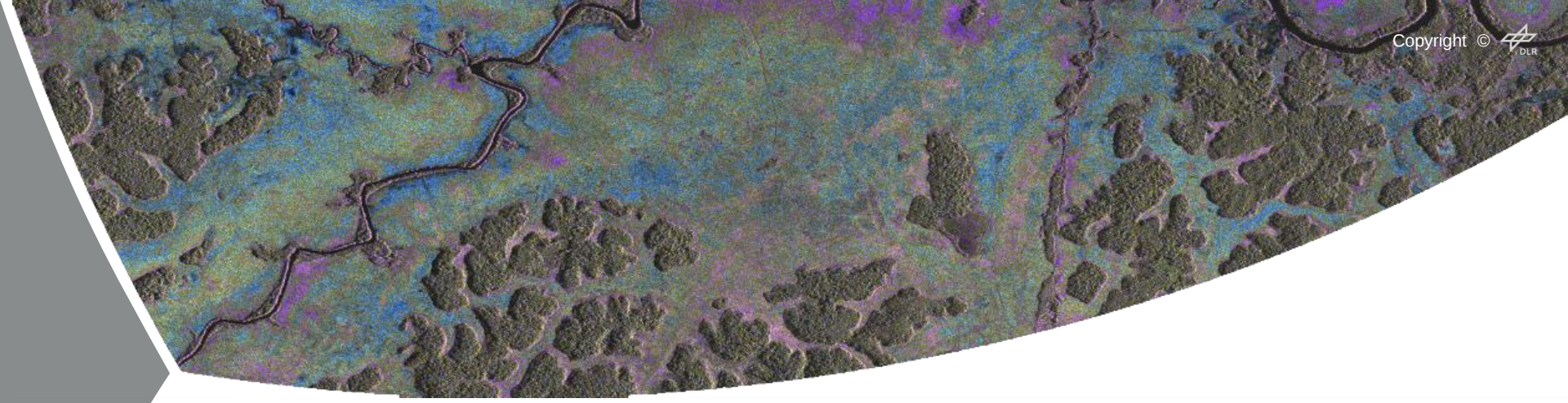


Copyright © DLR

Module 3201:
Biomass estimation using SAR data

Nicole Richter

Christian Thiel

Christiane Schmullius

Robert Eckardt

Friedrich-Schiller-University Jena
Department of Earth Observation
Jena, Germany

Copyright © DLR

Educational Objectives

- To learn how SAR data can be used for biomass estimation
- To understand advantages of SAR techniques over traditional measuring techniques
- To understand the limitations of SAR data for biomass estimation
- To learn optimal sensor and acquisition parameters for biomass estimation using SAR data

Copyright ©

Requirements

- You know the basic concept of complex SAR data

  Module ID 1100: Mathematics & Physics – Mathematic Basics

  Module ID 1300: SAR basics

- You know and understand physical basics

  Module ID 1104: Mathematics & Physics – Physics

- You know and understand SAR processing steps

  Module ID 1207: Data processing – SAR specific data formats & SAR data processing

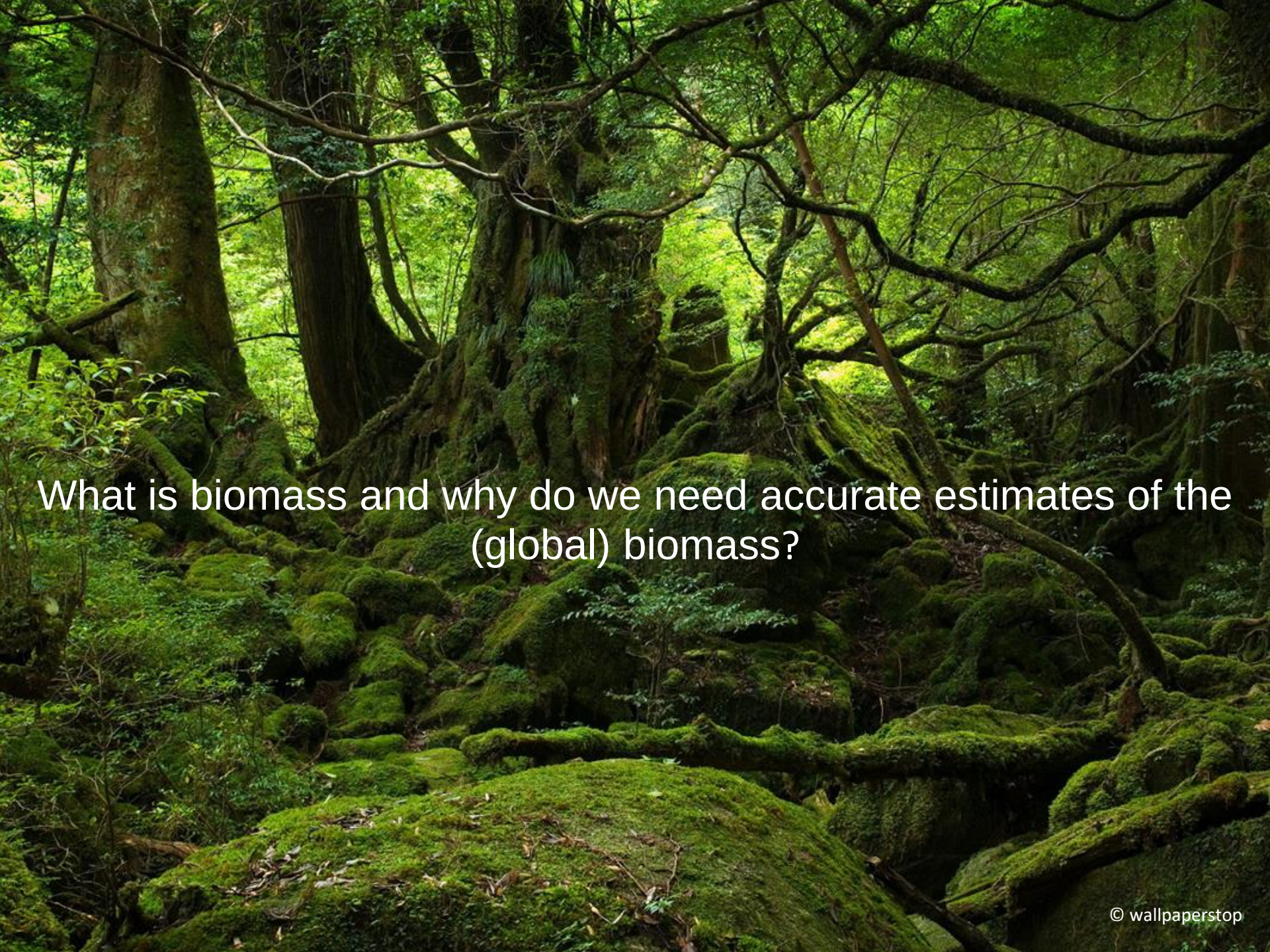
- You know and understand SAR technology

  Module ID 1300: SAR basics

Copyright © DLR

Structure

- Introduction: What is biomass and why do we need accurate estimates of the (global) biomass?
- Basics of biomass estimation
  - Advantages and disadvantages of SAR data
  - Different wavelengths in biomass estimation
- Biomass estimation methods using SAR data
  - Overview
  - Backscatter analysis
  - SAR Interferometry
  - Indirect estimation methods
- Examples
- Summary


What is biomass and why do we need accurate estimates of the (global) biomass?
© wallpaperstop

Introduction

BIOMASS … *"is defined as mass of life or dead organic matter" (FAO/GTOS, 2009).*

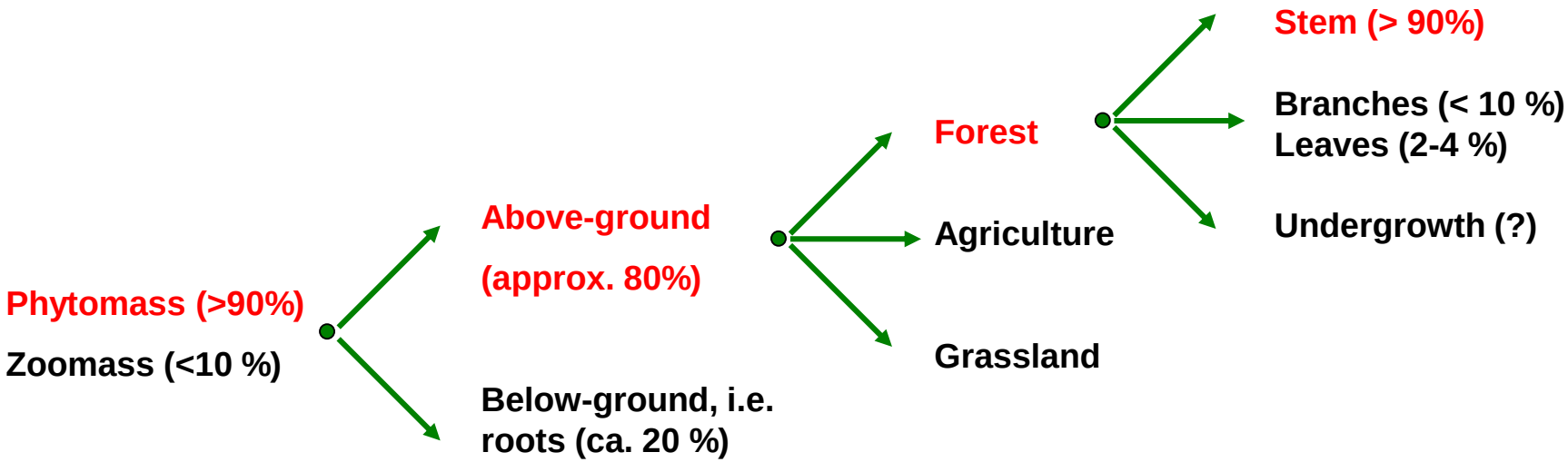


Fig.: Global Biomass (after METTE et al., 2002).

Here we will mainly address living terrestrial above-ground vegetation biomass, in particular woody biomass.

Copyright ©

Introduction

WHY DO WE NEED TO OBSERVE (GLOBAL) FOREST BIOMASS?

- For a better understanding and quantification of:
  - Terrestrial **carbon stocks and fluxes** in forests
  - Terrestrial **carbon sources and sinks**
  - **The global carbon cycle**
  - **Global climate change**
- Information of forest biomass is needed to **support sustainable forest resource management**

FAO, 2009; GHASEMI et al., 2011

Copyright ©

Introduction

DID YOU KNOW?

- **Forests** cover approximately **33% of the Earth's land surface** (JENSEN, 2000)
- Forests play an important role in the global carbon cycle, since **each year forests absorb approximately 1/12 of the Earth's atmospheric CO2 stock** (MALHI et al., 2002)
- Forested ecosystems account for app. **72% of the Earth's terrestrial carbon storage** (MALHI et al., 2002)
- Therefore, vegetation biomass is a **larger global store of carbon than the atmosphere** (FAO, 2009)
- Between 1850 and 2011, humans have released app. **480 Gt (480 BILLION TONS!!!) of CO2 into the atmosphere** through fossil fuel burning and land use changes (e.g. deforestation and fires) (GHASEMI et al., 2011)

Introduction

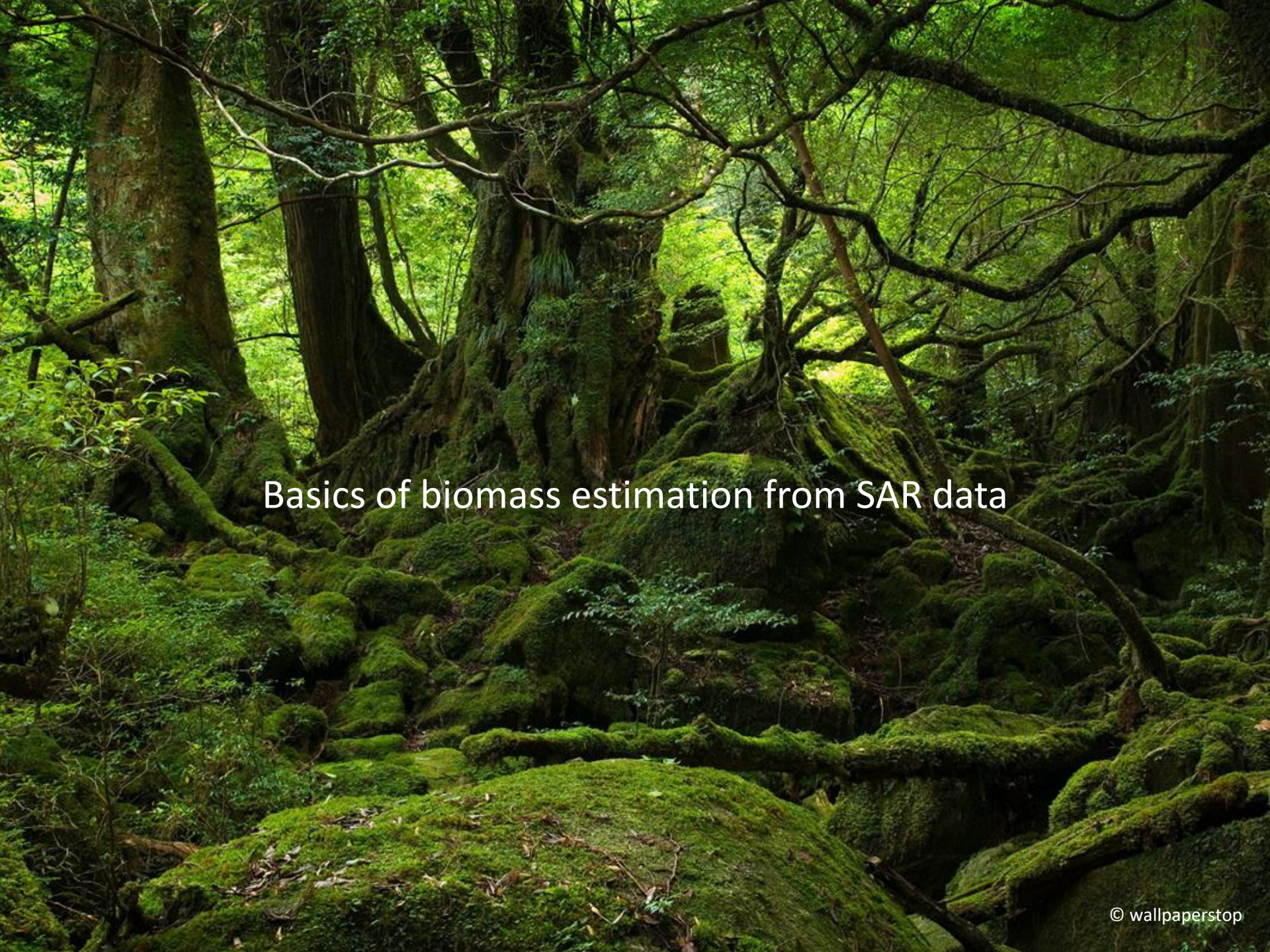
In Forestry, the biomass calculation is based on measurements of trunk diameter and height of sample populations of trees:

$$Biomass_{forest} = N \times \pi \times \left(\frac{1}{2}\,\mathrm{dbhmid}\right)^2 \times hmid \times \rho \times fz$$

Biomass$_{forest}$ **[t/ha]**	is defined as aboveground wood of trunks and branches where exceeding 7 cm diameter
$\mathbf{dbh_{mid}}$ **[cm]**	is the (dbh² weighted) mean diameter at breast height 1.3 m
$\boldsymbol{h_{mid}}$ **[m]**	is the height of the tree
$\boldsymbol{\rho}$ **[g/cm³]**	is the species-specific wood density
$\boldsymbol{f_z}$ **[]**	is a form factor (= 0.4-0.5, constant in a first order approximation)
$\boldsymbol{N}$	is the tree density (tree number per area unit)

The product of $\boldsymbol{N \times \pi \times \left(\frac{1}{2}\,\mathrm{dbh}_{mid}\right)^2}$ is also called **basal area g**.

METTE et al., 2004



Basics of biomass estimation from SAR data

© wallpaperstop

Advantages of SAR data

(compared to optical remote sensing data or in-situ measurements)

- Higher spatial coverage
- Higher temporal resolution (repeat cycle e.g. 11 days)

⇒ Remotely sensed data therefore can be used to fill spatial, attributional, and temporal gaps in forest inventory data

- Contactless

⇒ Detection of unknown regions

- Retrospective analysis
  (archived SAR data since 1991 (but not globally))
- Microwaves enable a weather- and illumination-independent imaging process

FAO, 2009, Balzter, 2001

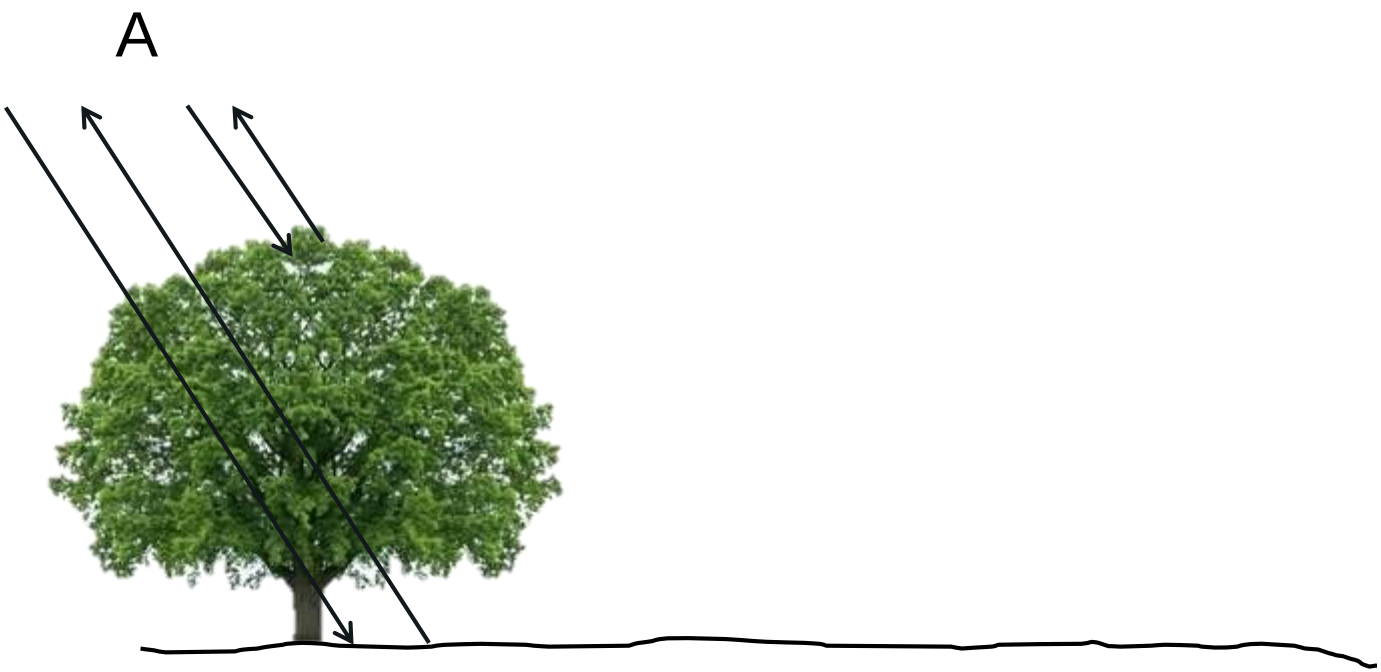
Disadvantages of SAR data

(compared to optical remote sensing data or in-situ measurements)

- Limitations in applicability of RS data for AGB estimation are related to
  - Backscatter saturation, especially in mature forests with complex stand structure
  - In rugged or mountainous regions, topography can affect vegetation reflectance and influence relationships between backscattering values and AGB → topographic correction is necessary
- Satellite approaches to estimate biomass are still in experimental stages and pre-operational with uncertain accuracy (resp. accuracies under certain constraints)

FAO, 2009; GHASEMI et al., 2011

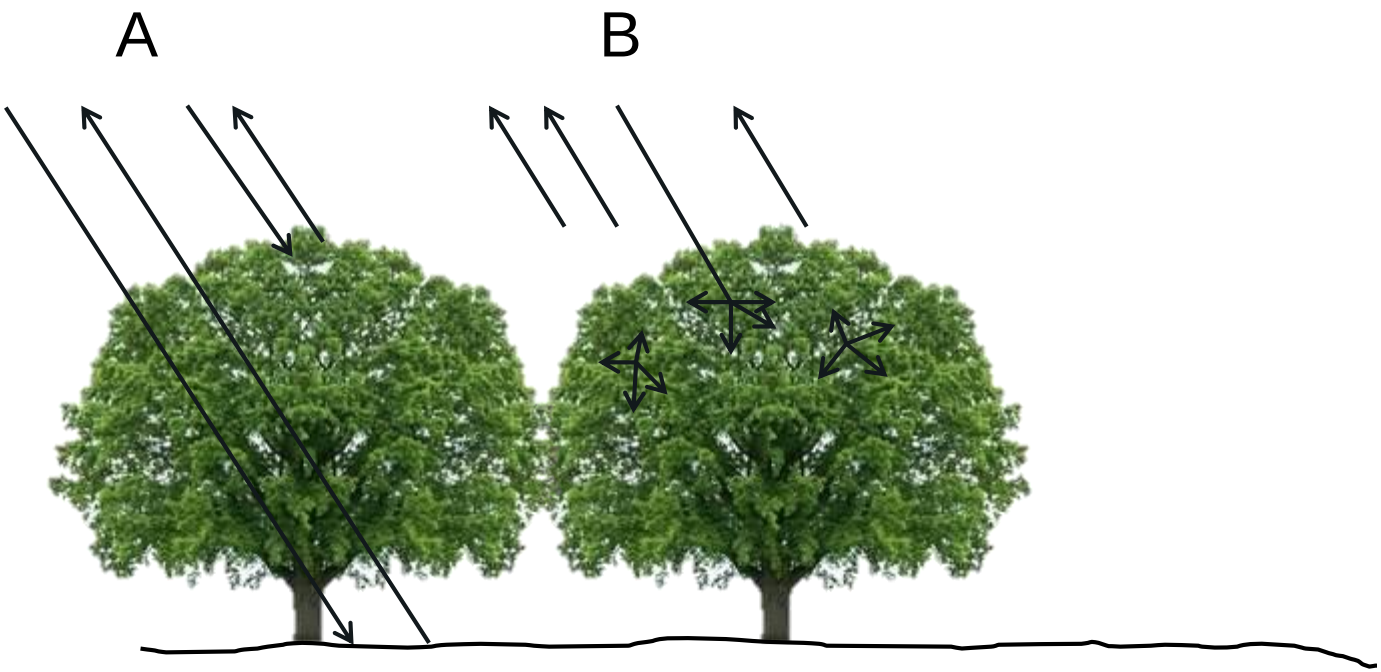
Different wavelengths in biomass estimation



A - When a wave reflects off only one target and returns to the instrument this is known as direct scattering (or “single bounce”). This occurs when the wave hits a target that is at an orientation such that the wave is returned directly to the radar.

Fig.: Global Biomass (after METTE et al., 2002).

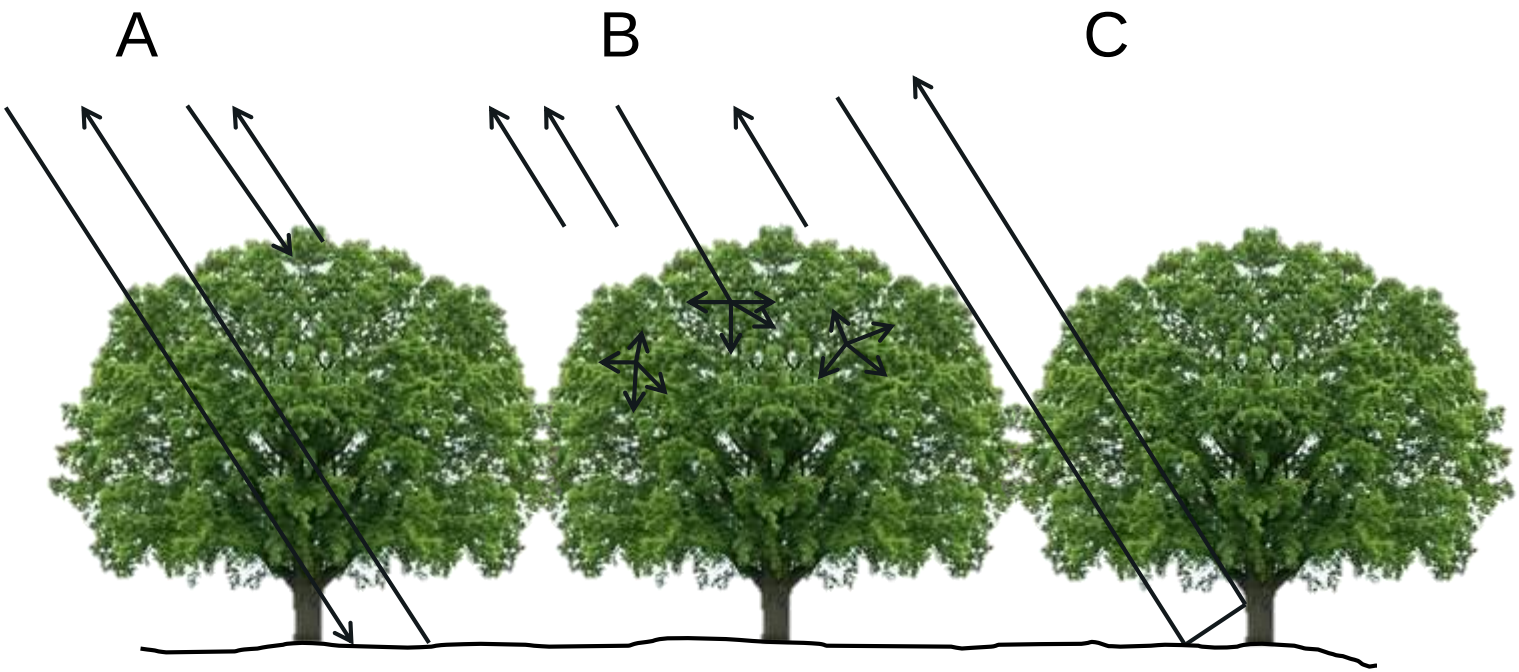
Different wavelengths in biomass estimation



B - Cases of more than two bounces are known as multiple scattering and occur frequently in environments such as dense forest canopies between trunks, branches, and twigs.

Fig.: Global Biomass (after METTE et al., 2002).

Different wavelengths in biomass estimation



C - If the wave reflects off two surfaces before returning to the instrument, such as often arises in urban areas between ground and wall, or in forests between ground and tree trunks or between trunks and twigs, this is termed “double bounce”.

Fig.: Global Biomass (after METTE et al., 2002).

Copyright ©

Different wavelengths in biomass estimation

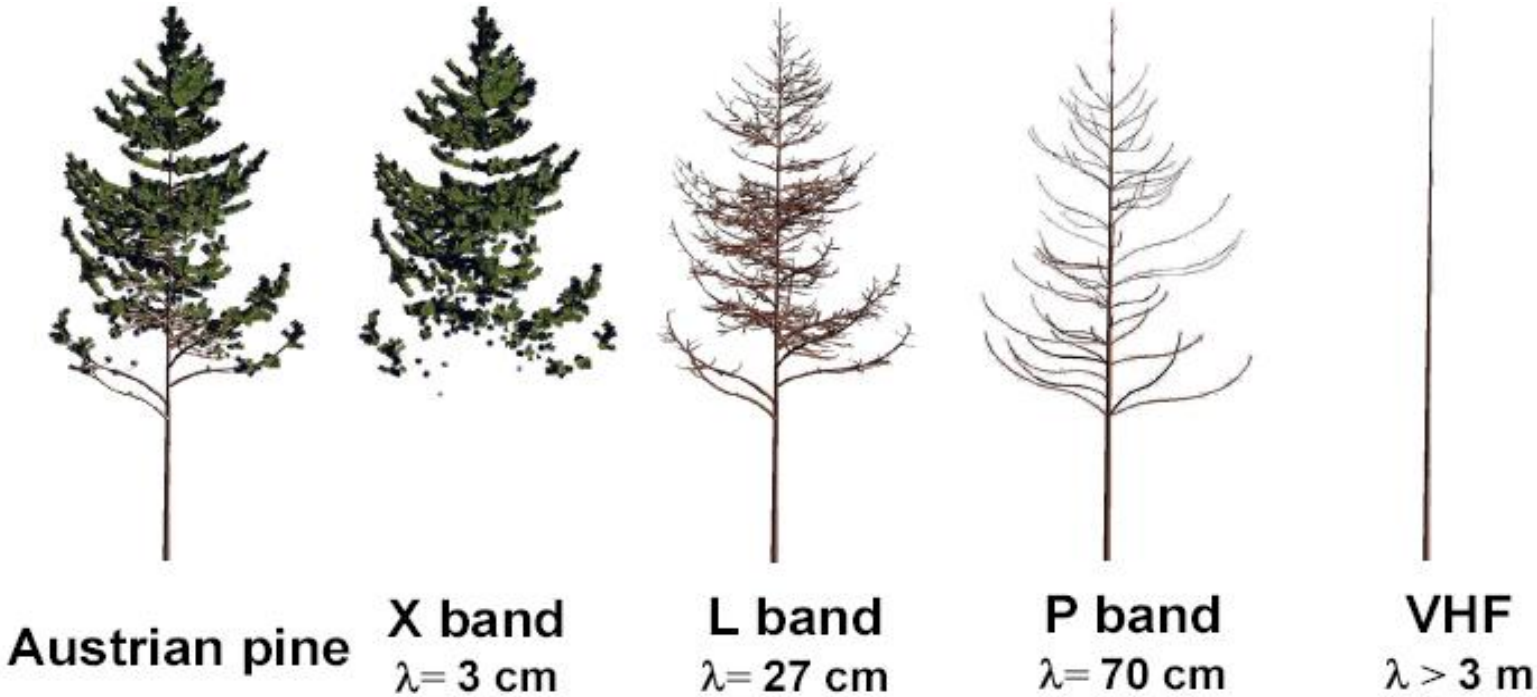


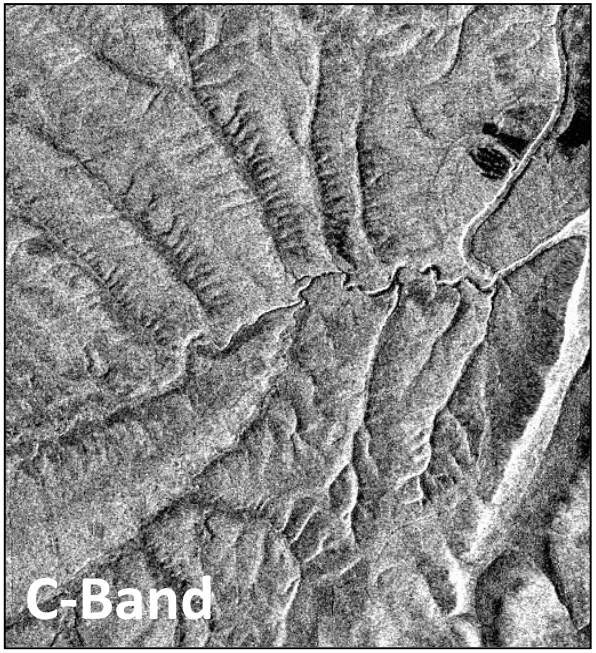
Fig. and Tab.: Main scatterers at different frequencies (Image credentials: THUY LE TOAN, Tab from LE TOAN ET AL., 2001).

Frequency band	X	C	L	P	VHF
Main scatterers	Leaves, Twigs	Leaves Small branches	Branches	Branches & Trunk	Trunk

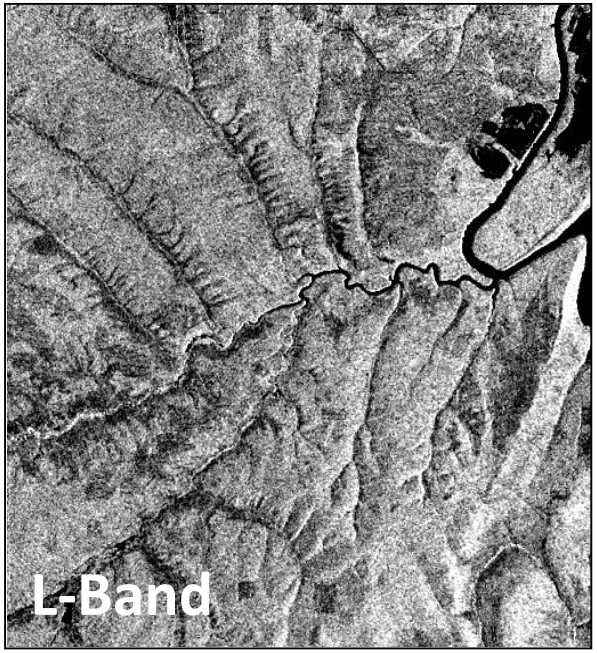
The main scatterers in a canopy are the elements having dimension of the order of the wavelength

Copyright ©

Different wavelengths in biomass estimation



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

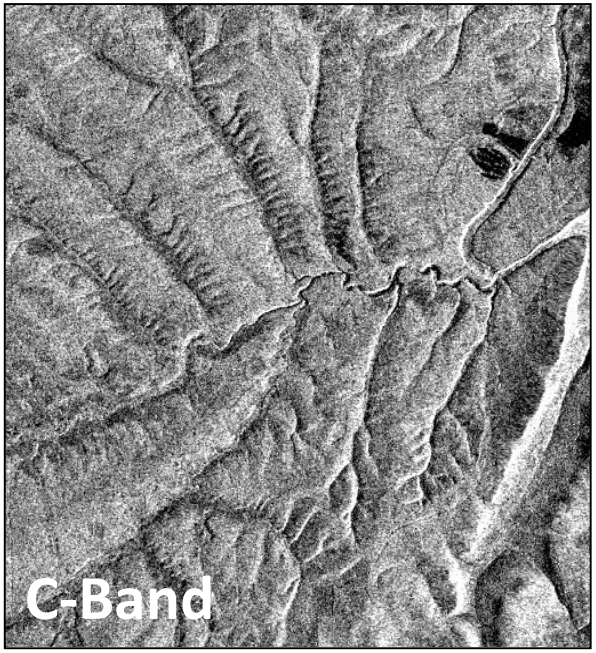


- *Medium dynamic range*
- *Stable response to water*
- *Possible to identify agricultural fields*
- *Higher frame to frame variations*

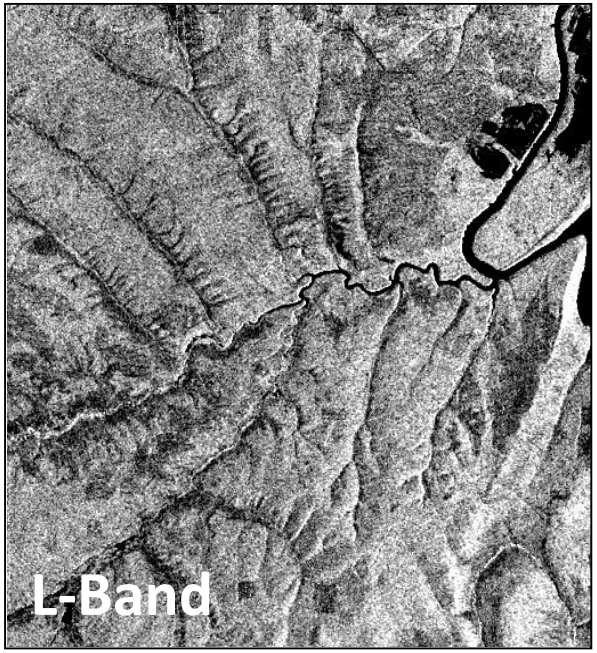
Fig.: Different wavelengths in biomass estimation (Le Toan et al., 2001).

