Vegetation Scenarios in Support of Climate Change Applications

A scientific view of the contribution of imaging spectroscopy

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Spectroscopy

Applications

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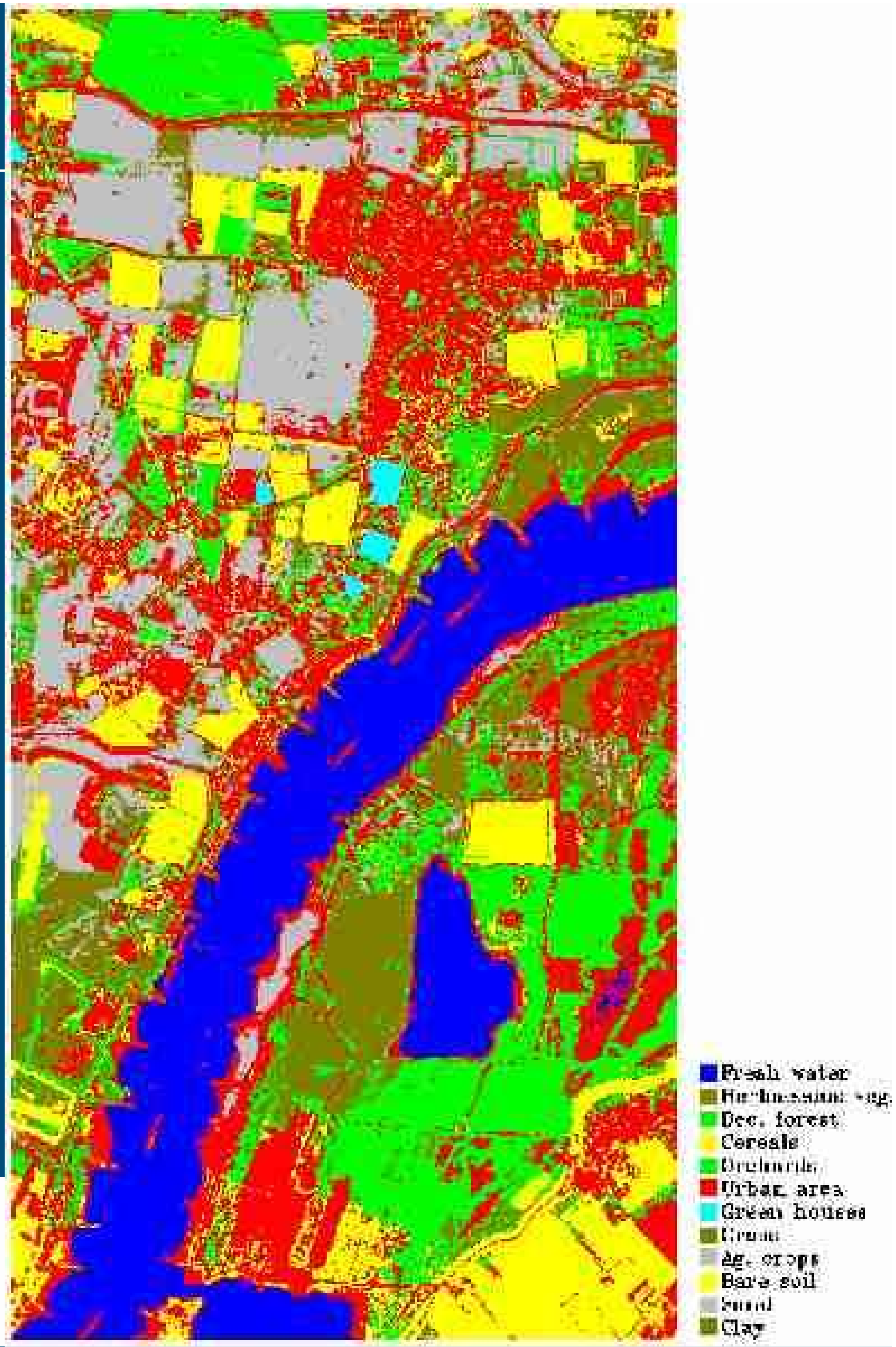
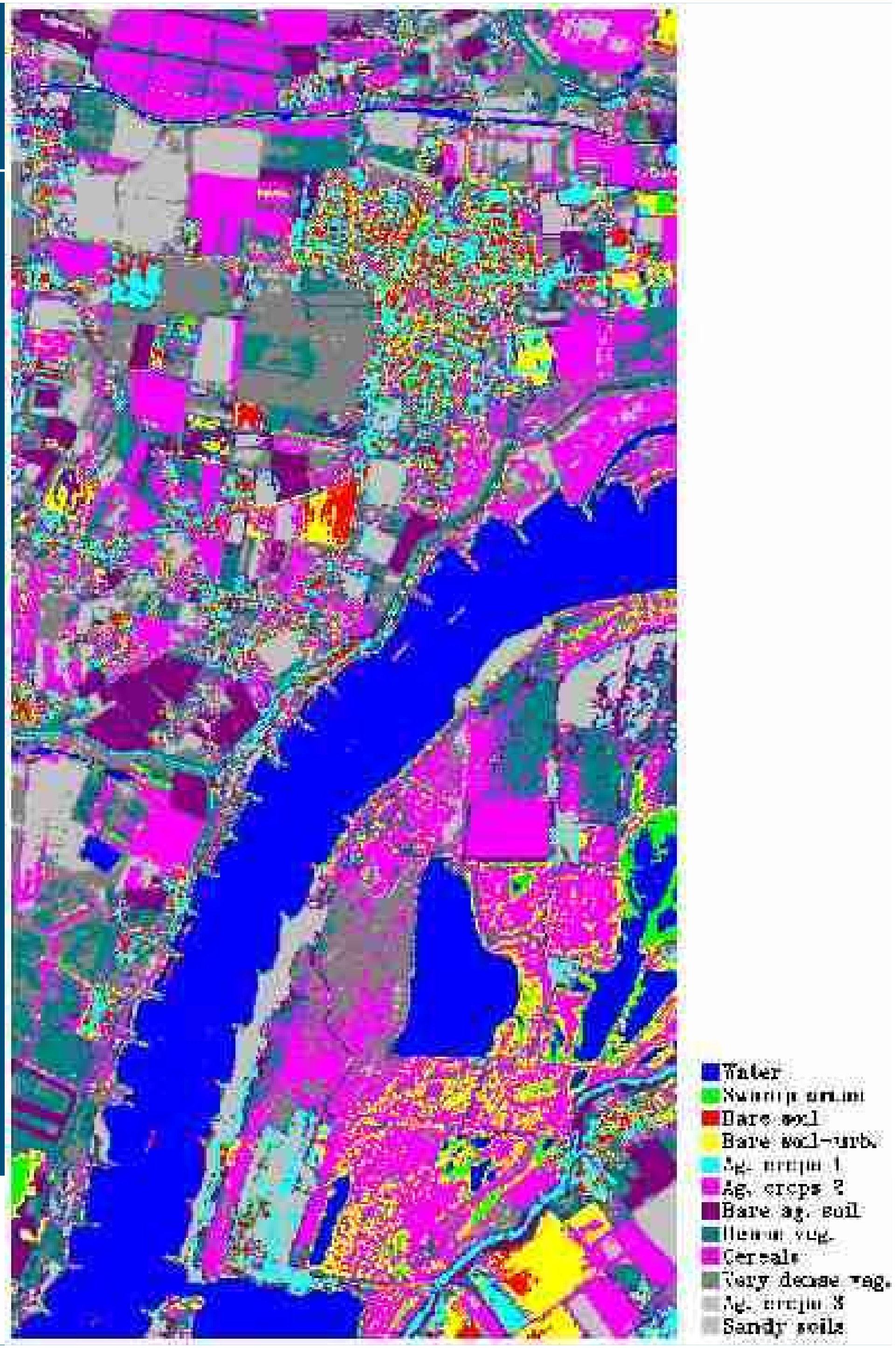
- ML Supervised Classification



