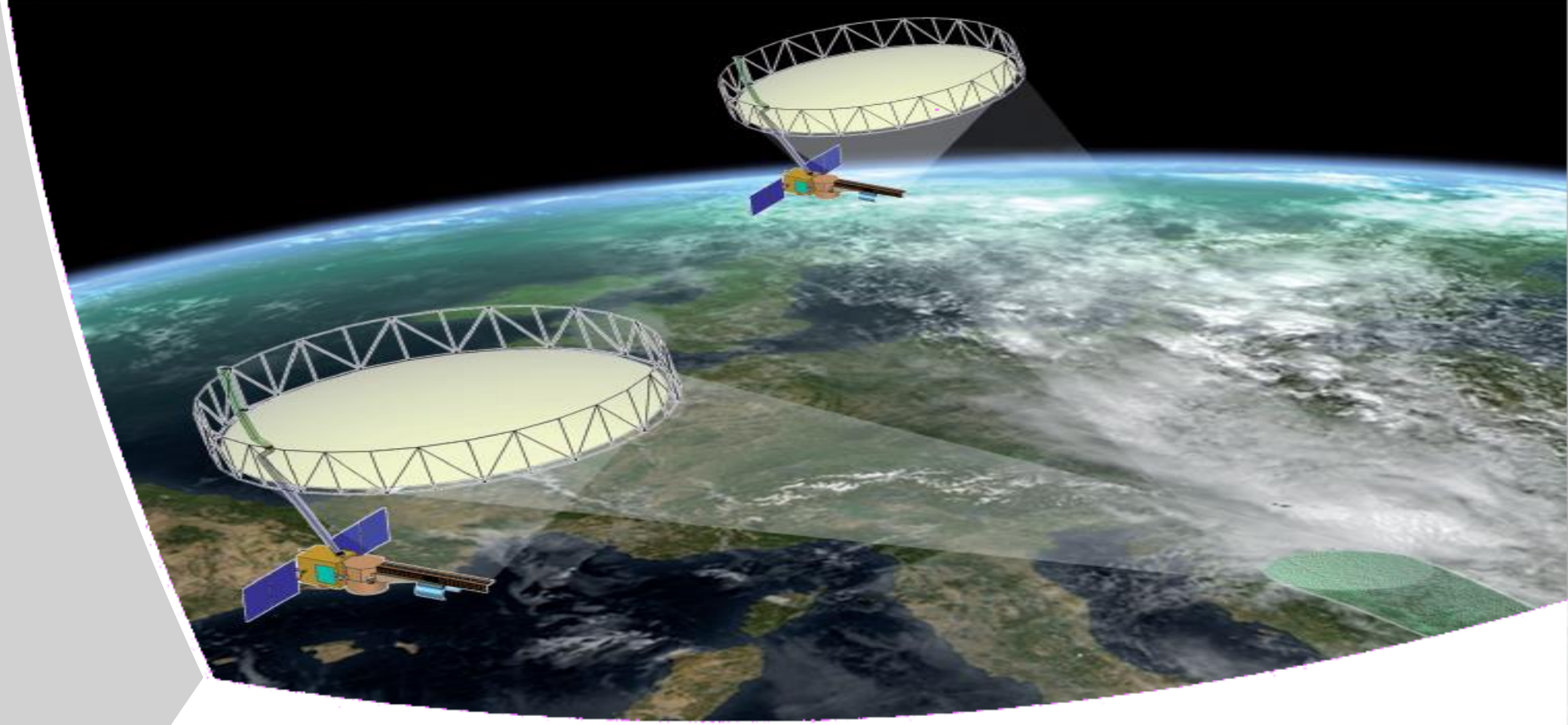
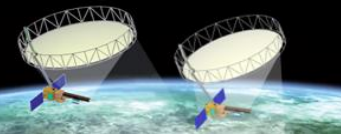


Tandem-L

Microwaves and Radar Institute

Dynamic Processes on the Earth Surface



Biosphere

- Deforestation, Degradation, Fires* (REDD)
- Forest Biomasse Change*
- Biodiversity
- ...

Geosphere

- Earthquakes
- Volcanic Activities
- Land Slides
- ...

Cryosphere

- Sea Ice Extent*
- Permafrost*
- Glacier & Ice Cap Dynamics*
- ...

Hydrosphere

- Soil Moisture*
- Flooding
- Ocean Currents*
- ...

*) Essential Climate Variables

Days — Weeks — Months — Years → **Observation Interval**

Attributes/ Parameters	Coverage	Avg. Uncertainties	Min. Mapping Unit [m]	Observation Frequency	Observation Interval	Description
Forest Height	global	~ 10% (-20%)	30x30-**50x50**	12 months	> 5 years	For biomass estimation
	regional	~ 10% (-20%)	**20x20**–30x30	**3**-5 years	> 5 years	For forest inventory
	local	(2.5) – **10%**	<<10x10– **20x20**	**2**-5 years	> 5 years	Site quality characterisation
Forest structure	global	**3 v-layers 5-10m**	30x30–**50x50**	Seasonal	> 5 years	Forest monitoring
	regional	**3 v-layers 5-10m**	**20x20**–30x30	on demand	> 5 years	Disturbance, Monitoring
Forest Biomass	global	**≥20t/ha 20** - 30%	70x70- **100x100**	12 months	> 5 years	Carbon stock
	regional	**10 – 15t/ha ≤or 20%**	**≤ 50x50**	5 years	> 5 years	For forest inventory
Underlying topography	global	< 4 m	30x30-**50x50**	12 months	> 5 years	Water dynamics

Biosphere: Observation Requirements

Attributes/ Parameters	Coverage	Avg. Uncertainties	Min. Mapping Unit [m]	Observation Frequency	Observation Interval	Description
Forest Height Change	global	From 1m to 20 - 30% (of change)	30x30-50x50	Yearly	>5 years	For biomass change
	regional	From 1m to 20 - 30% (of change)	20x20–30x30	On demand	>5 years	Disturbance Monitoring
Forest Structure Change	global	± 1 layer of change	30x30–50x50	Seasonal Yearly	>5 years	Forest characterisation
	regional	± 1 layer of change	20x20–30x30	On demand	>5 years	Forest monitoring
Forest Biomass Change	global	From 5t/ha to 30% (of change)	70x70-100x100	Yearly	>5 years	Carbon change
	regional	From 5t/ha 20 - 30% (of change)	≤ 50x50	5 years	>5 years	For F. inventory
Underlying topography change	regional	From 1m to 20 - 30% (of change)	30x30-50x50	on demand	>5 years	Flooding events

Biosphere

Biodiversity & Forest

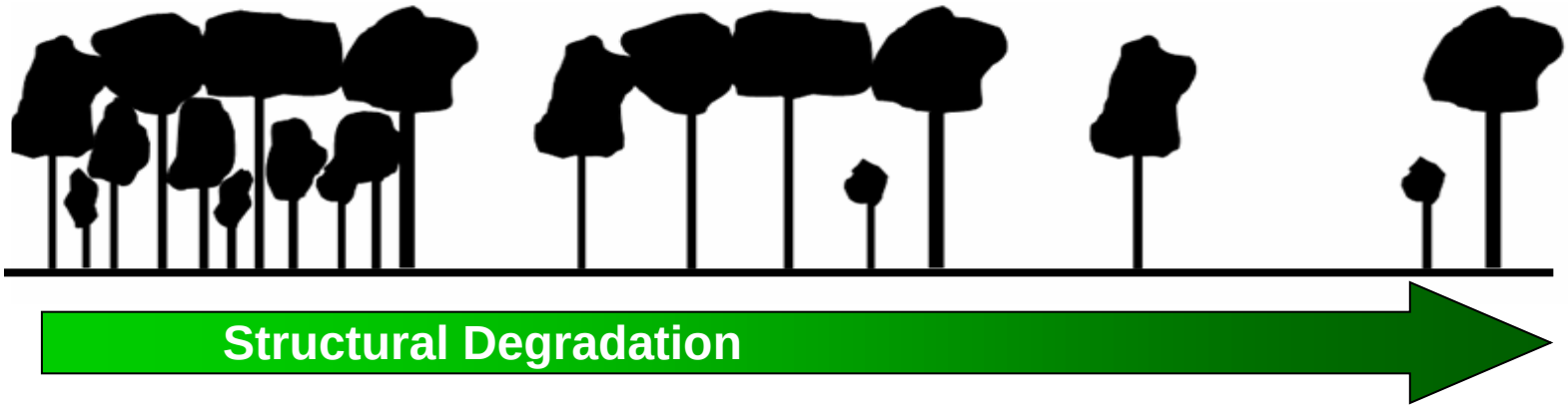
- 80% of the terrestrial Biodiversity lives in - primarily tropical – Forest-Ecosystems.

