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Remote sensing for forest mapping and monitoring

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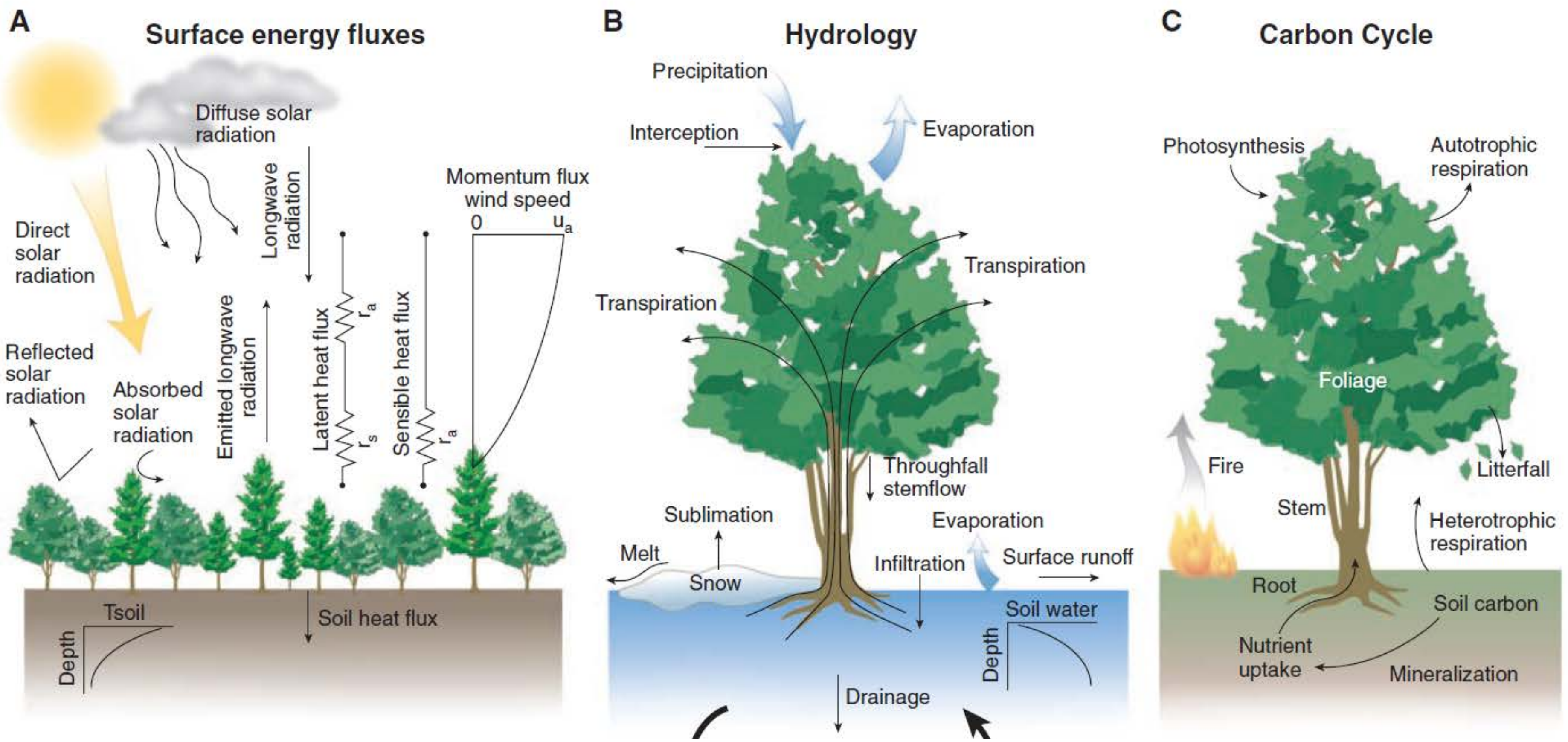
Forests and spatial ecohydrology



Bonan (2008): Science

Forest mapping and monitoring

- Forest biomass is one of the world's most important carbon pools and is at risk from tropical deforestation and land use change.
- International policies aim to reduce greenhouse gas emissions from deforestation and forest degradation (REDD+ initiative).
- Forest habitats are home to a very diverse range of species, but complex to map.

Forest structural parameters

- Forest stand top height
- Mean canopy height
- Crown depth
- Tree density
- Diameter at breast height
- Woody biomass
- Total aboveground biomass
- Total above- and below-ground biomass
- ...

But what is a "forest", actually ?

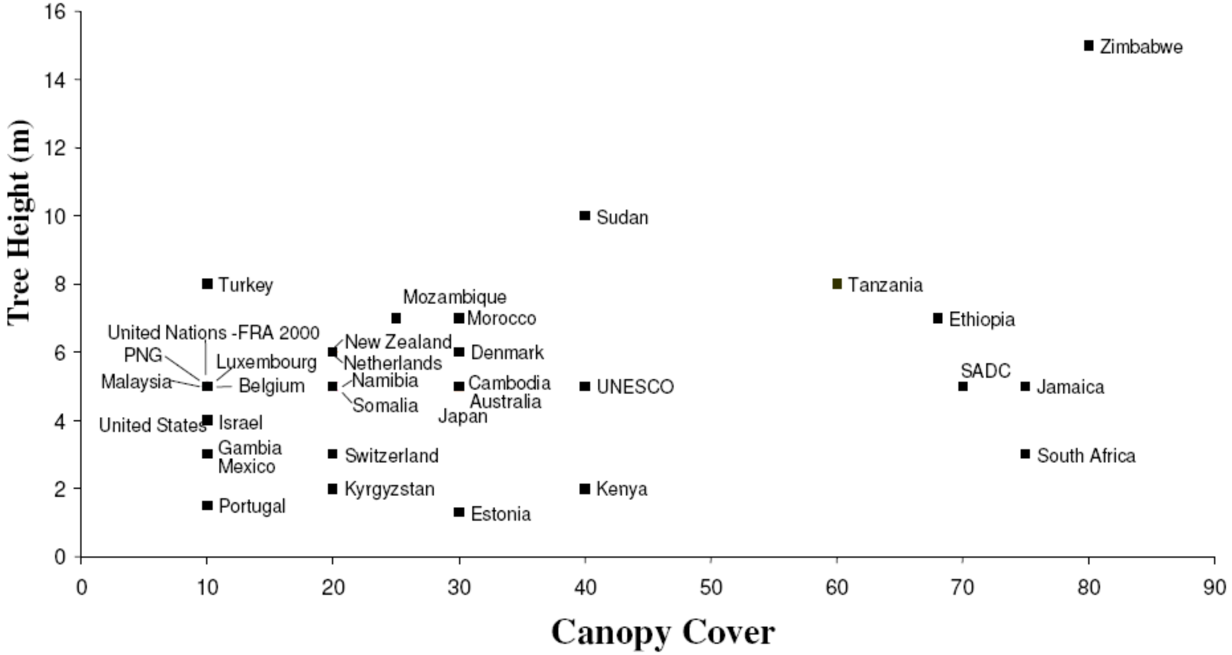


Figure 1: Illustration of a range of different definitions of the land cover class "Forest". The class label can be (mis-)interpreted in many different ways (data from Gyde Lund 2005).

From Wadsworth et al. (2009), Journal of Land Use Science

Data from: GYDE LUND, H., 2005, Definitions of Forest, Deforestation, Afforestation, and Reforestation. Forest Information Services, Gainesville, VA, *http://home.comcast.net/~gyde/DEFpaper.htm*, date accessed: 27/9/2007.

What do we mean by forest dynamics?

- Temporal change of 3D structural properties
- Includes
  - deforestation = loss of forest cover, leading to land cover change
  - forest degradation = loss of a proportion of biomass from a forest
- Processes and drivers
  - selective & clearcut logging, incl. legal & illegal logging
  - forest fires
  - forest management, e.g. thinning practices
  - natural disturbances, incl. windfall, insect damage and natural succession
  - changing microclimatic conditions, e.g. rainfall patterns, temperature etc.

