Earth System Monitoring and Modelling

# Overview of Land Surface Parameters From Earth Observation

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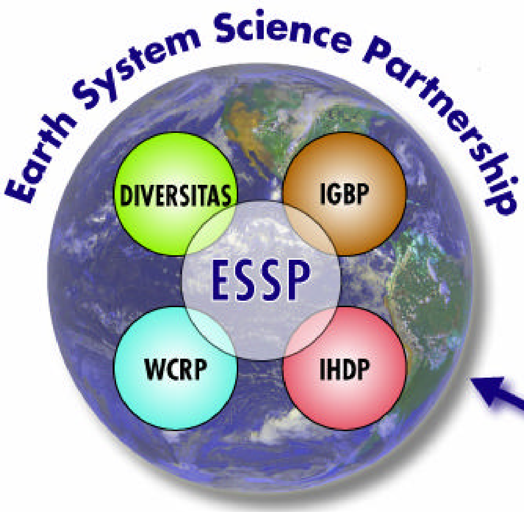
Department of Geoinformatics and Remote Sensing

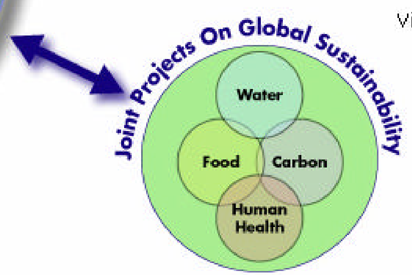




The Earth System Science Partnership (ESSP) is a joint initiative of four global change programmes:

- **DIVERSITAS** – an integrated programme of biodiversity science
- **IGBP** – International Geosphere-Biosphere Programme
- **IHDP** – International Human Dimensions Programme on Global Environmental Change
- **WCRP** – World Climate Research Programme

Learn more about ESSP ...

Visit also our new page: ESSP News

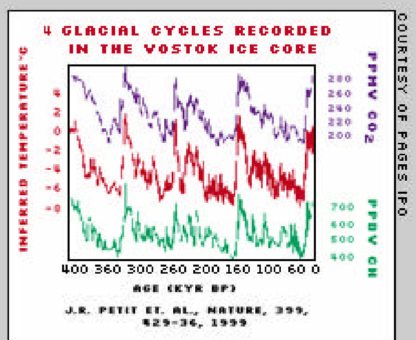



TOP

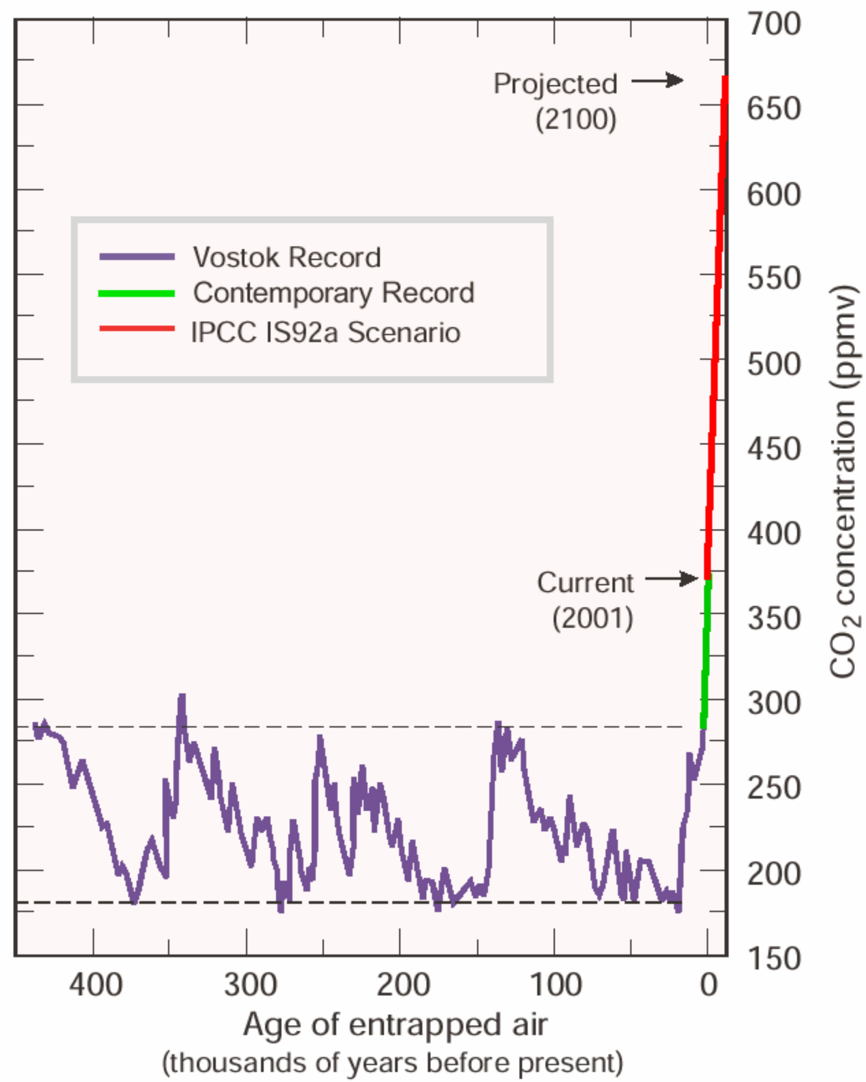
## Why is IGBP needed?

### Earth is a System

The Vostok ice core data give a wealth of insights into how our home planet functions. Analysis of the gases trapped in air bubbles in layers of Antarctic ice reveals a rhythmic pattern of 'planetary breathing' for nearly half a million years. In particular, three striking characteristics together demonstrate beyond any doubt that the Earth IS a system, with properties and behaviour that are characteristic of the system as a whole.




- The Earth's temperature and the concentration of the greenhouse gases carbon dioxide ($CO_2$) and methane ($CH_4$) are tightly coupled and show very similar patterns throughout the record.
- Temperature and gas concentrations follow a regular, cyclic beat through time, each cycle spanning approximately 100,000 years.
- The 'operating range' over which temperature and $CO_2$ and $CH_4$ concentrations vary is bounded at both the upper and lower limits; these limits do not vary over at least four cycles of the system.



Projected
(2100)
Vostok Record
Contemporary Record
IPCC IS92a Scenario
Current
(2001)
700
650
600
550
500
450
400
350
300
250
200
150
$CO_2$ concentration (ppmv)
400
300
200
100
0
Age of entrapped air
(thousands of years before present)

Adresse http://www.igbp.kva.se/cgi-bin/php/frameset.php

**IGBP**
**INTERNATIONAL GEOSPHERE-BIOSPHERE PROGRAMME**

GLOBAL IGBP CHANGE

- ABOUT US
- STRUCTURE
  - IGBP
  - ESSP
- CONTACTS
- PRODUCTS
- MEETINGS & EVENTS
- HOME

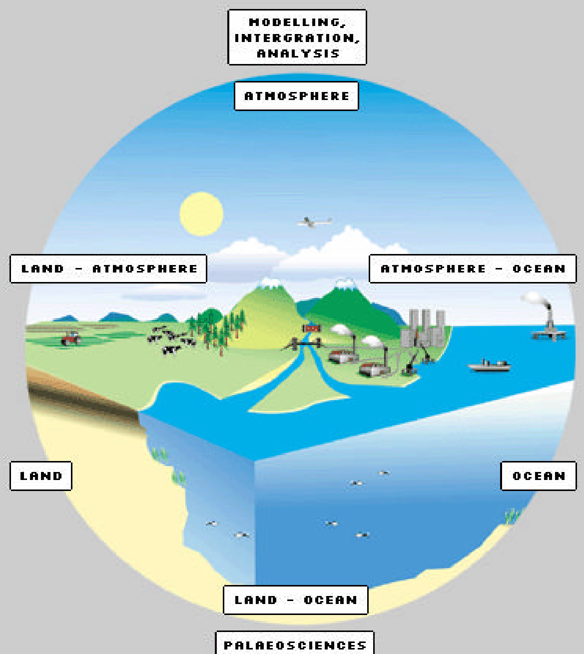
SEARCH:

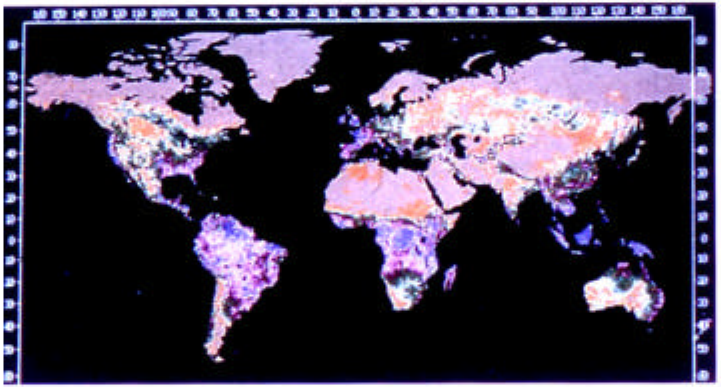
- IGBP WEB
- PEOPLE
- PDF FILES

GO»

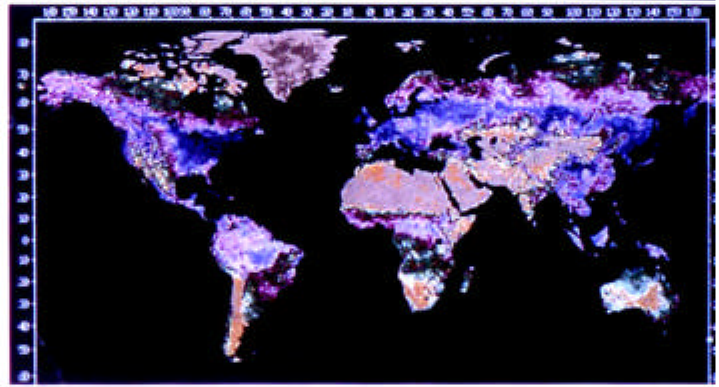
## IGBP

IGBP is in its second decade of research, continuing to focus on global biogeochemistry. To meet the challenges of a more integrated Earth System science, IGBP has adopted a new structure of eight projects in total (see imagemap below). Six projects are centred on the three major Earth System compartments - ocean, land and atmosphere - and the interfaces between them. Two projects - PAGES and GAIM - focus on a whole system perspective, from the past into the future. In general, there is a focus on interaction between and integration across the IGBP projects.