Biosphere

Biodiversity & Forest

- 80% of the terrestrial Biodiversity lives in - primarily tropical – Forest-Ecosystems.
- Besides the reduction of forested areas (deforestation), forest fragmentation and degradation impacts biodiversity seriously.

Structural degradation of forest (caused by legal / illegal logging, fire and other human activities) is not possible to be detected with conventional remote sensing techniques.



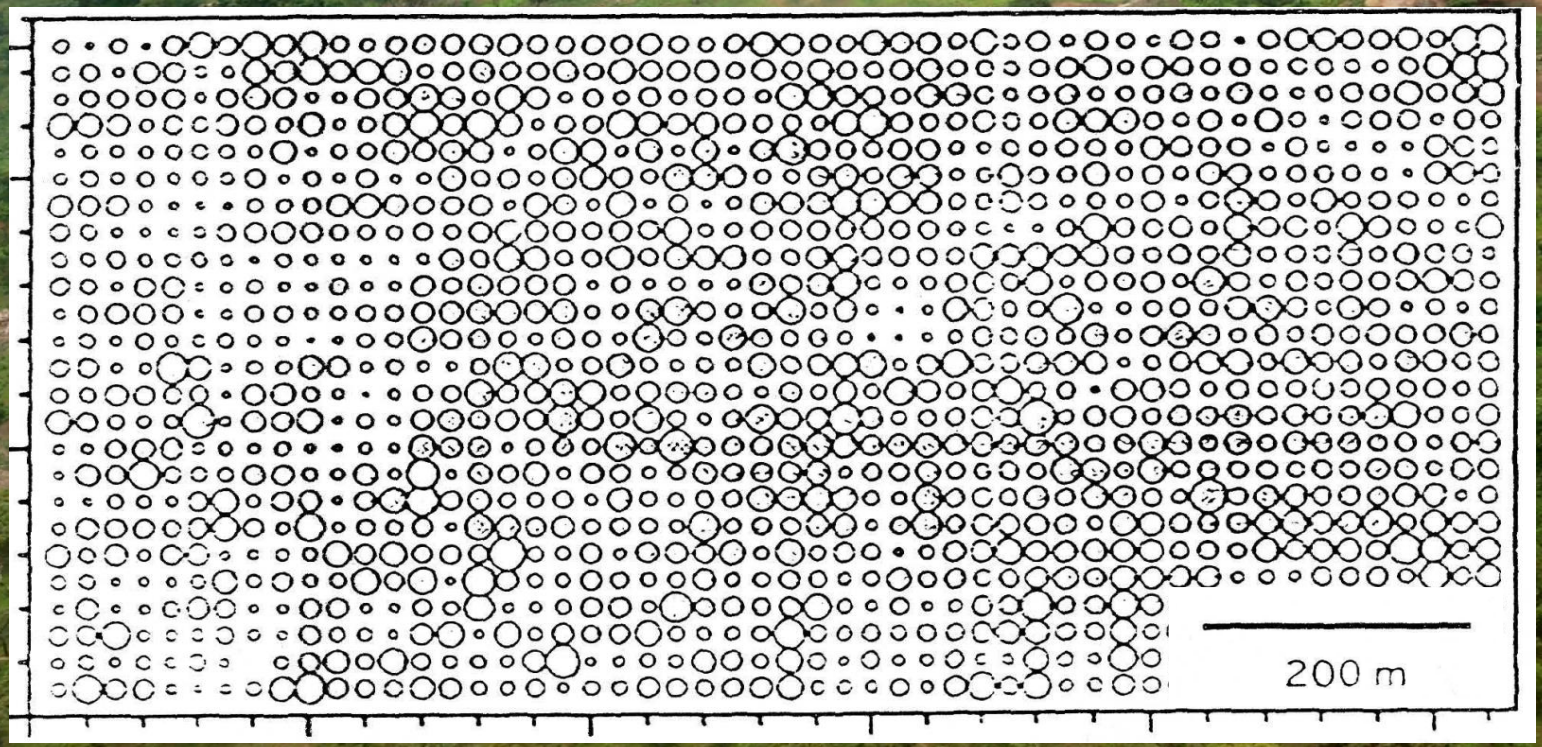
Institute for World Forestry

Biosphere

Challenge

High spatial variability of local biomass (due to natural disturbance regimes and human activities) and structure (vertical & horizontal):

Example: Lowland tropical forest in Lambir, Malaysia (Yoneda et al. 1996, 50ha, 200.000 trees)



Size of circles indicate local biomass (20x20 m, 1300 plots)

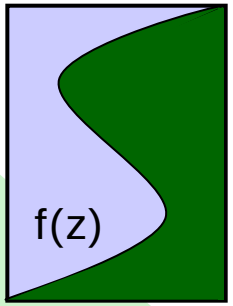
Interferometric Coherence

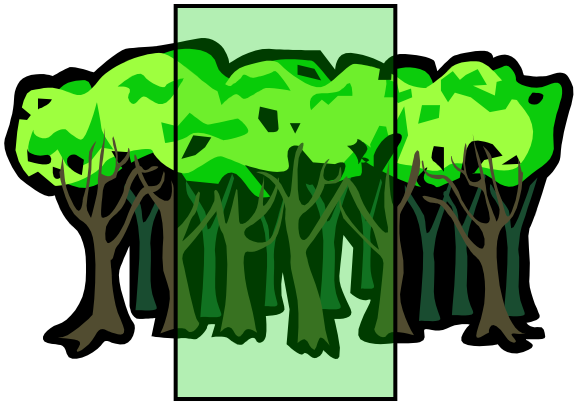
$$\tilde{\gamma}(S_1\,S_2) = \frac{< S_1\,S_2^* >}{\sqrt{< S_1\,S_1^* >\,< S_2\,S_2^* >}}$$

SAR Interferometry for Volume Structure

Volume Coherence

$$\tilde{\gamma}_{Vol}(f(z)) = e^{ik_z z_o} \frac{\int_o^{h_v} f(z)\, e^{ik_z z} dz}{\int_o^{h_v} f(z)\, dz}$$





f(z) … vertical reflectivity function

$$\tilde{\gamma} = \tilde{\gamma}_{Temporal}\,\gamma_{SNR}\,\tilde{\gamma}_{Volume}$$

- $\tilde{\gamma}_{Temporal}$ … temporal decorrelation
- γ_{SNR} … additive noise decorrelation
- $\tilde{\gamma}_{Volume}$ … geometric decorrelation

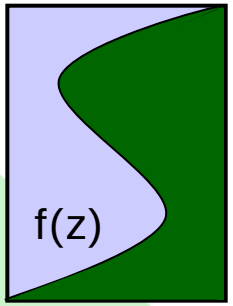
Vertical Wavenumber: $\kappa_z = \frac{\kappa \Delta\theta}{\sin(\theta_0)}$

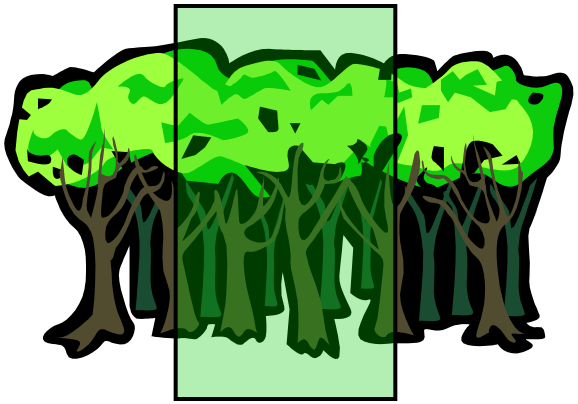
Polarimetric Coherence Tomography

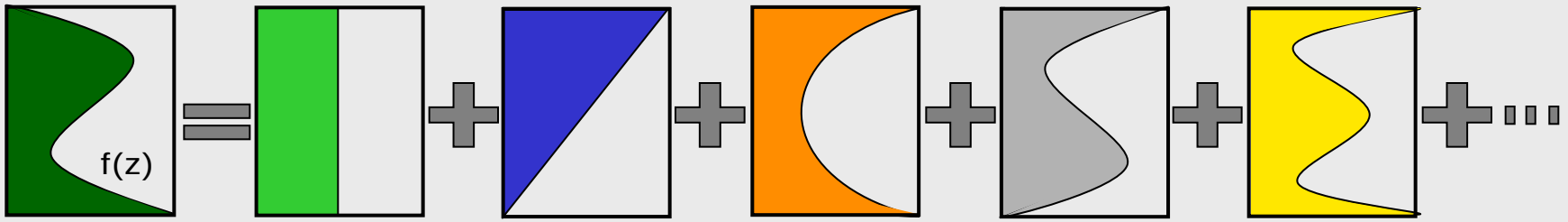
f(z) … vertical reflectivity function

Volume Coherence

$$\tilde{\gamma}_{Vol}(f(z)) = e^{ik_z z_o} \frac{\int_o^{h_v} f(z)\, e^{ik_z z} dz}{\int_o^{h_v} f(z)\, dz}$$







$$\tilde{\gamma}_{Vol}(f(z)) = e^{ik_z z_o} \frac{\int_o^{h_v} f(z)\, e^{ik_z z} dz}{\int_o^{h_v} f(z)\, dz}$$

$$\int_0^{h_v} f(z)\, e^{ik_z z} dz = \frac{h_v}{2} e^{i\frac{k_z h_v}{2}} \int_{-1}^{1} (1 + f(z'))\, e^{i\frac{k_z h_v}{2} z'} dz'$$