- Unsupervised k-Means



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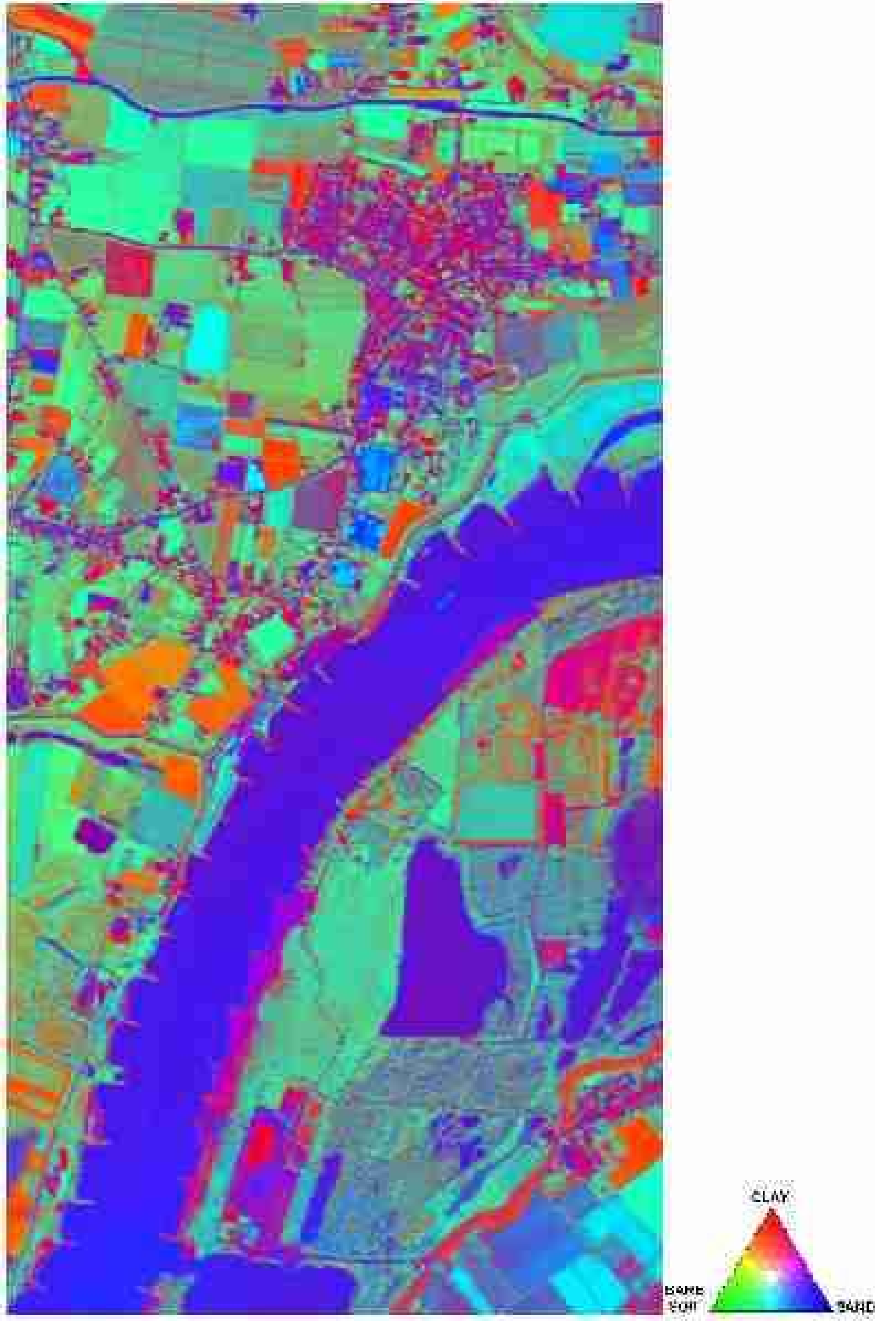
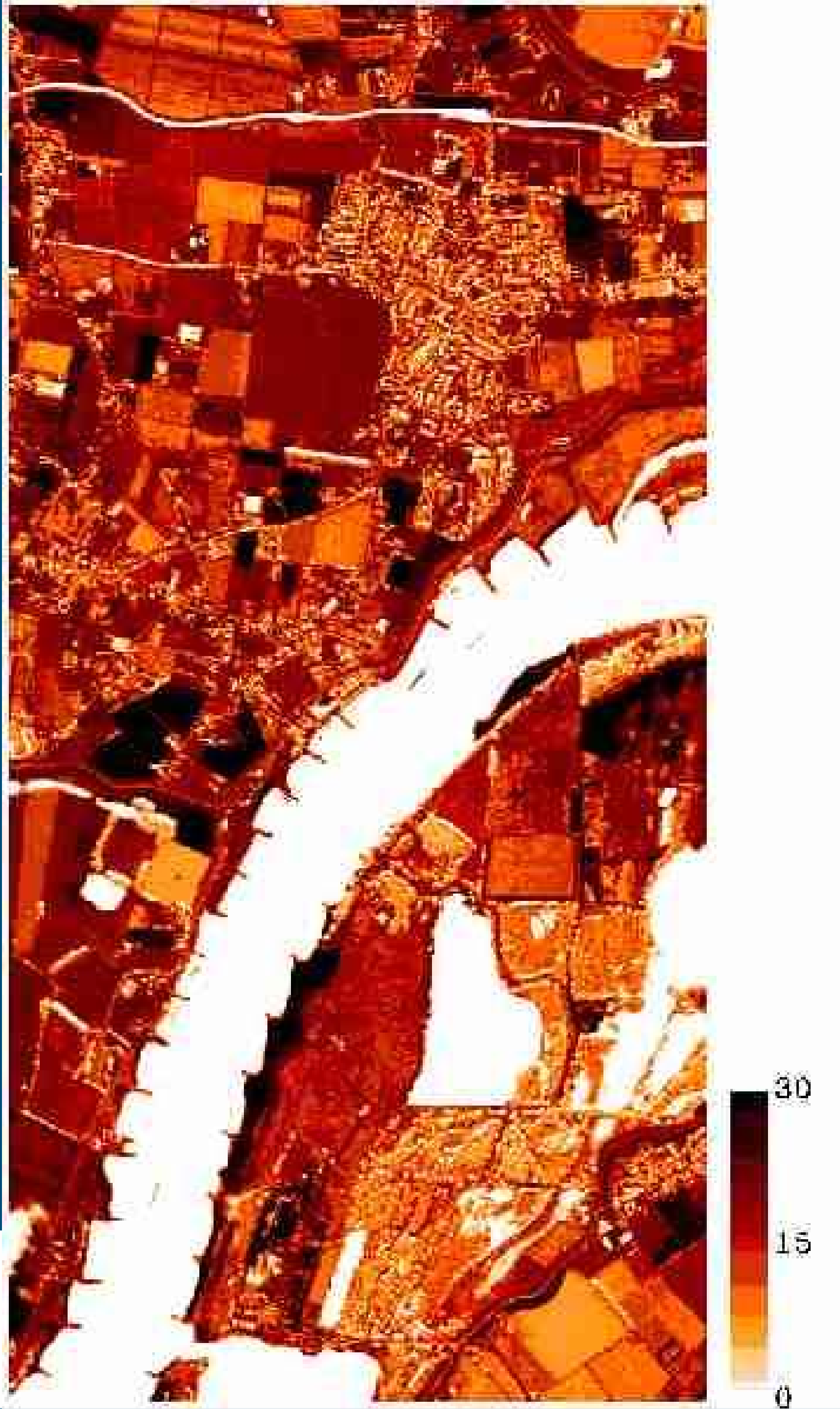
- Clay – Sand – Bare Soil Abundances (Fractions)



- Hydrocarbon Index (1705/1729 nm)



