, 1 (red, green, blue) TOA reflectance

Before radiometric normalization

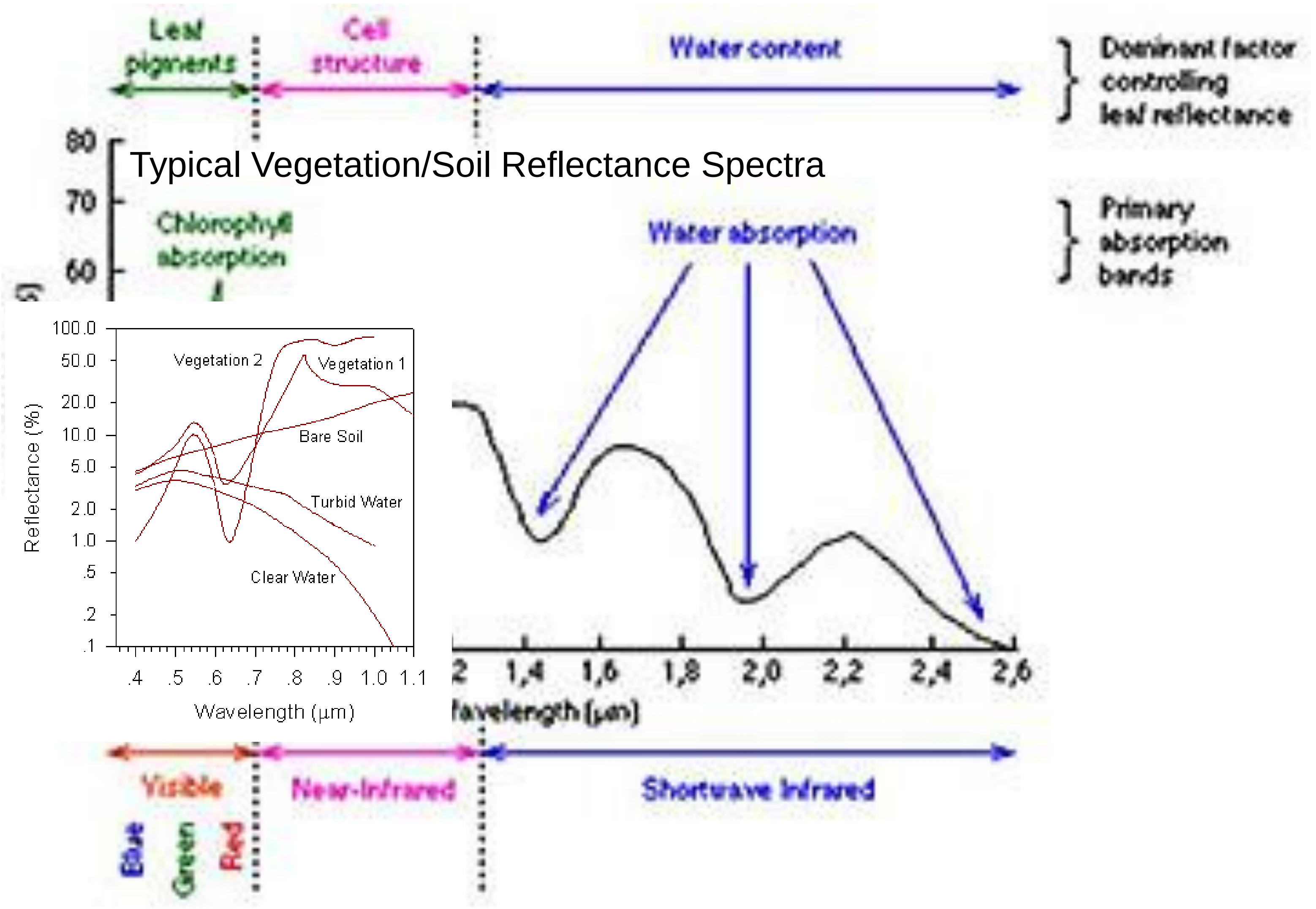


# Path 23 Row 38, July 12 & Path 22 Row 38, July 5, 2008
# Band 3, 2, 1 (red, green, blue) TOA reflectance
# After radiometric normalization