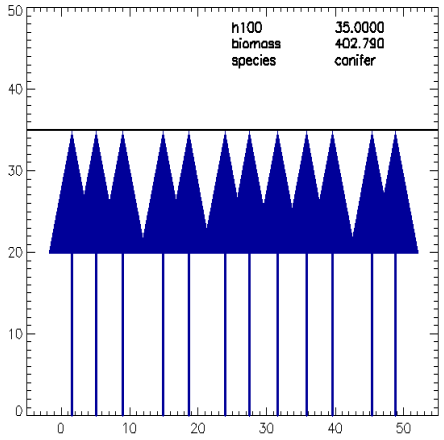
$$\int_0^{h_v} f(z)\, dz = \frac{h_v}{2} \int_{-1}^{1} (1 + f(z'))\, dz'$$

Fourier Legendre Series:

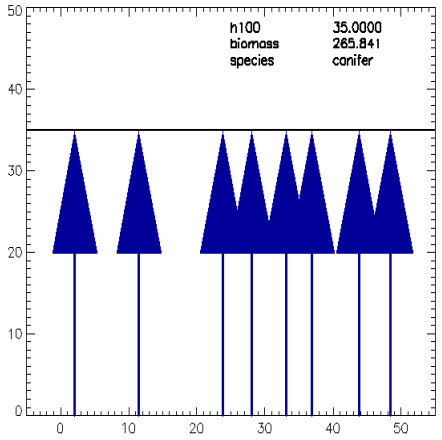
$$f(z') = \sum_n a_n P_n(z') \quad \textbf{where} \quad a_n = \frac{2n+1}{2} \int_{-1}^{1} f(z') P_n(z') dz'$$

Limitations of Biomass Estimation from Height

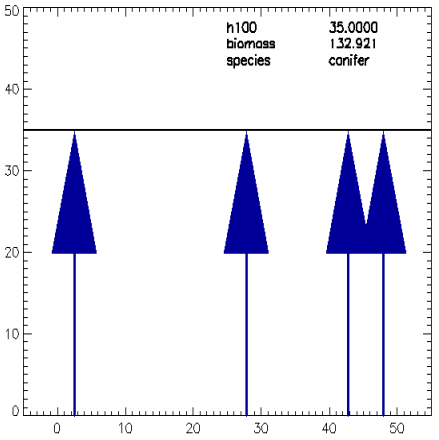
Height (H 100) 2 Biomass (B) Relationship: $B = la * 1.66H^{1.50}$



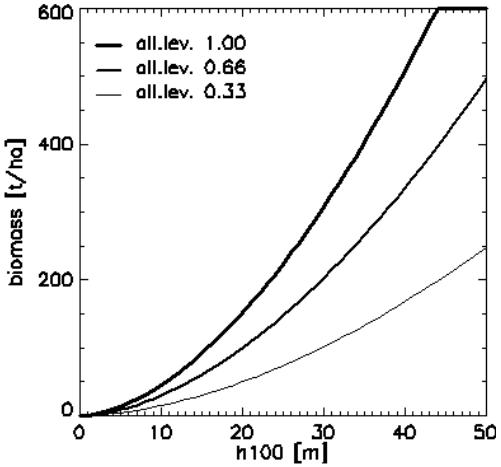
100 % (=0.80*$h^{1.75}$)

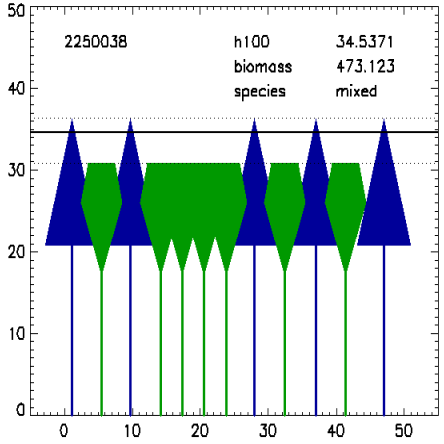


66 % (=0.54*$h^{1.75}$)

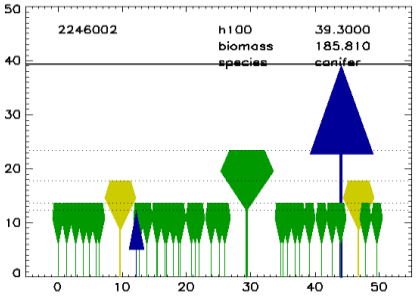


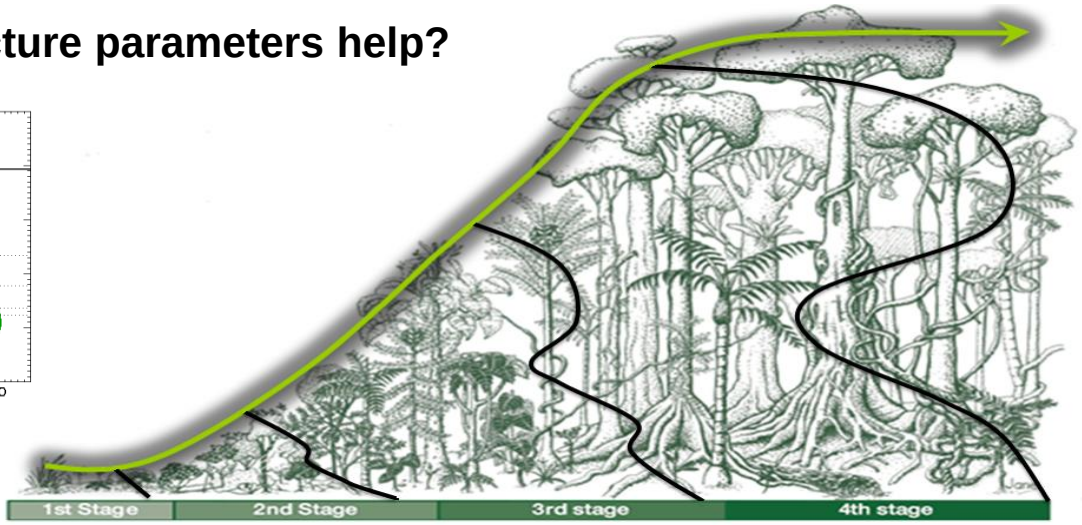
33 % (=0.27*$h^{1.75}$)



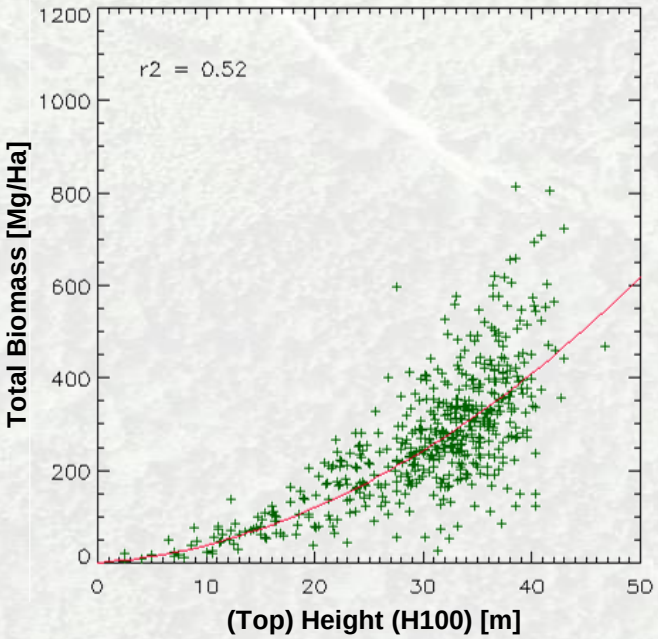


Can vertical structure parameters help?