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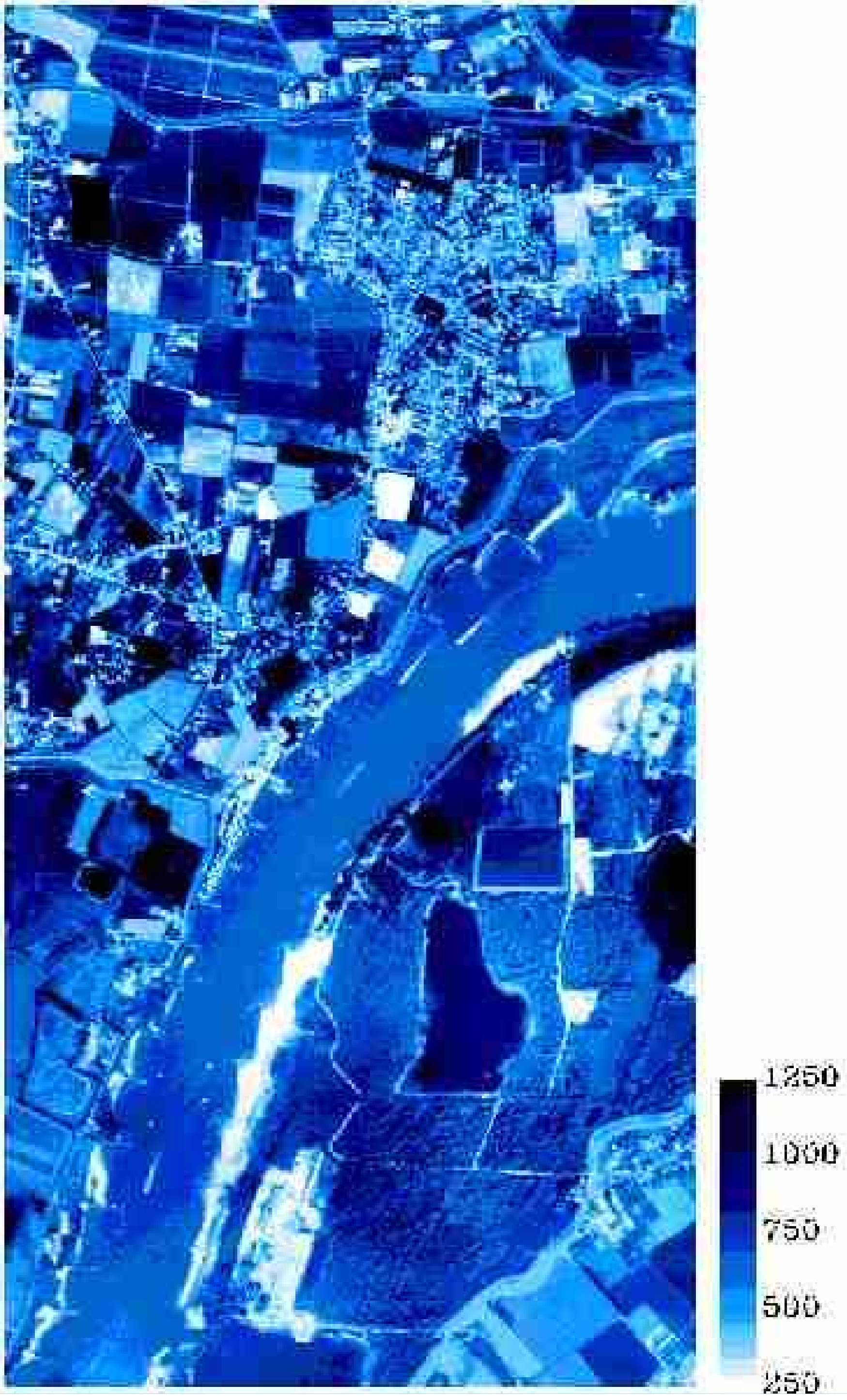
- Columnar Water Vapor (Gao / Kaufman, 2003)



- Turbidity Index (Jackson candle)

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- Total Suspended Sediments (Ghezzy, 1998)

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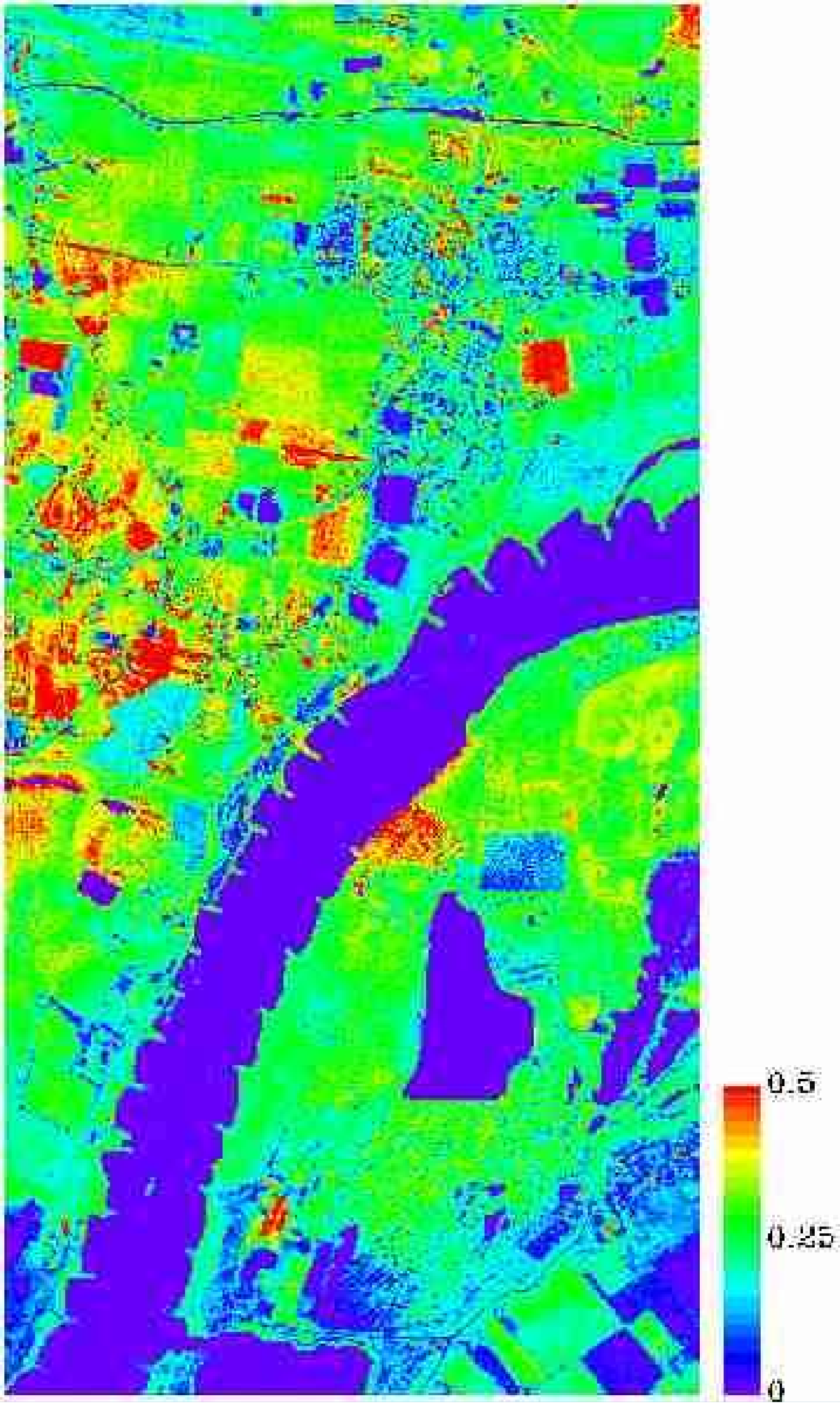
- Difference VI

- NDVIgreen (Gitelson, 1996)

- MSAVI (Huete, 1988)

- Photochemical Reflectance Index (Gamon, 1998)