Copyright © DLR

Different wavelengths in biomass estimation



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

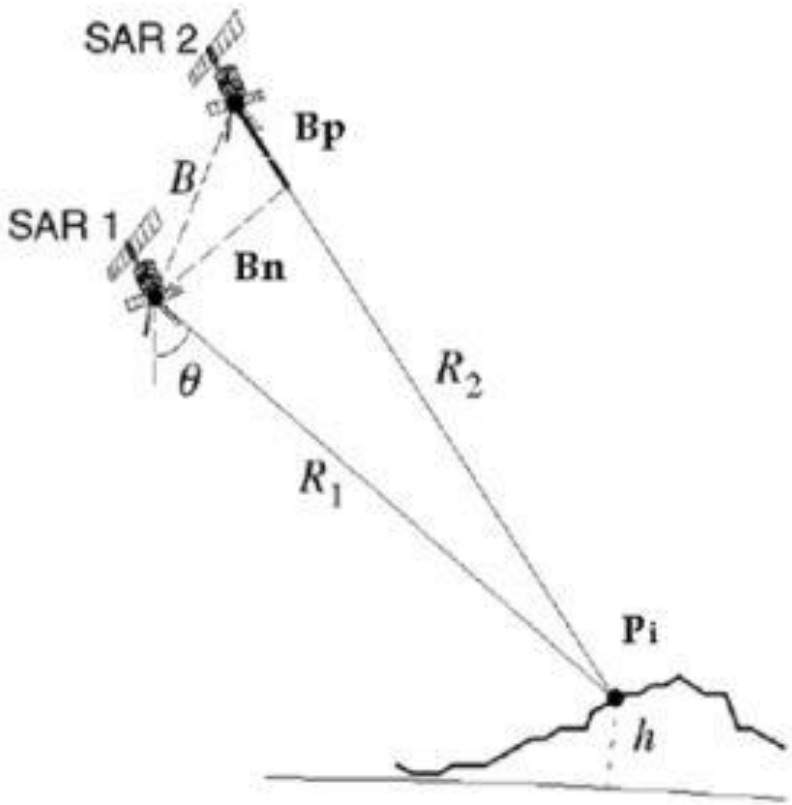


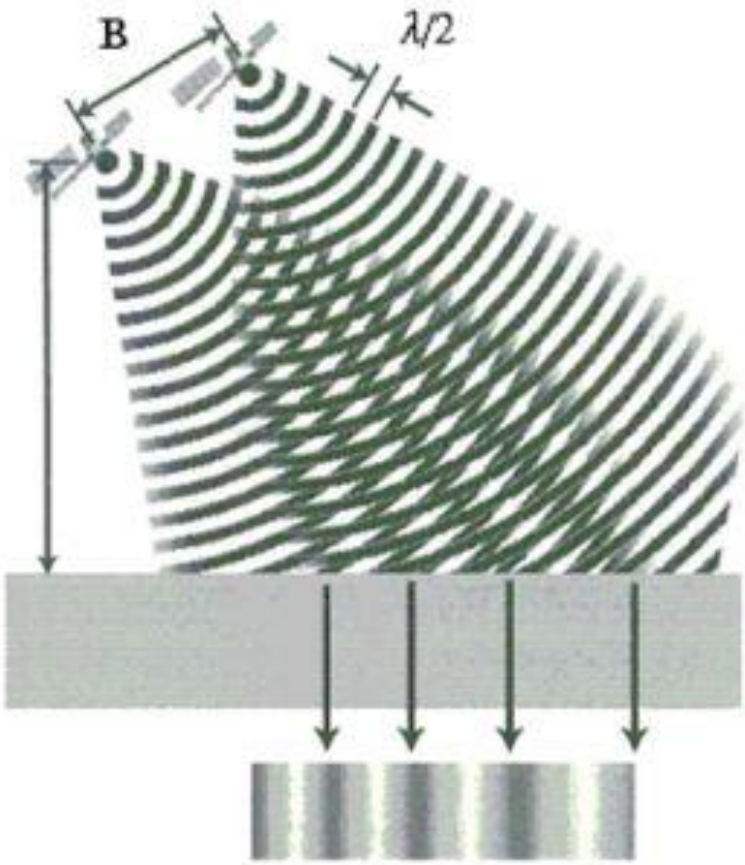
- *Medium dynamic range*
- *Stable response to water*
- *Possible to identify agricultural fields*
- *Higher frame to frame variations*

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

Fig.: Different wavelengths in biomass estimation and coherence (Le Toan et al., 2001).

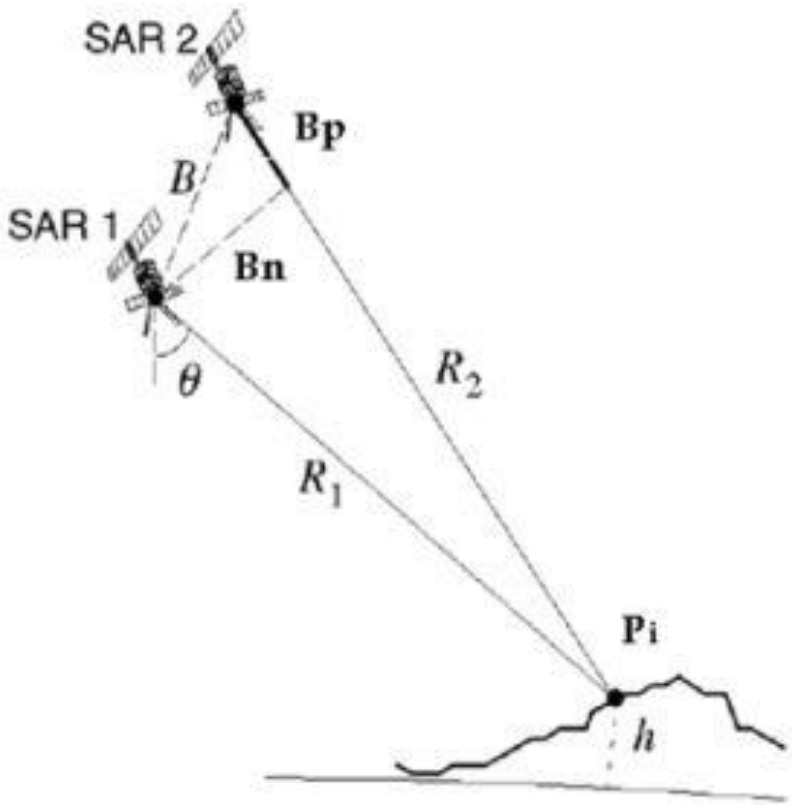
Additional slide

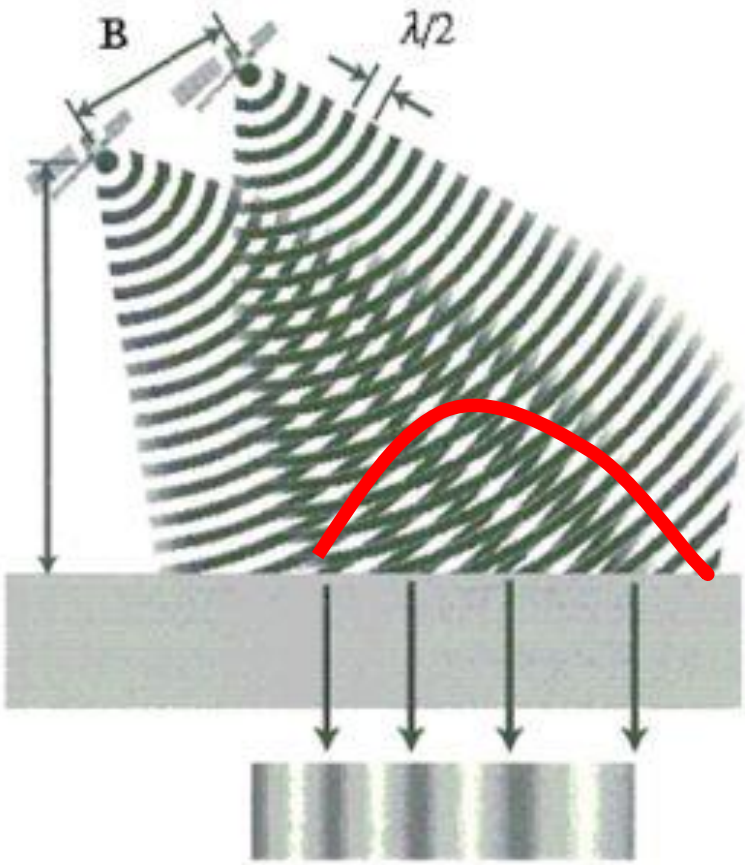




(Left) InSAR geometry. The along the track direction is perpendicular to the graph plane. (Right) the rationale of the fringes formation due to baseline (Modified from Shang-Ho, 2008).
In: Ground Based SAR Interferometry: a Novel Tool for Geoscience. -Guido Luzi DOI: 10.5772/9090

Additional slide

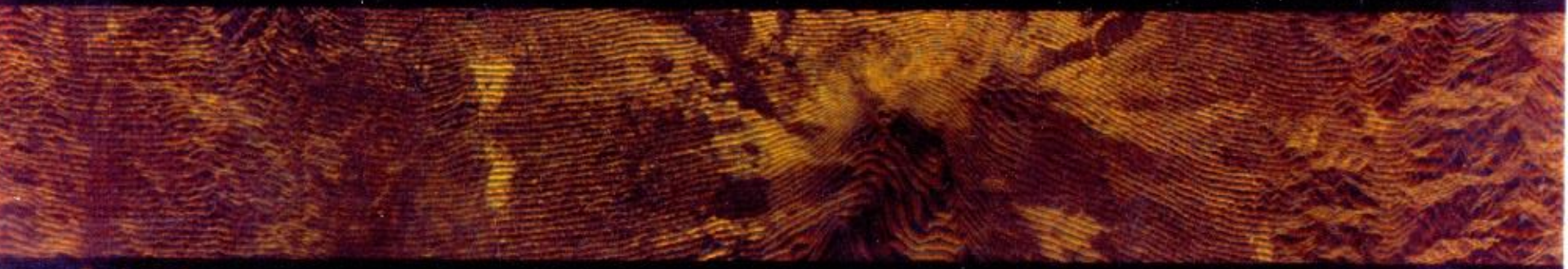




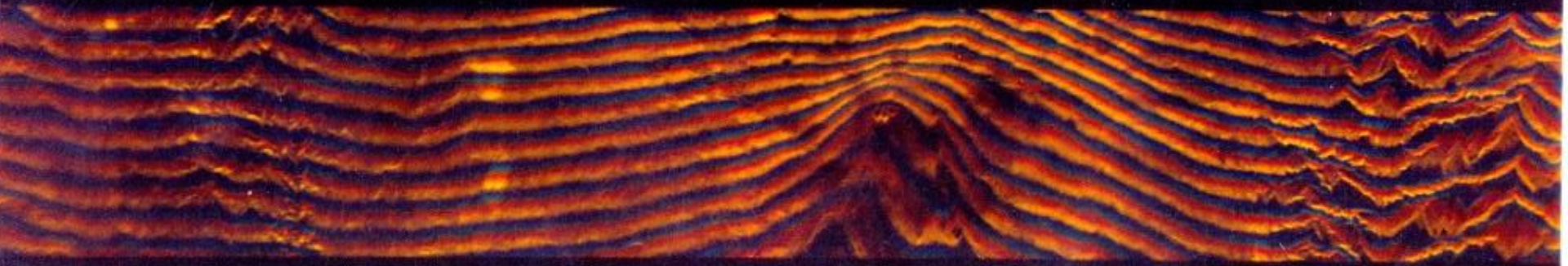
(Left) InSAR geometry. The along the track direction is perpendicular to the graph plane. (Right) the rationale of the fringes formation due to baseline (Modified from Shang-Ho, 2008).
In: Ground Based SAR Interferometry: a Novel Tool for Geoscience. -Guido Luzi DOI: 10.5772/9090

Phase of the Interferogram

X-band



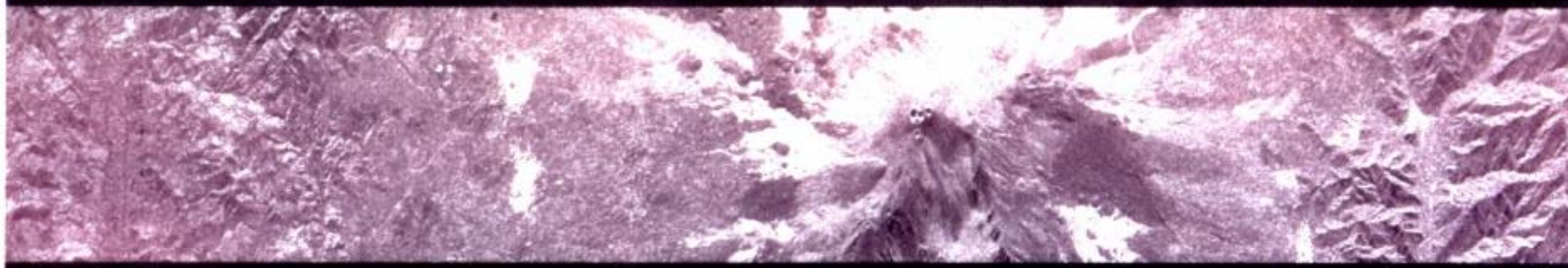
C-band



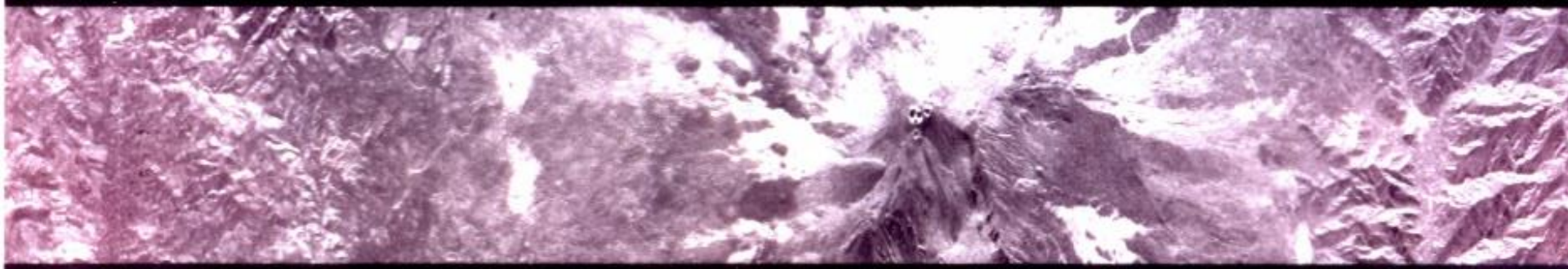
L-band

Test Site: Mt. Etna / Sicily, Italy

Magnitude of the Interferogram



X–band

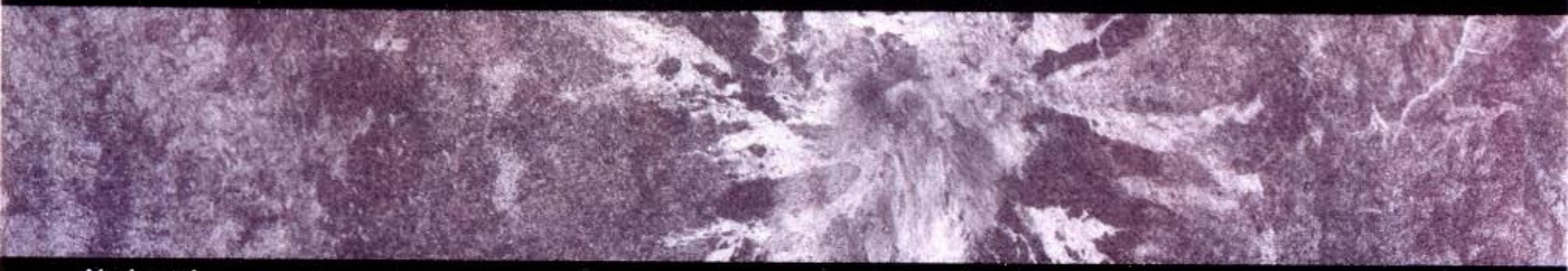


C–band

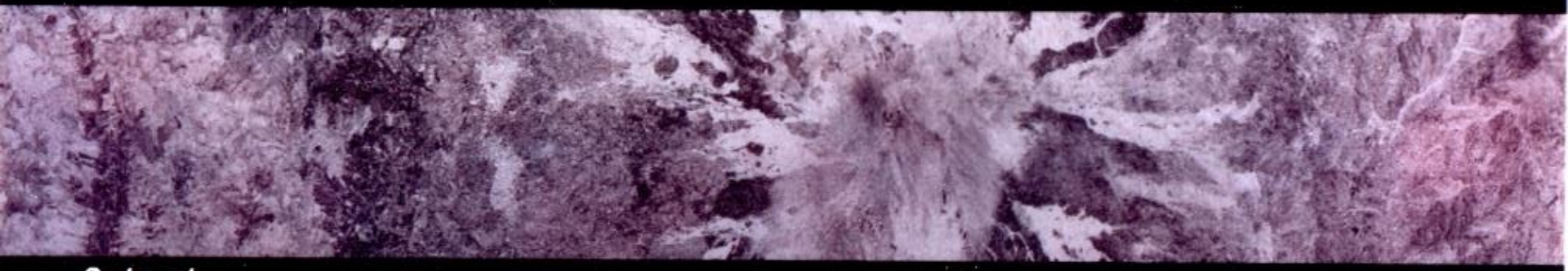
L–band

Test Site: Mt. Etna / Sicily, Italy

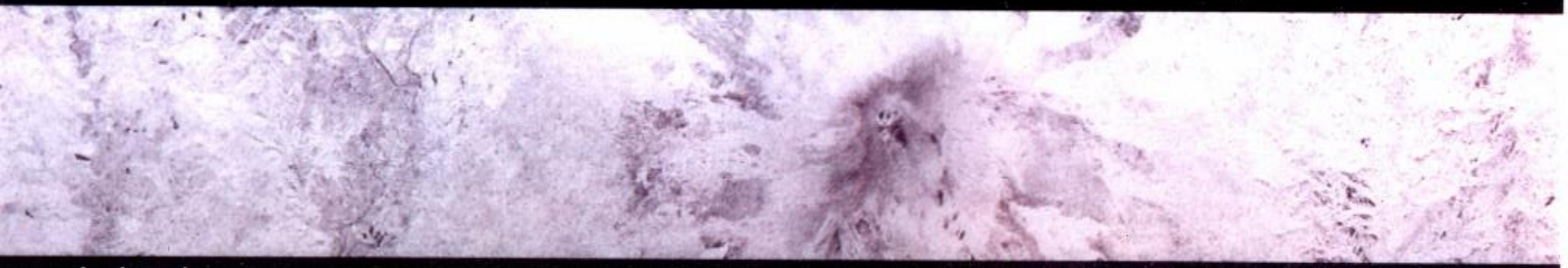
Coherency Maps



X–band



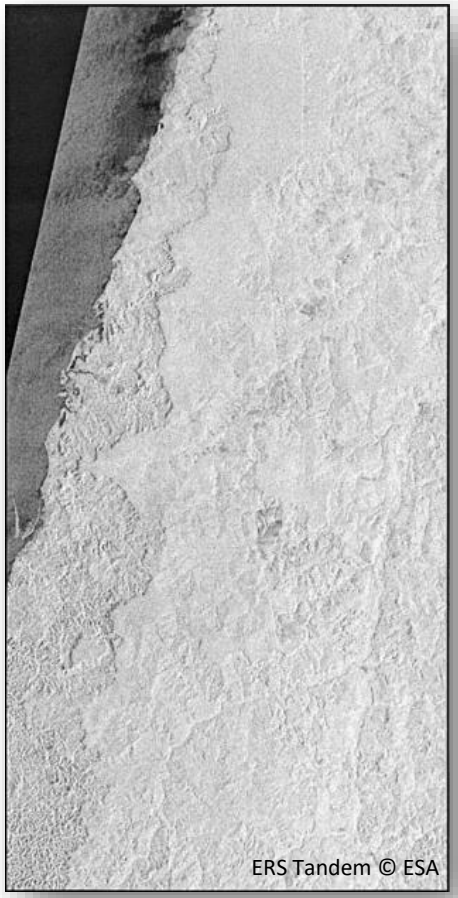
C–band



L–band

Test Site: Mt. Etna / Sicily, Italy

Different wavelengths in biomass estimation



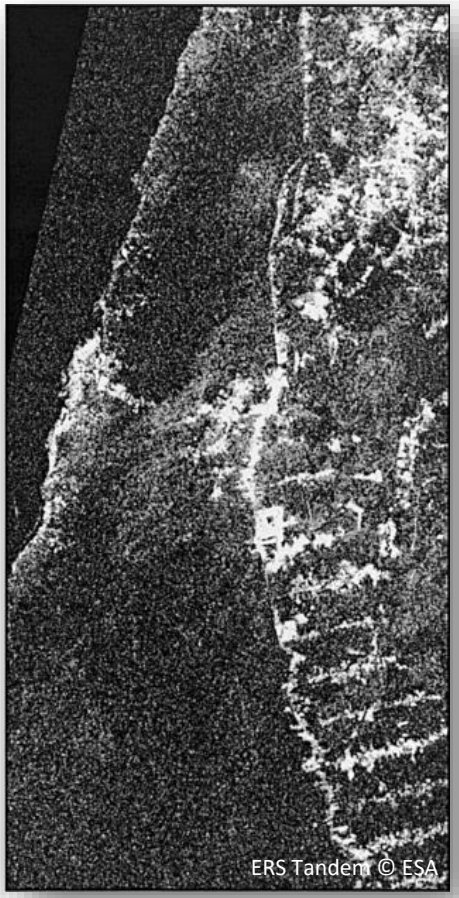


Fig.: ERS-Tandem intensity image and 1-day repeat-pass phase coherence image (size 50 km by 100 km) (LUCKMAN et al., 2000).

Different wavelengths in biomass estimation

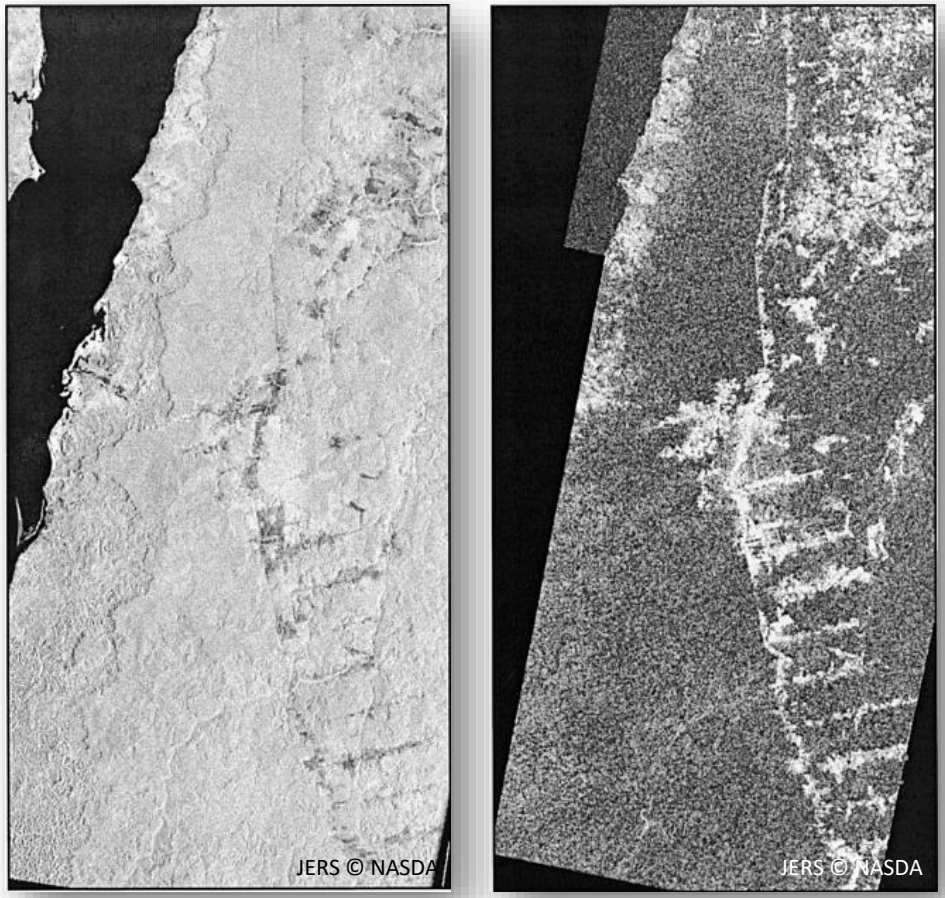


Fig.: JERS intensity image and 44-day repeat-pass phase coherence image (size 50 km by 100 km) (LUCKMAN et al., 2000).

Different wavelengths in biomass estimation

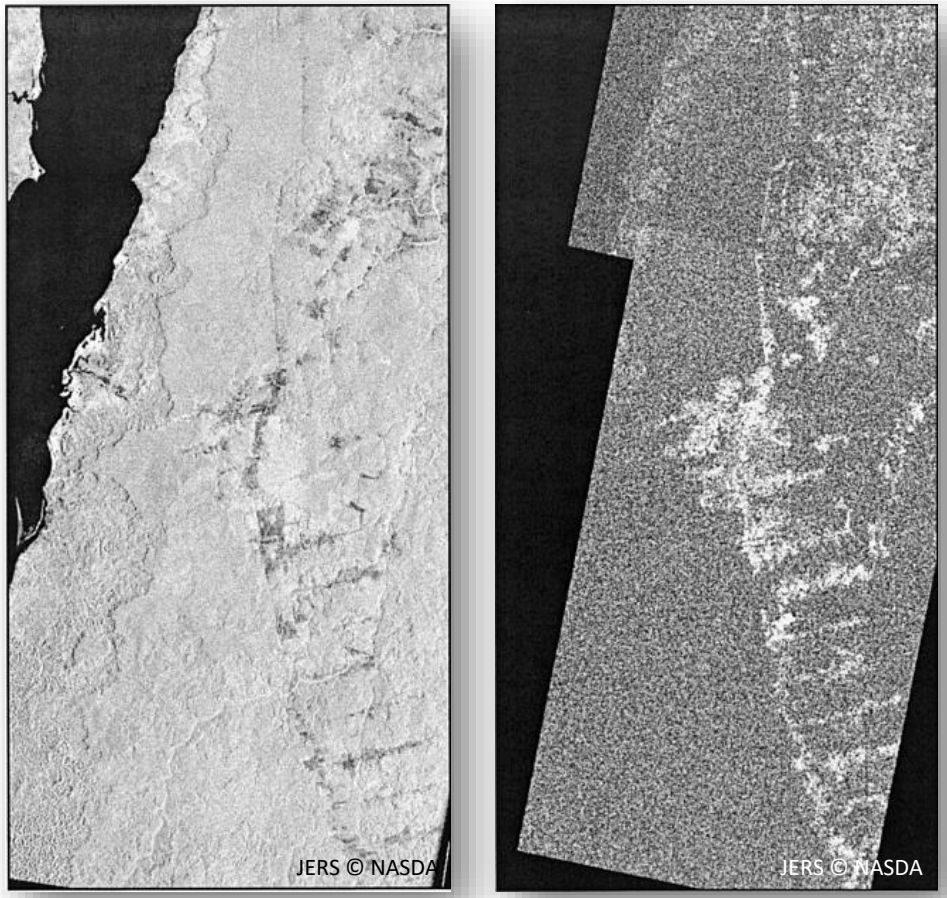
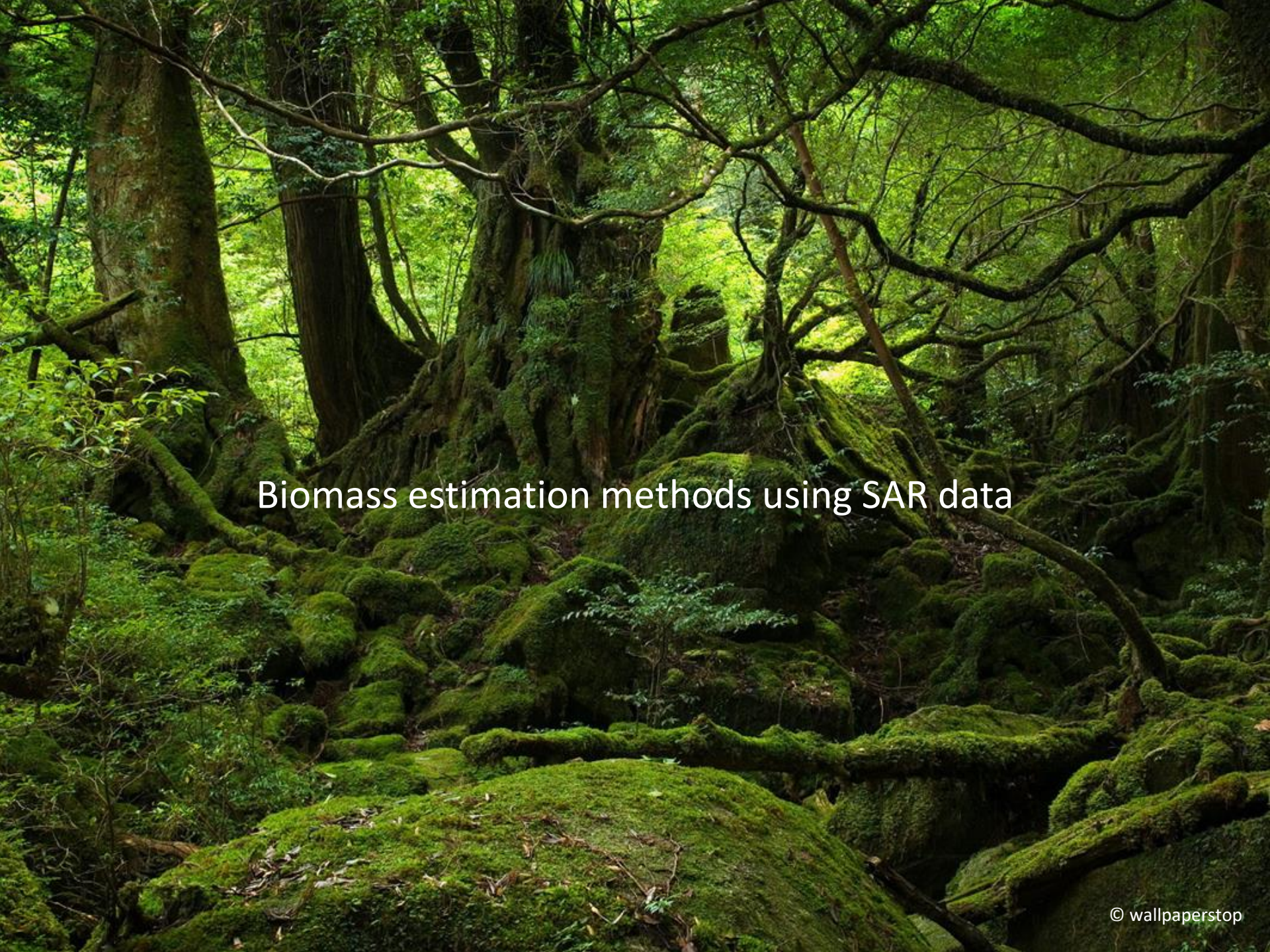


Fig.: JERS intensity image and 132-day repeat-pass phase coherence image (size 50 km by 100 km) (LUCKMAN et al., 2000).


Biomass estimation methods using SAR data
© wallpaperstop

SAR techniques for forest monitoring

- **Backscatter analysis** (wavelength, polarisation, incidence angle, number of images)
- **Interferometry: coherence analysis** (wavelength, polarisation, incidence angle, temporal and spatial baseline, number of images, acquisition conditions)
- **Interferometry: phase analysis** (wavelength, incidence angle, high coherence required, acquisition conditions)
- **Polarimetry** (wavelength, incidence angle, number of images)
- **Polarimetric interferometry** (wavelength, polarisation, incidence angle, temporal and spatial baseline)
- **SAR (polarimetric) tomography** (wavelength, polarisation, incidence angle, spatial baseline, high coherence required, number of images)

Module 2200: SAR interferometry

Module 2200: SAR interferometry

Module 2300: SAR polarimetry

Biomass estimation methods

AGB

Backscatter

Relating the backscatter values to field biomass measurements using regression analysis

regression

InSAR

Examining the coherence of two SAR images collected from similar viewing positions with a short time-lag

Conversion from forest parameter

e.g. forest height estimates from single frequency polarimetric-interferometric SAR data

Conversion through allometric height-biomass relations

indirectly

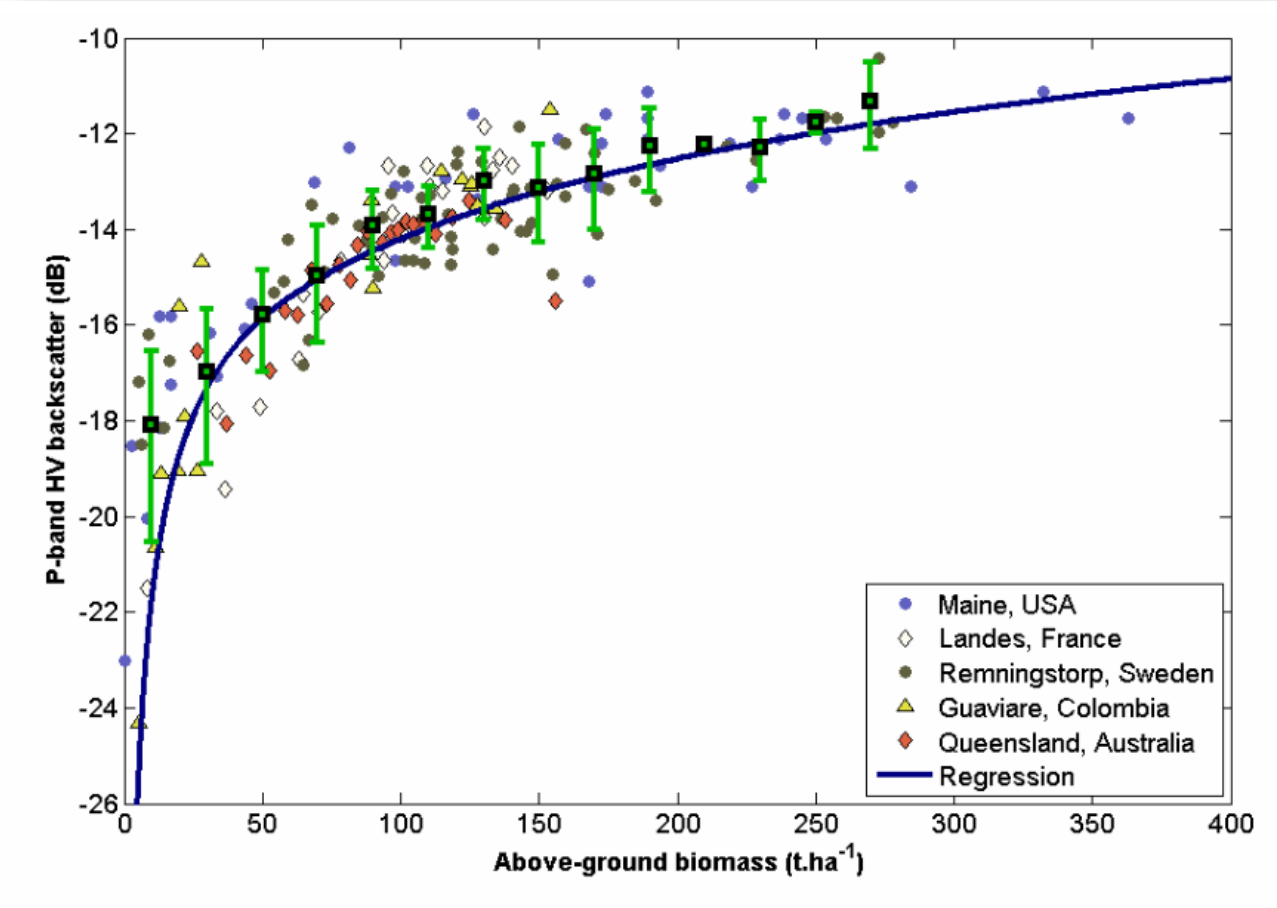
[after GHASEMI, 2011]

Copyright ©

Biomass estimation methods

- Backscatter analysis
- SAR interferometry
- Indirect biomass estimation – biomass from forest height

Backscatter analysis



SATURATION PROBLEM

Fig.: Regression analysis of radar backscatter with forest AGB. P-band HV backscattering coefficient plotted against AGB from experiments conducted at five different forests. The green points with error bars represent the mean value and standard deviation of all points falling within a biomass bin of +/- 10 tons/ha. The line is a regression curve applied to the full dataset. The corresponding RMSE in biomass is 51.6 tons/ha and the coefficient of determination r^2 = 0.67 (Credis: LE TOAN, in ESA, 2008).

