Earth Observation Measurements in Terrestrial Carbon Cycle Science

Shaun Quegan (+ CTCD, CESBIO, JRC, KCL et al.)

NERC Centre for Terrestrial Carbon Dynamics
& University of Sheffield

Lecture content

- EO data relevant to C calculations
- Interfacing the data to the models
- Data types and their limitations

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The Terrestrial Carbon Balance

Mass balance: $\Delta C = \Delta B_A + \Delta B_B + \Delta L + \Delta S$

Process equation: $\Delta C = GPP - R_P - R_H - D$

ΔC	carbon sequestration by vegetation and soil,
B	biomass (*A*: above and *B*: below ground),
L	litter,
S	soil carbon,
GPP	gross primary production (photosynthesis),
R	respiration (*P*: plant and *H*: heterotrophic),
D	carbon loss by disturbance.

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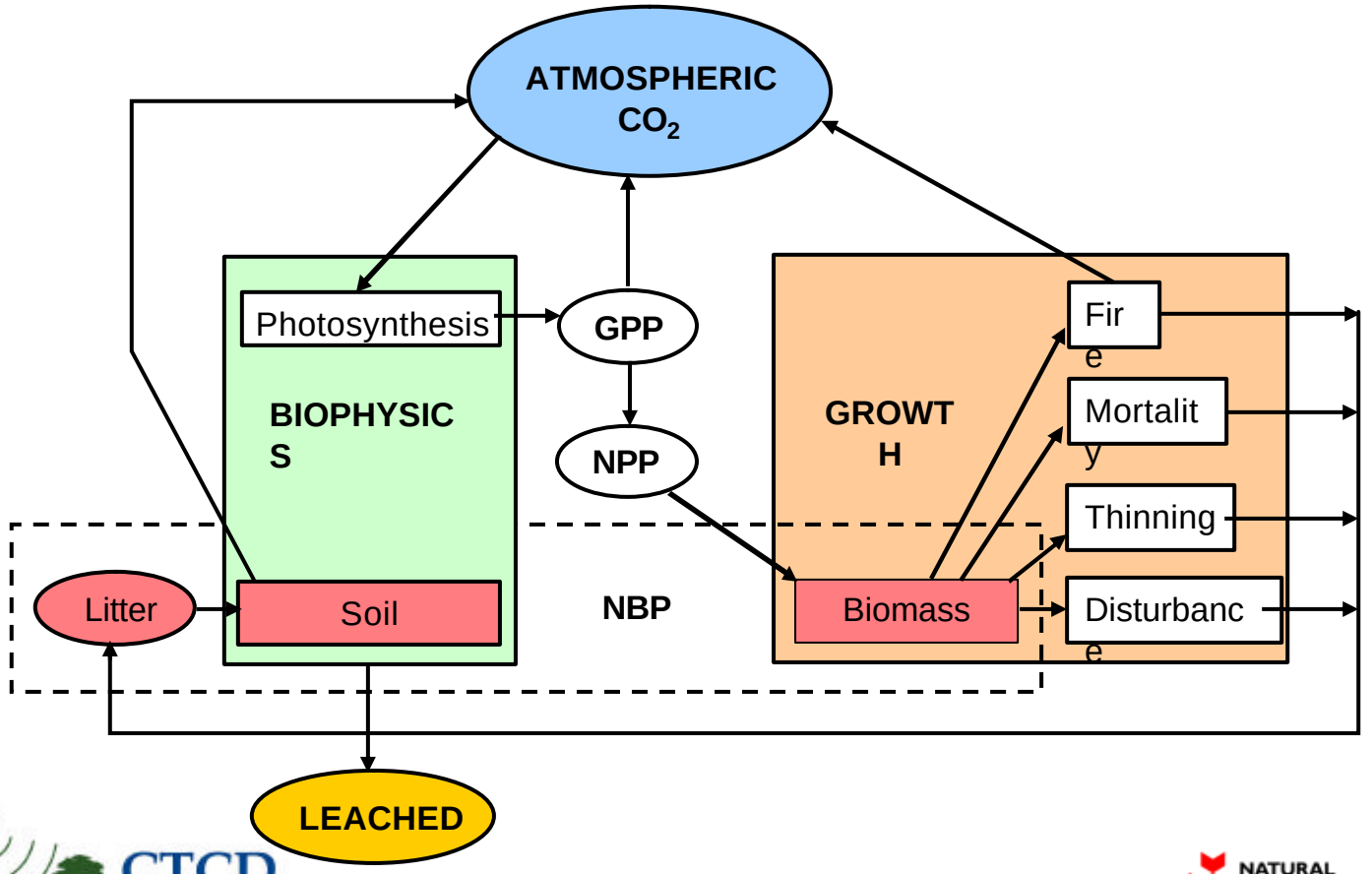
The SDGVM carbon cycle



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Model Representation of Vegetation Processes

Important features:

- Plant functional types (PFTs), not species
- Grid cells contain proportions of PFTs
- Can run using only climate and soil data
- Point models, with no interaction between gridpoints
- The current condition of the system is described by a state vector

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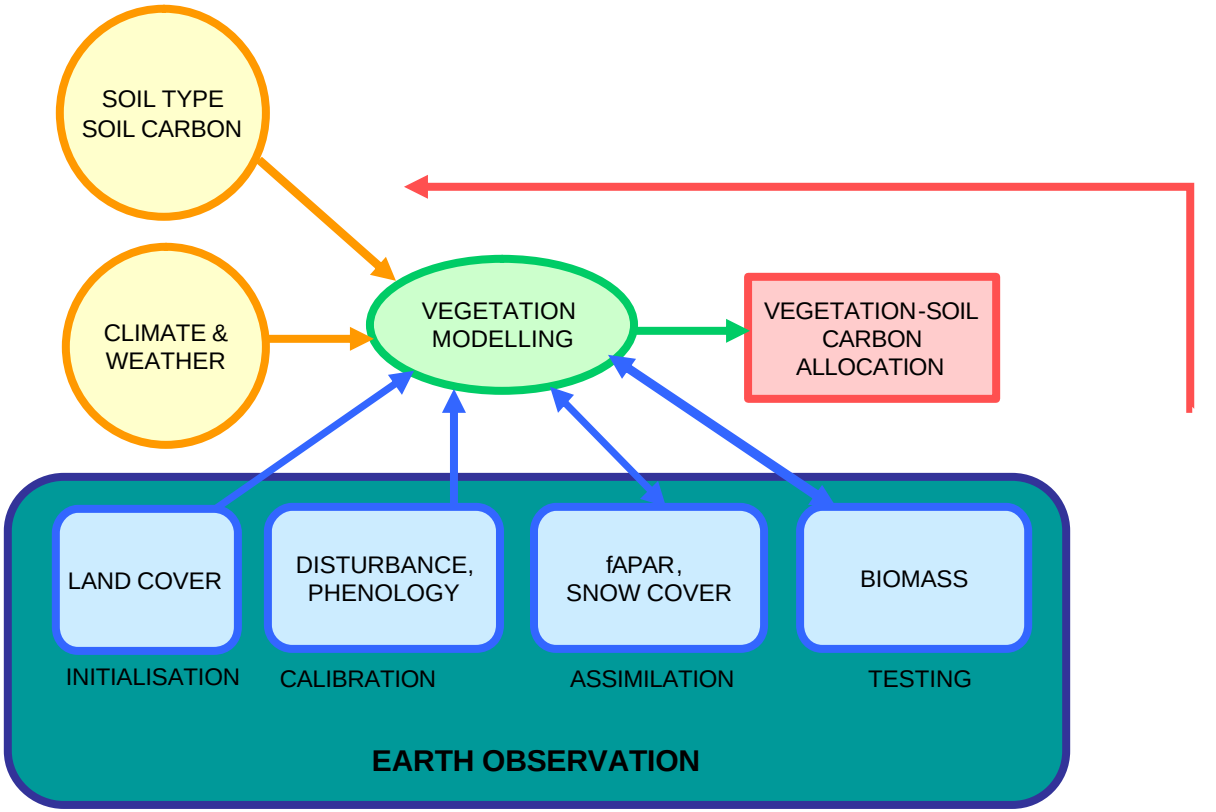
Carbon Cycle – Earth Observation Interfaces



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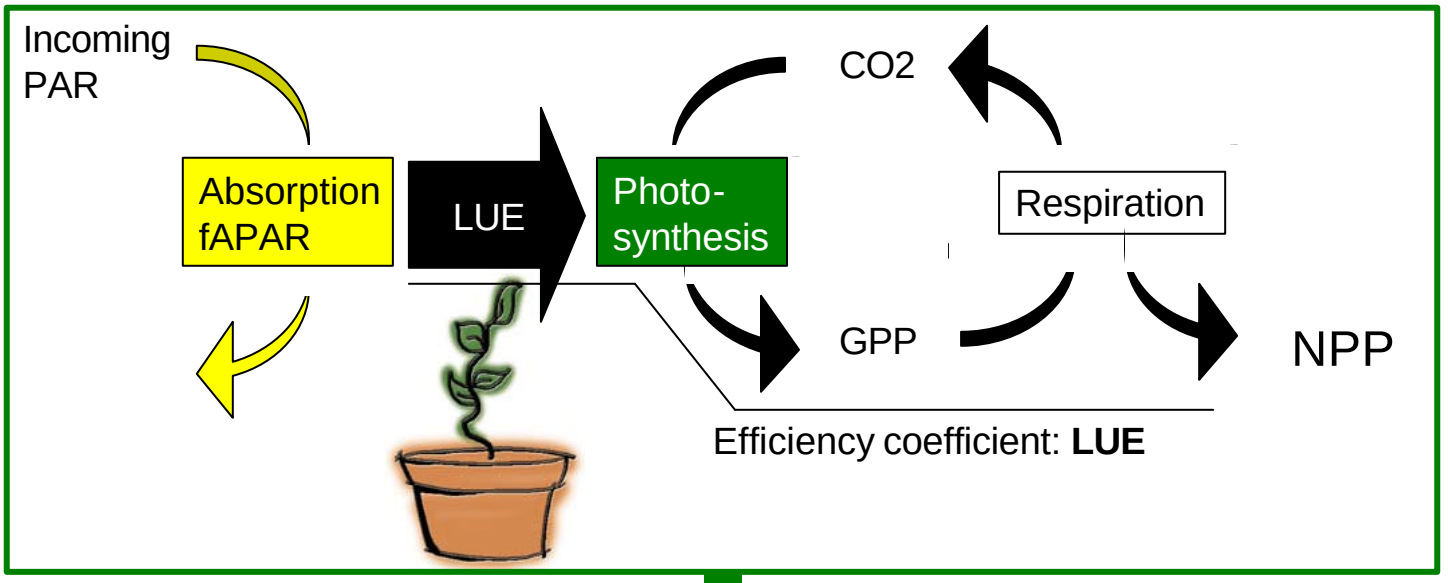
Light Use Efficiency models



$$NPP = LUE \cdot \sum_{day=1}^{365} fAPAR \cdot PAR$$

The LUE may depend on the biome, the soil moisture, the temperature, the nutrients, the age,…

Measured by satellites

Modeled or measured by satellites

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Model Data Needs

- Typically, models require data on:
  - Climate – Radiation, Precipitation, …..
  - Topography
  - Hydrology, including snow cover (snow water equivalent)
  - Soils
  - Land Cover
  - Disturbance, especially fires
  - Photosynthetic activity
  - Biomass
- These data should be:
  - Global and on a consistent Earth grid
  - Extended in time

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Climate Data Sources

- GCMs (e.g. HadCM2, ECHAM4)
- Interpolated observational data, e.g. ISLSCP-I (1987-88) and II (1982-90) - 1º (and ¼º and ½º in ISLSCP-II); UEA Climate Research Unit (20th Century to 2001)
- Re-analysed model data (e.g. ECMWF, to 2001, 1.25º; NCAR-NCEP, 1 month delay, 2.5º)

ISSUES:

Currency, overlap with modern satellite record, resolution

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Land cover

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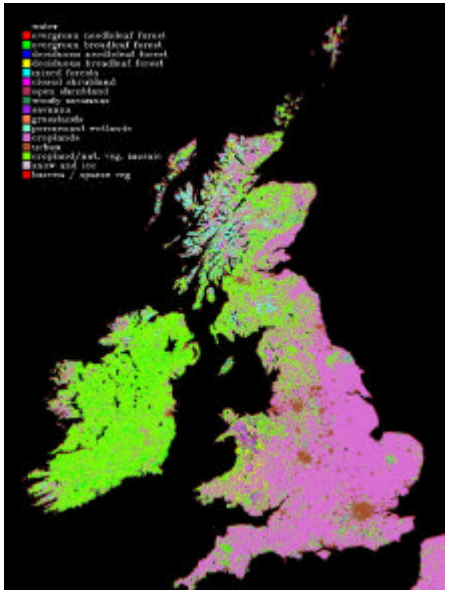
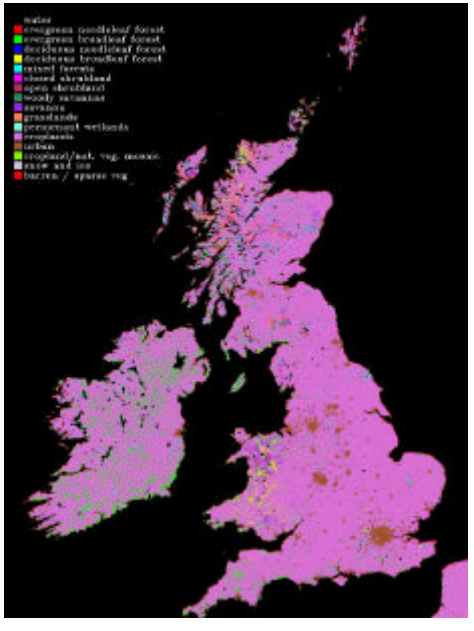
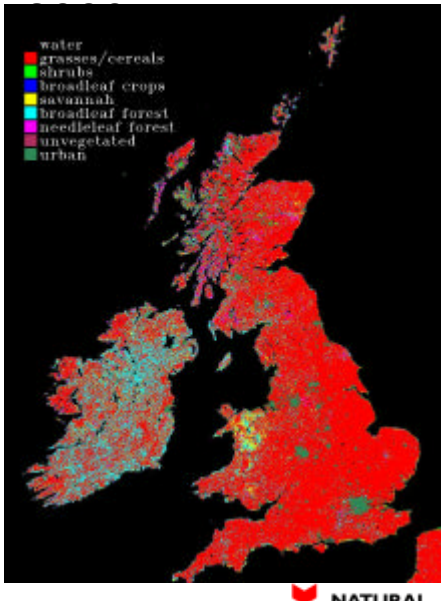