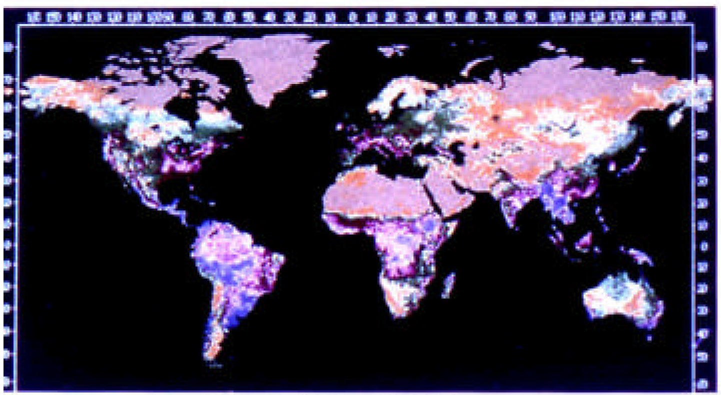




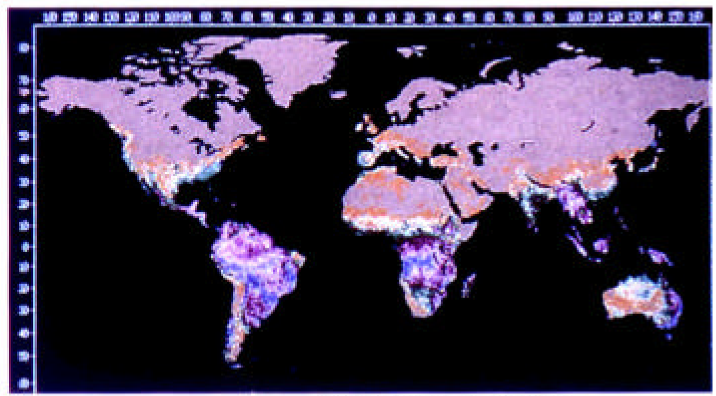
A) April 1982



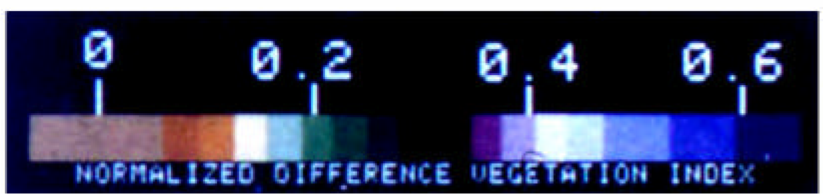
B) July 1982

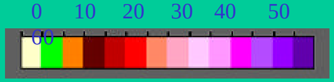


C) October 1982



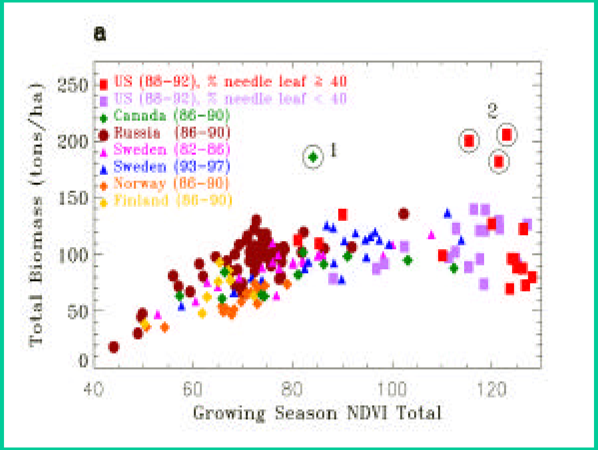
D) January 1983

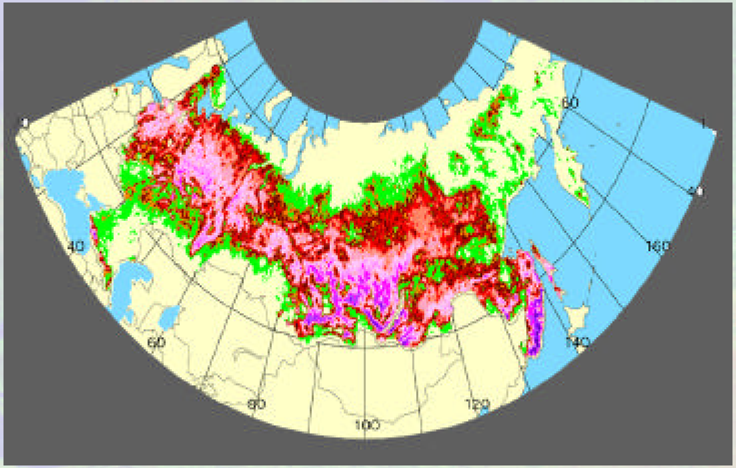


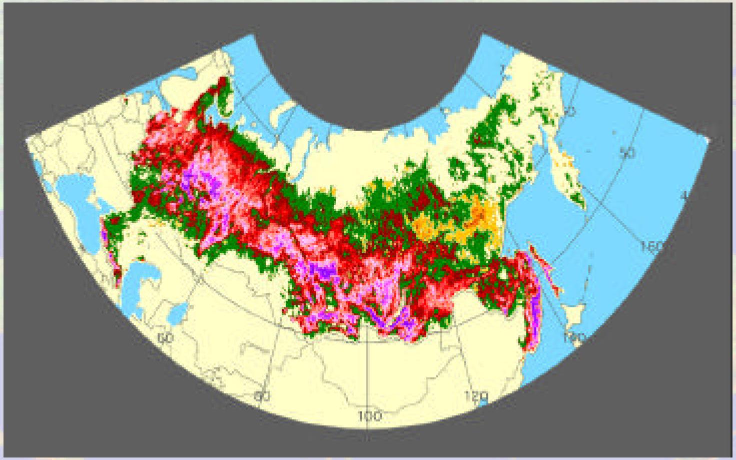


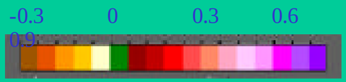

**Carbon Pool (tons C/ha)**

**1995 to 1999**





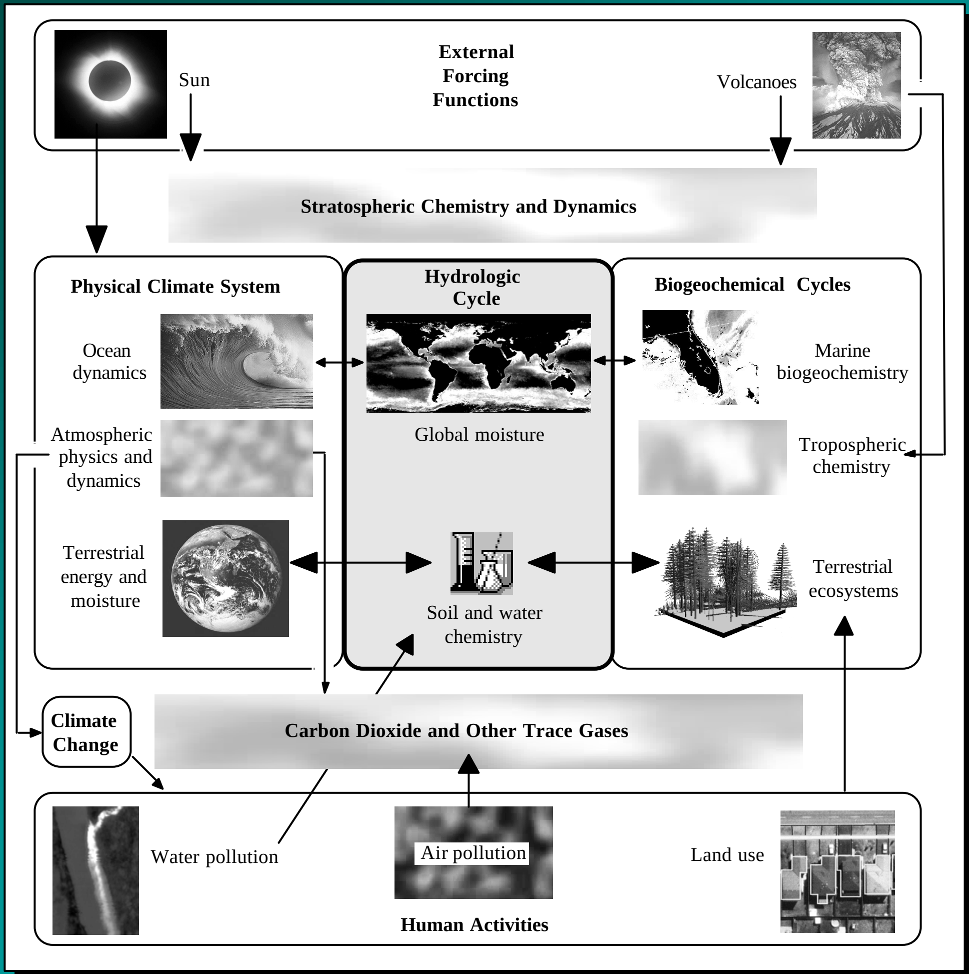




**Source** **Sinks**

**Changes in Carbon Pool**
**(tons C/ha/yr)**
**1980s & 90s**

Source:
Myneni, Tucker et al.

# Remote Sensing Earth System Science




Jensen, 2000

# Some important questions about the future Earth System

- Clouds, water vapor, radiation, and precipitation
  - Will changing cloud cover enhance or offset warming caused by increasing $CO_2$?
  - Is California likely to get more rain and less snow in the future?
- Ocean productivity and climate
  - How will air-sea exchange of $CO_2$ respond to changing atmospheric concentrations and warmer temperatures?
  - How will precipitation change over the ocean, and how will such changes affect circulation?



[Dozier, UCSB]

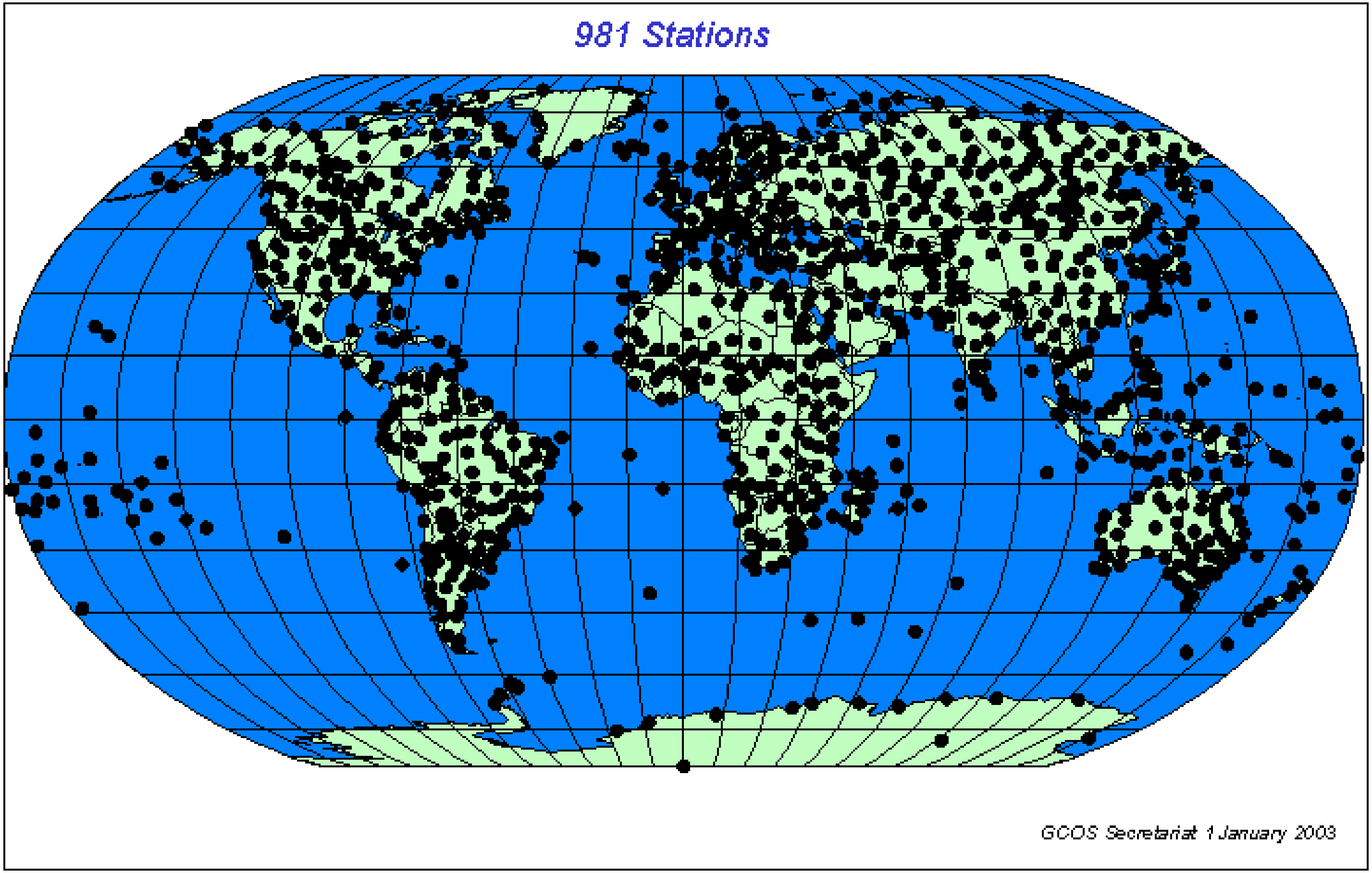
# Questions, cont.

- Changes in land use, land cover, and the hydrologic cycle?
  - How will land cover change affect climate?
  - What are the likely effects of future changes in precipitation chemistry?
- Polar ice sheets and sea level
  - Will a warmer climate cause sea level to rise? Over what time scale?



[Dozier, UCSB]

# GCOS Surface Network (GSN)



# Essential Climate Variables

This appendix contains a statement of the Essential Climate Variables that are required to support the work of the Convention and that are technically and economically feasible for systematic observation. It is these variables for which international exchange is required for both current and historical observations. Additional variables required for research purposes are not included in this listing. Additional information and specification of these variables is contained in the annex to this document. It is emphasized that the ordering within the listing is simply for convenience and is not an indicator of relative priority.

## 1. Atmospheric Variables

The following essential atmospheric variables are required over land, sea and ice:

### 1.1 Surface

Air temperature
Precipitation
Air pressure
Surface radiation budget
Wind speed and direction
Water vapour

### 1.2 Upper-air

Earth radiation budget (including solar irradiance)
Upper-air temperature (including MSU radiances)
Wind speed and direction
Water vapour
Cloud properties

### 1.3 Composition

Carbon dioxide
Methane
Ozone
Other long-lived greenhouse gases[16]
Aerosol properties

## 2. Oceanic Variables

### 2.1 Surface

Sea-surface temperature
Sea-surface salinity
Sea level
Sea state
Sea ice

Current
Ocean colour (for biological activity)
Carbon dioxide partial pressure

### 2.2 Sub-surface

Temperature
Salinity
Current
Nutrients
Carbon
Ocean tracers
Phytoplankton

## 3. Terrestrial Variables

River discharge
Water use
Ground water
✓ Lake levels
(✓) Snow cover
(✓) Glaciers and ice caps
Permafrost and seasonally-frozen ground
✓ Albedo
Land cover (including vegetation type)
✓ Fraction of absorbed photosynthetically active radiation (FAPAR)
Leaf area index (LAI)
Biomass
Fire disturbance

**3 (-5) directly retrievable from EO out of 13**

The good news: all variables can be retrieved using EO and modells, BUT how to validate?