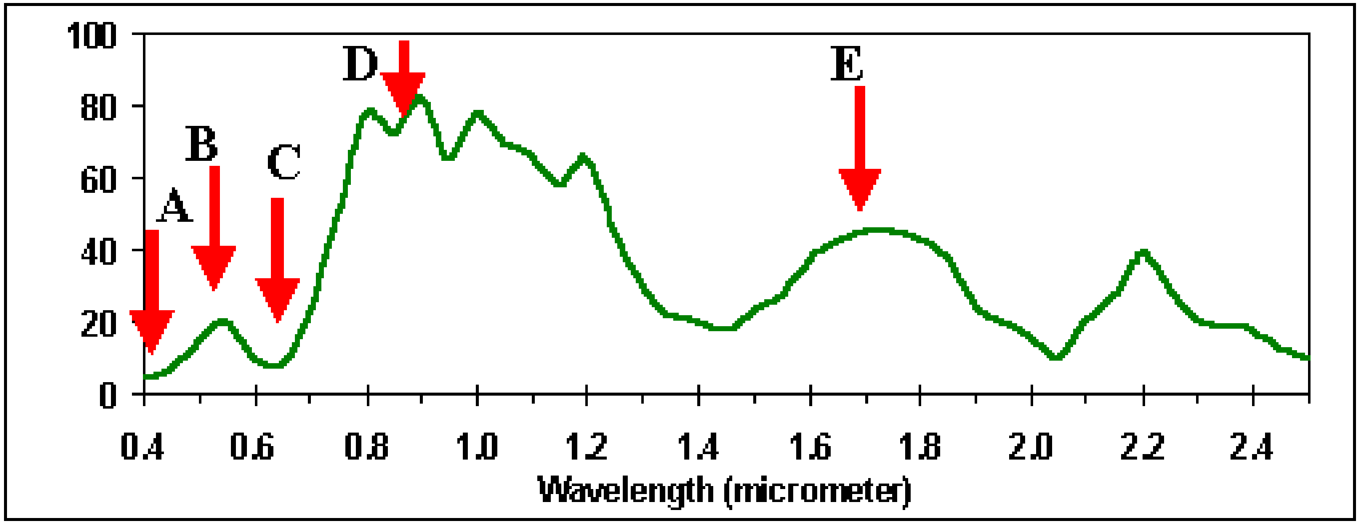


# 3. Land Remote Sensing (Vegetation and Soils)

# 3.1 Basic Principles


Typical Vegetation/Soil Reflectance Spectra

# Selecting Wave Bands for RS of Vegetation

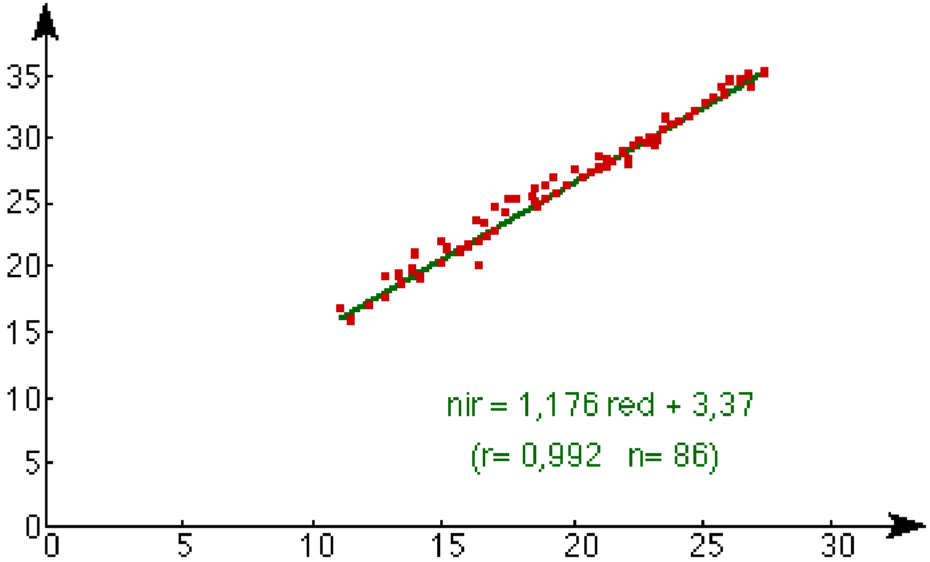


The labelled arrows indicate the common wavelength bands used in optical remote sensing of vegetation: A: blue band, B: green band; C: red band; D: near IR (NIR); E: short-wave IR (SWIR)