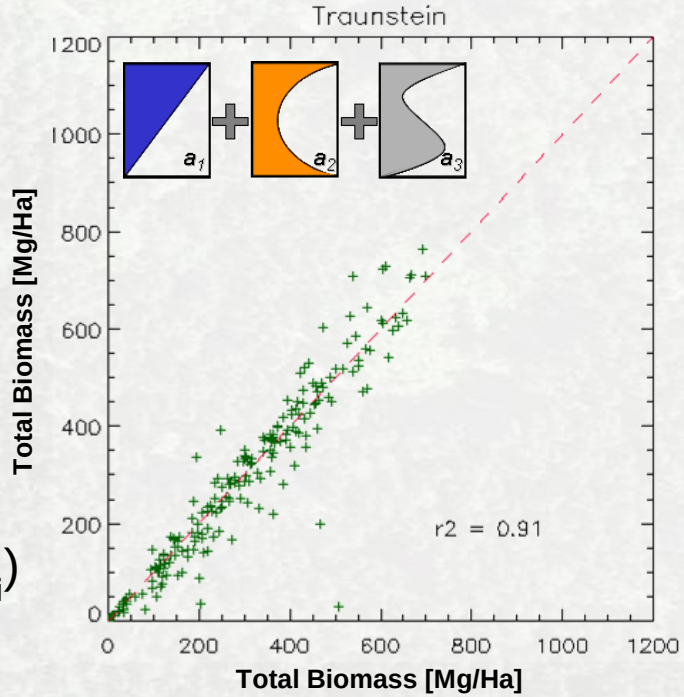


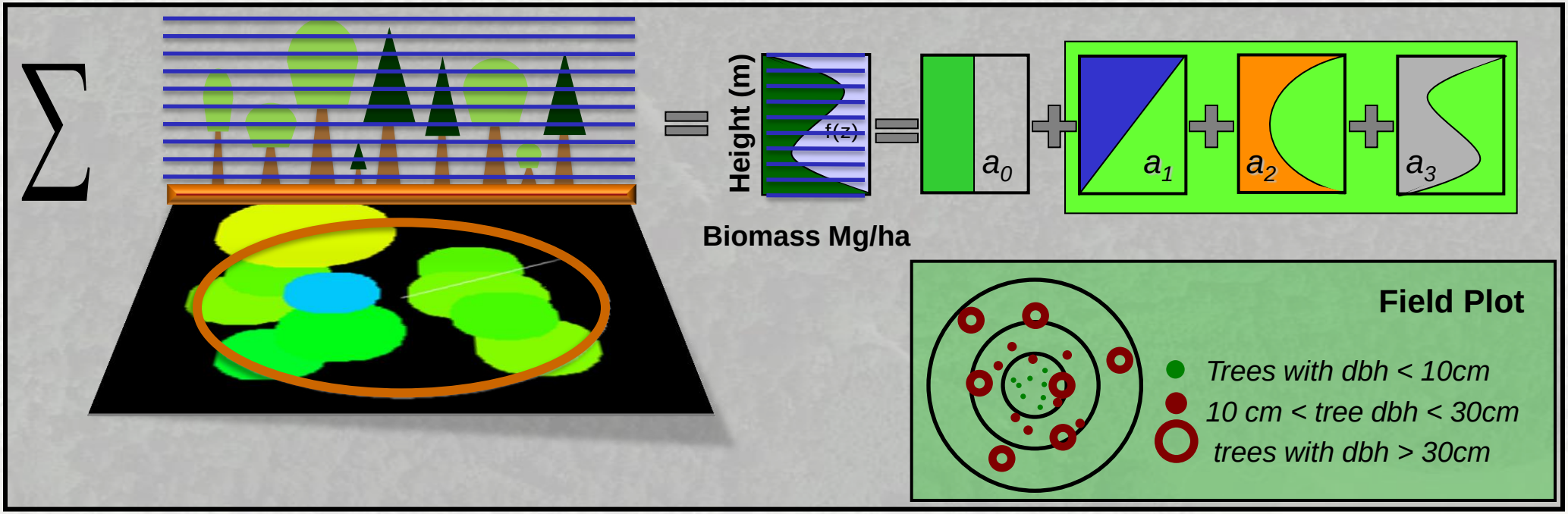
Structure-to-Biomass Allometry



$$B = la * 1.66\, H^{1.50}$$

$$B = 3.11 * \sum_{i=0}^{H} \sum_{j=1}^{3} a_j * P_j(z_i)$$





Boreal Forest Site: Krycklan

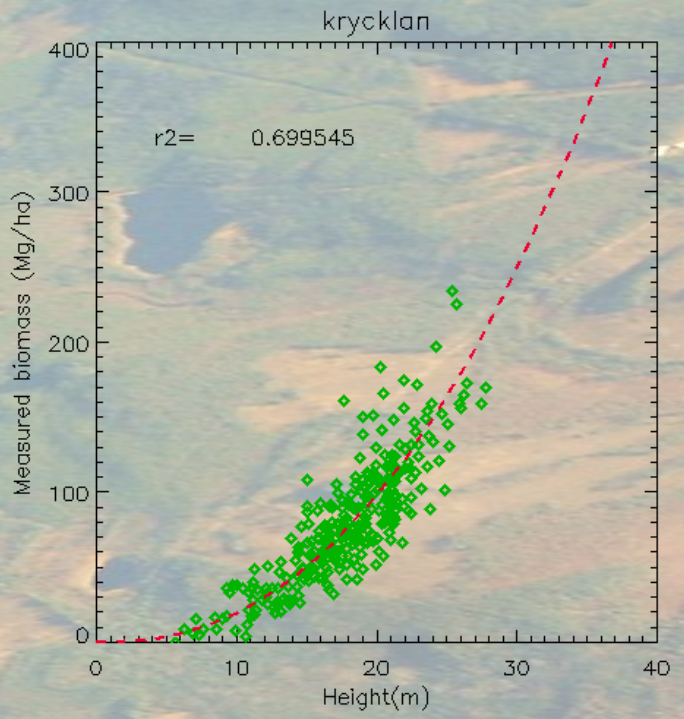
Pine, Spruce, Birch & Mixed stands

Height Range (H100): 5 - 30m

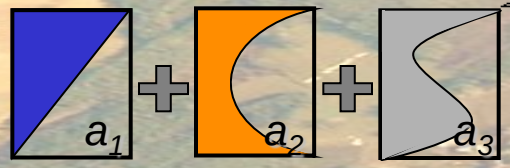
Biomass Range: up to 200 t/ha

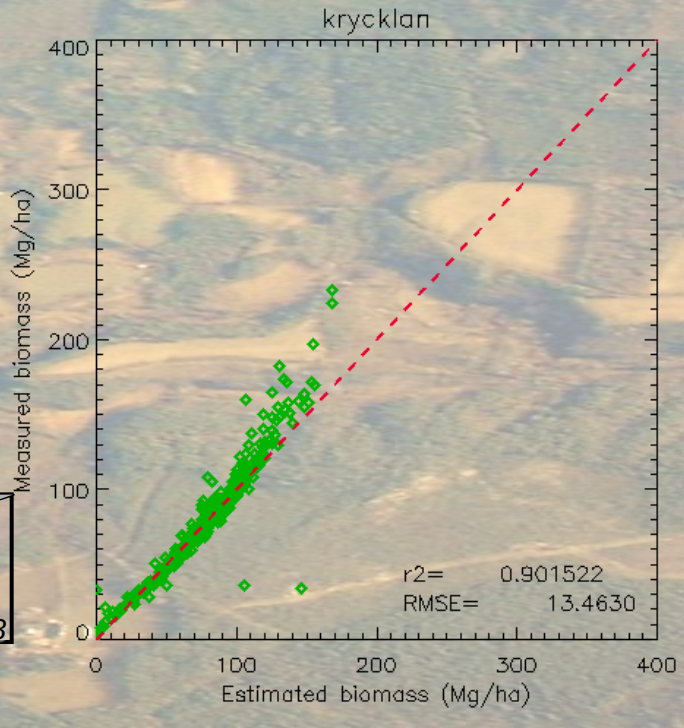
Steep Slopes

$$B = la * 1.66\, H^{1.50}$$

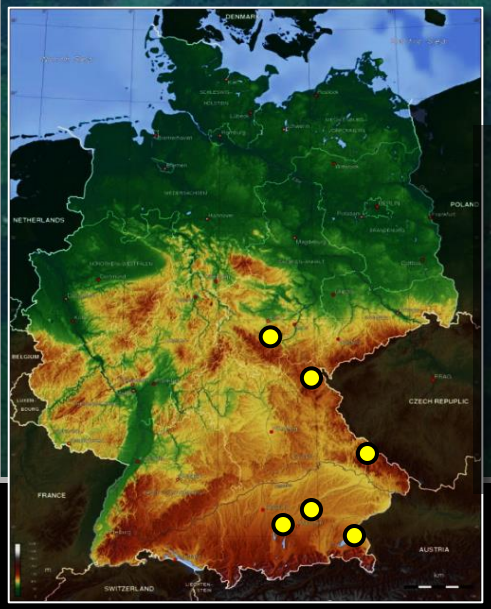


$$B = 3.11 * \sum_{i=0}^{H} \sum_{j=1}^{3} a_j * P_j$$



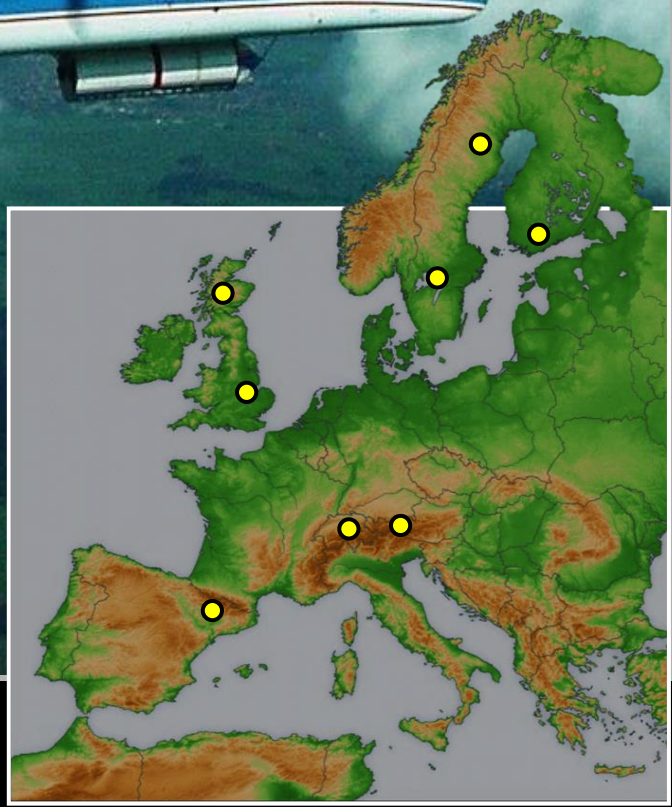