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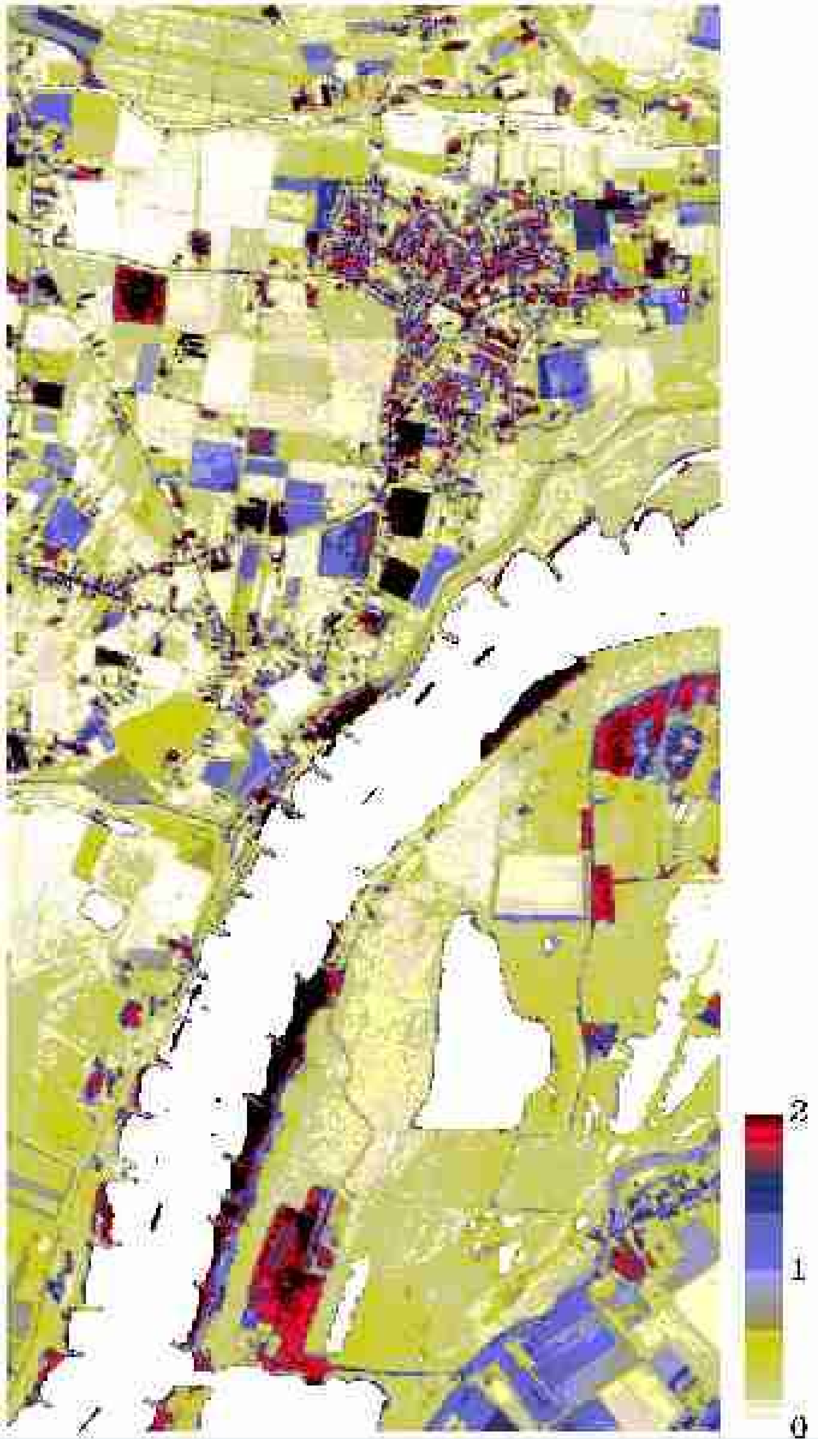
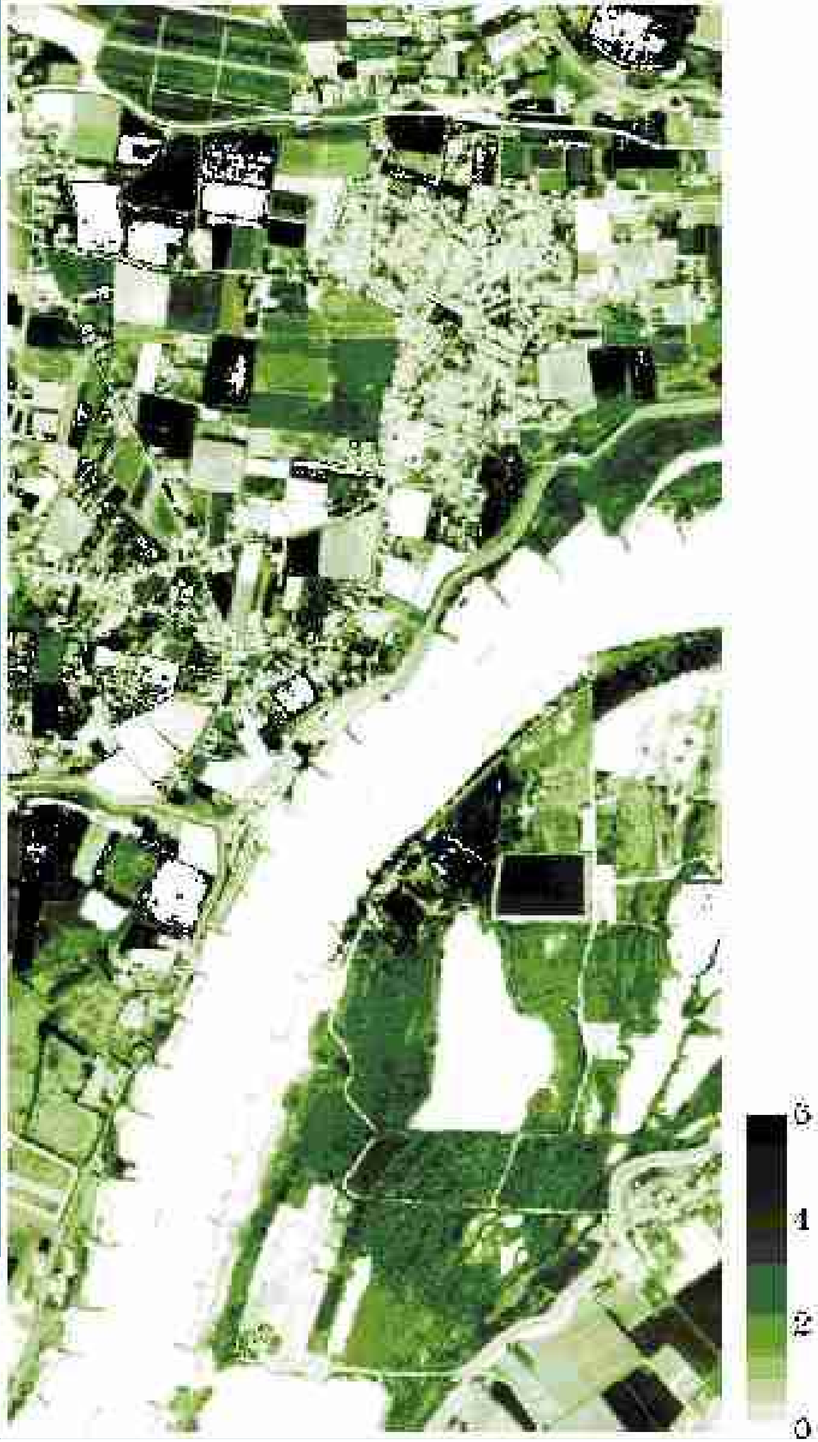
- Structure Independent Pigment Index (Peñuelas, 1995)

- Carter-Miller Stress Inde
(1994)



- LAI (based on RSR) (Chen, 2002)



- NPP (Ruimy, 1994)