Backscatter analysis

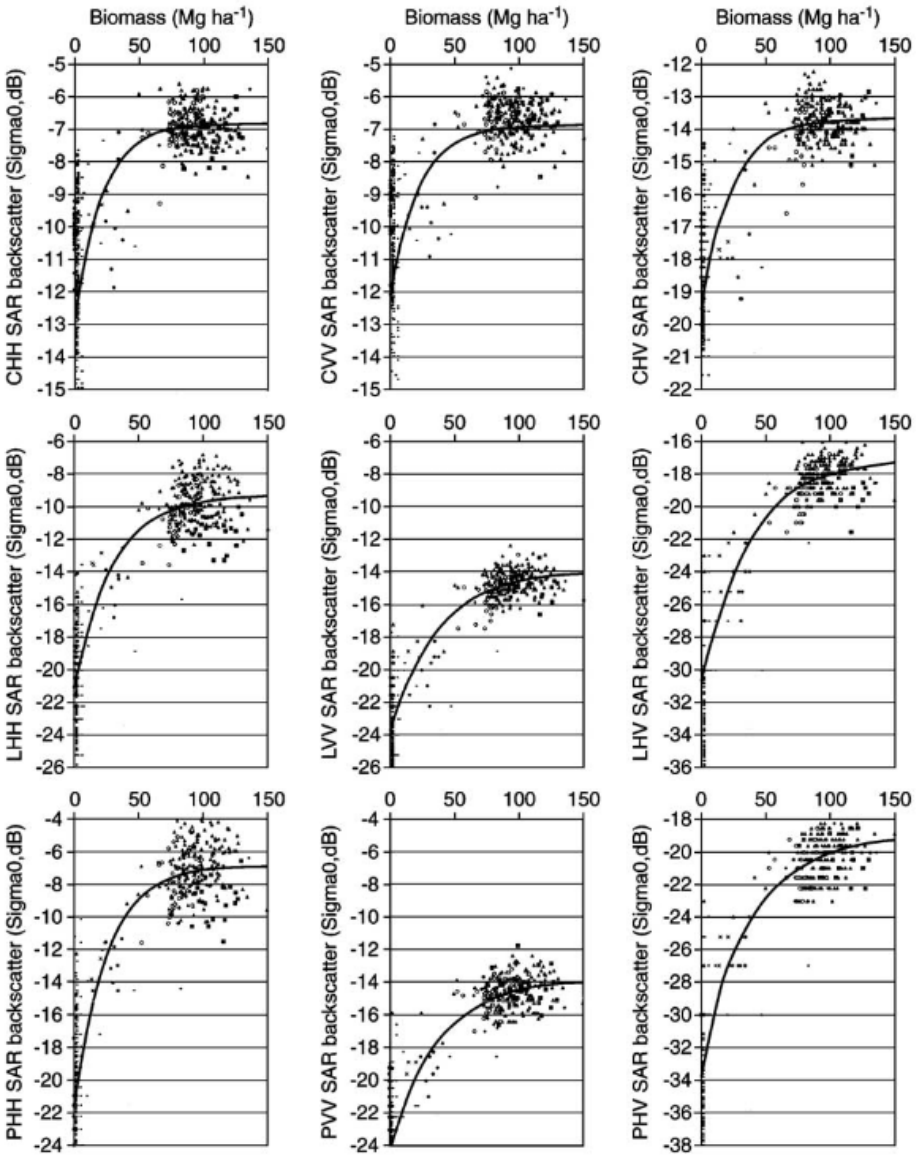


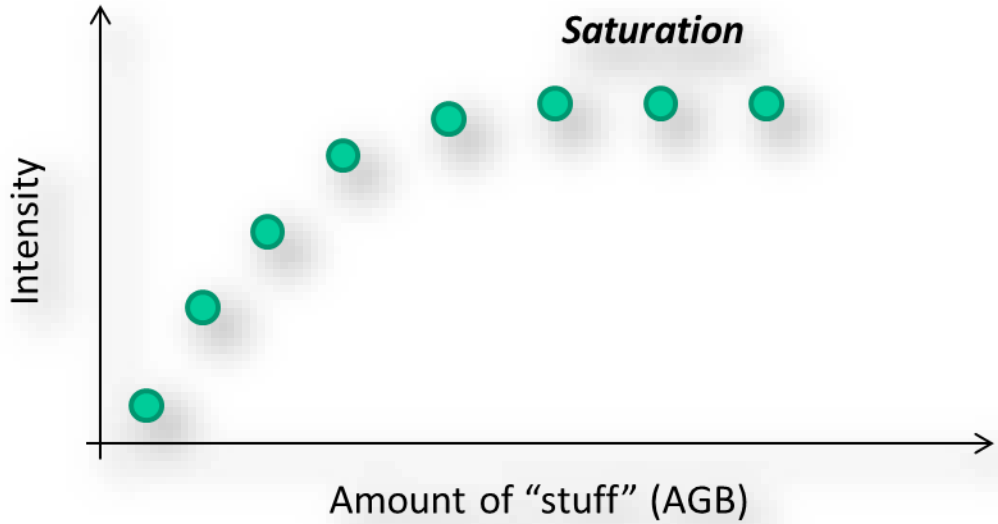
Fig.: Relationship between SAR backscatter (AIRSAR data) and LiDAR derived above ground biomass, Queensland, Australia (LUCAS et al., 2006).

Copyright ©

Backscatter analysis

SATURATION PROBLEM

- Saturation means the ***SAR response levels offs***, i.e. the slope of the regression line approach zero.
- ***Biomass is not longer predictable from the signal***.



[after WOODHOUSE]

Backscatter analysis

SATURATION PROBLEM

The saturation level of different wavelengths and polarizations depends on:

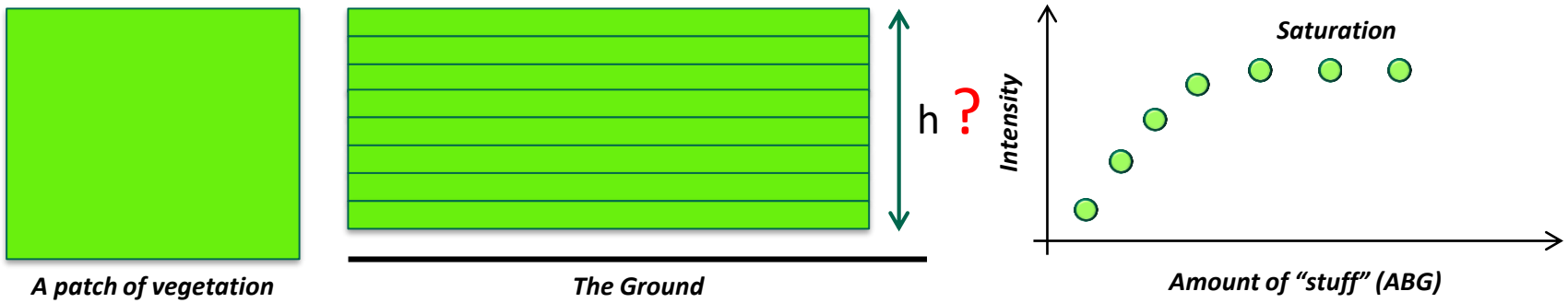
- ***Wavelength*** (i.e. different bands, such as C, L, P)
- ***Polarization*** (HV, HH and VV)
- ***Object characteristics*** (vegetation stand structure and ground conditions)
- ***Available time series***

[Lu, 2006]

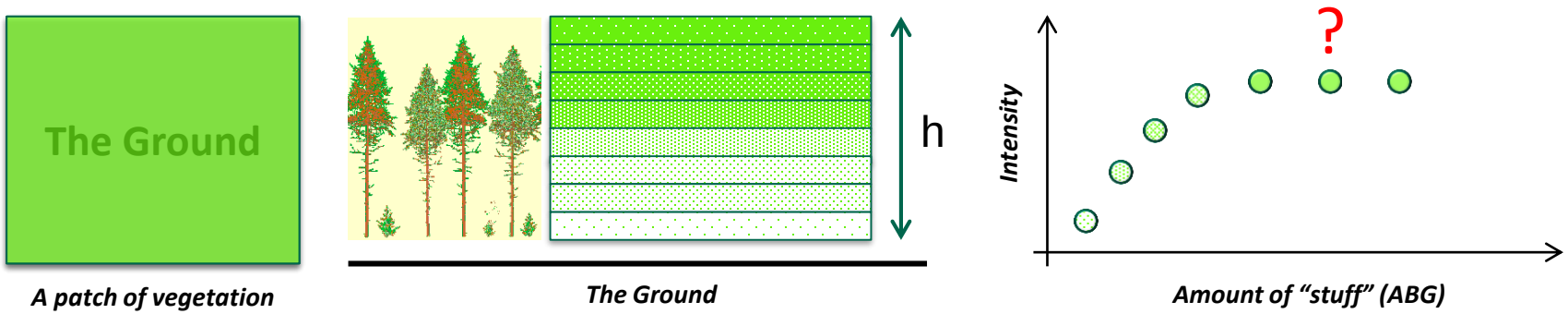
Copyright ©

Backscatter analysis

SATURATION PROBLEM – The Water Cloud Model Explanation



But do trees look like that?



[after WOODHOUSE]

Copyright ©

Backscatter analysis

A Water Cloud-like Model

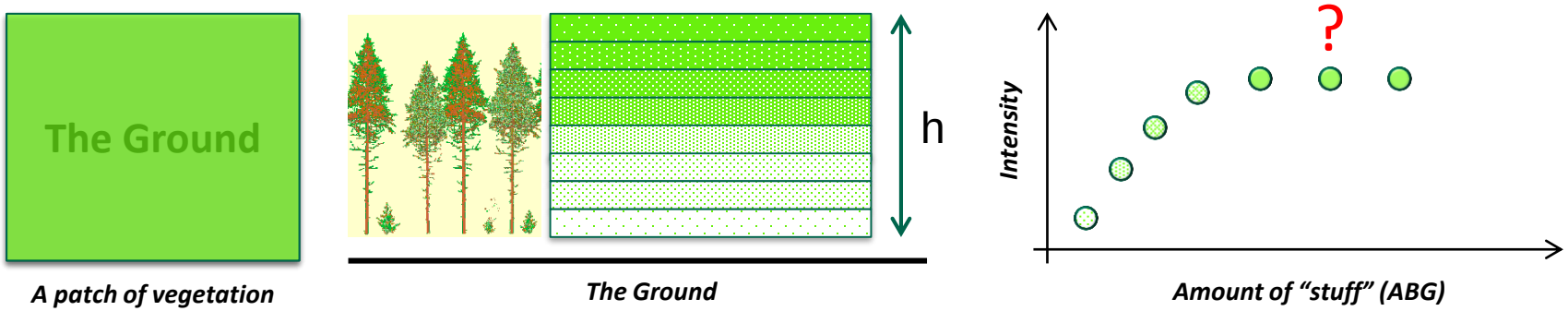


FIG.: WOODHOUSE

A water cloud with gaps is close to reality and easy to handle

$$\sigma^o_{for} = (1-\eta)\sigma^o_{gr} + \eta\sigma^o_{gr}T_{tree} + \eta\sigma^o_{veg}(1-T_{tree})$$

η ↓ canopy cover

T_{tree} ↓ tree transmissivity (depends on tree height and signal attenuation)

The model expresses the forest backscatter as function of the area-fill factor η, i.e. the forest canopy cover

[after WOODHOUSE; THIEL, 2012]

Backscatter analysis

A Water Cloud-like Model

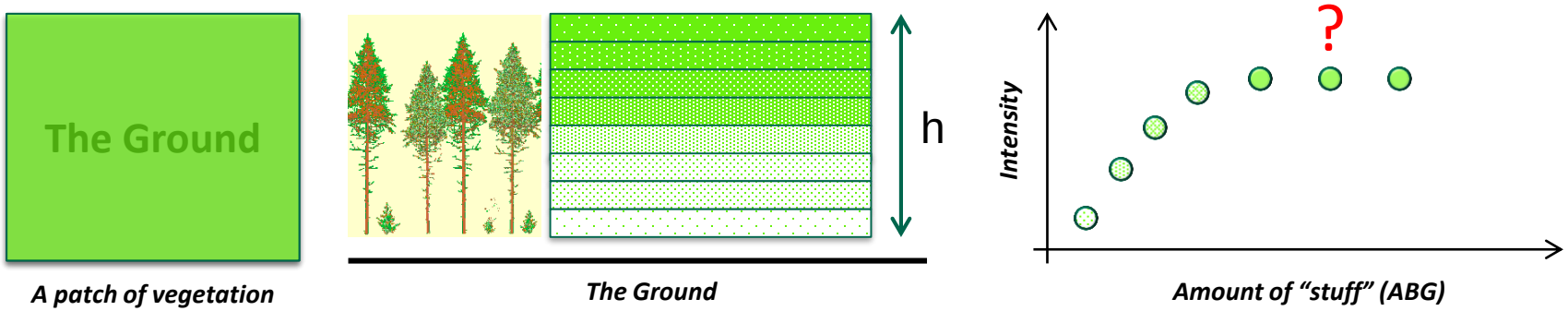


FIG.: WOODHOUSE

For applications it can be written in terms of growing stock volume

$$\sigma^o_{for} = \sigma^o_{veg}\left(1 - e^{-\beta V}\right) + \sigma^o_{gr} e^{-\beta V}$$

Unknown

σ_{gr}	ground backscatter
σ_{veg}	canopy backscatter
β	forest transmissivity coefficient

[after WOODHOUSE; THIEL, 2012]

Copyright © DLR

Backscatter analysis

SATURATION PROBLEM

Imhoff, 1995

Data/Instrument:

- NASA/JPL polarimetric AIRSAR operating at C-, L-, and P-band
- Incidence angle 40°-50°
- Mono-temporal acquisitions!

C-band ≈ 20 tons/ha (2 kg/m²)

L-band ≈ 40 tons/ha (4 kg/m²)

P-band ≈ 100 tons/ha (10 kg/m²)

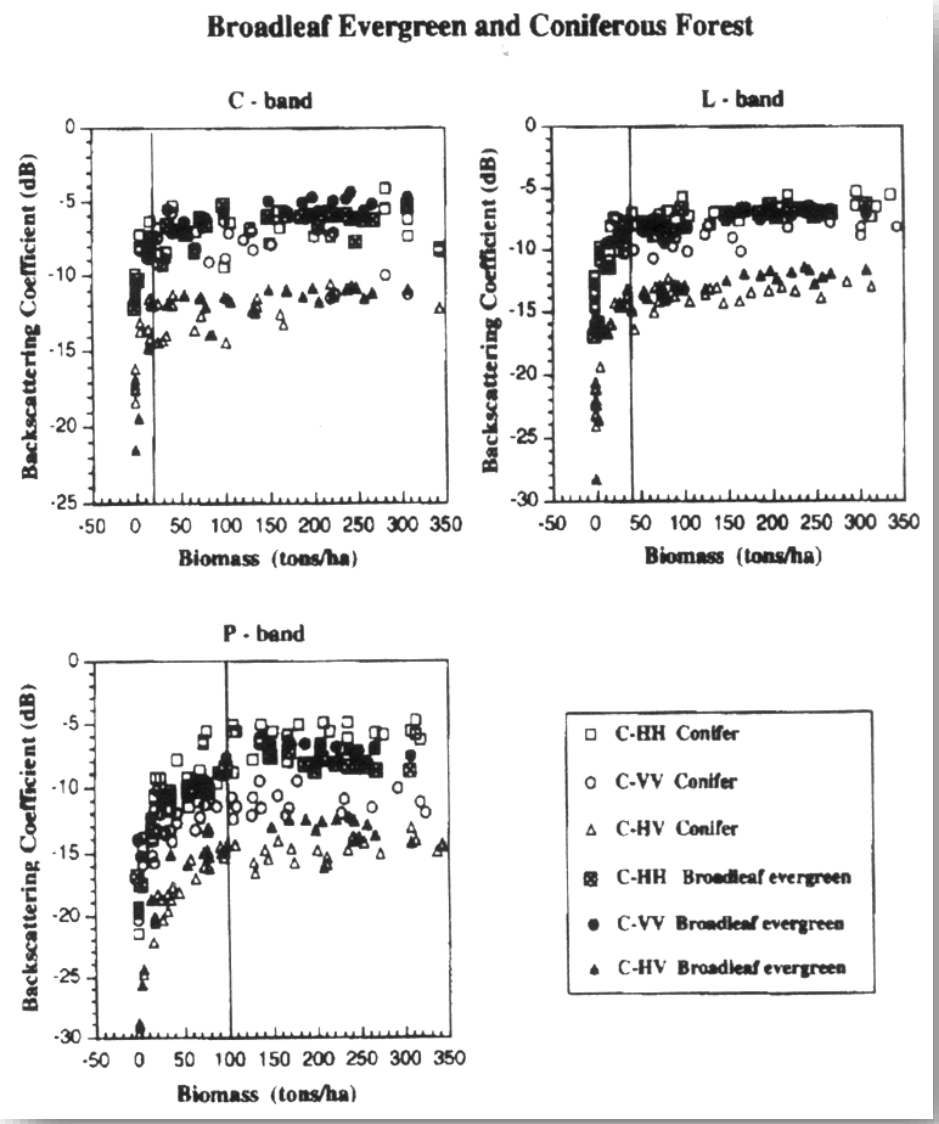


Fig.: Saturation (IMHOFF, 1995:514).

Copyright ©

Backscatter analysis

SATURATION PROBLEM

Imhoff, 1995

Objects of study:

Conifer: *a combined data set of coniferous forest stands from Northern America and Europe*

Broadleaf evergreen: *tropical broadleaf evergreen forests of mixed ages in natural settings located along a moisture gradient on the Island of Hawai'i.*

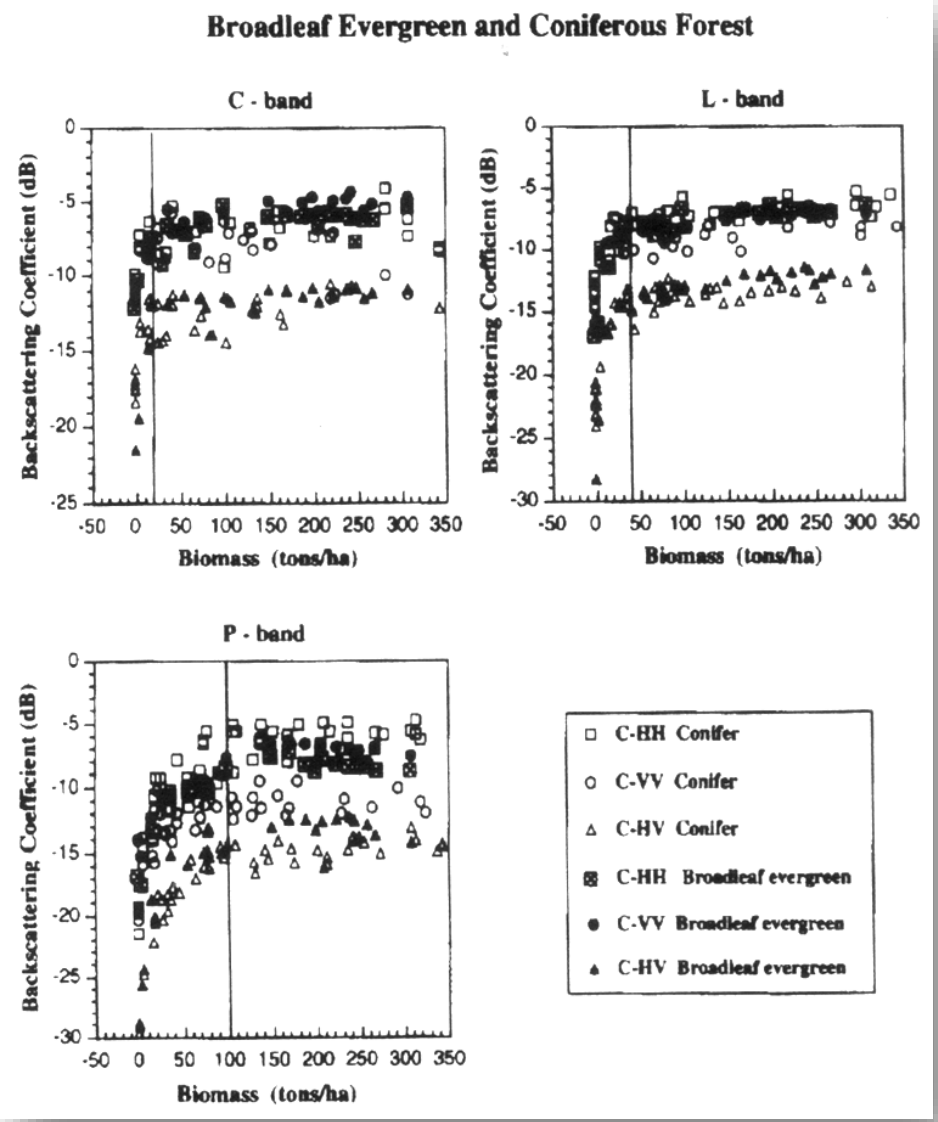


Fig.: Saturation (IMHOFF, 1995:514).

Copyright ©

Backscatter analysis

SATURATION PROBLEM

Dobson, 1992

Data/Instrument:

- NASA/JPL polarimetric AIRSAR operating at C-, L-, and P-band
- Incidence angle 40°-50°
- Mono-temporal acquisitions!

P-band *≈ 100-200 tons/ha*

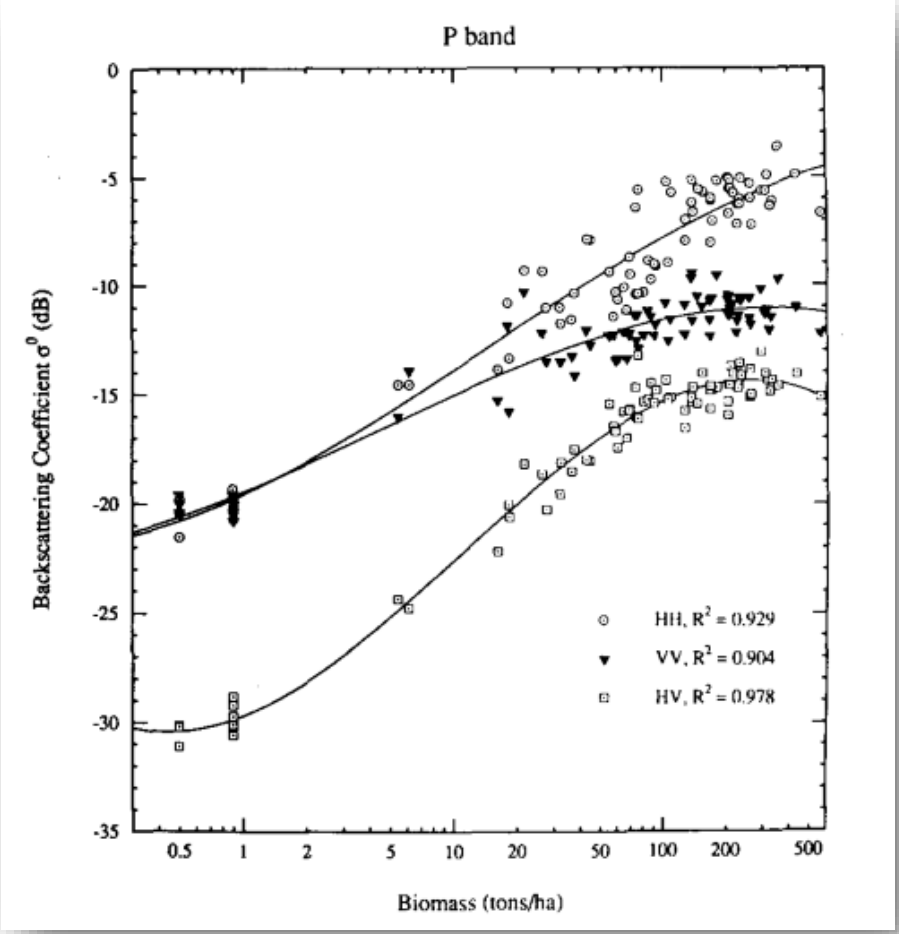


Fig: Calibrated P-band backscatter as a function of the log of total above-ground biomass (tons/ha) of maritime pine and loblolly pine (DOBSON, 1992:413f).

Backscatter analysis

SATURATION PROBLEM

Dobson, 1992

Data/Instrument:

- NASA/JPL polarimetric AIRSAR operating at C-, L-, and P-band
- Incidence angle 40°-50°
- Mono-temporal acquisitions!

L-band *≈ 60-100 tons/ha*

(Luckman et al. 1998, also found that L-band in tropical forests saturates at 60 tons/ha)

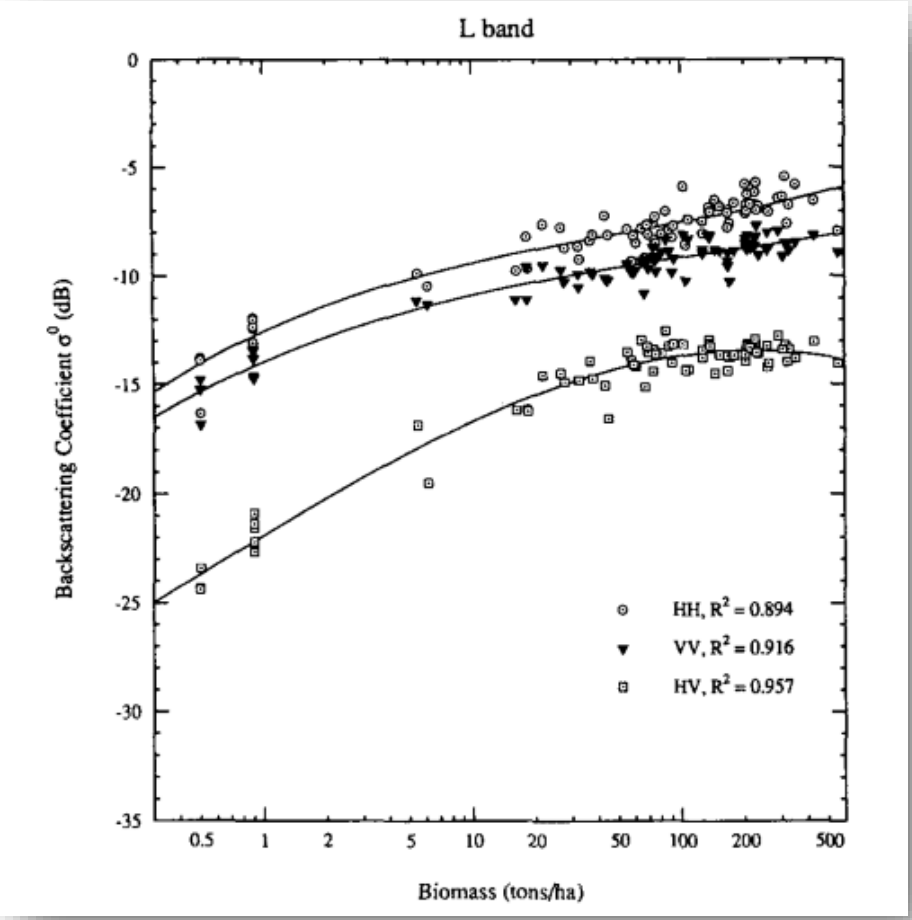
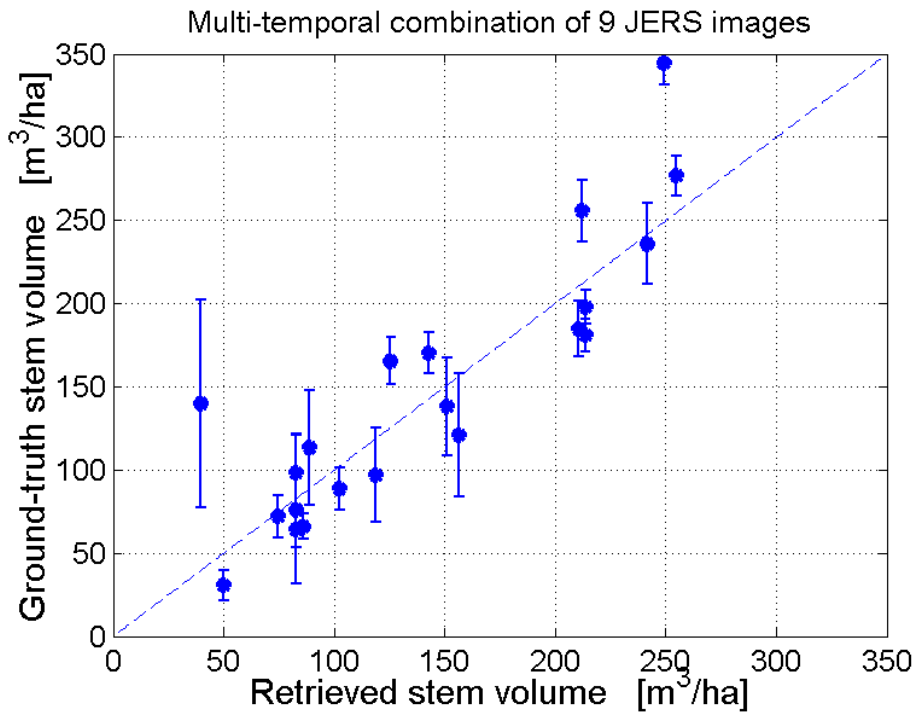


Fig: Calibrated L-band backscatter as a function of the log of total above-ground biomass (tons/ha) of maritime pine and loblolly pine (DOBSON, 1992:413f).

Copyright ©

Backscatter analysis

STRENGTH OF MULTITEMPORAL DATA



JERS Backscatter

RMSE: 33 m^3/ha

Relative RMSE: 22 %

Fig.: Multitemporal data (SANTORO et al., 2006).

Backscatter analysis

SUMMARY

- At ***C-Band*** backscatter ***saturation occurs at relatively low values of biomass density*** and only under certain conditions, such as dry soil, it is possible to differentiate between forests and other types of vegetation (LUCKMAN et al., 2000; GHASEMI, 2011:776).
- At ***L-Band backscatter saturation*** seems to ***depend on forest type*** (IMHOFF, 1995).
- In critical ***tropical forest*** areas where aboveground biomass density ***can reach values of 600 tons/ha***, space-borne ***L-Band SAR sensitivity to biomass is found only up to 50 tons/ha*** (LUCKMAN et al., 1998).
- Using a ***combination of C and L band*** has shown ***better results*** than using one of the bands solely (HOEKMAN & QUIÑONES, 1997).

Backscatter analysis

SUMMARY

- ***Correlation*** between AGB and backscatter is ***best for longer wavelengths (L and P band) and cross-polarized*** measurements (WOODHOUSE, 2006:143, GHASEMI, 2011:776).
- ***Co-polarized*** data (HH and VV) at the ***longer wavelengths***, especially P band, is ***sensitive to changing surface conditions*** (GHASEMI, 2011:776, BALZTER, 2001:169).
- ***Cross-polarized*** (HV and VH) backscattering ***mainly originates from*** multiple scattering within the ***tree canopy*** and ***is less influenced by the surface condition*** (GHASEMI, 2011:776).

Copyright ©

Biomass estimation methods

- Backscatter analysis
- SAR interferometry
- Indirect biomass estimation – biomass from forest height

See also module 2200: SAR interferometry

SAR interferometry

Coherence and INSAR phase contain information on forest

Interferometric Coherence – correlation of two complex SAR images

Complex interferogram:

$$\gamma = \frac{\langle s_2 s_1 * \rangle}{\sqrt{\langle s_1 s_1 * \rangle \langle s_2 s_2 * \rangle}} \qquad \gamma = |\gamma| e^{-i\phi}$$

$|\gamma| =$ degree of coherence

$\phi =$ interferometric phase

$\langle \ \rangle =$ ensemble average

$s_2, s_1 =$ co-registered complex image values

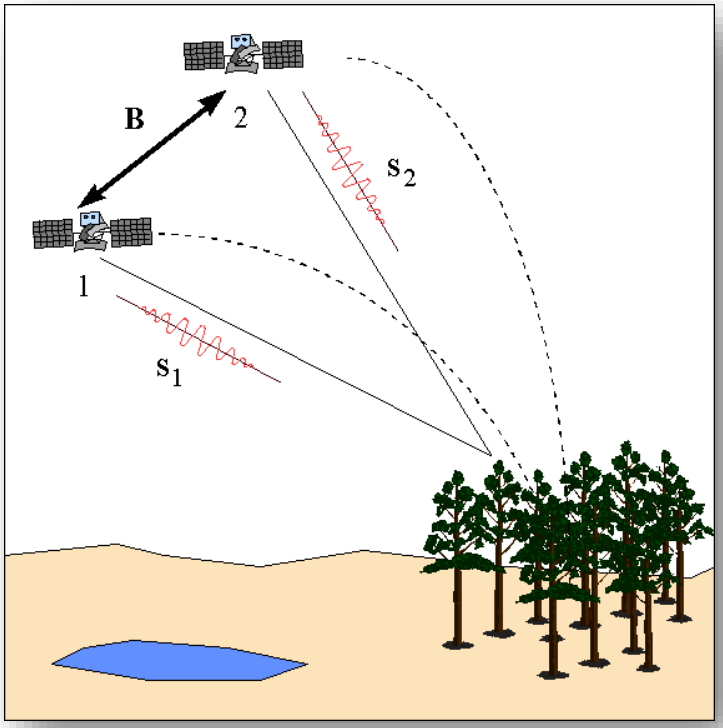


Fig.: Concept InSAR (Ribbes et al., 1997).

Copyright ©

SAR interferometry

Coherence and INSAR phase contain information on forest

Interferometric Coherence – correlation of two complex SAR images

Interferometric coherence is reduced by:

- Temporal decorrelation
- Geometric decorrelation
- Atmosphere
- Noise

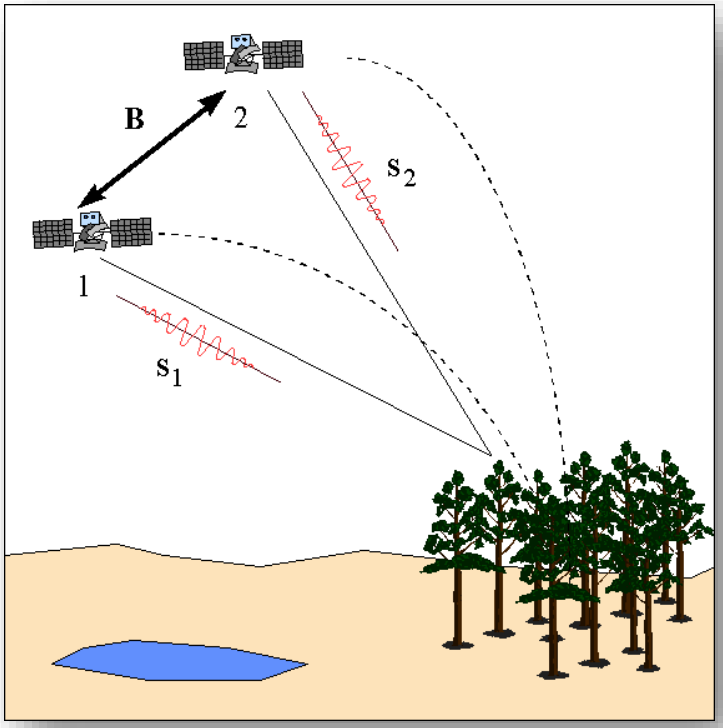


Fig.: Concept InSAR (RIBBES et al., 1997).

[STROZZI, InSAR Sommerschule 2002]

SAR interferometry

Coherence and INSAR phase contain information on forest

Interferometric Coherence – correlation of two complex SAR images

Spatial decorrelation

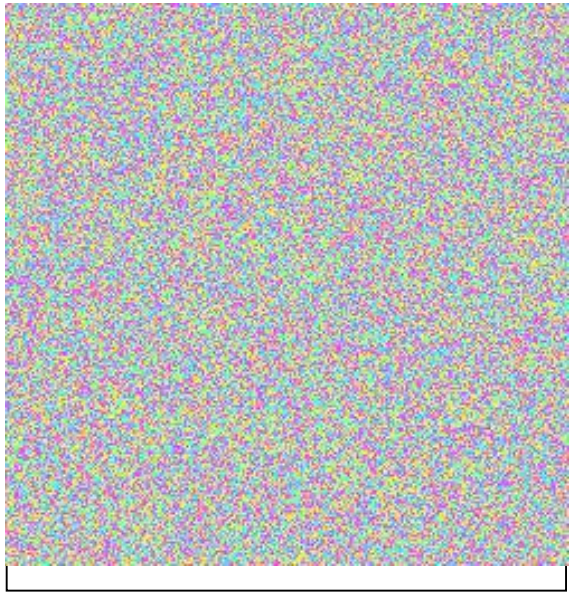


Fig.: Simplified concept of the critical baseline (RELLICH, 2006, edited).

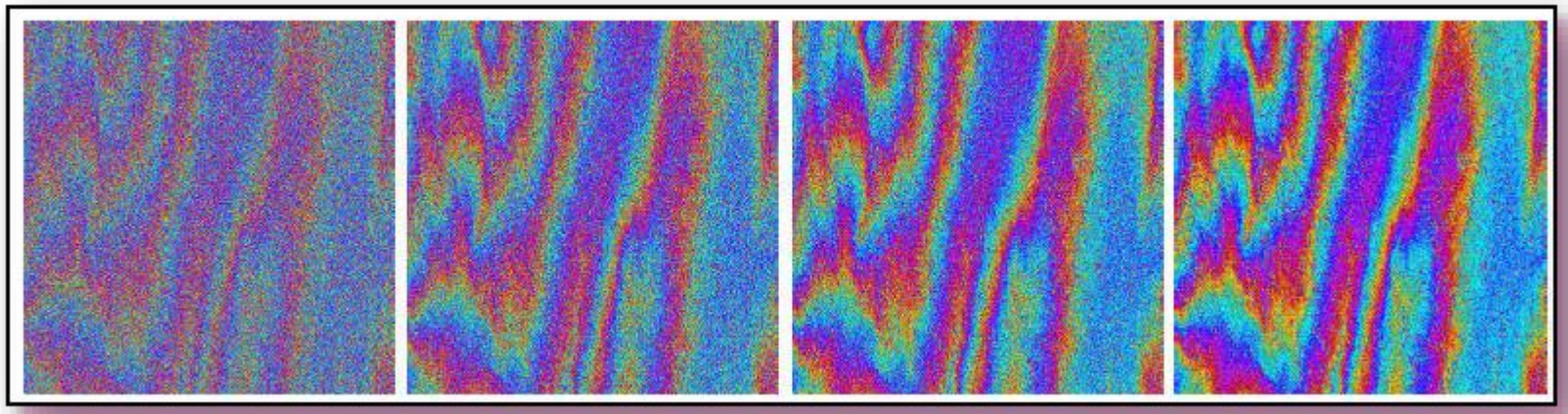
Temporal decorrelation

Fig.: Temporal change of the surface (PALLAN, w.y.,w.p.).