# Remote Sensing Process

## Statement of the Problem

- **Select Appropriate Logic**
  - Inductive
  - Deductive
  - Technological
- **Formulate Hypothesis**

## Data Collection

- ***In Situ***
  - Field
  - Laboratory
  - Collateral data
- **Remote Sensing of Biophysical and Hybrid Data**
  - Passive analog
    - Camera
    - Videography
  - Passive digital
    - Camera
    - Multispectral scanners
    - Linear and area arrays
    - Spectroradiometers
  - Active
    - Microwave (radar)
    - Laser (Lidar)
    - Sonar

## Data Analysis

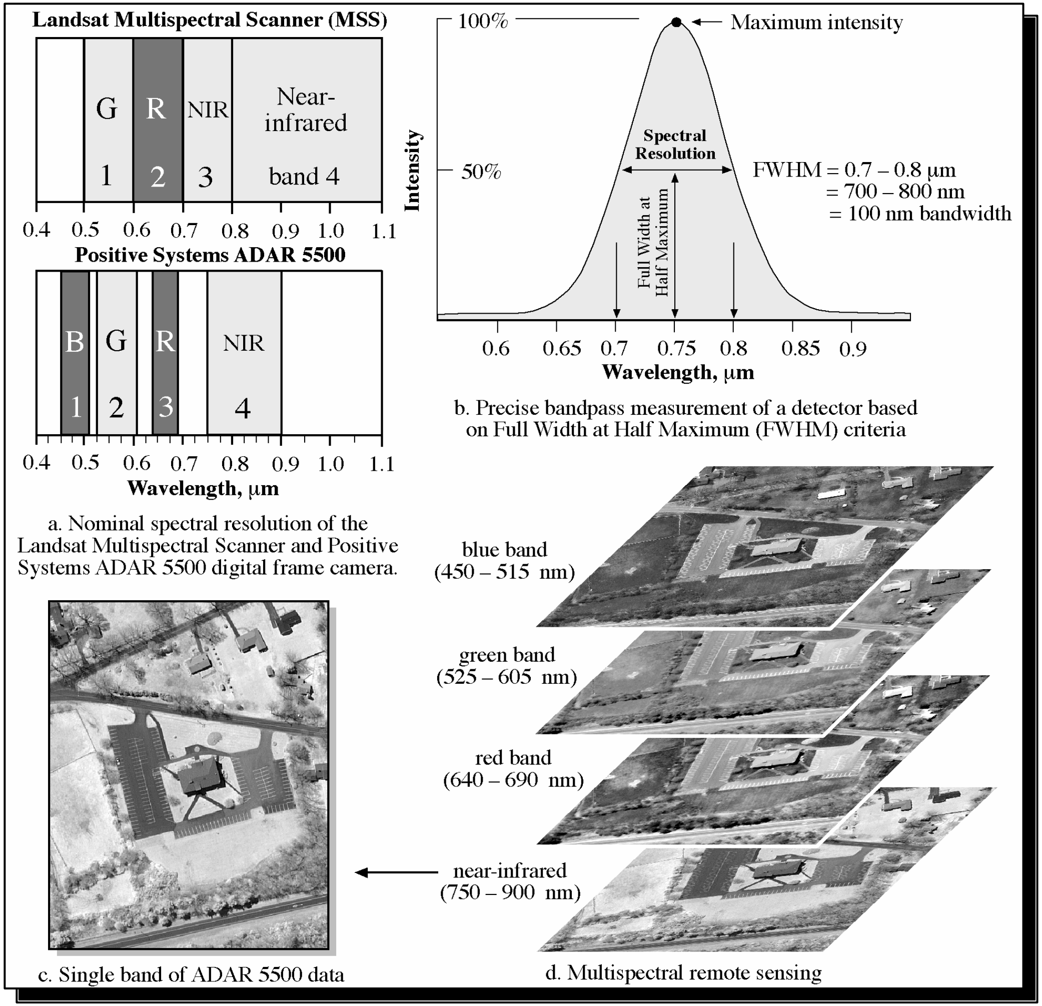
- **Analog (Visual) Image Processing**
  - Using the "Elements of Image Interpretation"
- **Digital Image Processing**
  - Pattern recognition
    - Statistical, syntactical
  - Expert systems
    - Using a knowledge base and inference engine
  - Neural networks
  - Modeling
    - Spatial modeling using GIS data
    - Scene modeling based on physics of energy/matter interactions
- **Scientific Visualization**
- **Hypothesis Testing**
  - Accept or reject hypothesis

## Information Presentation

- **Analog and Digital**
  - Images
  - Image maps
  - Orthophotomaps
  - Thematic maps
  - Spatial databases
- **Error Report**
  - Geometric
  - Thematic
- **Image Lineage**
  - Genealogy
- **Statistics**
  - Univariate
  - Multivariate
- **Graphs**
  - 1d, 2d, 3-dimension

Jensen, 2000

# Spectral Resolution



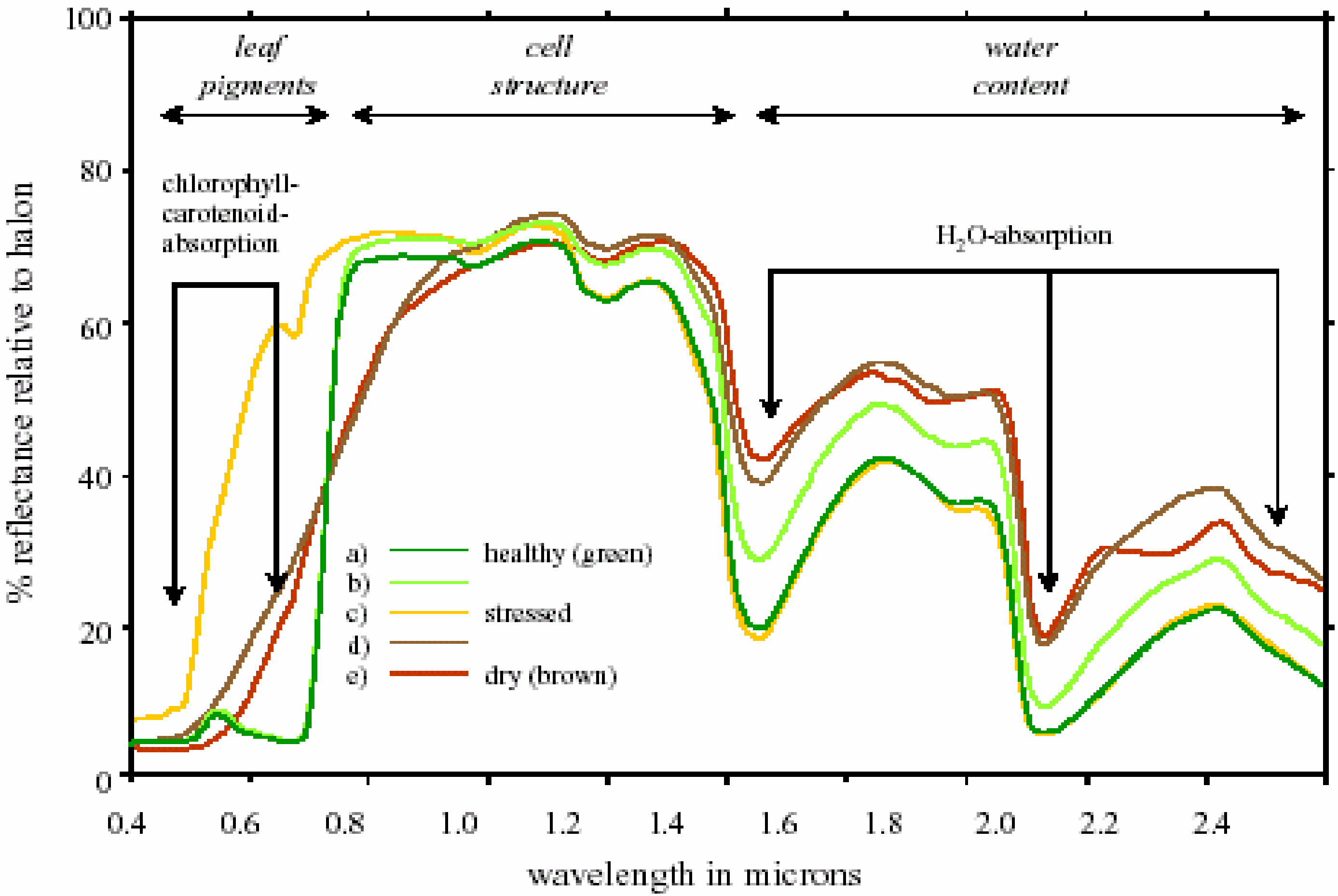

a. Nominal spectral resolution of the Landsat Multispectral Scanner and Positive Systems ADAR 5500 digital frame camera.

b. Precise bandpass measurement of a detector based on Full Width at Half Maximum (FWHM) criteria

c. Single band of ADAR 5500 data

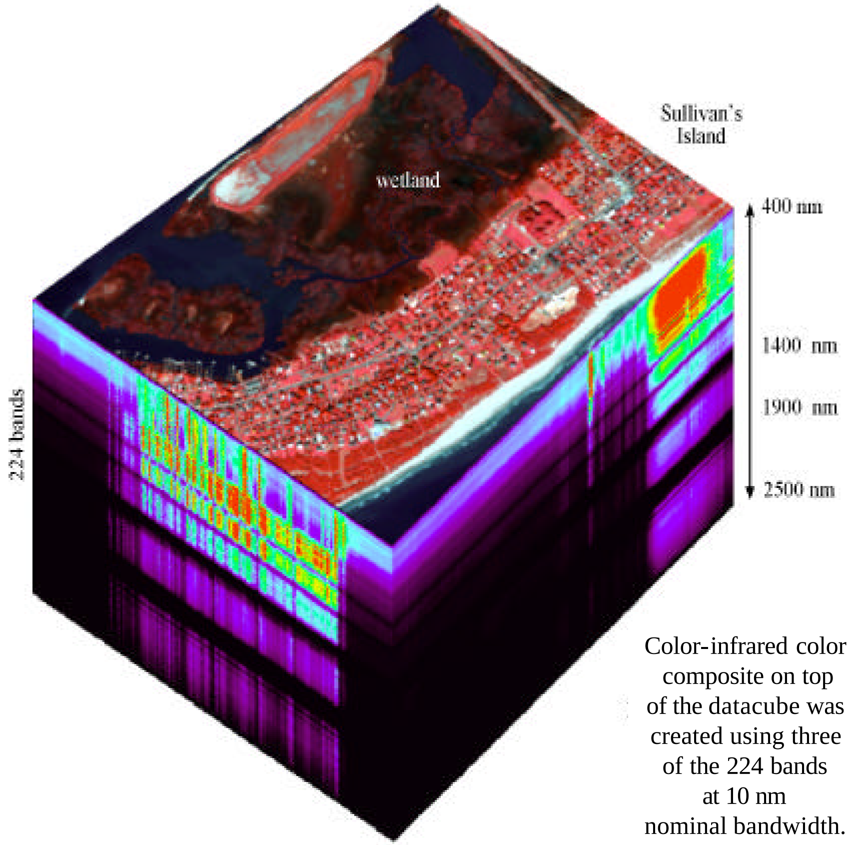
d. Multispectral remote sensing

Jensen, 2000



leaf pigments
cell structure
water content
chlorophyll-carotenoid-absorption
H2O-absorption
a) healthy (green)
b)
c) stressed
d)
e) dry (brown)
% reflectance relative to halon
wavelength in microns
0
20
40
60
80
100
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4

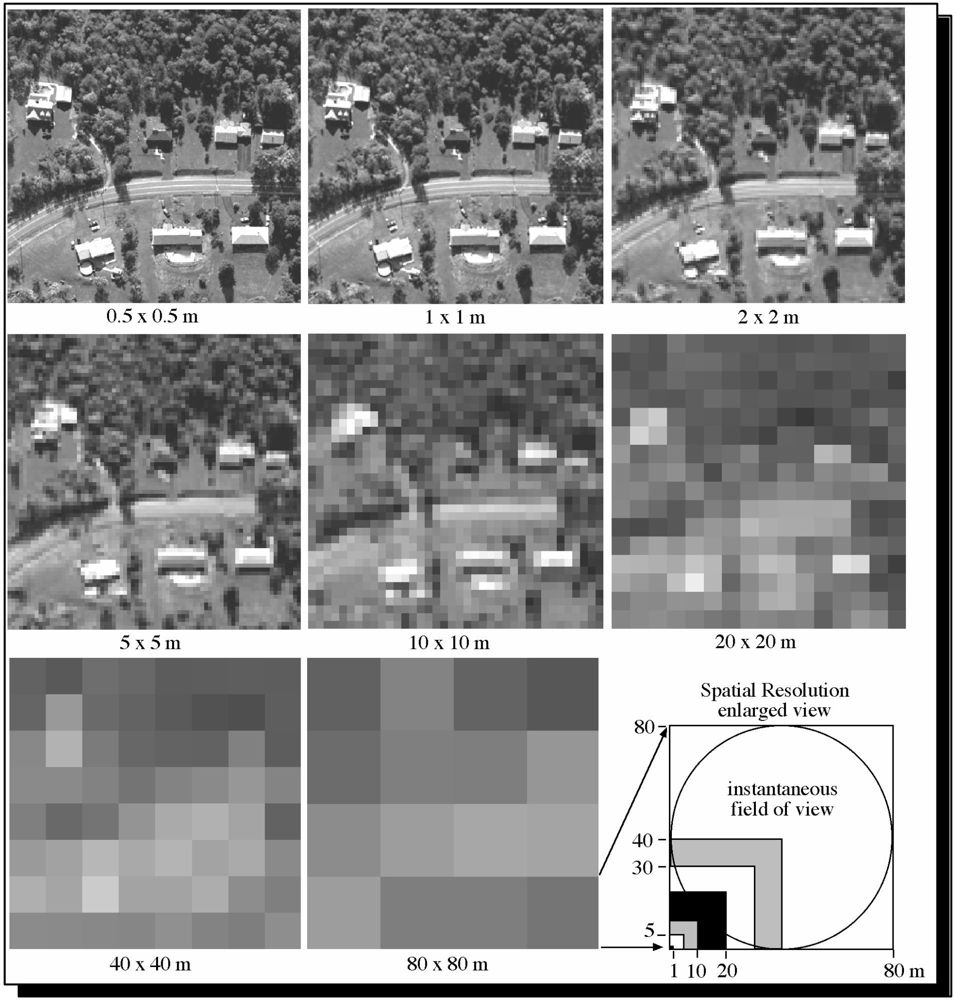
# Airborne Visible Infrared Imaging Spectrometer (AVIRIS) Datacube of Sullivan's Island Obtained on October 26, 1998