MODIS/IGBP
Landcover 2000



MODIS/UMD
Landcover 2000

MODIS
LAI/fAPAR biome
Landcover



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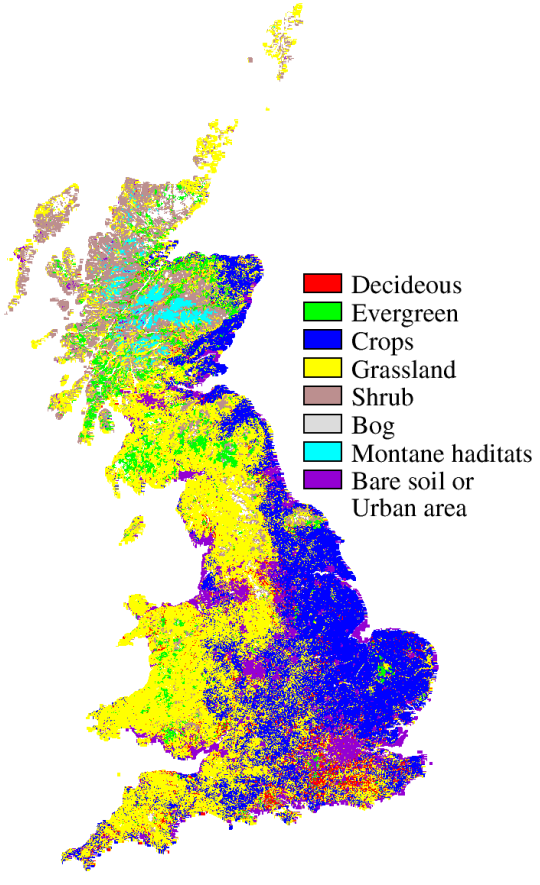
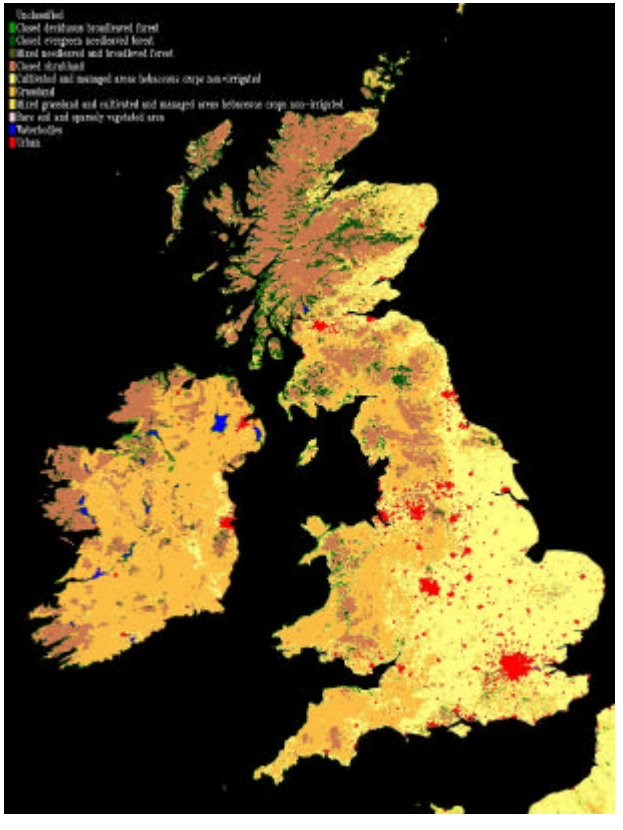


CEH LCM2000



GLC2000 (SPOT-VGT)

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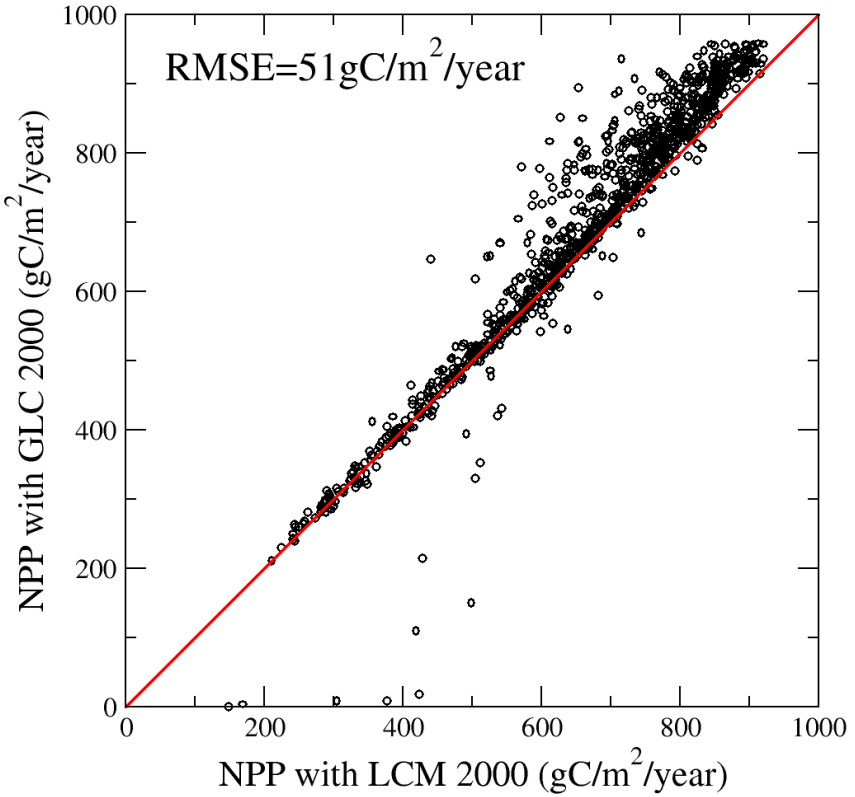

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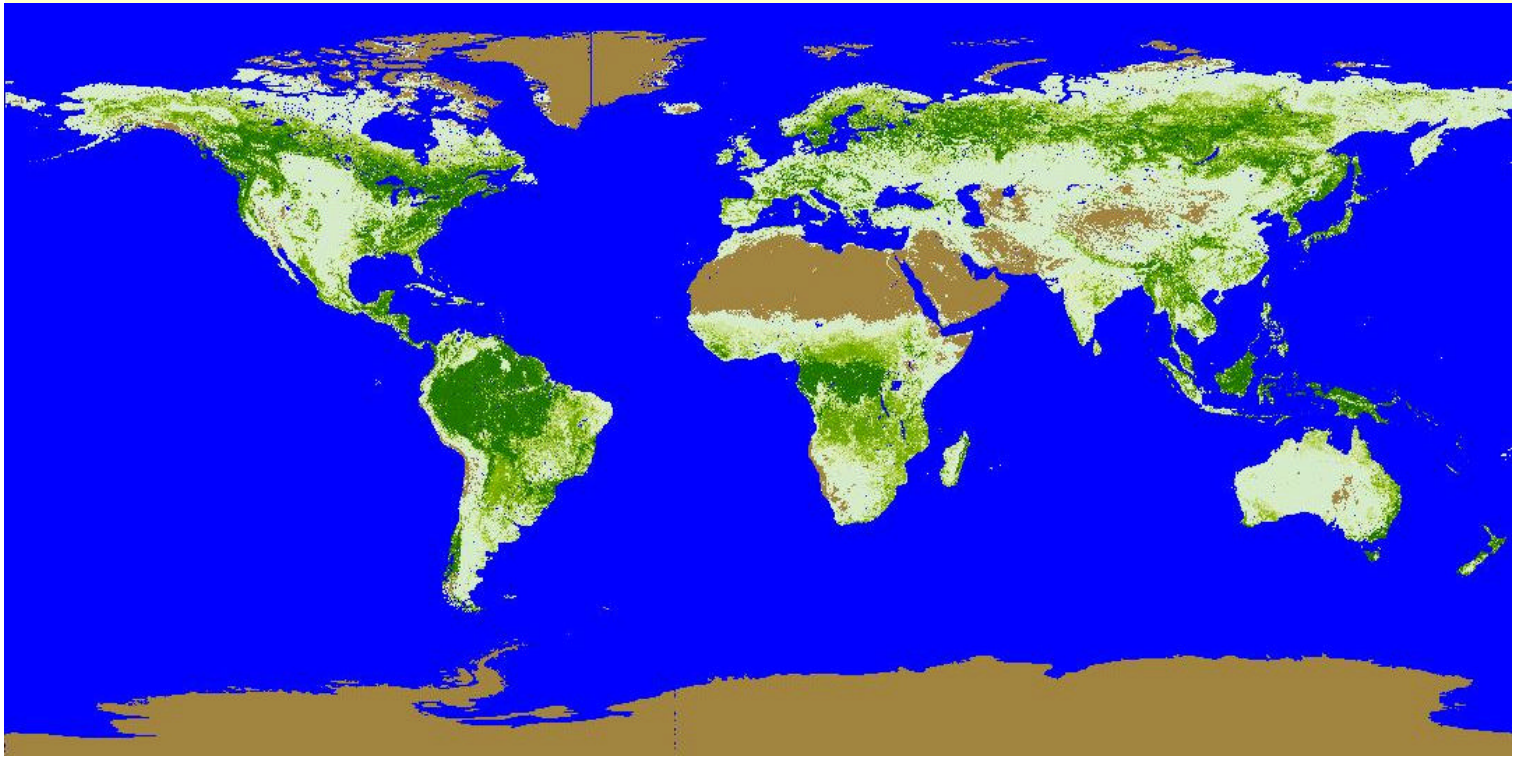
MODIS VCF



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Defries et al., 2000
Hansen et al., 2002

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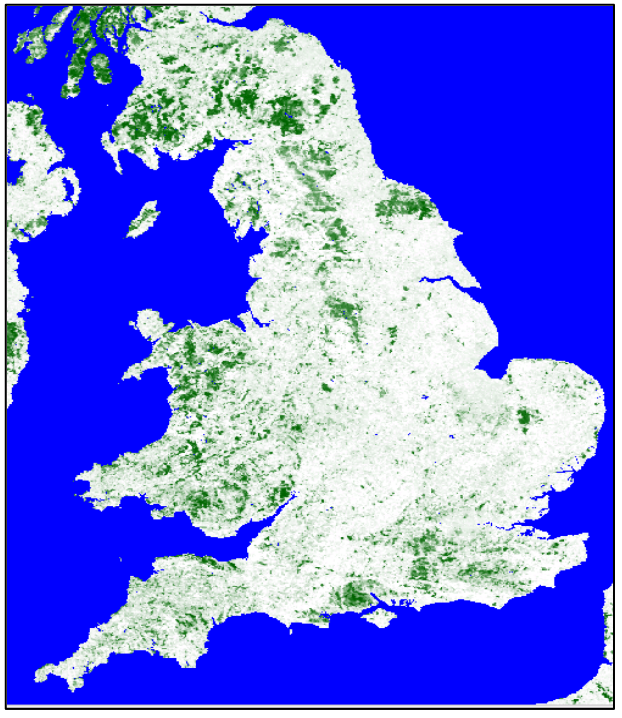
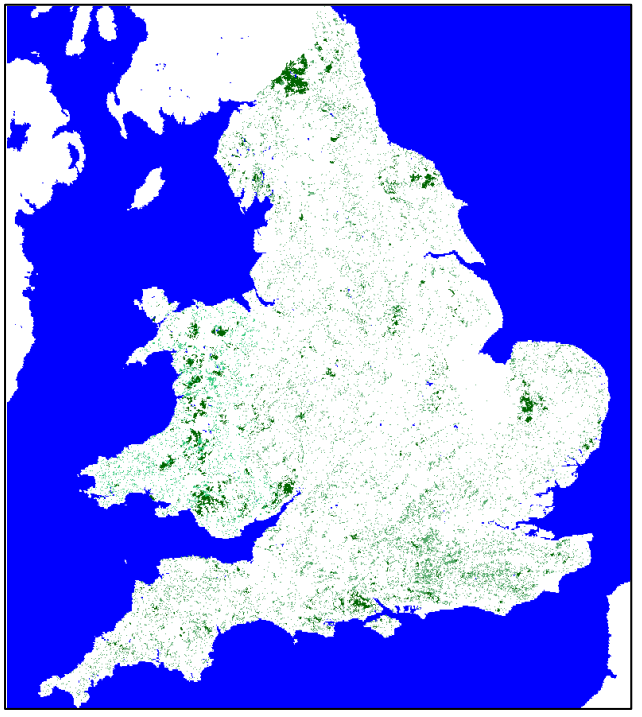
MODIS VCF *vs* Ground data

MODIS VCF
(Satellite)



FR Woodland Survey
(Ground monitoring)



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Surface comparison for **England+Wales only**

	Modis VCF	*National Inventory (GIS)*
surface of land (Km^2)	1508	1508
surface of forest (Km^2)	255.8	133.4
% of forested land	**16.96 %**	**8.84 %**

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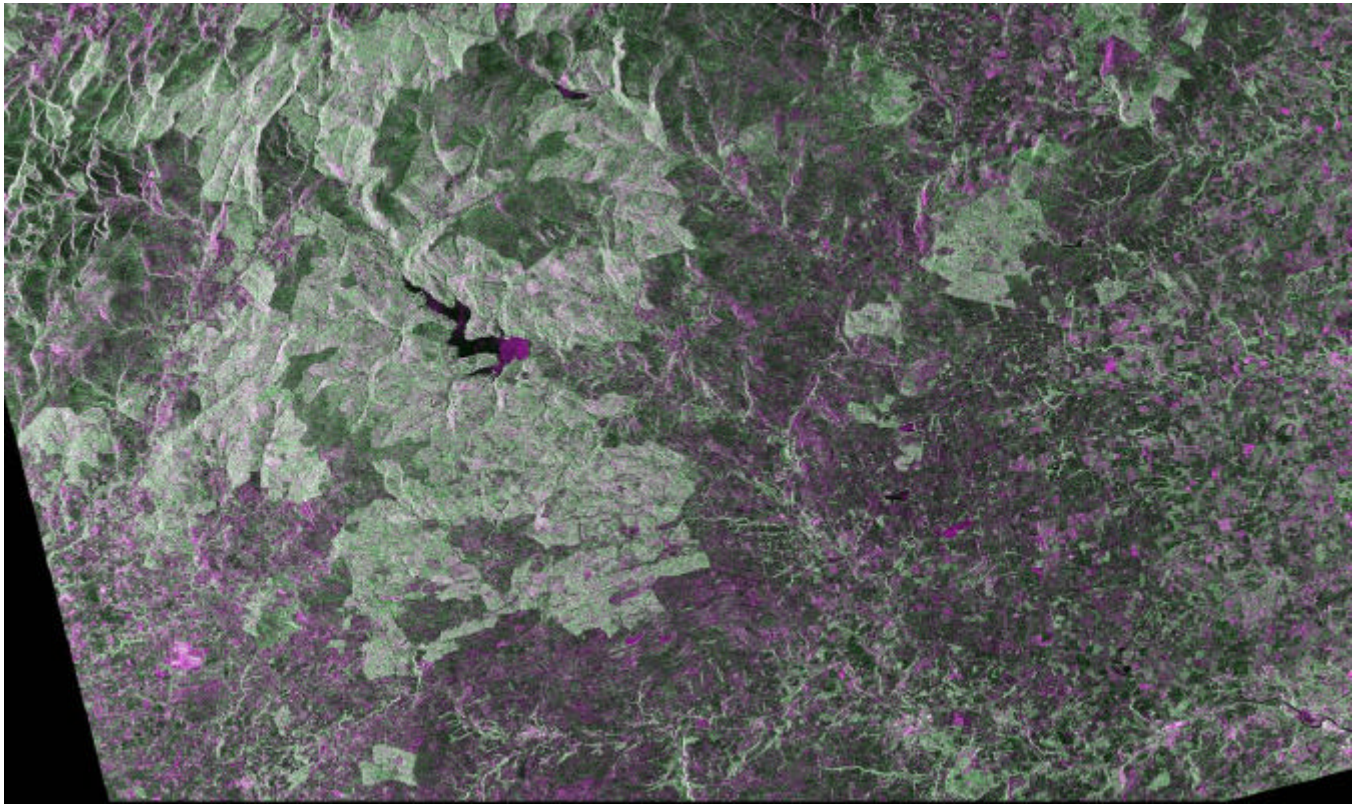
ASAR image of Kielder Forest (April 2003)



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green:vh, purple:vv
The forest-moorland confusion is removed

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Land cover change

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Rondônia, Brazil

1975

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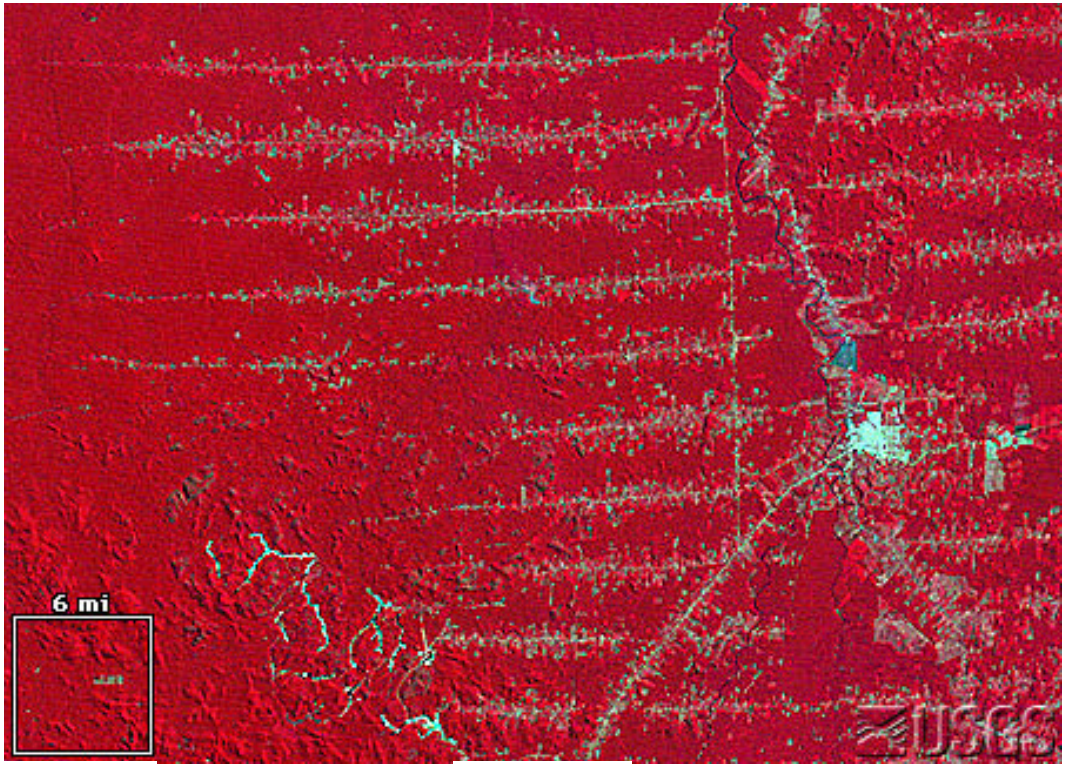
Rondônia, Brazil