SAR interferometry

Coherence and INSAR phase contain information on forest

Interferometric Coherence – correlation of two complex SAR images



$|\gamma| = 0{,}28$ $|\gamma| = 0{,}5$ $|\gamma| = 0{,}65$ $|\gamma| = 0{,}82$

$|\gamma| =$ *degree of coherence*

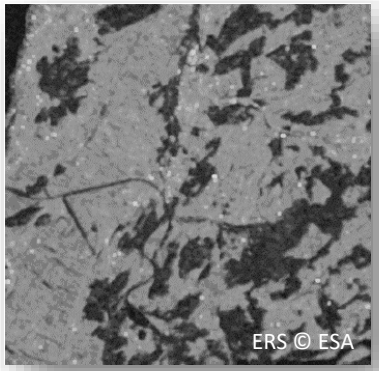
[MFFU Sommerschule, 2000]

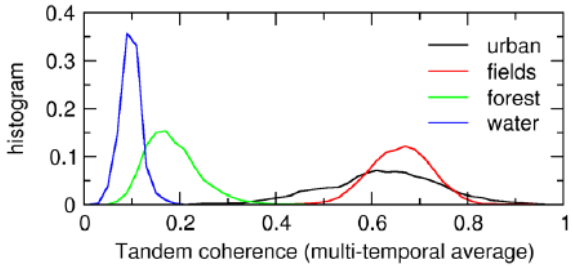
SAR interferometry

Coherence and INSAR phase contain information on forest

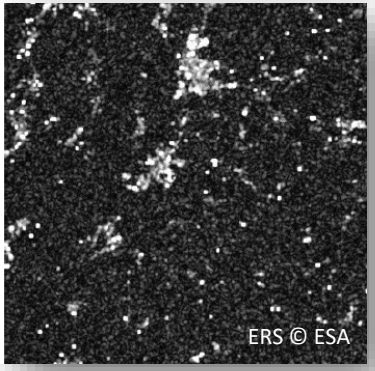
Histogram of averaged coherence of main classes:

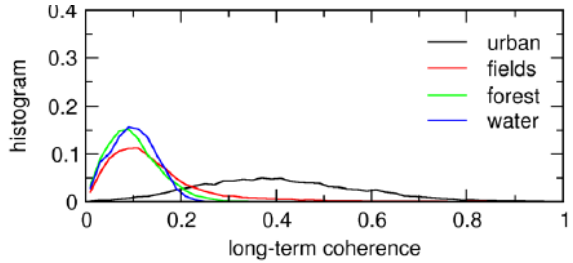
ERS tandem (1 day)





ERS long-term (35 days)





[STROZZI, InSAR Sommerschule 2002]

Copyright © DLR

SAR interferometry

Coherence and INSAR phase contain information on forest

Interferometric Coherence – correlation of two complex SAR images

Coherence vs. Biomass (C-band)

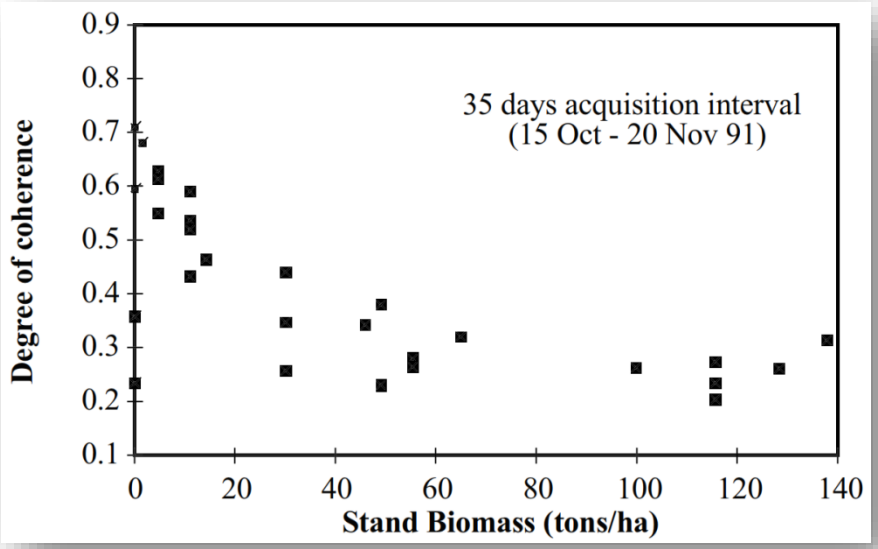


Fig.: Variation of the coherence vs. stand biomass (Ribbes et al. 1997).

Coherence vs. Stem volume (L-band)

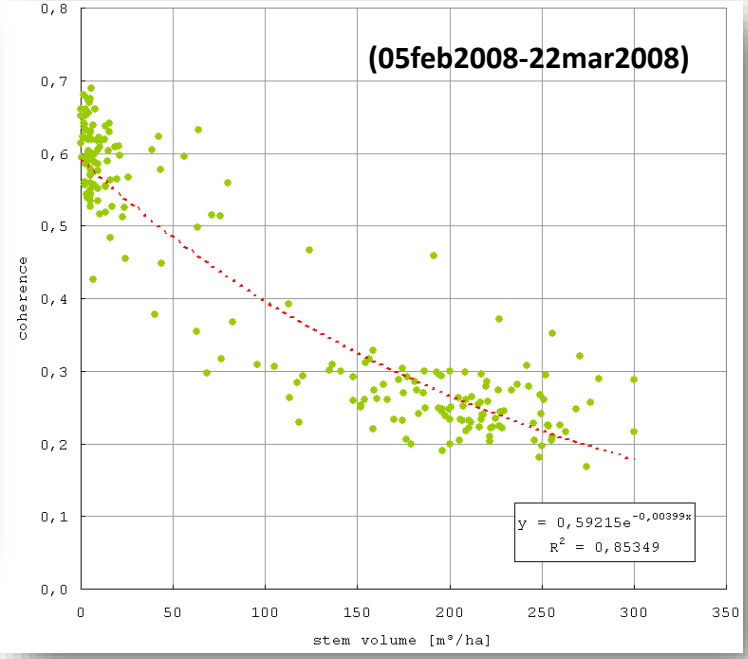
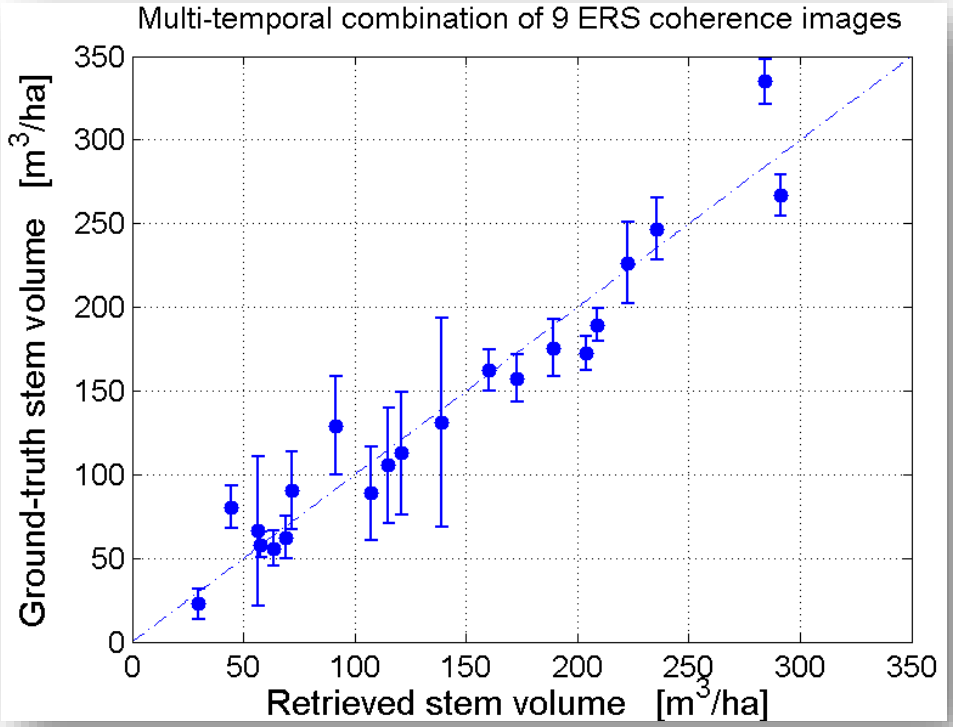


Fig.: Variation of the coherence vs. stem volume (Thiel, unpublished).

SAR interferometry

STRENGTH OF MULTITEMPORAL DATA



ERS Tandem Coherence

RMSE: 10 m^3/ha

Relative RMSE: 7 %

Fig.: Multitemporal data (SANTORO et al., 2002).

Copyright ©

Biomass estimation methods

- Backscatter analysis
- SAR interferometry
- Indirect biomass estimation – biomass from forest height

Copyright © DLR

Biomass from forest height

- Indirect forest biomass estimates through a forest parameter, that can be extracted more accurately than biomass
- Forest height is closely related to forest biomass
- Indirect biomass estimation :

1 - FOREST HEIGHT
↓
2 - CONVERSION
↓
3 - FOREST BIOMASS

- **BUT**: The total error includes both, the error in the height extraction and in the height-biomass conversion!

Biomass from forest height

1 - FOREST HEIGHT
↓
2 - CONVERSION
↓
3 - FOREST BIOMASS

Forest height estimates using remote sensing methods:

1. Directly from ***LIDAR*** data

2. From single frequency, fully ***polarimetric-interferometric SAR data (PolInSAR)*** through model-based inversion (e.g. METTE et al. 2002, METTE et al. 2004)

3. Stereoscopic aerial photography

Copyright ©

Biomass from forest height

1 - FOREST HEIGHT
↓
2 - CONVERSION
↓
3 - FOREST BIOMASS

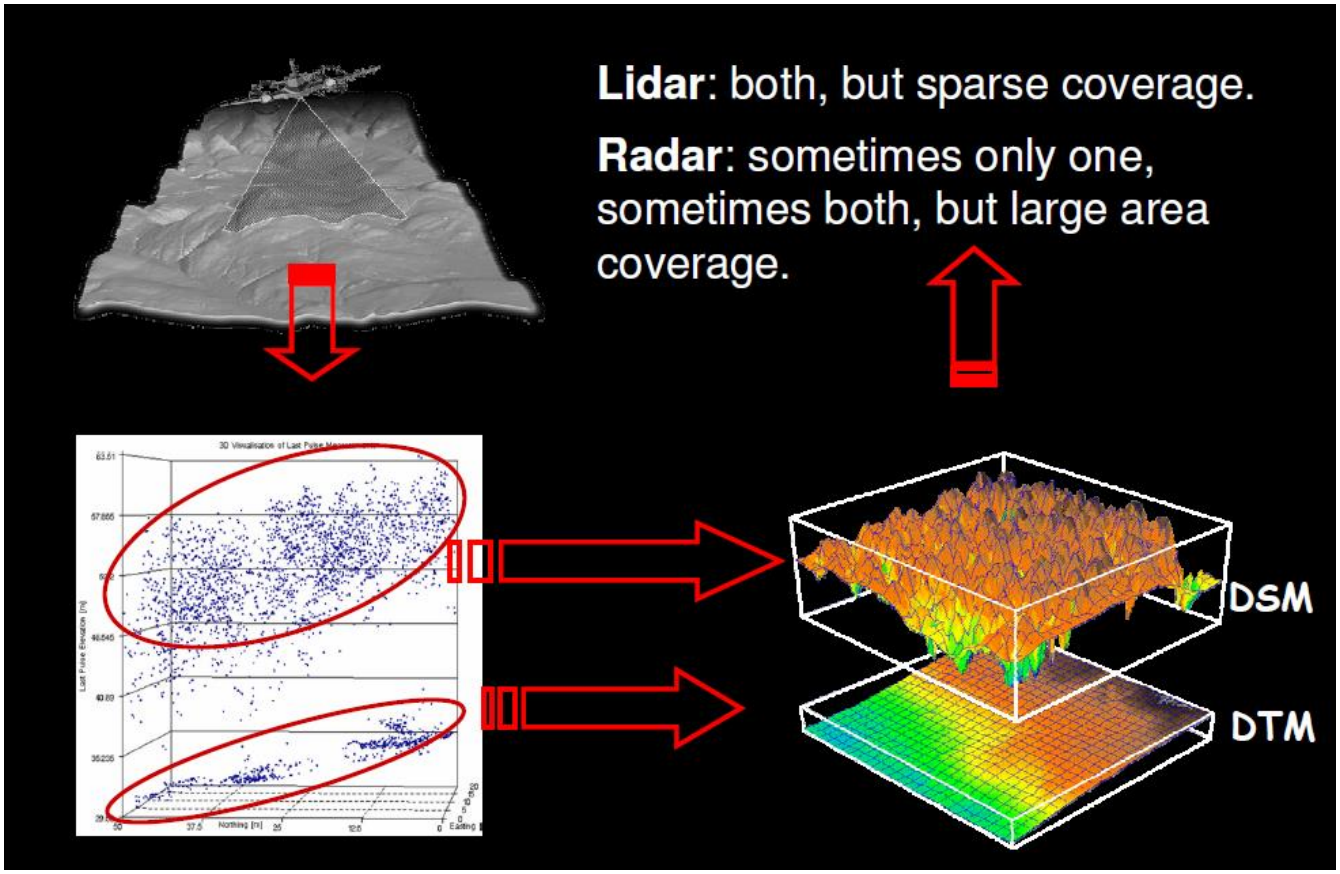


Fig.: WOODHOUSE.

Copyright ©

Biomass from forest height

1 - Forest Height
↓
2 - Conversion
↓
3 - Forest Biomass

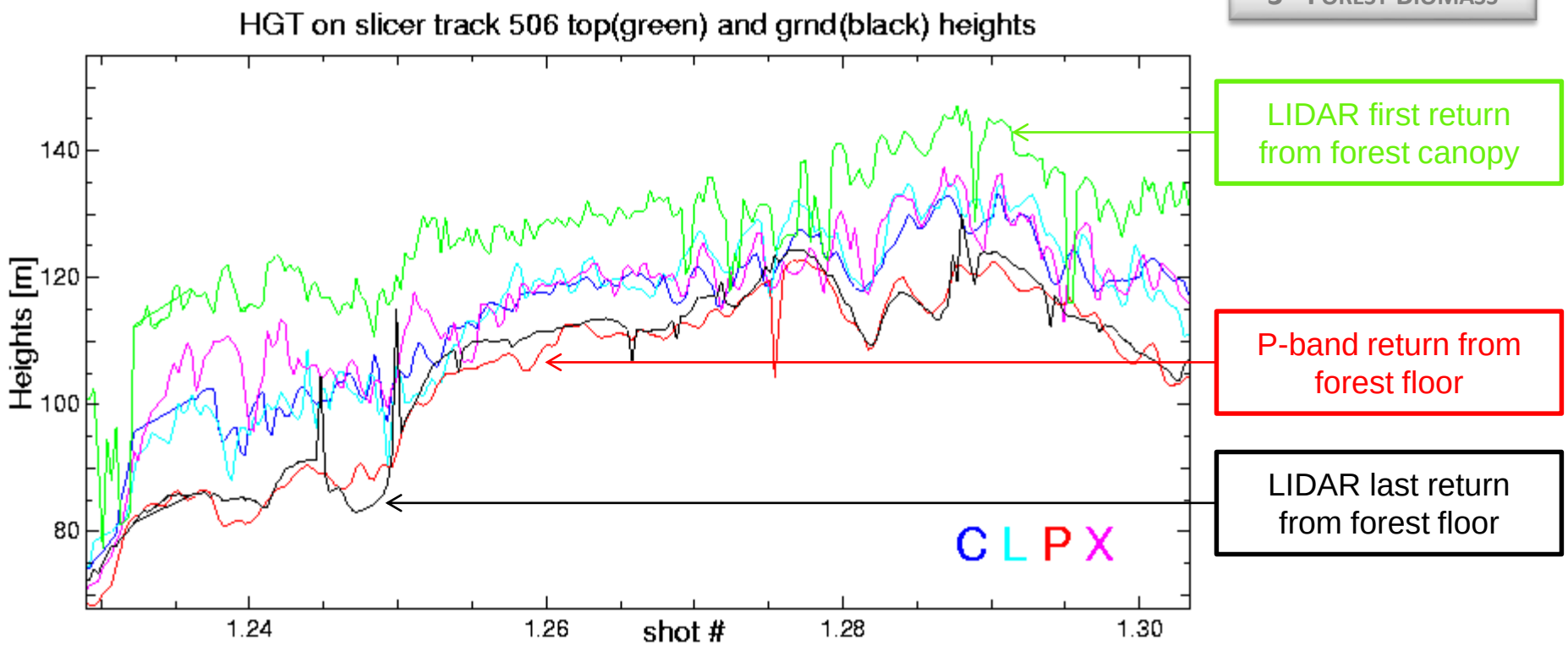


Fig.: Woodhouse; data from Sassan Saatchi, JPL.

Biomass from forest height

1 - FOREST HEIGHT
↓
2 - CONVERSION
↓
3 - FOREST BIOMASS

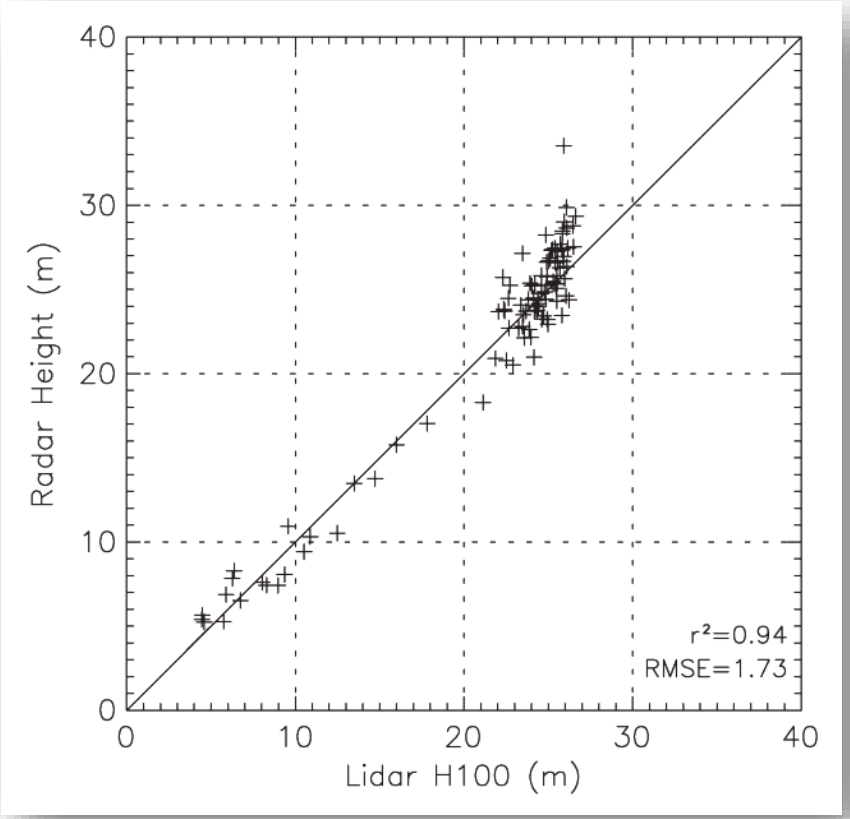


Fig.: Pol-InSAR height estimates at P-Band versus LIDAR H100 validation plot for the Mawas River test site (100 samples) (HAJNSEK et al., 2009).

Biomass from forest height

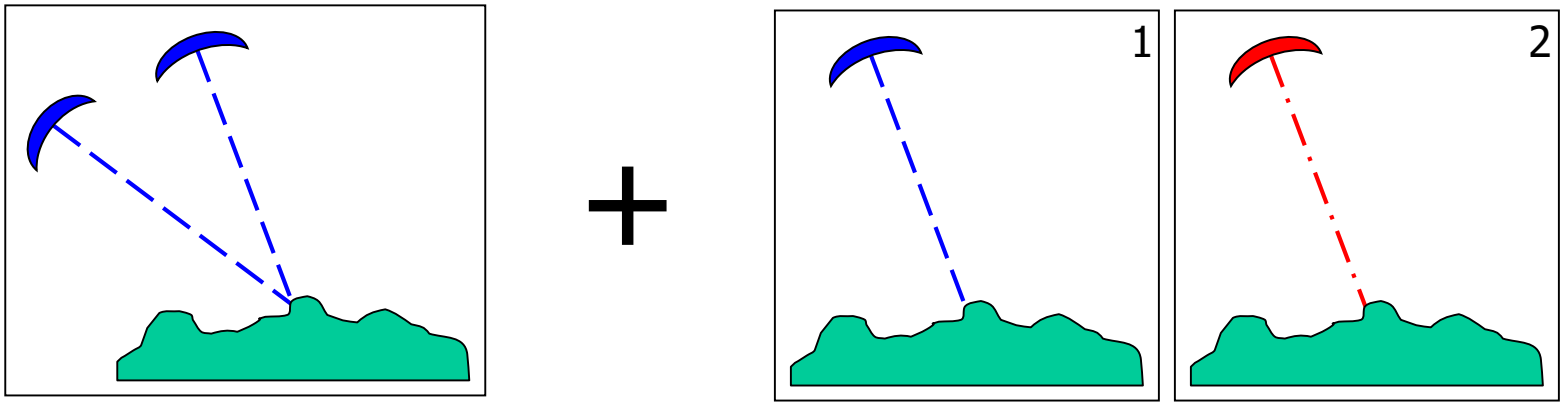
1 - FOREST HEIGHT
↓
2 - CONVERSION
↓
3 - FOREST BIOMASS

Tree height from POLINSAR:

- Height localisation of different scattering mechanism
- Requires coherent interferometric pair of polarimetric data

A) Same polarisation – different position

B) Same position – different polarisation



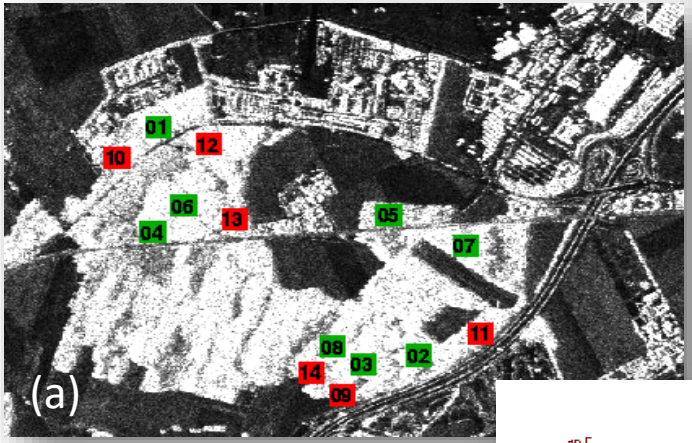
Interferometry + ***Polarimetry***

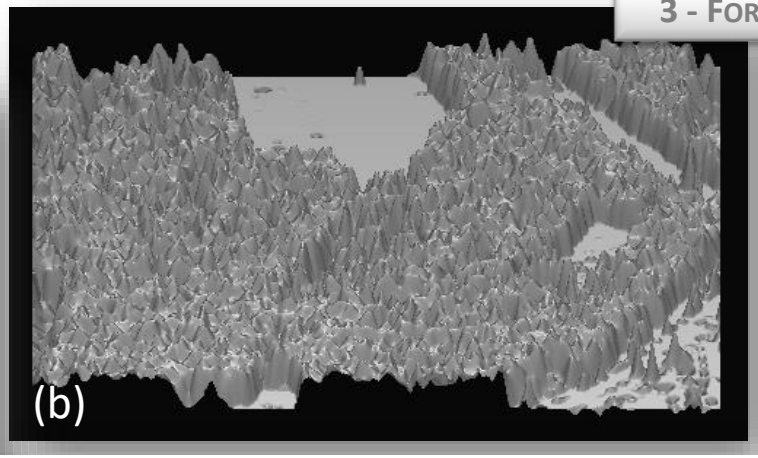
Fig.: THIEL, 2012.

Biomass from forest height

1 - FOREST HEIGHT
↓
2 - CONVERSION
↓
3 - FOREST BIOMASS

Tree height from POLINSAR:





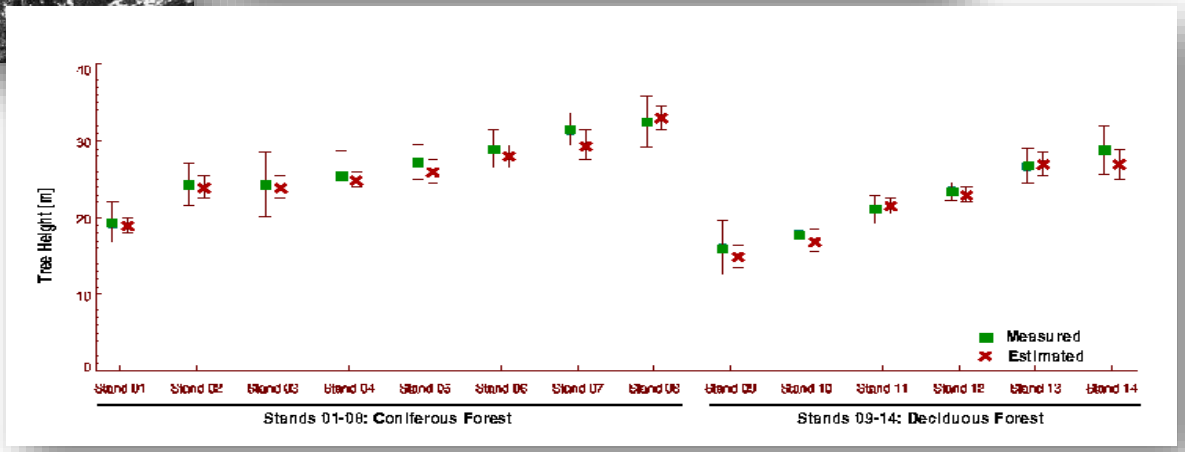


Fig.:

(a) L-Band SAR data of the airfield in Oberpfaffenhofen, Germany and

(b) Tree height from L-Band pol. InSAR result.

© DLR

Biomass from forest height

1 - Forest Height
↓
2 - Conversion
↓
3 - Forest Biomass

Tree height from POLINSAR:

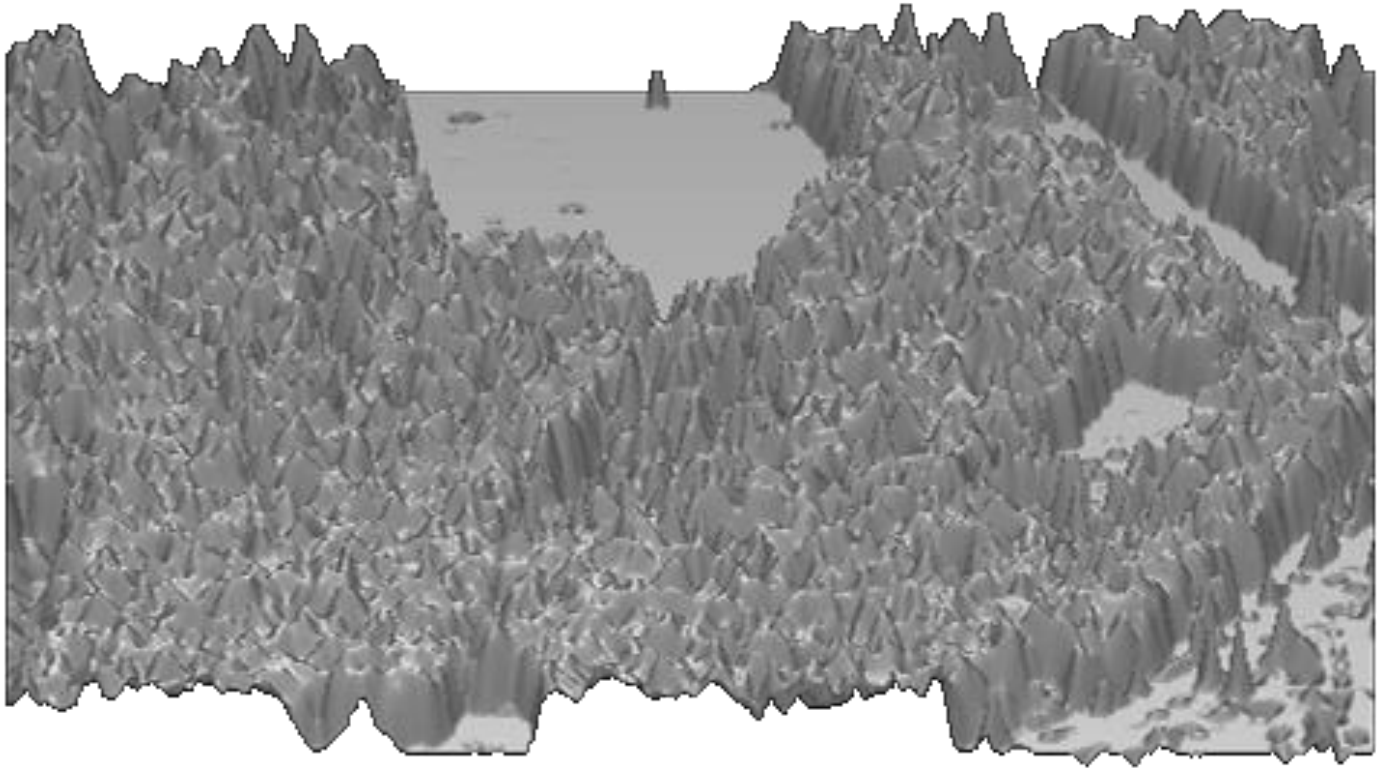
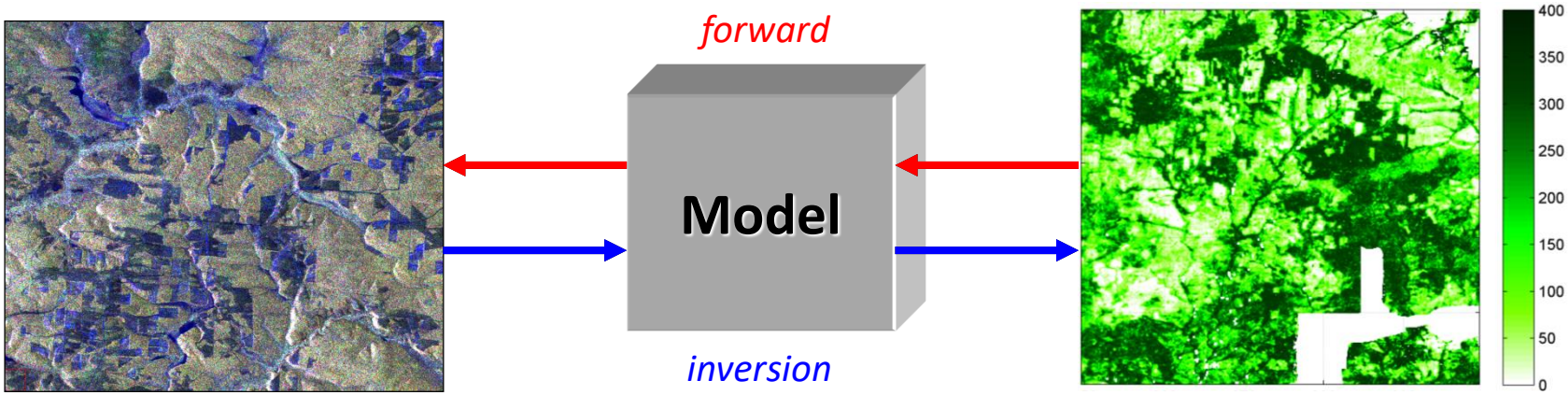


Fig.: Tree height from L-Band pol. InSAR result. © DLR

Biomass from forest height

1 - FOREST HEIGHT
↓
2 - CONVERSION
↓
3 - FOREST BIOMASS

Forest height estimates from single frequency, fully polarimetric-interferometric SAR data through model-based inversion



SAR measures **Forest Parameters**

Fig.: Linking SAR measures and forest parameters (THIEL, 2012).

Biomass from forest height

1 - FOREST HEIGHT
↓
2 - CONVERSION
↓
3 - FOREST BIOMASS

Interferometric volume decorrelation is defined as the (normalized) Fourier transform of the vertical distribution of the scatterers, and it is dependent on forest height.

It is necessary to develop a model that:

- Considers attenuation and ground contribution, but
- Is still simple enough to be solved with a limited number of input variables

→ **Random Volume over Ground-model (RVoG)**

… interprets the interferometric coherence as a function of forest height and extinction (both polarization independent), and a polarization dependent ground.

[METTE et al. 2004]

Biomass from forest height

1 - Forest Height
↓
2 - Conversion
↓
3 - Forest Biomass

In forestry, the biomass calculation is based on measurements of **trunk diameter** and **height** of sample populations of trees:

$$Biomass_{forest} = N \times \pi \times \left(\frac{1}{2}\,\mathrm{dbhmid}\right)^2 \times hmid \times \rho \times fz$$

Biomass$_{forest}$ **[t/ha]**	is defined as aboveground woody of trunk and branches where exceeding 7 cm diameter
$\mathbf{dbh_{mid}}$ **[cm]**	is the (dbh² weighted) mean diameter at breast height 1.3 m
h_{mid} **[m]**	is the height of the tree
ρ **[g/cm³]**	is the species-specific wood density
f_z **[]**	is a form factor (= 0.4-0.5, constant in a first order approximation)
N	is the tree density (tree number per area unit)

Repetition Introduction: slide 11

The product of $N \times \pi \times \left(\frac{1}{2}\,\mathbf{dbh}_{mid}\right)^2$ is also called **basal area g**.