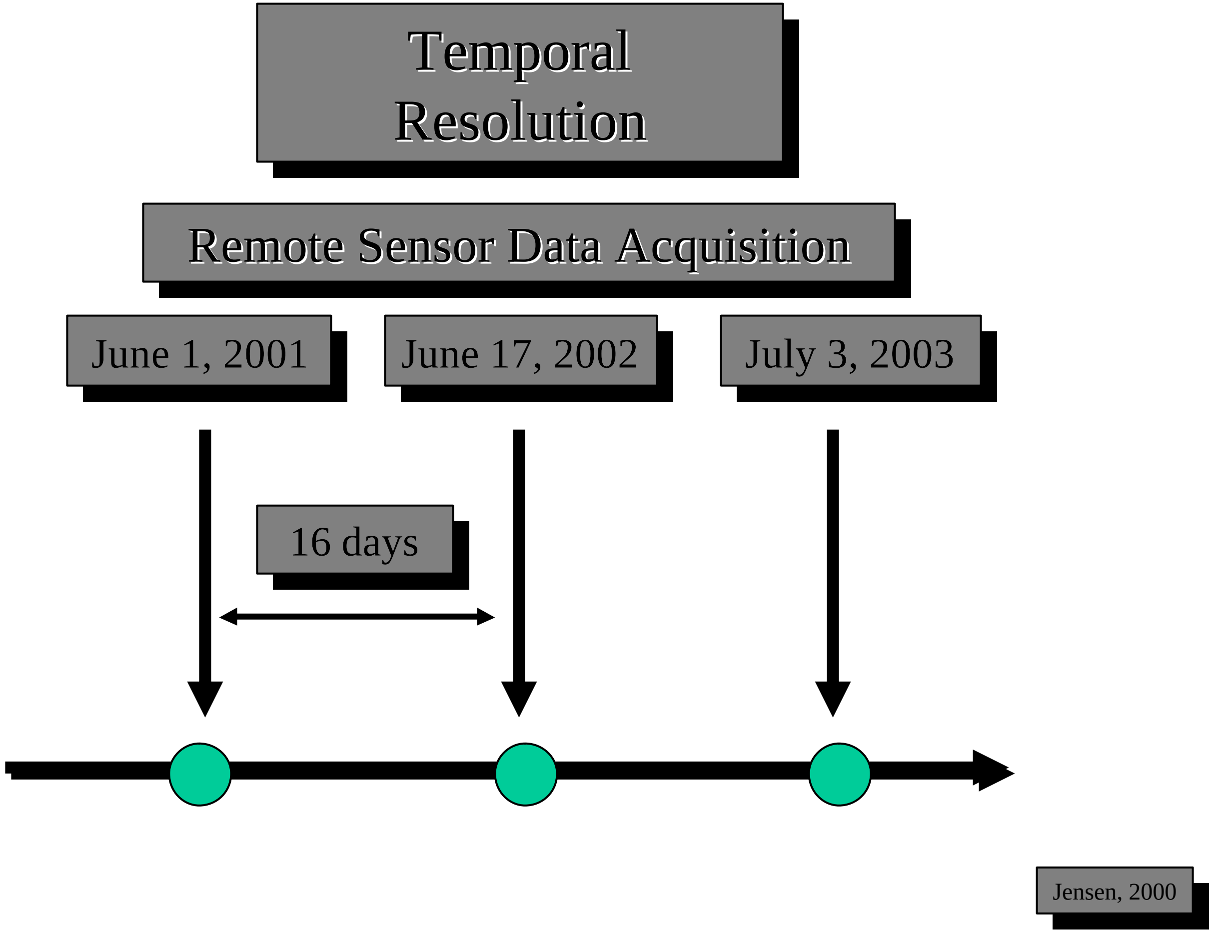

Color-infrared color composite on top of the datacube was created using three of the 224 bands at 10 nm nominal bandwidth.

Jensen, 2000

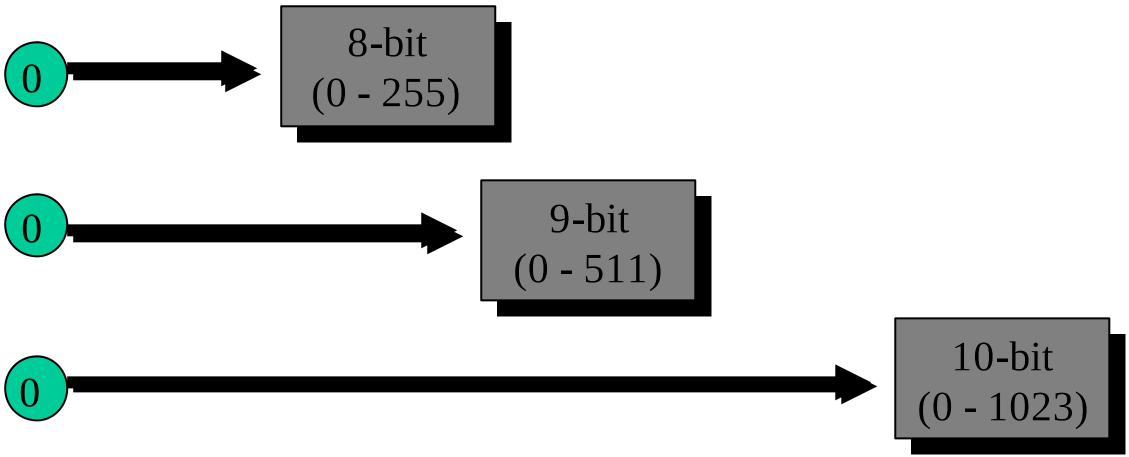
# Spatial Resolution




Jensen, 2000

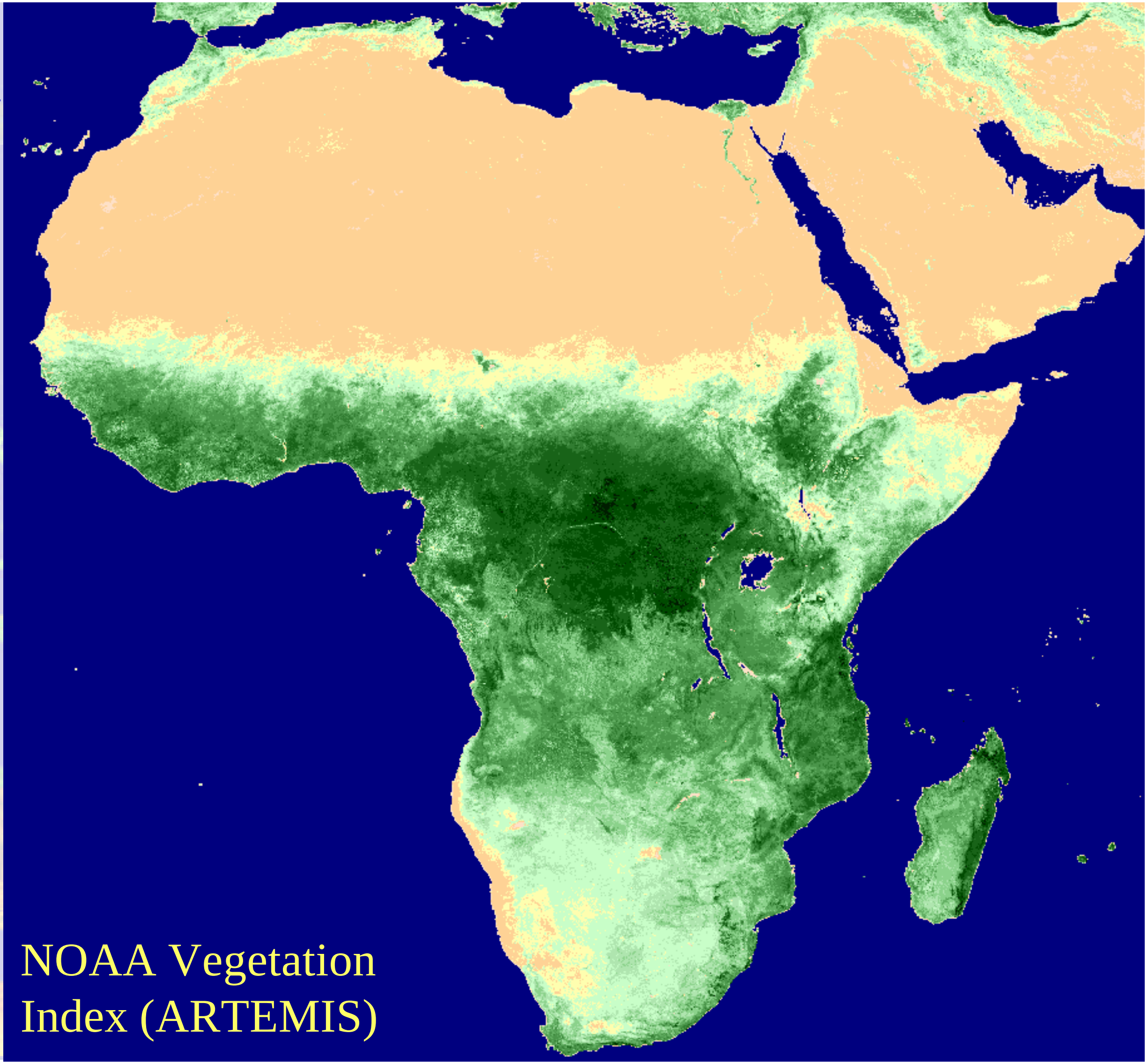

Temporal Resolution
Remote Sensor Data Acquisition
June 1, 2001
June 17, 2002
July 3, 2003
16 days
Jensen, 2000

# Radiometric Resolution



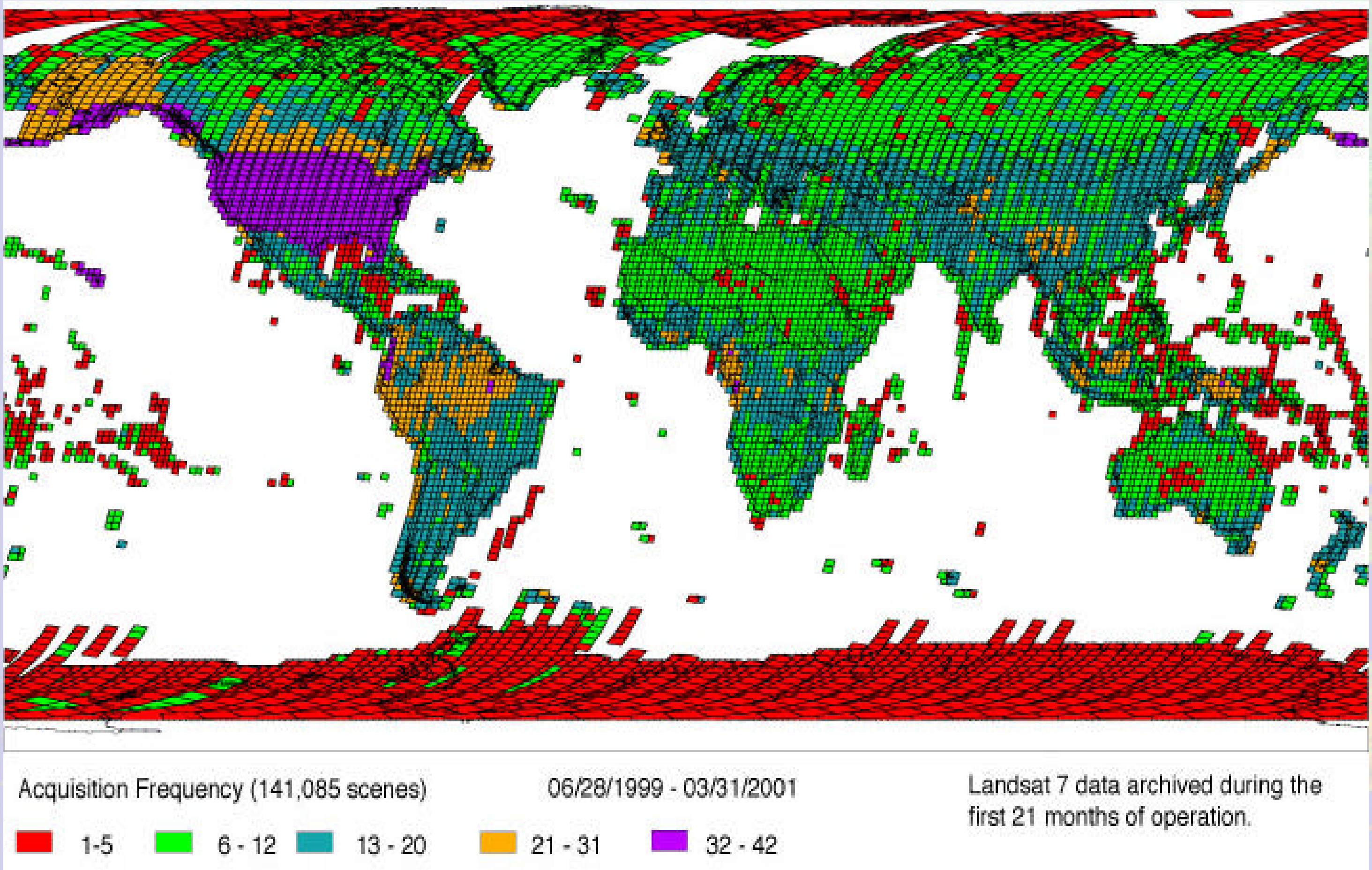

Jensen, 2000

# Data Availability



NOAA Vegetation Index (ARTEMIS)