1986

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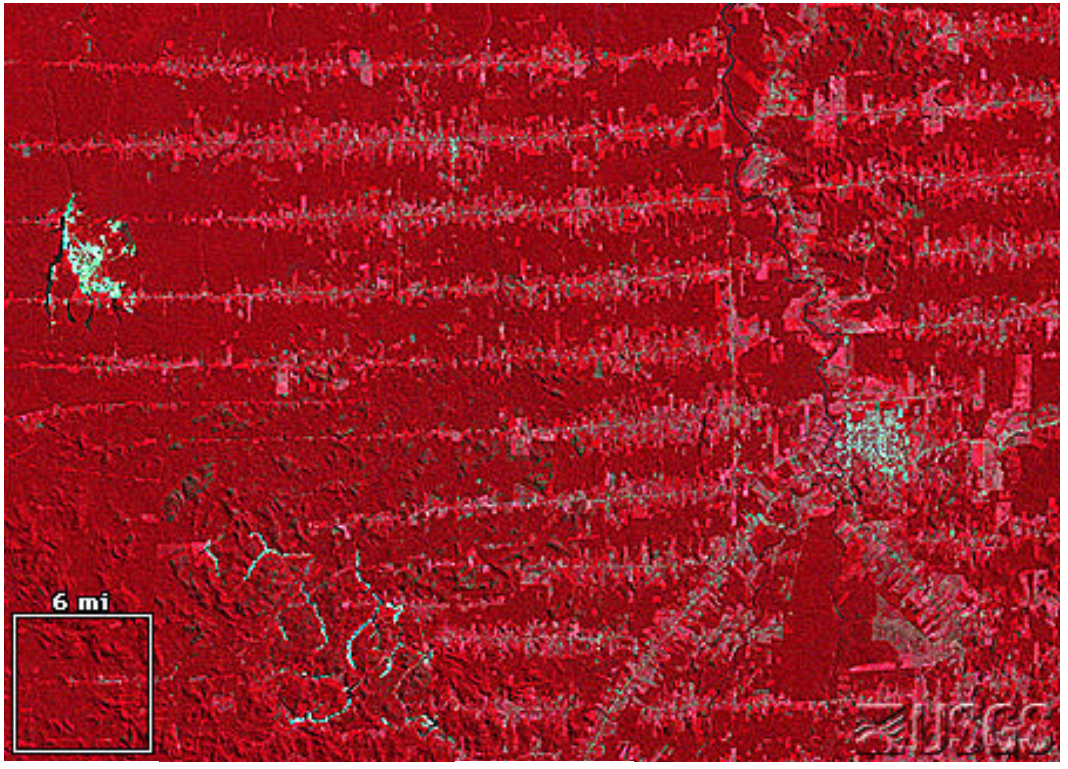
Rondônia, Brazil



1992

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IPCC (2001) reservations on LCC

	1980s	1990s
Atmospheric increase	3.3 +/- 0.1	3.2 +/- 0.1
Emissions	5.4 +/- 0.3	6.3 +/- 0.4
Ocean-atmosphere flux	-1.9 +/- 0.6	-1.7 +/- 0.5
Land-atmosphere flux	-0.2 +/- 0.7	-1.4 +/- 0.6
* land-use change	1.7 (0.6 to 2.5)	NA
* residual land sink	-1.9 (-3.8 to 0.3)	NA

Units: Gt C y^{-1}

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Uncertainties in forest area change: JRC, FAO & UMD estimates (10^6 ha yr^{-1})

	Humid domain		All Tropics		
Continent	TREES	FAO CS	FAO RSS	FAO CS	NASA LP
Southeast Asia	-2.0 ±0.8	**-2.5**	-2.0 ±1.2	**-2.4**	-2.0 ± 1.2
Africa	**-0.7 ±0.3**	**-1.2**	**-2.2 ±0.8**	-5.2	-0.4 ± 0.3
Latin America	**-2.2 ±1.2**	**-2.7**	**-4.1 ±2.2**	**-4.4**	**-3.2 ± 1.2**
Global	-4.9 ±1.3	-6.4	-8.3 ±2.6	-12.0	-5.6 ± 2.7

Refs: FAO, *Global Forest Resources Assessment 2000* (FAO, Rome, 2001)
Achard F, Eva HD, Stibig H-J, *et al.*, *Science* 297:999 (2002)
DeFries RS, Houghton RA, Hansen MC *et al.*, *Proc Nat Acad Sciences*, 99:14256 (2002)

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Photosynthesis and vegetation activity

Information inferred from radiance data:

- Derived products
  - Vegetation indices
  - Fraction of absorbed photosynthetically active radiation (fAPAR)
  - Leaf area index (LAI)
- Time-series
  - Phenology

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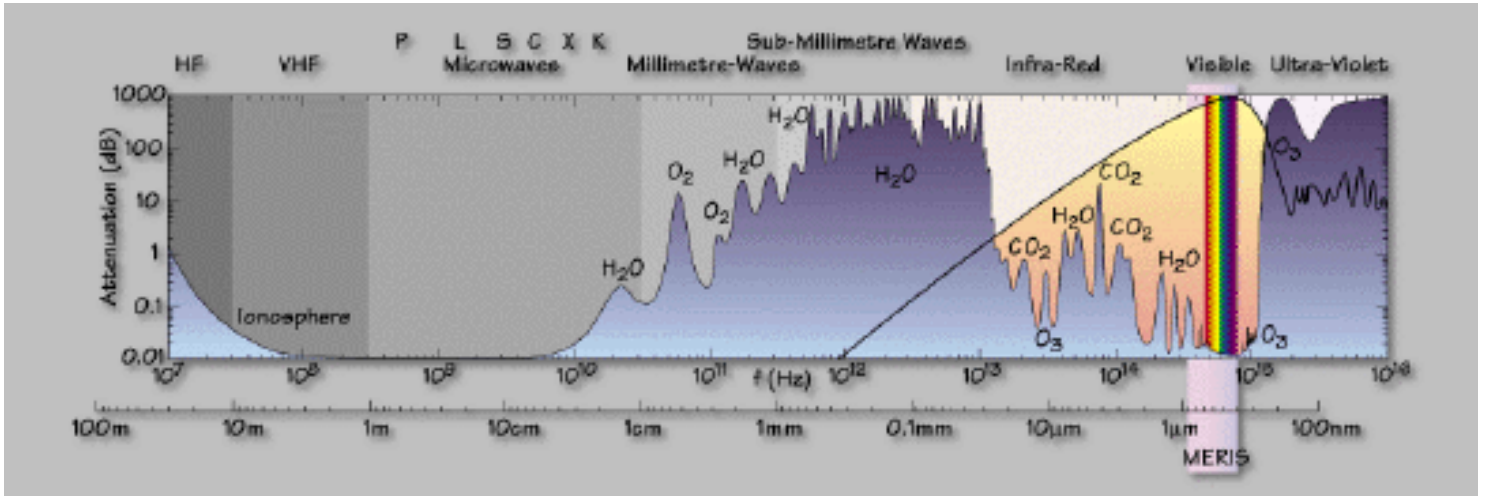
MERIS bands
(http://envisat.esa.int/instruments/meris/)



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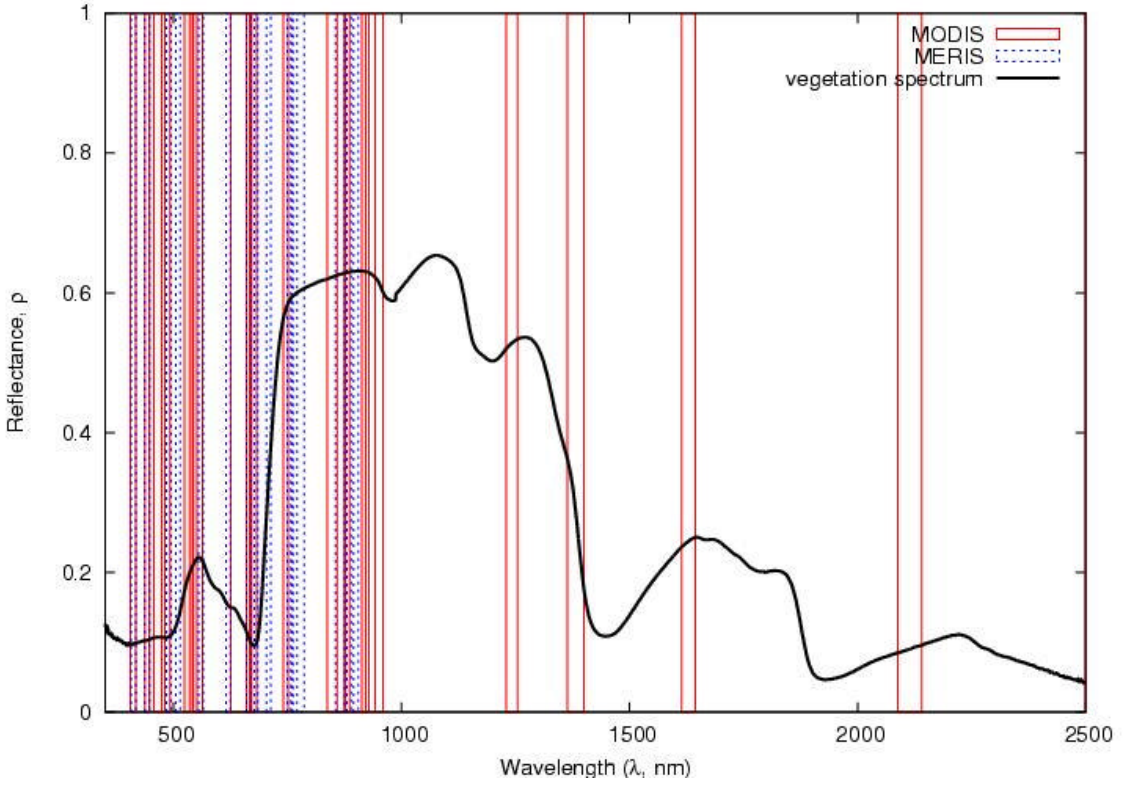
MODIS & MERIS bands in the VIS/NIR



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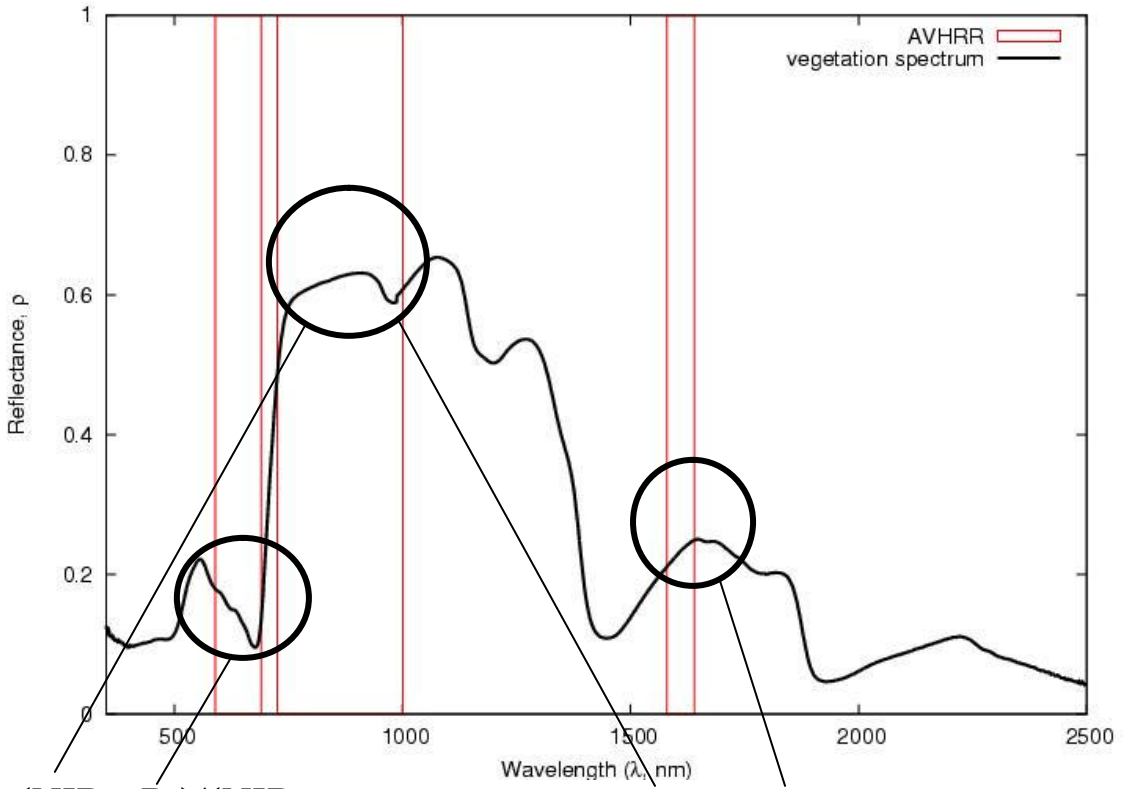
AVHRR bands in the VIS/NIR



NDVI = (NIR - R)/(NIR + R)

NDWI = (NIR - SWIR) /(NIR + SWIR)

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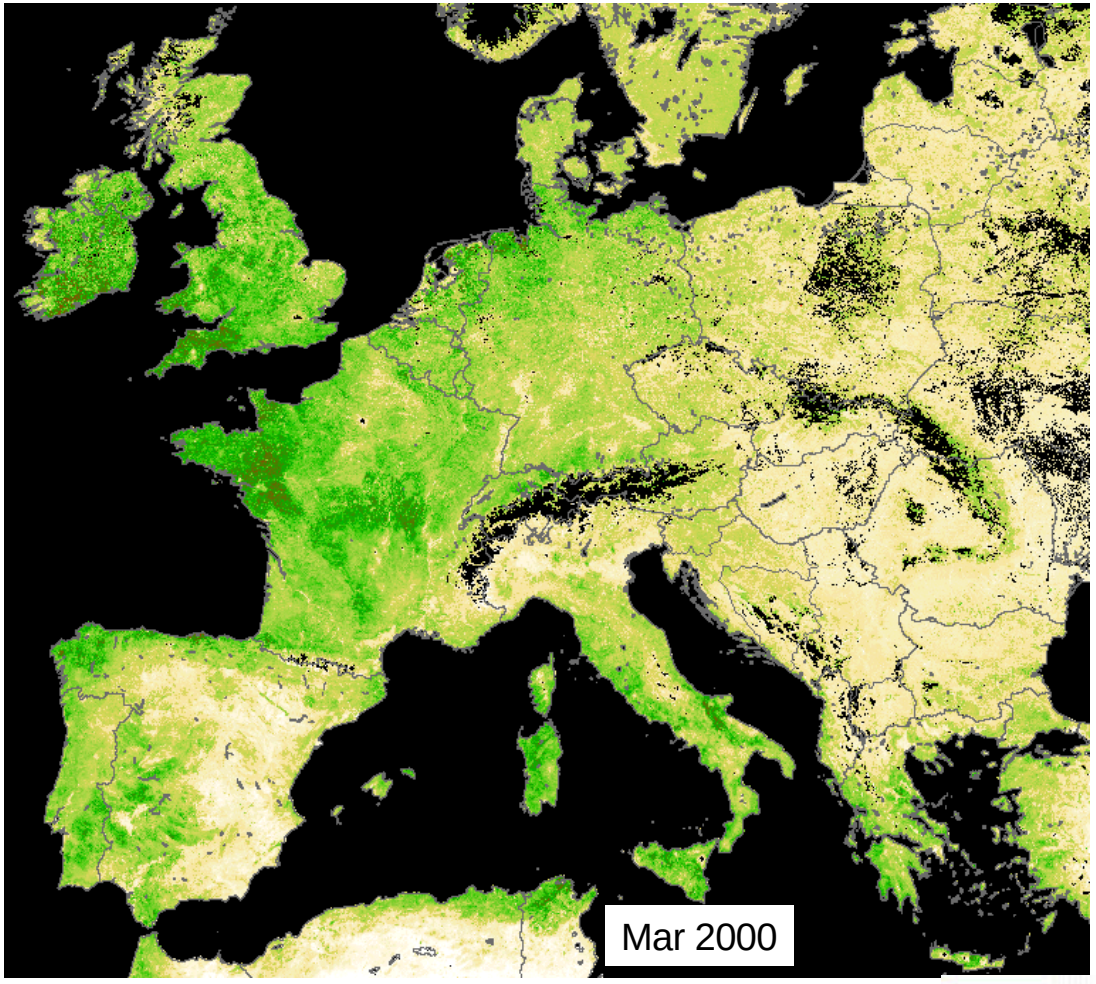