[Mette et al. 2004]

Copyright ©

Biomass from forest height

1 - Forest Height
↓
2 - Conversion
↓
3 - Forest Biomass

Conversion through **allometric height-biomass relations**:

$$\text{Biomass}_{\text{forest}} = a \times \text{height}^{c}$$

Parameters **a** and **c** are studied from **yield tables**

- Yield tables contain stand parameters, such as: height, dbh, tree number, basal area, as a function of age and site condition
- Yield tables are based on long-term records of even-aged single species forests under defined thinning conditions

Constraints:

Mathematically - h, dbh and N (or g) are allometrically interrelated

Biologically - the growth rates of h, dbh, and N (or g) have to maintain constant relations

[Mette et al. 2004]

Biomass from forest height

1 - FOREST HEIGHT
↓
2 - CONVERSION
↓
3 - FOREST BIOMASS

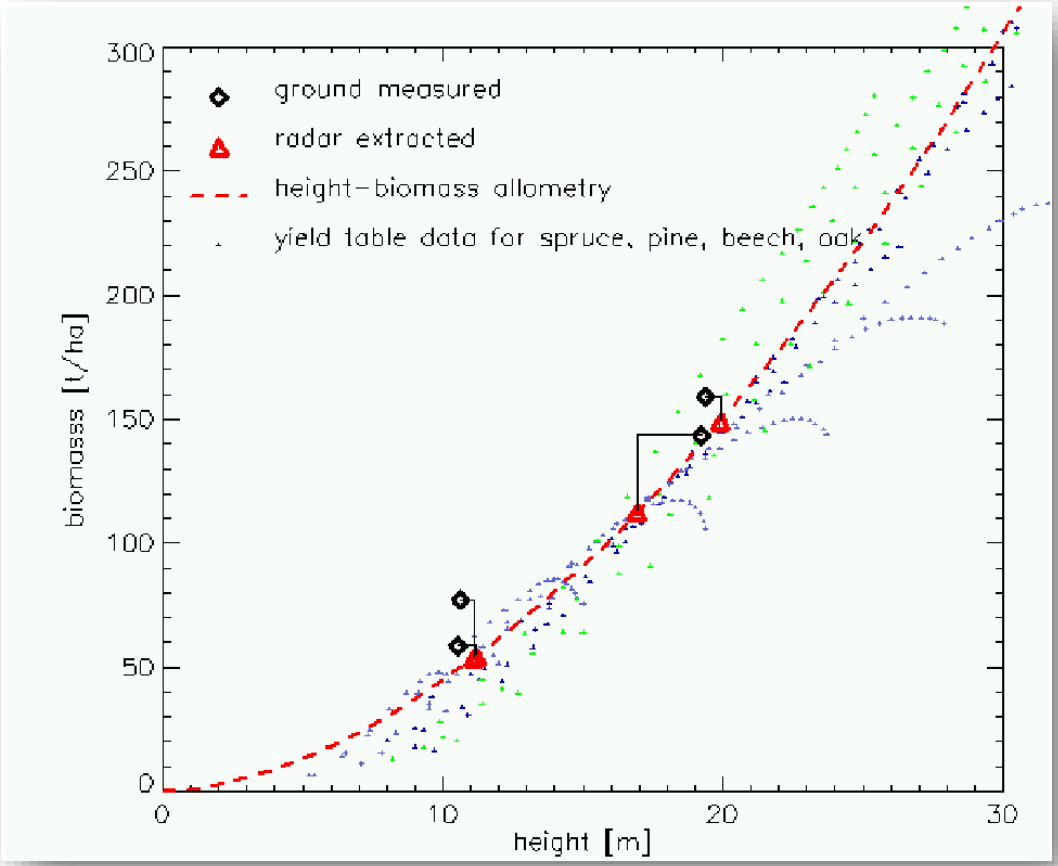
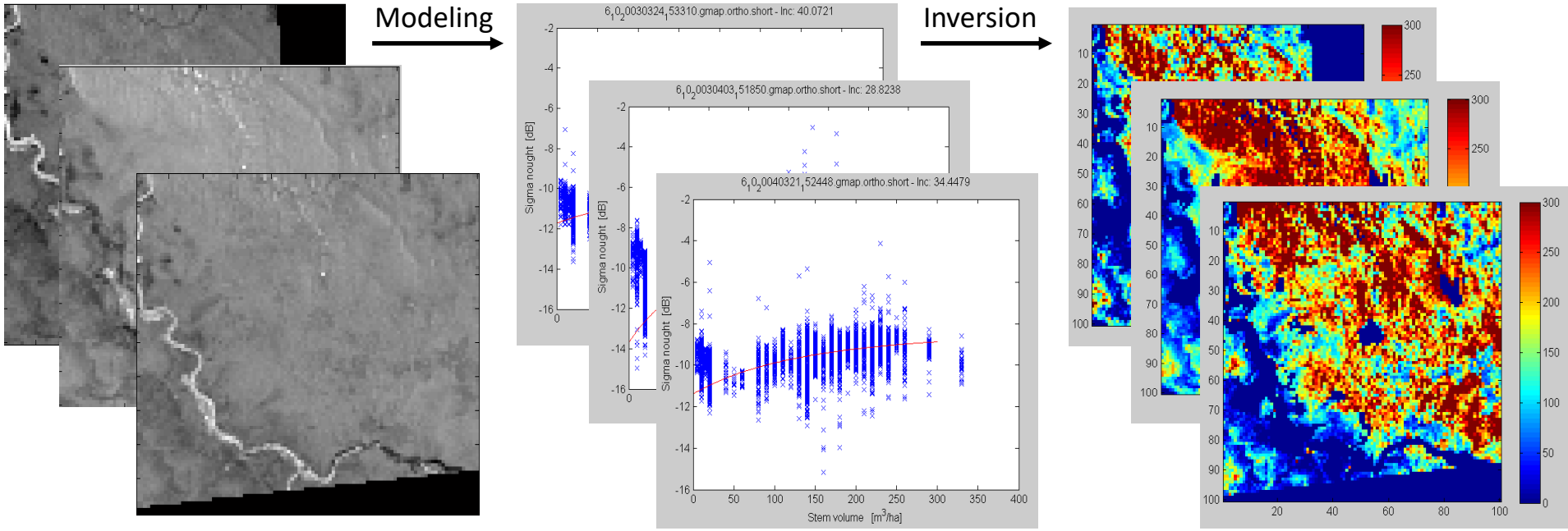


Fig.: Correlation of forest heights vs. biomass for the ground measurements and Pol-InSAR extracted heights that were converted to biomass through height-biomass allometry **[Biomass = 0.801 x $h_{100}^{1.748}$]** (METTE et al., 2004).

Biomass from forest height

1 - FOREST HEIGHT
↓
2 - CONVERSION
↓
3 - FOREST BIOMASS

Multi-temporal combination of single biomass estimates



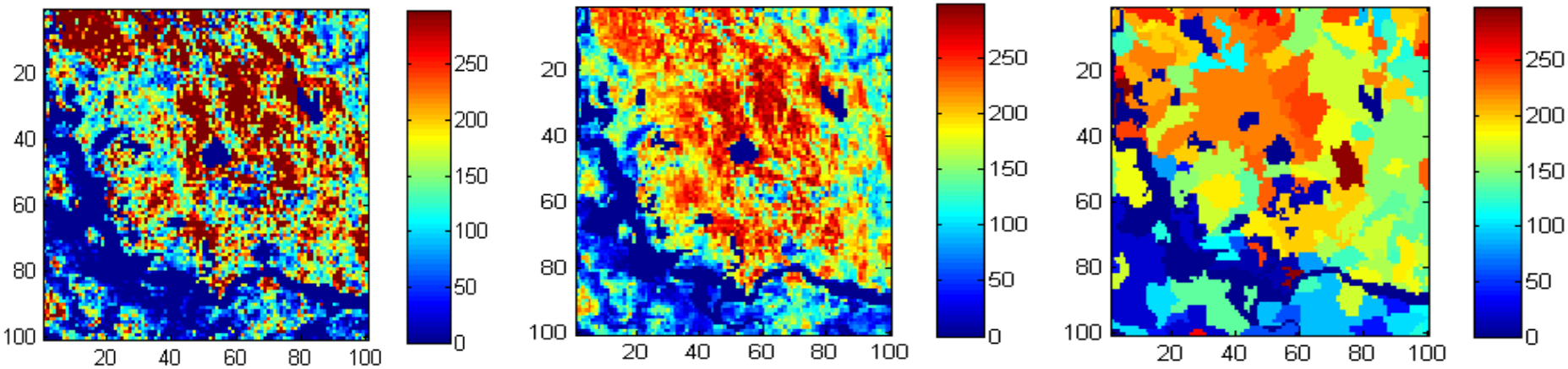
A multi-temporal combination of single estimates with weights determined by the backscatter contrast σ^0_{veg} - σ^0_{gr} allows obtaining the final estimate

[ESA BIOMASAR Project, MAURIZIO SANTORO, 2007]

Biomass from forest height

1 - Forest Height
↓
2 - Conversion
↓
3 - Forest Biomass

Multi-temporal combination of single biomass estimates



Single-image

Multi-temporal
(29 images)

Inventory

- From a single image it is possible to identify sparse/dense forest patterns at most
- From multi-temporal combination it is possible to identify biomass levels

[ESA BIOMASAR Project, Maurizio Santoro, 2007]

EXAMPLES
© wallpaperstop

Copyright ©

Application examples

- SIBERIA - Biomass mapping in Siberia
- ESA DRAGON – Biomass mapping in China
- BIOMASAR – Panboreal forest growing stock volume maps
- SARvanna – Vegetation structure mapping in the Kruger National Park
- Biomass from forest height – Fichtelgebirge, Germany

Copyright ©

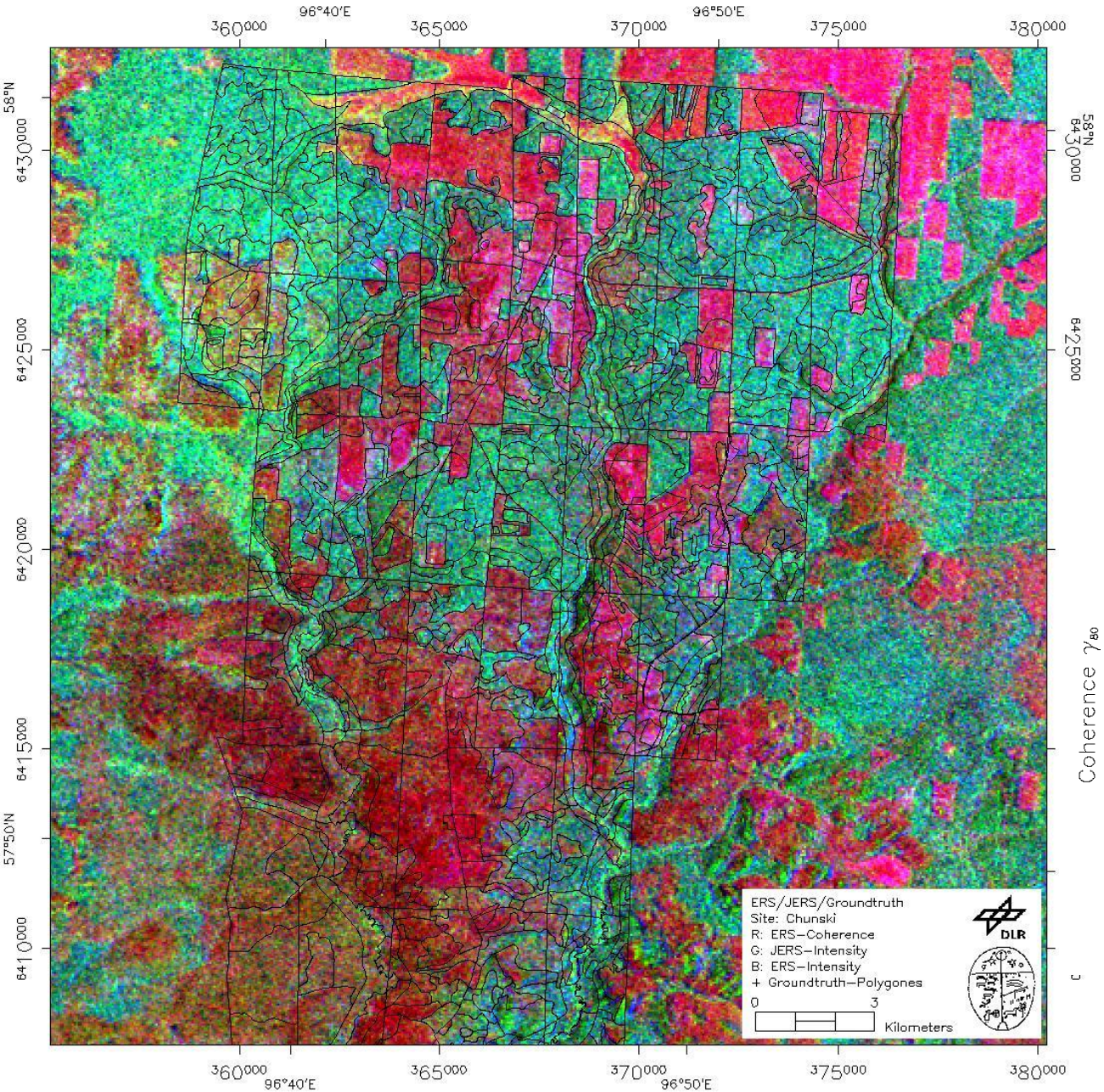
Application examples

- SIBERIA - Biomass mapping in Siberia
- ESA DRAGON – Biomass mapping in China
- BIOMASAR – Panboreal forest growing stock volume maps
- SARvanna – Vegetation structure mapping in the Kruger National Park
- Biomass from forest height – Fichtelgebirge, Germany

Copyright ©

SIBERIA project

- SAR coherence and intensity overlaid with co-registered forest-GIS-polygons



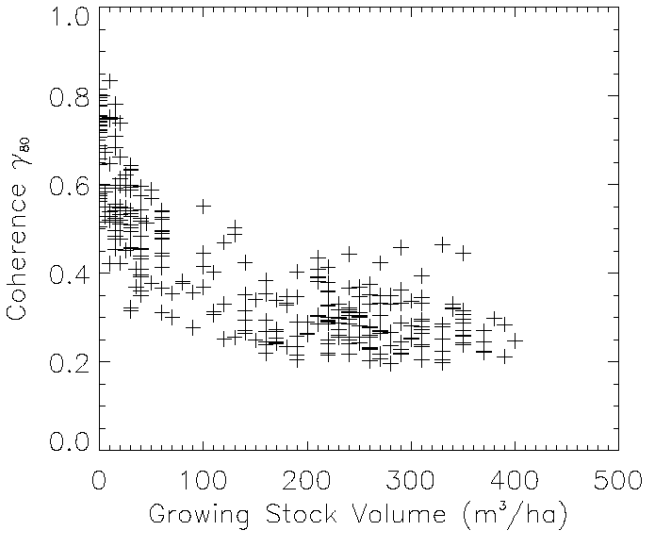
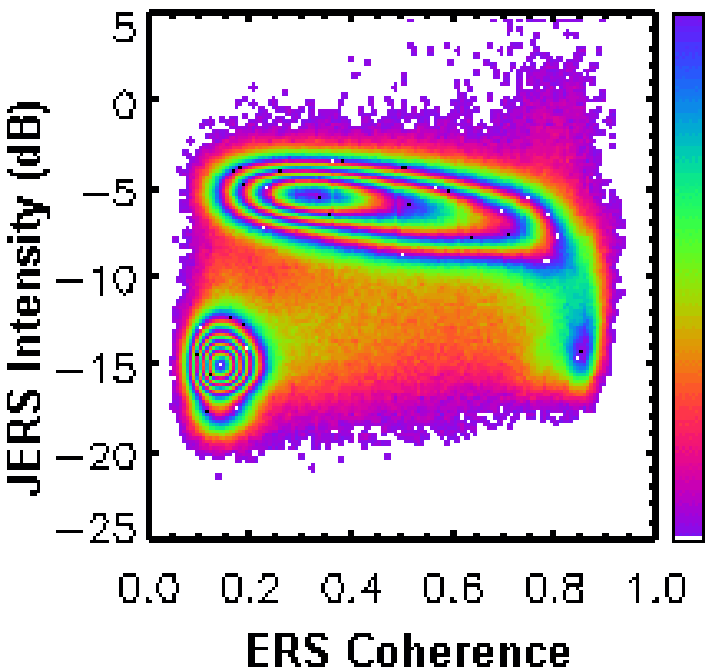


Fig. (top): ERS Tandem coherence versus growing stock volume (© SIBERIA project, 1999, 2000)

SIBERIA project

- Class separability



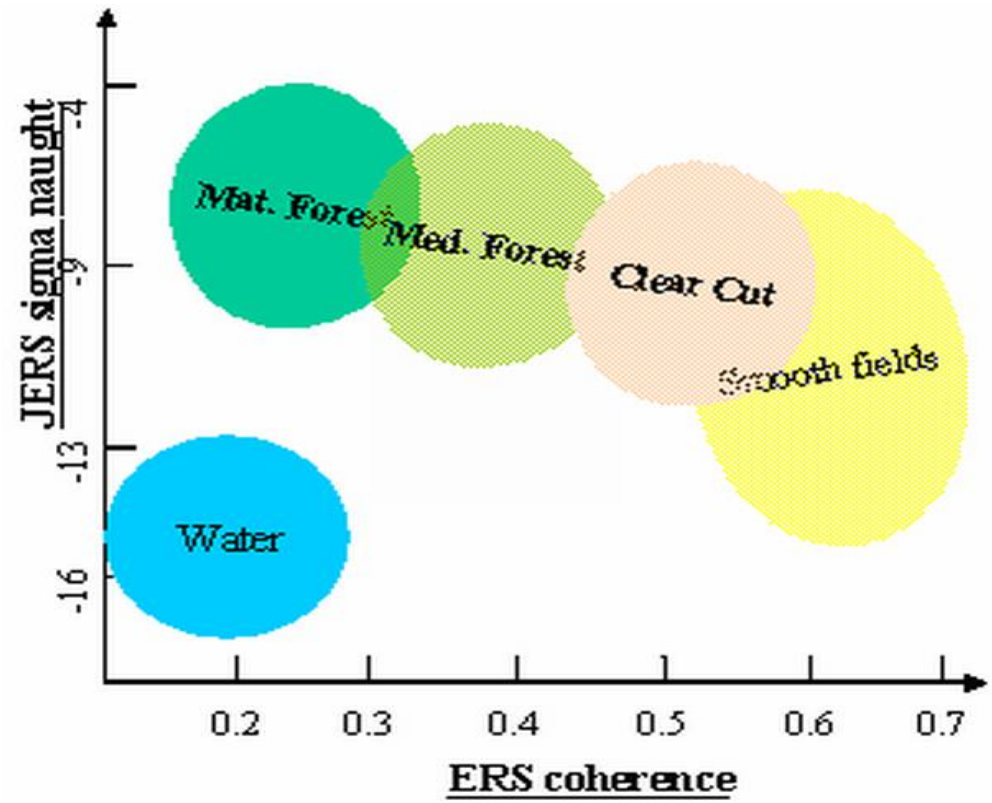
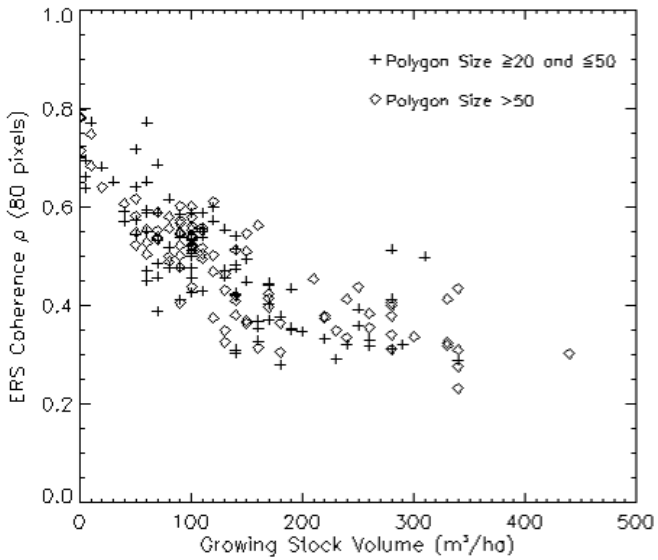
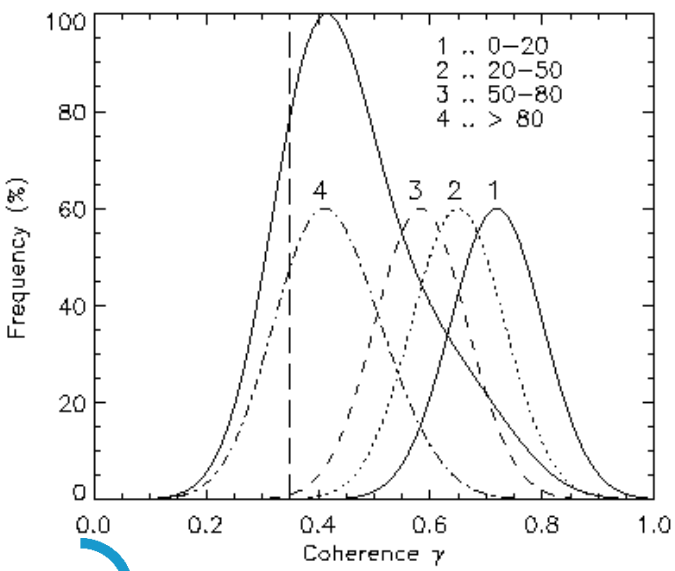


Fig.: © SIBERIA project, 1999, 2000

SIBERIA project





Model definition for coherence

$$\gamma(v) = \gamma_\infty + (\gamma_0 - \gamma_\infty) \cdot e^{-\frac{v}{V_\gamma}}$$

$$\gamma_\infty \approx \gamma_{75}$$

$$\gamma_0 = a_\gamma + b_\gamma \cdot \gamma_{75}$$

$$\gamma(v) = \gamma_{75} + \left(a_\gamma + (b_\gamma - 1)\gamma_{75}\right) \cdot e^{-\frac{v}{V_\gamma}}$$

$$\gamma(v) = \gamma_{75} + \left(0.330 + 0.581 \cdot \gamma_{75}\right) \cdot e^{-\frac{v}{1221}}$$

v = growing stock volume

γ_0 = coherence at v = 0 m³/ha (non-forest)

γ_∞ = coherence for asymptotic values of v (corresponding to dense forest)

γ_{75} = value where the coherence distribution reach 75% of the maximum value (Fig.)

V_γ = characteristic v value where the exponential function has decreased by e^{-1}

Wagner et al., 2003

SIBERIA project

ERS coherence image →

JERS intensity image →

Use model to calculate class means → Maximum Likelihood Classifier → Iterated Contextual Probability Classifier (ICP) →

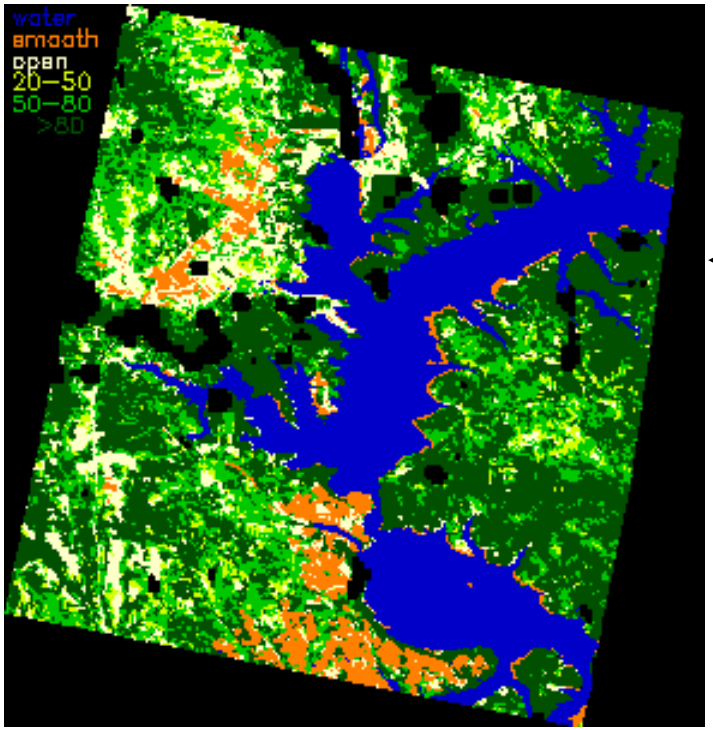


Fig.: Classification chain
(© SIBERIA project, 1999, 2000)

SIBERIA project

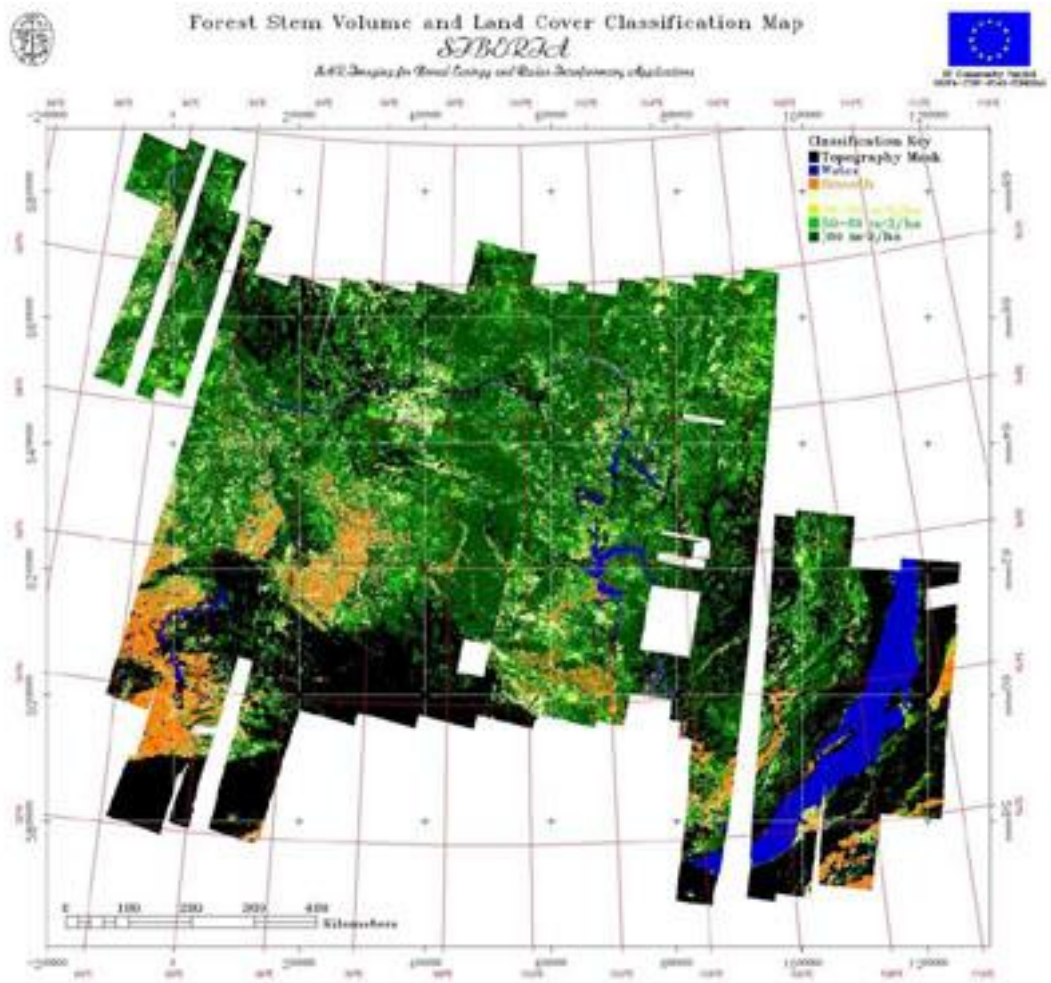
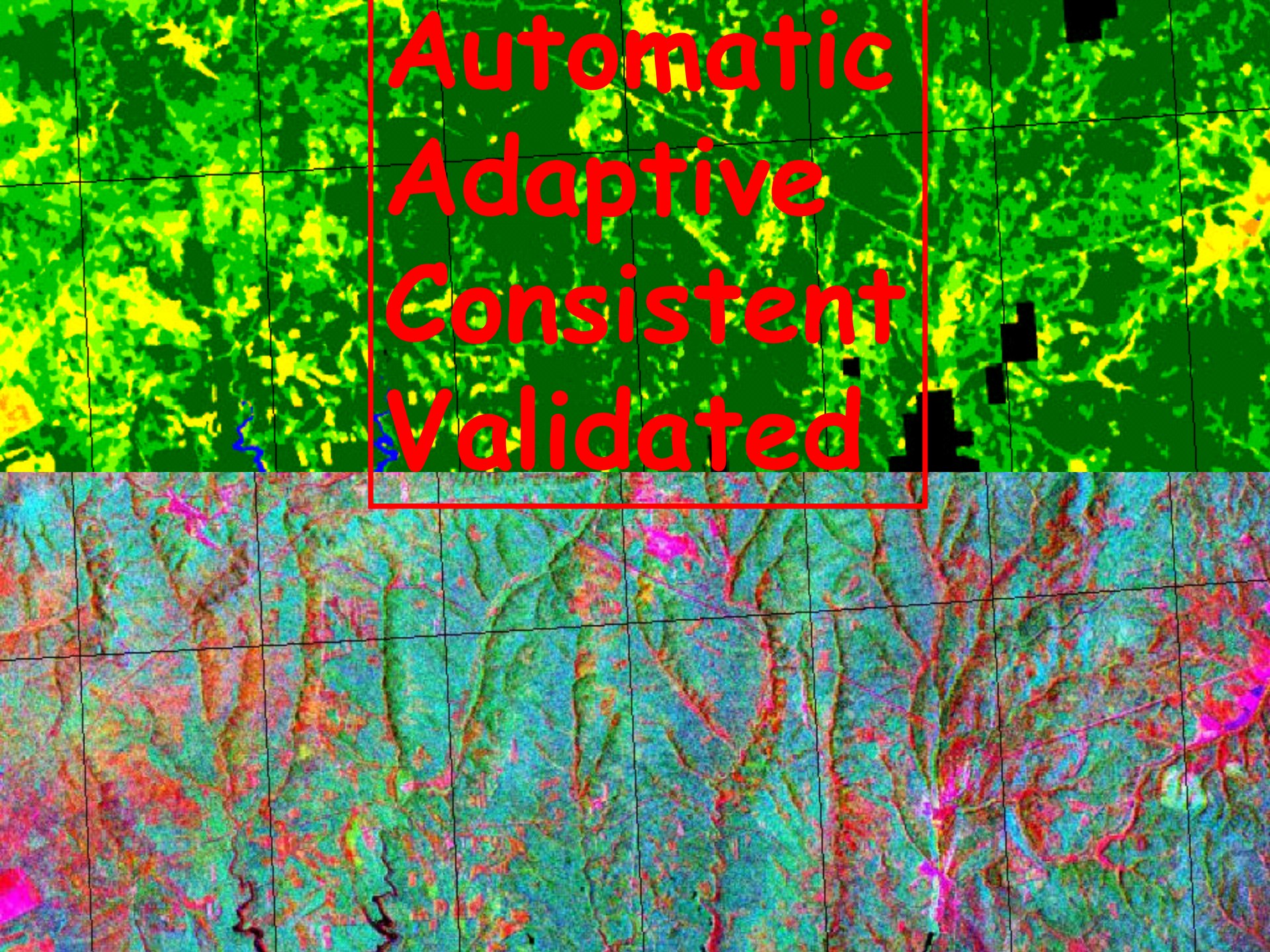


Fig.: Final forest biomass map – Siberia project (© SIBERIA Project 1999, 2000)

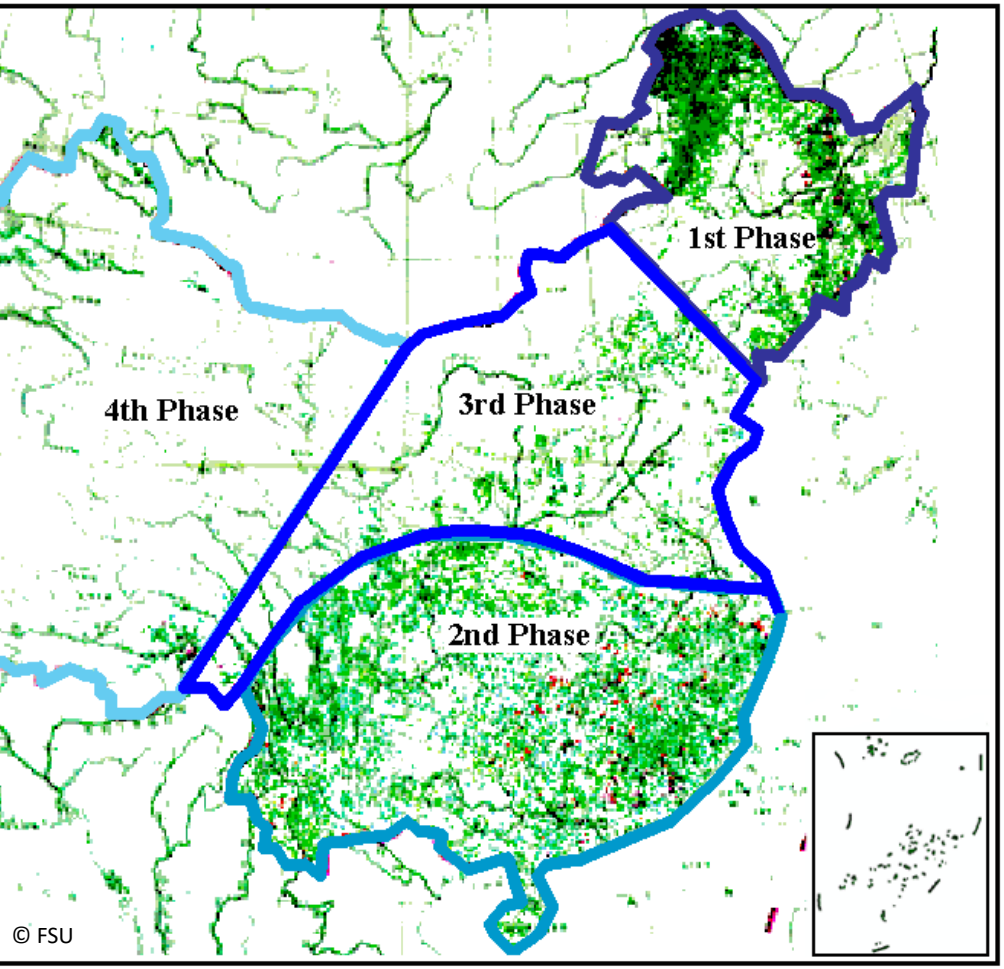
- Nothing as yet global and accessible as Above Ground Biomass
- Regional – SIBERIA (1 Mio. km² at 50m, 1998) based on SAR interferometry

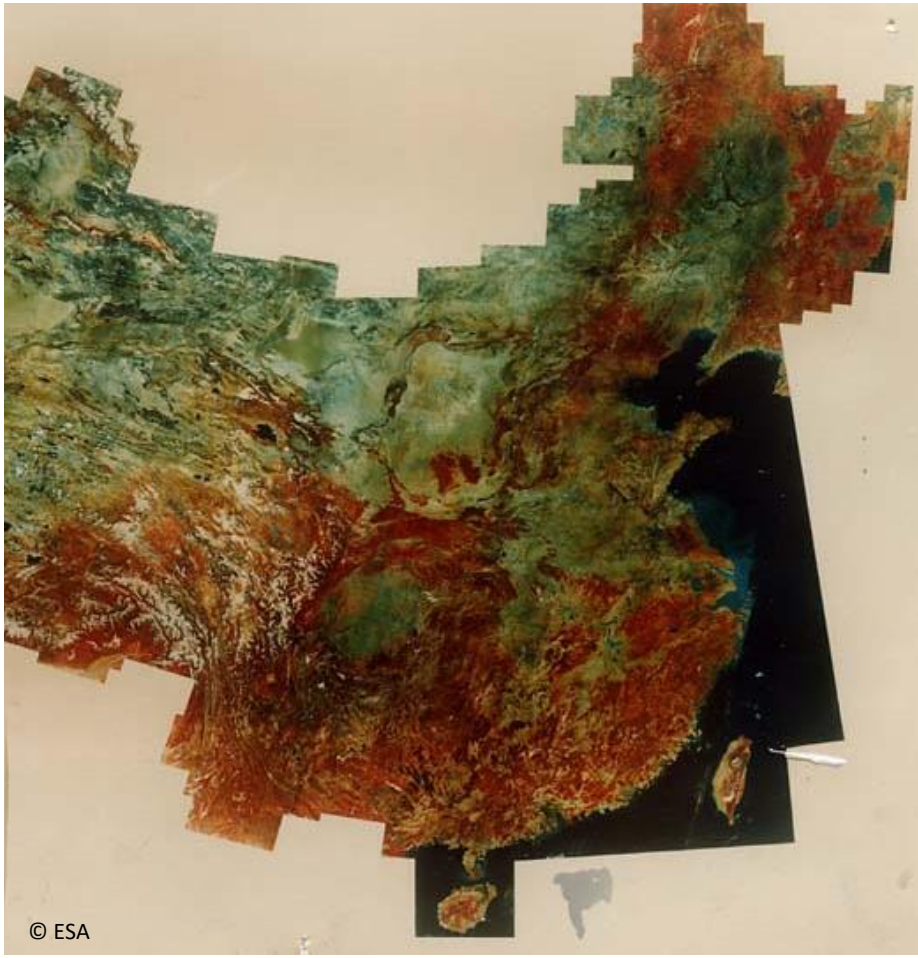

Automatic
Adaptive
Consistent
Validated

Application examples

- SIBERIA - Biomass mapping in Siberia
- ESA DRAGON – Biomass mapping in China
- BIOMASAR – Panboreal forest growing stock volume maps
- SARvanna – Vegetation structure mapping in the Kruger National Park
- Biomass from forest height – Fichtelgebirge, Germany