# Data Availability (example ETM+)



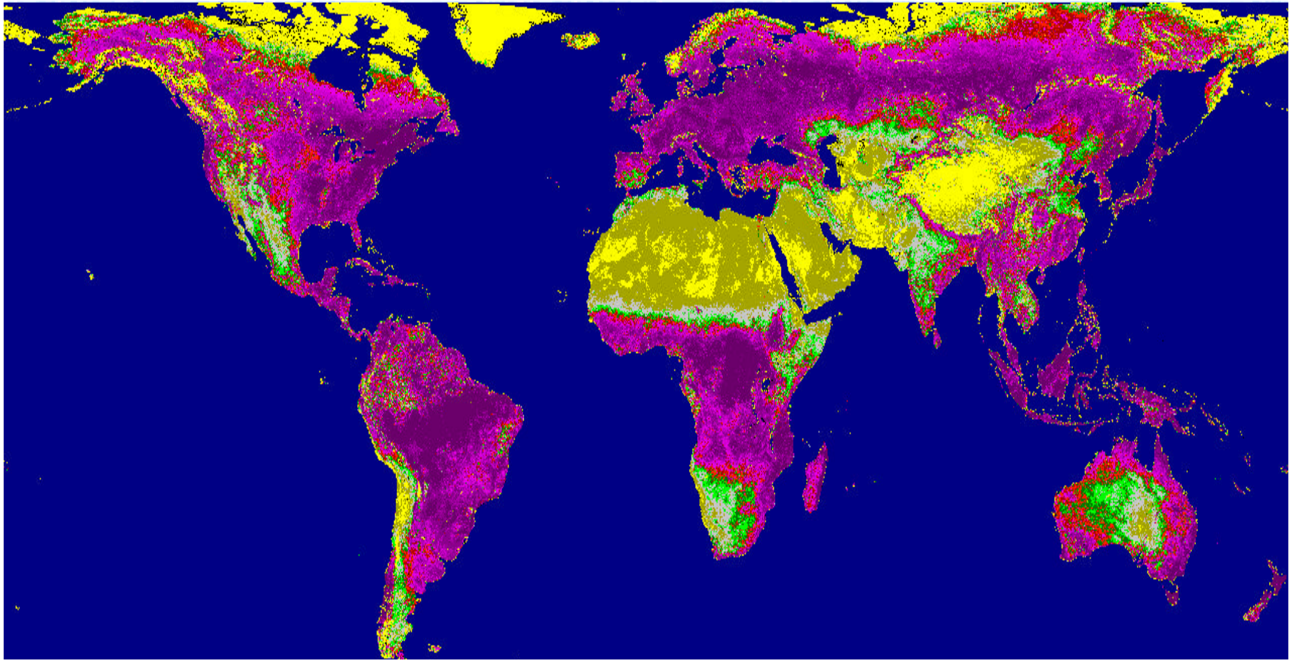

From: Scole & Gunawan, GOFC Implementation

# VEGETATION (on SPOT)

- Launch: 24.3.1998
- Altitude: 820 km
- Swath 2250 km, Revisit 1 day, off nadir viewing
- Spatial Res. 1160 m
- Spectral Res.: red, nir, mr

GLC2000 (Global Landcover 2000 Project)

**SPOT-4 VEGETATION** the first <u>operational global</u> vegetation monitoring capability at 1 km resolution; FAO access to global VEGETATION data enabled in April 1999 on demonstration basis through a cooperative agreement with the EC Joint Research Centre, Ispra; near realtime access on fully operational basis through SPOT Image with EC funding support since May 2000



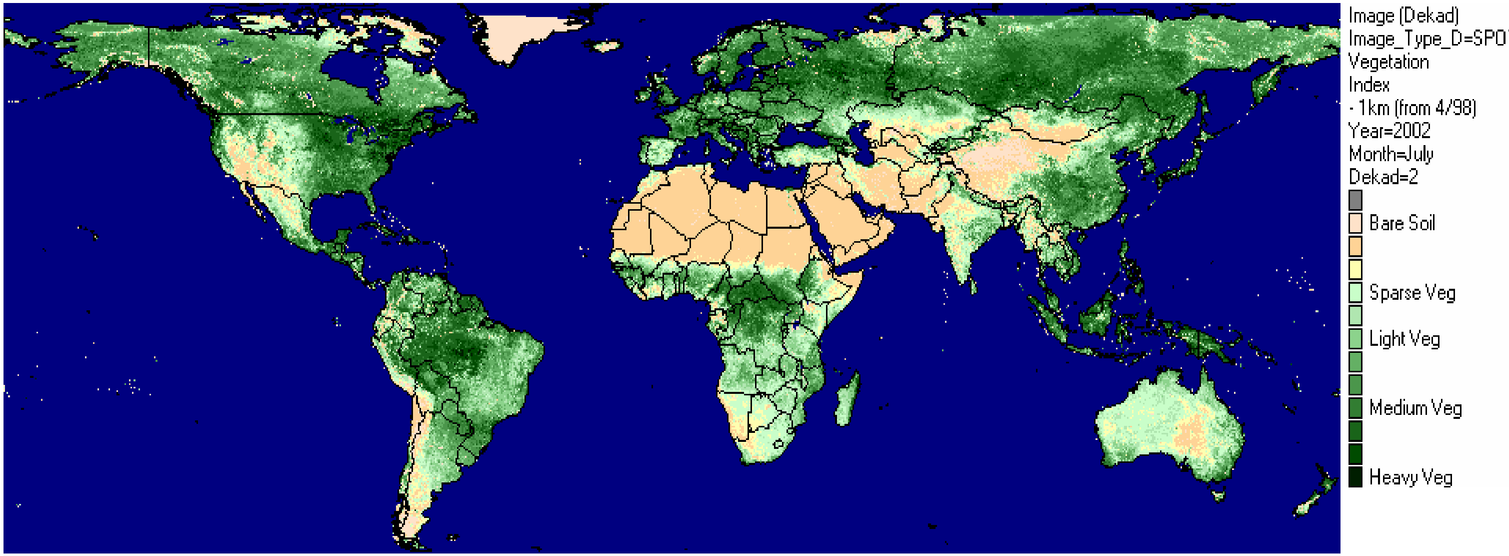
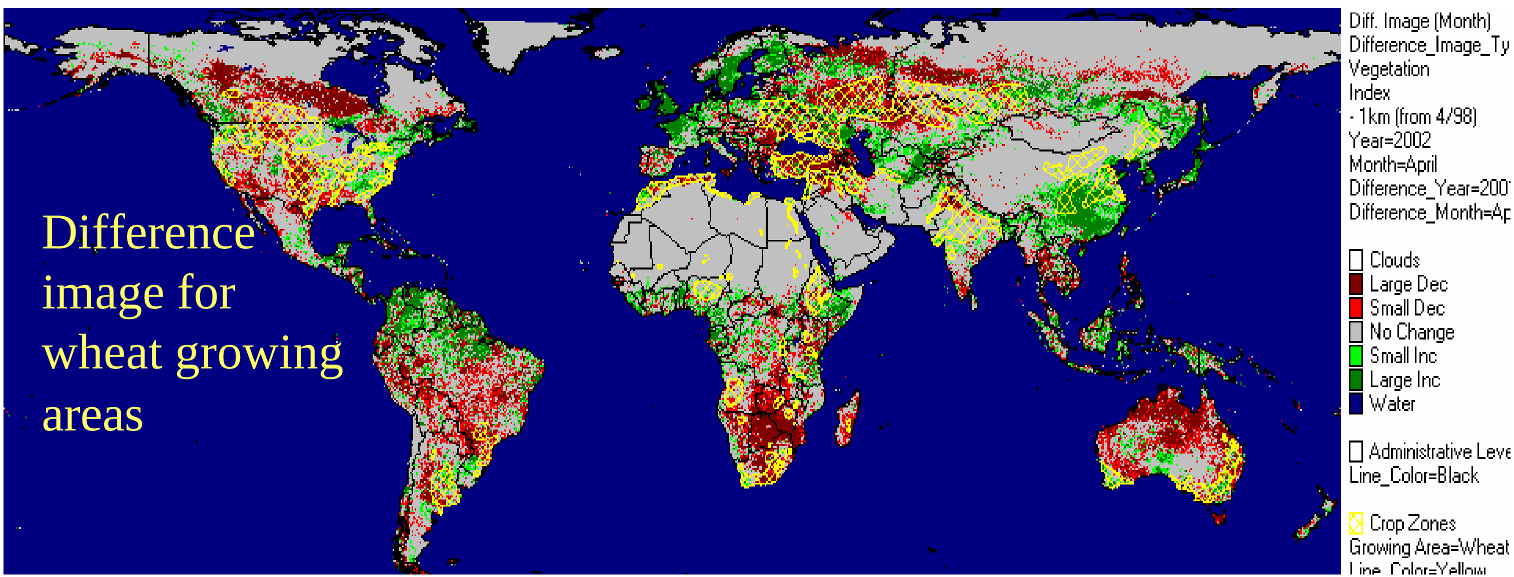


Image (Dekad)
Image_Type_D=SPOT
Vegetation
Index
- 1km (from 4/98)
Year=2002
Month=July
Dekad=2
Bare Soil
Sparse Veg
Light Veg
Medium Veg
Heavy Veg


Diff. Image (Month)
Difference_Image_Ty
Vegetation
Index
- 1km (from 4/98)
Year=2002
Month=April
Difference_Year=200
Difference_Month=Ap
Clouds
Large Dec
Small Dec
No Change
Small Inc
Large Inc
Water
Administrative Leve
Line_Color=Black
Crop Zones
Growing Area=Wheat
Difference image for wheat growing areas

# MODIS

(Moderate Resolution Imaging Spectroradiometer) :

| Primary Use | Band No. | Bandwidth (µm) | Spectral Radiance NESR ($W\ m^{-2}\ \mu m^{-1}\ sr^{-1}$) | Required SNR (Required NE$\Delta$T in K) | Spatial Resolution at nadir |
|---|---|---|---|---|---|
| Land/Cloud Boundaries | 1 | 0.620 - 0.670 | 21.8 | 128 | 250 m |
| | 2 | 0.841 - 0.876 | 24.7 | 201 | |
| Land/Cloud Properties | 3 | 0.459 - 0.479 | 35.3 | 243 | 500 m |
| | 4 | 0.545 - 0.565 | 29.0 | 228 | |
| | 5 | 1.230 - 1.250 | 5.4 | 74 | |
| | 6 | 1.628 - 1.652 | 7.3 | 275 | |
| | 7 | 2.105 - 2.155 | 1.0 | 110 | |
| Ocean Color/ Phytoplankton/ Biogeochemistry | 8 | 0.405 - 0.420 | 44.9 | 880 | 1000 m |
| | 9 | 0.438 - 0.448 | 41.9 | 838 | |
| | 10 | 0.483 - 0.493 | 32.1 | 802 | |
| | 11 | 0.526 - 0.536 | 27.9 | 754 | |
| | 12 | 0.546 - 0.556 | 21.0 | 750 | |
| | 13 | 0.662 - 0.672 | 9.5 | 910 | |
| | 14 | 0.673 - 0.683 | 8.7 | 1087 | |
| | 15 | 0.743 - 0.753 | 10.2 | 586 | |
| | 16 | 0.862 - 0.877 | 6.2 | 516 | |
| Atmospheric Water Vapor | 17 | 0.890 - 0.920 | 10.0 | 167 | |
| | 18 | 0.931 - 0.941 | 3.6 | 57 | |
| | 19 | 0.915 - 0.965 | 15.0 | 250 | |
| Surface/Cloud Temperature | 20 | 3.660 - 3.840 | 0.45 | (0.05) | |
| | 21 | 3.929 - 3.989 | 2.38 | (2.00) | |
| | 22 | 3.929 - 3.989 | 0.67 | (0.07) | |
| | 23 | 4.020 - 4.080 | 0.79 | (0.07) | |
| Atmospheric Temperature | 24 | 4.433 - 4.598 | 0.17 | (0.25) | |
| | 25 | 4.482 - 4.549 | 0.59 | (0.25) | |
| Cirrus Clouds | 26 | 1.360 - 1.390 | 6.00 | 150 | |
| Water Vapor | 27 | 6.535 - 6.895 | 1.16 | (0.25) | |
| | 28 | 7.175 - 7.475 | 2.18 | (0.25) | |
| | 29 | 8.400 - 8.700 | 9.58 | (0.25) | |
| Ozone | 30 | 9.580 - 9.880 | 3.69 | (0.25) | |
| Surface/Cloud Temperature | 31 | 10.780 - 11.280 | 9.55 | (0.05) | |
| | 32 | 11.770 - 12.270 | 8.94 | (0.05) | |
| Cloud Top Altitude | 33 | 13.185 - 13.485 | 4.52 | (0.25) | |
| | 34 | 13.485 - 13.785 | 3.76 | (0.25) | |
| | 35 | 13.785 - 14.085 | 3.11 | (0.25) | |
| | 36 | 14.085 - 14.385 | 2.08 | (0.35) | |

**Table 169: MODIS spectral performance parameters**

# TERRA – MODIS-Produkte

- surface temperature
- water leaving radiance
- chlorophyll fluorescence
- concentration of chlorophyll-a within 35 percent, net ocean primary productivity, other optical properties;
- vegetation/land-surface cover, conditions, and productivity;
- cloud mask containing confidence of clear sky (or the probability of cloud), shadow, fire, and heavy aerosol at 1-km resolution;
- cloud properties characterized by cloud phase, optical thickness, particle size and mass transport;
- fire occurrence, temperature, and burn scars;
- global distribution of total precipitable water;
- cirrus cloud cover.