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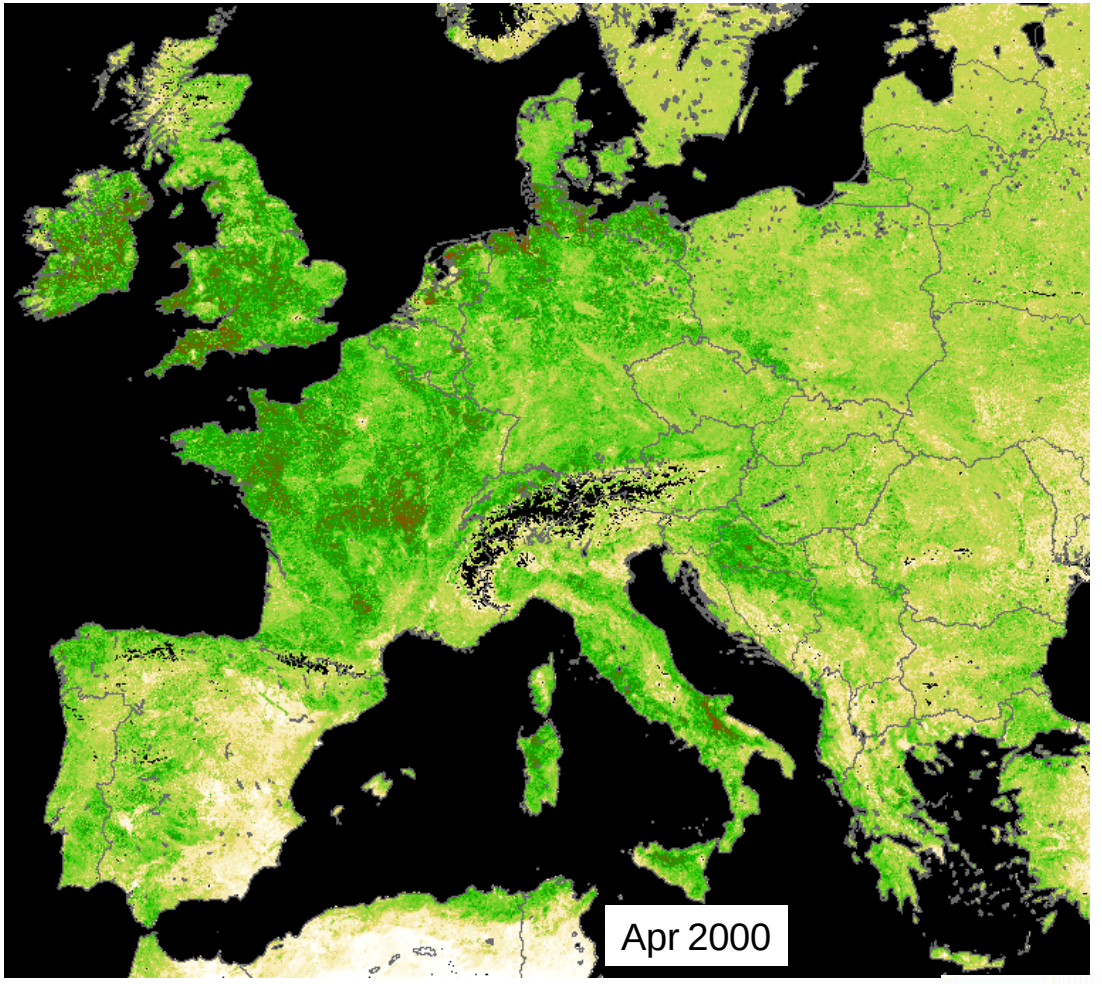

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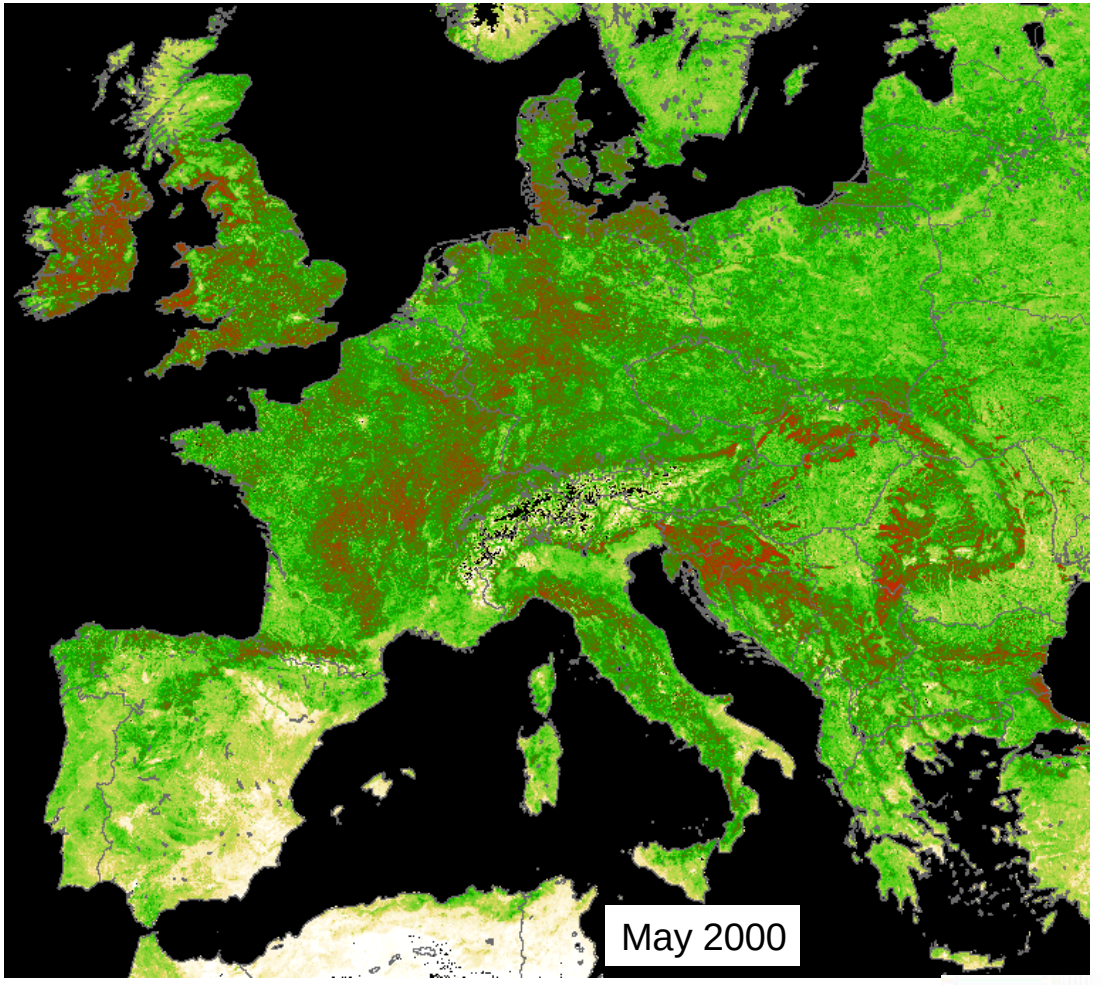

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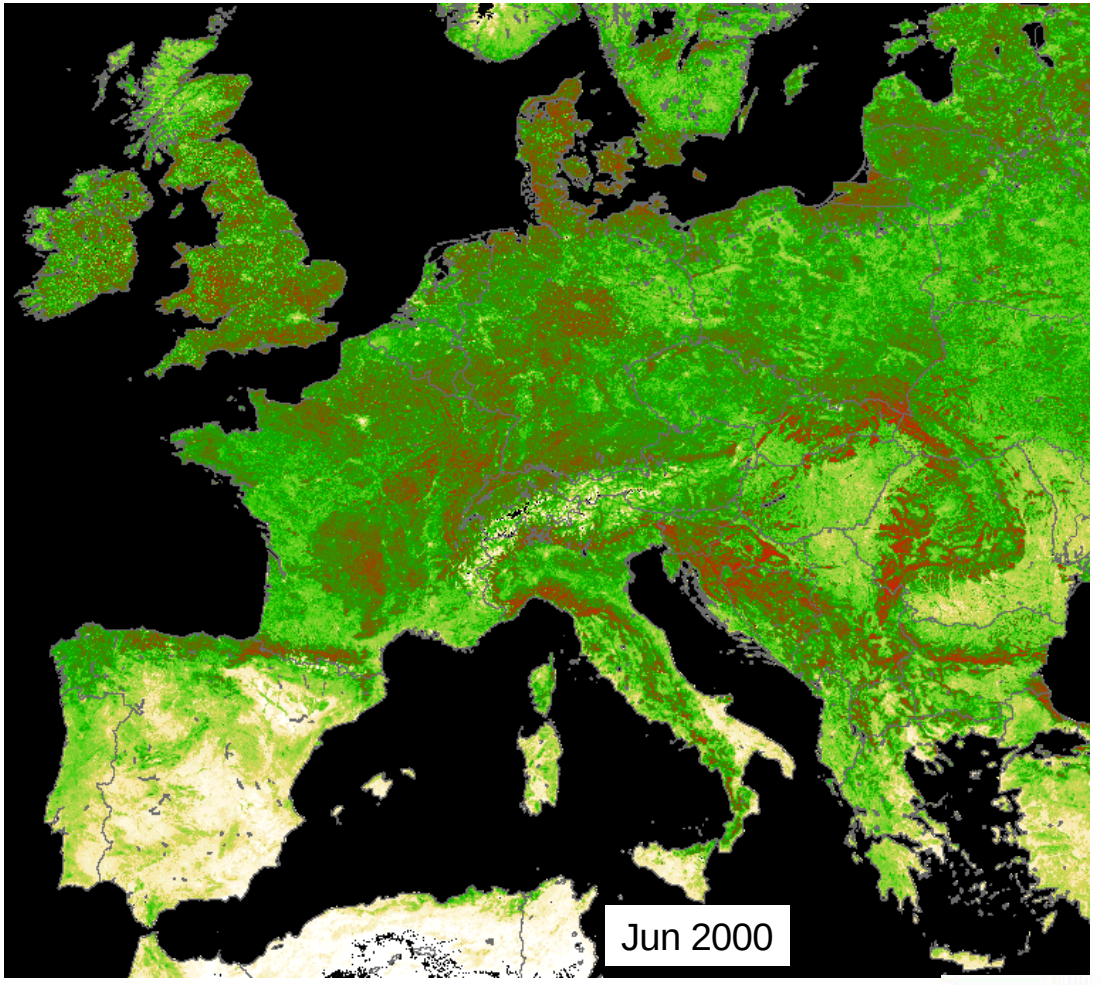

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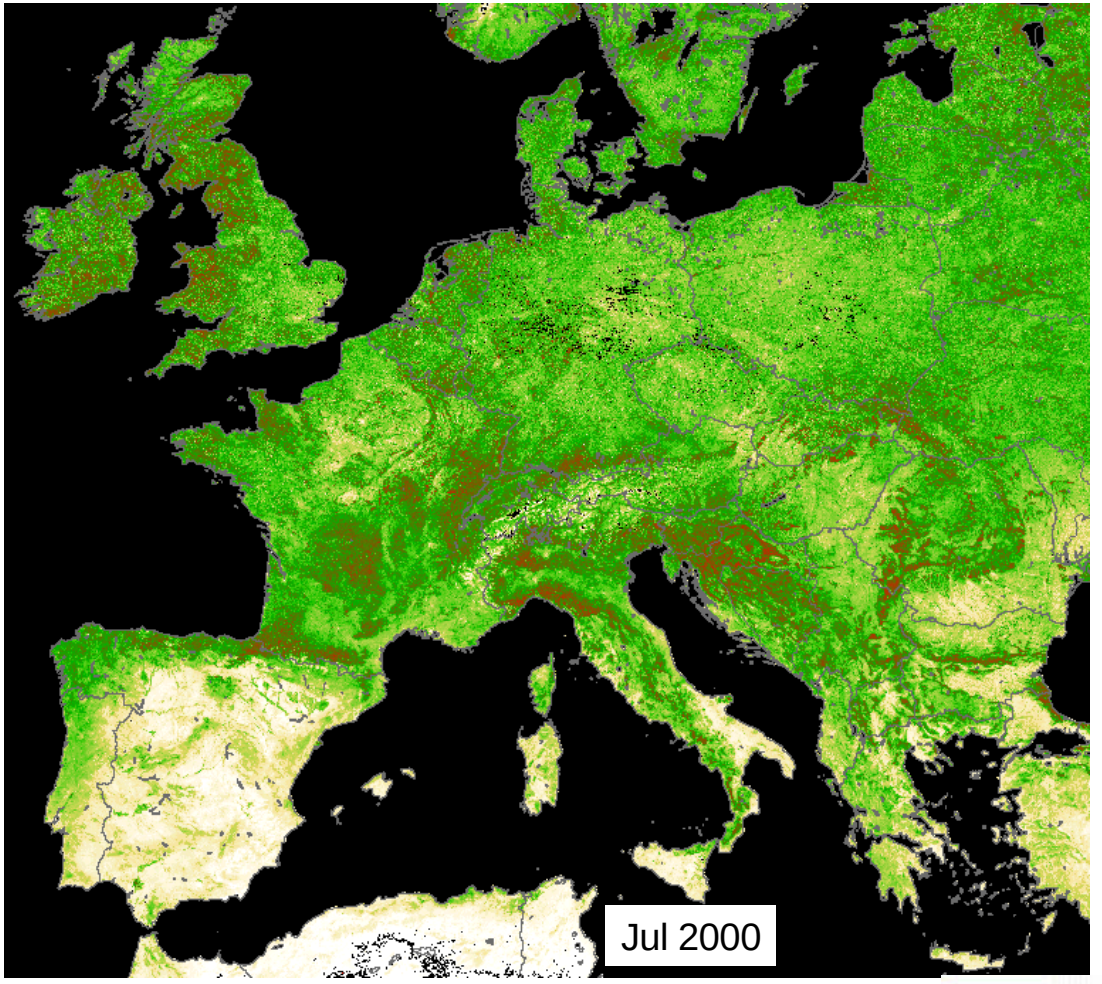