Pol-InSAR Validation Campaigns in Europe



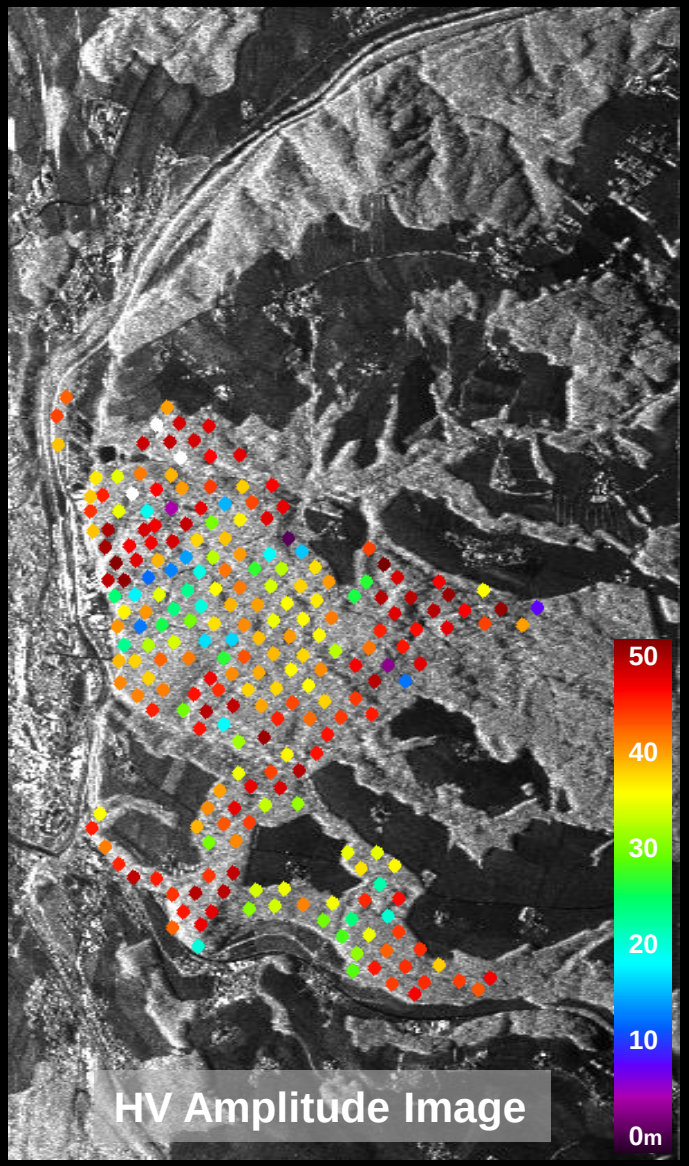
1. Traunstein Stadtwald
2. Fichtelgebirge
3. Bayerischer Wald
4. Ebersberger Forst
5. Oberpfaffenhofen
6. Thueringer Wald

1. Krycklan Forest, S
2. Remningstorp Forest, S
3. Helsinki Forest FIN
4. Glen Afric, UK
5. Thetford forest, UK
6. Kobernausser Wald, A
7. Hinwill, CH
8. Barrax, SP

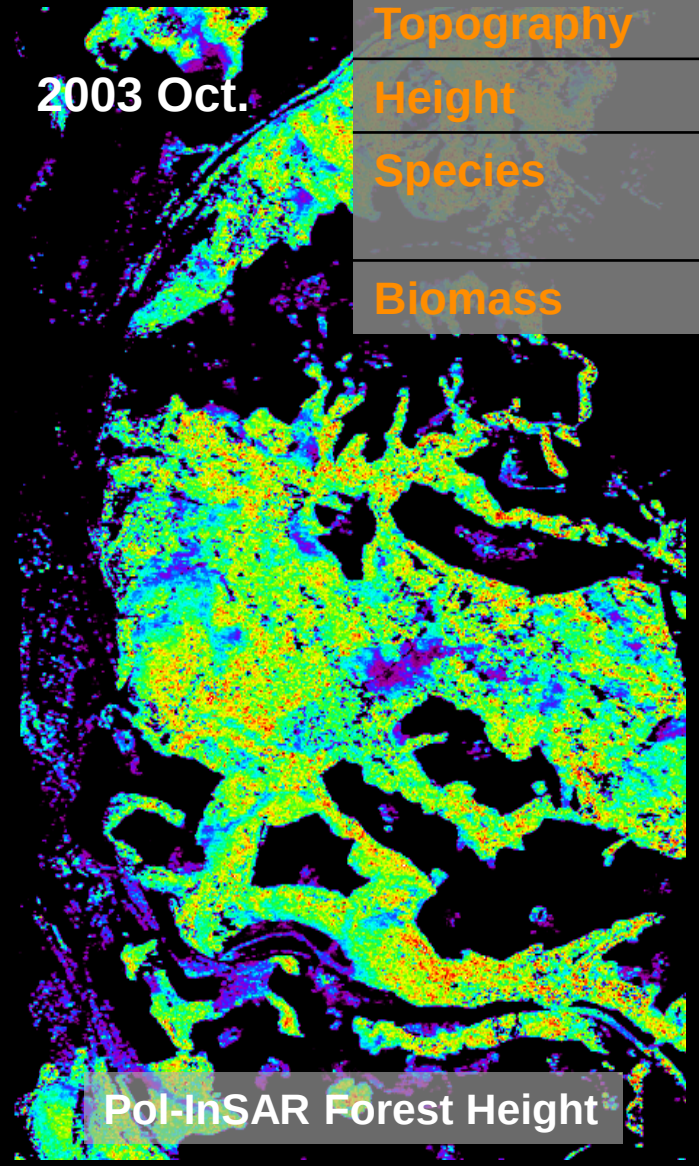


Traunstein Test Site

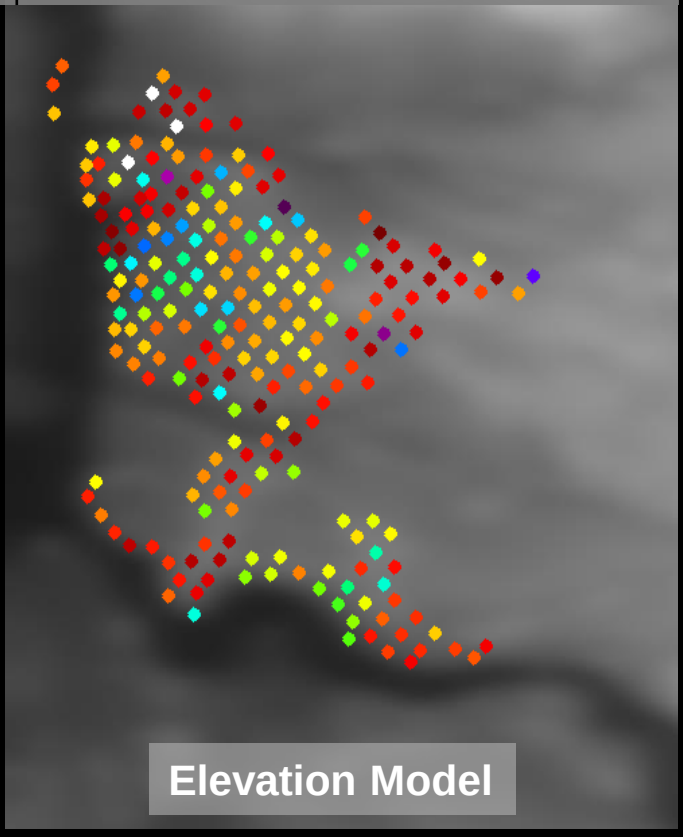
Forest type	Temperate
Topography	Moderate slopes
Height	25 ~ 35m
Species	N. Spruce, E. Beech, White Fir
Biomass	40 ~ 450 t/ha