## 3. Terrestrial Variables

- River discharge
- Water use
- Ground water
- ✓ Lake levels
- (✓) Snow cover
- (✓) Glaciers and ice caps
- Permafrost and seasonally-frozen ground
- ✓ Albedo
- Land cover (including vegetation type)
- ✓ Fraction of absorbed photosynthetically active radiation (FAPAR)
- Leaf area index (LAI)
- Biomass
- Fire disturbance

**3 (-5) directly retrievable from EO out of 13**

# Biomass information requirements

**The terrestrial carbon balance:**

- **Mass balance equation (Inventory approach)**

$\Delta$ C= $\Delta$ **Above Ground Biomass** + $\Delta$ Below Ground Biomass +
$\Delta$ Litter + $\Delta$ Soil Carbon

- **Process equation (Dynamic Vegetation Model Approach, Productivity Efficiency Approach)**

$\Delta$ C= Gross Primary Production- Autotrophic respiration-
Heterotrophic respiration - Loss by disturbances

(GPP and Ra: depend on biomass)

# Use of biomass in satellite driven models

**NPP=e * IPAR * fAPAR - Autotrophic Respiration**

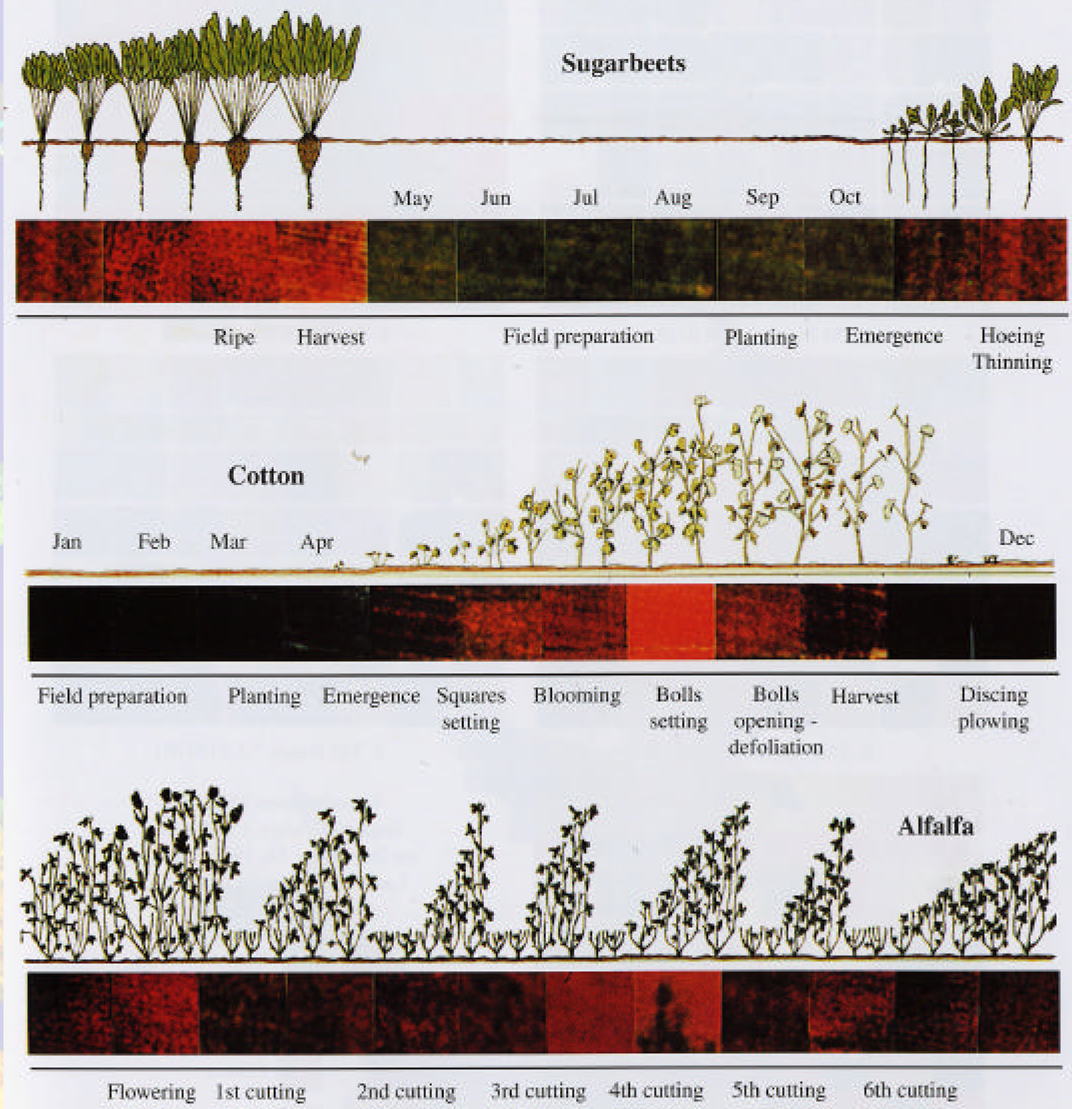
Photosynthetic Efficiency (literature)

From NDVI (e.g. Spot/Vegetation)

Incoming Radiation (e.g. ECMWF)

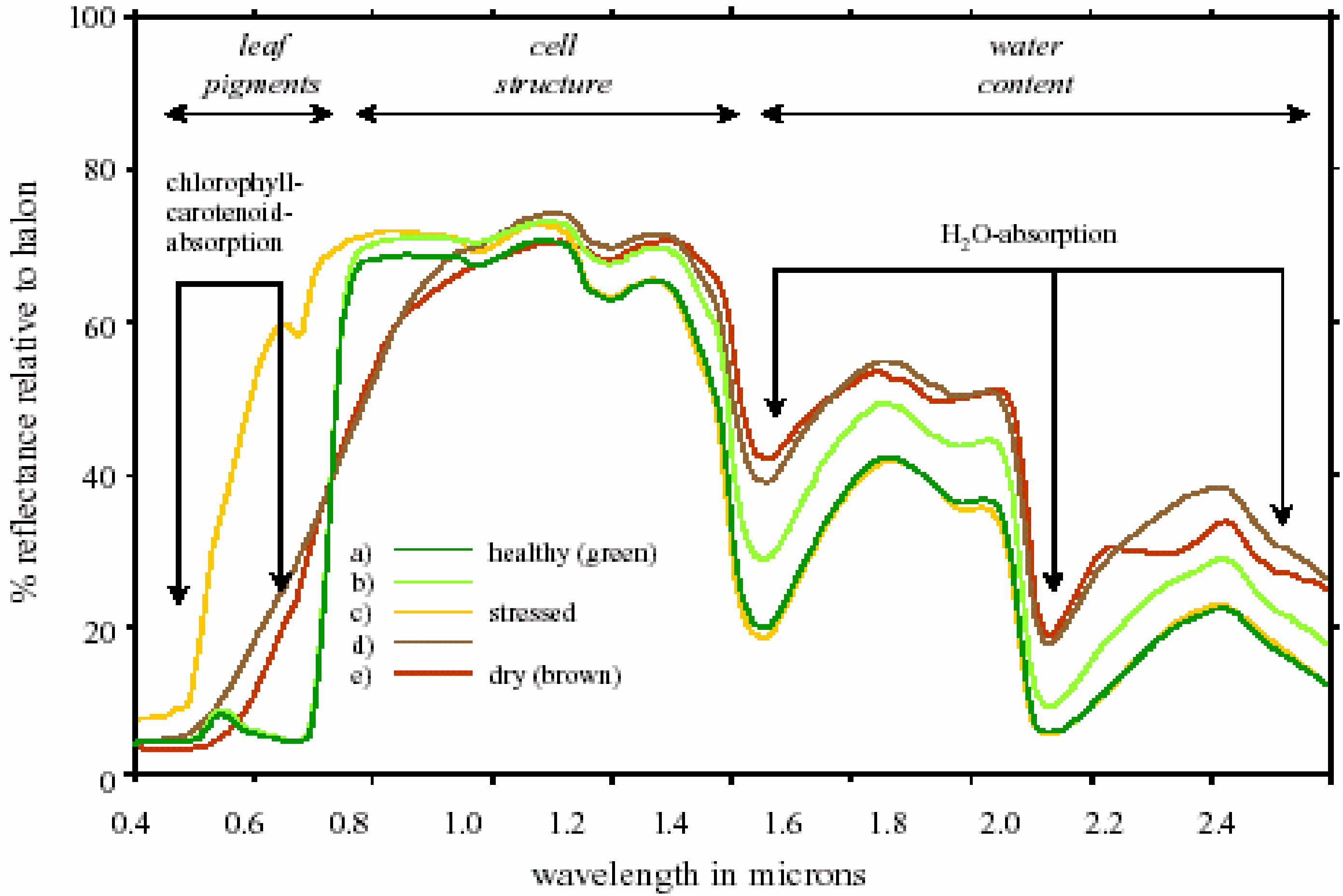
Autotrophic respiration = function of Temperature and Biomass (Biomass map (1°) by Olson (1985) used in models)

Kansas, Landsat 7 ETM+
ERDE Kunstwerk (DLR, GEO)

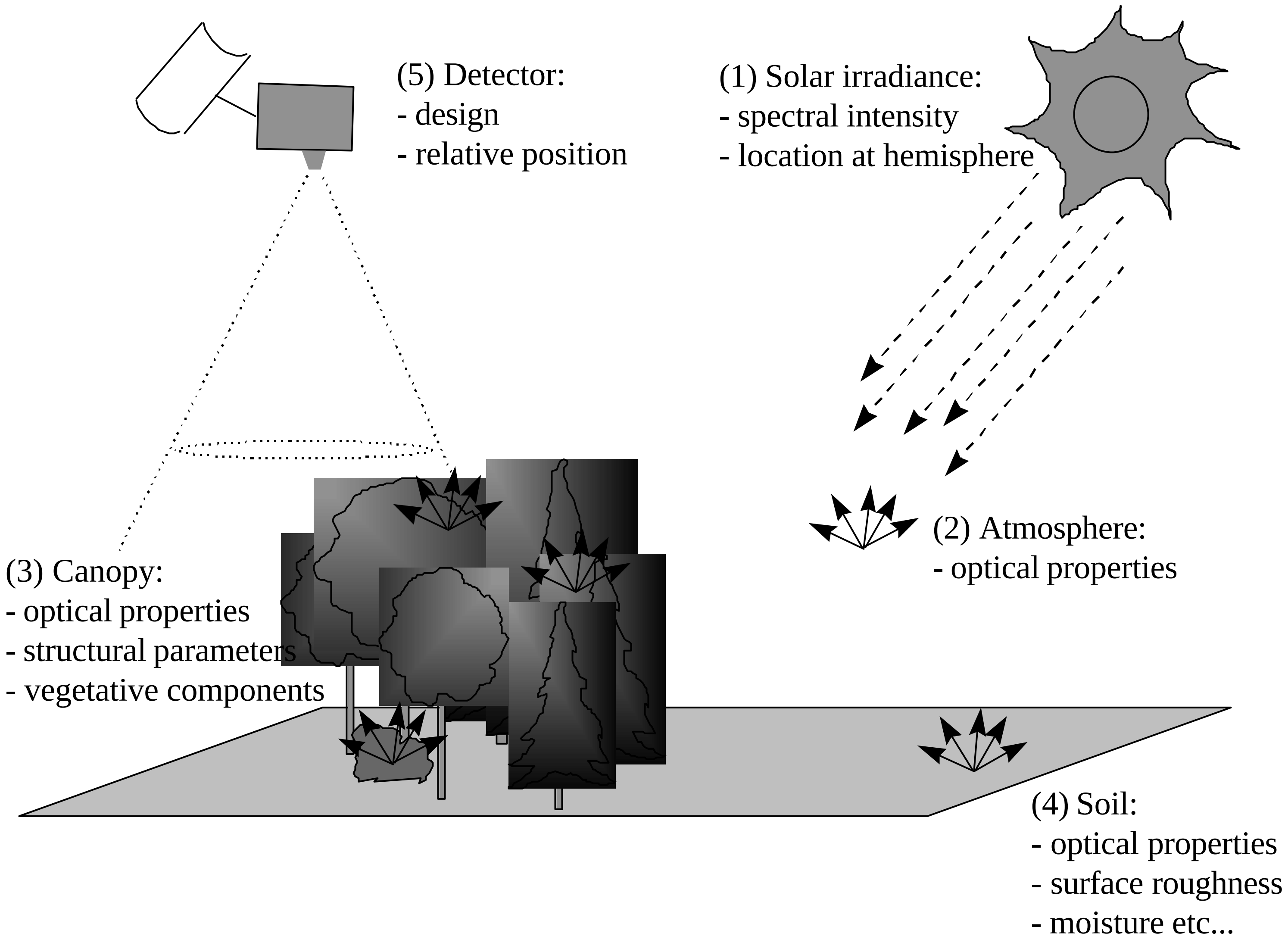


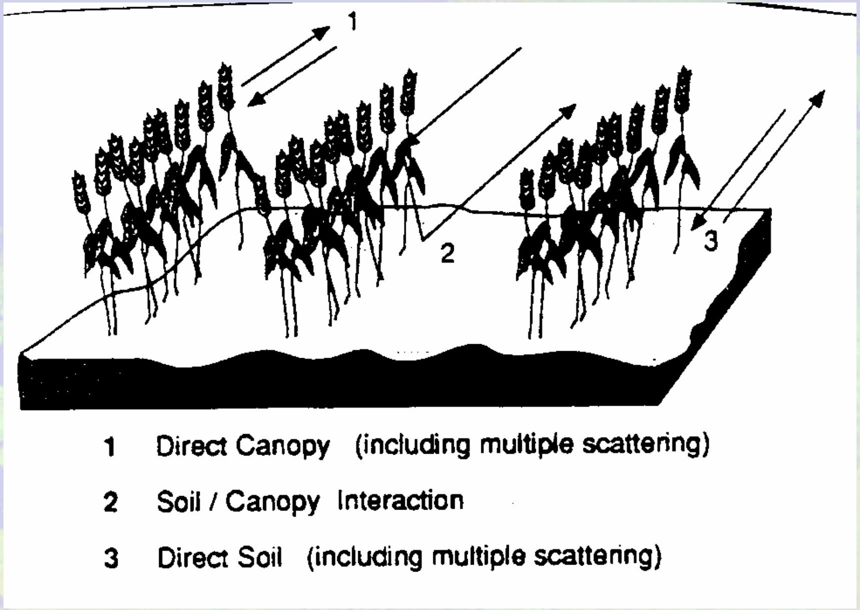
Sugarbeets
May
Jun
Jul
Aug
Sep
Oct
Ripe
Harvest
Field preparation
Planting
Emergence
Hoeing
Thinning
Cotton
Jan
Feb
Mar
Apr
Dec
Field preparation
Planting
Emergence
Squares setting
Blooming
Bolls setting
Bolls opening - defoliation
Harvest
Discing plowing
Alfalfa
Flowering
1st cutting
2nd cutting
3rd cutting
4th cutting
5th cutting
6th cutting