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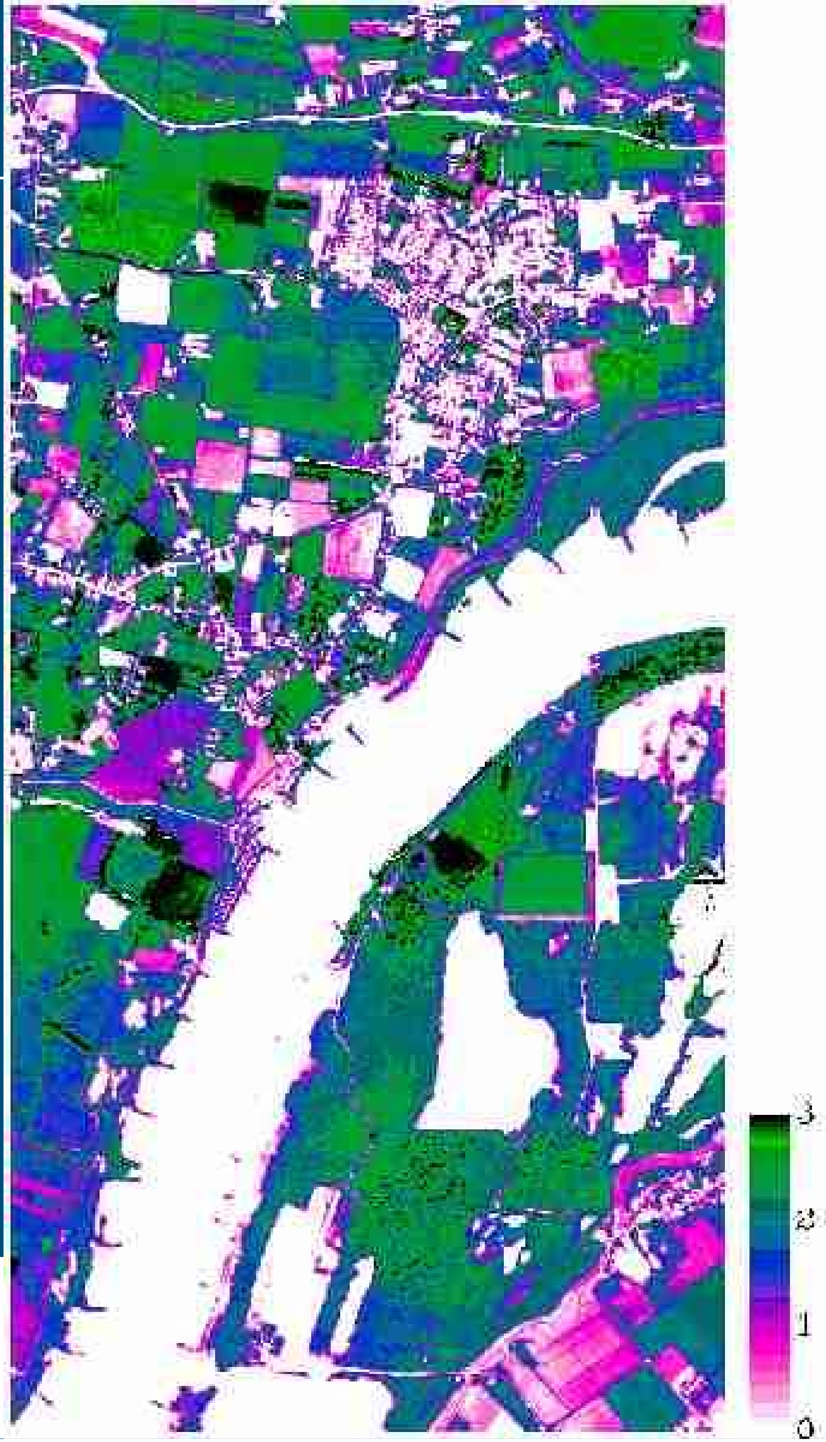
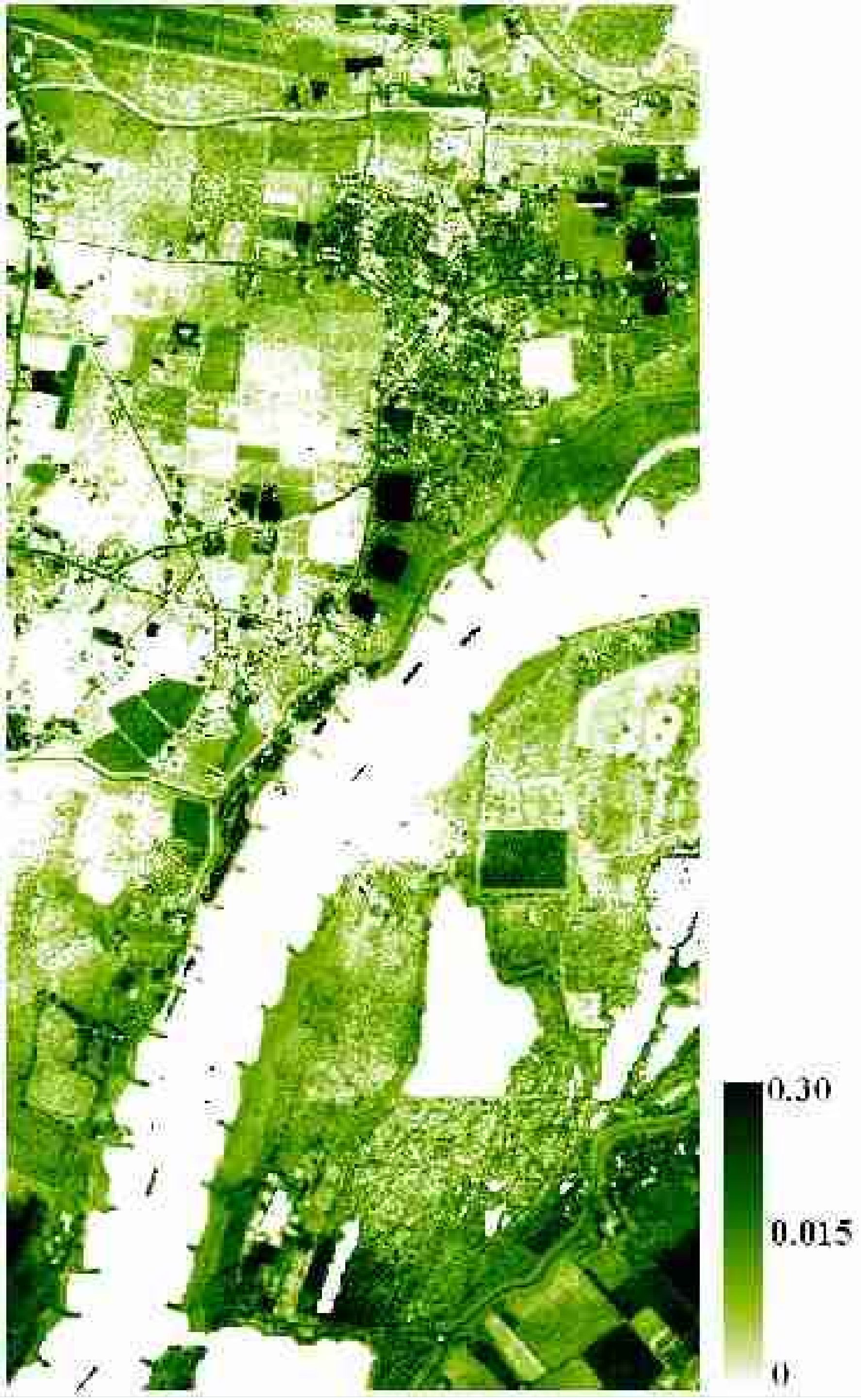
- fPAR (Gobron, 2002)



- LUE (Nichol, 2002)



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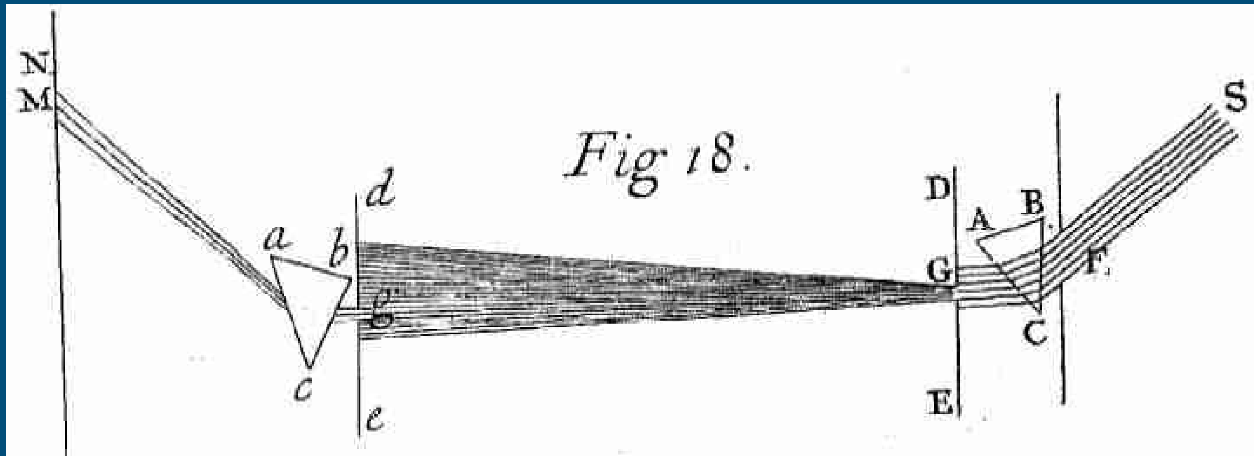
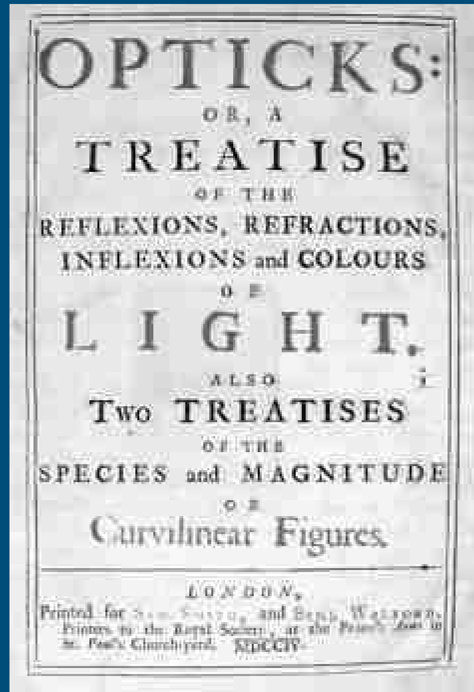
History of Spectroscopy