- Vegetation Indices
    - Normalized Difference Vegetation Index NDVI= (NIR- Vis)/(NIR+Vis)
    - Other indices: SAVI (soil adjusted), EVI (environmental), ARVI (atmospherically resistant), etc.

# 3.2 Soil Remote Sensing

- The soil line of the soil reflectance spectra, characterizes the soil type, defines vegetation indices, and corrects the plant canopy reflectances for the optical soil effects
- The least-square regression method will calculate the soil line



Soil line for a silt-loam soil in Avignon-Montfavet (France) (after Baret, 1986).

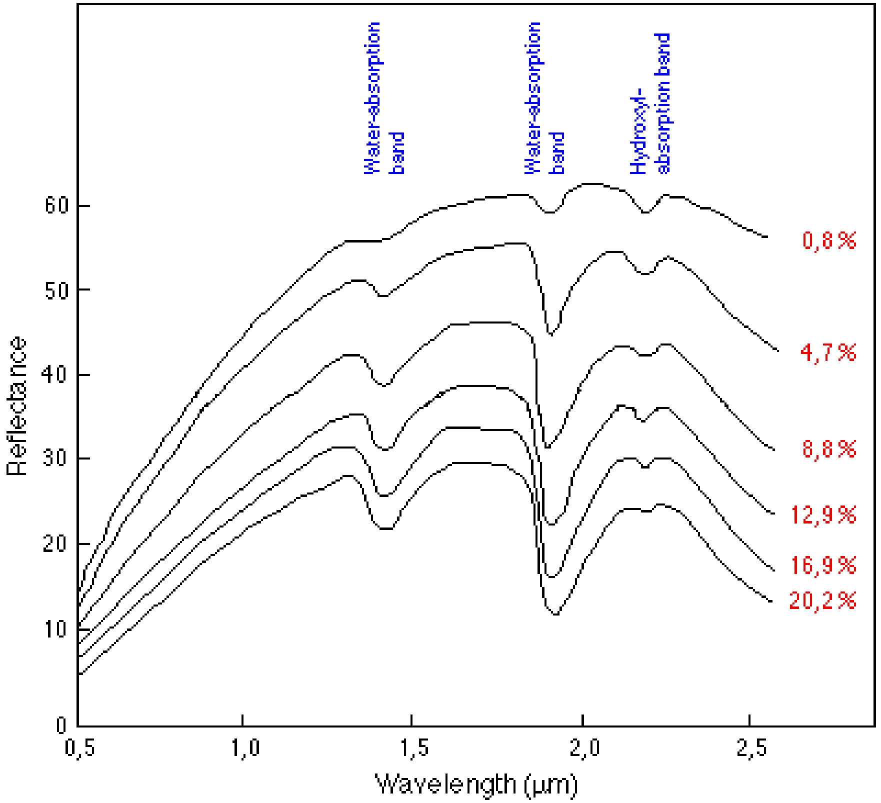
Source: B. Leblon; Faculty of Forestry and Environmental Management, University of New Brunswick, Canada

Near-IR (soil) = a*Red (soil) + b

# Factors Influencing Soil Reflectance

- mineral composition
- soil moisture
- organic matter content
- soil texture (roughness)
- Size and shape of the soil aggregate