HV Amplitude Image

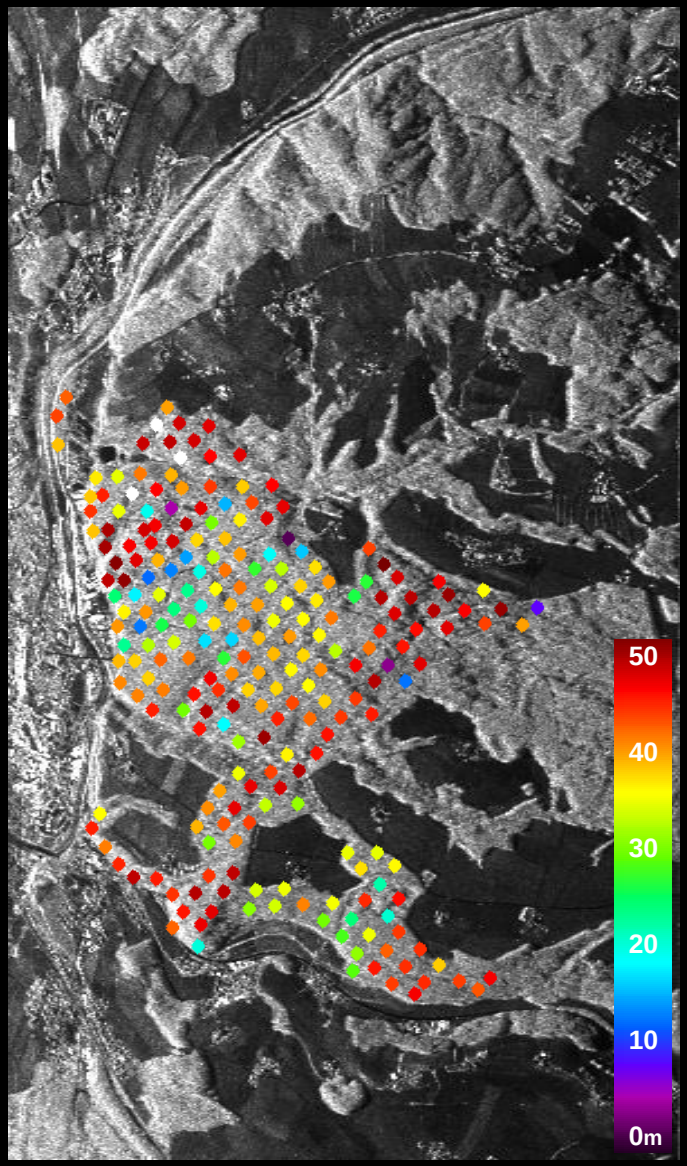


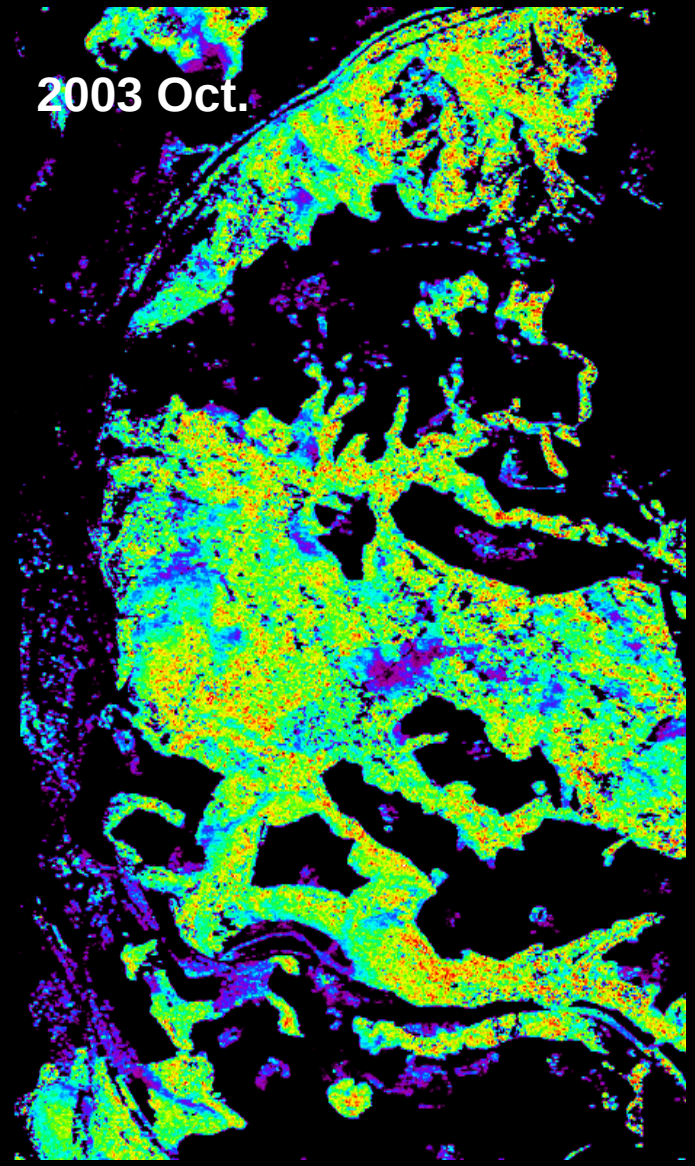
PolInSAR Forest Height

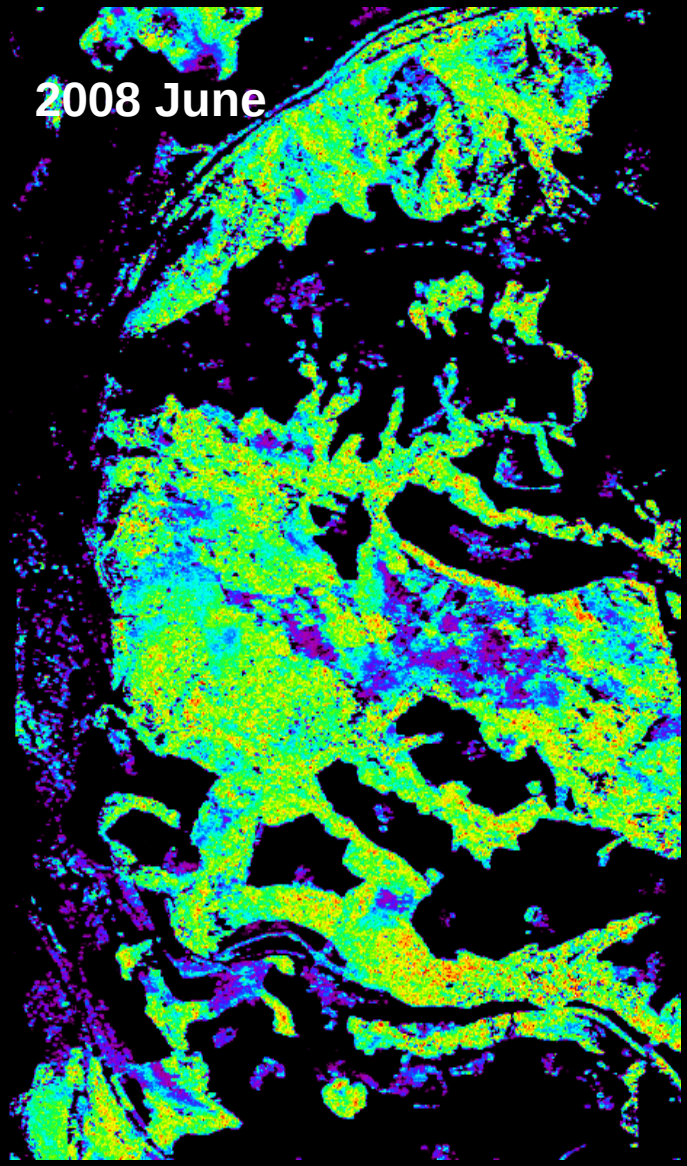


Elevation Model

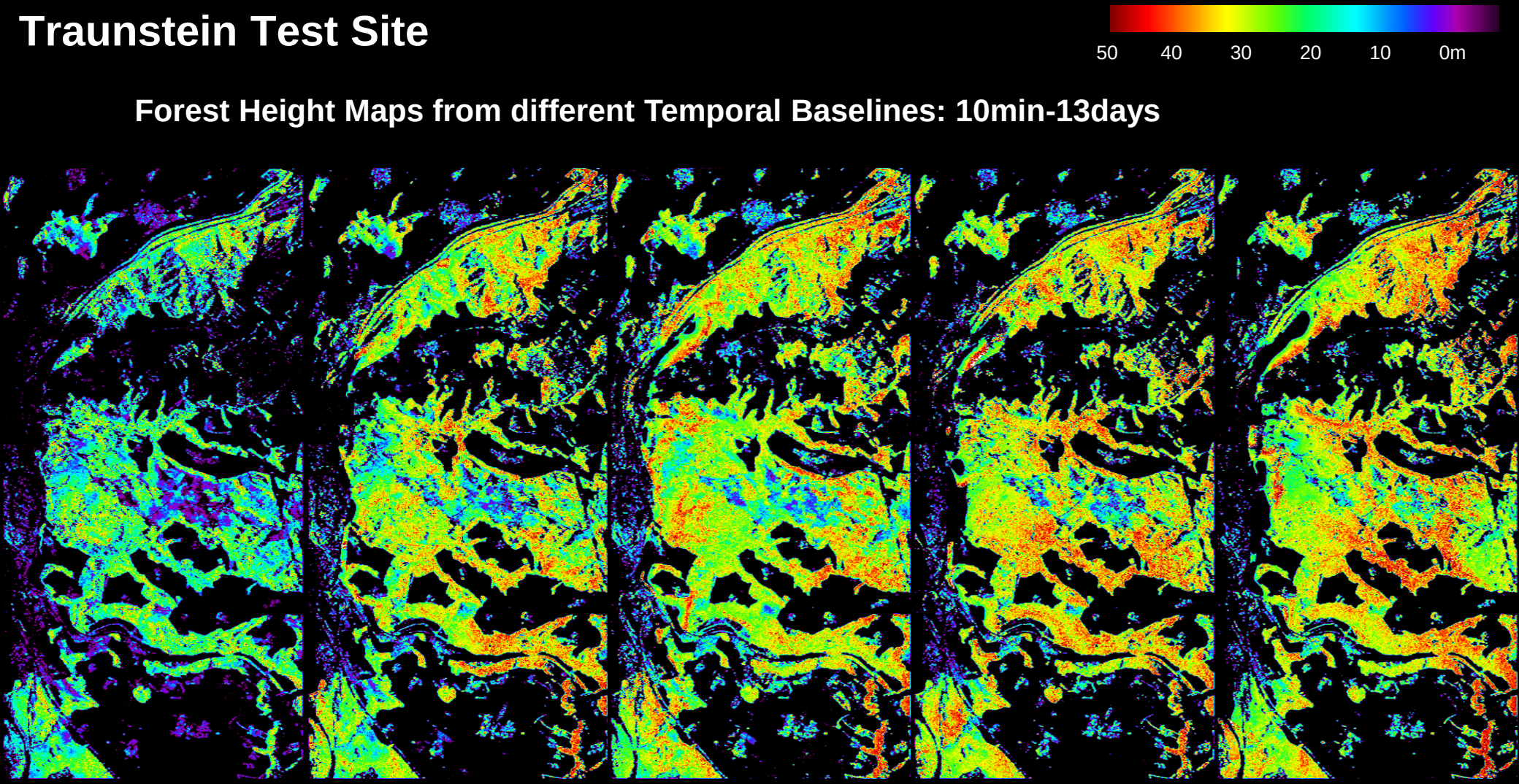