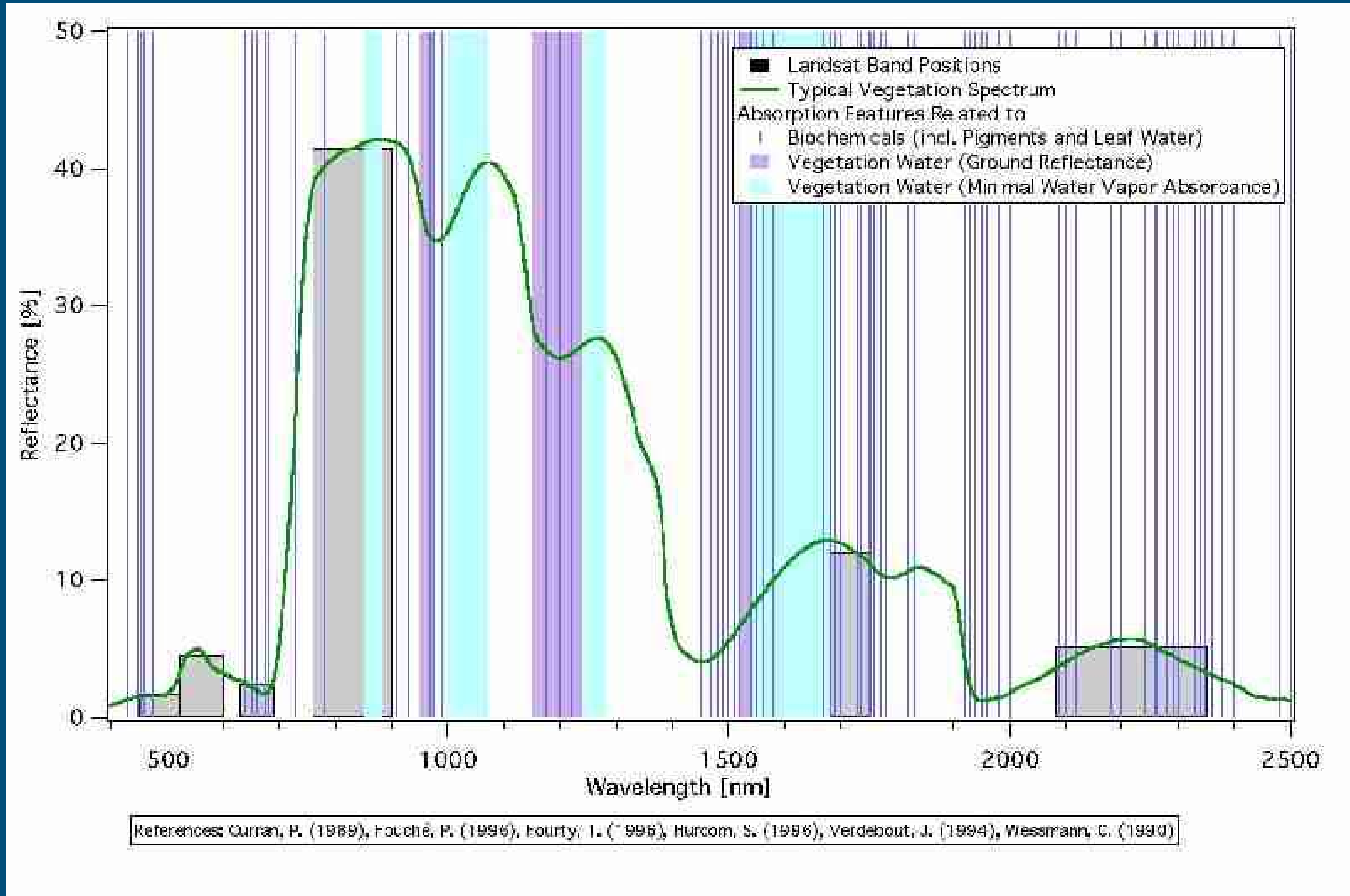

OPTICKS:
OR, A
TREATISE
OF THE
REFLEXIONS, REFRACTIONS, INFLEXIONS and COLOURS
OF
LIGHT.
ALSO
Two TREATISES
OF THE
SPECIES and MAGNITUDE
OF
Curvilinear Figures.

LONDON,
Printed for [illegible], and [illegible], Printers to the Royal Society, at the Prince's Arms in St. Paul's Church-yard. MDCCIV.

- Sir Isaac Newton (1642-1727): Spectral dispersion
- Joseph von Fraunhofer (1787-1826): Continuous spectrum, interrupted by dark lines
- Gustav Robert Kirchhoff (1824-1887): Explanation of Fraunhofer lines
- Robert Wilhelm Bunsen (1811-1899): Absorption in gas
- Sir William Huggins (1824-1910): Composition of astronomical objects
- NASA MODIS on TERRA 1999: First imaging spectrometer in space

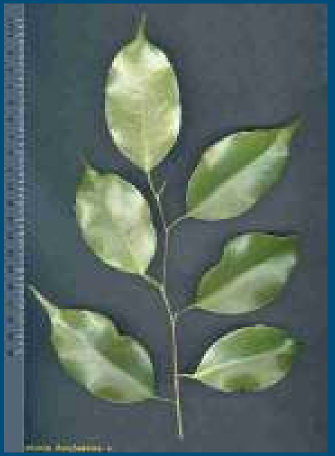
Source: Newton, I.: Opticks: or, a Treatise of the Reflexions, Refractions, Inflexions, and Colours of Light, Book I, Plate IV, Part I, Fig. 18, Sam Smith and Benj. Walford, St. Paul's Church-yard, 1704 – Burndy Library

Biochemicals Present in Vegetation Spectra



Source: Schaepman, M. (2005): Spectrodirectional Remote Sensing – From Pixels to Processes, Inaugural Address, Wageningen.

Decay of a *Ficus benjamina* L. Leaf



Undisturbed leaf

Each time step is 10 mins., total duration 8 hrs
Measurement is reflectance plus reflected transmittance

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Source:
Bartholomeus, H., and Schaepman M. (2004)
Decay of *Ficus benjamina* L. in 10 minutes steps over 8 hrs, unpublished

Current Status of Spectroscopy (in space)

- Operational instruments exist
  - CHRIS/PROBA
  - MODIS Terra/Aqua
  - Hyperion / EO-1
  - MERIS Envisat
- Future instruments do not exist (yet)
  - SPECTRA (ESA) – deselected FLORA (ESSP) – postponed
  - HERO (CCRS) – postponed
  - NEMO (Navy) - unknown
  - EnMap (D) – In evaluation
  - FLEX (ESA) – In evaluation