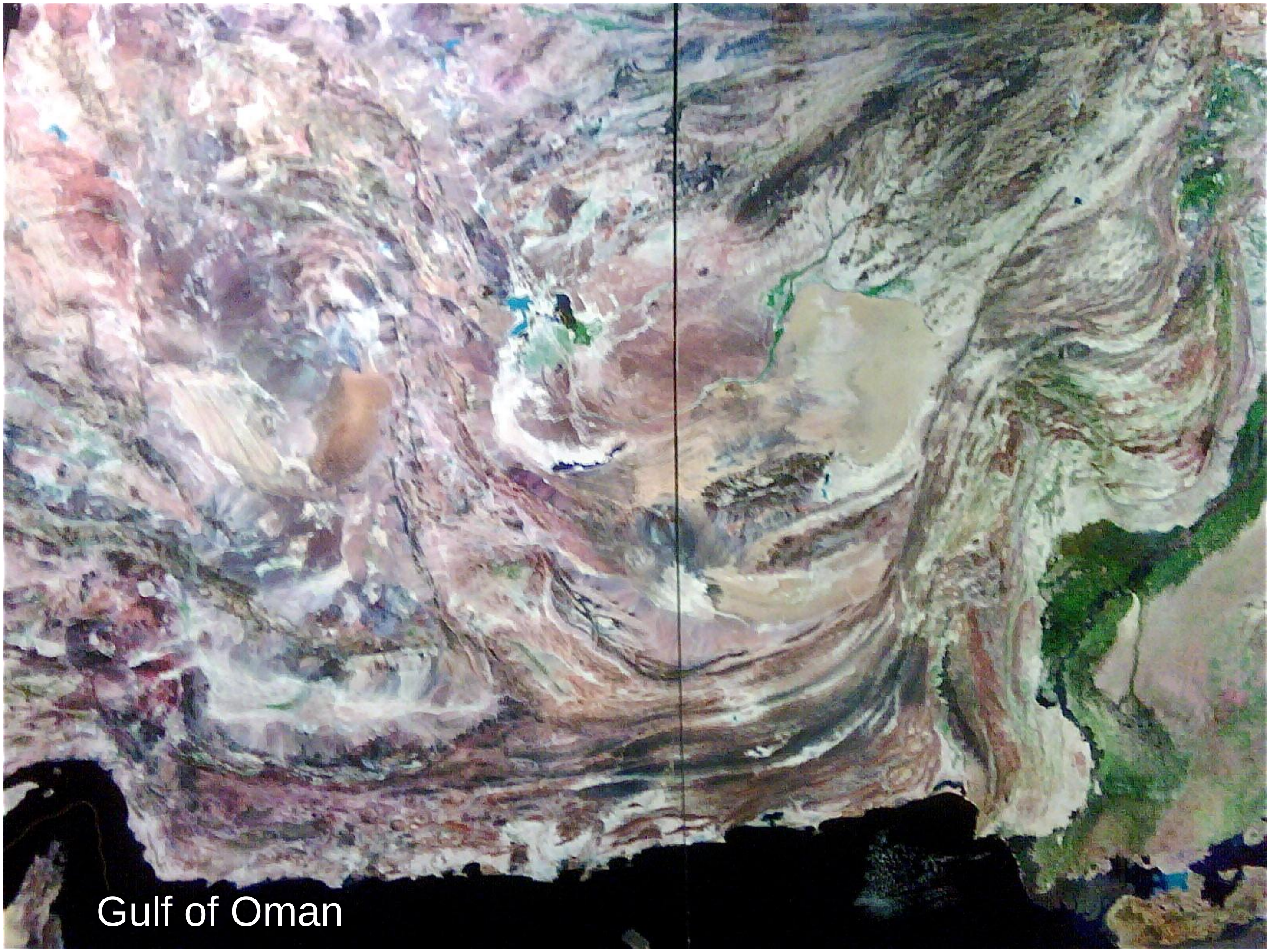
On the reflectance spectra, soil moisture dependence produces a family of almost parallel curves. Moisture has a similar effect over the whole spectrum.