Traunstein Test Site





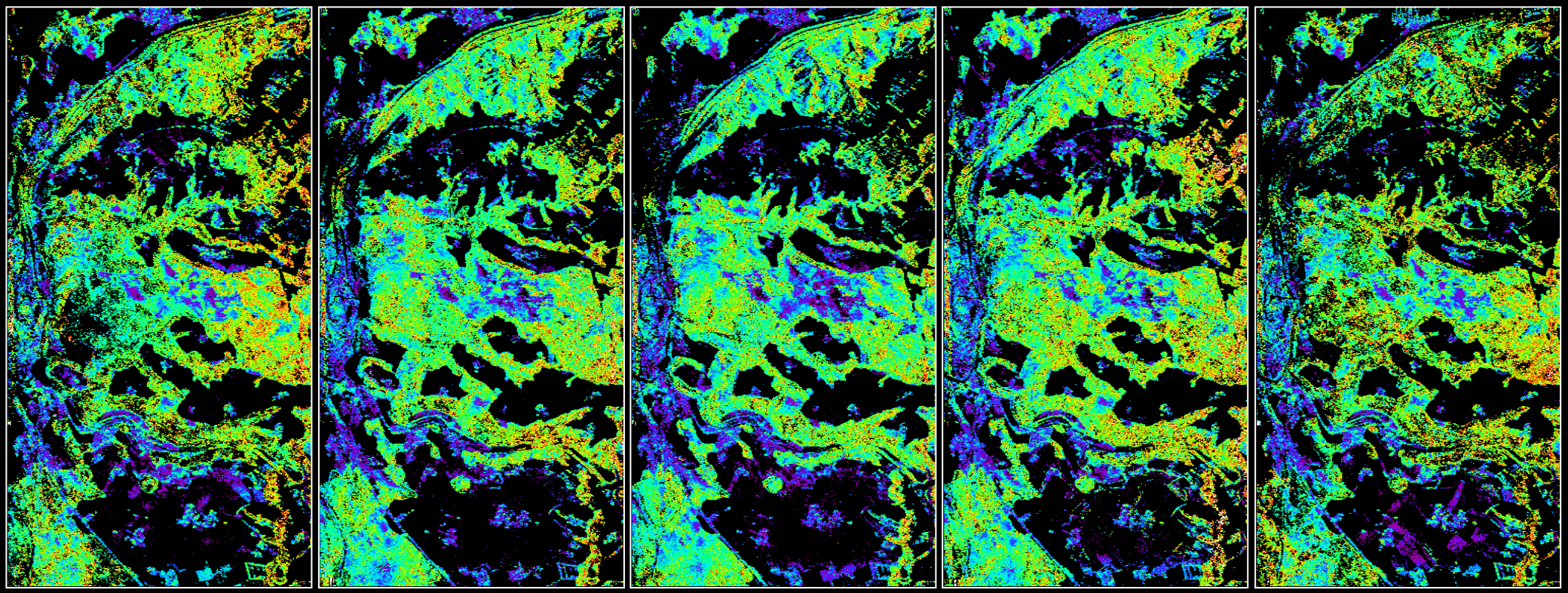


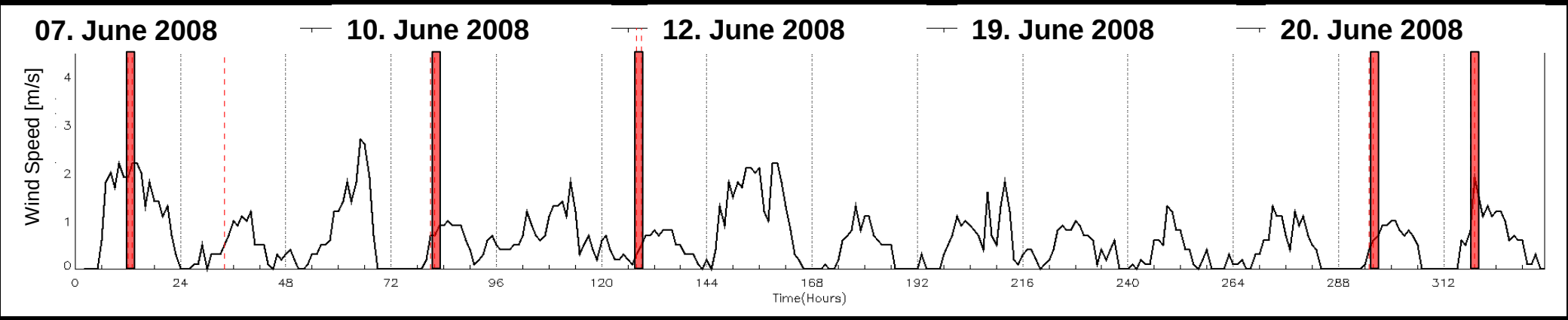
Traunstein Test Site



Traunstein Test Site

Forest Height Maps 10min Temporal Baseline





690

Topo Height [m]