Remote sensing methods

- Optical/near-infrared sensors
  - Forest cover
  - Fraction of absorbed photosynthetically active radiation, fAPAR
  - Green leaf area index, LAI
  - Forest canopy height from stereophotogrammetry
- Synthetic Aperture Radar (SAR)
  - Forest canopy height from interferometry, polarimetric interferometry or tomography
  - Aboveground biomass from radar backscatter
- Light Detection and Ranging (LiDAR)
  - Forest canopy height from first and last return
  - Undergrowth layer mapping
  - Woody and leafy components from multi-wavelength sensors

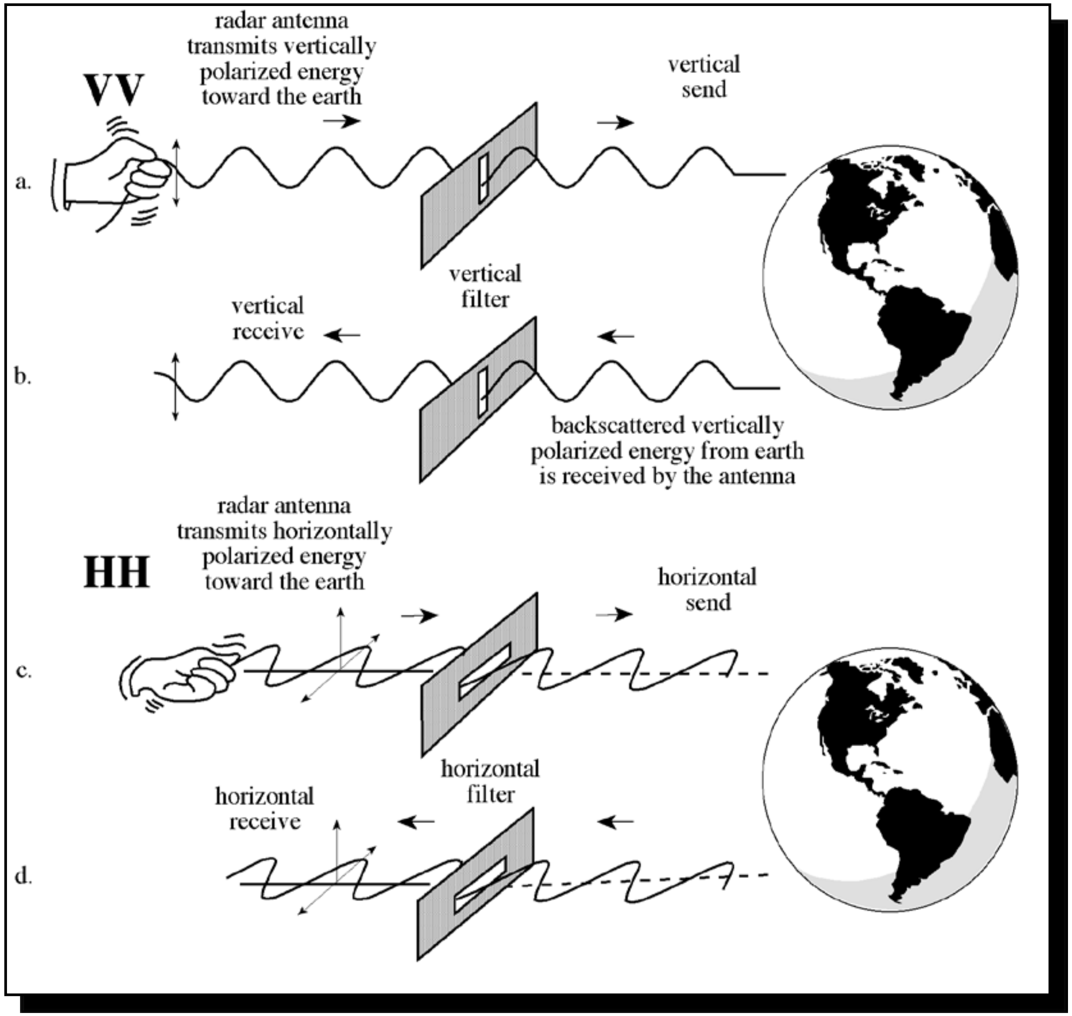
Synthetic Aperture Radar (SAR)

- Active microwave sensor
- Microwaves are scattered by vegetation canopy and soil, but penetrate clouds
- Radar backscatter is related to geometric and physical properties of the canopy (dielectric constant)
- Interferometric coherence between pairs of images can be used to map the land surface type.
- Interferometric phase is a measure of height (ground plus vegetation layer)

SAR Satellites

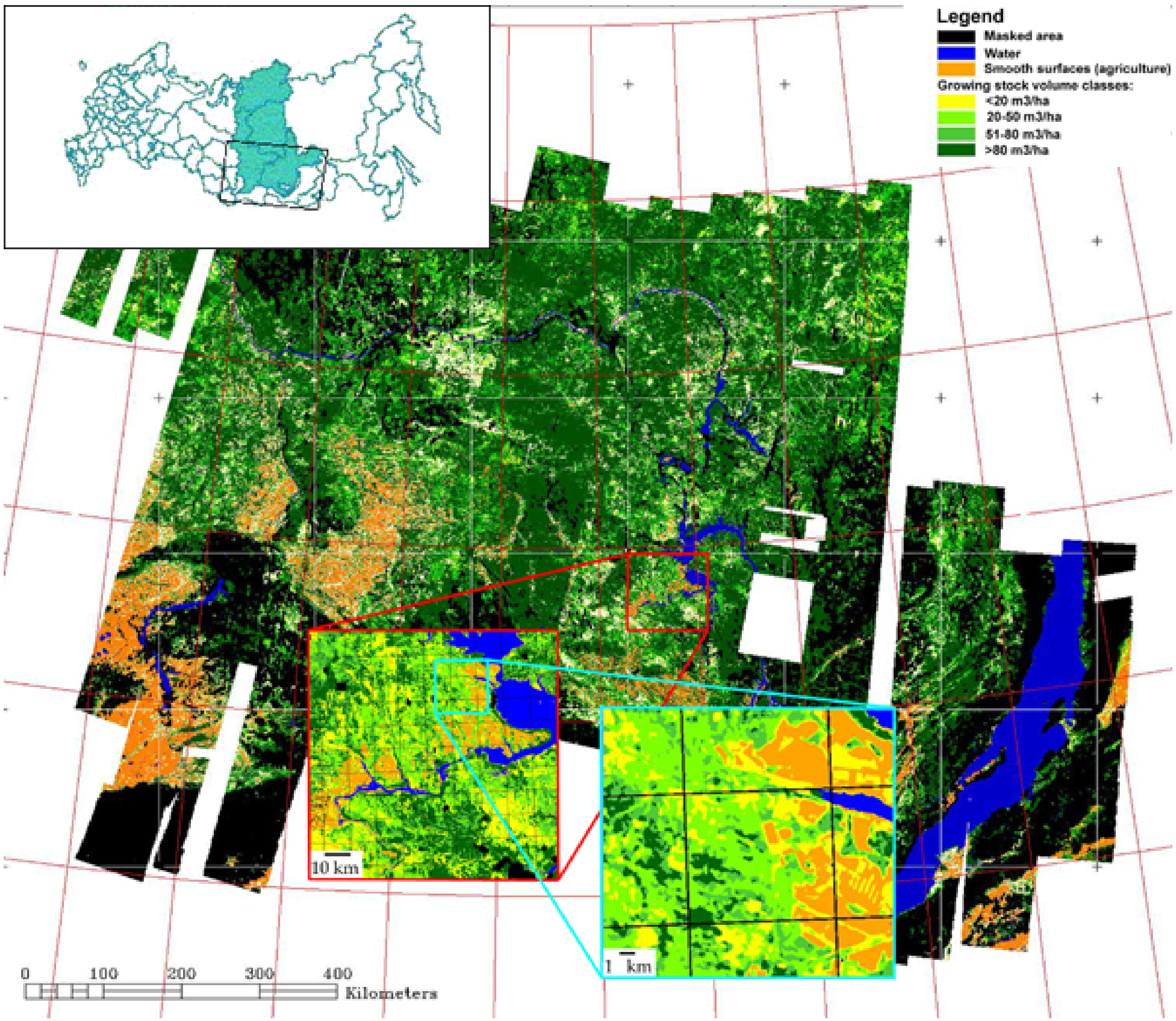
BAND	FREQUENCY (WAVELENGTH)	OPERATING SATELLITES	PLANNED SATELLITES
X band	8 – 12.5 GHz (2.4-3.8 cm)	TerraSAR-X Cosmo/SkyMed Tandem-X	Paz
C band	4 - 8 GHz (3.8 - 7.5 cm)	Radarsat 1 Radarsat 2	Sentinel-1
S band	2 - 4 GHz (7.5 - 15 cm)	Huanjing-1C	NovaSAR-S
L band	1 - 2 GHz (15 - 30 cm)		ALOS/PALSAR-2 SAOCOM
P Band	0.3 - 1 GHz (30 - 100 cm)		BIOMASS