Spectral reflectance curves for Newtonia silt loam at various moisture contacts (after Bowers and Hanks, 1965)

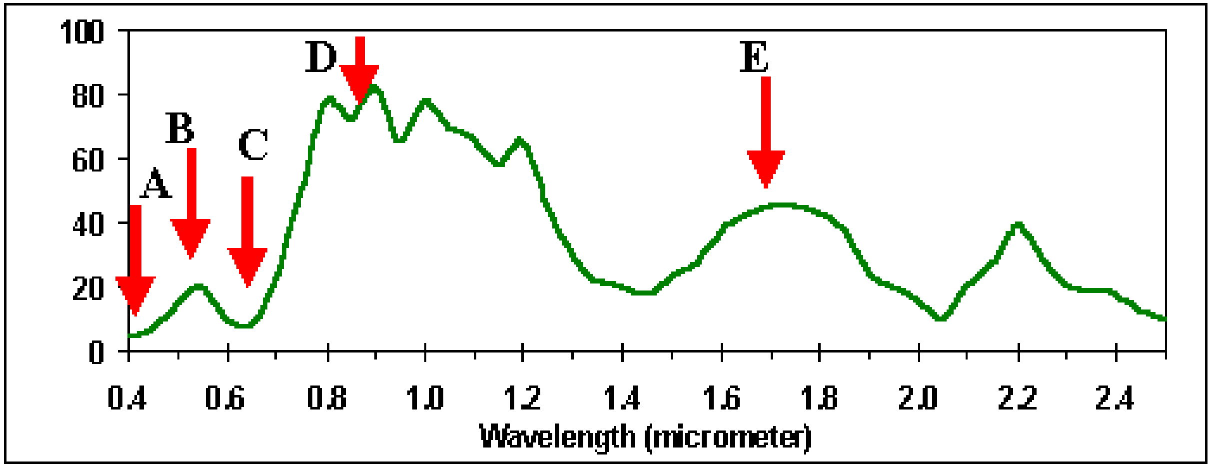
Source: B. Leblon, Faculty of Forestry