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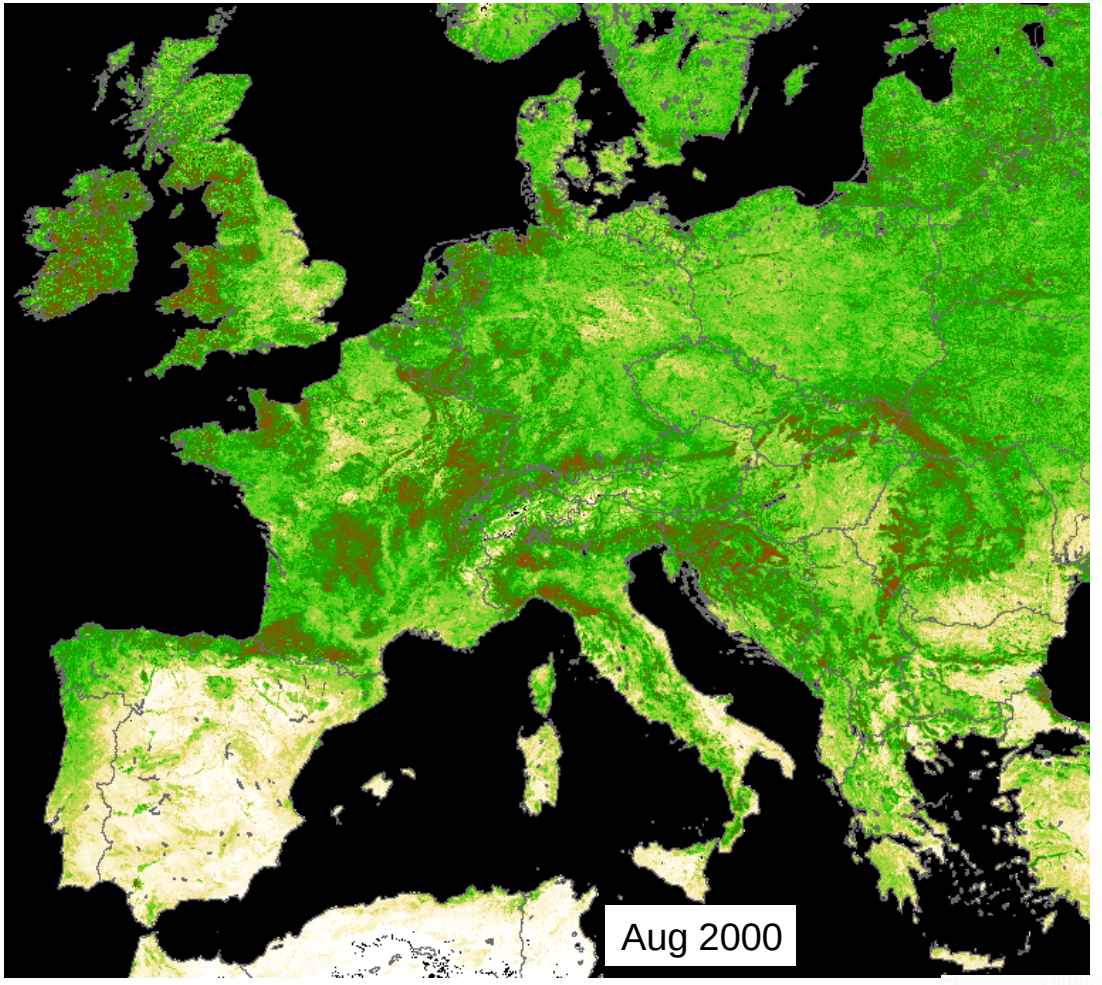

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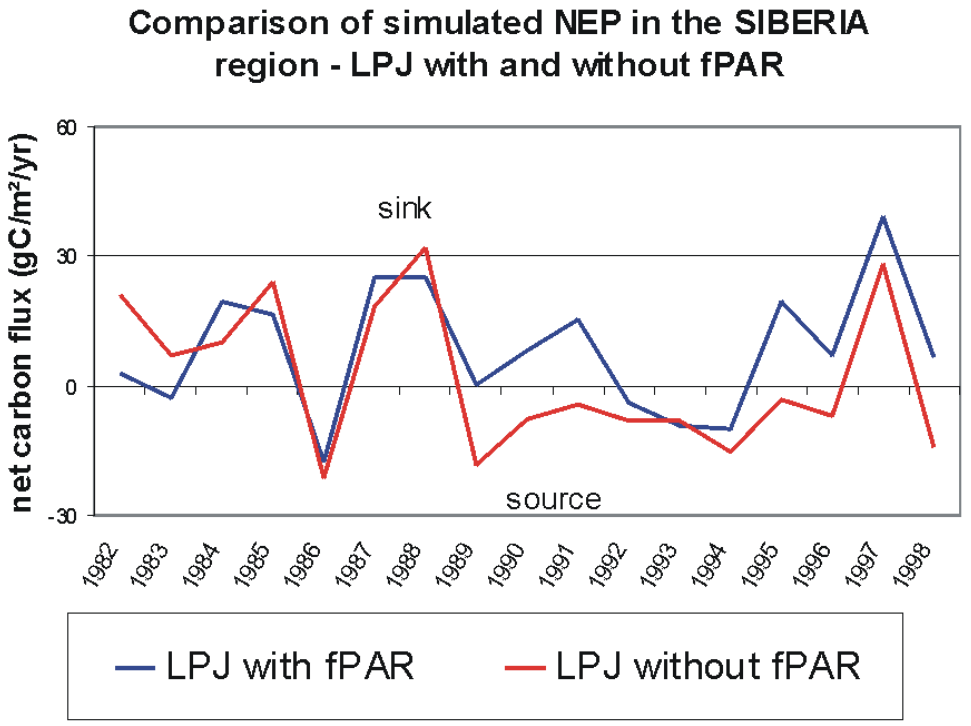
Constraining LPJ with fAPAR



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Slide from Wolfgang Lucht, PIK

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Phenology

- Timing of vegetation ‘events’
  - Green-up, maturity, leaf fall etc.

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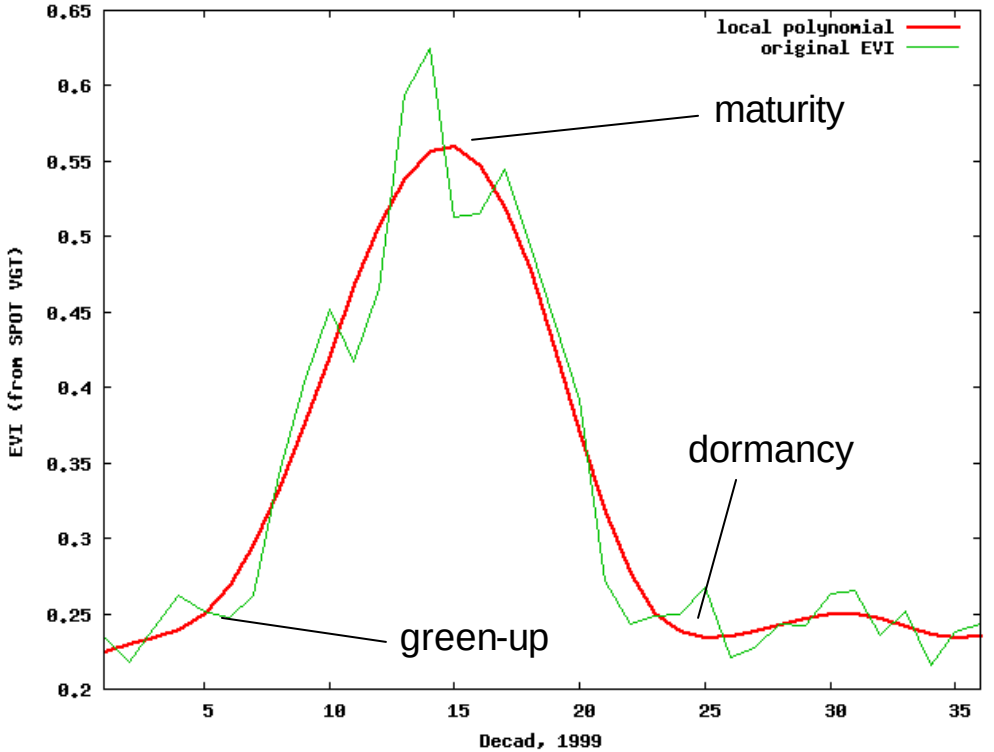
Phenology from EO data



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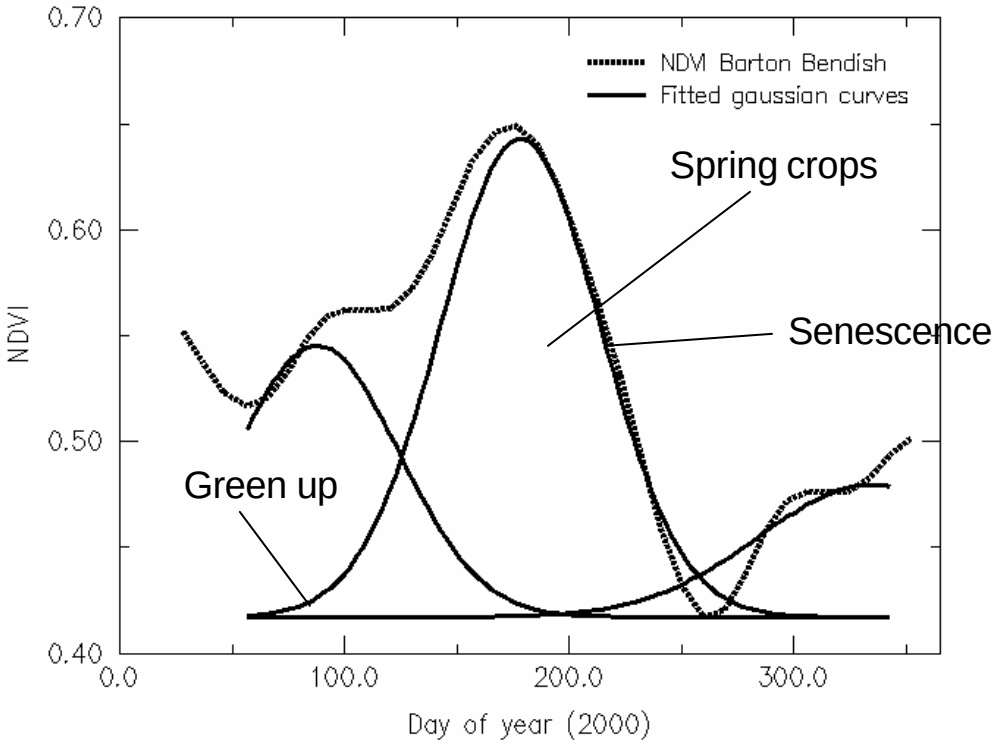
Phenological metrics



Complexities:

- mixed signal at moderate resolution

-samples lost due to cloud

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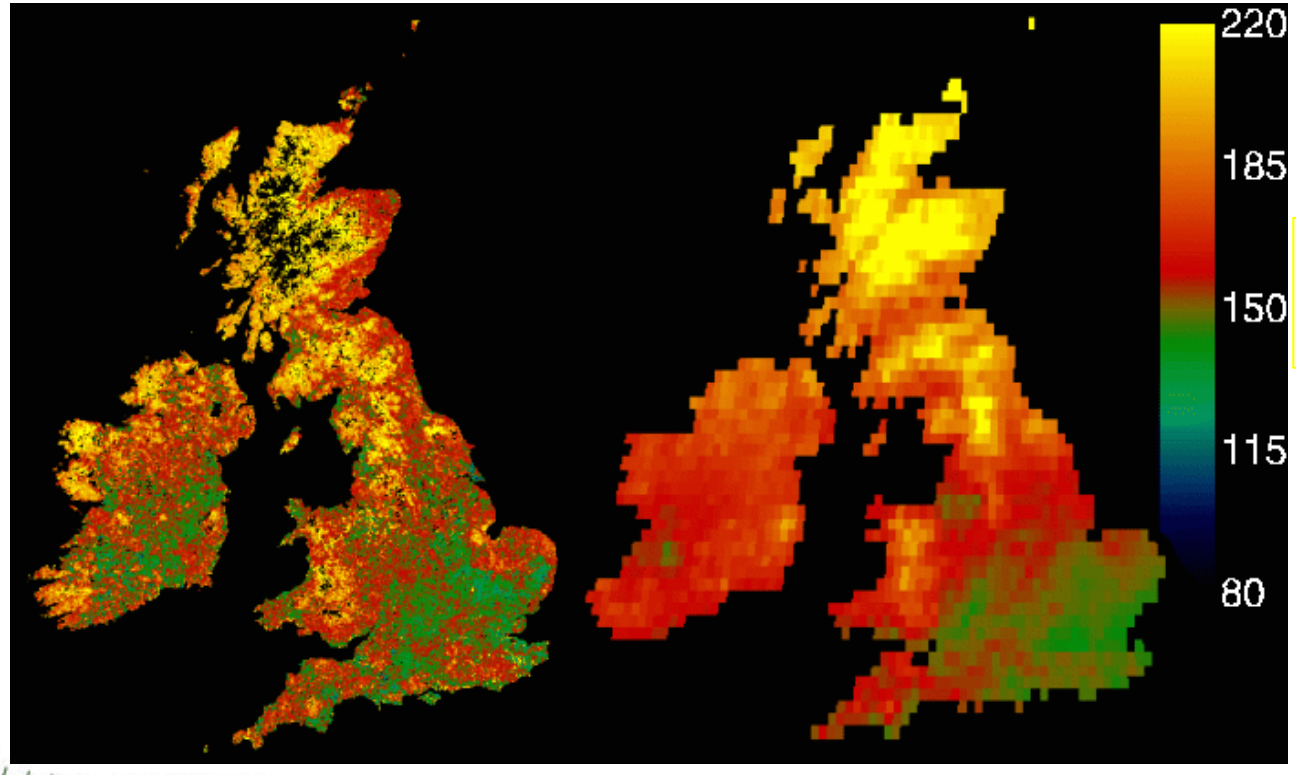
Day of full greening-up (MODIS, 2001)

Phenology model driven by daily temperature series, optimised using EO data.



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Fire

Models need to estimate the amount of C emitted due to burning in each grid-cell:

- fraction of cell burnt
- biomass consumed

In the models fire is treated statistically.

