Spectrodirectional Remote Sensing

From Pixels to Processes

Michael Schaepman

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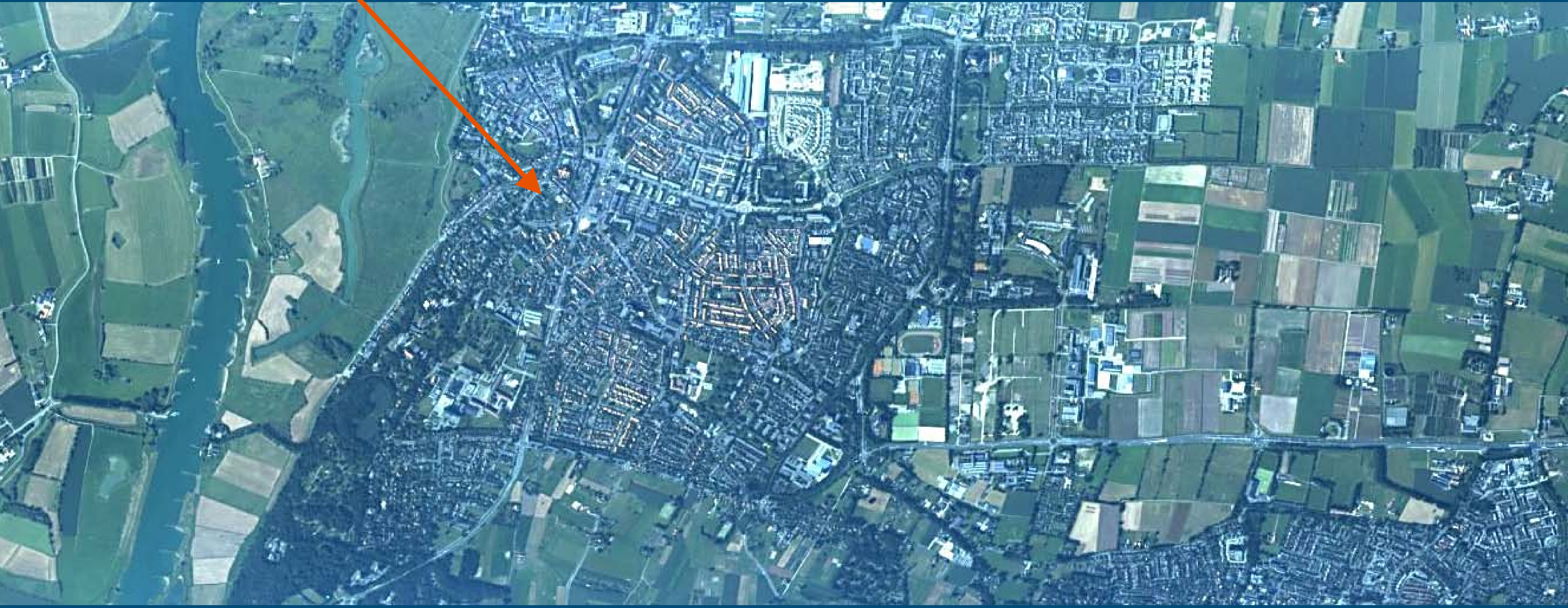
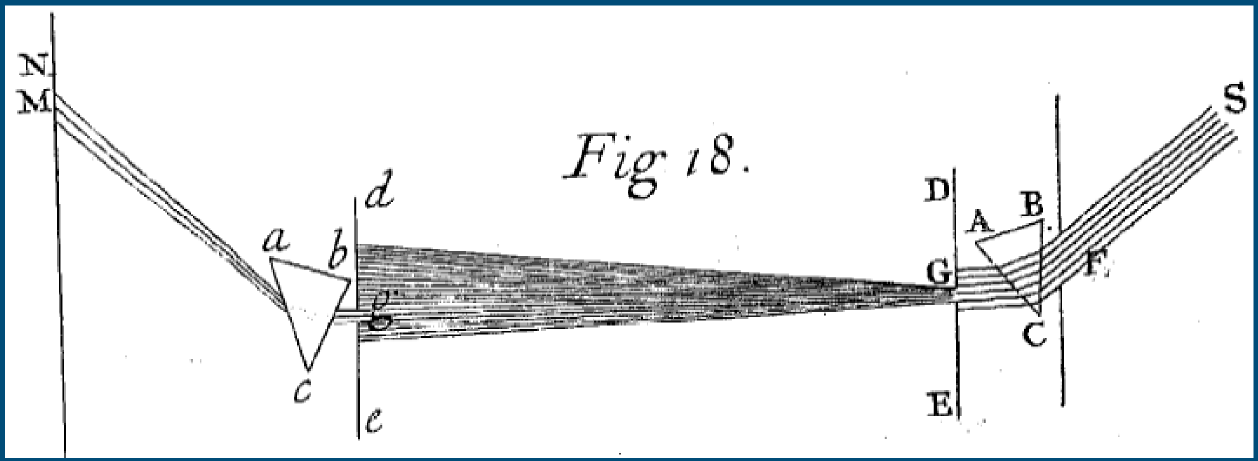
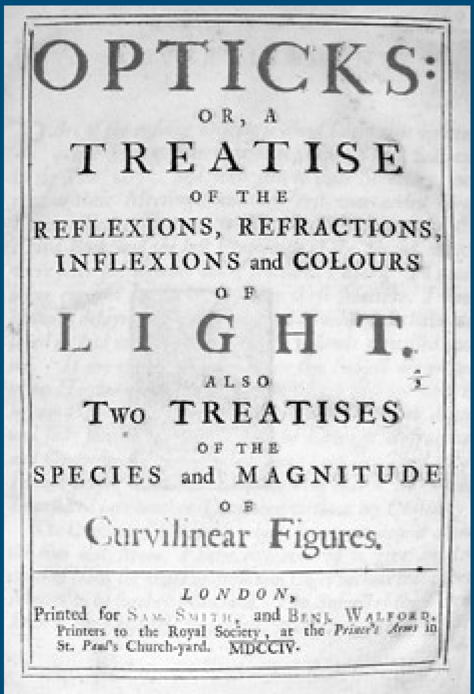
Introduction



Source:
Bunnik, N. and Verhoef W., Farewell workshop presentations, 2004
HyMap data Wageningen, courtesy Belspo, VITO, DLR, 2.8.2004

History of Spectroscopy





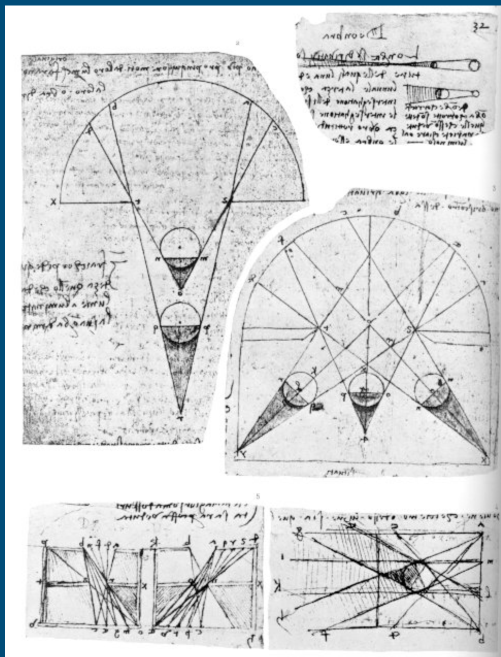
OPTICKS:
OR, A
TREATISE
OF THE
REFLEXIONS, REFRACTIONS, INFLEXIONS and COLOURS
OF
LIGHT.
ALSO
Two TREATISES
OF THE
SPECIES and MAGNITUDE
OF
Curvilinear Figures.

LONDON,
Printed for Sam. Smith, and Benj. Walford, 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

History of Directionality



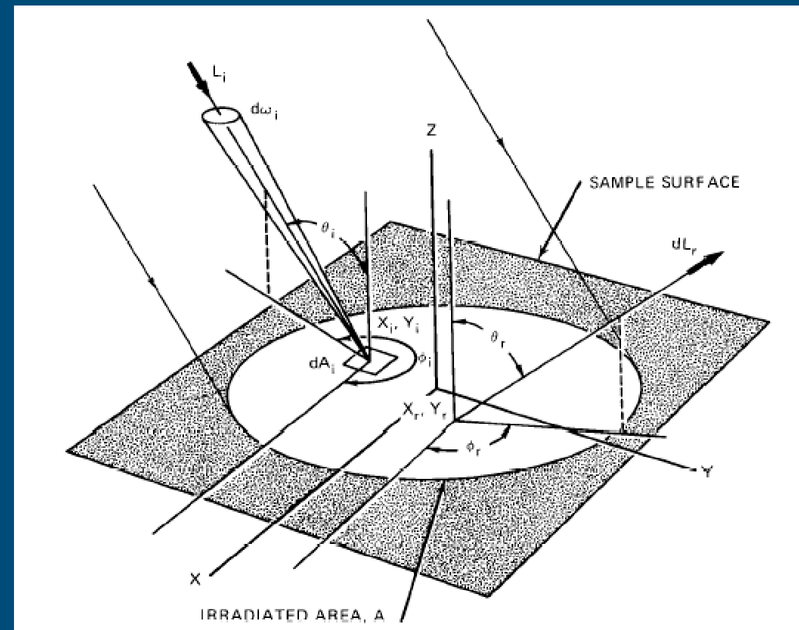


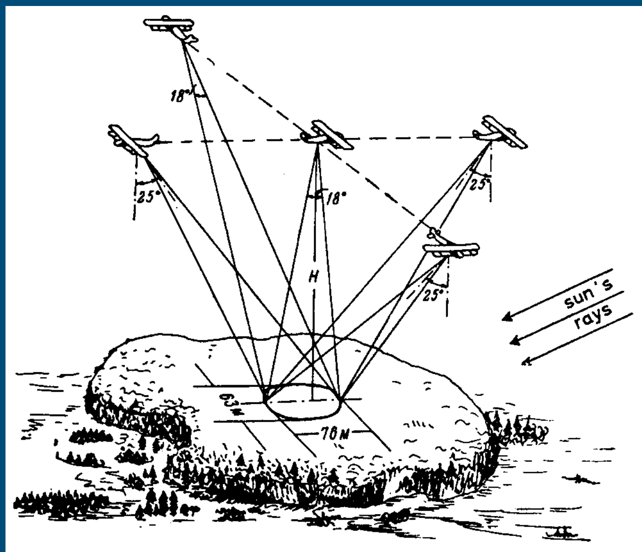
FIGURE 1. *Geometry of incident and reflected beams (for general cases where sub-surface scattering is involved).*

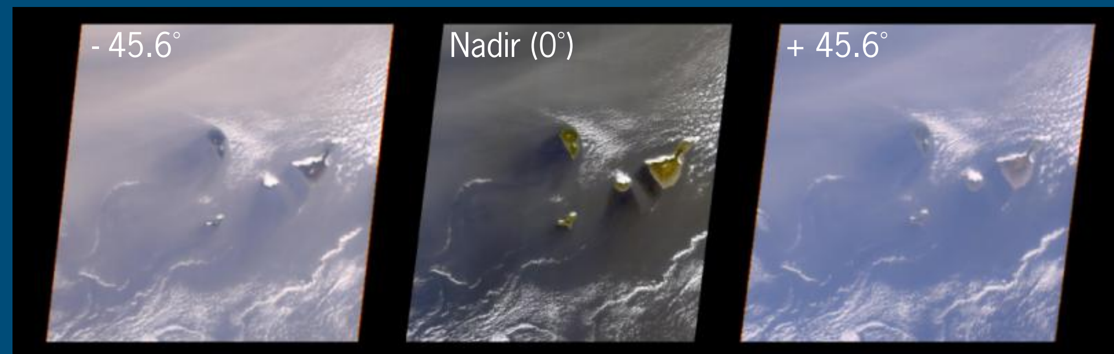
- Leonardo Da Vinci (1452-1519) — Experimental methods
- Pierre de Fermat 1658 — Geometric optics
- John W. Strutt (Third Baron Rayleigh) 1871 — 'Rayleigh' scattering
- Cox and Munk 1954 — Hot spot
- Fred Nicodemus 1965 — BRDF
- ESA ATSR-1 on ERS-1, 1991 — First directional satellite in space

Sources:
Richter, J.P. (ed): The Notebooks of Leonardo Da Vinci, Vol. 1, Dover Publ. Inc., New York, 367 pp., 1970

Nicodemus, F.: Geometrical Considerations and Nomenclature for Reflectance, NBS Monograph 160, 52 pp., 1977