Polarization



Jensen, 2000

Siberia forest cover map

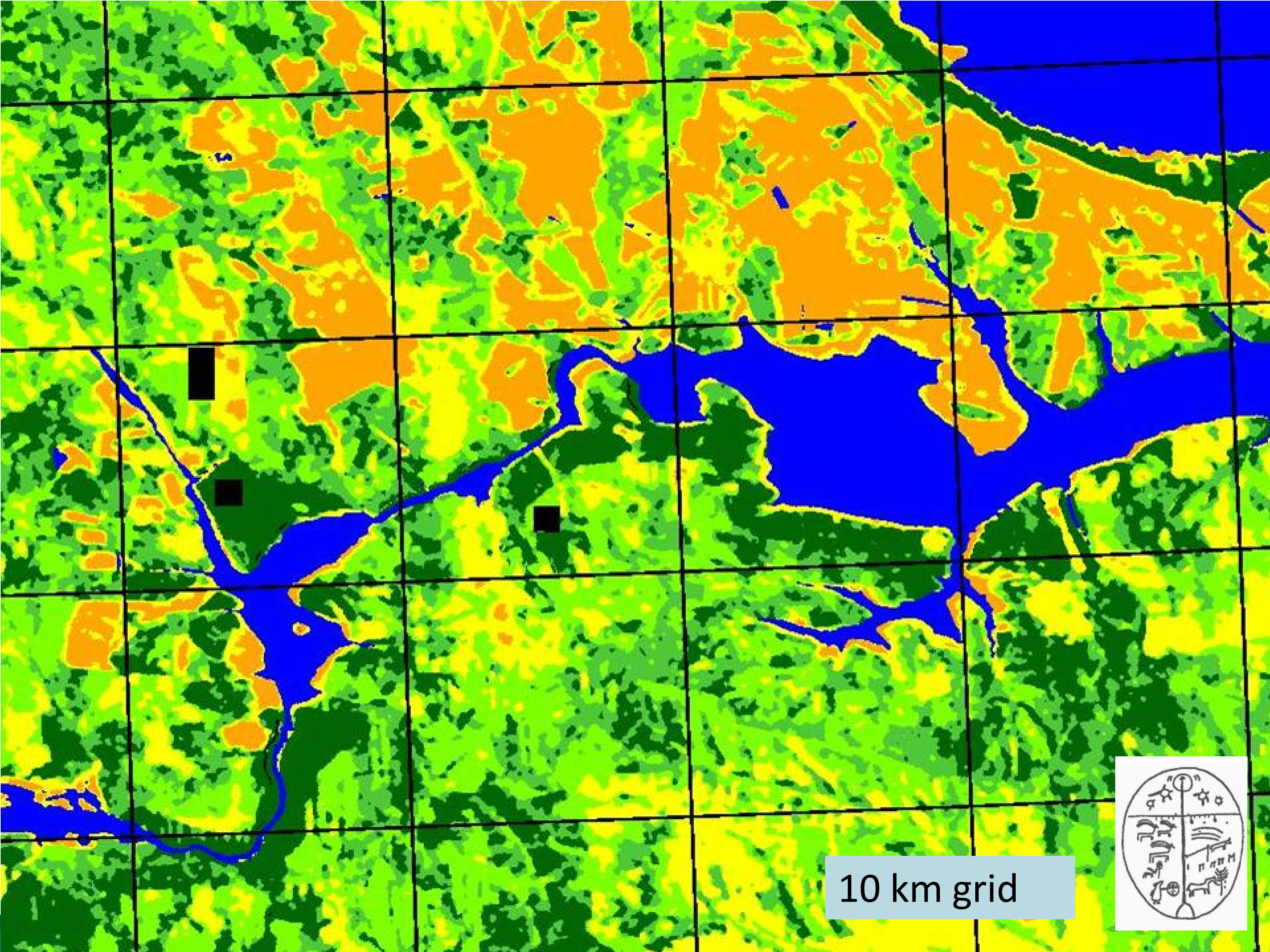


Produced using 600 ERS-1/2 and JERS-1 SAR images

4 forest biomass classes

Area 1,000,000 km^2

Balzter et al. (2002), *Canadian Journal of Remote Sensing 28, 719-737.*


10 km grid

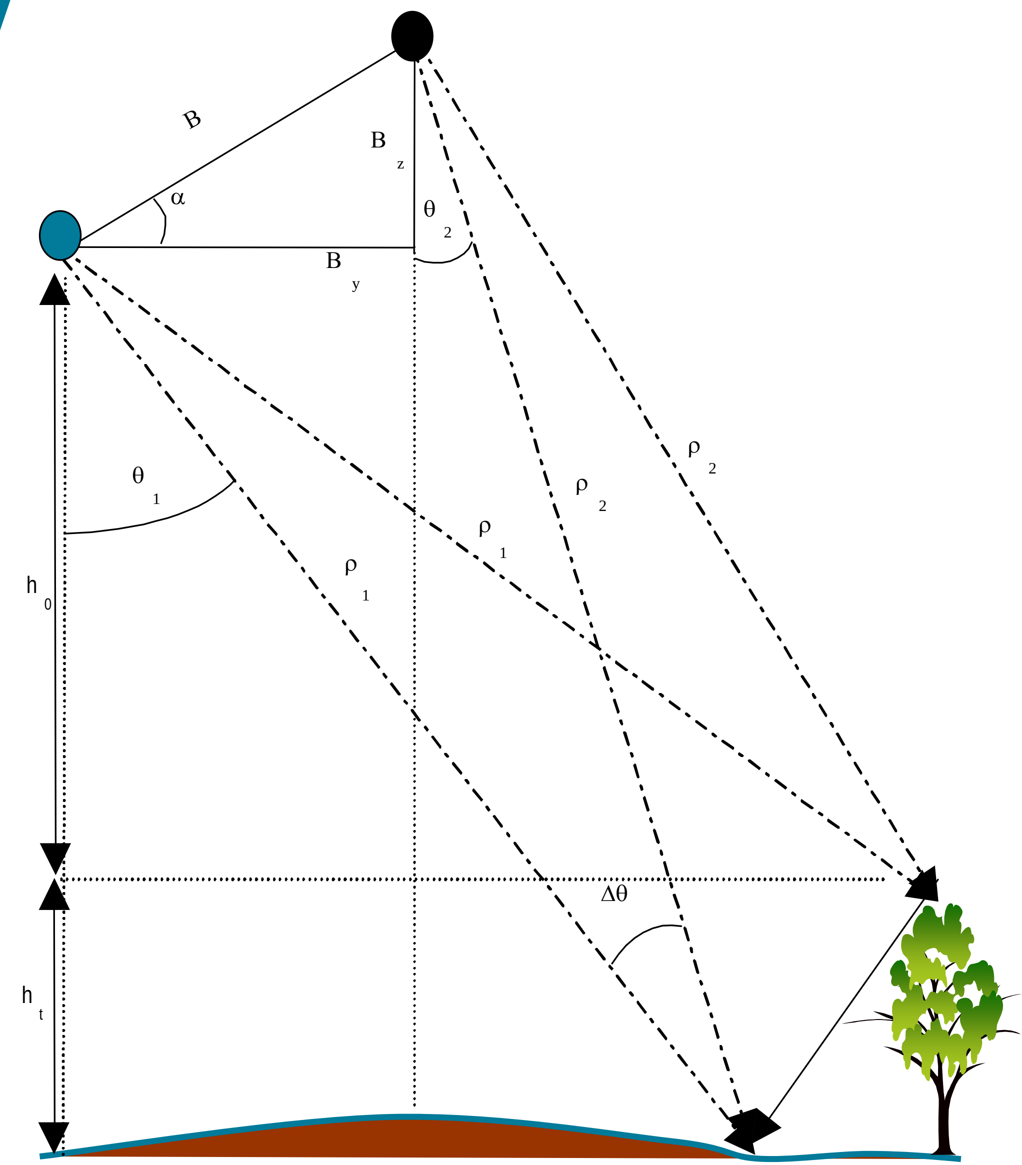
SAR interferometry

$\Delta\Phi$ = Phase difference

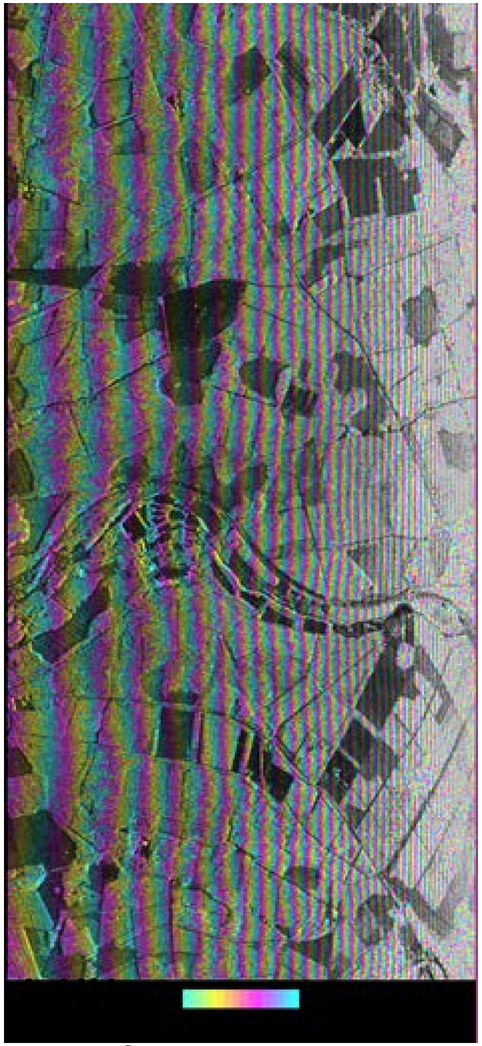
Path difference = $\Delta\rho = \rho_1 - \rho_2$