DRAGON project





Phased project areas and Landsat mosaic

DRAGON project

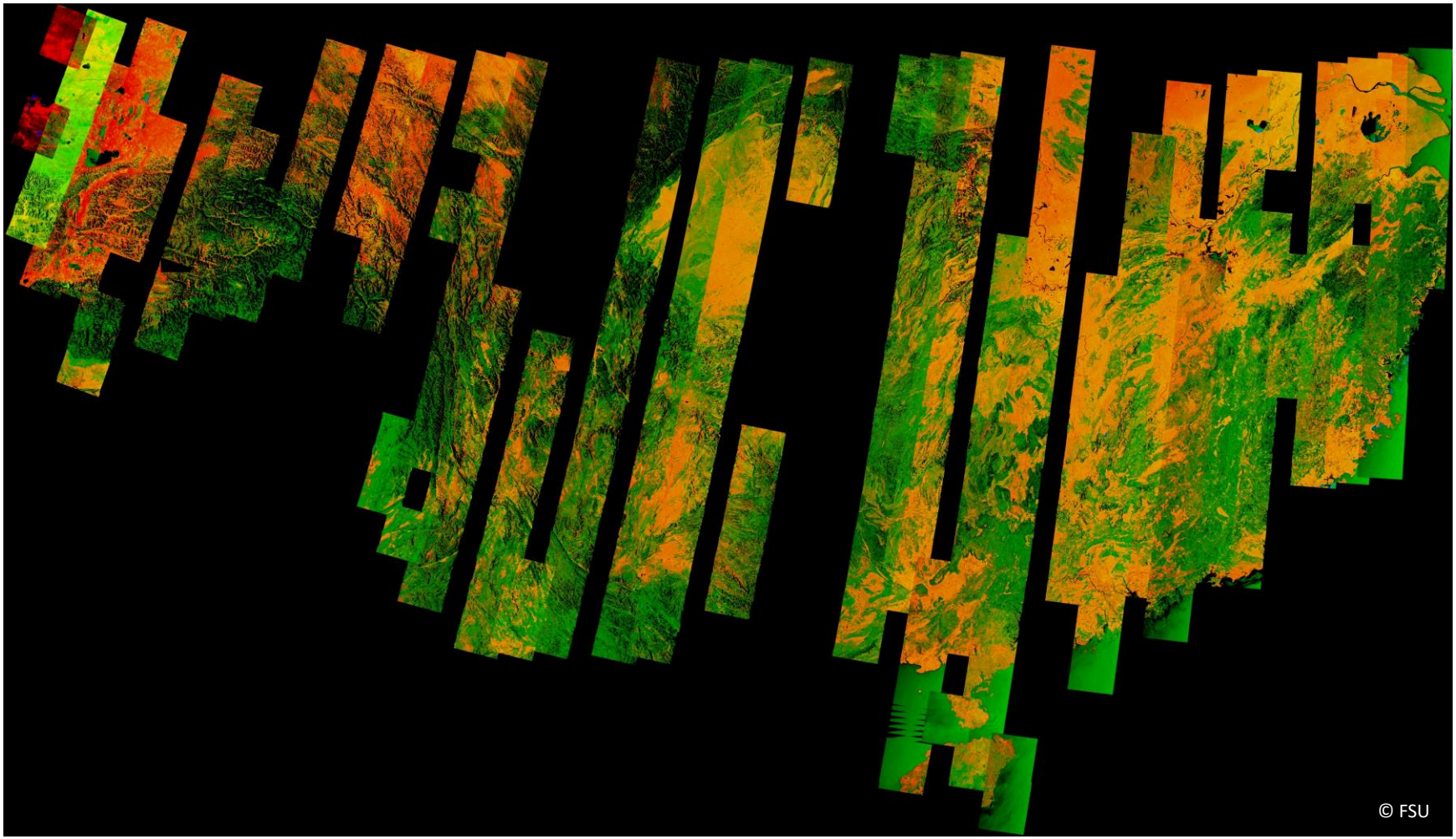
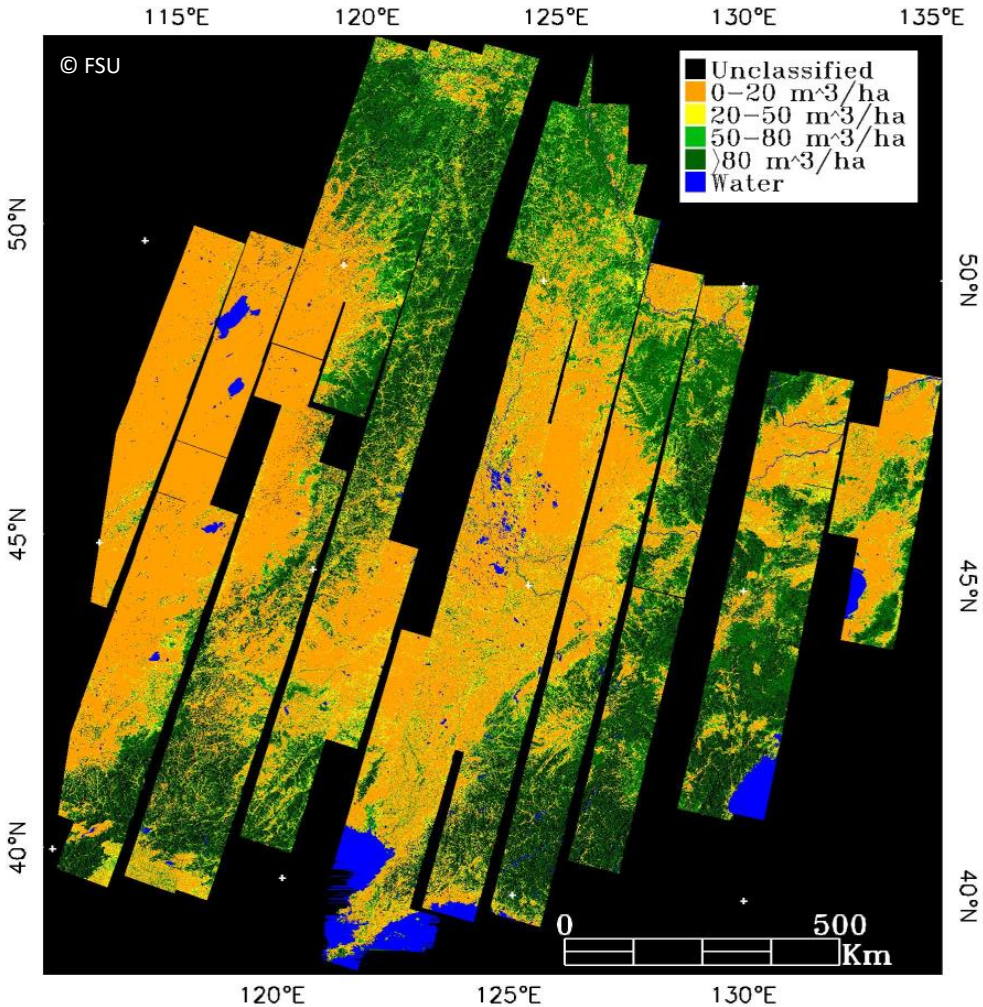
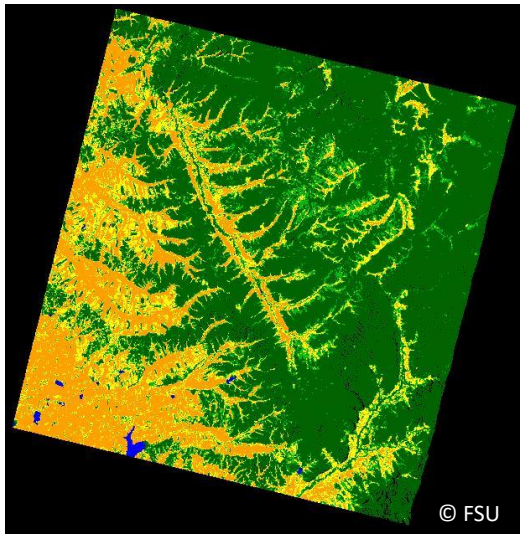
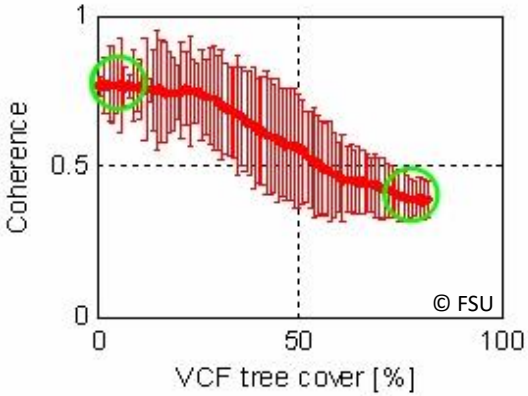


Fig.: ERS-1/2 tandem coherence map of Southern China (Courtesy ESA DRAGON Project (O. Cartus, M. Santoro))

DRAGON project







Courtesy ESA DRAGON Project (O. Cartus, M. Santoro)

DRAGON project

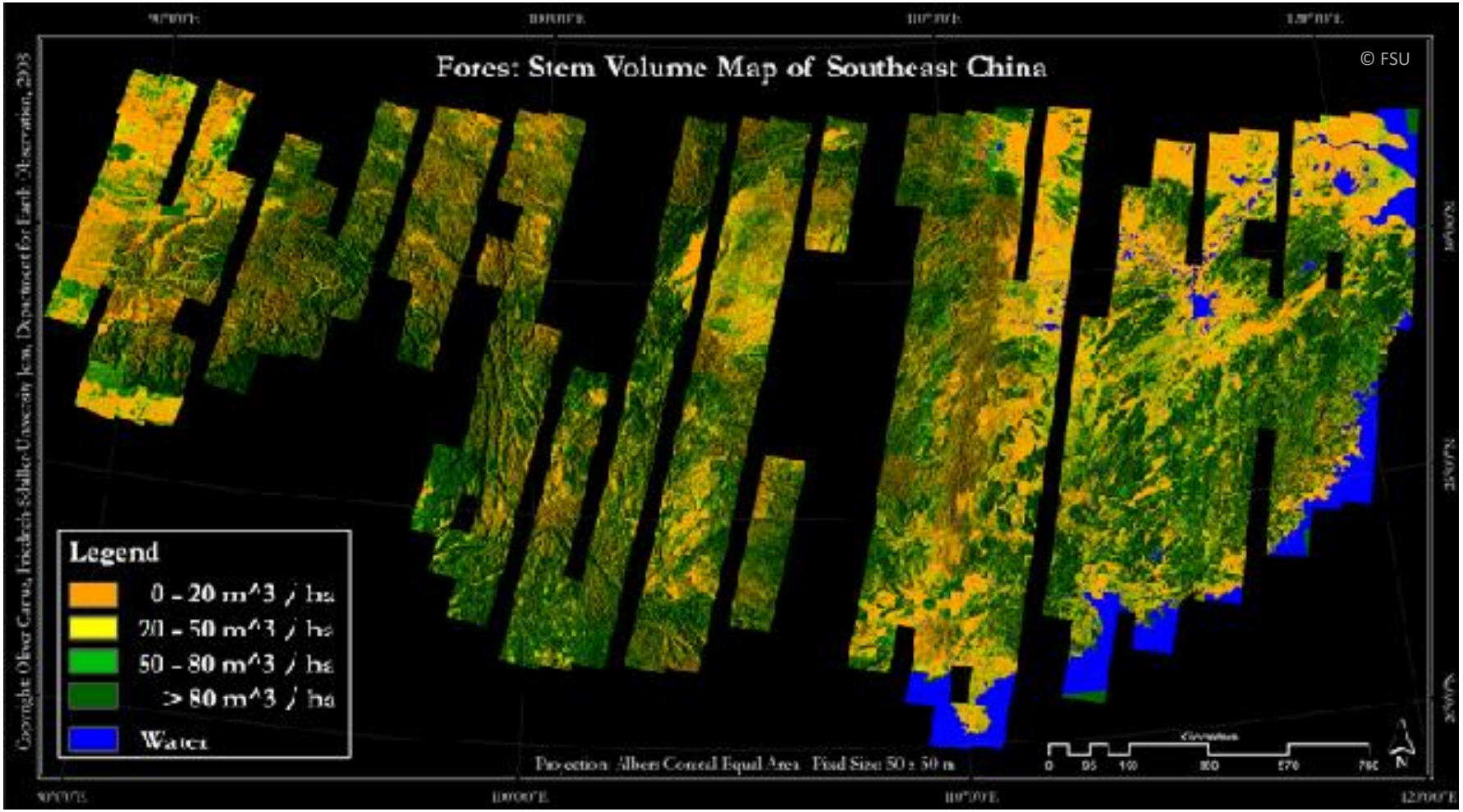
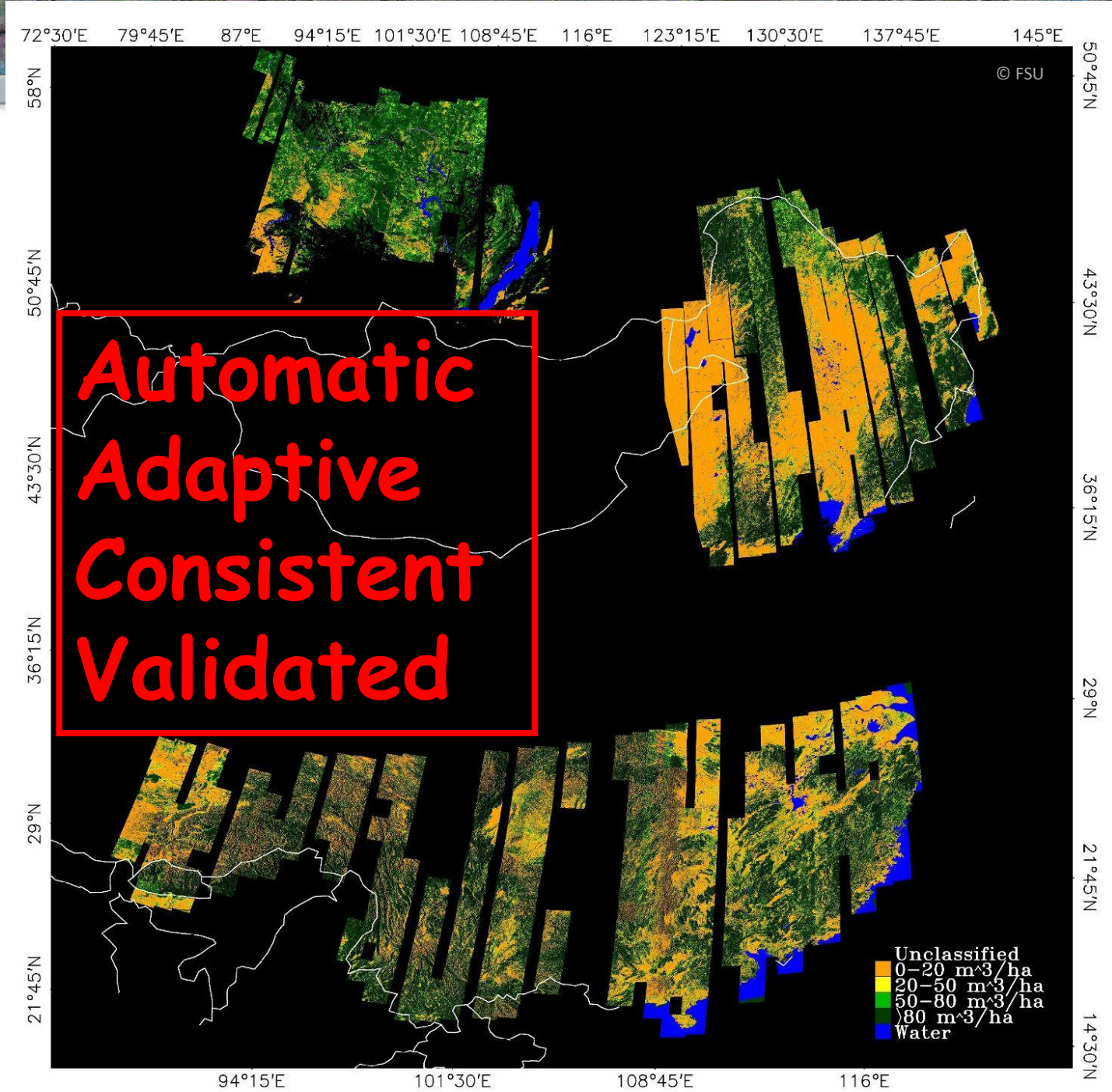


Fig.: ERS-1/2 tandem coherence **stem volume map 1995/98** of Southern China (Courtesy ESA DRAGON Project (O. Cartus, M. Santoro))

DRAGON project



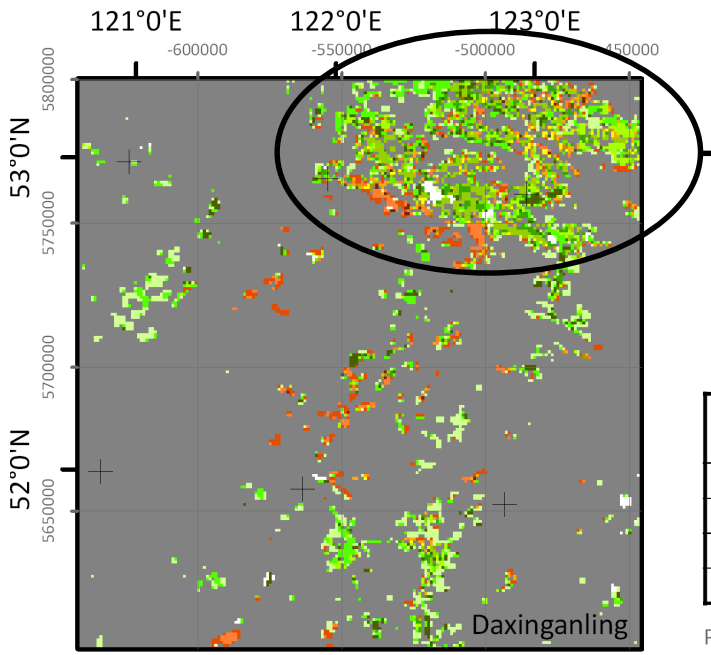
Courtesy ESA DRAGON Project (O. Cartus, M. Santoro)

SAREDU Remote Sensing Education Initiative

DRAGON-2 project

Forest Cover (Structure) Change – First Results

1995-1997 (ERS-1/2 Tandem, previous slides, resampled) - 2007/08 (ASAR GMM, BIOMASAR algorithm – see slides 85ff.)



Regrowing forest after forest fire in 1987

ASAR / ERS	0-20 m³/ha	20-50 m³/ha	50-80 m³/ha	> 80 m³/ha
0-20 m³/ha				
20-50 m³/ha				
50-80 m³/ha				
> 80 m³/ha				

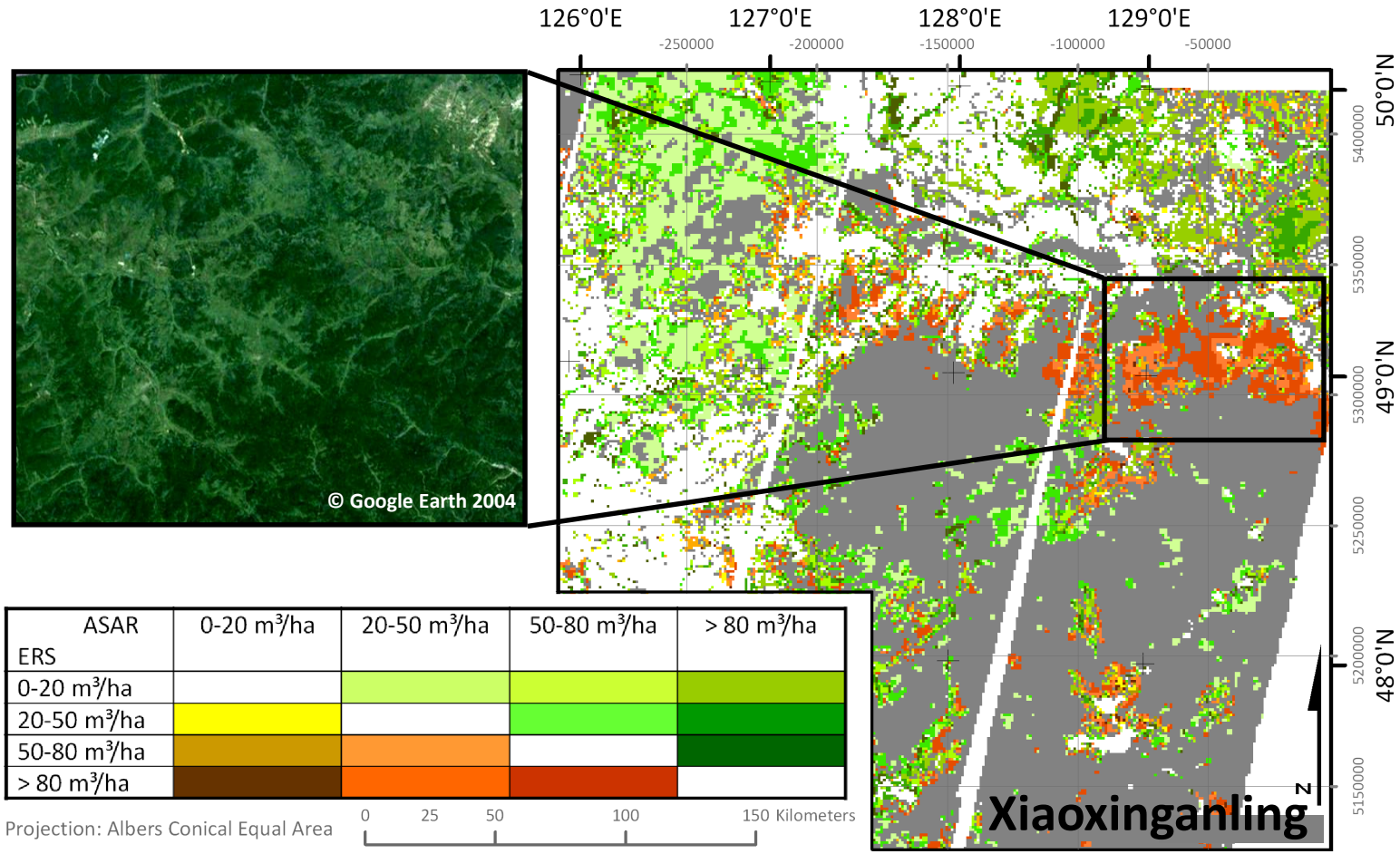
Projection: Albers Conical Equal Area

0 25 50 100 150 Kilometers

© **FOREST DRAGON 2:** Mid-Term Results of the European Partners

DRAGON-2 project

Forest Cover (Structure) Change – First Results



ASAR / ERS	0-20 m³/ha	20-50 m³/ha	50-80 m³/ha	> 80 m³/ha
0-20 m³/ha				
20-50 m³/ha				
50-80 m³/ha				
> 80 m³/ha				

© **FOREST DRAGON 2:** Mid-Term Results of the European Partners

DRAGON-2 project

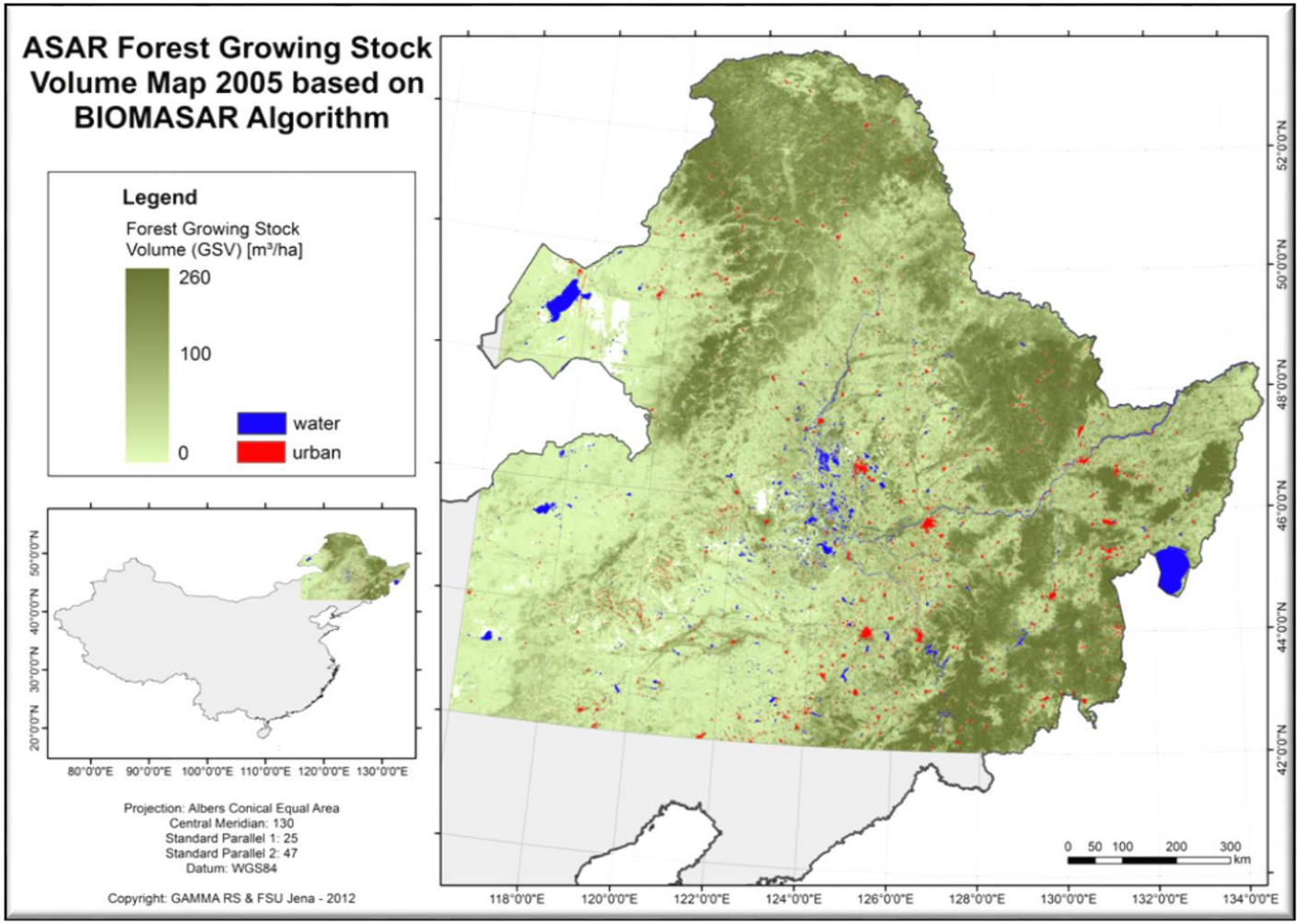


Fig.: Forest growing stock volume map from 2005 for Northeast China, produced with the BIOMASAR algorithm by Santoro, et al. 2011 (© ESA FOREST DRAGON-2)

DRAGON-2 project

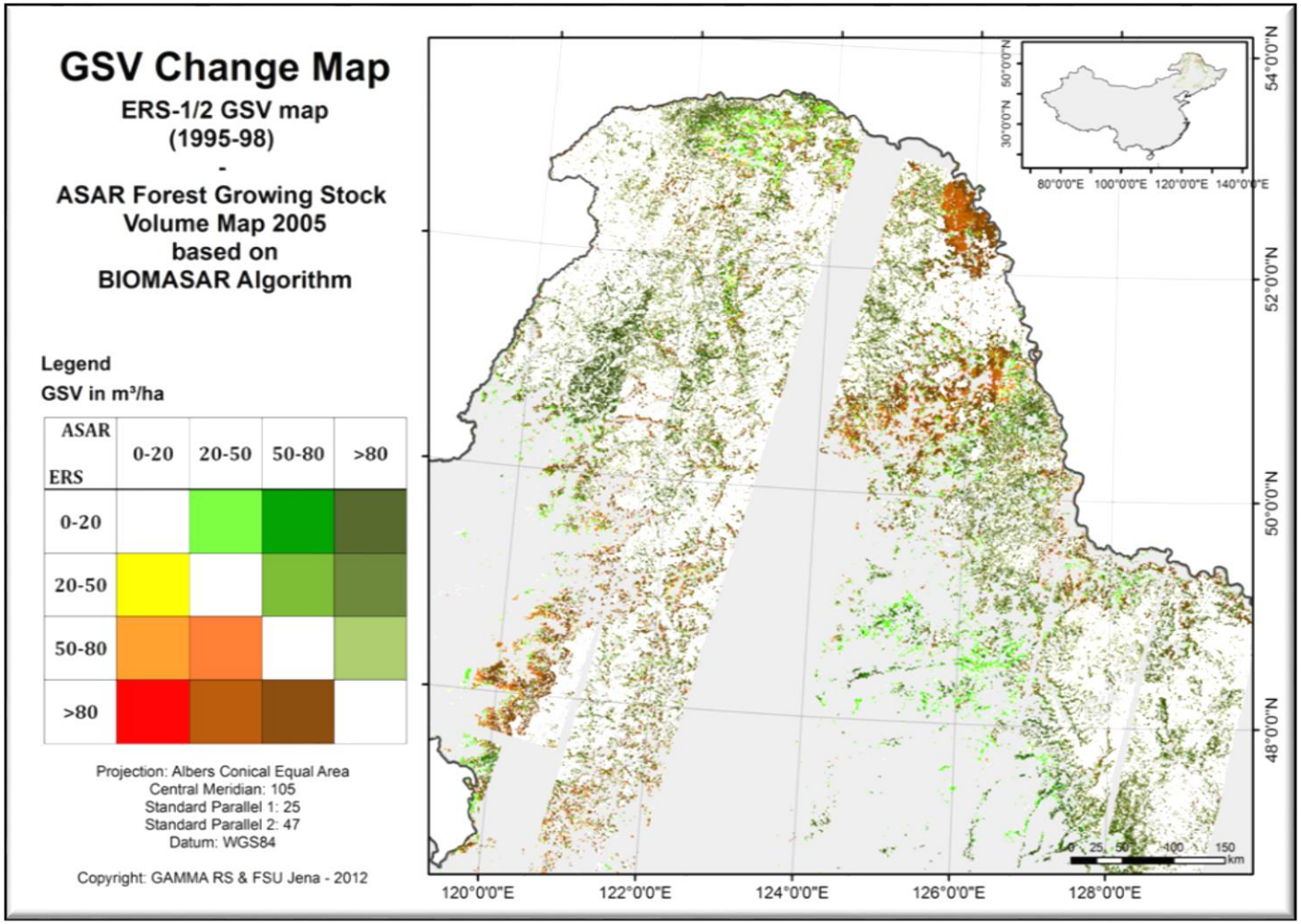
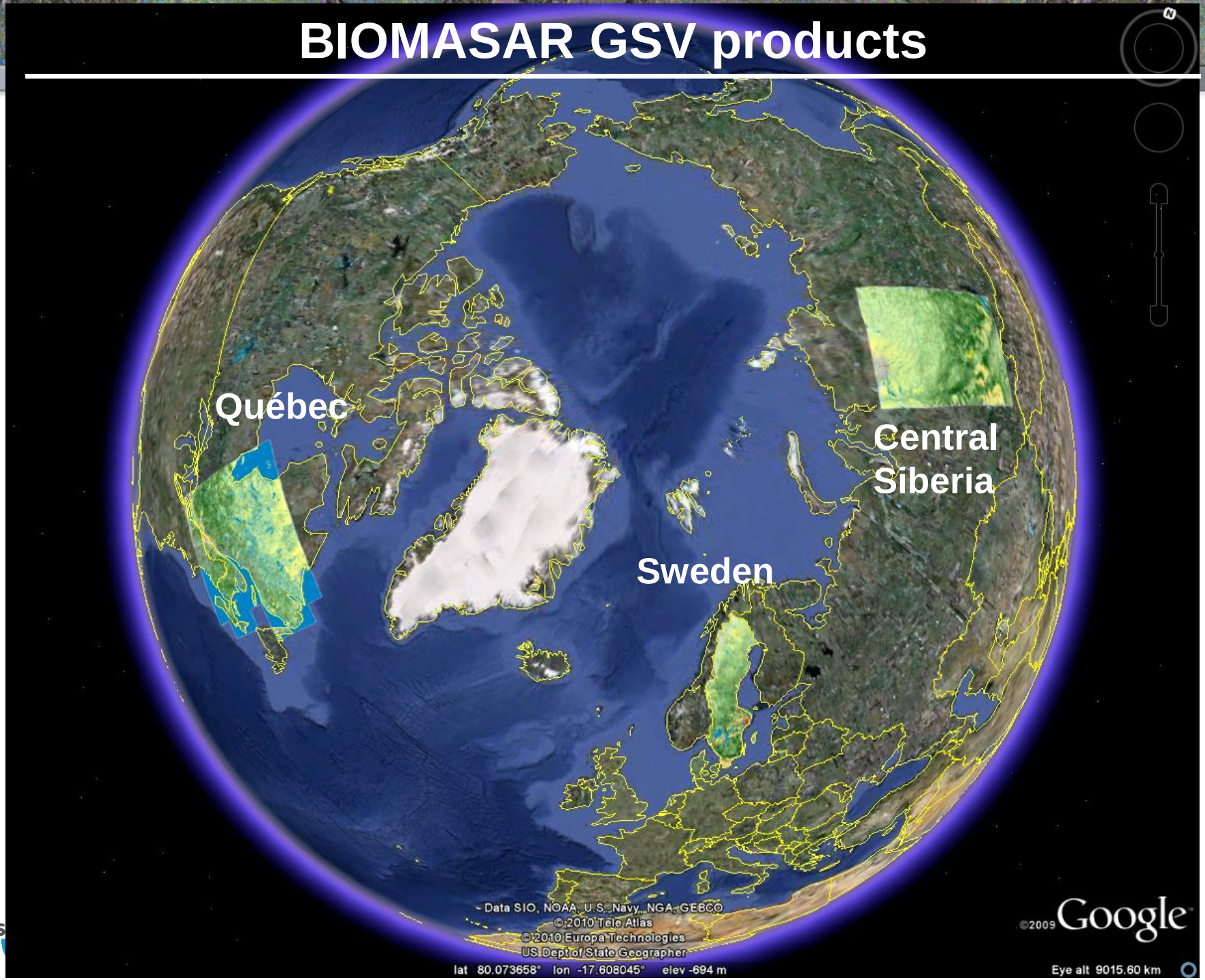


Fig.: Forest growing stock volume (GSV) change map. This map shows the difference in GSV values between the years 1995/98 and 2005. The map considers the 4 classes of the ERS-1/2 GSV map (0-20m³/ha, 20-50m³/ha, 50-80m³/ha and greater than 80m³/ha) (© ESA FOREST DRAGON-2)

Application examples

- SIBERIA - Biomass mapping in Siberia
- ESA DRAGON – Biomass mapping in China
- BIOMASAR – Panboreal forest growing stock volume maps
- SARvanna – Vegetation structure mapping in the Kruger National Park
- Biomass from forest height – Fichtelgebirge, Germany