History of Spectrodirectional Remote Sensing



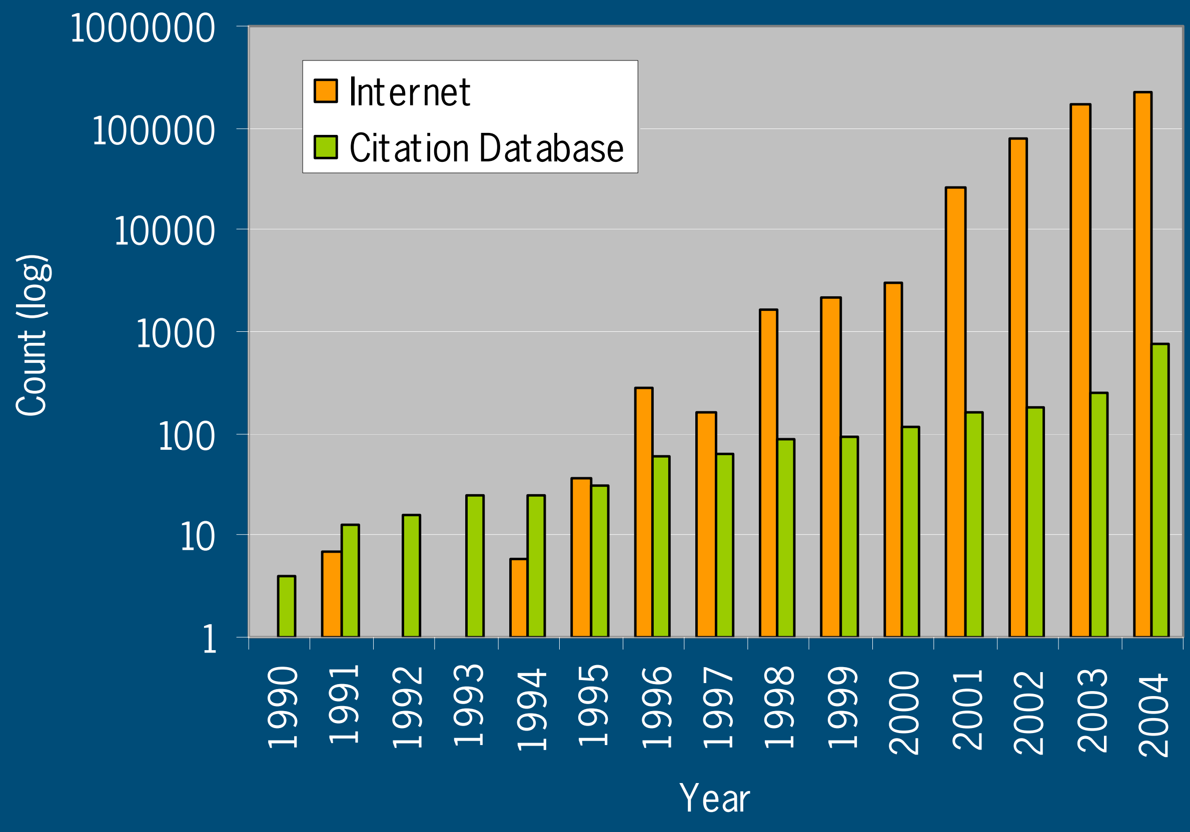


V.V. Kolcov 1958	ESA ATSR-1 on ERS-1 1991	CNES POLDER on ADEOS 1996	NASA MISR on Terra 1999	ESA CHRIS on PROBA 2001	John Martonchik, Michel Verstraete, Gabriela Schaepman-Strub 2002/03
Experimental flight pattern	4 spectral bands, 2 view angles	9 spectral bands, var. view angles	4 spectral bands, 9 view angles	62 spectral bands, 5 view angles	First proposals & paper

Source: Arcybashev, E.S., and Belov, S.V.: The Reflectance of Tree Species; as translated in: Steiner, D., and Gutermann, T.: Russian Data on Spectral Reflectance of Vegetation, Soil, and Rock Types. Eur. Res. Office, US Army, Juris, 1966

NASA MISR Website, 2004

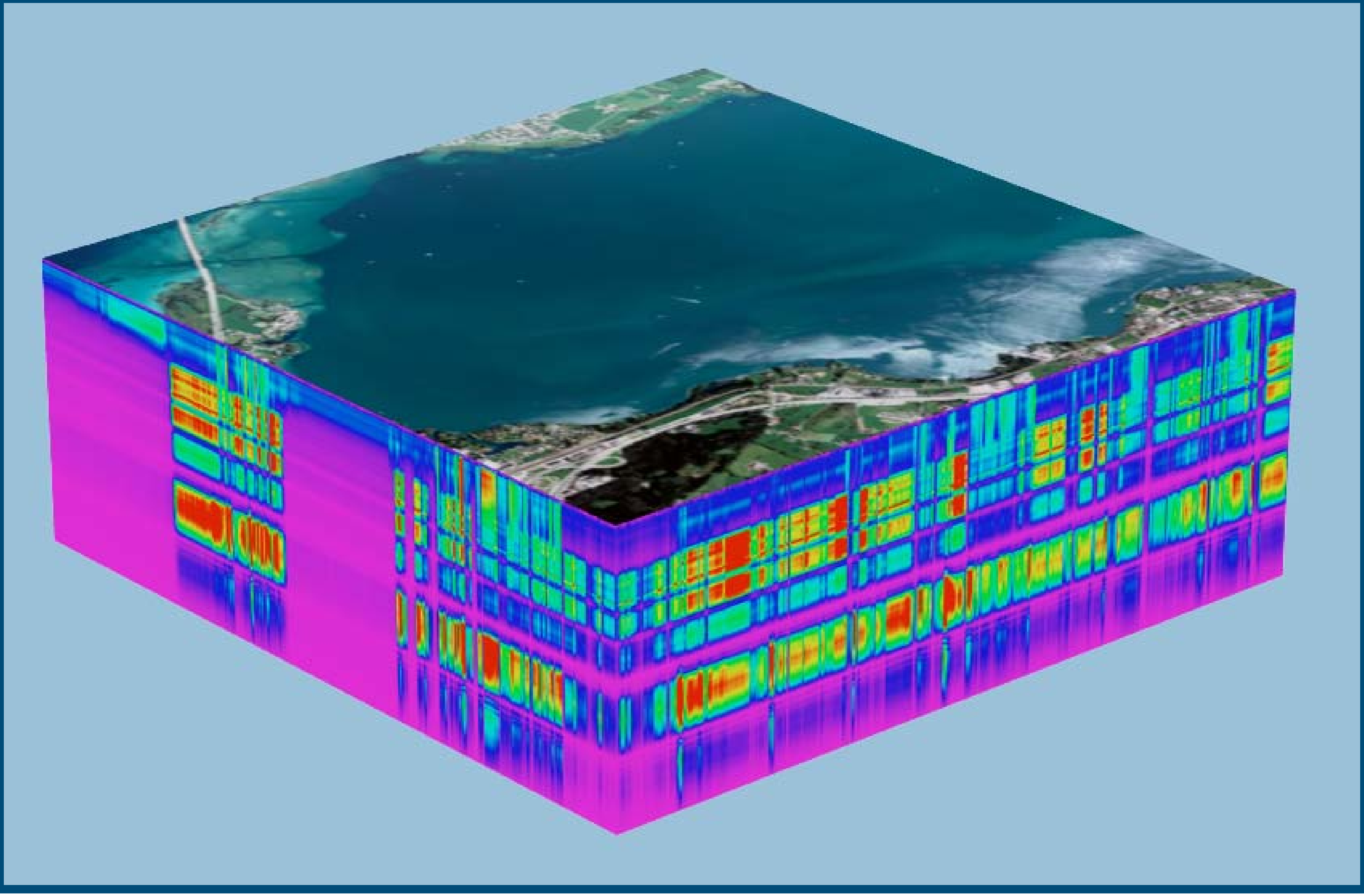
Quantitative Evolution of Spectrodirectional Research



Source: Internet - Altavista / Google keyword search per year; Citation Database – ISI Web of Science / Scopus search per year

Exclusive keyword match: hyperspectral, BRDF, directional, imaging spectroscopy, imaging spectrometry, spectrodirectional

The Art of Imaging Spectroscopy



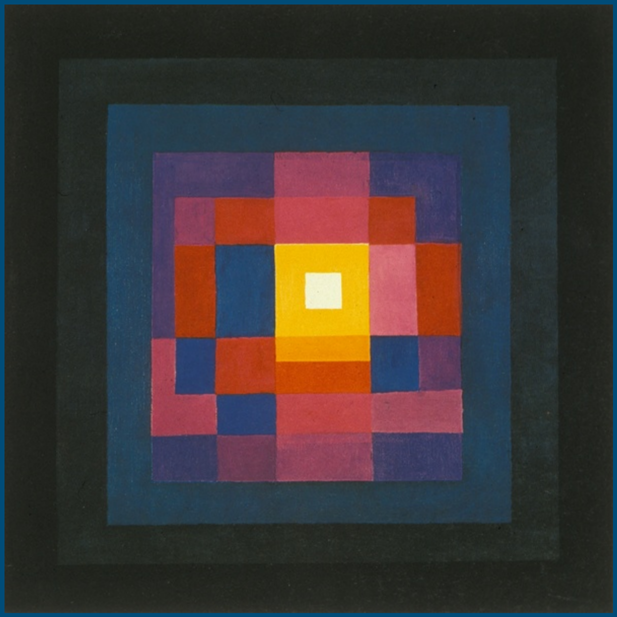
Source:
Sol LeWitt, Cubes in Color on Color, 2003, B. Krakow Gallery, USA
Schaepman, M. Lecture notes in imaging spectroscopy, Univ. Zurich, 2002

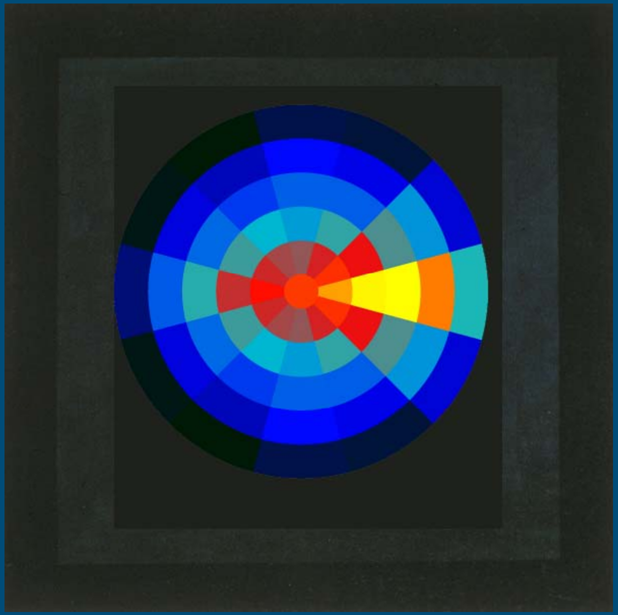
The Art of Directional Remote Sensing

Source:
Paul Klee, Ueberschach (1937), Kunsthaus Zurich

Beisl, U. (2001), Correction of Bidirectional Effects in Imaging Spectrometer Data, RSL, Univ. Zurich, p. 188

The Art of Spectrodirectional Modelling





Source:
Johannes Itten, Offenbarung (1967), Container Corp., New York

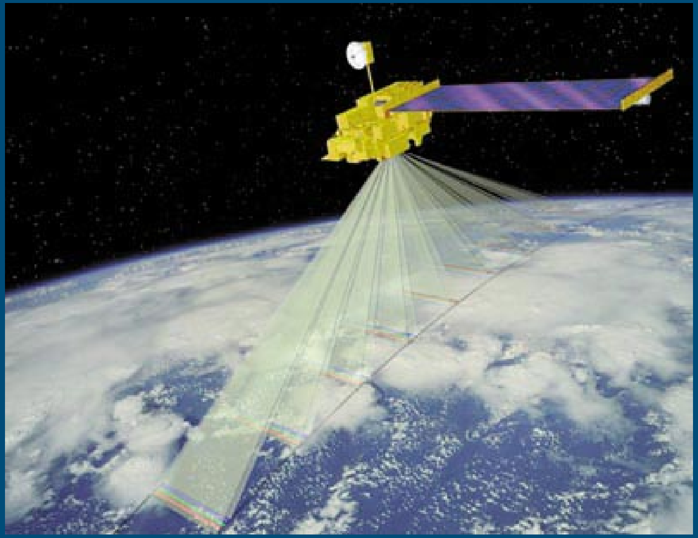
Dangel, S., Schopfer, J., Kneubuehler, M., Schaepman, M., and Itten, K., Towards a direct comparison of field- and laboratory goniometer measurements, IEEE TGRS, in prep., 2004

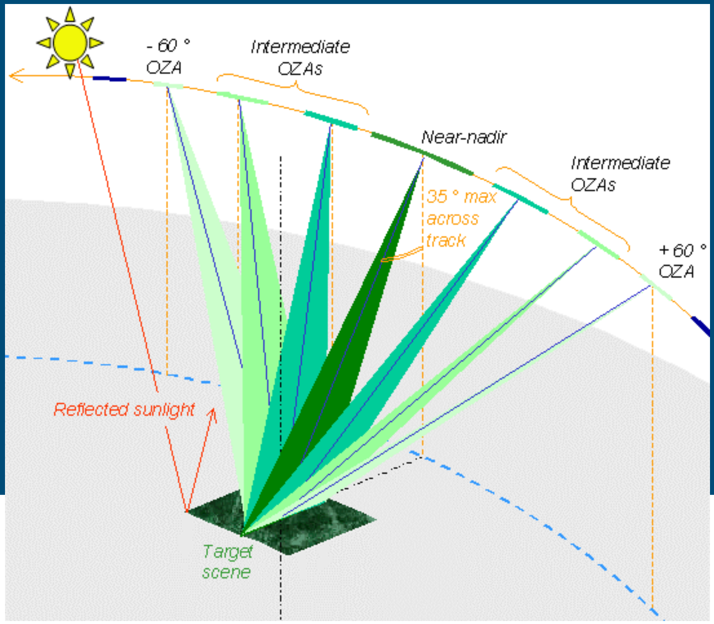
Spectrodirectional Remote Sensing

- Spectrodirectional Remote Sensing is defined as the

  Simultaneous acquisition of
  - Spatially *coregistered images*,
  - In many, *spectrally contiguous bands*,
  - At *various observation angles*,
  - In an internationally recognized *system of units*

  from a remotely operated platform (aircraft, satellite).