Phase difference = $\dfrac{4.\pi.\Delta\rho}{\lambda} = \dfrac{4.\pi}{\lambda}.\Delta\theta.\dfrac{h_t}{\sin(\theta_0)}$

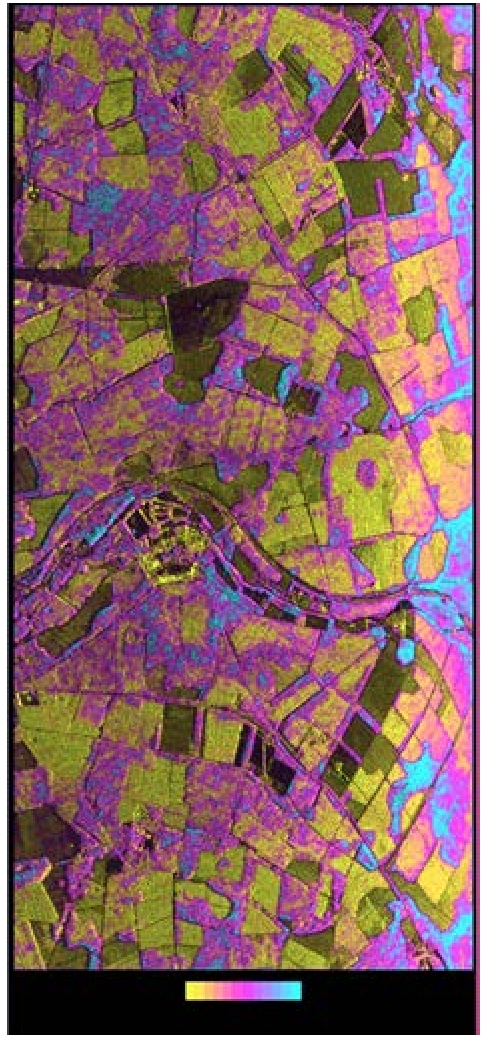
Tree height = $h_t = \Delta\phi/(\sin(\theta_0)\lambda/(4.\pi.\Delta\theta))$



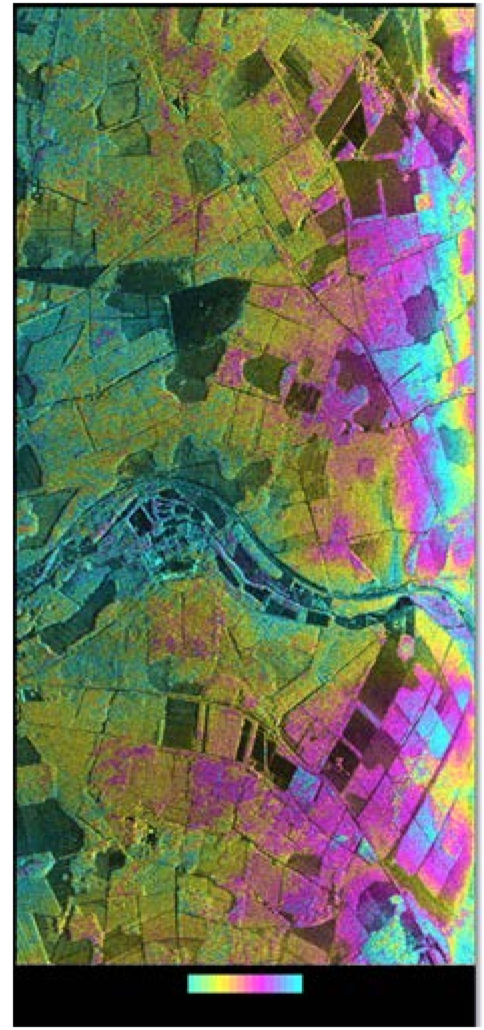
Airborne radar interferometry at Thetford Forest



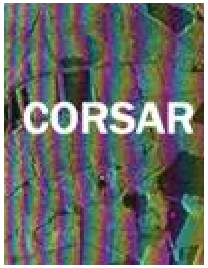
interferogram



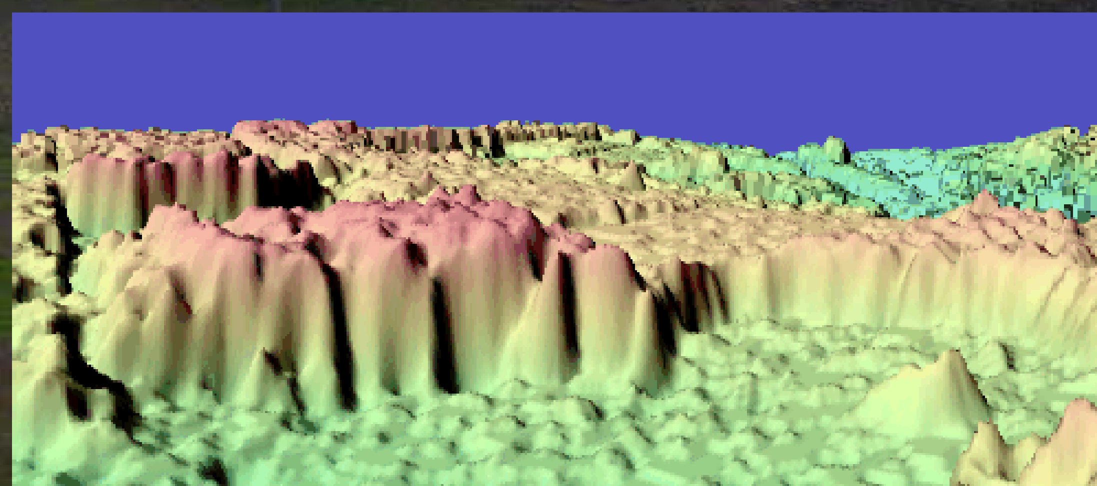
coherence



flattened phase

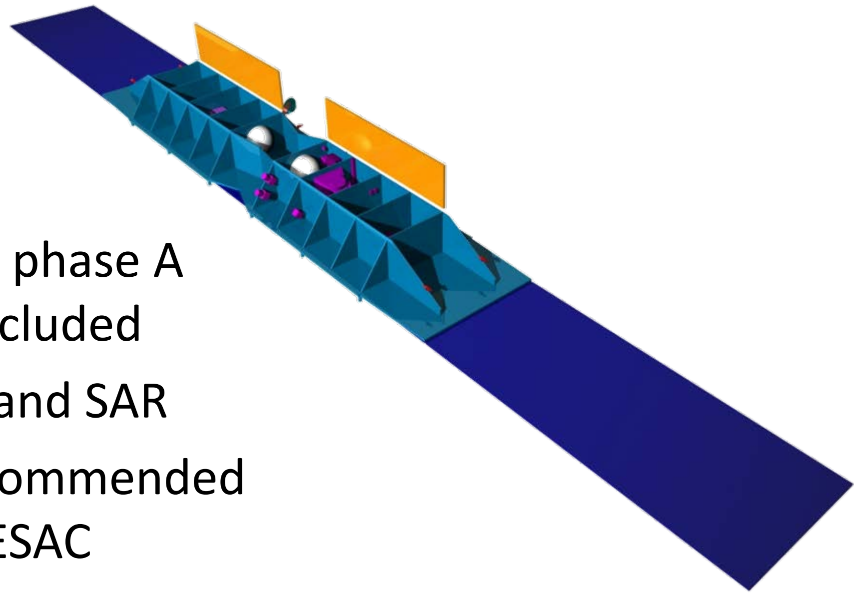


Tree height at Thetford Forest from SAR interferometry (X-band VV pol, single-pass E-SAR data)