and Environmental Management, University of New Brunswick, Canada.

# Iran/Pakistan from Landsat



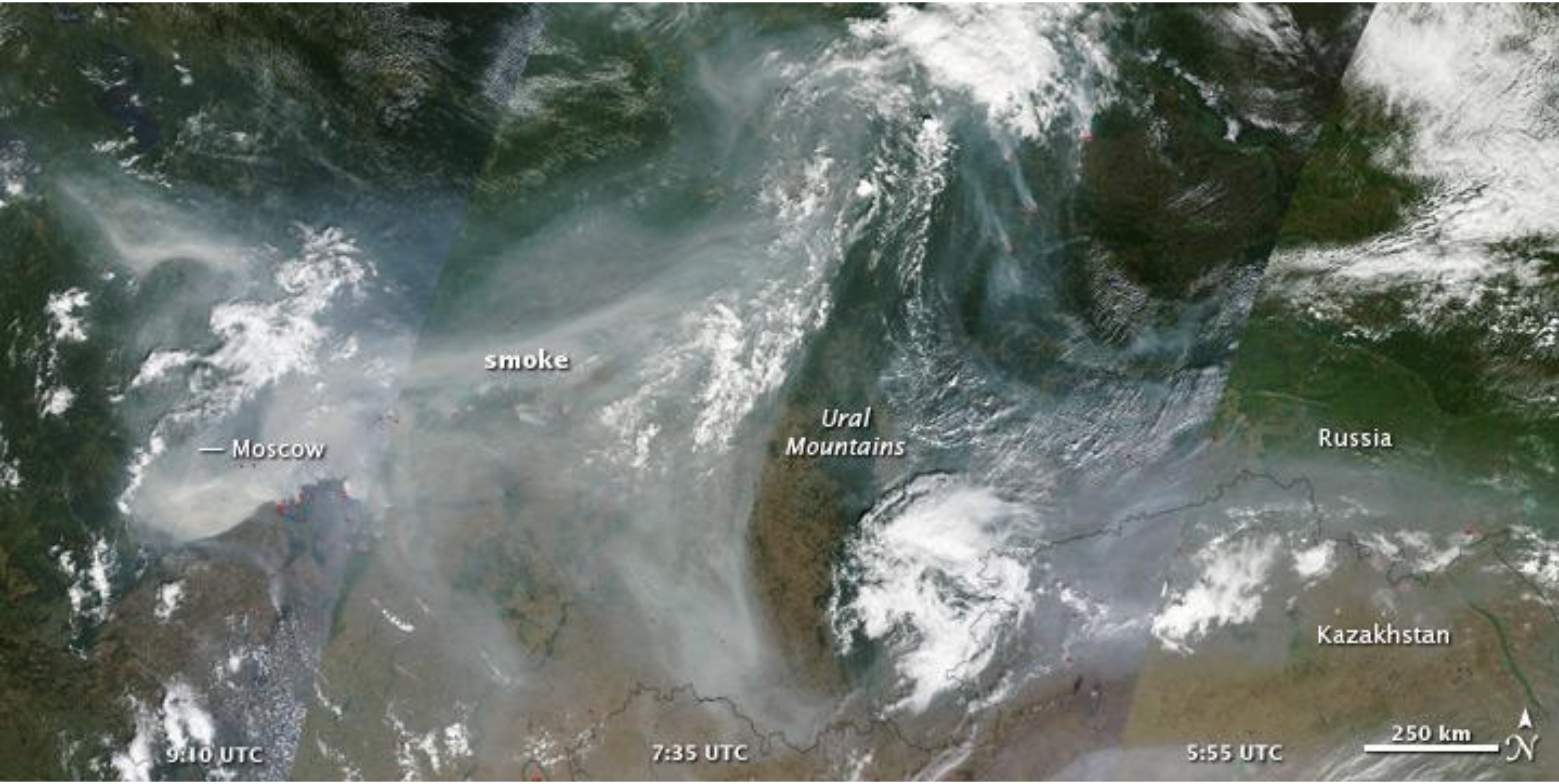
# Multispectral Red-Green-Blue Composite Images