Source: NASA MISR; ESA SPECTRA, 2004

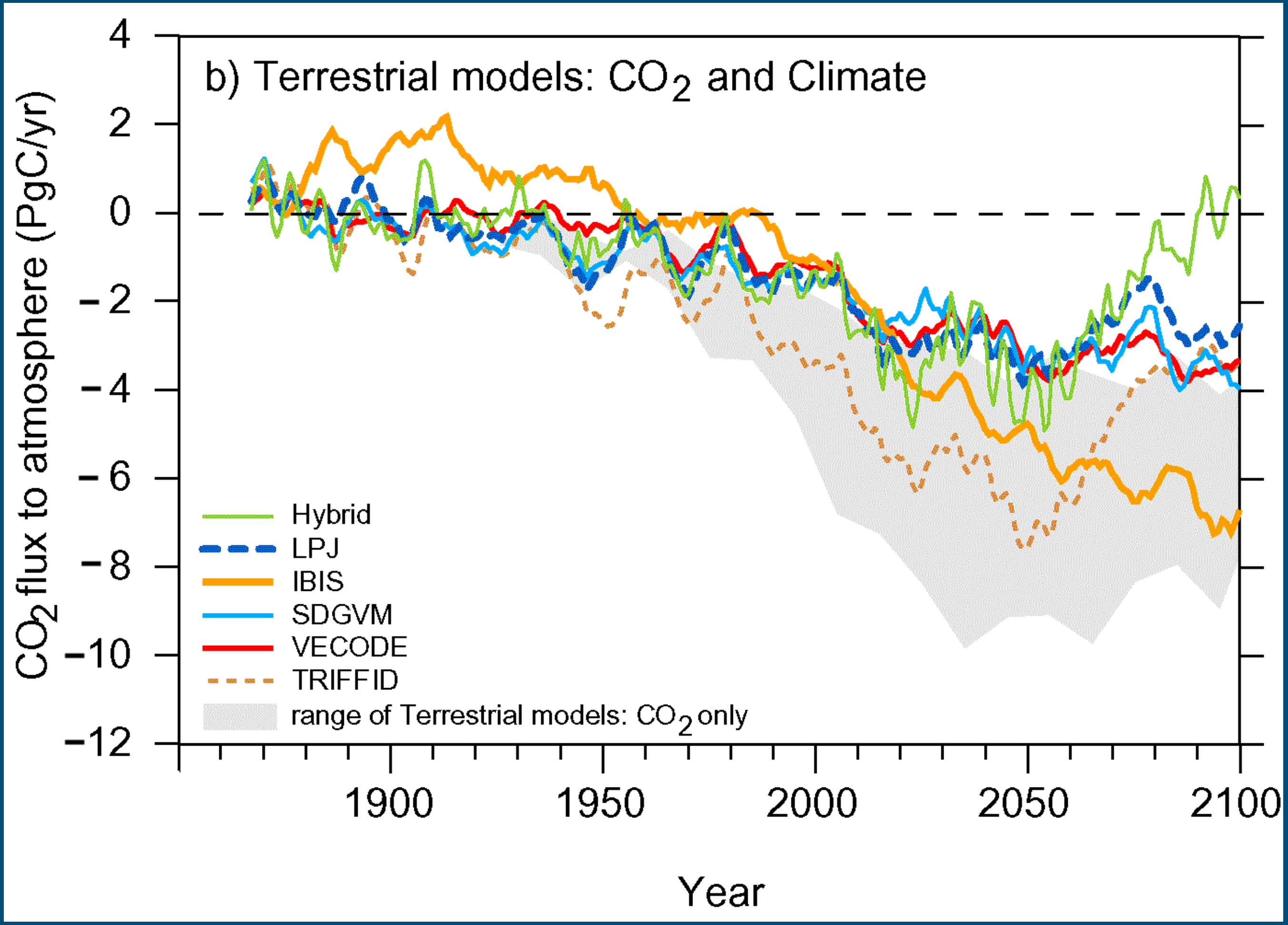
Research Agenda: Spectrodirectional Remote Sensing

- Research
- Products / Applications
- Observations by Data Acquisition Systems
- Technology

Research Agenda: Research

- Research
  - Focus on carbon cycle and ecosystems
- Products / Applications
- Observations by Data Acquisition Systems
- Technology

Research – Carbon: Model Divergence



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.

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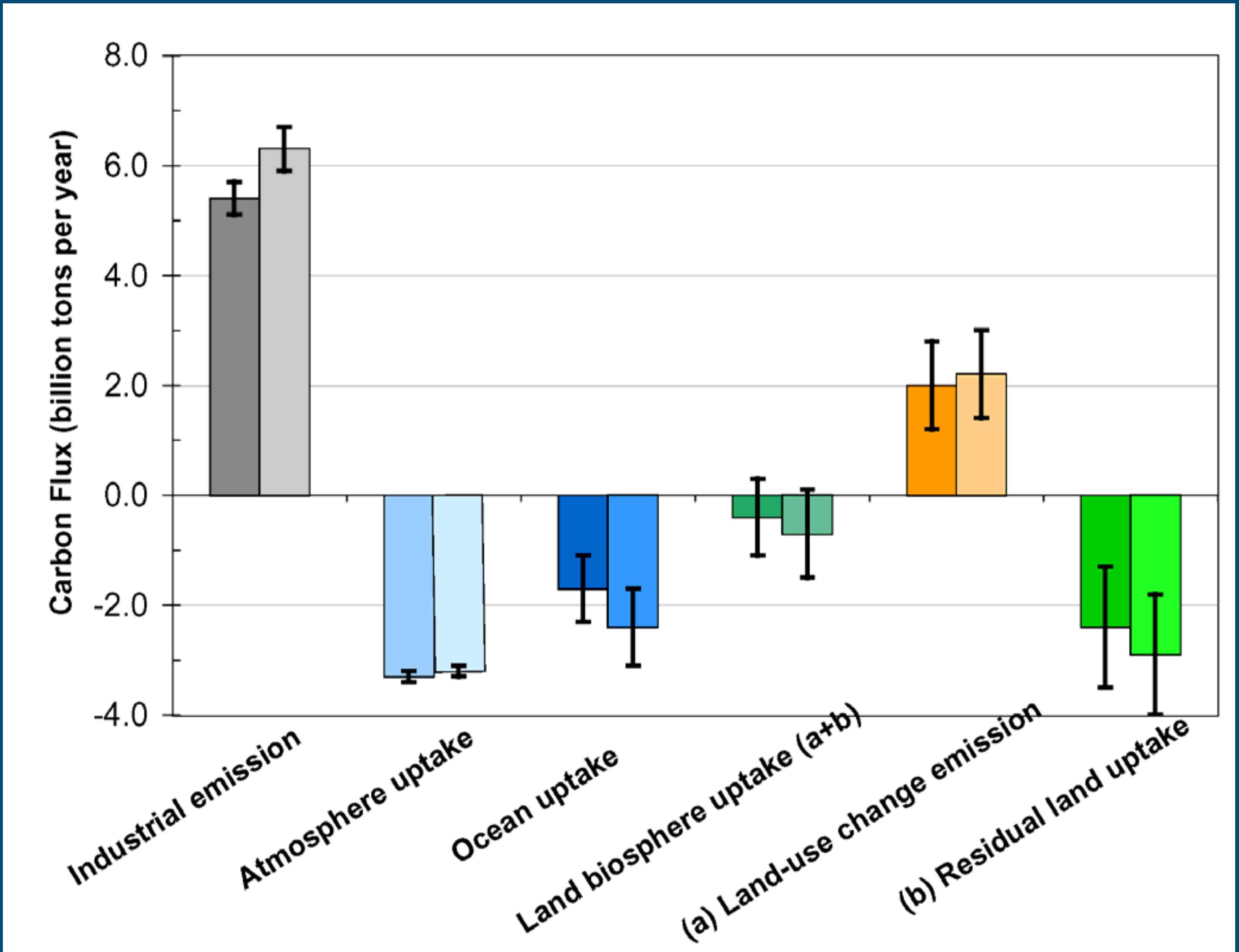
Research – Global Net Carbon Balance



Bars indicate a decade each

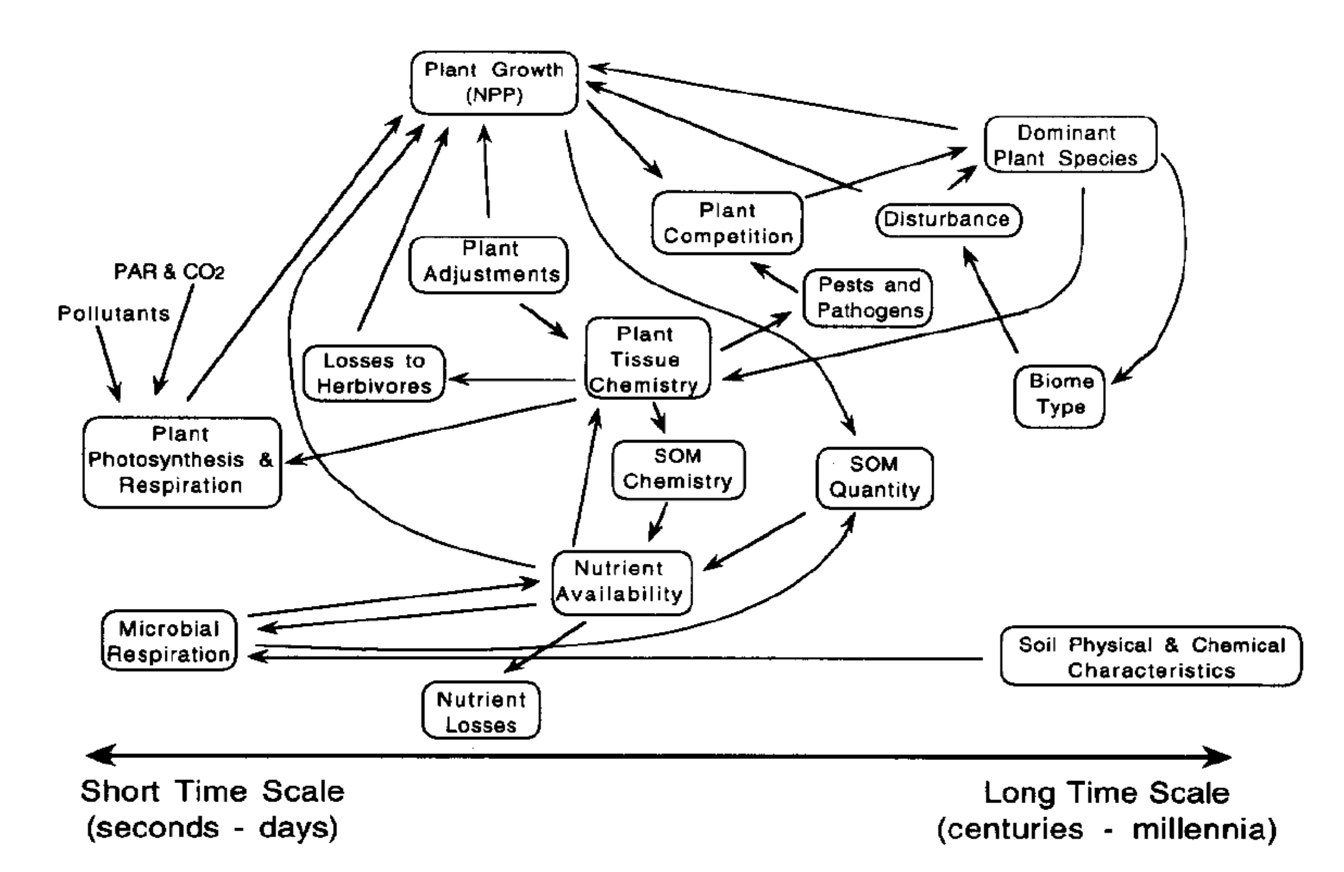
Uncertainties are in black

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.