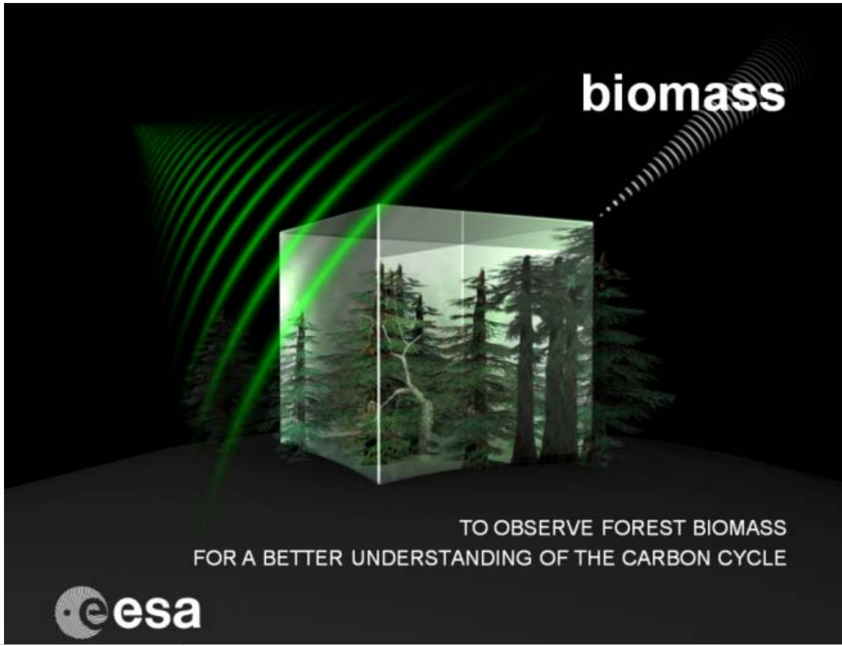


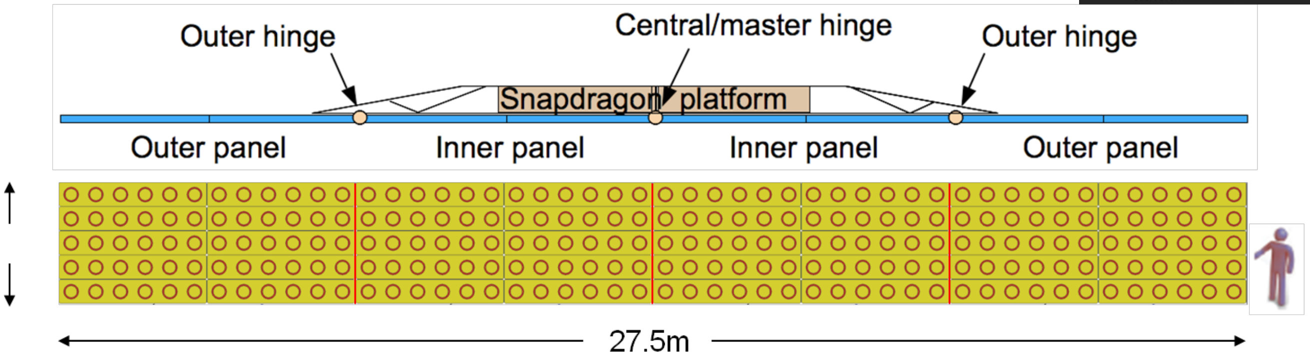
Balzter et al. (2007): International Journal of Remote Sensing

BIOMASS Earth Explorer Mission



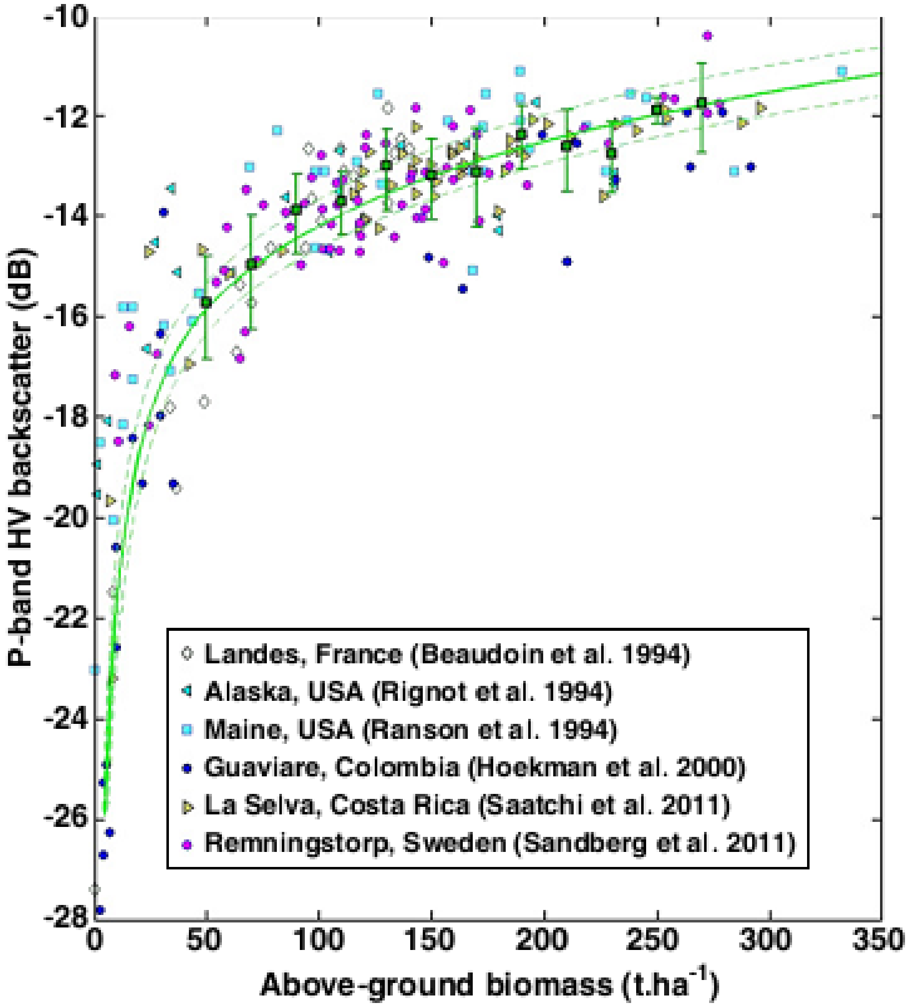
- ESA phase A concluded
- P-band SAR
- Recommended by ESAC





Le Toan et al. (2011), Remote Sensing of Environment

P-band SAR and forest biomass

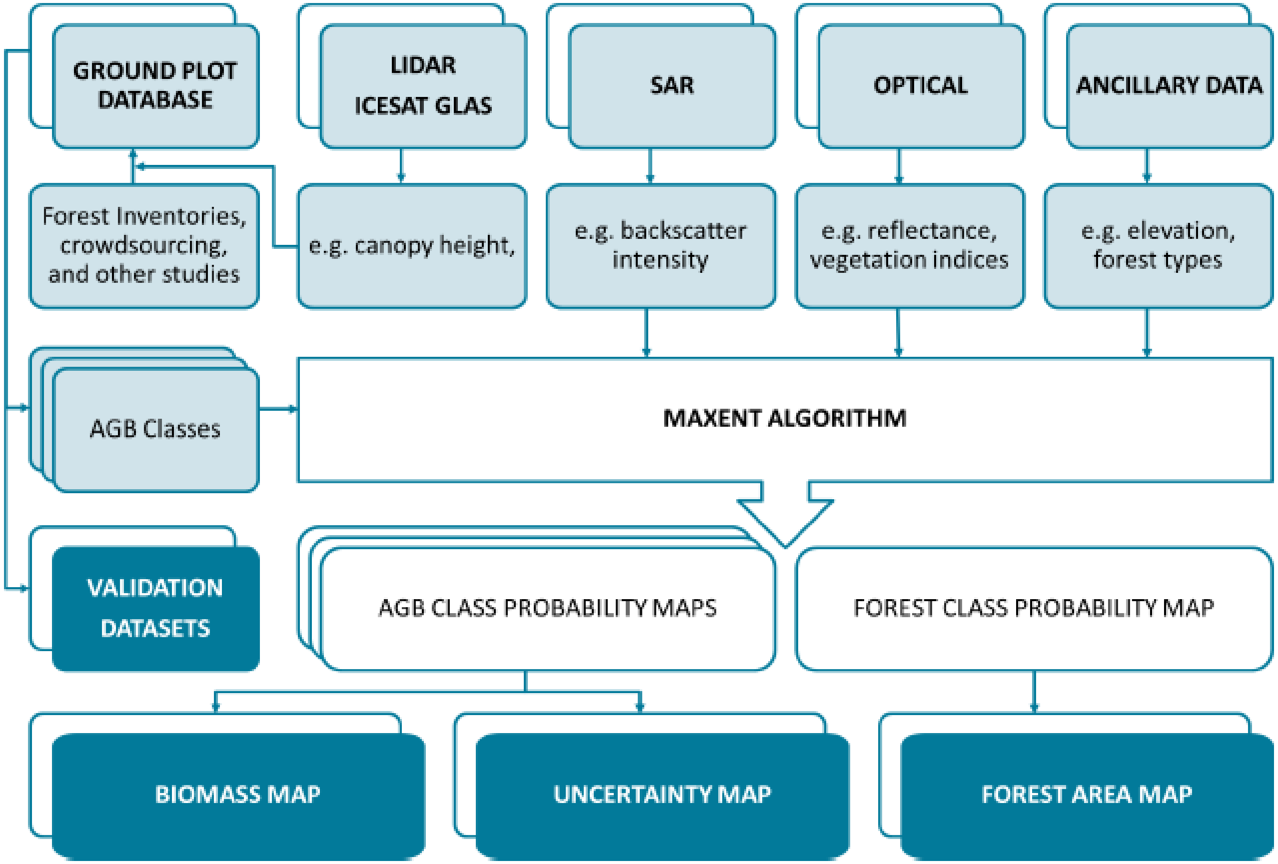


- P-band has the remarkable property that the biomass / backscatter relationship is independent of forest type.