Relevant EO products:

- active fire location (hot spots)
- burnt area
- fire radiative power/energy (FRP)

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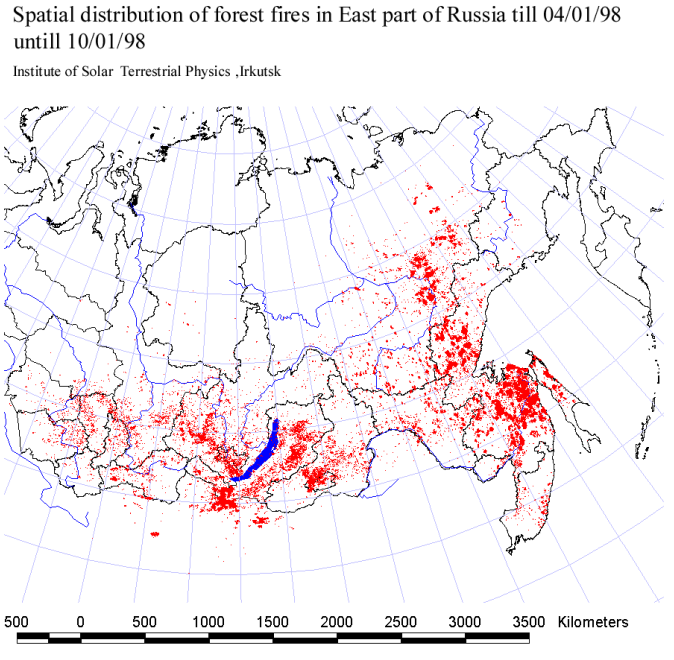
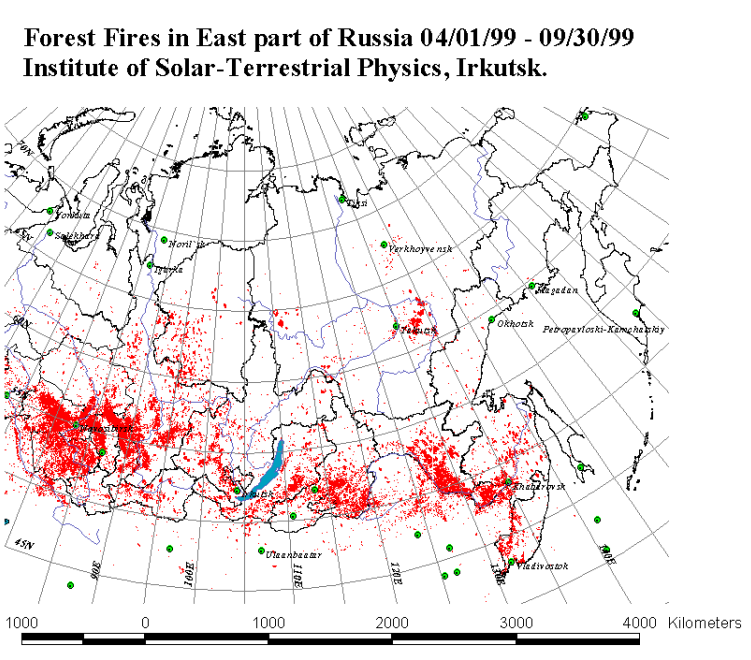
Fires in Eastern Russia, 1998 & 1999



1998



1999

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Created by Centre of Remote Sensing, Irkutsk

http://ckm.iszf.irk.ru

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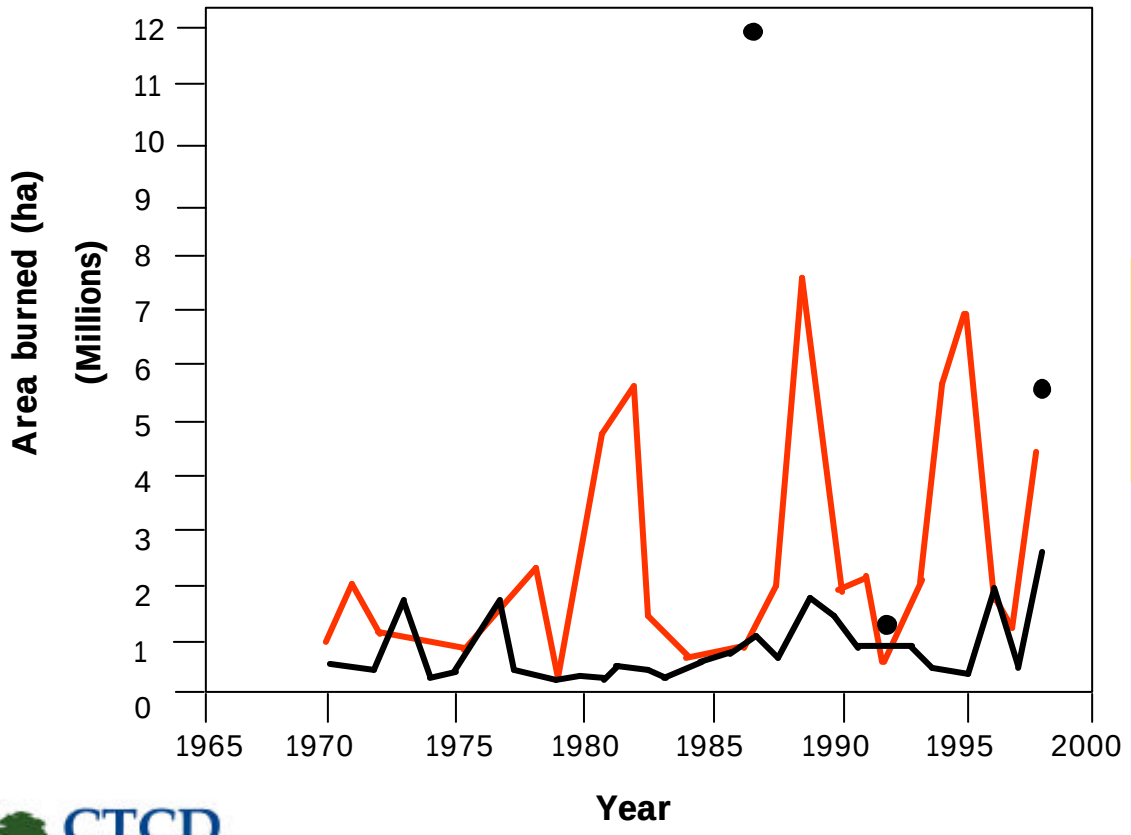
Reported annual area burned:
Russia —— N. American boreal forest ——



Dots show AVHRR estimates

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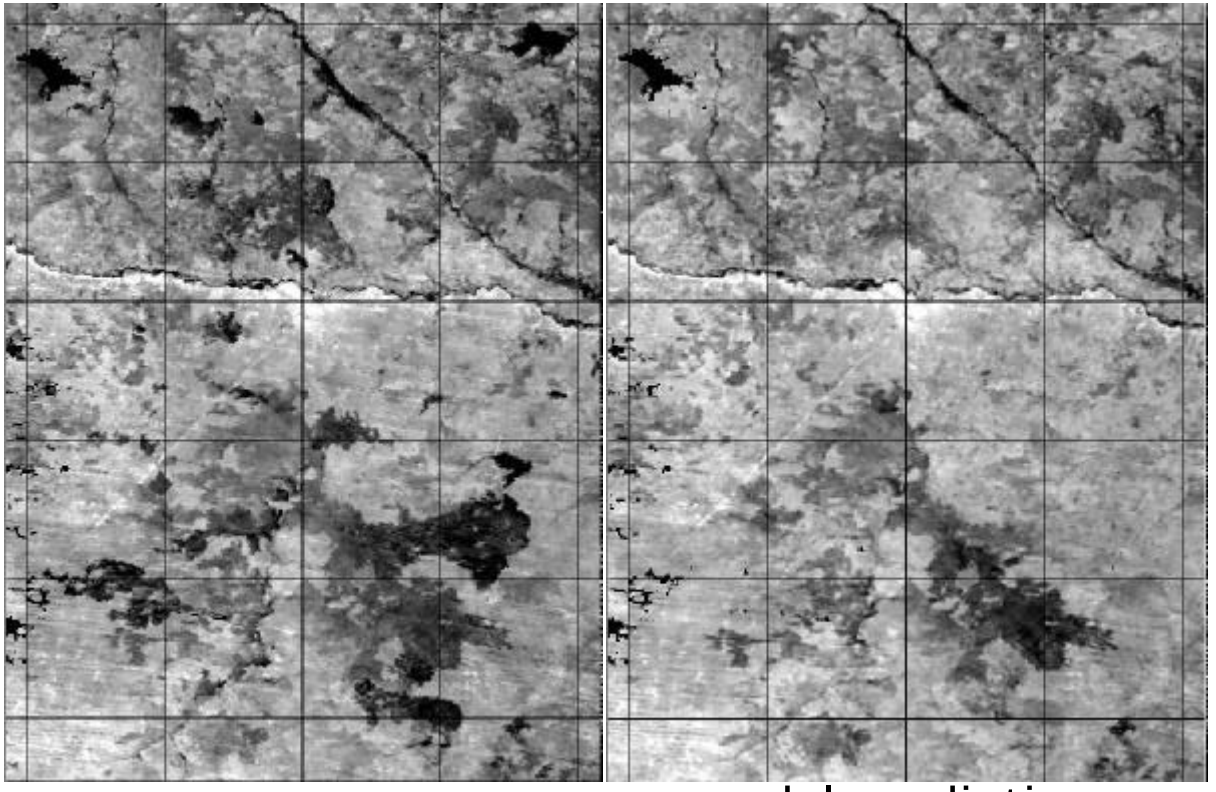
MODIS Burned Area



measurement

model prediction

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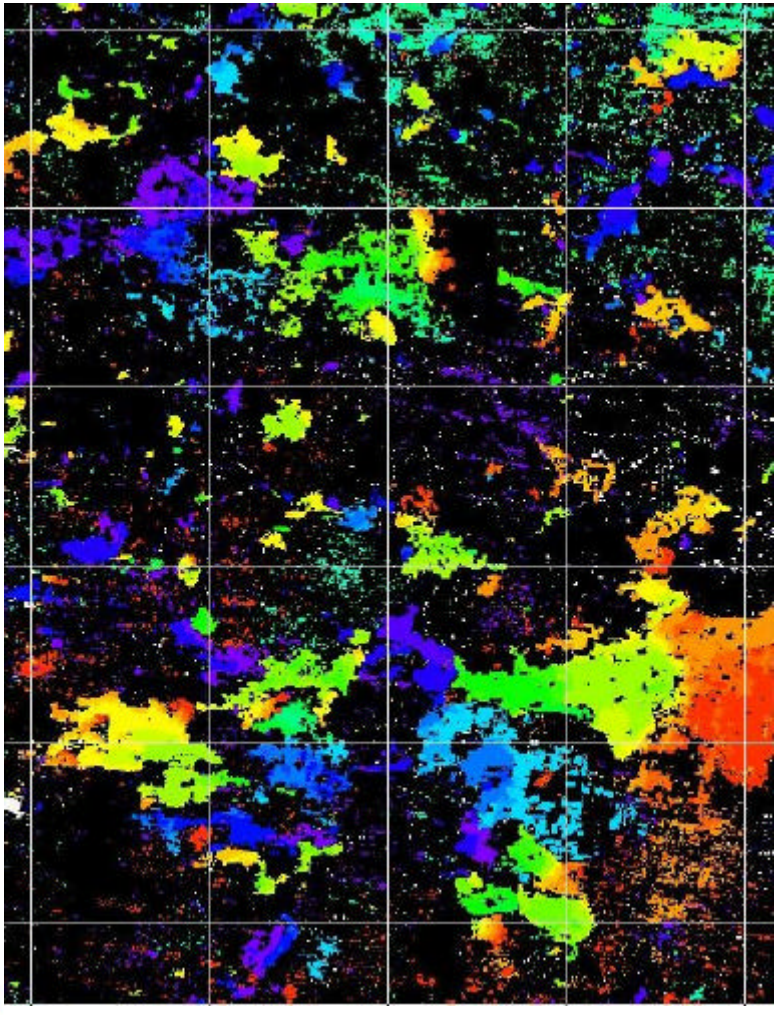
Day of burn

249 to 284



Temporal development of burn-scars

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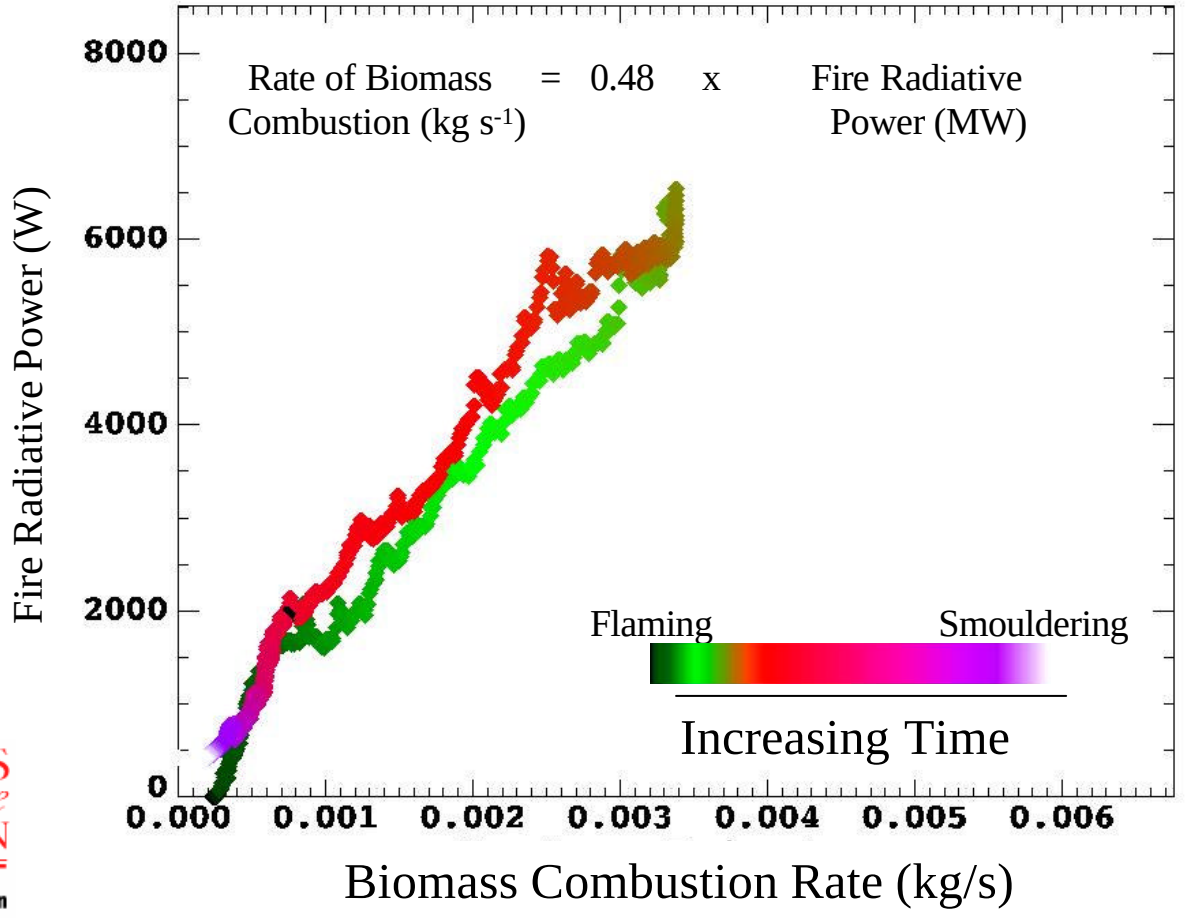
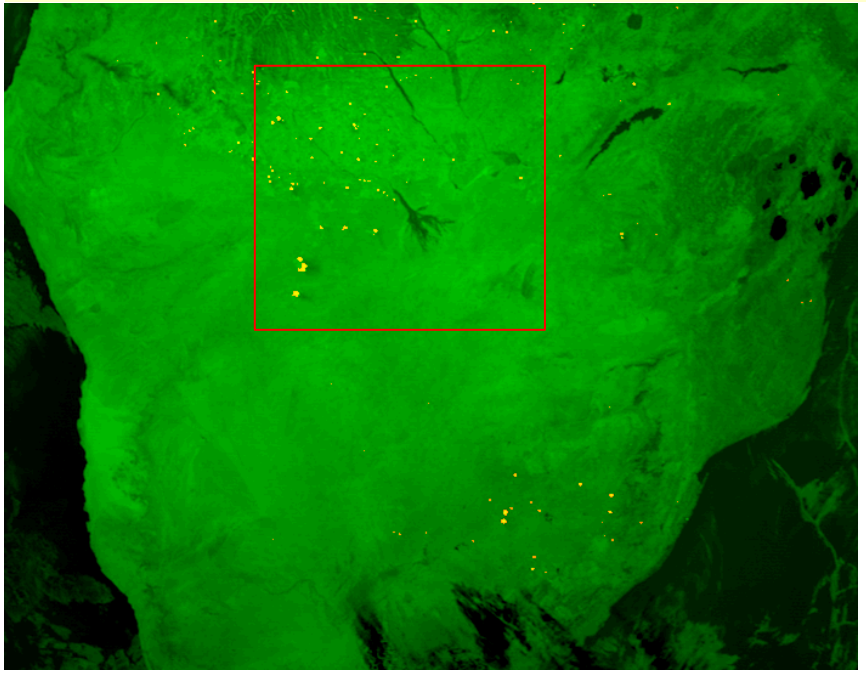
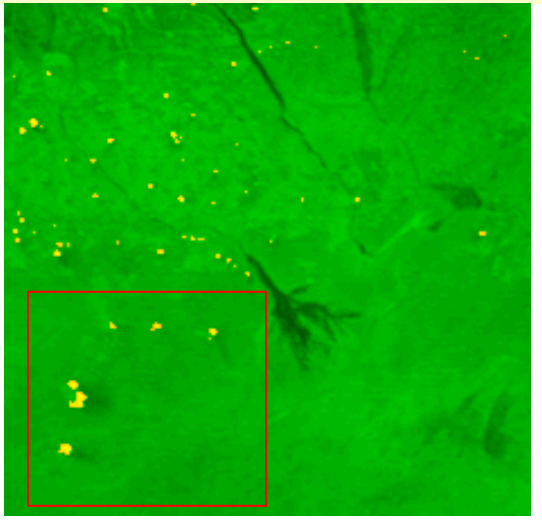
Rate of FRE Release vs. Rate of Fuel Combustion