Research – Contribution of Remote Sensing

- Remote Sensing is particularly good suited to
  - Map spatially distributed phenomena at various scales
    - Ecosystems – Habitats – Plant Functional Groups/Types – Species
    - Continuous fields, such as biophysical and biochemical variables
  - Map temporal phenomena
    - Successional stages
  - Map spatio-temporally coupled processes
    - Phenology
  - Record disturbance
    - Human (land use change), fire, volcanoes
- But Remote Sensors must approximate:
  - NPP = aNPP (aboveground Net Primary Productivity)

Research – Major Controls on NPP



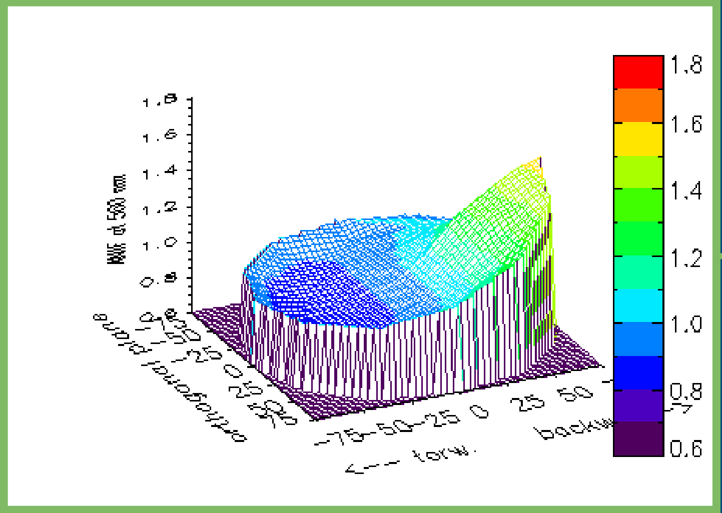
Abbreviations:

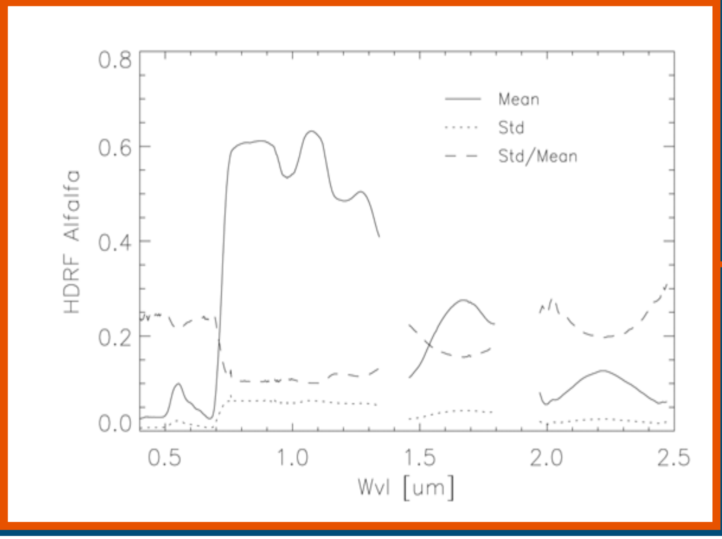
NPP:	Net Primary Productivity (Carbon fixed during photosynthesis minus respiration due to plant growth and maintenance)
SOM:	Soil organic matter
PAR:	Photosynthetically active radiation
Plant Adjustments:	Refers to changes in both physiology and biomass allocation

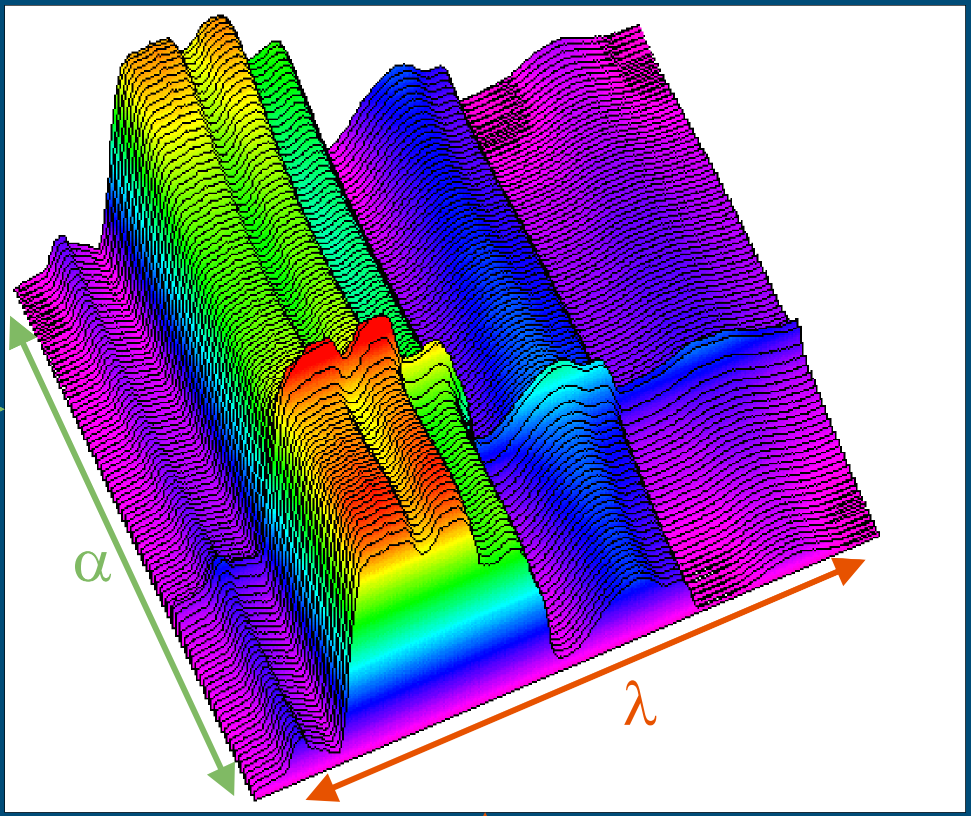
Temperature and moisture not shown, due to impact on almost all parameters

Source: Field, C., et al., Global Net Primary Production: Combining Ecology and Remote Sensing. Rem. Sens. Env.,51:74-88, 1995

Spectrodirectional Measurements at Pixel Level







Source:
M. Rast, Ed., *SPECTRA – Surface Processes and Ecosystem Changes Through Response Analysis*, ESA SP-1279(2), 2004, pp. 66; Data: J. Moreno
Strub, G., Schaepman, M.E., Knyazikhin, Y., & Itten, K.I. (2003) Evaluation of spectrodirectional Alfalfa canopy data acquired during DAISEX '99. *Ieee TGRS*, 41, 1034-1042.

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Spectral Field/Laboratory Measurements

Source:
HyEco'04 campaign, Wageningen and Millingerwaard, NL, 2004
CGI course 'Integration of GIS and Remote Sensing', 2004
MERCI programme, Bily Kriz, CZ, 2004

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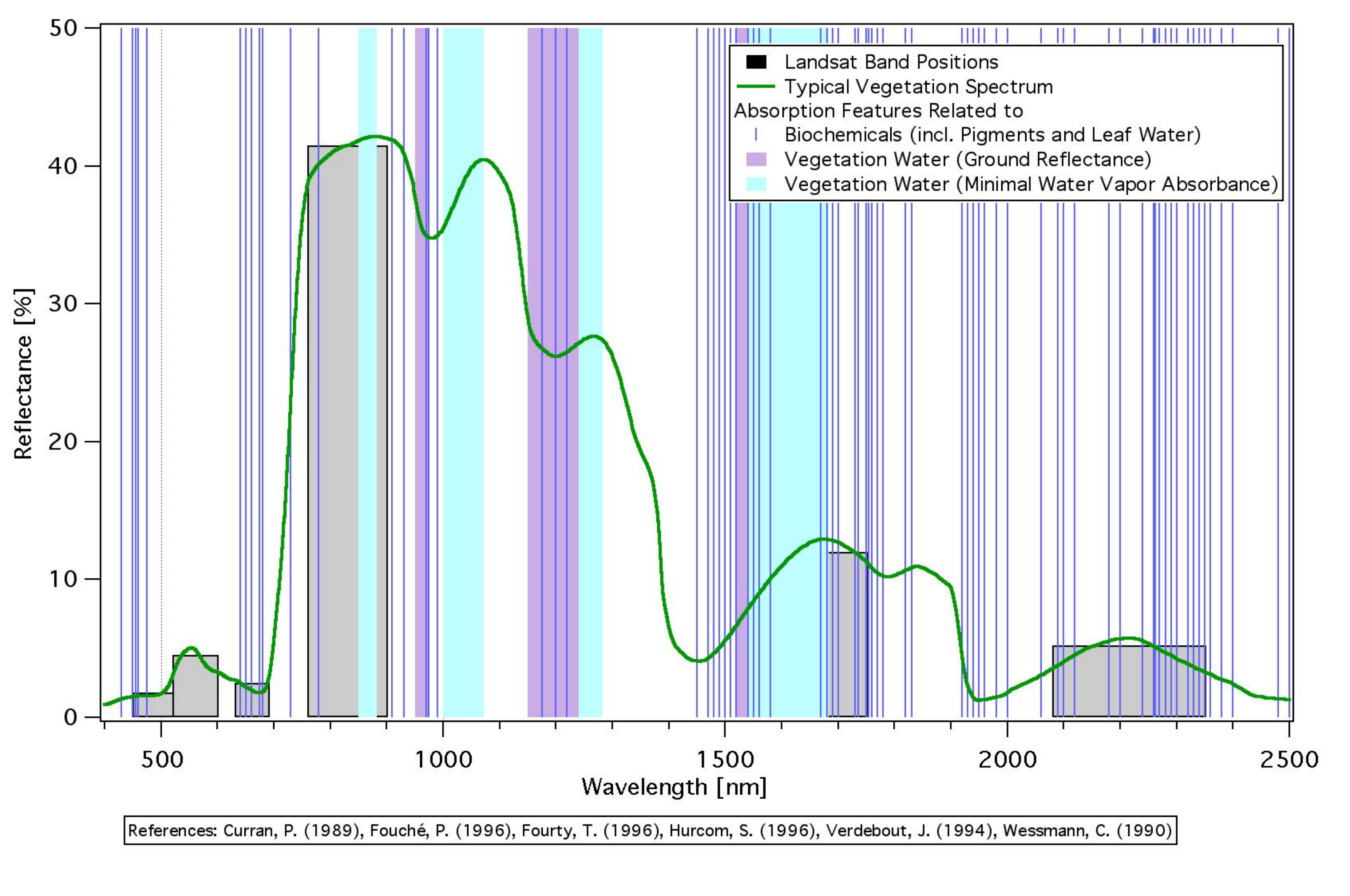
Biochemicals Present in Vegetation Spectra



Source: Schaepman, M., Koetz, B., Schaepman-Strub, G., Itten K., Spectrodirectional Remote Sensing for the Improved Estimation of Biophysical and –chemical Variables: Two Case Studies, JAG, accepted, 2004

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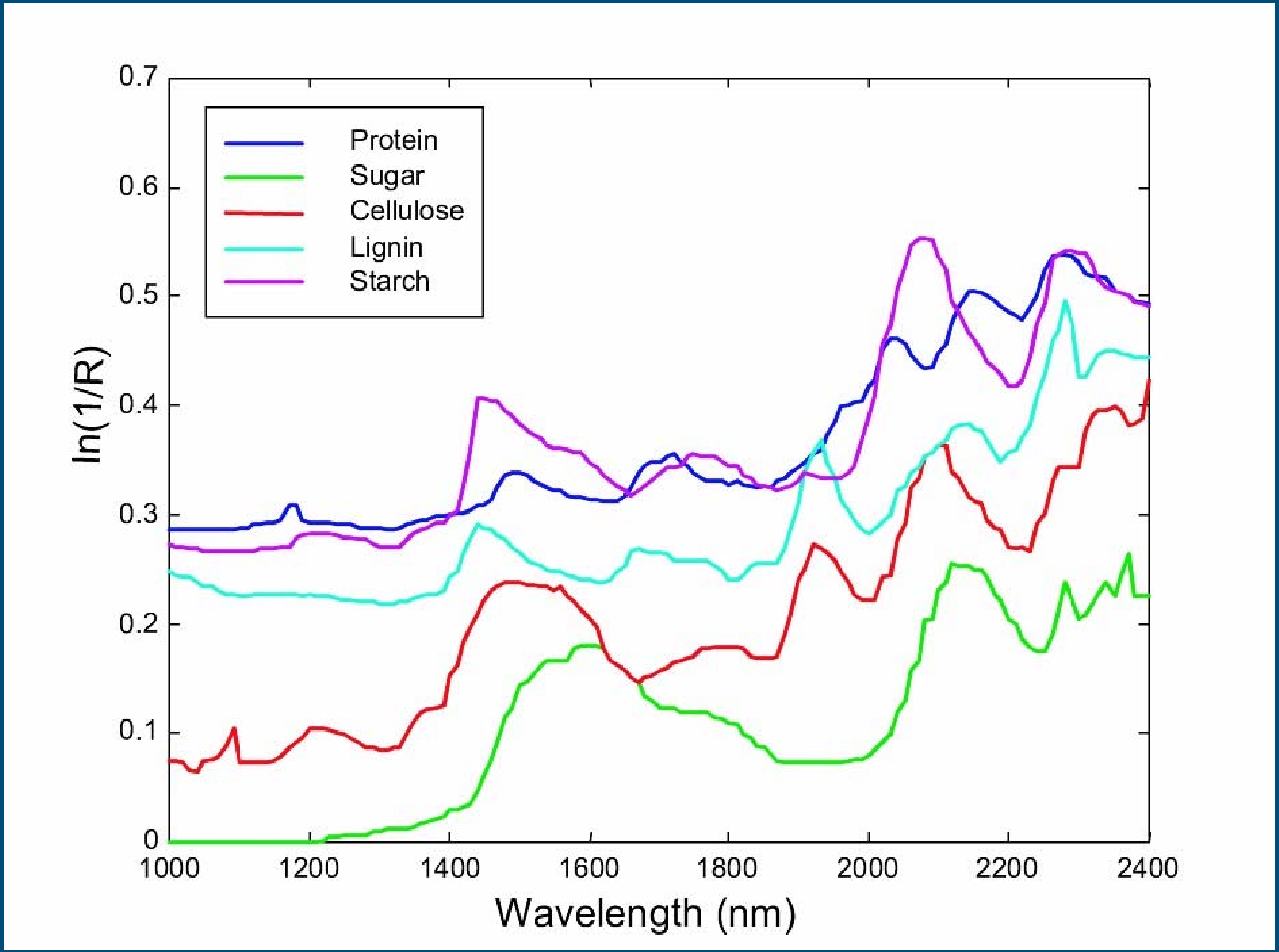
Biochemical Compounds of Interest in Vegetation