(Jensen, 10-4)

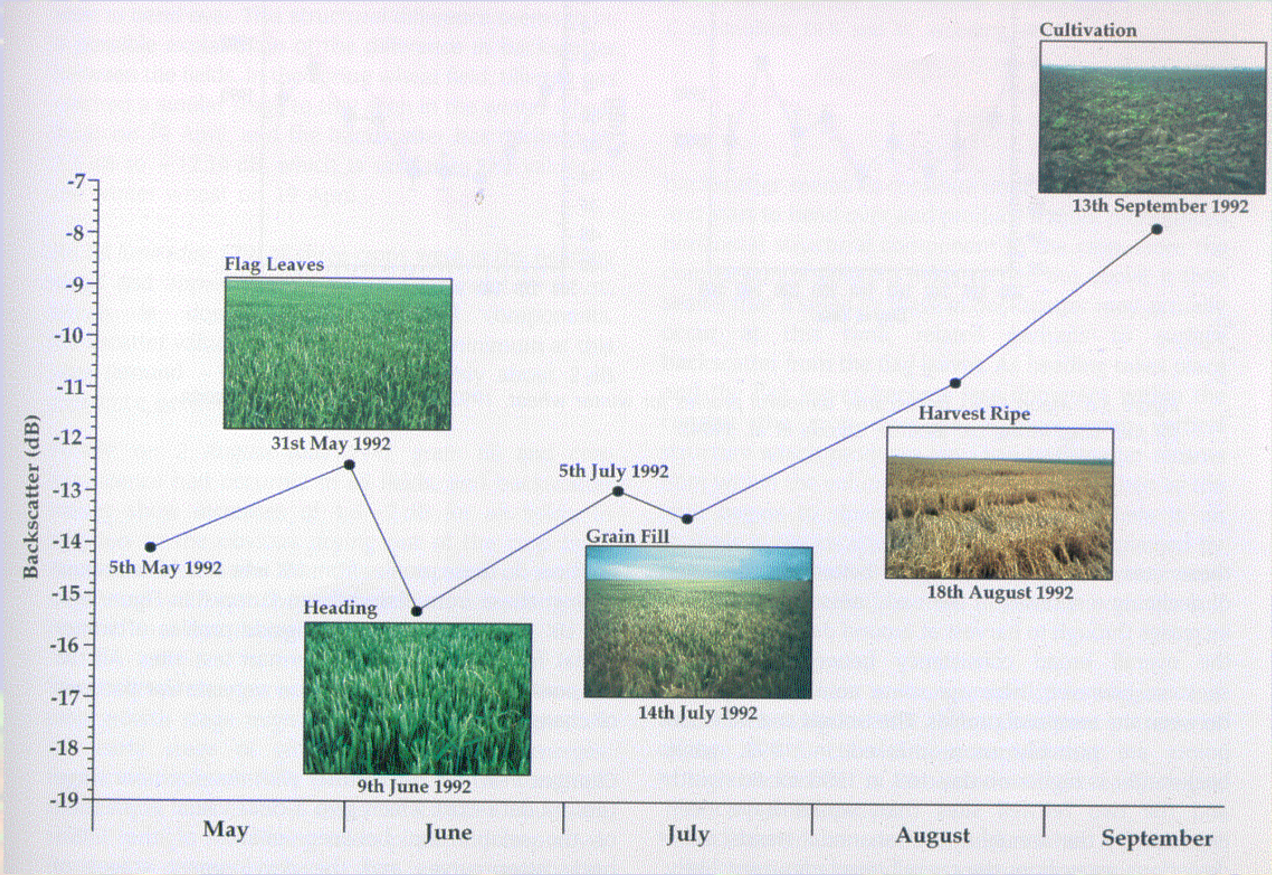



Normalised Difference Vegetation Index: no information on type and structure!
Multispectral and bi-directional information needed.


(5) Detector:
- design
- relative position
(1) Solar irradiance:
- spectral intensity
- location at hemisphere
(2) Atmosphere:
- optical properties
(3) Canopy:
- optical properties
- structural parameters
- vegetative components
(4) Soil:
- optical properties
- surface roughness
- moisture etc...

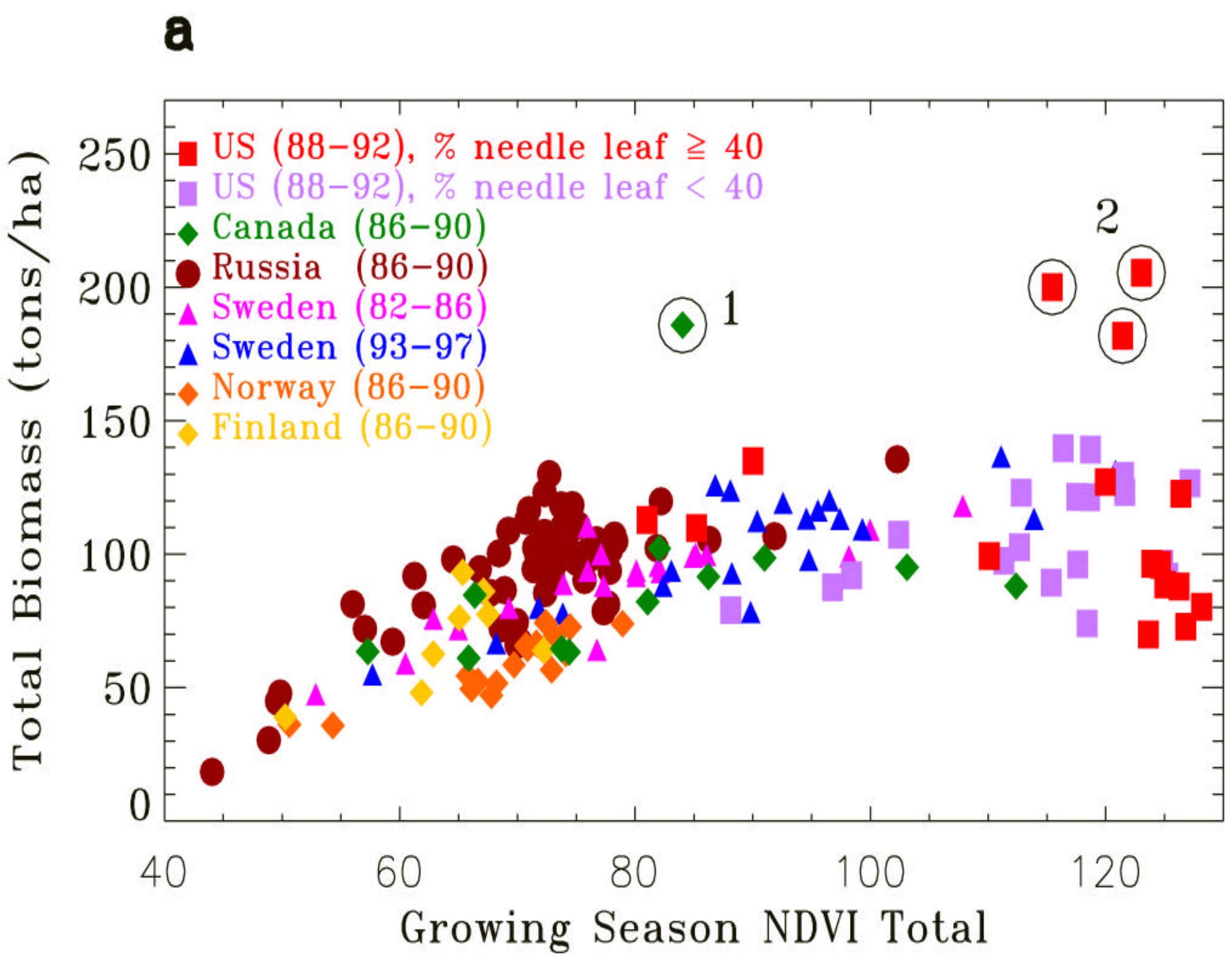



Schematic Illustration of Radar Backscatter Mechanisms from Crops in X-, C- and L-Band (~ 3, 5 and 20 cm).

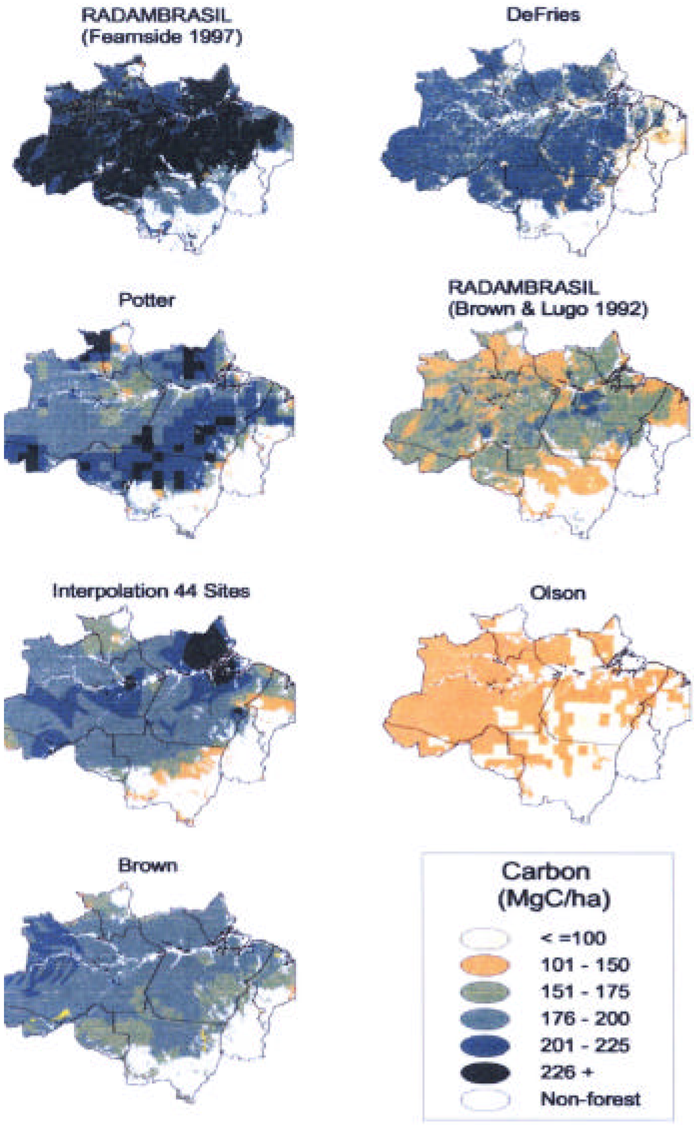



Multitemporal C-VV Radar Backscatter Profile from Wheat using ERS-1Time Series

(ESA-SP 1994)




Myneni, Tucker et al.




## Seven estimates of storage of carbon in forest biomass for the Brazilian Amazon

Houghton, R. A., K. T. Lawrence, J. L. Hackler, and S. Brown. 2001. The spatial distribution of forest biomass in the Brazilian Amazon: a comparison of estimates. Global Change Biology. 7: 731-746.

## Inventory approaches -

cannot be done with inaccurate biomass maps!

# What IS biomass?
# Main components of biomass distribution

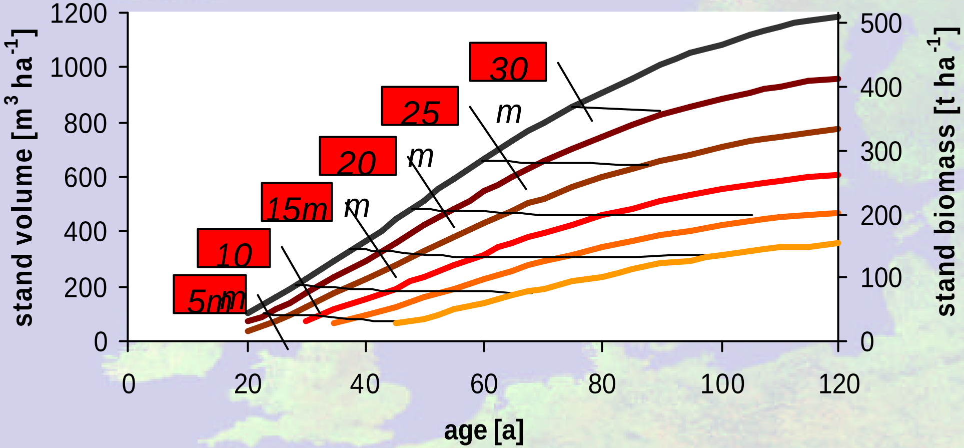
**Phytomass (> 90%)**
- **Above-ground ( approx. 80% )**
  - **Stem (> 90%)**
  - **Branches (< 10 %)**
  - **Leaves (2-4 %)**
  - **Undergrowth (?)**
- **Below-ground i.e. roots (ca. 20 %)**

**Zoomass (< 10 %)**

- Stem Biomass accounts for an estimated > 90% of the above-ground biomass in well developed natural forests and all comercial forests.
- Stem Biomass is strongly related to the commercially interesting biomass.
- The major part of forest biomass is concentrated in the major trees. The contribution of minor trees (and hidden biomass) to total biomass is rather low.
- Characterizing biomass using tree height will cover 75-95 % of the vegetated earth and could directly characterize 80-90% of the aboveground biomass stock