Le Toan et al. (2011), Remote Sensing of Environment

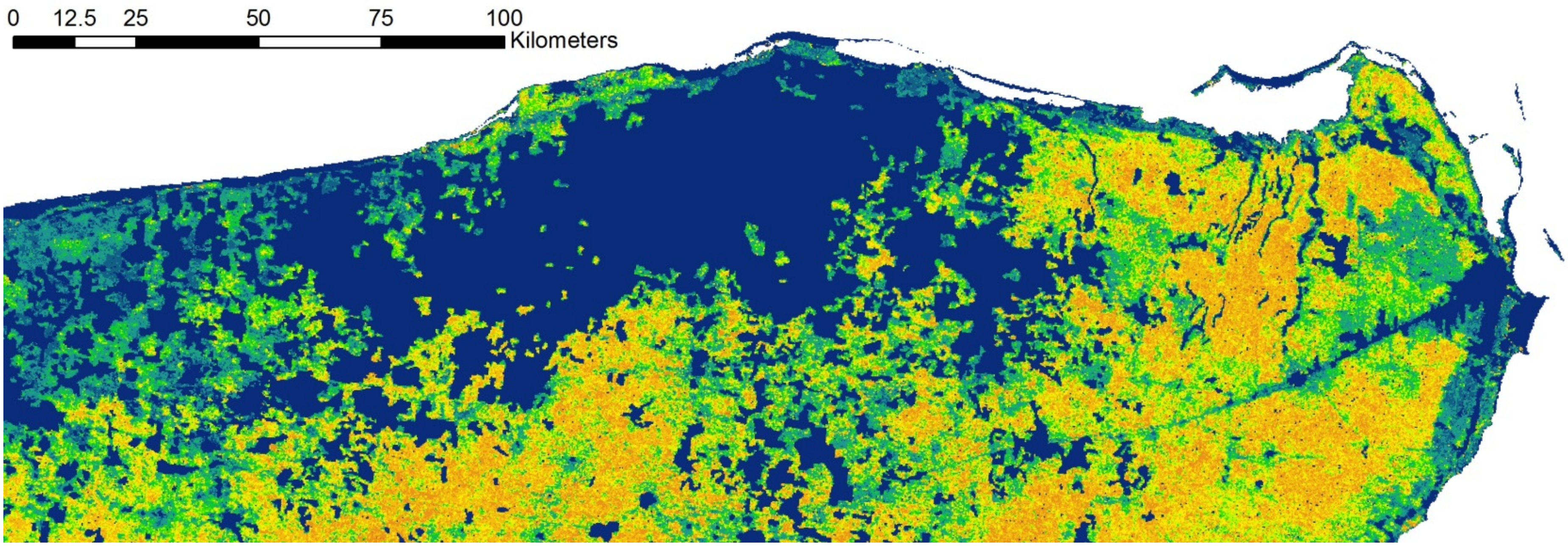
Mexico Forest Area and Above Ground Biomass mapping

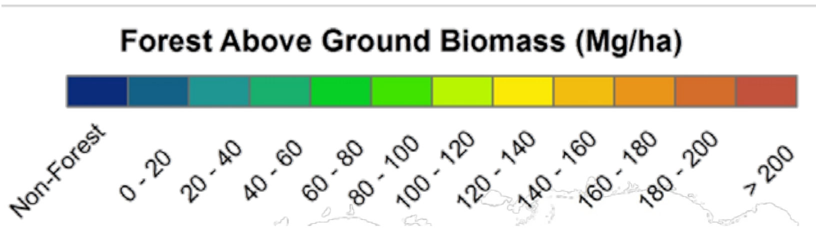
ALOS PALSAR, MODIS, SRTM and forest inventory data are used as inputs to estimate Forest Area and AGB



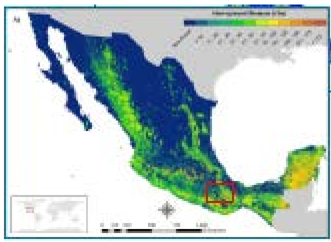
Rodríguez Veiga et al. (submitted)

Aboveground Biomass Map

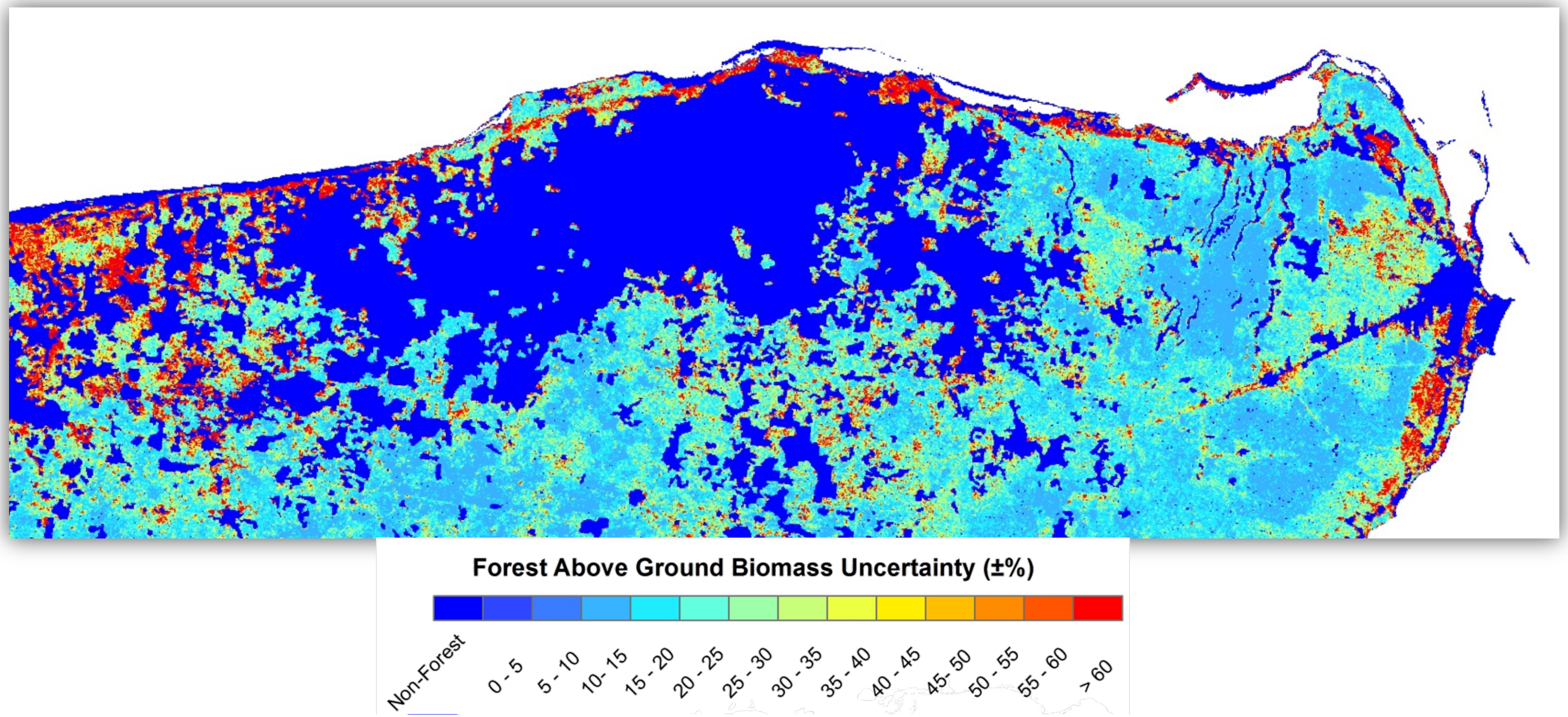




Rodríguez Veiga et al. (submitted)