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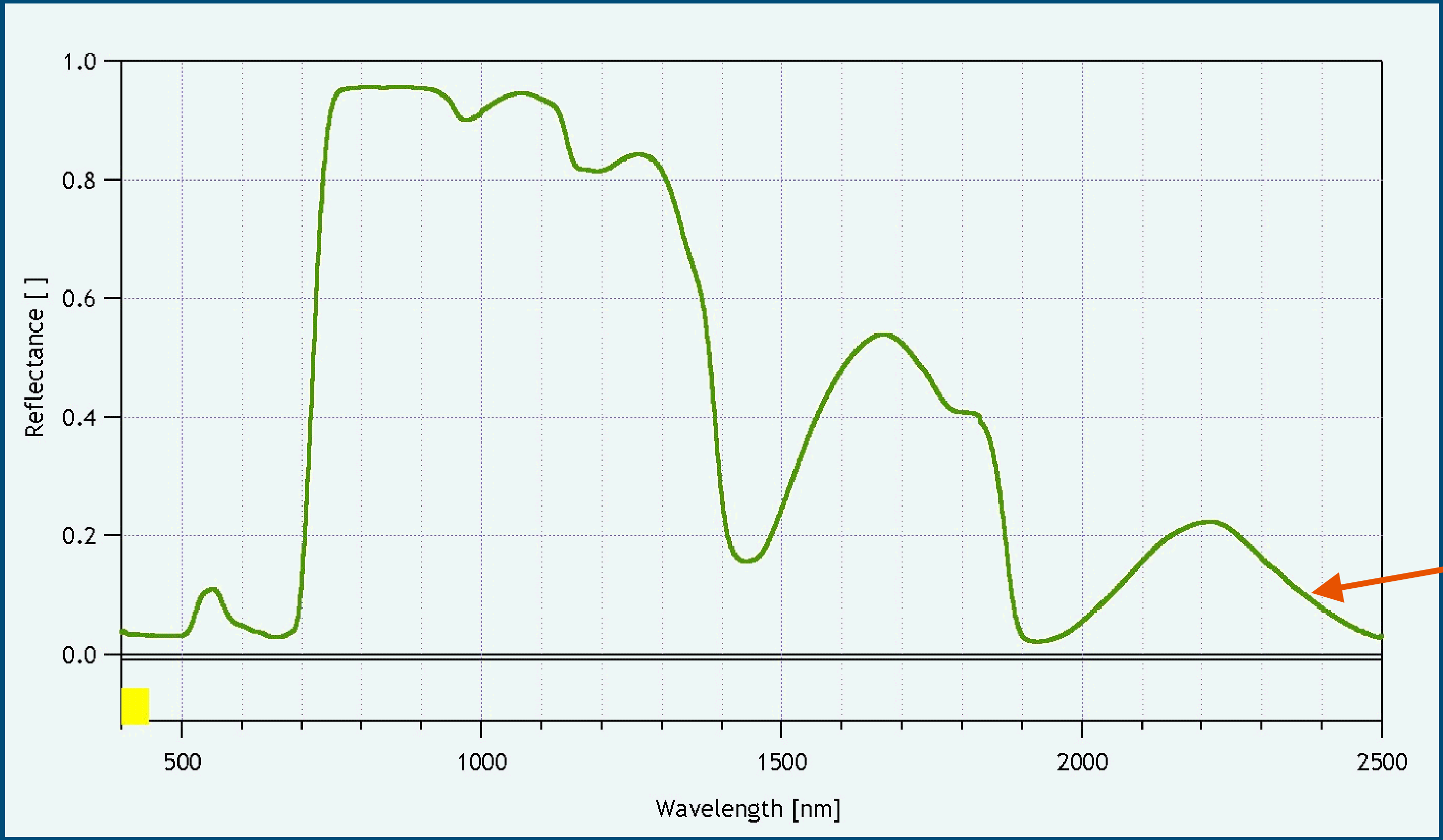
Source: Ustin, S., Zarco-Tejada, P., Jacquemoud, S., Asner, G., Remote Sensing of the Environment: State of the Science and New Directions, in: Manual of Remote Sensing, 3rd ed.,Vol. 4, p. 696, 2004

Decay of a *Ficus benjamina* L. Leaf

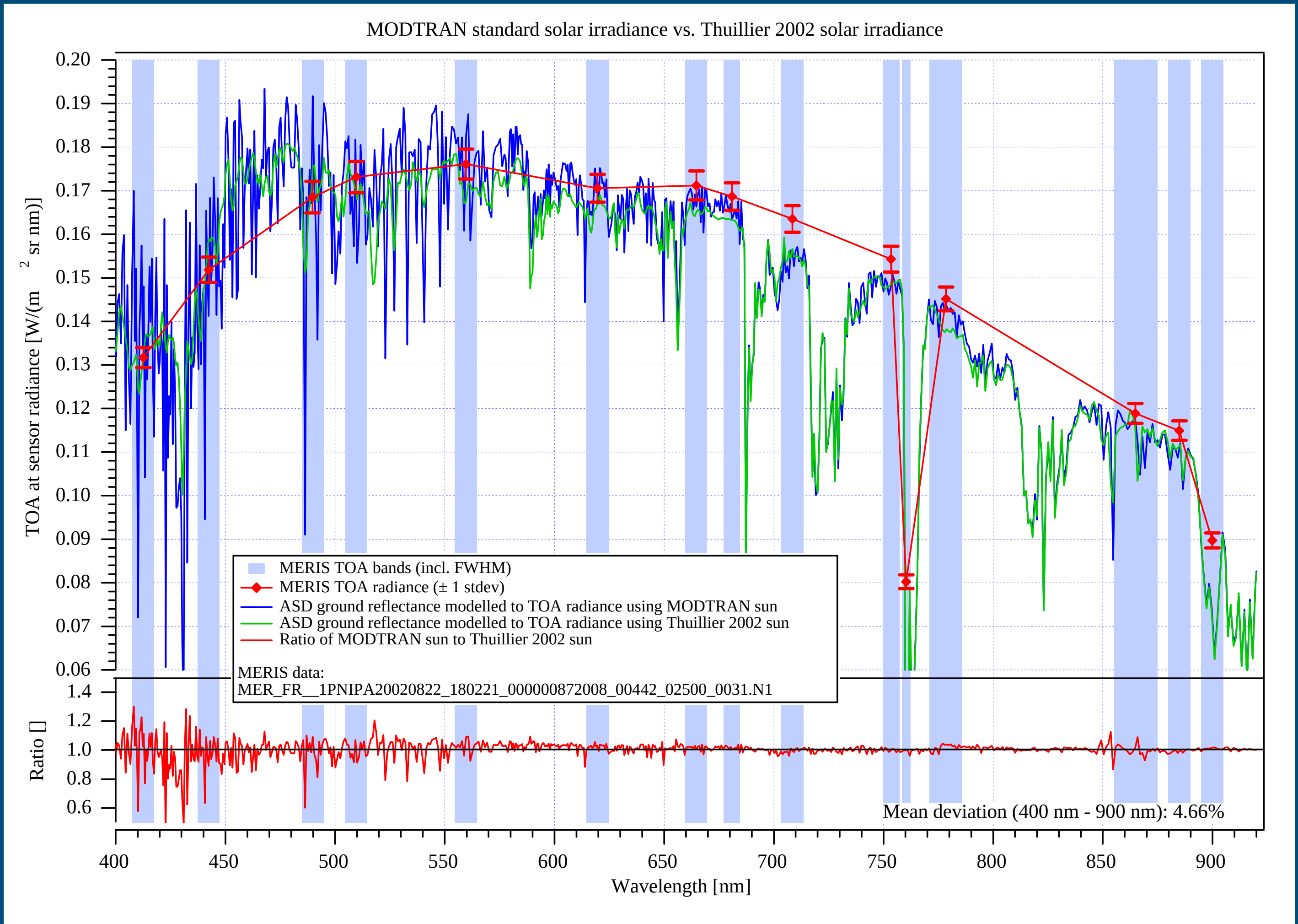


Undisturbed leaf

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

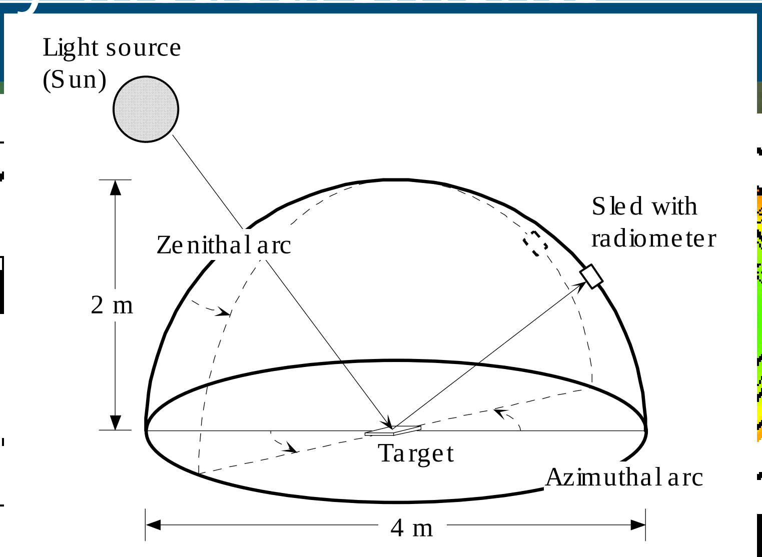
Source:
Bartholomeus, H., and Schaepman M. (2004) Decay of *Ficus benjamina* L. in 10 minutes steps over 8 hrs, unpublished

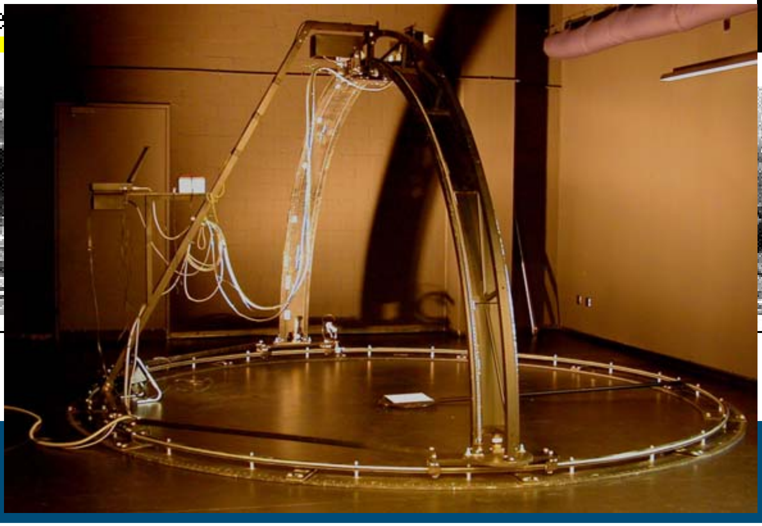
Maximal Spectral Resolution



Source:
Kneubühler, M., Schaepman, M.E., Thome, K.J., & Schläpfer, D.R. (2003) MERIS/ENVISAT vicarious calibration over land. In Sensors, Systems, and Next-Generation Satellites VII, Vol. 5234, pp. 614-623. SPIE, Barcelona.