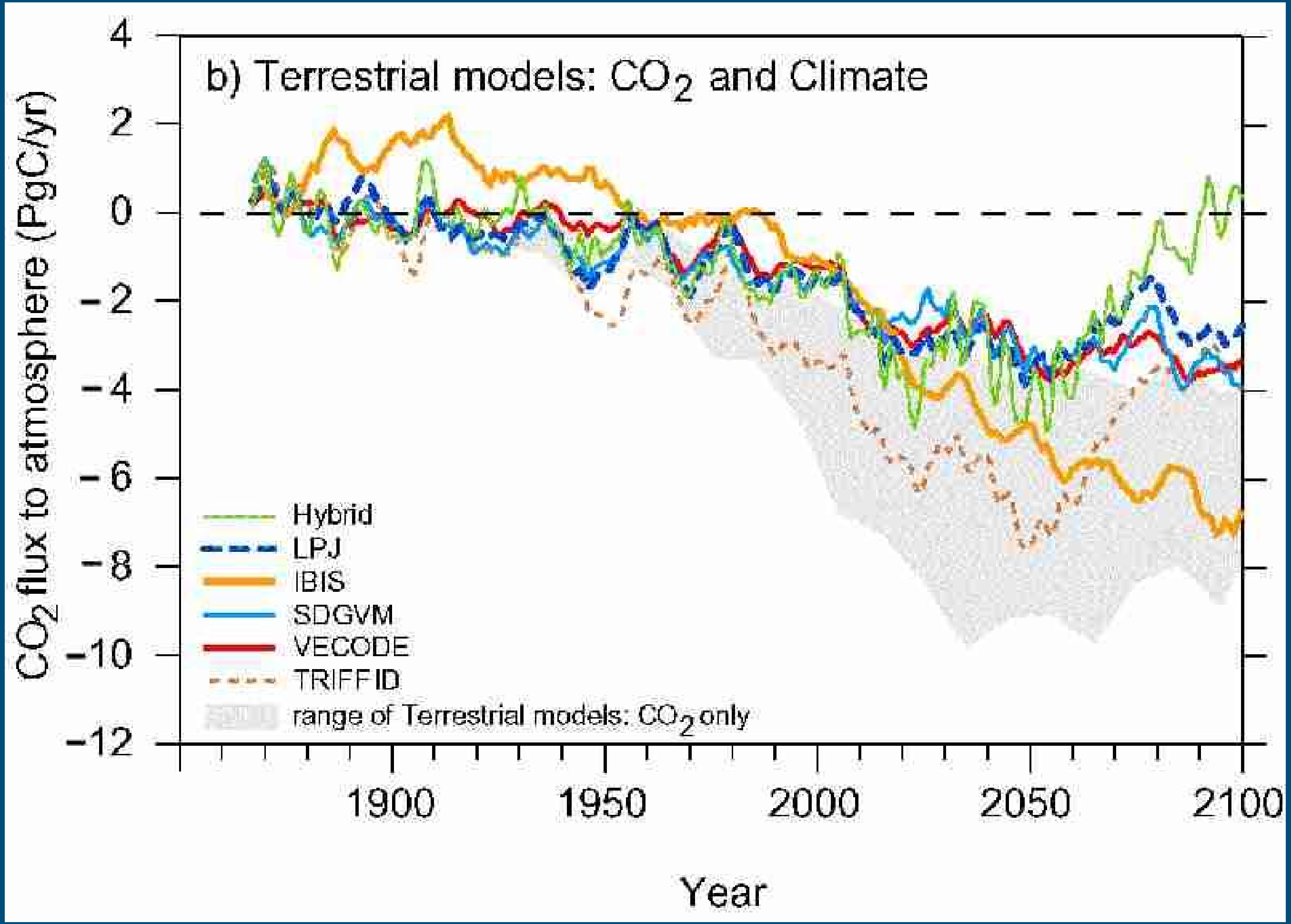
Outlook

- Planned Missions
  - ESA GMES Sentinel 2 / 3
    - Superspectral / Land Mission
  - …

- Within reasonable time, no global coverage imaging spectrometer will be available …

- Airborne initiatives are well received (ARES, APEX, HyMap, AHS, AVIRIS, etc.), but provide regional incentives only.

CO2 and Climate: Model Divergence



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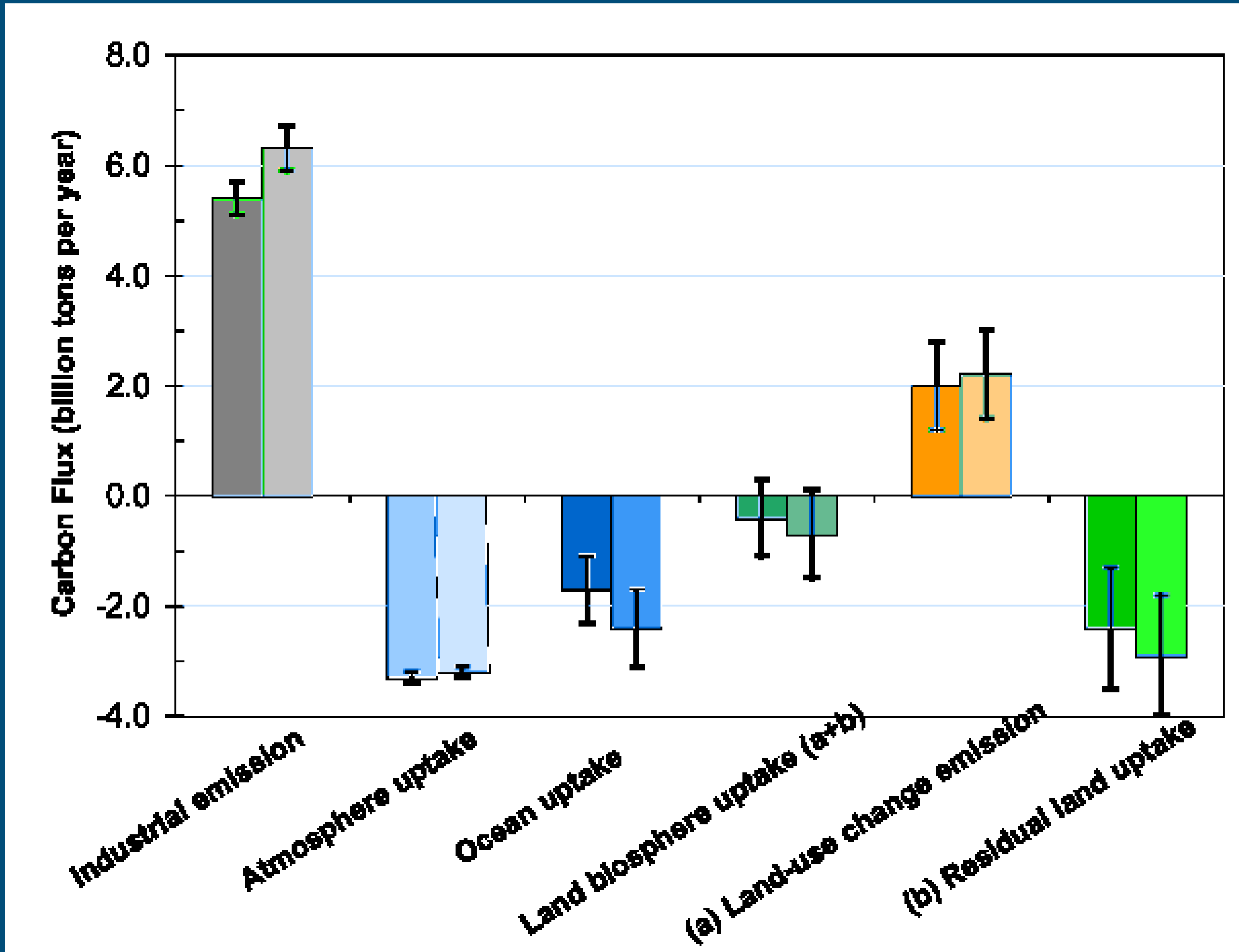
Source: M. Rast, Ed., *SPECTRA – Surface Processes and Ecosystem Changes Through Response Analysis*, ESA SP-1279(2), 2004, pp. 66; Data: IPCC (2001) Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K., 881pp.

Global Net Carbon Balance



Bars indicate a decade each

Uncertainties are in black

Source: M. Rast, Ed., *SPECTRA – Surface Processes and Ecosystem Changes Through Response Analysis*, ESA SP-1279(2), 2004, pp. 66; Data: Joos, F., G.-K. Plattner, T.F. Stocker, A. Körtzinger, and D.W.R. Wallace, 2003: Trends in Marine Dissolved Oxygen: Implications for Ocean Circulation Changes and the Carbon Budget, *EOS*, 84 (21), 197-201.

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Climate Scenarios vs. Vegetation Scenarios

- IPCC climate change predictions are only driven by climate scenarios:
  - Currently DGVMs do not consider (at all/well enough) the inter-/intra-year variability of vegetation
  - Vegetation changes at much faster rates due to phenology, disturbance (fire, land use change, etc.), rather than due to climate change -> interannual variability!
  - To better explain the uncertainty in the land sink/source domain, vegetation scenarios (analog to climate scenarios) should be developed

Millennium Ecosystem Assessment

- Conclusions: What are the most important uncertainties hindering decision making concerning ecosystems?
  - There are major gaps in global and national monitoring systems that result in the absence of well-documented, comparable, time-series information for many ecosystem features and that pose significant barriers in assessing conditions and trends in ecosystem services. Moreover, in a number of cases, including hydrological systems, the condition of the monitoring systems that do exist is declining.
  - Although for 30 years remote sensing capacity has been available that could enable rigorous global monitoring of land cover change, financial resources have not been available to process this information, and thus accurate measurements of land cover change are only available on a case study basis.