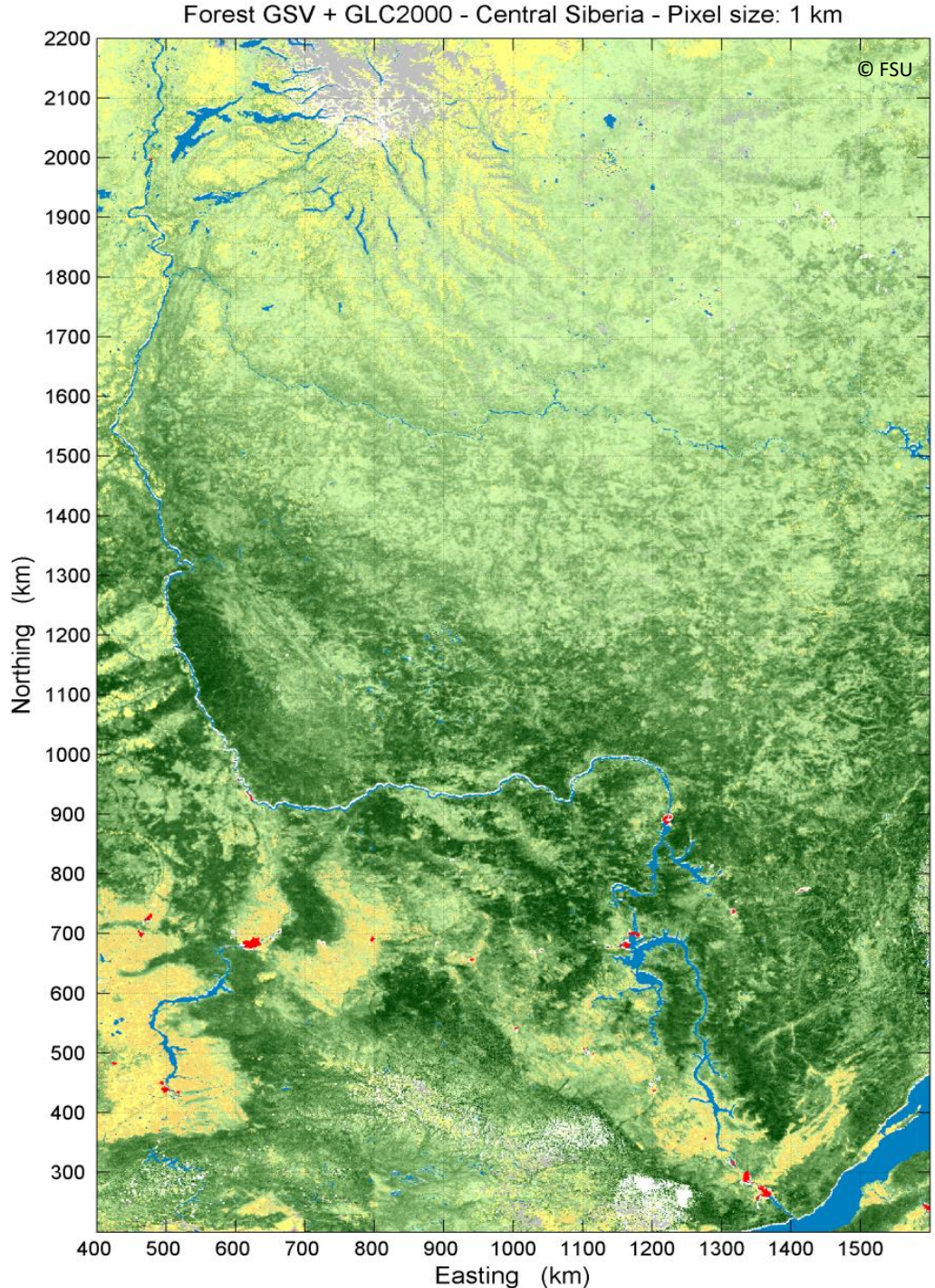
BIOMASAR GSV products

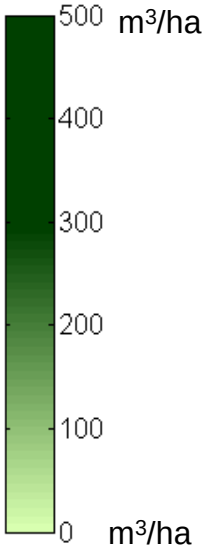


BIOMASAR project

1-km forest GSV map of Central Siberia

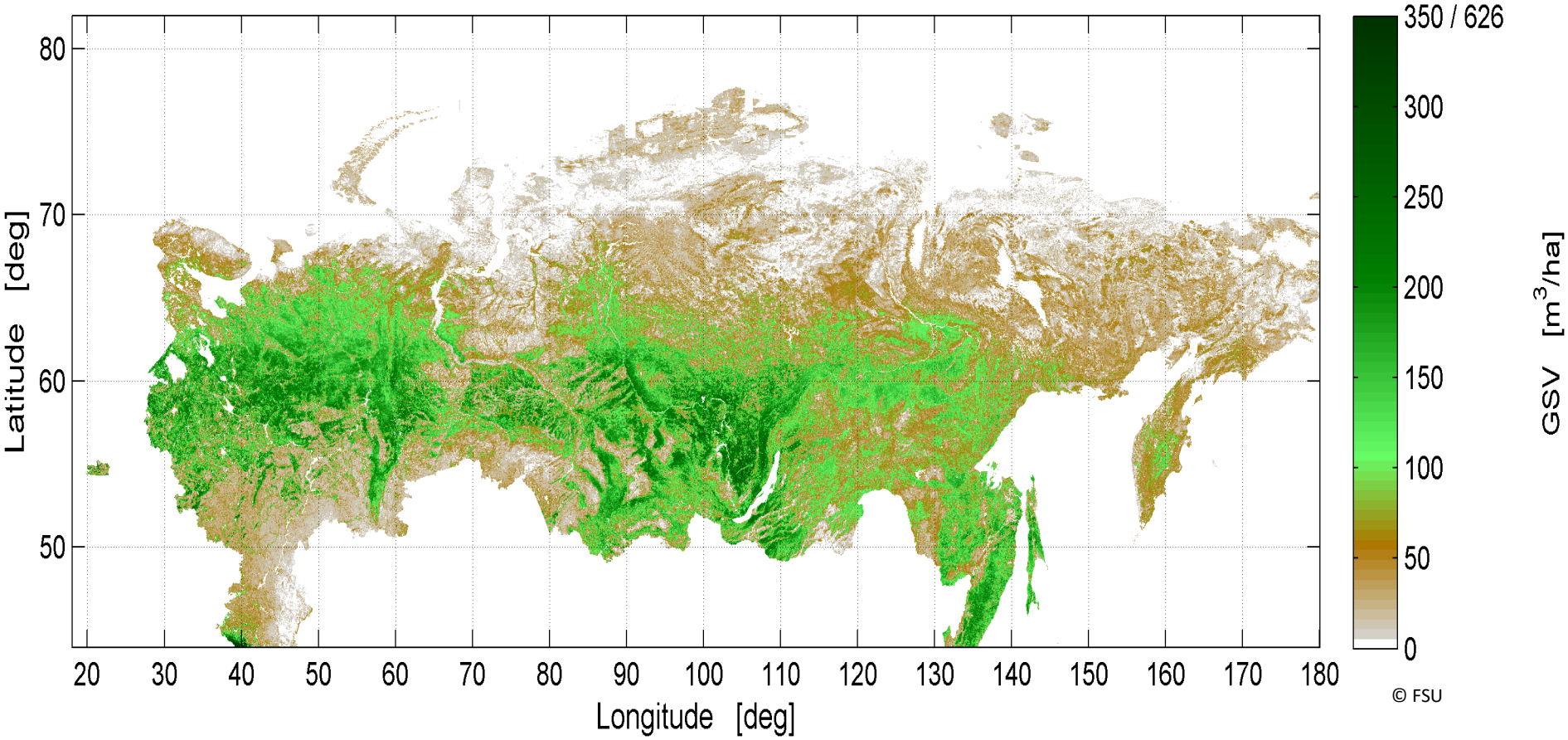
- 2,400,000 km²
- ENVISAT ASAR Global Monitoring mode (Jan. 2005 – Feb. 2006)
- GLC 2000 land cover used as background





BIOMASAR project

Pan-boreal growing stock volume

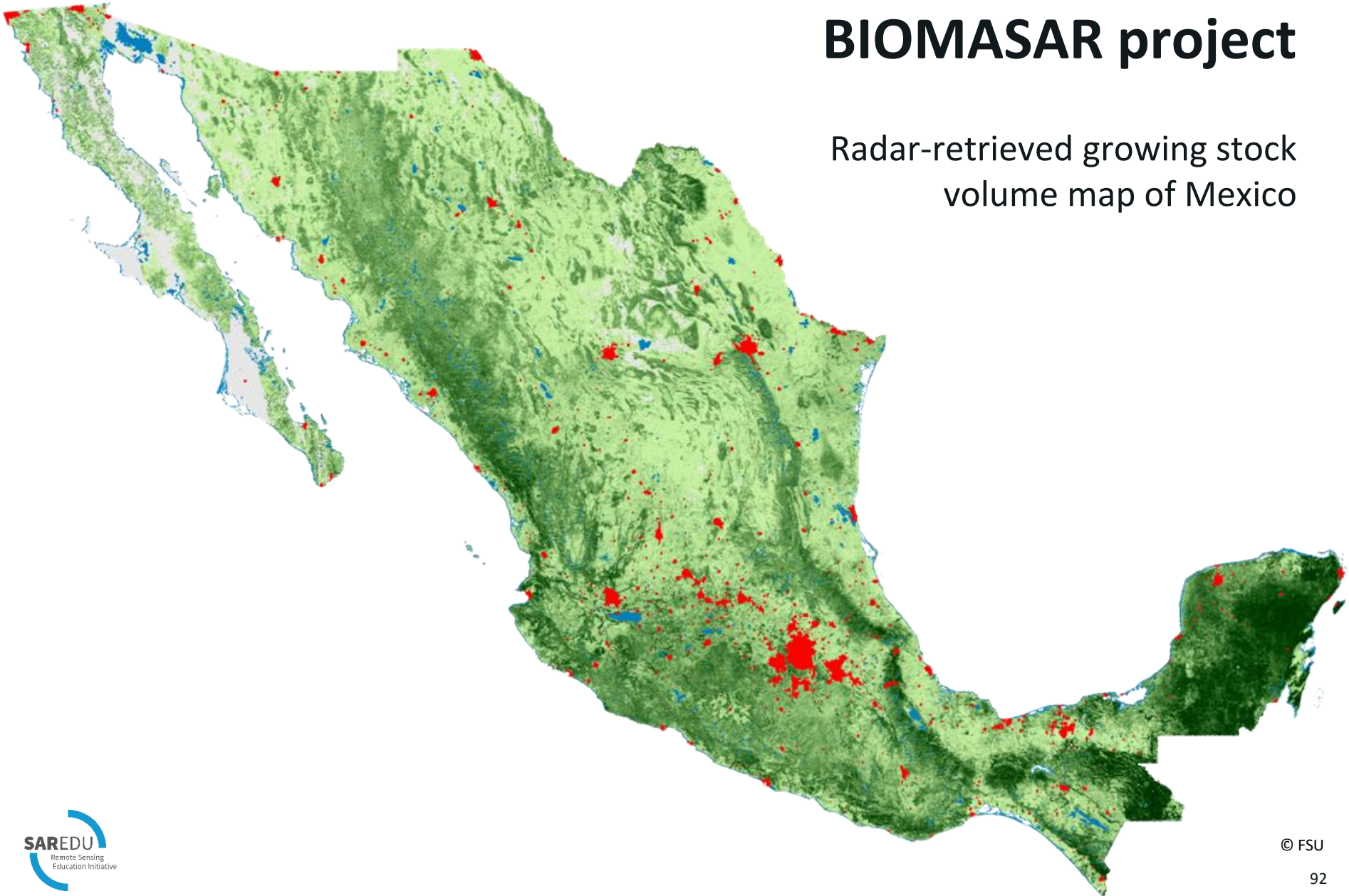


© FSU

Copyright ©

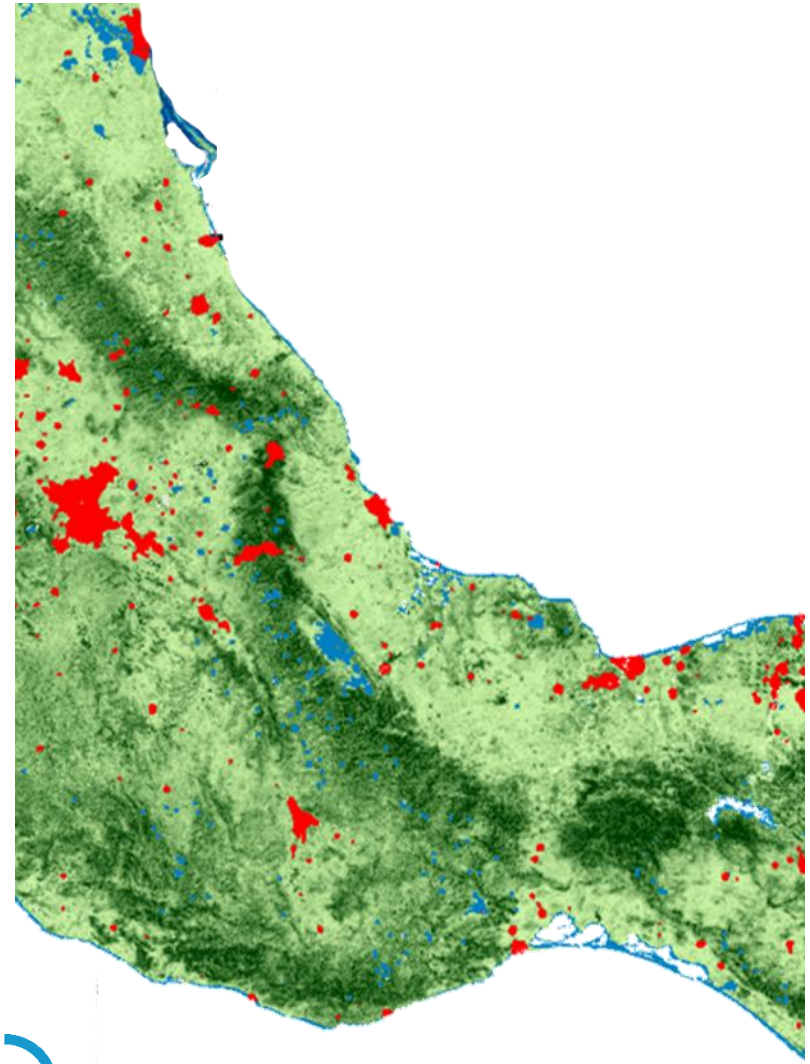
BIOMASAR project

Radar-retrieved growing stock volume map of Mexico

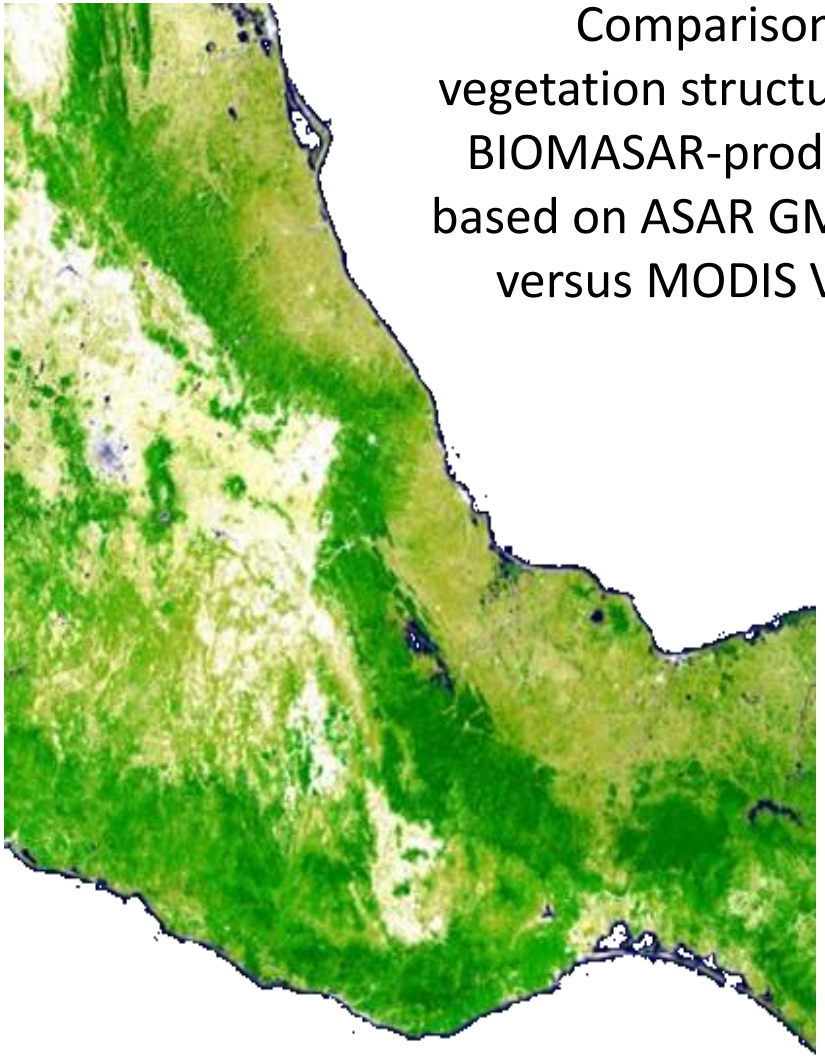


© FSU

BIOMASAR project



© FSU



© GLCF

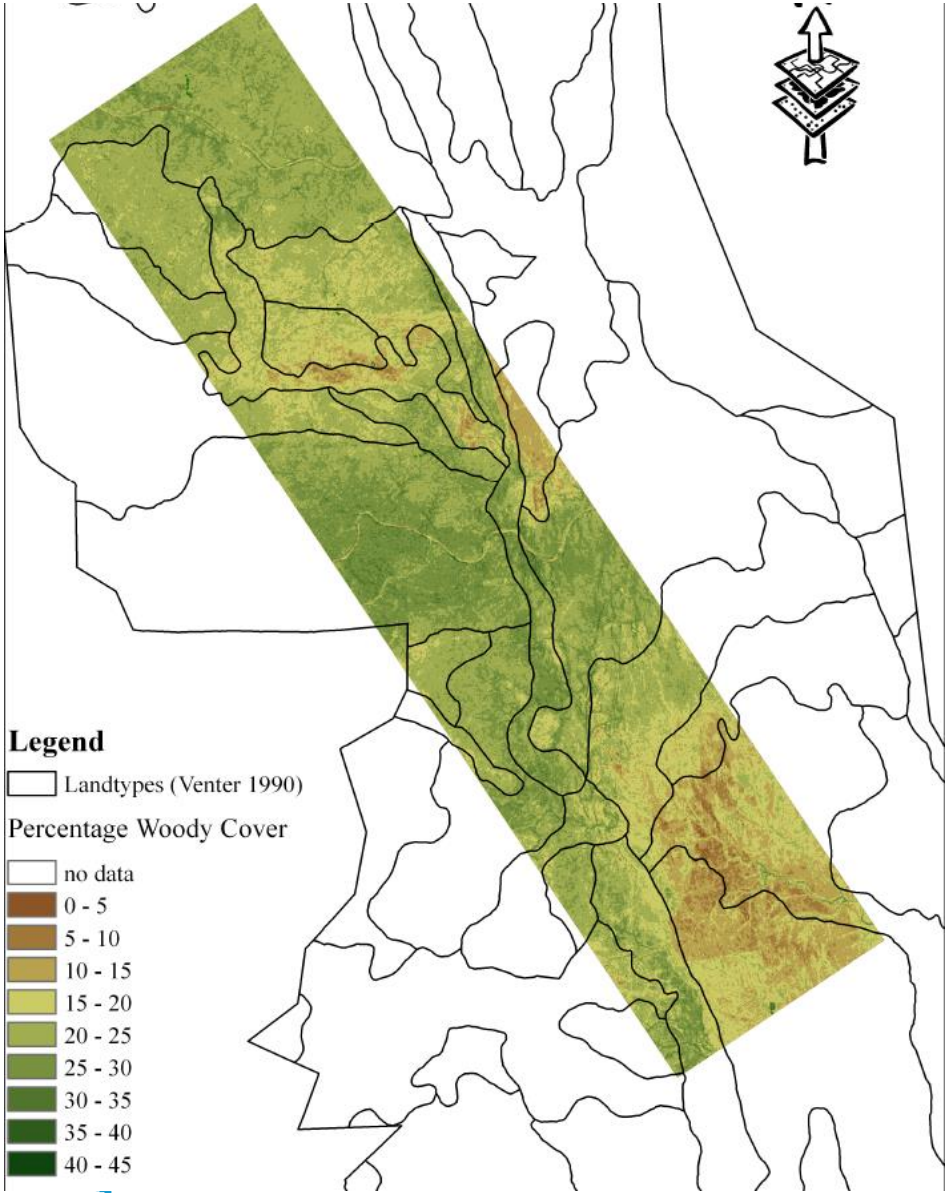
Comparison of vegetation structure: BIOMASAR-product based on ASAR GMM versus MODIS VCF

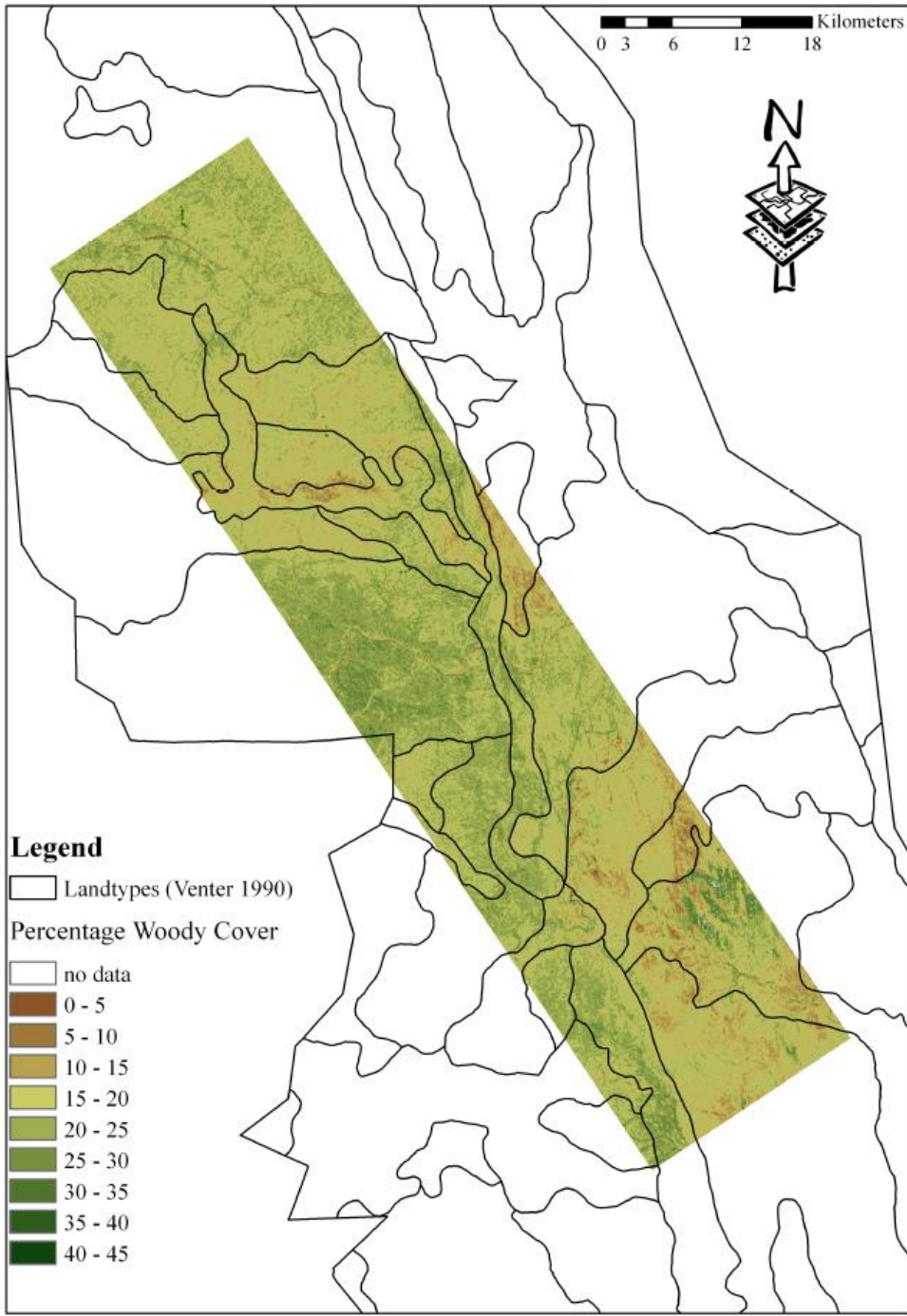
Application examples

- SIBERIA - Biomass mapping in Siberia
- ESA DRAGON – Biomass mapping in China
- BIOMASAR – Panboreal forest growing stock volume maps
- SARvanna – Vegetation structure mapping in the Kruger National Park
- Biomass from forest height – Fichtelgebirge, Germany

Kruger National Park Woody Cover Maps based on April 1994 SIR-C C- (right) and L-band data (left) at 37 deg incidence angle.
Retrieval algorithm: Volume Component from Freeman Decomposition

Copyright ©

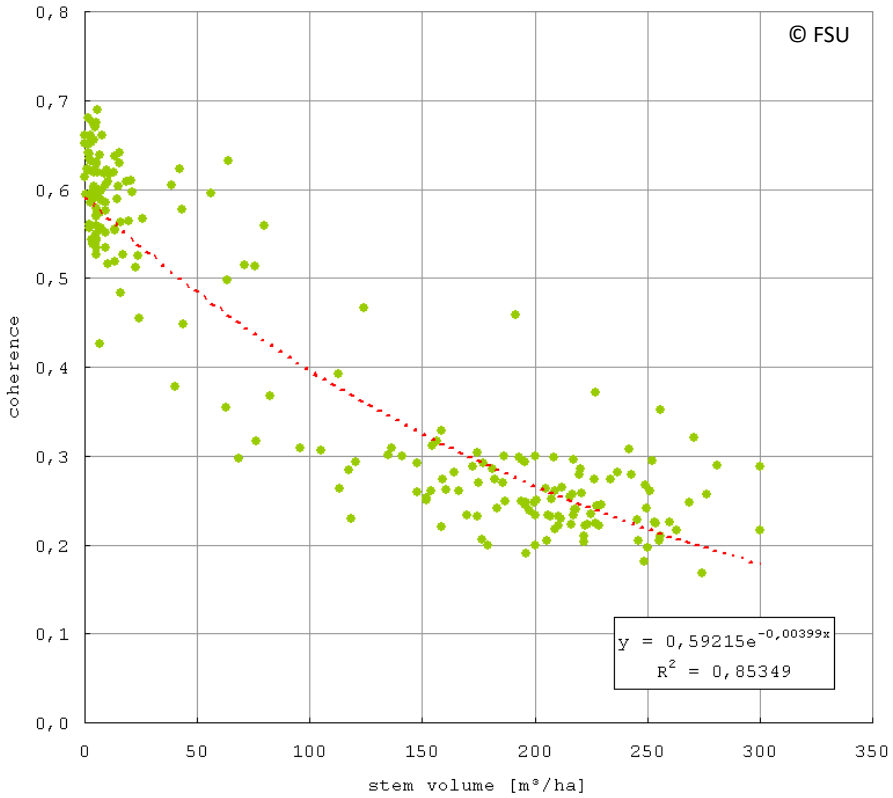




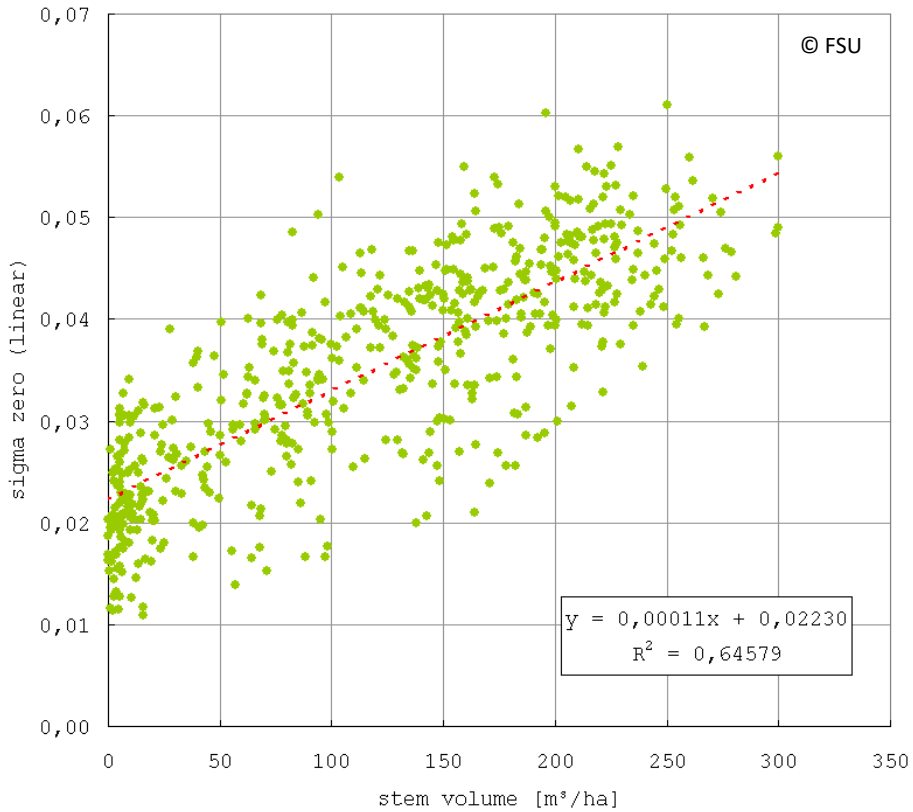
SARvanna project

Methodology – Jena IWC-model – excursus

Chunsky North – Regression Analysis for ALOS PALSAR Data



Stem volume vs. coherence
(05feb2008-22mar2008) – 12.5 m data

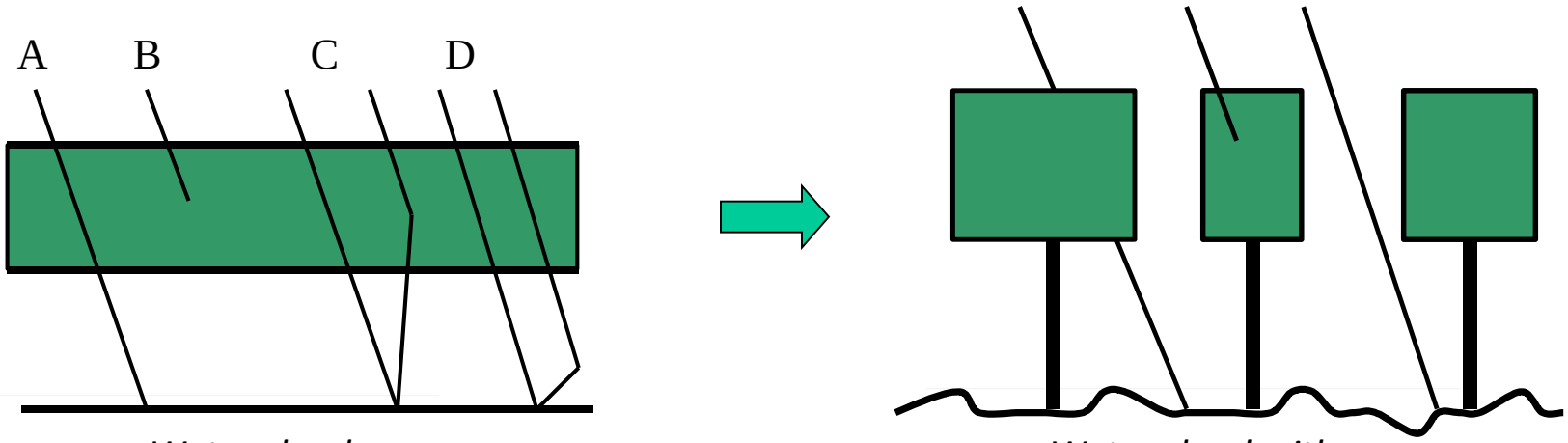


Stem volume vs. backscatter (HV)
(05aug2007) – 12.5 m data

Very significant correlation between SAR data and stem volume!

SARvanna project © FSU Jena

Methodology – backscatter model



Water cloud

Water cloud with gaps

- A water cloud with gaps is closer to reality and easy to handle

$$\sigma^o_{for} = \sigma^o_{gr} e^{-\beta V} + \sigma^o_{veg}\left(1 - e^{-\beta V}\right)$$

Ground backscatter

Forest transmissivity

Vegetation backscatter

- Forest transmissivity is related to canopy closure and tree attenuation

SARvanna project

Coherence modelling - Interferometric Water Cloud Model (IWCM)

$$\gamma_{for} = \gamma_{gr} \frac{\sigma^o_{gr}}{\sigma^o_{for}} e^{-\beta V} + \gamma_{veg} \frac{\sigma^o_{veg}}{\sigma^o_{for}} \left(\frac{1-e^{-\beta V}}{1-e^{-\alpha h}} \right) \left(\frac{\alpha}{\alpha - j\omega} \right) \left(e^{-j\omega h} - e^{-\alpha h} \right)$$

The total forest coherence is a sum of 2 contributions:

Ground coherence, Γ_{gr}

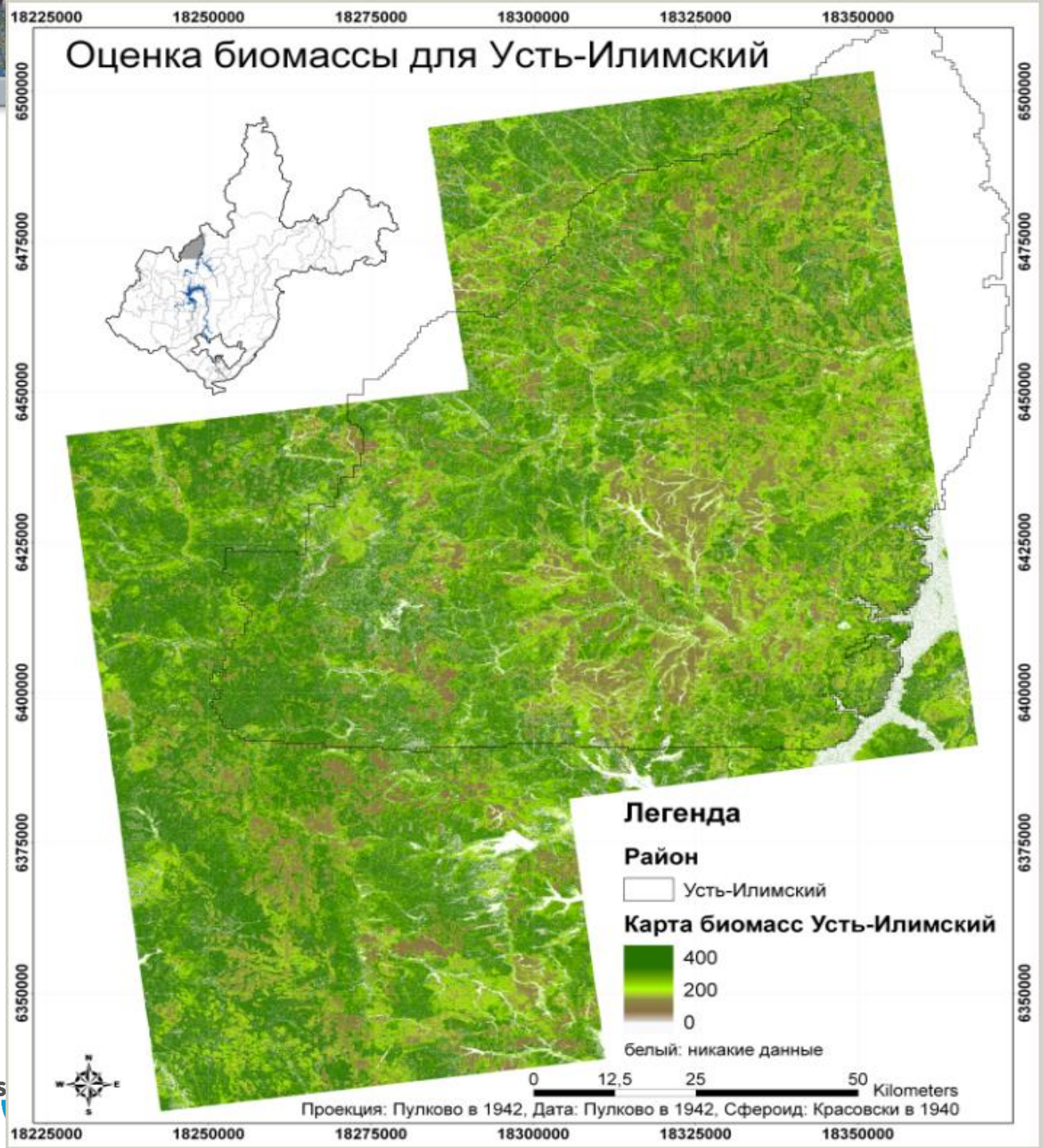
Vegetation coherence, Γ_{veg}

Model considers tree attenuation (α), gaps (β), InSAR geometry (ω)

Empirical relationship

$$\gamma_{for} = \gamma_{gr} e^{-\beta V} + \gamma_{veg} \left(1 - e^{-\beta V} \right)$$

No dependence upon InSAR geometry, forest backscatter and canopy structure



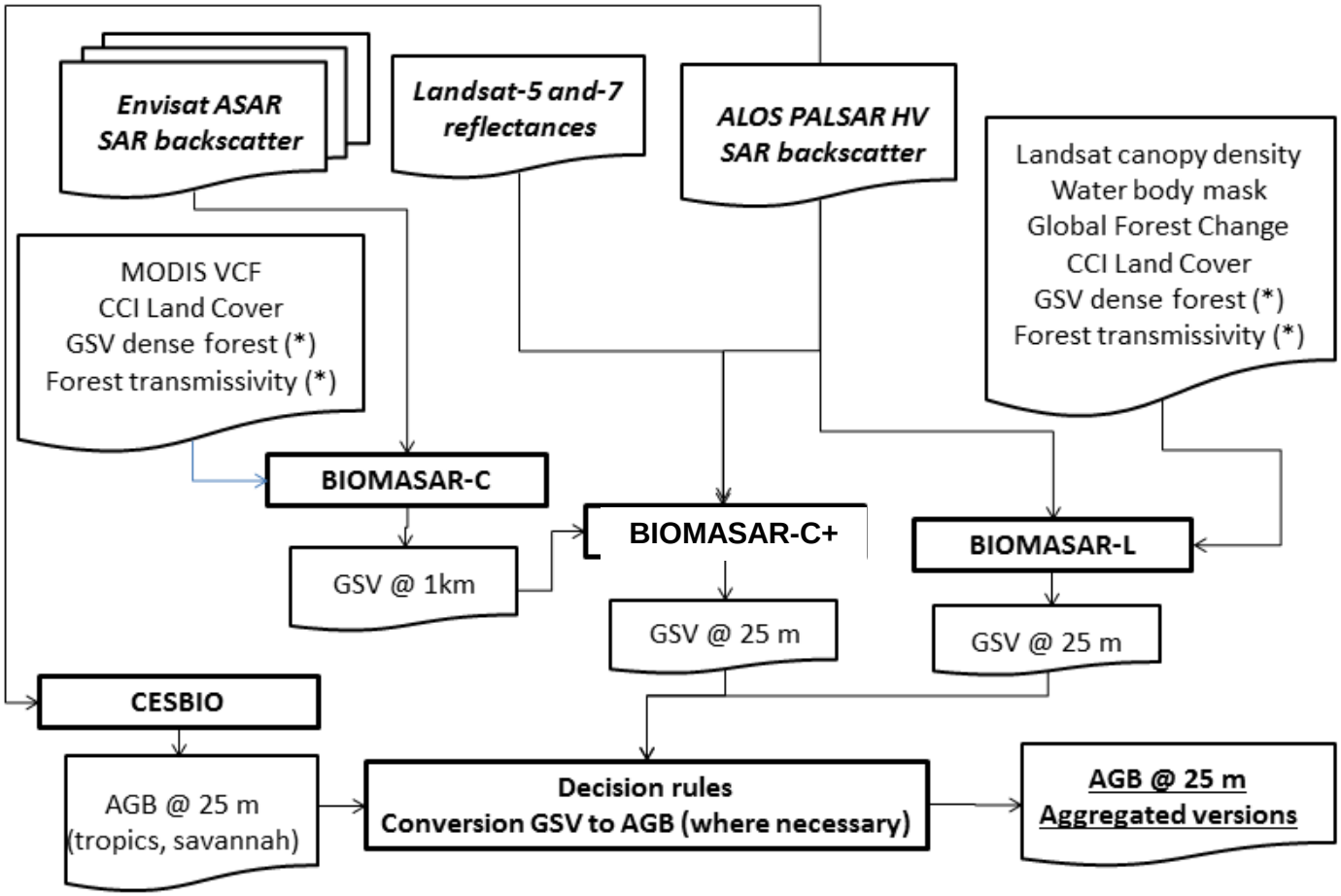
SARvanna project

Biomass map based on the **Jena IWC-Model** (Interferometric Water Cloud Model). Resolution 12,5 m.