Directional Field/Laboratory Measurements





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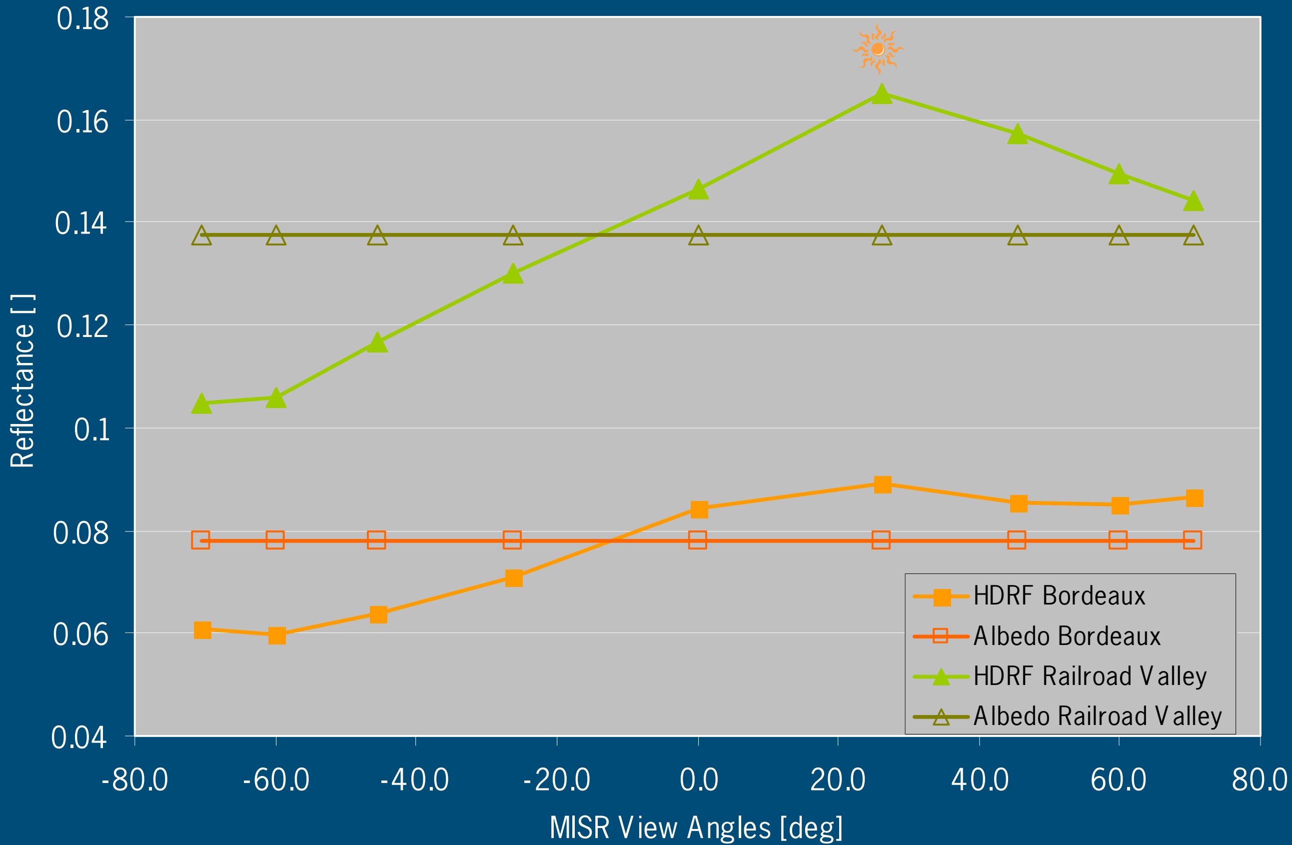
Source:
Bruegge, C.J., Schaepman, M., Strub, G., Beisl, U., Itten, K.I., Demircan, A., Geiger, B., Helmlinger, M.C., Martonchik, J., Abdou, W.A., Painter, T.H., Paden, B.E., & Dozier, J. (2004). Field Measurements of Bi-Directional Reflectance. In *Reflection Properties of Vegetation and Soil with a BRDF Database*, Vol. 1, pp. 195-224. Wissenschaft und Technik Verlag, Berlin.

View Angle Dependence of Reflectance Products



MISR Green Spectral Band at 558 nm

Bordeaux – Forest/Croplands

Railroad Valley – Open Shrubland/Grassland

Source:
Schaepman-Strub, G., Schaepman, M., Painter, T.H., Dangel, S., Martonchik, J., & Verstraete, M.M. (2004) Review of Reflectance Nomenclature Used in Optical Remote Sensing with Quantitative Comparisons. *in preparation*.

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Research Agenda: Products / Applications

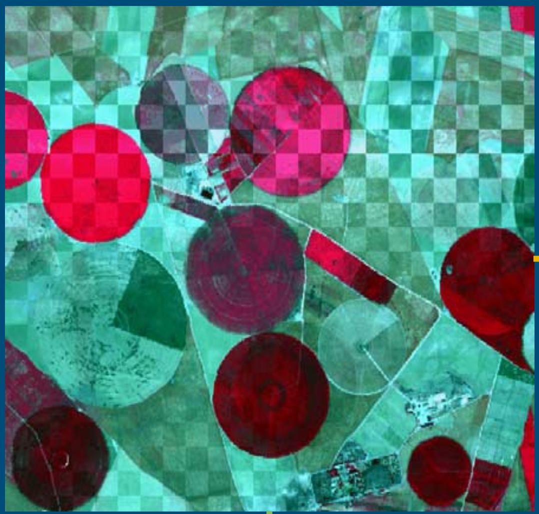
- Research
- Products / Applications
  - Parameters (Variables)
  - Products
  - Processes
- Observations by Data Acquisition Systems
- Technology

Vegetation Variables (Parameters) of Interest

- Vegetation spatial distribution and phenology
  - Fractional vegetation cover (fCover)
  - Leaf Area Index (LAI)
  - Fraction living / dead biomass
  - Canopy structure
  - Vegetation height
- Vegetation interaction with radiation
  - Albedo
  - Fraction of Absorbed Photosynthetically Active Radiation (fAPAR)
- Foliage chemistry and water status
  - Leaf chlorophyll
  - Leaf water content
  - Leaf dry matter
  - Leaf nitrogen / foliage nitrogen
- Vegetation energy balance
  - Foliage temperature (related to stomatal evaporation rate)
  - Soil temperature (related to water stress)

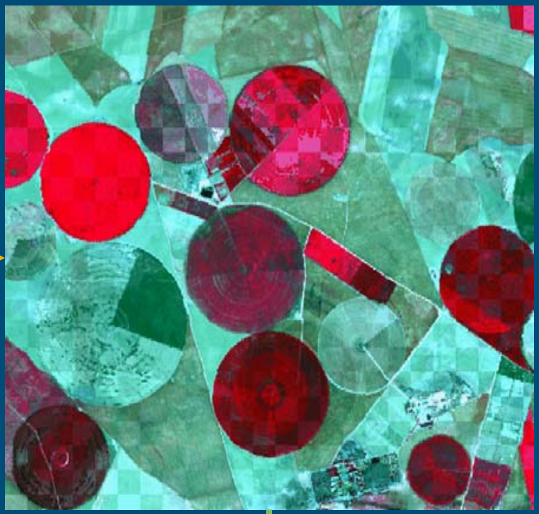
SAR
LIDAR
Spectrodirectional reflective
Spectrodirectional emissive

Directionality and Impact on Product Quality

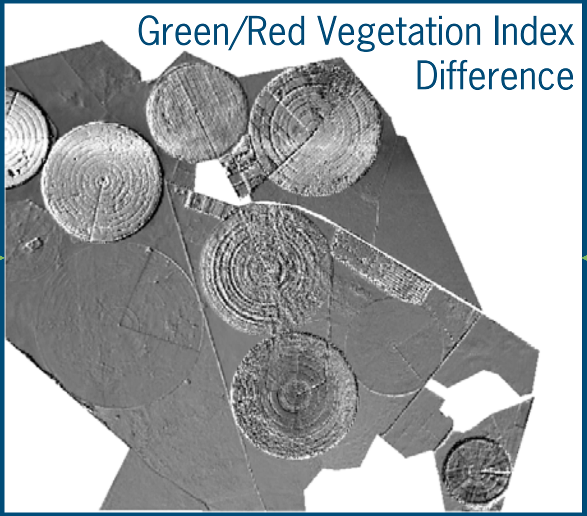


BRDF Correction

(Class specific Ambrals fit)



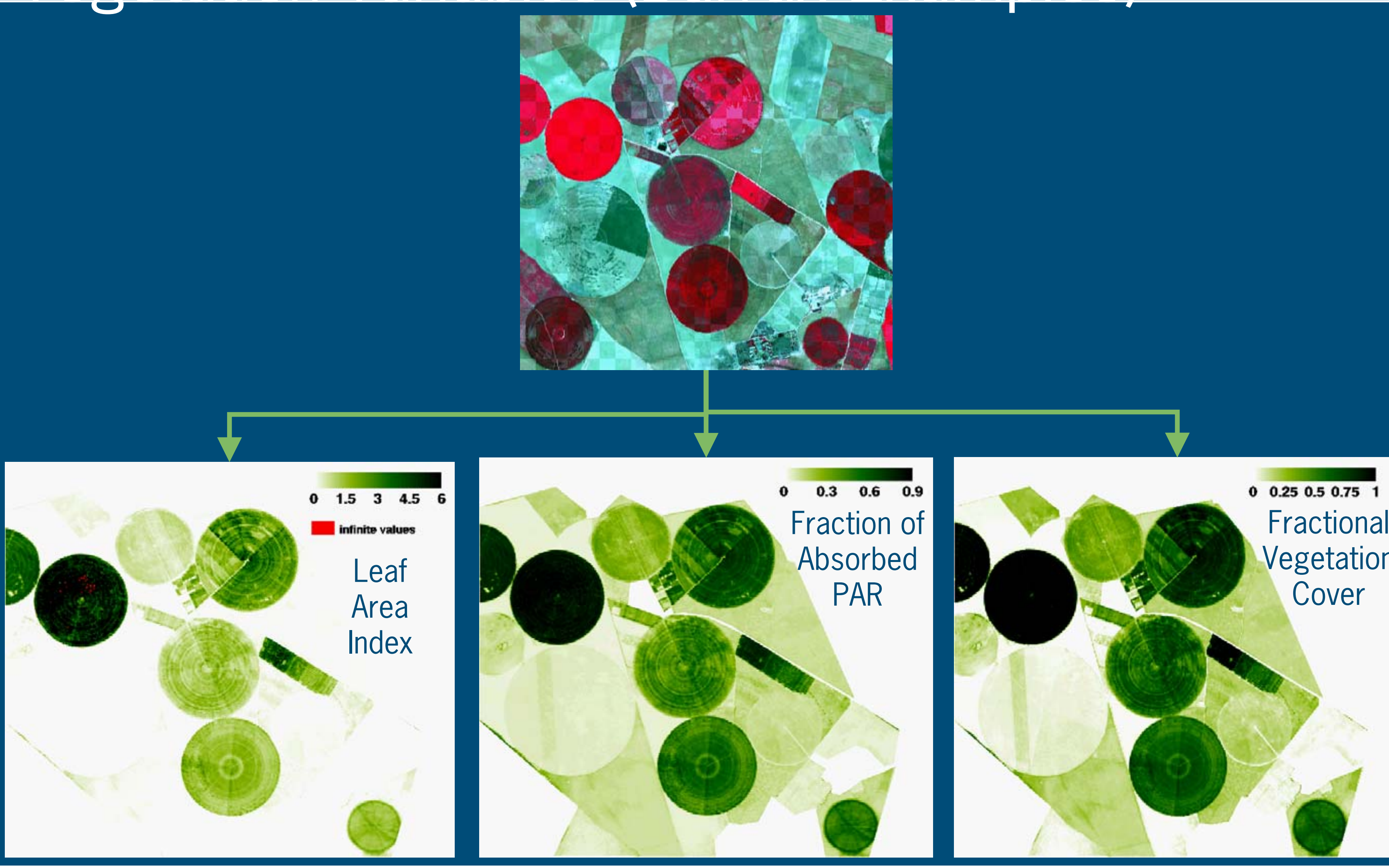
GRVI
(non corrected)



GRVI
(corrected)

Source:
Schaepman-Strub, G., M. Schaepman, and K. Itten, Ground BRDF Data Analysis, Normalization and Modelling, in Scientific Analysis of the ESA Airborne Multi-Annual Imaging Spectrometer Campaign, Final Report, ESA Contract-No. 15343/01/NL/MM, J. Moreno (ed.), in print, 2004

Vegetation Variables (Barrax Examples)



Source:
Schaepman, G., M. Schaepman, S. Huber, and K. Itten, Retrieval of Vegetation Parameters from Hyperspectral Imaging Sensor Data, Final Report, Astrium GmbH, 75 p., 2003.