Uncertainty map

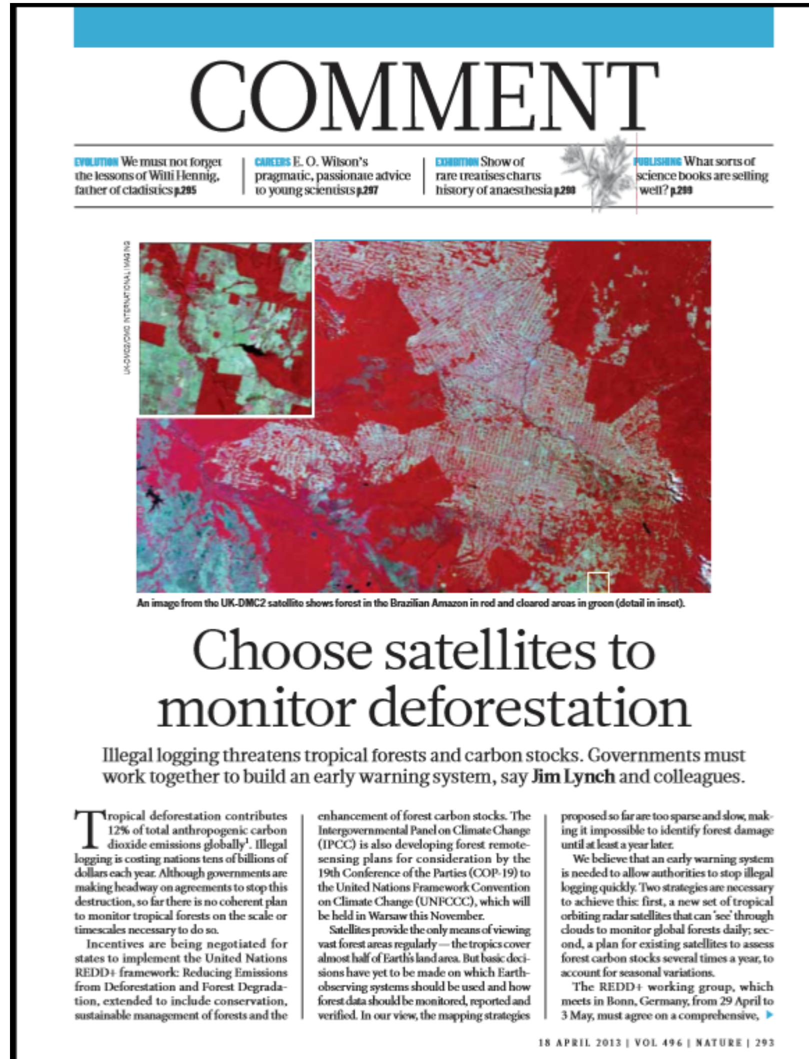


Rodríguez Veiga et al. (submitted)

Monitoring global forest cover change

A radar satellite constellation could monitor global forest cover change independent of cloud cover every 3-10 days.

This would support combating illegal logging and deforestation, e.g. for REDD+.



COMMENT

EVOLUTION We must not forget the lessons of Willi Hennig, father of cladistics p.295

CAREERS E. O. Wilson's pragmatic, passionate advice to young scientists p.297

EXHIBITION Show of rare treatises charts history of anaesthesia p.298

PUBLISHING What sorts of science books are selling well? p.299

An image from the UK-DMC2 satellite shows forest in the Brazilian Amazon in red and cleared areas in green (detail in inset).

Choose satellites to monitor deforestation

Illegal logging threatens tropical forests and carbon stocks. Governments must work together to build an early warning system, say **Jim Lynch** and colleagues.

Tropical deforestation contributes 12% of total anthropogenic carbon dioxide emissions globally[1]. Illegal logging is costing nations tens of billions of dollars each year. Although governments are making headway on agreements to stop this destruction, so far there is no coherent plan to monitor tropical forests on the scale or timescales necessary to do so.

Incentives are being negotiated for states to implement the United Nations REDD+ framework: Reducing Emissions from Deforestation and Forest Degradation, extended to include conservation, sustainable management of forests and the enhancement of forest carbon stocks. The Intergovernmental Panel on Climate Change (IPCC) is also developing forest remote-sensing plans for consideration by the 19th Conference of the Parties (COP-19) to the United Nations Framework Convention on Climate Change (UNFCCC), which will be held in Warsaw this November.

Satellites provide the only means of viewing vast forest areas regularly — the tropics cover almost half of Earth's land area. But basic decisions have yet to be made on which Earth-observing systems should be used and how forest data should be monitored, reported and verified. In our view, the mapping strategies proposed so far are too sparse and slow, making it impossible to identify forest damage until at least a year later.

We believe that an early warning system is needed to allow authorities to stop illegal logging quickly. Two strategies are necessary to achieve this: first, a new set of tropical orbiting radar satellites that can 'see' through clouds to monitor global forests daily; second, a plan for existing satellites to assess forest carbon stocks several times a year, to account for seasonal variations.

The REDD+ working group, which meets in Bonn, Germany, from 29 April to 3 May, must agree on a comprehensive,

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Lynch, J., Maslin, M., Balzter, H. and Sweeting, M. (2013): Sustainability: Choose satellites to monitor deforestation, Nature 496, 293-294.

NovaSAR satellite mission

- Concept for a new S-band, low-cost radar satellite constellation
- Aims to monitor tropical deforestation, maritime surveillance and other applications

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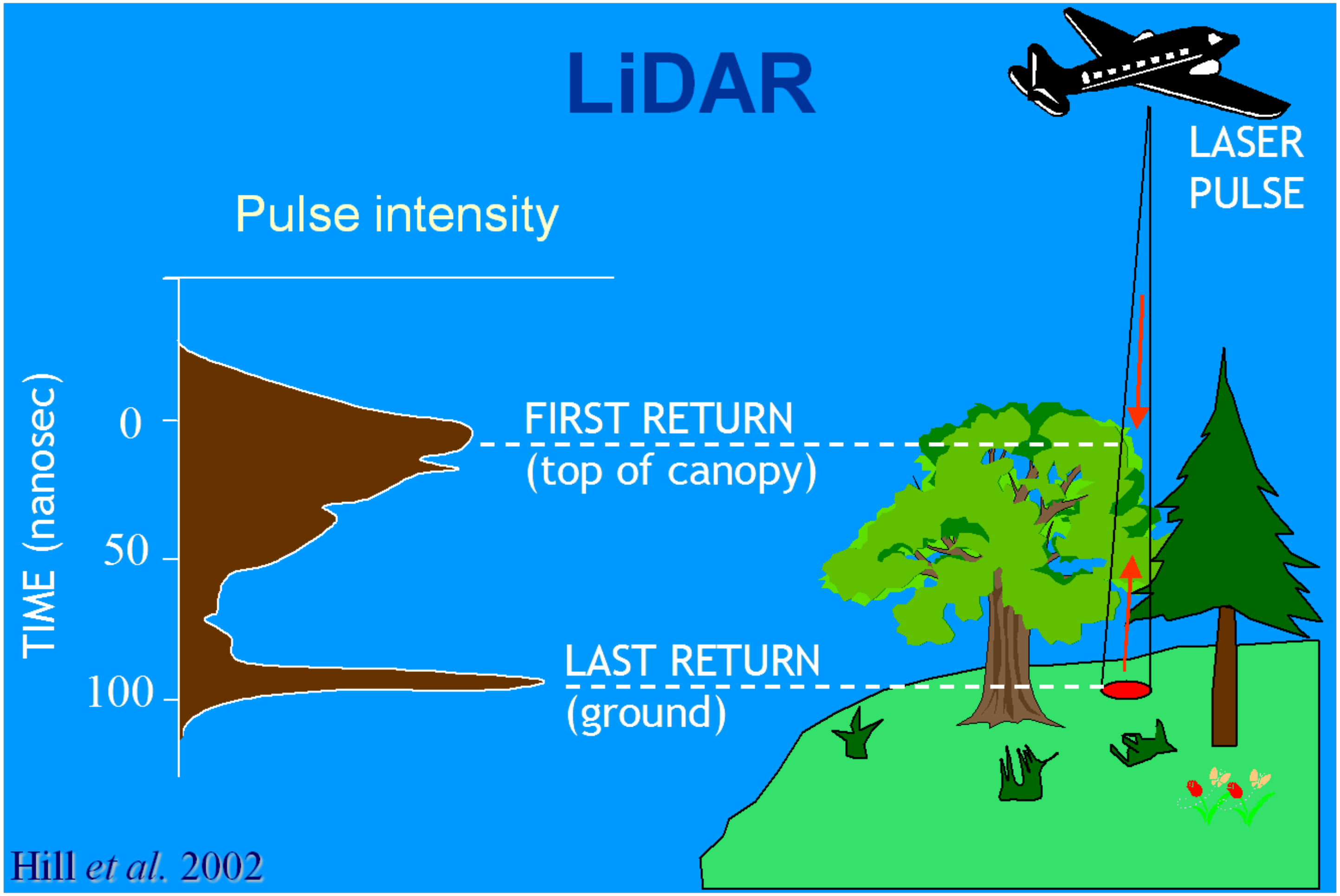
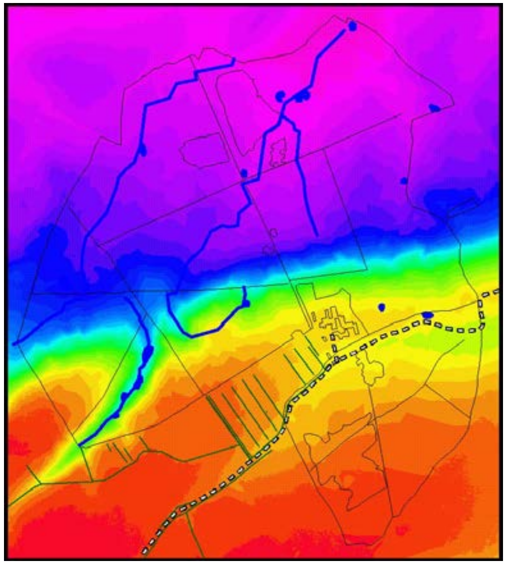
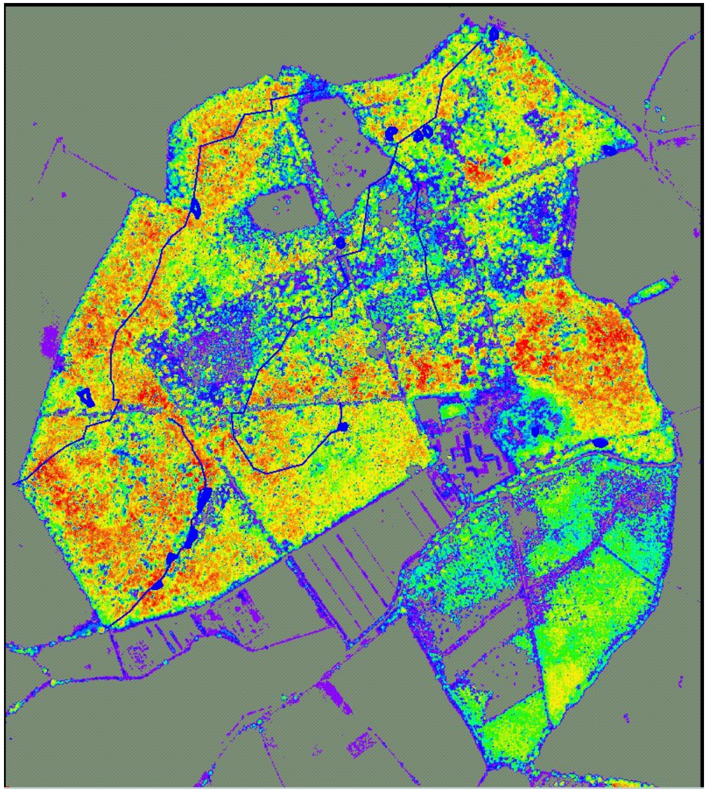
Light Detection and Ranging (LiDAR)