Typical Reflectance Spectrum of Vegetation:
A: blue
B: green
C: red
D: near IR  (NIR)
E: short-wave IR (SWIR)



- SWIR reflectance depends on the types of plants and the plant's water content.
- Outside of absorption bands reflectance of leaves generally increases when leaf liquid water content decreases.
- Used for identifying tree types and plant conditions, such as plant drought stress, burnt areas.
- Also sensitive to the thermal radiation emitted by intense fires, and hence is used to detect active fires, especially during night-time when the background interference from SWIR in reflected sunlight is absent.

# Clouds and Fire Smoke Over Russia as Observed by MODIS on August 4, 2010



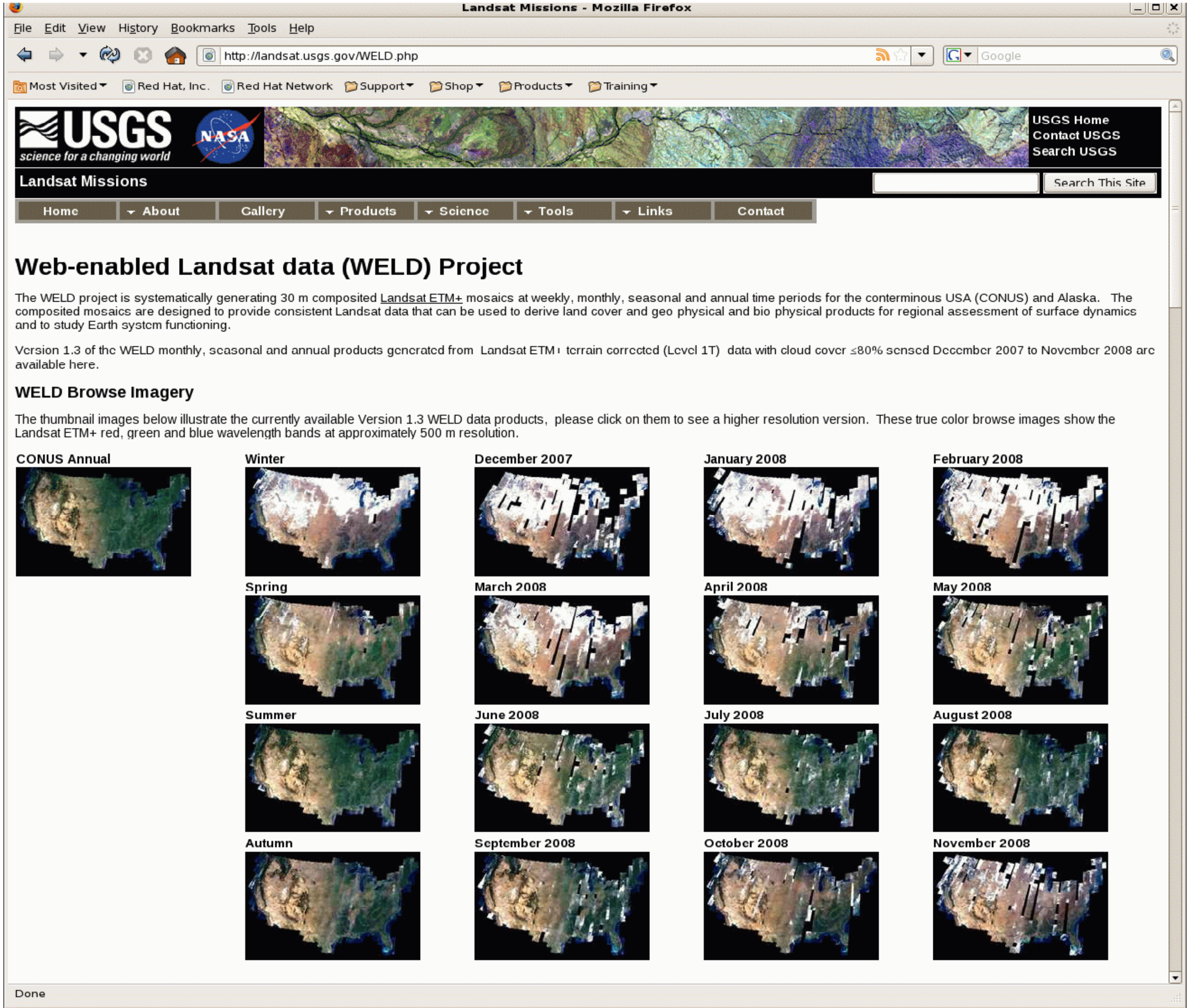
# Cloud-free composites

- Technology level is high, data are free
- Instead of selecting a single least cloudy scene it is possible to develop fuller time series
- Compositing on a pixel basis
- Monthly composite 30-m resolution maps can potentially be produced

Available at http://landsat.usgs.gov/WELD.php

Version 1.3 with documentation

2008 CONUS & Alaska, annual, seasonal, monthly composited mosaics



## Web-enabled Landsat data (WELD) Project

The WELD project is systematically generating 30 m composited Landsat ETM+ mosaics at weekly, monthly, seasonal and annual time periods for the conterminous USA (CONUS) and Alaska. The composited mosaics are designed to provide consistent Landsat data that can be used to derive land cover and geo physical and bio physical products for regional assessment of surface dynamics and to study Earth system functioning.

Version 1.3 of the WELD monthly, seasonal and annual products generated from Landsat ETM+ terrain corrected (Level 1T) data with cloud cover ≤80% sensed December 2007 to November 2008 are available here.

### WELD Browse Imagery

The thumbnail images below illustrate the currently available Version 1.3 WELD data products, please click on them to see a higher resolution version. These true color browse images show the Landsat ETM+ red, green and blue wavelength bands at approximately 500 m resolution.