Land biosphere models – Processes to be mapped

- Carbon engine
  - *f* (CO_2, light, water availability, temperature, nutrients)
- Carbon allocation
  - *f* (geometry, physiology, plant functional type, species)
- "Remineralisation"
  - *f* (plant functional type, physiology, microbiology, molecular structure (e.g. lignin vs. waxes or cellulose))
- Hydrology
  - root depths
- Population dynamics
  - Succession
    - *f* (stand height, stand age, physiology)
  - Disturbance
    - *f* (climate, humans)

Source: Gloor, M., pers. comm., 2004

Land biosphere models – Processes Supported

- Carbon engine
  - *f*(CO_2, light, water availability, temperature, nutrients)
- Carbon allocation
  - *f*(geometry, physiology, plant functional type, species)
- "Remineralisation"
  - *f*(plant functional type, physiology, microbiology, molecular structure (e.g. lignin vs. waxes or cellulose))
- Hydrology
  - root depths
- Population dynamics
  - Succession
    - *f*(stand height, stand age, physiology)
  - Disturbance
    - *f*(climate, humans)

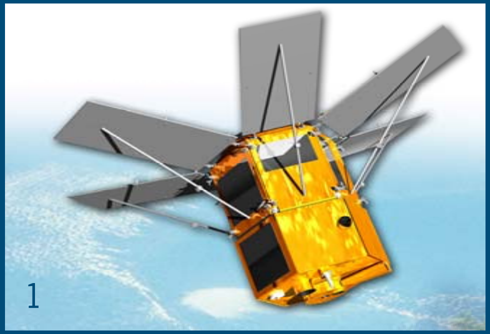
Legend:
Green – Spectrodirectional RS
Orange – Other RS

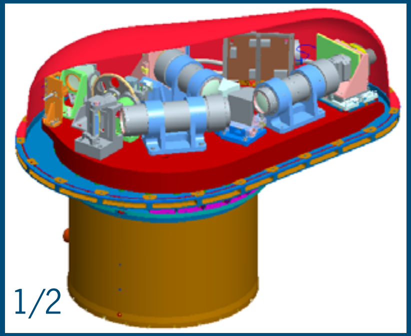
Research Agenda: Observations

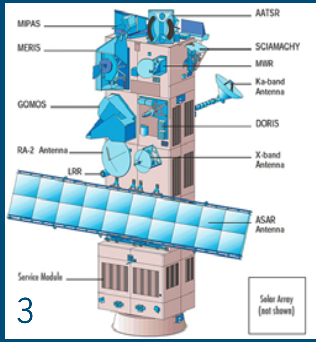
- Research
- Products / Applications
- Observations by Data Acquisition Systems
- Technology

Observations by Data Acquisition Systems

- Four categories of sensors
  - Exploratory missions
    - ESA: SPECTRA (1) and APEX (1/2); NASA: ESSP and AVIRIS
  - Technology demonstrators / operational precursor missions
    - ESA: CHRIS/PROBA (2) and APEX (1/2); NASA: Hyperion/EO-1
  - Systematic measurement missions
    - ESA: MERIS/ENVISAT (3); NASA: MODIS/TERRA and on AQUA
  - Operational missions
    - ESA: MSG-1 (4); NASA: NOAA AVHRR







Source:
http://www.esa.int
http://www.apex-esa.org

Research Agenda: Technology

- Research
- Products / Applications
- Observations by Data Acquisition Systems
- Technology

Technology

- ~~Integration of GIS and Remote Sensing~~
- Integrated systems solutions
  - Scalable approaches
  - Integration of multiple data sources
  - Collaborative environments
  - Intelligent distributed systems
  - Quantitative methods

Technology

- Focus on technology shall
  - aim at cost reduction and increase of detectability by smart sensor development
- SensorWeb
  - specifying interoperability interfaces and metadata encodings that enable real time integration of heterogeneous sensor webs into the information infrastructure

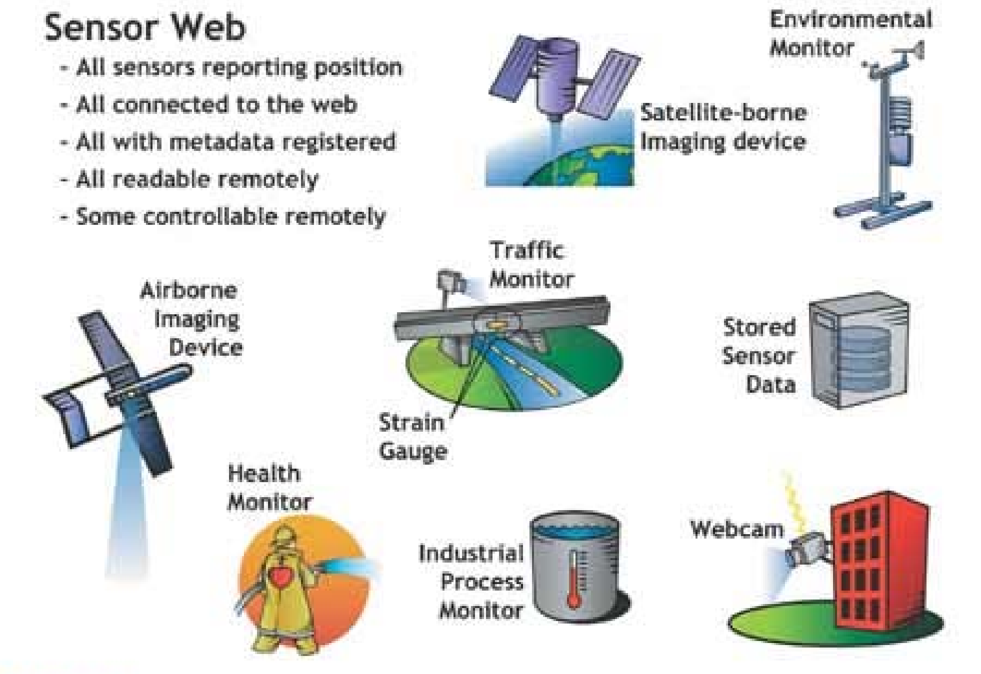


FIGURE 1 The Sensor Web will comprise diverse, location-aware environmental sensing devices that report data about their surroundings in real time.

Source: http://www.opengeospatial.org

Achievements

- Spectrodirectional Remote Sensing enables biophysical and biochemical variables of the Earth's surface to be mapped with unprecedented accuracy.
- The particular success is based on improved data quality and wider availability of consistent observations to the user community.
- Significant advances have been made in the quantitative understanding of the interaction of light with matter.

Future

- New emerging applications in spectrodirectional remote sensing will focus on
  - Transitional zones (Ecotones)
    - Ecosystem, communities, or habitat boundaries (e.g., Tundra – Boreal forest, Forest – heathland, etc.)
  - Managed ecosystems
    - Precision appliance
  - Unmanaged ecosystems
    - Succession, plant functional types, invasive species

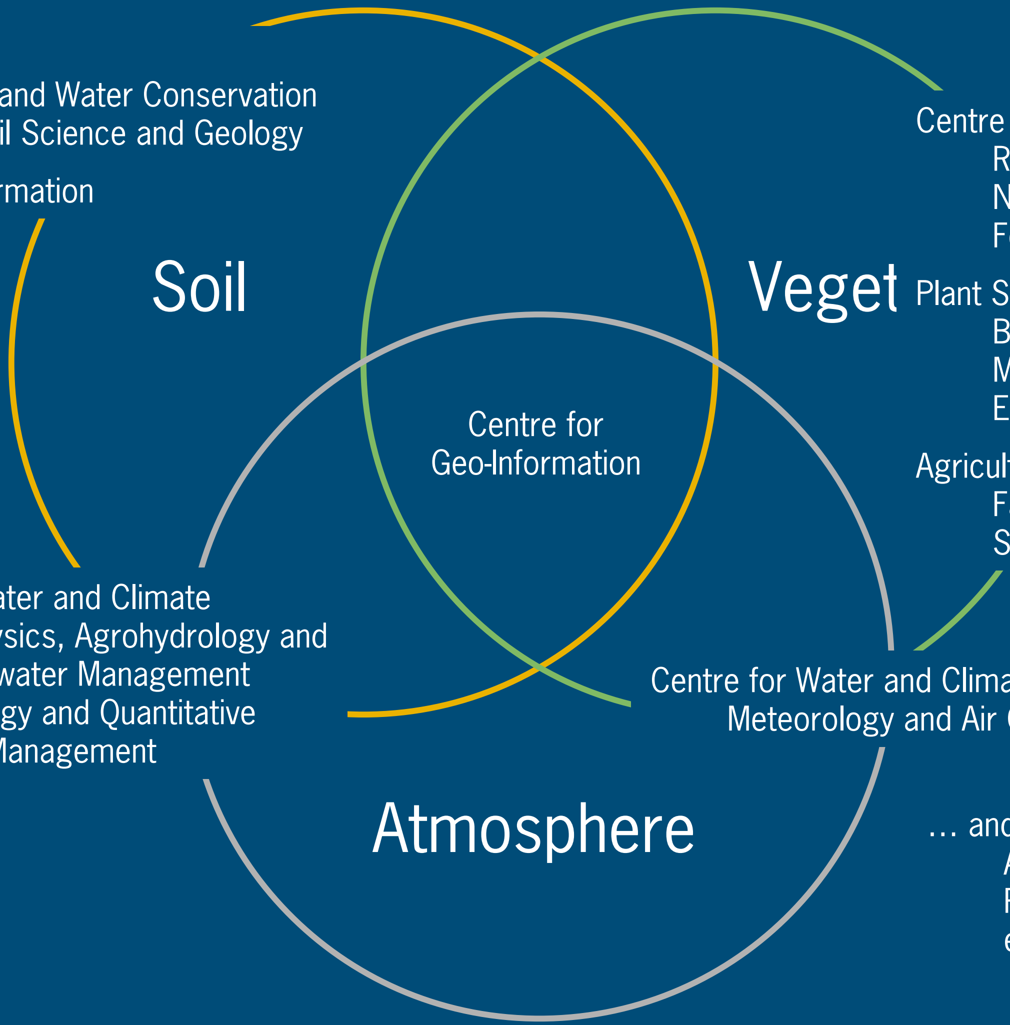
Challenges

- Potential mismatch of spatio-temporal scales of field, airborne and spaceborne measurements, and model requirements
- Spatio-temporal discontinuities in measurements may result in variable data and product quality
- Disturbance processes difficult to capture, due to limited mission duration times and missing backward compatibility
- Convergence to Earth System Sciences

Solution – A Multidisciplinary Curriculum

Soil Science Centre
- Erosion and Soil and Water Conservation
- Laboratory of Soil Science and Geology

ISRIC – World Soil Information



Centre for Ecosystem Studies
- Resource Ecology
- Nature Conservation and Plant Ecology
- Forest Ecology and Forest Management

Plant Sciences
- Biological Farming Systems
- Mathematical and Statistical Methods
- Entomology

Agricultural Engineering and Physics
- Farm Technology
- Soil Technology

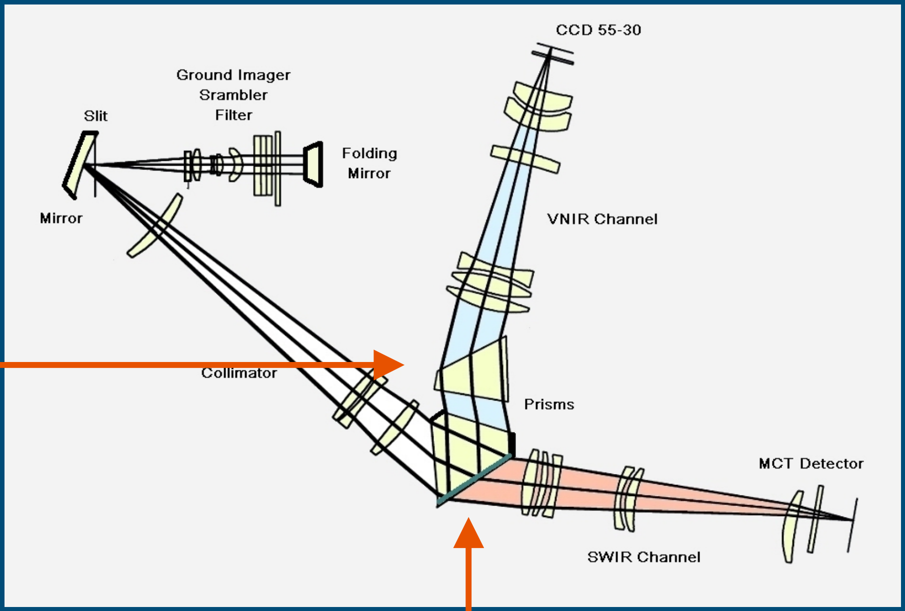
Centre for Water and Climate
- Soil Physics, Agrohydrology and Groundwater Management
- Hydrology and Quantitative Water Management