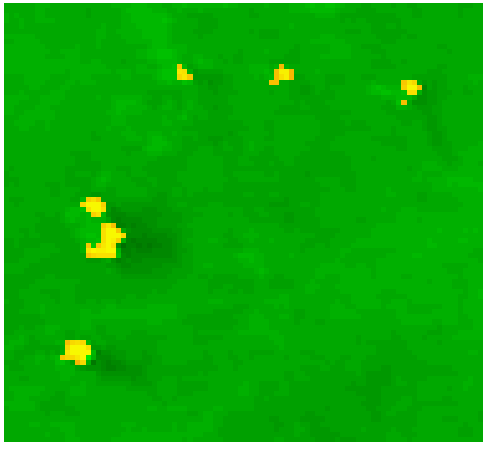


KING'S College LONDON
University of London

SEVIRI image (1st Sept.2003)







Green : MIR (3.9µm)
Yellow : detected active fires

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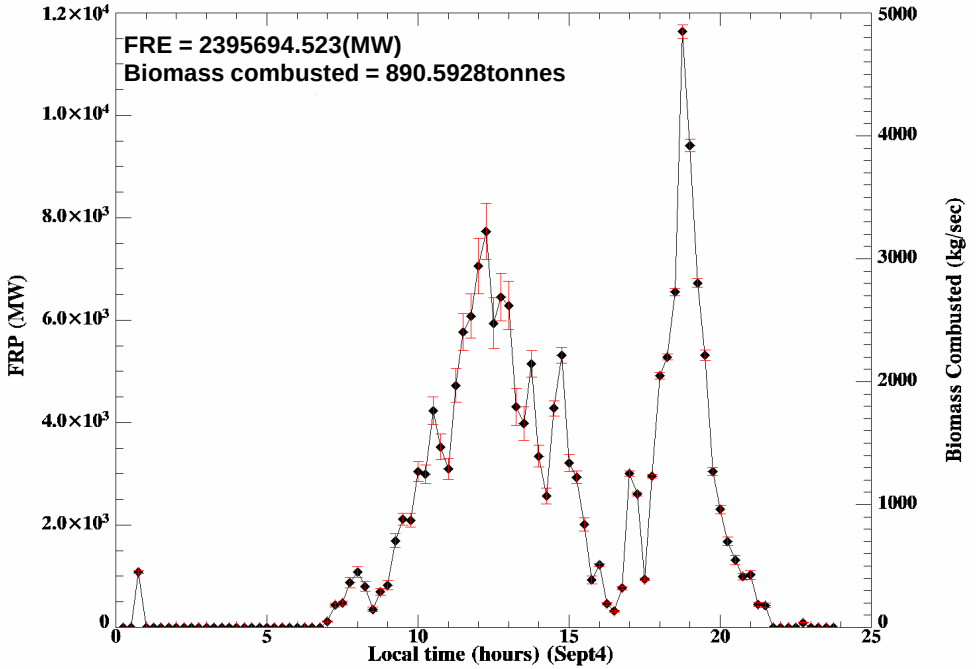
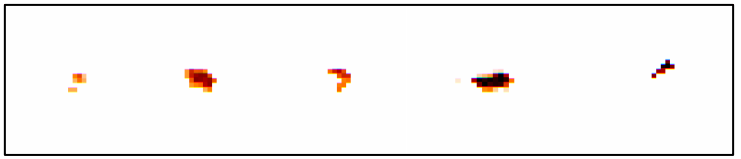


Fire size evolution



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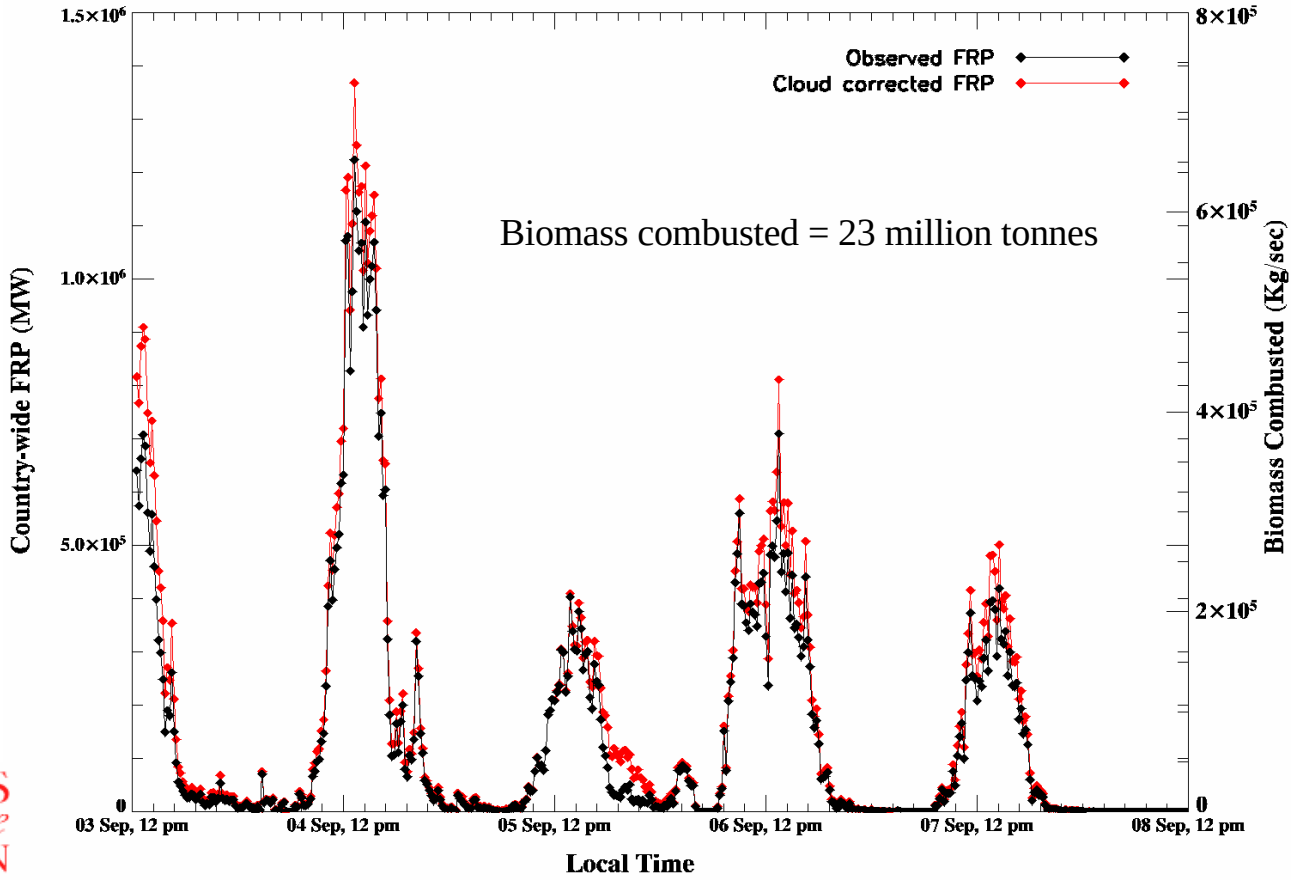
Southern Africa FRP, 3-8 September 2003



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Biomass & Age

- Biomass is not an element of the state vector, but can be calculated from it
- Tree age is in the state vector: forest age is crucial for knowing the future behaviour of forest as a carbon sink (or source)

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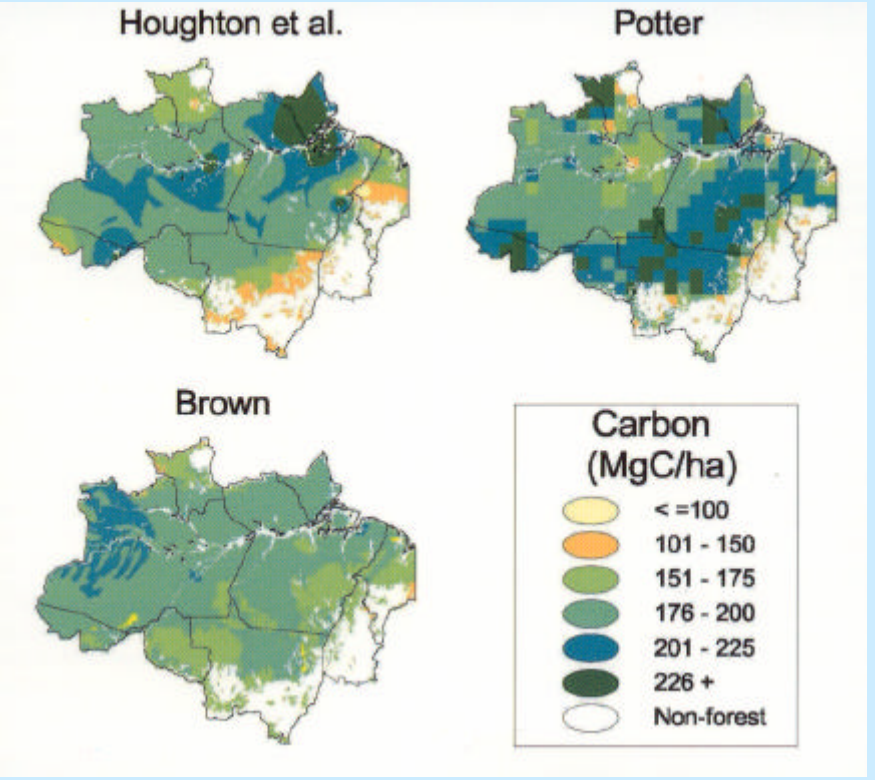
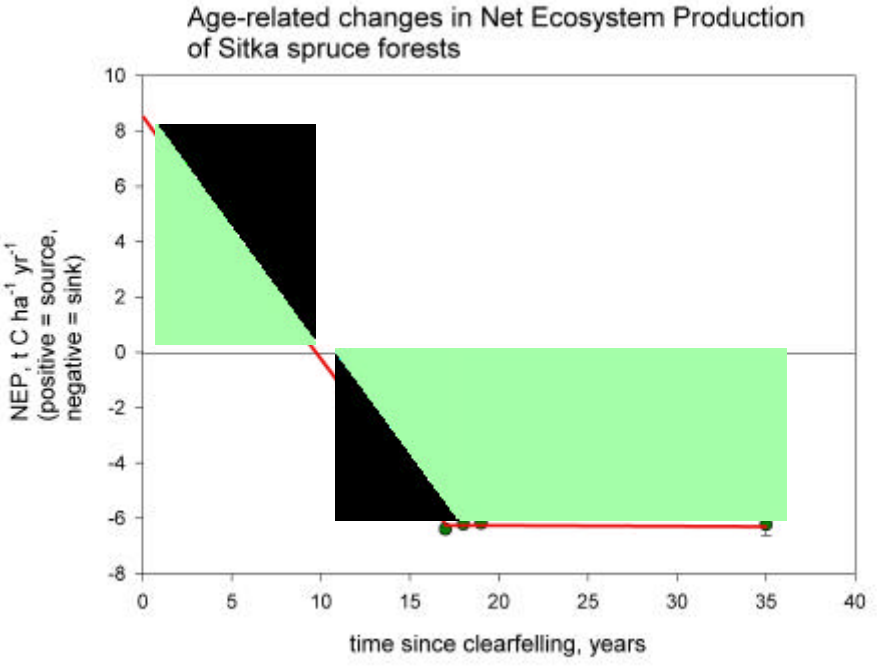
Huge uncertainty in our knowledge of carbon stocks



Houghton et al (2001) Global Change Biology

CarboAge NEP net C fluxes over one rotation
Spruce on a peaty gley: N. England
(Mencuccini, Rayment & Grace *in prep*)



Σ NEP » 149.3 tC /ha over 40 years, i.e., 3.7 t C ha $^{-1}$ y^{-1}

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Biomass by remote sensing

Biomass range	Remote sensing type
0-30 t/ha (dubious)	Optical via NDVI, C - band SAR
up to 50 t/ha	L-band SAR, C & L InSAR
up to 120-150 t/ha	P-band SAR
>150 t/ha	VHF SAR
Measure height, infer biomass (therefore no saturation)	lidar or polarimetric InSAR

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How does a radar see the forest?

Interaction with scatterers whose size is of the order of the wavelength

Austrianpine

X band
l = 3 cm

L band
l = 27 cm

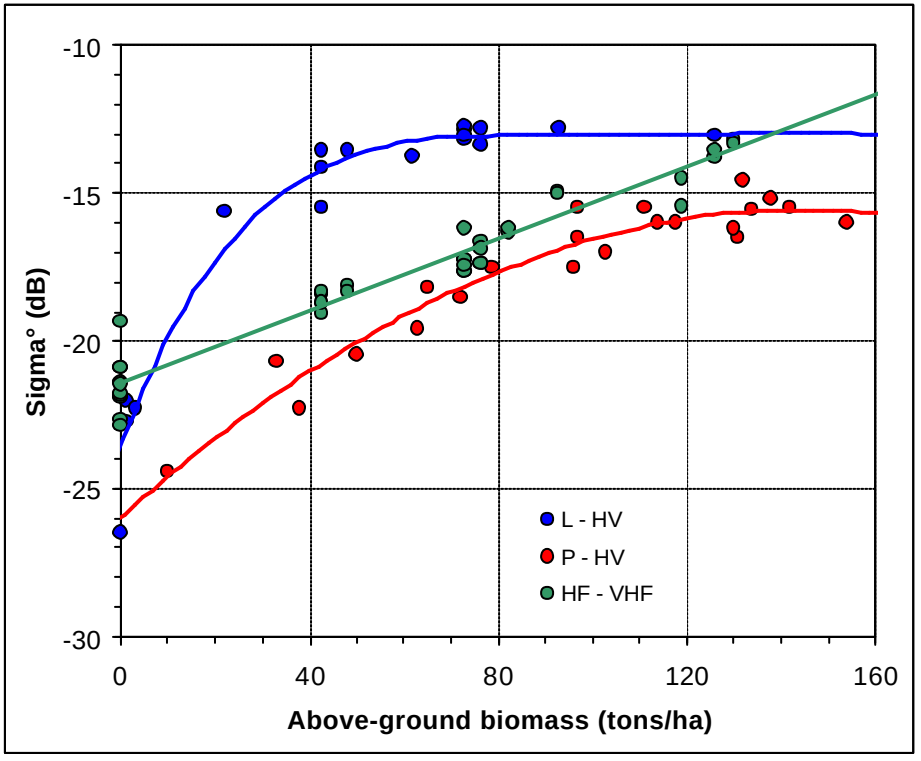
P band
l = 70 cm

VHF
l > 3 m

CESBIO

Relation of radar backscatter to above-ground biomass at L, P, VHF bands

Landes forest, France

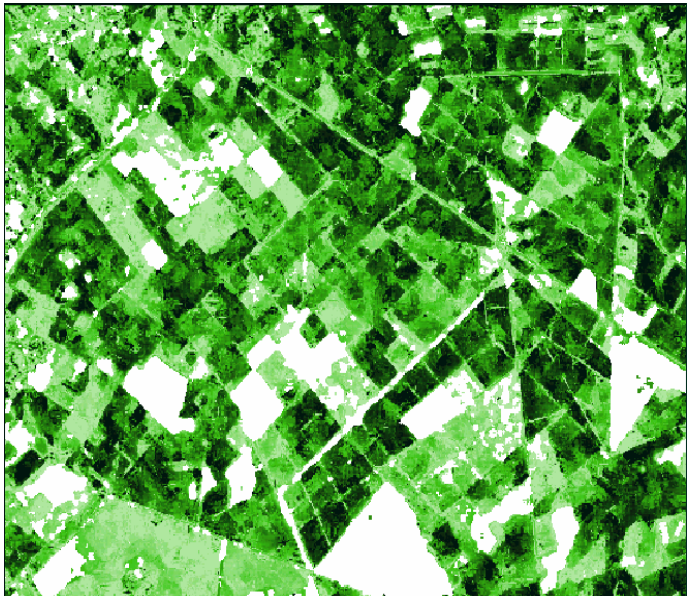


CESBIO

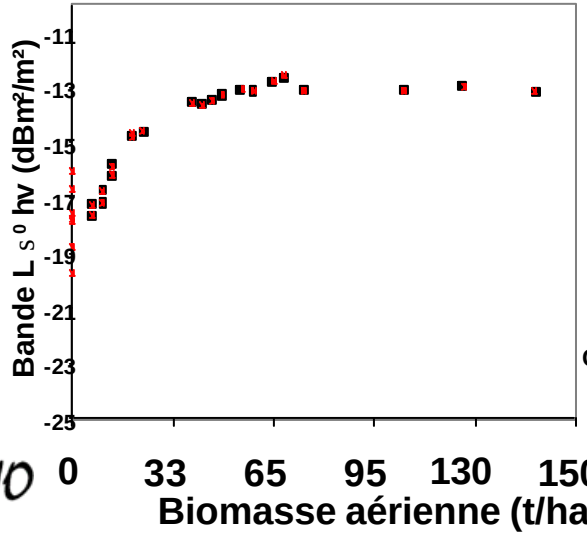
L - HV - 26° (SIR-C)