LIDAR images of Monks Wood NNR



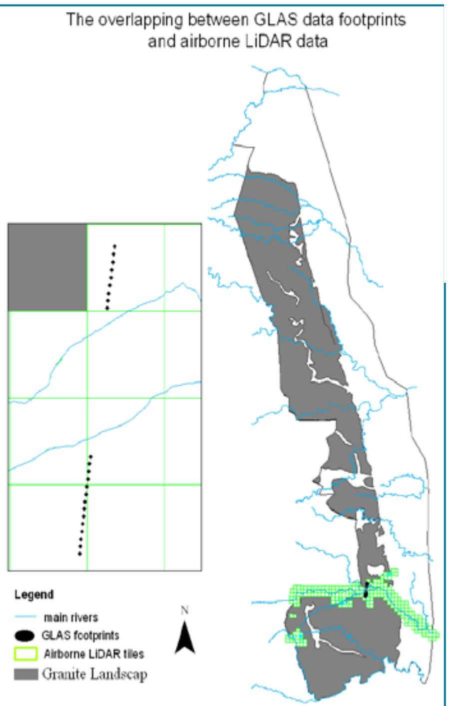


Digital Surface Model = Digital Terrain Model + Canopy Height Model

Spaceborne LiDAR for savanna mapping

Terrain variation within the footprint influences the retrieval of vegetation height.

Below: Savanna vegetation mapping in Skukuza, South Africa.



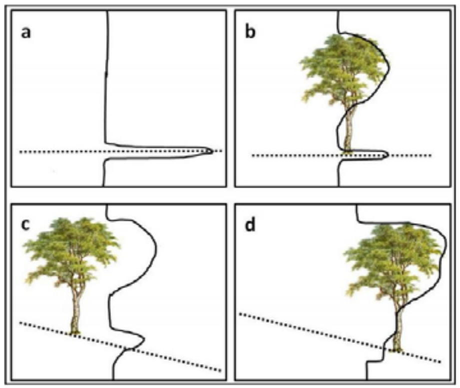
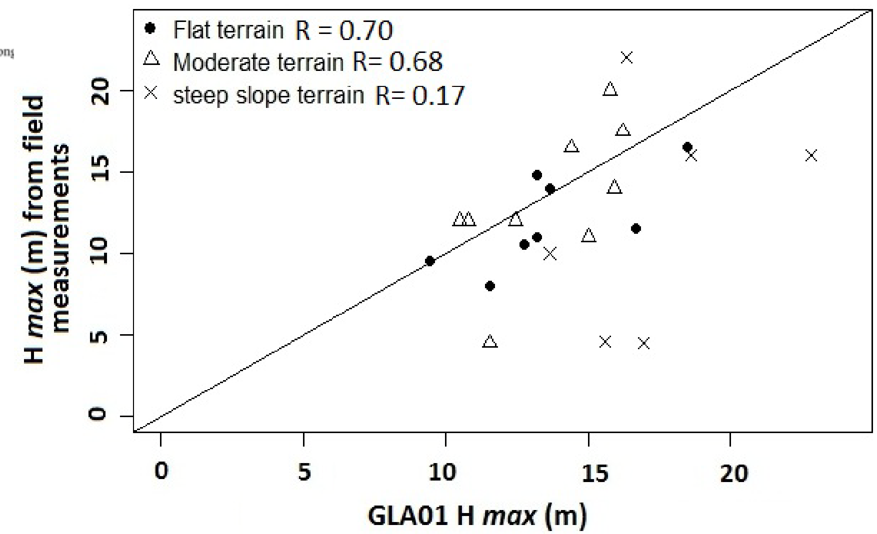


Figure 3.15: Structure of the returned waveform over flat areas (a, b) and sloped areas (c, d) (Duong 2010).



Terrain correction of ICESAT-GLAS data can give R^2>0.8 (E. Khalefa)

Outlook on GLOBBIOMASS

- ESA funded project, coordinated by Prof. Schmullius, University of Jena
- Kick-off in January 2015
- Will produce forest biomass maps for three time steps: 2005, 2010 and 2015
- Preparation for the BIOMASS mission

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References

- Ghent, D., Kaduk, J., Remedios, J. and Balzter, H. (2011): Data assimilation into land surface models: the implications for climate feedbacks. International Journal of Remote Sensing 32, 617-632, https://lra.le.ac.uk/handle/2381/9376
- Lynch, J., Maslin, M., Balzter, H. and Sweeting, M. (2013): Sustainability: Choose satellites to monitor deforestation, Nature 496, 293-294. http://hdl.handle.net/2381/28888
- Palmer, S.C.J., Hunter, P.D., Lankester, T., Hubbard, S., Spyrakos, E., Tyler, A., Présing, M., Horváth, H., Lamb, A., Balzter, H. and Tóth, V.R. (in press): Validation of Envisat MERIS- and Sentinel-3 OLCI-compatible algorithms for chlorophyll retrieval in a large, turbid and optically complex shallow lake. Remote Sensing of Environment, http://www.sciencedirect.com/science/article/pii/S0034425714002739
- Palmer, S.C.J., Pelevin, V.V., Goncharenko, I., Kovács, A.W., Zlinszky, A., Présing, M., Horváth, H., Nicolás-Perea, V., Balzter, H. and Tóth, V.R. (2013): Ultraviolet Fluorescence LiDAR (UFL) as a robust measurement tool for water quality parameters in turbid lake conditions, Remote Sensing 5, 4405-4422; doi:10.3390/rs5094405, http://hdl.handle.net/2381/28884
- Remedios, J., Balzter, H., Burrows, J., Eves, S., Johnson, M., Lavender, S., Monks, P., O'Neill, A., Shepherd, A. (2012): Earth observation: A revolutionary leap into the future, Astronomy and Geophysics 53, 3.16-3.18.
- Rodriguez Veiga, P., Saatchi, S., Wheeler, J., Tansey, K. and Balzter, H., in press, Forest Biomass Mapping: Integrating Regional Forest Allometry, In situ Measurements, and Earth Observation data. In Balzter, H. (Ed.): *“Earth Observation for Land and Emergency Monitoring - Innovative concepts for environmental monitoring from space”*. Wiley-Blackwell, Chichester.
- Stratoulias, D., Balzter, H., Sykioti, O., Zlinszky, A. and Tóth, V.R. (2014). Simulation of Sentinel-2 image from AISA Eagle and Hawk hyperspectral imagery in a lakeshore vegetation environment. *Proceedings of the ESA Sentinel-2 for Science Workshop*, special publication SP-726, 2-22 May 2014, ESA-ESRIN, Frascati, Italy.
- Stratoulias, D., Balzter, H., Zlinszky, A. and Tóth, V.R. (in press): Assessment of ecophysiology of lake shore reed vegetation based on chlorophyll fluorescence, field spectroscopy and hyperspectral airborne imagery, Remote Sensing of Environment, doi 10.1016/j.rse.2014.05.021, http://www.sciencedirect.com/science/article/pii/S0034425714002351