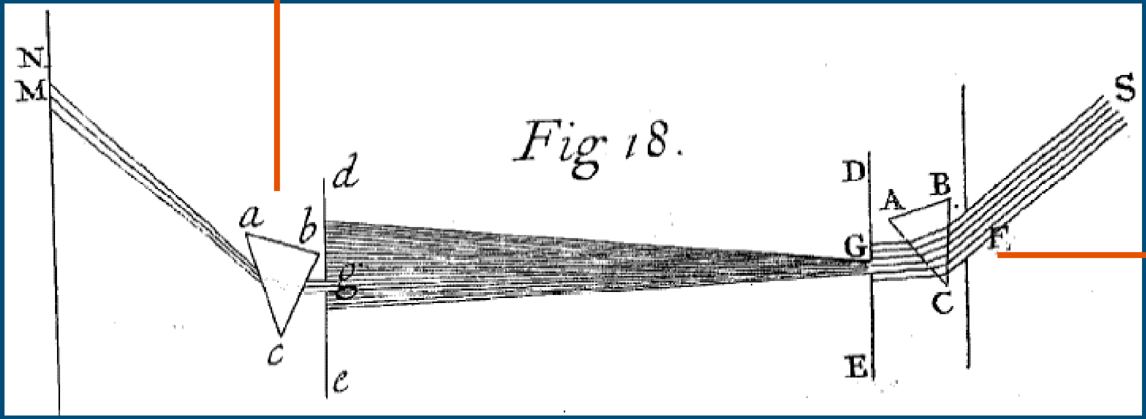
Centre for Water and Climate
- Meteorology and Air Quality

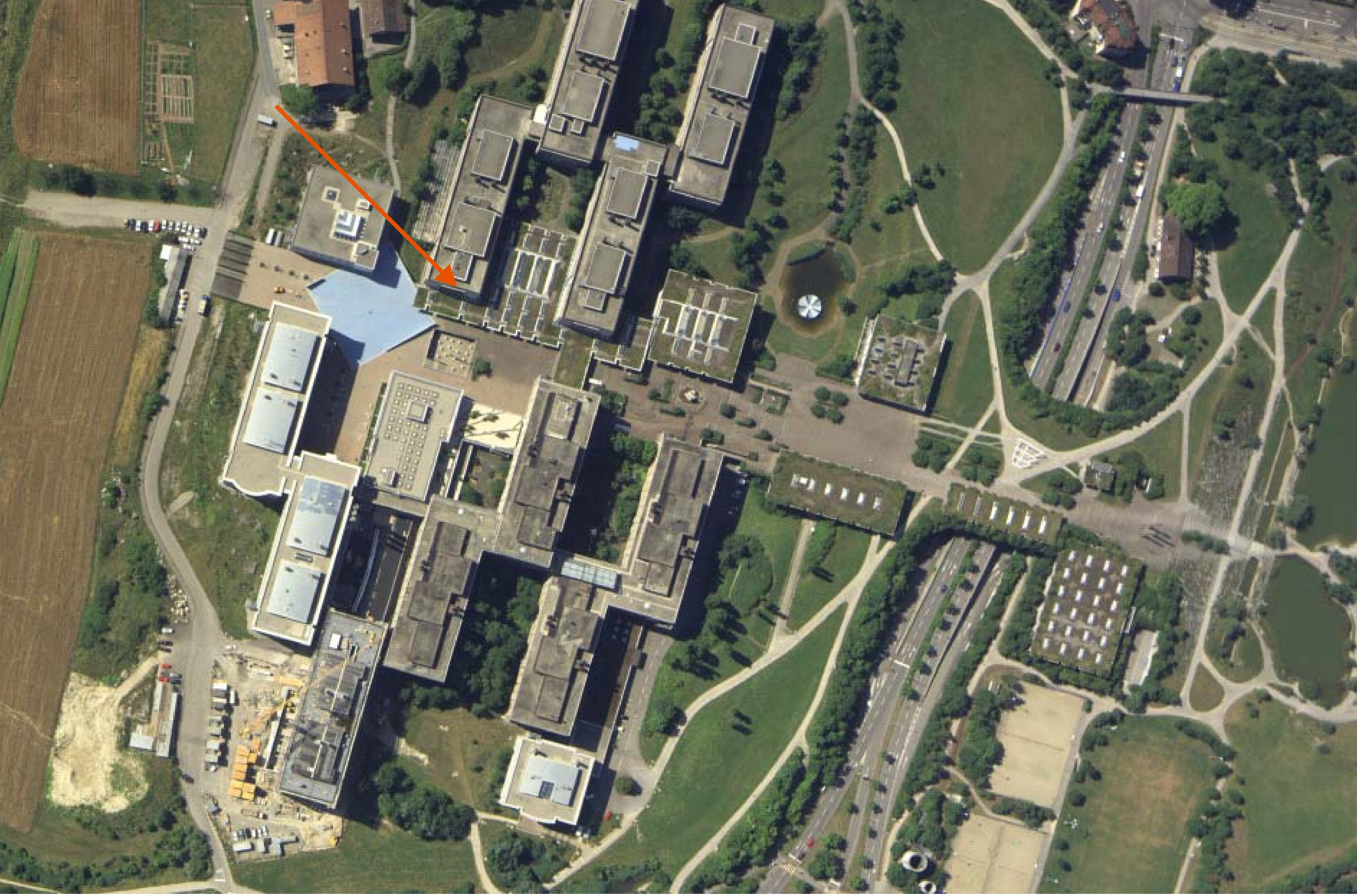
… and certainly our institutional counterparts
- Alterra
- Plant Research International
- etc.

300 years later ...

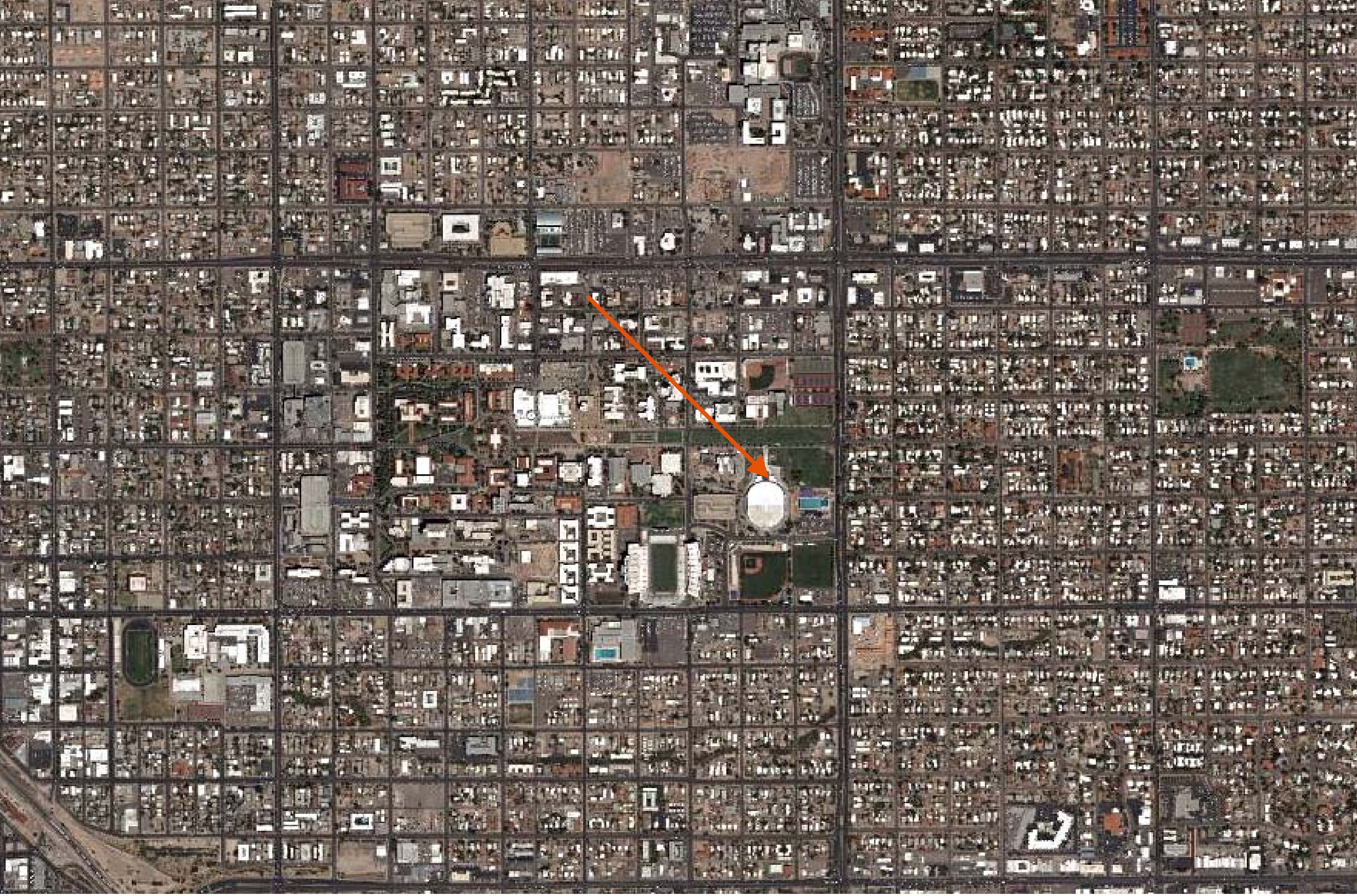
- Spectral Dispersion of Light
  - Newton 1704
  - APEX 2004







Source:
Leica RC-30, August 17, 1997
Courtesy Erich Meier
RSL, Univ. Zurich
Univ. Zurich, Irchel campus, CH



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Source:
OrbView, 24.4.2004
DigitalGlobe
Tucson, Arizona, USA

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Source:
Vexcel UltraData, July 28, 2004
Courtesy Fred Hagman
Aerodata International Surveys
North part of Wageningen, NL

Thank you for your attention!

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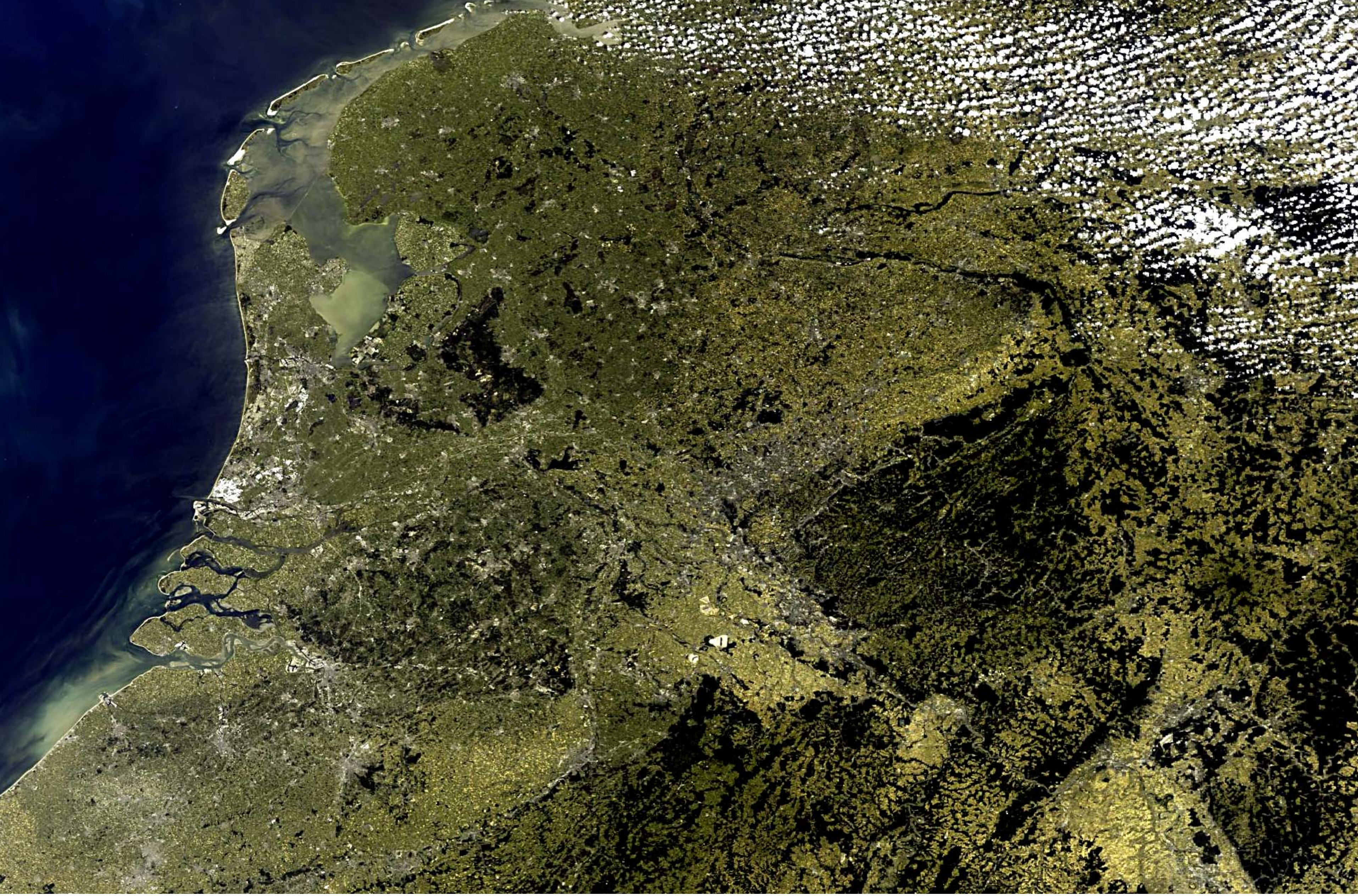

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Source:
ESA ENVISAT/MERIS FR Data
July 14, 2003
300 m spatial resolution