MA Board (2005). Millennium Ecosystem Assessment Synthesis Report, Reid, W.V., (ed.), p. 219, http://www.maweb.org

Land-Biosphere Models

What processes are / should be mapped by land biosphere models ?

- Carbon Engine
  - carbon fixed per unit time = f(CO_2, light, water availability, temperature, nutrients)
- Carbon allocation
  - distribution of C fixed to different living tissue (e.g. stems or roots) = f(geometry, physiology,plant functional type, species)
- “Remineralisation ”
  - Carbon flow to nonliving forms and decomposition (fast and slow soil pools) = f(plant functional type, physiology, microbiology, molecular structure (e.g. lignin vs. waxes or cellulose))
- Hydrology
  - soil water balance, (root depths)
- Population dynamics
  - early versus late successional species through competition for resources (light, nutrients, water) = f(stand height, stand age, physiology)
  - disturbance: humans (land use), fire, windfall, insects = f(climate, humans)

Gloor, M. (2005), Schaepman (2005)

Comparison of 5 Different Land-Biosphere Models

	CASA	BETHY	PnET	LM3	SMART/SUMO
Carbon Engine	Light use efficiency, PAR, fPAR	(Farquhar, Ball, Berry) or LUE	Pmax=a+b*N, where N is foliar Nitrogen	Farquhar, Ball, Berry	C-ass = f(light, N,P,water availability, temp)
Phenology	fPAR	?	Predicted	fPAR	Not relevant (timestep = 1y)
Allocation	Globally fixed ratios; leaf, litter, roots	?	Simple allocation rules for tissue types	Allometries	Ratios (root, shoot, leaf) fixed per vegetation type
Remineralisation	5 litter, 2 organic pools, first order decay	?	No soil carbon component	Fast and slow pools of C and N	Litter + 2 organic pools, fixed ratio + 1st order decay
Hydrology	Bucket type	Bucket type	One soil layer	Bucket type	Supplied by external hydrological model (WATBAL, SWAP)
Discretization	PFT’s	PFT’s	Biomass produced only by tissue type (foliage)	Defined by mortality and fecundity functions (species build a continuum)	5 FT's that compete for light, N, P, water
Demography	None	None	None	Core of model	None (but tree mortality included)
Reference	Potter et al., Global Biogeochem. Cycles, 7(4): 811-841, 1993	Knorr, Global Ecology & Biogeography, 9:225-252, 2000	Aber, Oecologica, 92(4): 463-474, 1992	Carbon Mitigation Initiative, Princeton Univ., 2005	Wamelink & al. in prep., 2005

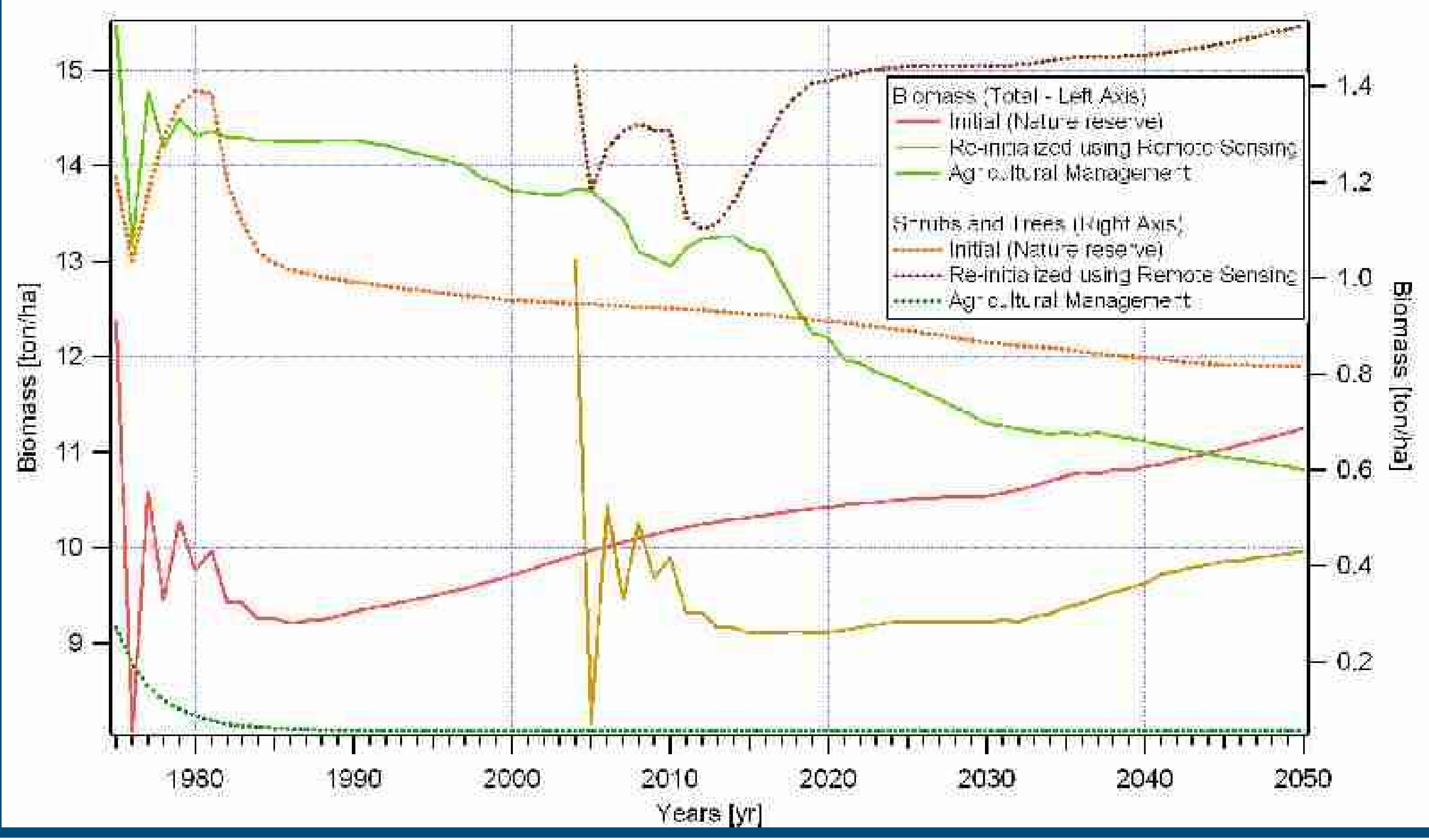
Gloor, M. (2005), van Dobben, H. (2005), pers. comm.

RS Derived Variables and Models

Variable	**Instrument**	**CASA Model**	**ED Model**	**SMART/SUMO**
fPAR	Optical	NPP	-	NPP
LAI	Optical	-	Eval. predicted LAI	Eval. predicted LAI
Albedo	Optical/Thermal/IS	-	Eval. predicted Albedo	-
fCover	Optical	-	Eval. predicted fCover	-
fLiving/Dead Biomass	Optical	-	Eval. predicted mortality	-
Leaf Chlorophyll	Optical/IS	-	-	-
Leaf Water	Optical/IS	-	?	-
Leaf Dry Matter	Optical/IS	-	Eval. leaf dry matter	-
Foliage Temperature	Thermal	-	Important for eval. of water loss during photosynthesis	Eval. potential evapotransp.
Soil Temperature	Thermal	-	Water stress eval.	Water stress eval.
Leaf Nitrogen	IS	-	-	Eval predicted leaf N

Schaepman (2005)

Biomass Divergence due to Management



Schaepman et al. (2005)

Conclusions

- Imaging spectroscopy as an enabling technology has achieved significant advances in understanding the interaction of light with the Earth surface
- Current mission durations of imaging spectrometers will enable to contribute to climate change research (e.g., MODIS – 5 year continuous acquisition)
- Close integration of vegetation change science and climate change science is emerging

Outlook

- Upcoming activities (using IS) will focus on
  - C:N:P ratios
  - PFT determination
  - Biodiversity ‘measures’
    dominant species, species composition
  - Soil properties
  - Pigments (Chl a/b, Xantophyll, etc.) and other relevant leaf molecules (Cellulose, Lignin, etc.)

Comment

- Several initiatives to further foster imaging spectroscopy are underway, however

- The IS community needs to further convince with striking results that
  - Multidisciplinary research is a benefit, and not a drawback
  - Long-term data continuity is a prime requirement
  - Many spectral bands result in a multitude of opportunities and not in many problems

Thank you for your attention!