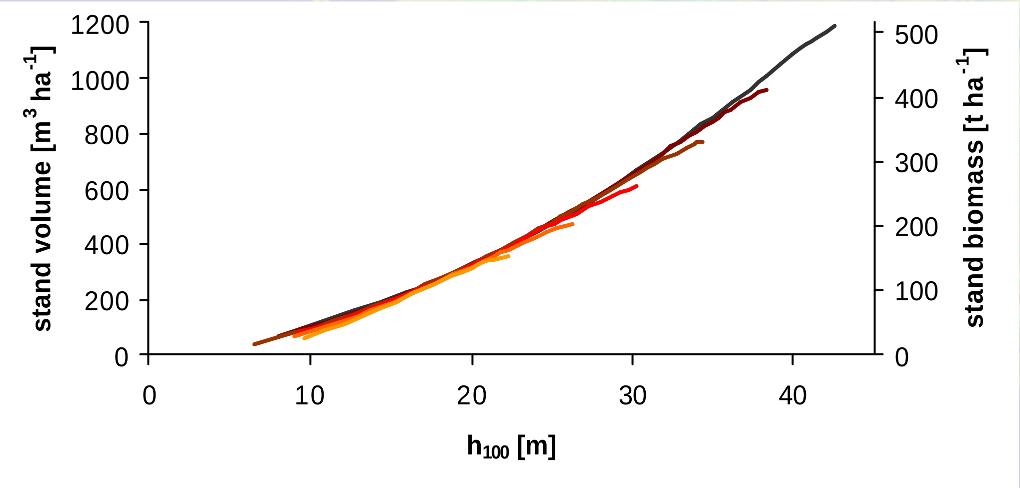
After Mette et al. (2002)

# The Effect of Age and Stand Conditions




***Picea abies***
***(Norway Spruce)***

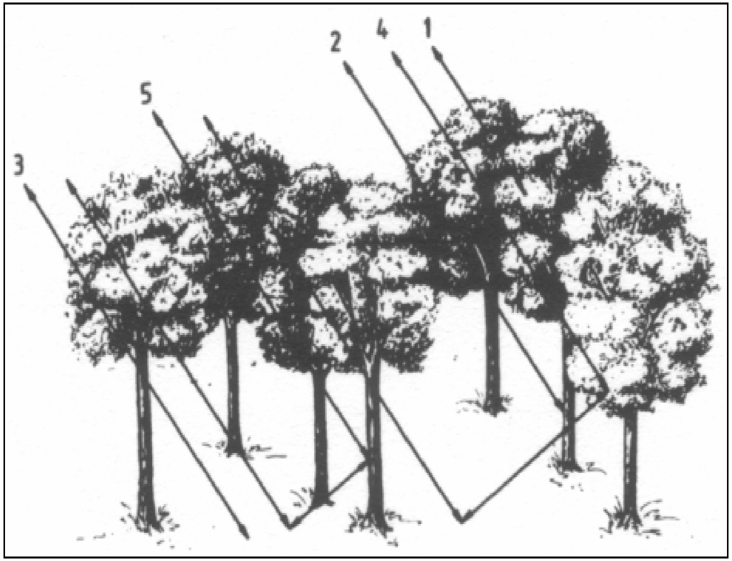
*Assmann 1963*
*(moderate thinning)*




***Stand conditions affect the forest growth rate, but typically not the allometry between height & biomass***

Mette, Hajinsek, Papathionassou et al. (2002), DLR

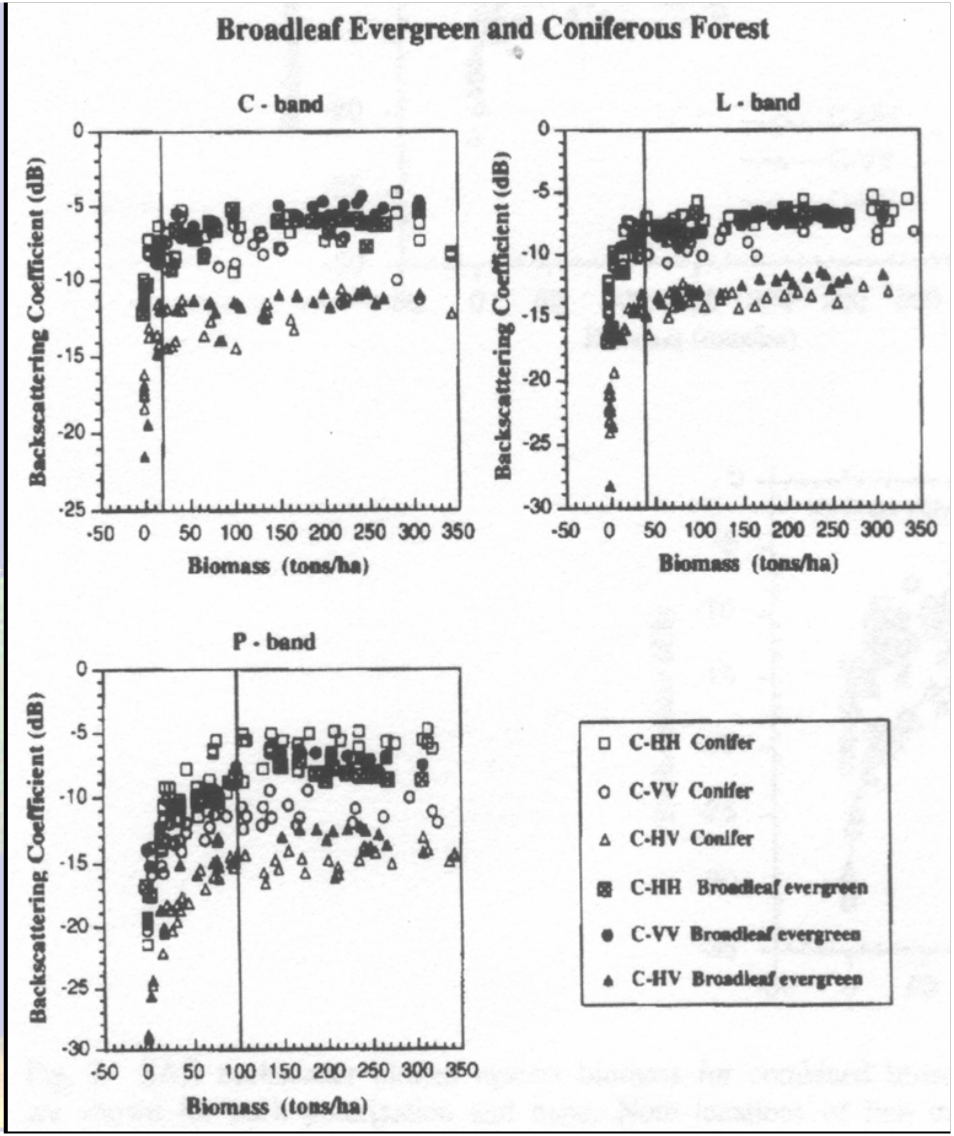
# Backscatter Mechanisms in a Forest Canopy




| Frequen-cy band | X | C | L | P | VHF |
|---|---|---|---|---|---|
| Main scatterers | Leaves, Twigs | Leaves Small branches | Branches | Branches & Trunk | Trunk |

LE TOAN et al. 2001: 4

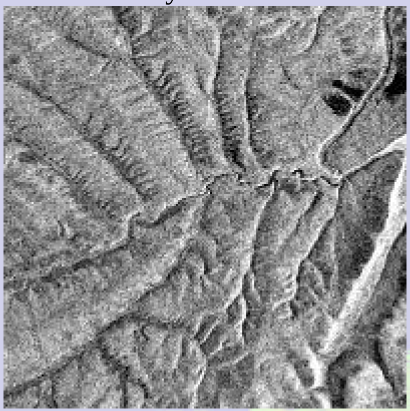
- AIRSAR (NASA/JPL) polarimetric C-, L- and P-Band with Incidence Angles of 40° and 50°




IMHOFF 1995: 514

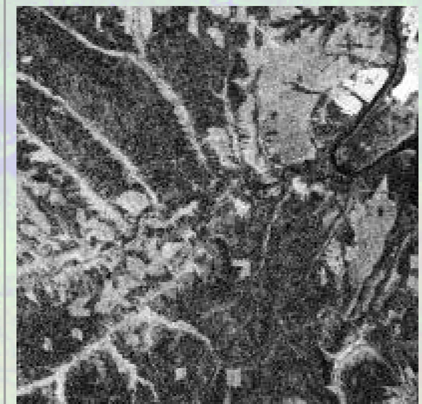
# Classification Source Data

ERS intensity



JERS intensity

ERS Tandem Coherence

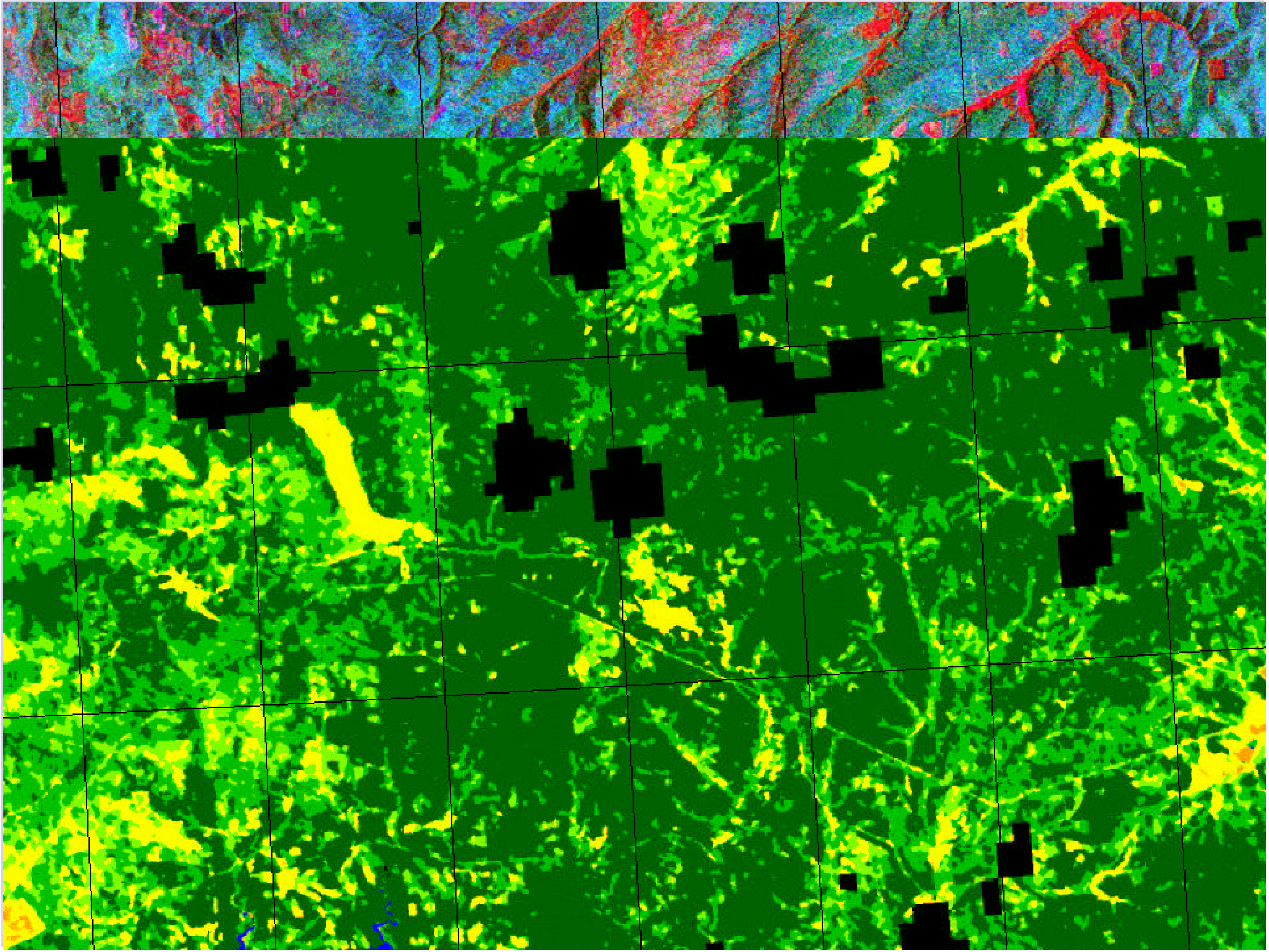


- Small dynamic range
- Variable response to water
- Variable response to open areas
- Can be used as indicator of environmental effects effecting the coherence

- Medium dynamic range
- Stable response to water
- Possible to identify agricultural fields
- Higher frame to frame variations

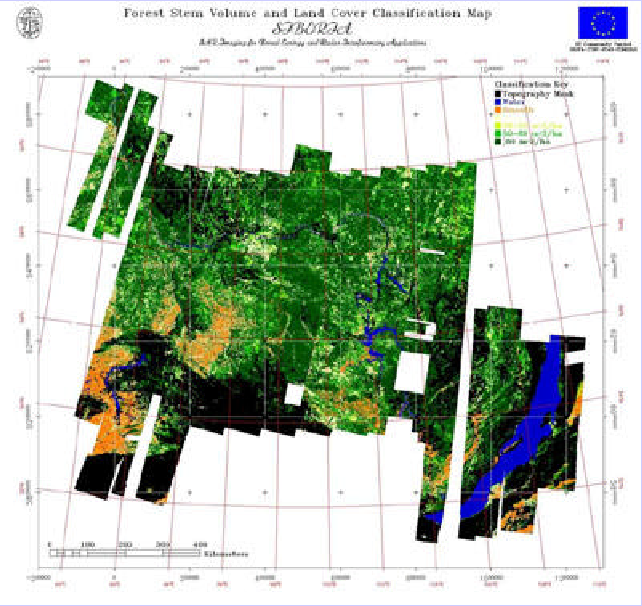
- Higher contrast between forest/non forest
- Higher sensitivity to forest volume
- Confusion between water and dense forest
- Frame to frame variations

(L. Eriksson)



## Vegetation Data Resources

Above Ground Biomass




**Nothing** as yet global and accessible as Above Ground Biomass

Regional - SIBERIA (1mio $km^2$ at 50m, 1998) based on SAR Interferometry

Future - SIBERIA-II (from 2002-5)
Other SAR methods
ESSP VCL?

http://pipeline.swan.ac.uk/siberia/