# Fly across 2008 annual composited mosaic, 500m browse
# Seattle to Houston, 36 frames/sec.

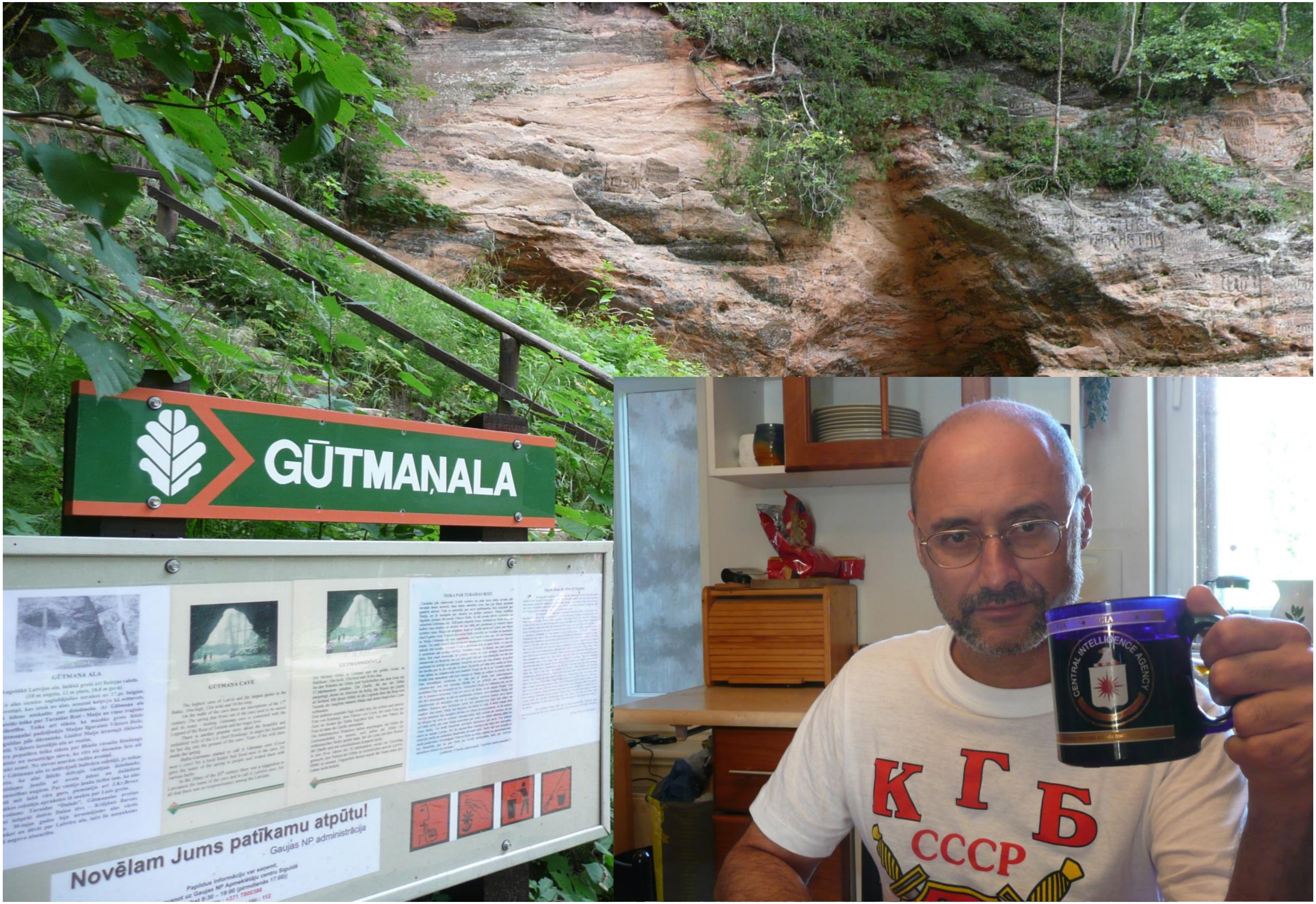
# Materials

- http://rst.gsfc.nasa.gov/
- http://www.crisp.nus.edu.sg/~research/tutorial/rsmain.htm
- http://earthobservatory.nasa.gov/

# Thanks go to

- Greg for
  - Inviting me to give an intro RS lecture
  - For putting together a great team of instructors
  - All the logistics and arrangements with Vidzeme U.
- Vidzeme U. for their hosting and in-kind support
- Team of instructors for willingness to travel overseas to train students
- Students for their patience during my lecture

2 years ago, Riga: Drinking beer with “vobla” (dry fish) – the Russian way!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