Data Source:
ALOS PALSAR,
L-HH coherence from December 2008 until February 2009.

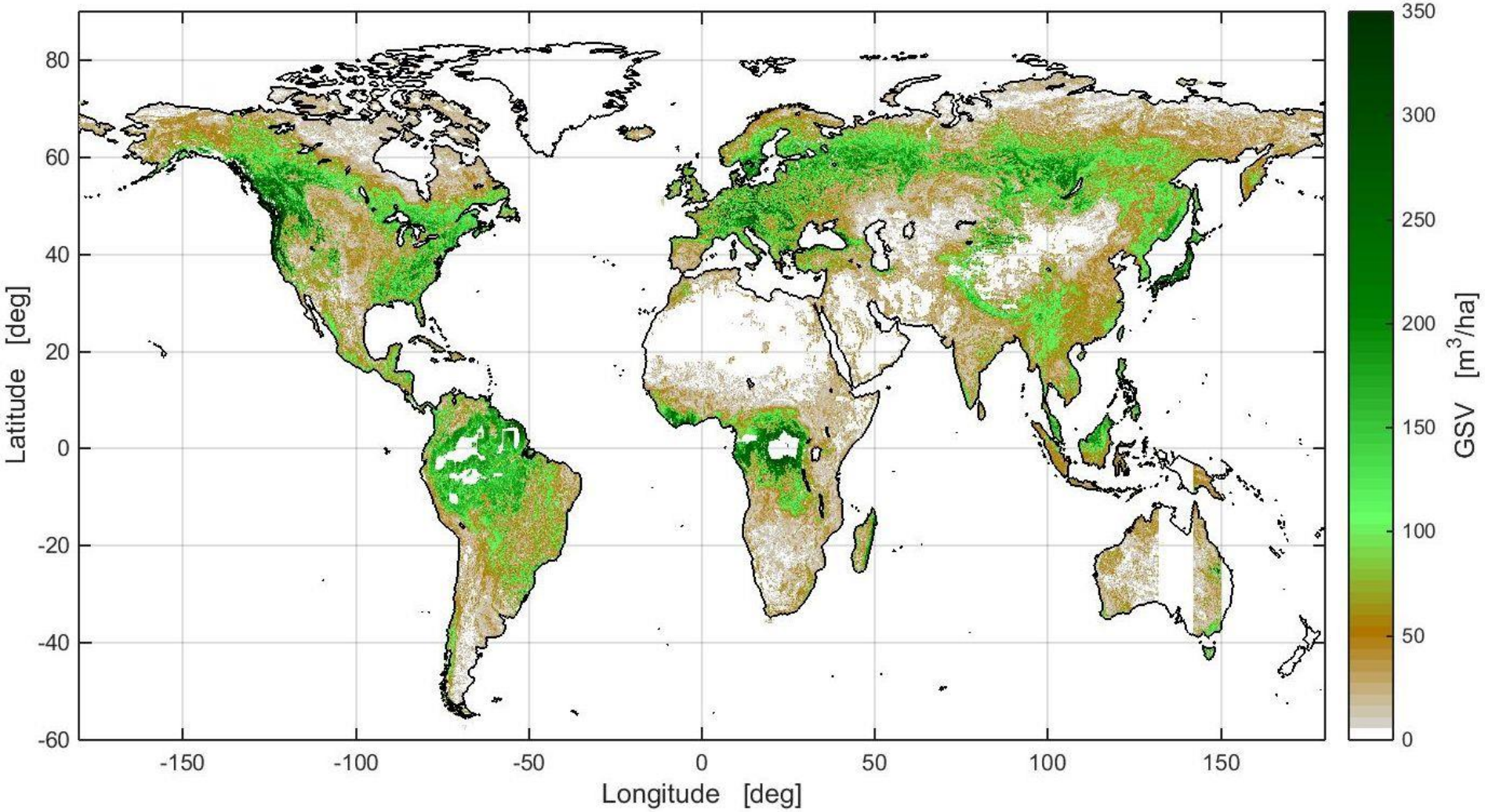
GlobBiomass
global retrieval algorithm

It is unlikely that the desired accuracy can be achieved with a single approach/data type!!!



(*) Estimation supported by vegetation height and cover from ICESAT GLAS waveforms

A global GSV-map for the year 2010



Application examples

- SIBERIA - Biomass mapping in Siberia
- ESA DRAGON – Biomass mapping in China
- BIOMASAR – Panboreal forest growing stock volume maps
- SARvanna – Vegetation structure mapping in the Kruger National Park
- Biomass from forest height – Fichtelgebirge, Germany

Copyright ©

Indirect biomass estimation from forest height

Mette et al., 2002 & 2004

- E-SAR data from May 11, 2001
- L-Band fully polarimetric data with an effective baseline of 8-10 m (at 45° incidence angle) and 14 min temporal baseline
- Test site Fichtelgebirge, Germany
- Forest height → inversion using the RVoG model

Copyright ©

Indirect biomass estimation from forest height

1 - FOREST HEIGHT
↓
2 - CONVERSION
↓
3 - FOREST BIOMASS

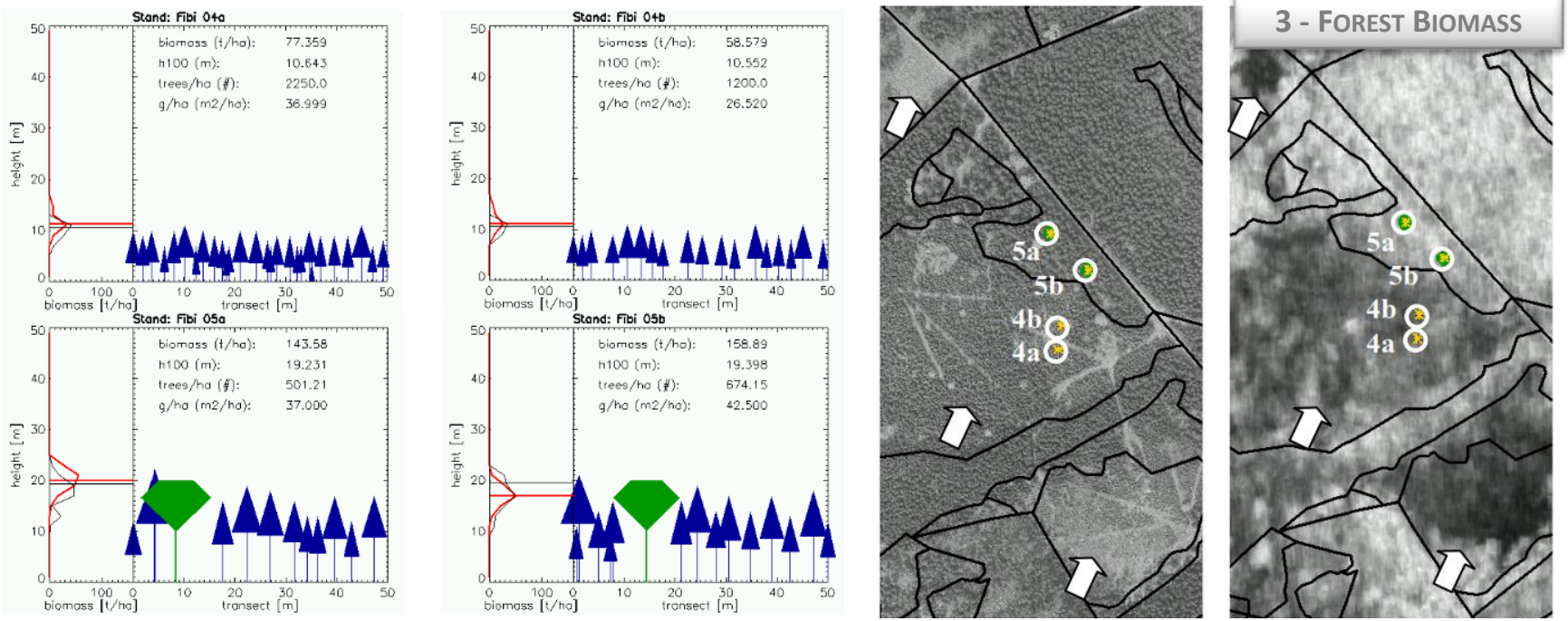


Fig.: Validation of forest heights extracted from Pol-InSAR data. (Left) aerial photograph, and extracted forest heights (scaling 0-25m), arrows=recent reforestations, small circles=selected test sites, (right) transect through four test sites: coneshaped=spruce, balloon shaped=beech, the right graph illustrates how much biomass is concentrated in each tree height class (2m interval). The thin line on the left depicts the height distribution and h determined from the ground measurements, the thick line the height distribution and h 100 from the extracted heights (METTE et al., 2004).

Indirect biomass estimation from forest height

1 - FOREST HEIGHT
↓
2 - CONVERSION
↓
3 - FOREST BIOMASS

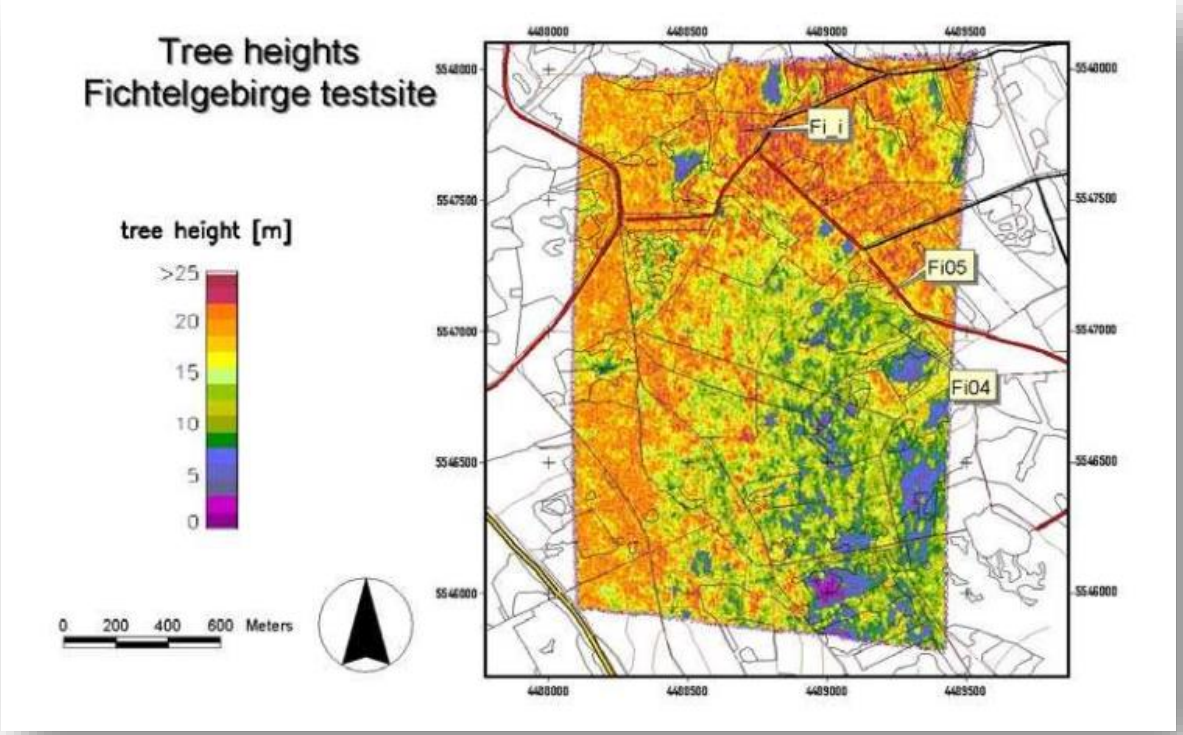


Fig.: Forest height image of a part of the Fichtelgebirge where forest height was extracted from the Pol-InSAR data using **the random volume over ground scattering model**. It is overlayed with a vector layer that contains the stand borders. Where two stands of different height meet, the stand border becomes clearly visible (METTE et al., 2002).

Indirect biomass estimation from forest height

1 - FOREST HEIGHT
↓
2 - CONVERSION
↓
3 - FOREST BIOMASS

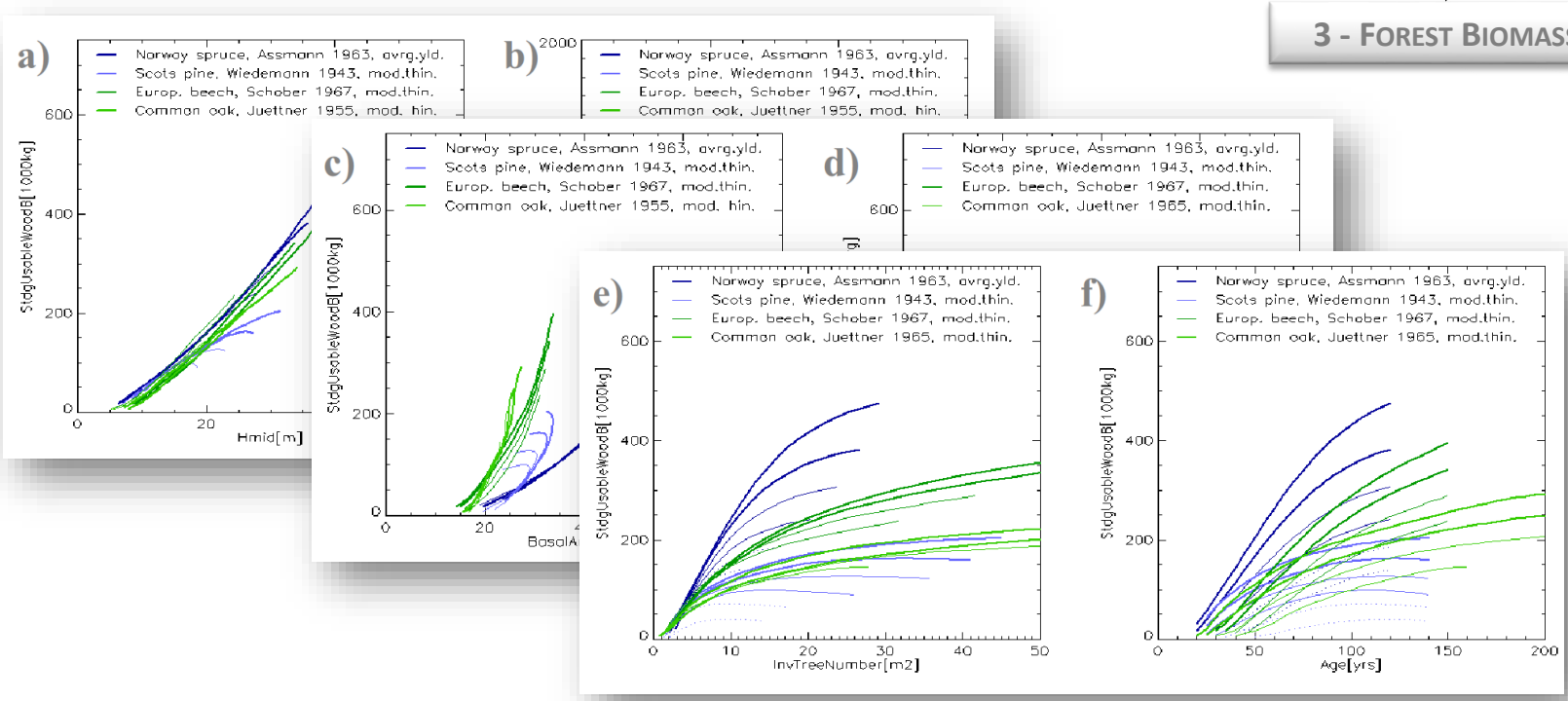


Fig.: Forest biomass allometry from yield tables of temperate forest species using different input parameters: (a) height, (b) heightvolume, (c) basal area, (d) dbh, (e) inverse tree density, (f) age. Each plot represents four species (=colors): spruce, pine, beech and oak. The different curves of each color stand for the different yield classes (METTE et al., 2004).

Indirect biomass estimation from forest height

1 - FOREST HEIGHT
↓
2 - CONVERSION
↓
3 - FOREST BIOMASS

Reference data

- $\boldsymbol{Biomass_{forest}}$= usable wood biomass (includes trunk and branches exceeding 7 cm diameter)

$$Biomass = volume \times \rho$$ (where ρ is the species' raw density)

- Reference heights:

h_{mid} = Corresponding to the mid dbh which is an area weighted (dbh^2) arithmetic mean for all trees per area unit (hectare [ha])

h_{100} = Upper canopy height, top height (average height of the highest 100 trees per hectare

METTE ET AL., 2002

Copyright © DLR

Indirect biomass estimation from forest height

1 - Forest Height
↓
2 - Conversion
↓
3 - Forest Biomass

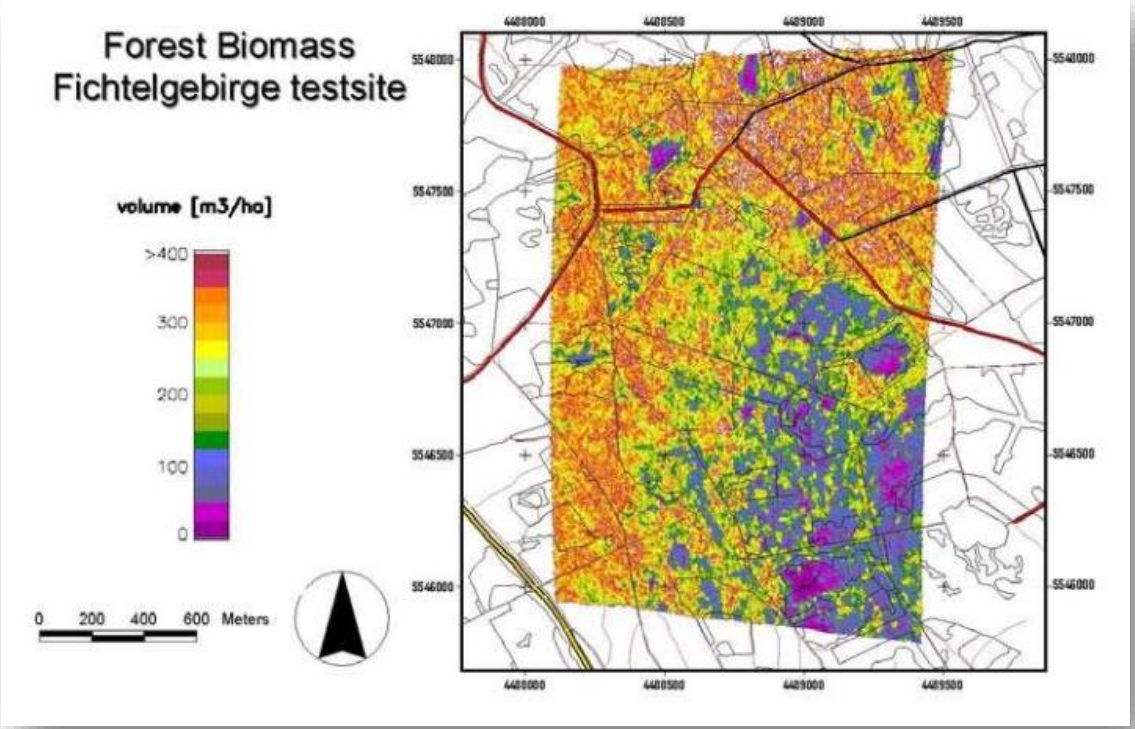


Fig.: Forest stem biomass image calculated from forest heights. Assuming that the extracted height of each pixel equals the h of that pixel, the height-biomass allometry for Norway spruce was applied to calculate stem biomass. Since the test site is dominated by managed Norway spruce stands the accuracy should not fail by more than +/- 15 % (Mette et al., 2002).

Indirect biomass estimation from forest height

1 - Forest Height
↓
2 - Conversion
↓
3 - Forest Biomass

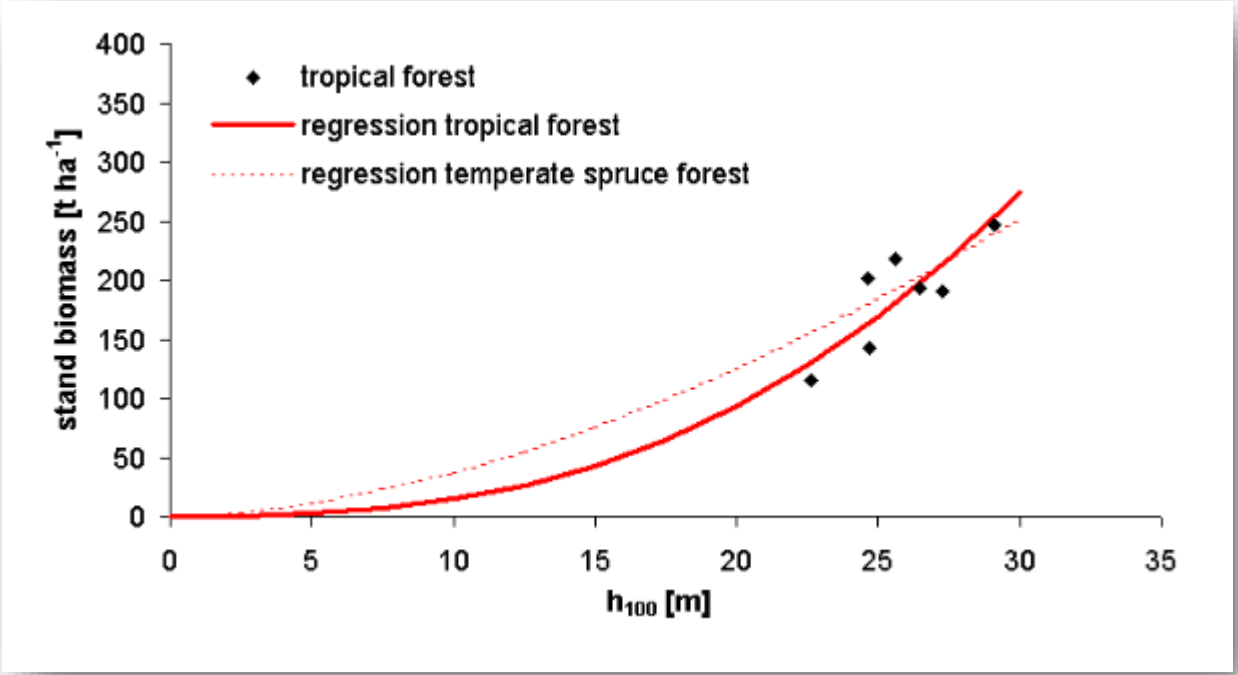
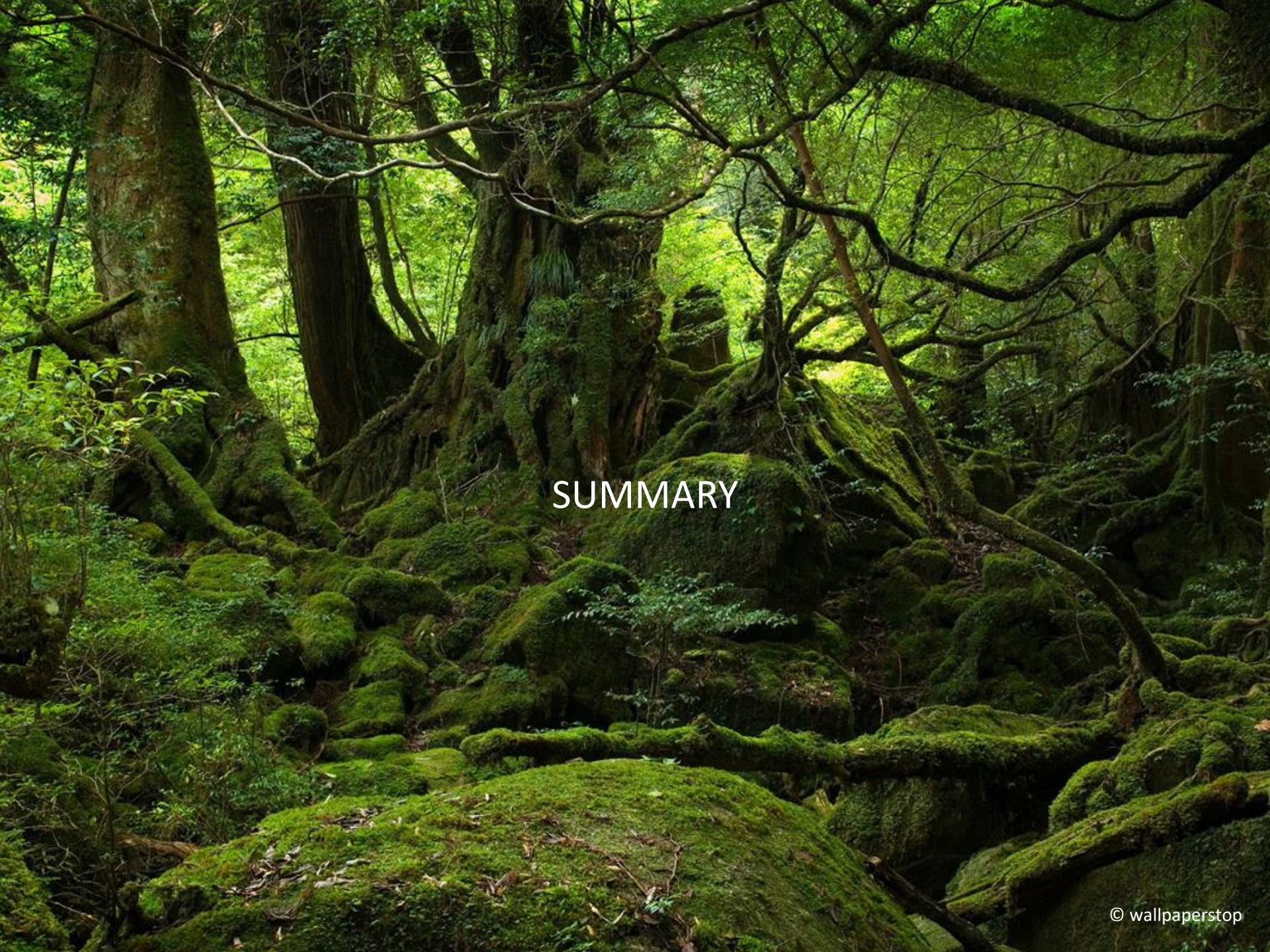


Fig.: Height-biomass allometry for a montane tropical rain forest (Peru) and a temperate spruce forest (Germany) (Mette et al., 2002).


SUMMARY
© wallpaperstop

Summary

SAR techniques for forest monitoring

- **Backscatter analysis** (long wavelength, HV polarisation, the shorter the wave-length – the more images, summer data in boreal zone) – Sentinel-1, ALOS-2
- **Interferometry: Coherence** analysis (shorter wavelengths require shorter temporal and spatial baselines, frozen conditions in the boreal zone), new results show great potential of single pass TanDEM-X coherence
- **Interferometry:** Phase analysis (multi wavelength, polarisation, single-pass, acquisition conditions!) – no operational sensor constellation yet, but…
- **Polarimetry** (long wavelength, high number of images) – still matter of research, some potential was demonstrated
- **Polarimetric Interferometry** (long wavelength, spatial baseline, single-pass, acquisition conditions!) – no operational sensors yet, but…
- **(Polarimetric) Tomography** (long wavelength, polarisation, spatial baselines, quasi single-pass, acquisition conditions!) – no operational sensors (and no planning for the future)

Summary

Biomass from RADAR REMOTE SENSING

METHOD			EXAMPLE
Backscatter analysis	Estimation of AGB at different scales	Relation between radar backscatter and forest biomass is often ambiguous and saturates rapidly with biomass except with hyper-temporal approach (BIOMASAR)	Le Toan et al. 1992 Dobson et al. 1992 Santoro et al. 2011
Interferometric coherence	No saturation problem	Strong dependency on the time span and the conditions between the 2 acquisitions	Hyyppä et al. 2000 Fransson et al. 2001 Pulliainen et al. 2003
Inversion from other forest parameters, e.g. forest height	Forest height easier to measure using RS techniques Close relationship between forest height and biomass	Total error includes both, the error in the height extraction and in the height –biomass conversion	Mette et al. 2004 Mette et al. 2002

[Ghasemi et al., 2011; Mette et al., 2004]

https://registrierung.cdonline.de/erdbeobachtung/downloads/vortraege/Tag2/4a/3_Urbazaev_Sentinel4REDD.pdf

Sen4REDD ESA-Project with a testsite in Chapas

Copyright ©

References

- Balzter, H. (2001). Forest mapping and monitoring with interferometric synthetic aperture radar (InSAR). *Progress in Physical Geography, 25*(2), 159-177.
- Dobson, M. C., Ulaby, F .T., LeToan, T., Beaudoin, A., Kasischke, E. S., & Christensen, N. (1992). Dependence of radar backscatter on coniferous forest biomass. *IEEE Transactions on Geoscience and Remote Sensing, 30*, 412-415.
- European Space Agency (ESA) (2008). *Candidate Earth Explorer Core Missions – Reports for Assessment: BIOMASS* (ESA SP-1313/2). Noordwijk, The Netherlands: ESA Communication Production Office.
- FAO (2009). *Assessment of the status of the development of the standards for the terrestrial essential climate variables: BIOMASS*. Rome, Italy: GTOS Secretariat, NRL, FAO.
- Fransson, J. E. (2001). Stem volume estimation in boreal forests using ERS1/2 coherence and SPOT XS optical data. *International Journal of Remote Sensing, 25*, 2777-2791.
- Ghasemi, N., Sahebi, M. R., & Mohammadzadeh, A. (2011). A review on biomass estimation methods using synthetic aperture radar data. *International Journal of Geomatics and Geosciences, 1*(4), 776-788.
- Hajnsek, I., Kugler, F., Lee, S.-K., & Papathanassiou, K. (2009). Tropical-forest-parameter estimation by means of Pol-InSAR: The INDREX-II campaign. *IEEE Transactions on Geoscience and Remote Sensing, 47*(2), 481-493.

Copyright ©

References

- Hoekman, D & M.J. Quiñones, 1997. Land Cover Type and Forest Biomass Assessment in the Colombian Amazon. Proceedings Geoscience and Remote Sensing Symposium IGARSS 1997 (pp. 1728-1730), Aug 03-08, 1997, Singapore.
- Hyyppä, J. H.-H. (2000). Accuracy comparison of various remote sensing data sources in the retrieval of forest stand attributes. *Forest Ecology and Management, 128*(1-2), 109-120.
- Imhoff, M. L. (1995). Radar backscatter and biomass saturation: ramifications for global biomass inventory. *IEEE Transactions on Geoscience and Remote Sensing, 33*(2), 511-518.
- Jensen, J. R. (2000). *Remote Sensing of the Environment: An Earth Resource Perspective*. Upper Saddle River, New Jersey: Prentice Hall.
- Le Toan, T. (2001). On the relationships between Radar measurements and forest structure and biomass. Proceedings of the *Third International Symposium on* Retrieval of Bio- and Geophysical Parameters from SAR Data for Land Applications, September 11.-14., Sheffield, UK.
- Le Toan, T., Beaudoin, A., Riom, J., & Guyon, D. (1992). Relating Forest Biomass to SAR Data. *IEEE Transactions on Geoscience and Remote Sensing*, *30*(2), 403-411.
- Lu, R. (2006): The potential and challenge of remote sensing-based biomass estimation. *International Journal of Remote Sensing,* 27(7), 1297-1328.
- Lucas, R. M., Cronin, N., Lee, A., Moghaddam, M., Witte, C., & Tickle, P. (2006). Empirical relationship between AIRSAR backscatter and LIDAR-derived forest biomass, Queensland, Australia. *Remote Sensing of Environment, 100*, 407-425.

Copyright ©

References

- Luckman, A., Baker, J. R., & Wegmüller, U. (2000). Repeat-Pass interferometric coherence measurements of disturbed tropical forest from JERS and ERS satellites. *Remote Sensing of Environment, 73*, 350-360.
- Luckman, A., Baker, J. R., Honzak, M., & Lucas, R. (1998). Tropical forest biomass density estimation using JERS-1 SAR: seasonal variation, confidence limits and application to image mosaics. *Remote Sensing of Environment, 63*, 126-139.
- Malhi, Y. P. (2002). Forests, carbon and global climate. *Philosophical Transactions of the Royal Society of London A, 360*(1797), 1567-1591.
- Mette, T., Papathanassiou, K. P., Hajnsek, I., & Zimmermann, R. (2002). Forest biomass estimation using polarimetric SAR interferometry. Proceedings Geoscience and Remote Sensing Symposium IGARSS 2002 (pp. 817-819), June 24-28, 2002, Toronto, Canada.
- Mette, T. (2004). Applying a common allometric equation to convert forest height from Pol-InSAR data to forest biomass. Proceedings Geoscience and Remote Sensing Symposium IGARSS 2004 (pp. 269-272), Sep 20-24, 2004, Anchorage, USA.
- Pulliainen, J. M. (2003). Feasibility of multitemporal interferometric SAR data for stand-level estimation of boreal forest stem volume. *Remote Sensing of Environment, 85*(4), 397-409.

Copyright ©

References

- Ribbes, F., Le Toan, T., Bruniquel, J., Floury, N., Stussi, N., Liew, S. C. & Wasrin, U. R. (1997). Forest mapping in tropical region using multitemporal and interferometric ERS-1/2 data. *Proceedings of Congrès. Space at the service of our environment, 3rd ERS Symposium*, March 14-21, 1997, Florence, Italy.
- Santoro, M., Eriksson, L., Askne, J., Schmullius, C. (2006). Assessment of stand-wise stem volume retrieval in boreal forest from JERS-1 L-band SAR backscatter. *International Journal of Remote Sensing, 27(16),* 3425-3454.
- Santoro, M., Beer, C., Cartus, O., Schmullius, C., Shvidenko, A., McCallum, I., Wegmüller, U., & Wiesmann, A. (2011). Retrieval of growing stock volume in boreal forest using hyper-temporal series of Envisat ASAR ScanSAR backscatter measurements. *Remote Sensing of Environment, 115*(2), 490-507.
- Thiel, C. & C. Schmullius (2012): Effect of tree specieson PalSAR InSAR coherence over Siberian forest at frozen and unfrozen conditions. Proceedings of Geoscience and Remote Sensing Symposium (IGARSS), July 22-27, 2012, Munich.
- Wagner, W., Luckman, A. , Vietmeier, J., Tansey, K., Balzter, H., Schmullius, C. ,Davidson, M., Gaveau, D. , Gluck, M.,Le Toan, T.,Quegan, S., Shvidenko, A., Wiesmann, A. & Yu, J.J. (2003). Large-scale mapping of boreal forest in SIBERIA using ERS tandem coherence and JERS backscatter data. *Remote Sensing of Environment, 85*(5), 125-144.
- Woodhouse (not specified): Forest biomass from active remote sensing? University of Edinburgh. Edinburgh Earth Observatory. Retrieved on August, 10, 2012 from <http://www.geos.ed.ac.uk/ conferences/measuring-carbon-in-practice/presentation_IW.pdf>

SAREDU Remote Sensing Education Initiative

Copyright ©

SAR-EDU – SAR Remote Sensing Educational Initiative

https://saredu.dlr.de/

Supported by:

Federal Ministry
of Economics
and Technology

on the basis of a decision
by the German Bundestag

SAREDU
Remote Sensing
Education Initiative