Nézer Site (Landes Forest)

Biomass Map

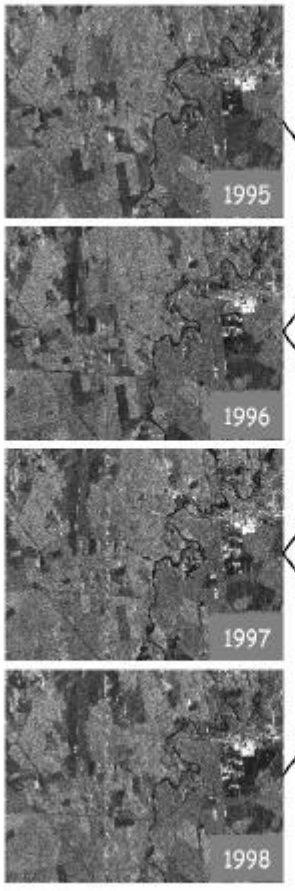


Coupes rases 25 t/ha 50t/ha 75 t/ha

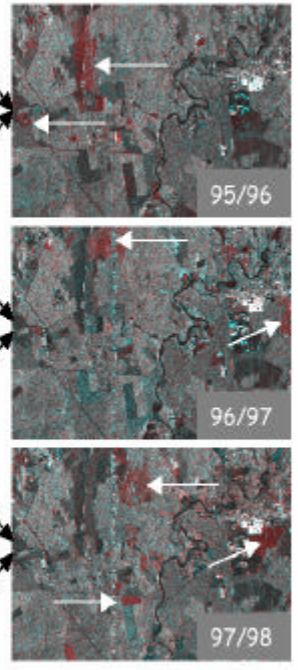


CESBIO

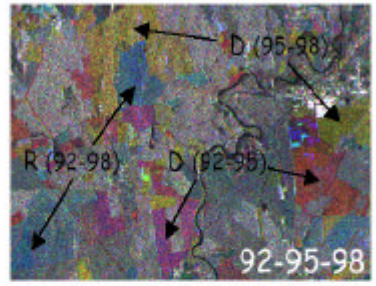
(2) Detection and quantification of changes in land cover and biomass stocks.



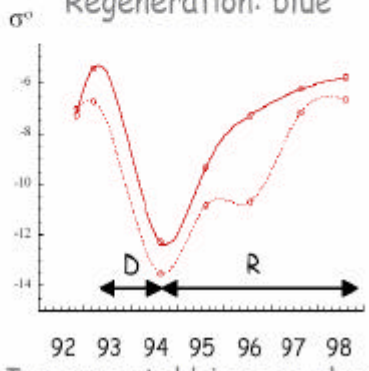
SAR time sequence



Annual forest change
(red areas)



Multi-annual forest change
Clearings: red/yellow/magenta
Regeneration: blue



Incremental biomass change
(< ~100 t/ha)

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Slide from Ake Rosenqvist, JAXA

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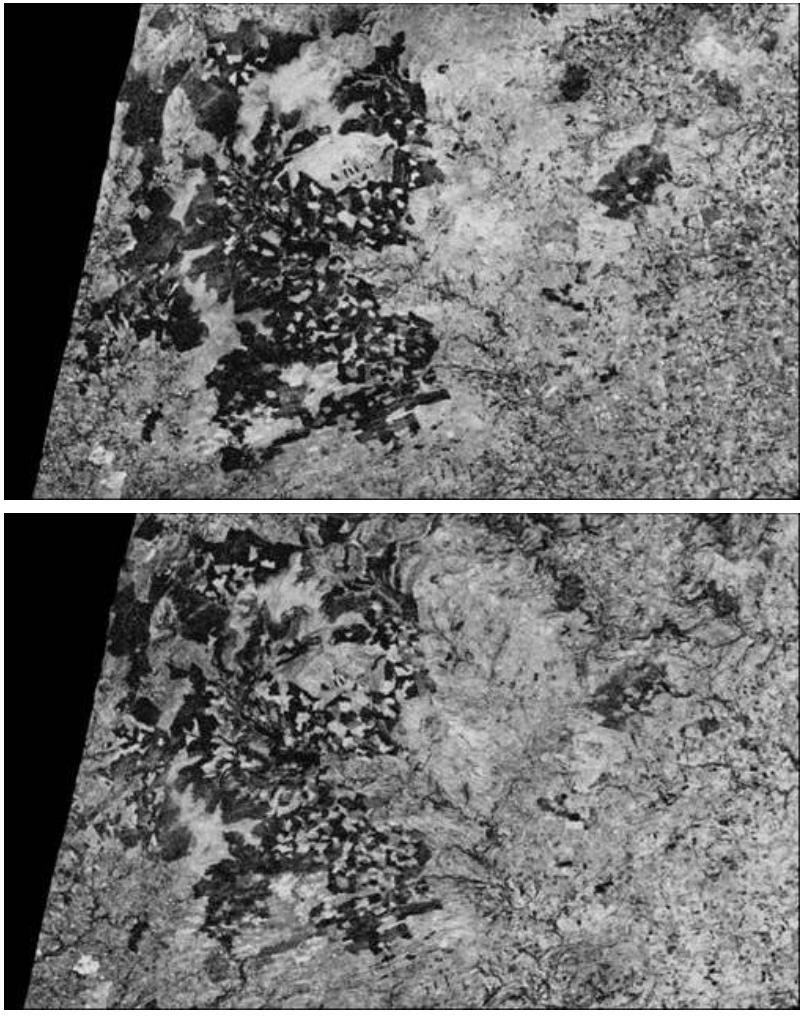
Tandem Coherence: Kielder Forest UK



July 1995

August 1999

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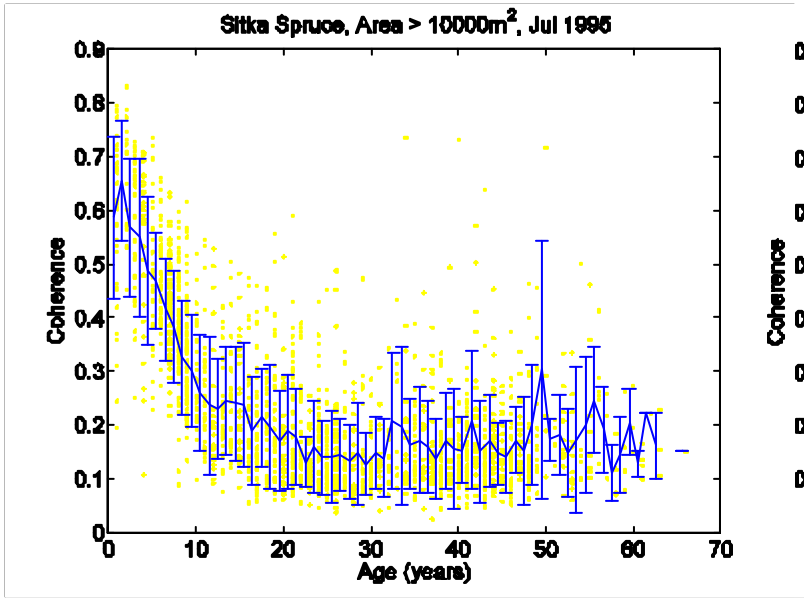
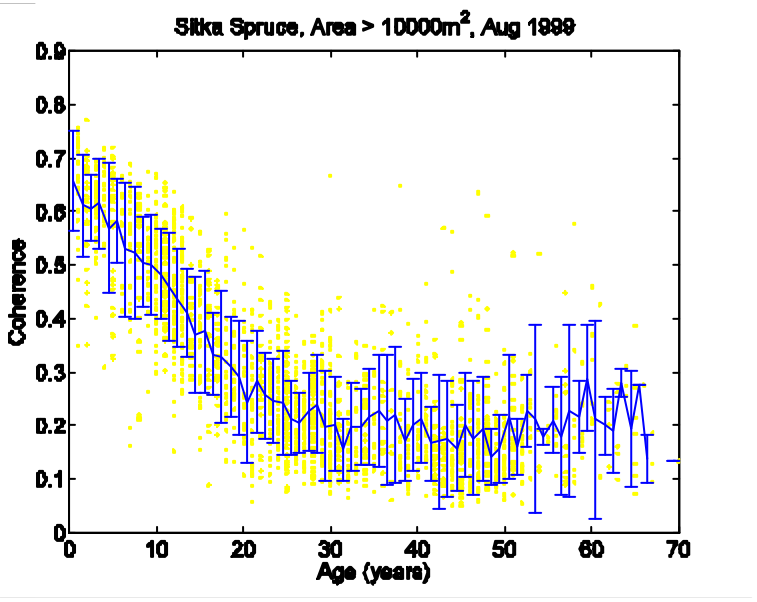
Coherence-Age plots



July 1995



August 1999

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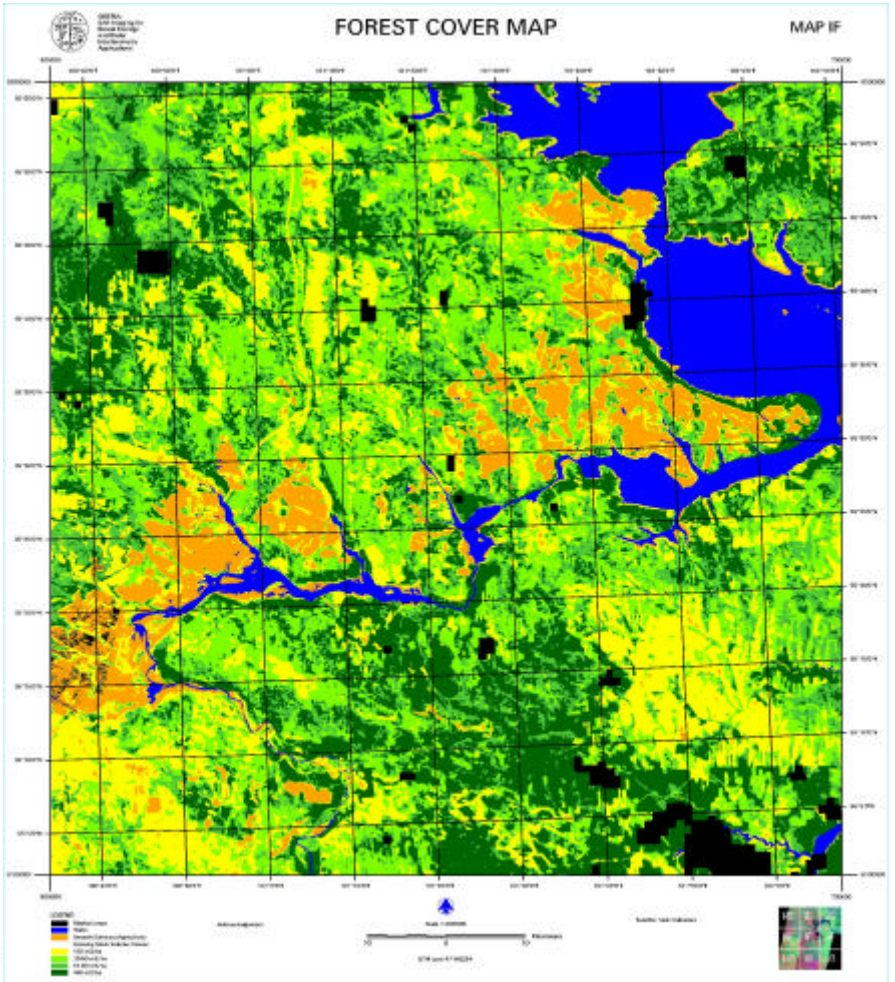
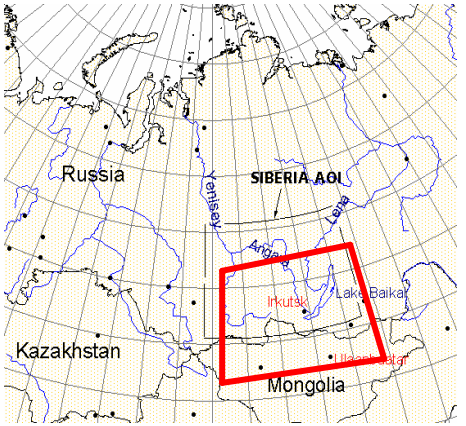


SIBERIA (SAR Imaging for Boreal Ecology and Radar Interferometry Applications), EU/CEO project no ENV4-CT97-0743.

OBJECTIVE: Generation of a forest map of central Siberia from SAR data

- one ERS-1/ERS-2 Tandem coverage from 1997 + one coverage from 1998
- one JERS coverage from 1998



RESULTS: 96 forest cover maps (100 km X 100 km) covering 650000 km2.An example of map is shown on the left.

- Water
- Smooth surfaces
- 0-20 m^3/ha: open forest, clear-cut, burnt forest
- 20-50 m^3/ha
- 50-80 m^3/ha
- > 80 m^3/ha

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Concluding remarks

EO data can provide different forms of information for models.

- boundary conditions
- calibration
- assimilation
- testing

The use of EO data in models must be matched to model structure (or model structure needs to be adapted). **The challenge is to make this match.**

Quality, consistency and availability (also the frequent need for long time-series) all affect the usefulness of the data.

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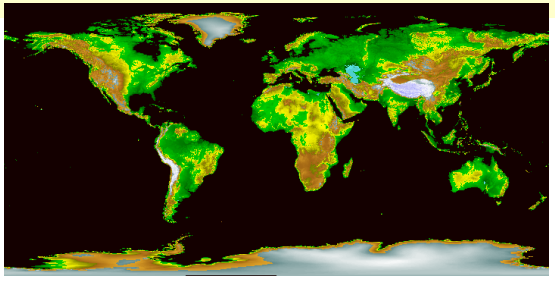
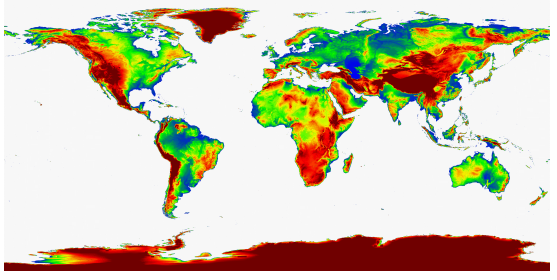
Topography - Data Sources



GLOBE

Elevations regularly spaced at 30 arc-seconds. Accuracy variable but at best ±18 m vertical (http://www.ngdc.noaa.gov/seg/topo/globe.shtml)

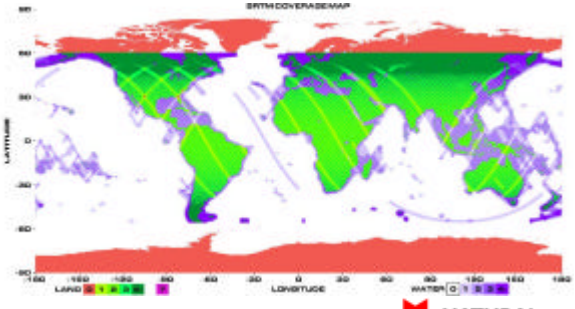


ACE

30 arc-second GDEM, improved with altimeter data. Has quality information (http://www.cse.dmu.ac.uk/geomatics/ace/index.html)

SRTM (2003)

1 x 1 arc-second elevation between 60º N and S, vertical accuracy ±16 m, being processed one continent at a time (http://seamless.usgs.gov/, http://www.jpl.nasa.gov/srtm/)



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