570

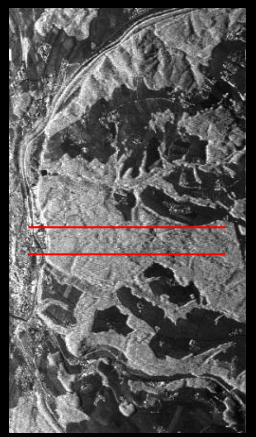
Mixed Forest Stands

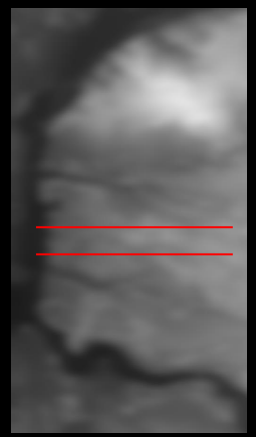
Mature Spruce Stands

Topo Height [m]

570

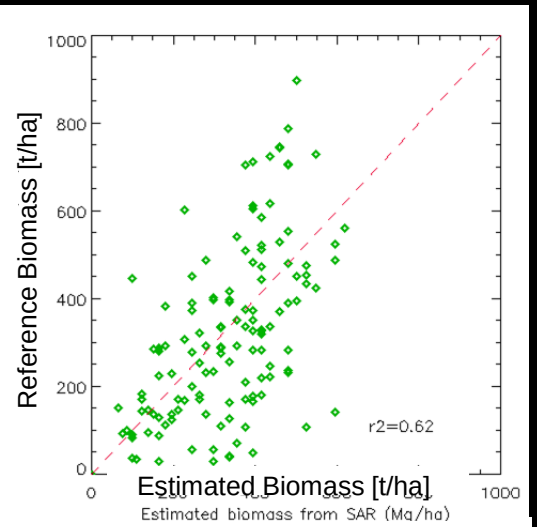
PCT Reconstruction from 2 Baselines

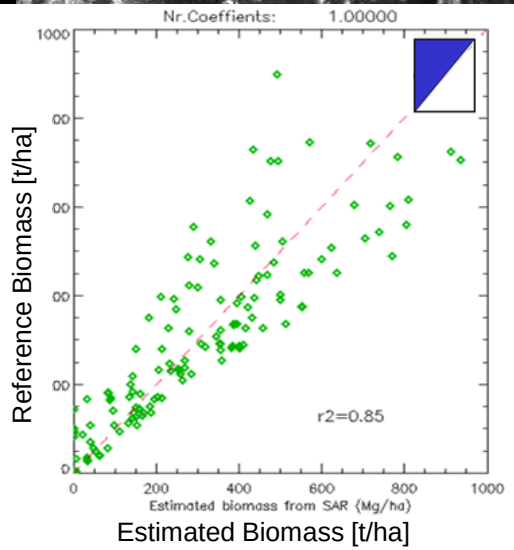


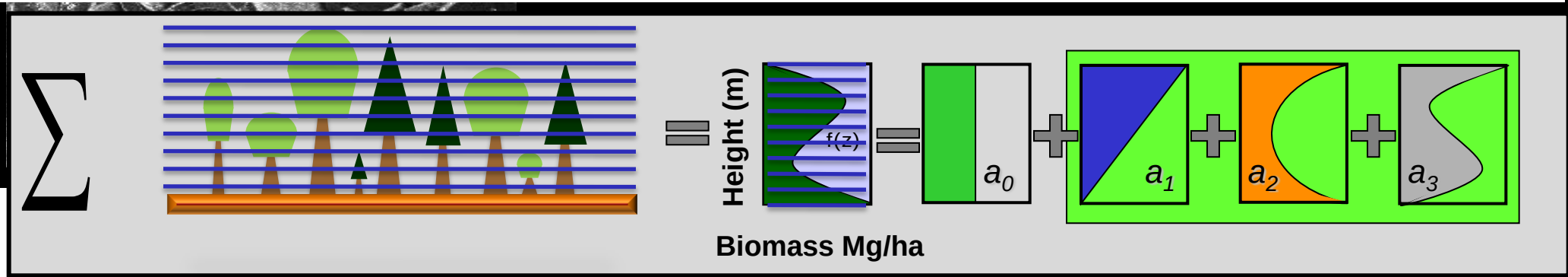


Test site: Traunstein, Germany, L-band @ HV Polarisation

Traunstein Test Site







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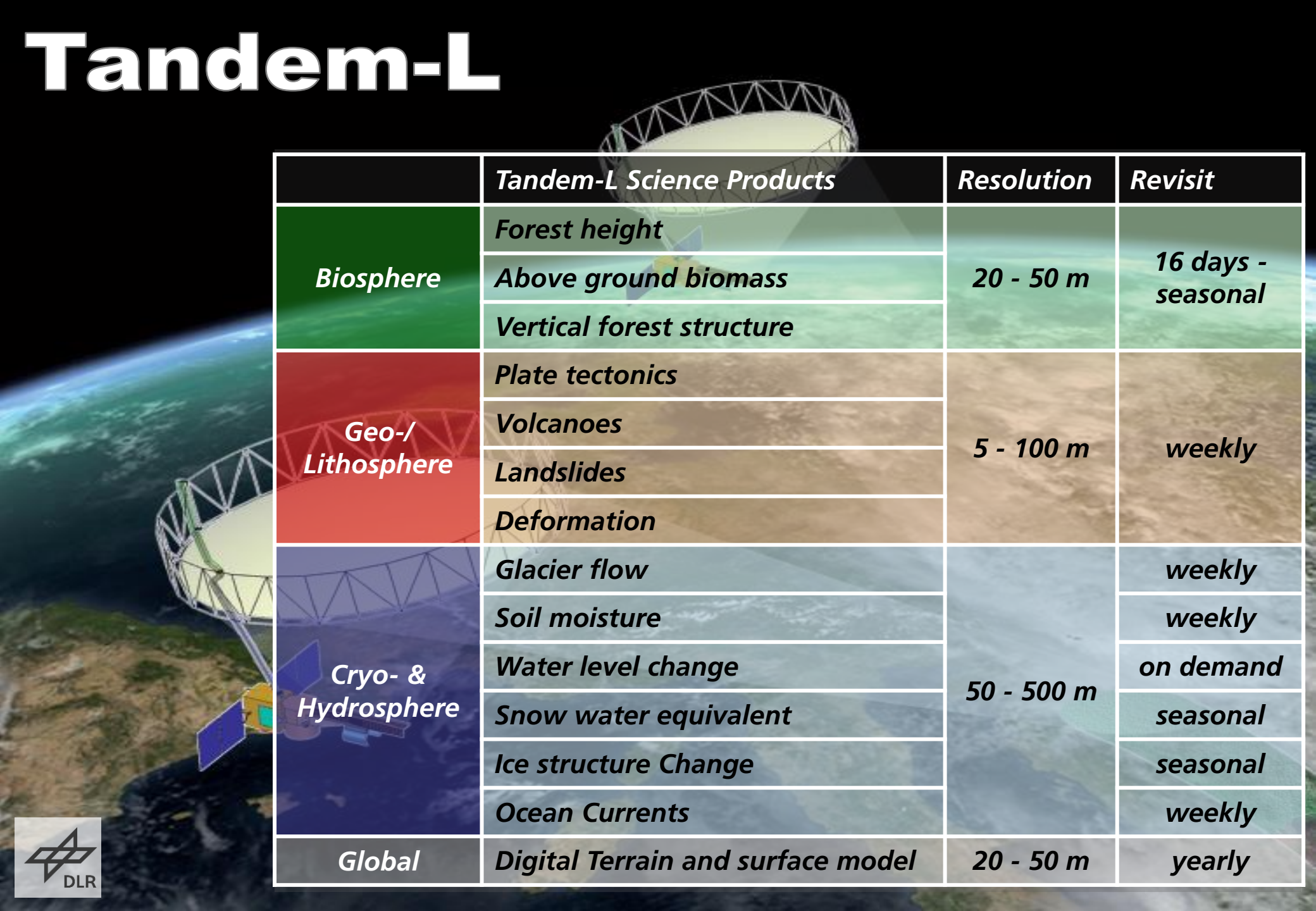
	regional	~ 10% (-20%)	**20x20**–30x30	**3**-5 years	> 5 years	For forest inventory
	local	(2.5) – **10%**	<<10x10– **20x20**	**2**-5 years	> 5 years	Site quality characterisation
Forest structure	global	**3 v-layers 5-10m**	30x30–**50x50**	Seasonal	> 5 years	Forest monitoring
	regional	**3 v-layers 5-10m**	**20x20**–30x30	on demand	> 5 years	Disturbance, Monitoring
Forest Biomass	global	**≥20t/ha 20** - 30%	70x70- **100x100**	12 months	> 5 years	Carbon stock
	regional	**10 – 15t/ha ≤or 20%**	**≤ 50x50**	5 years	> 5 years	For forest inventory
Underlying topography	global	< 4 m	30x30-**50x50**	12 months	> 5 years	Water dynamics

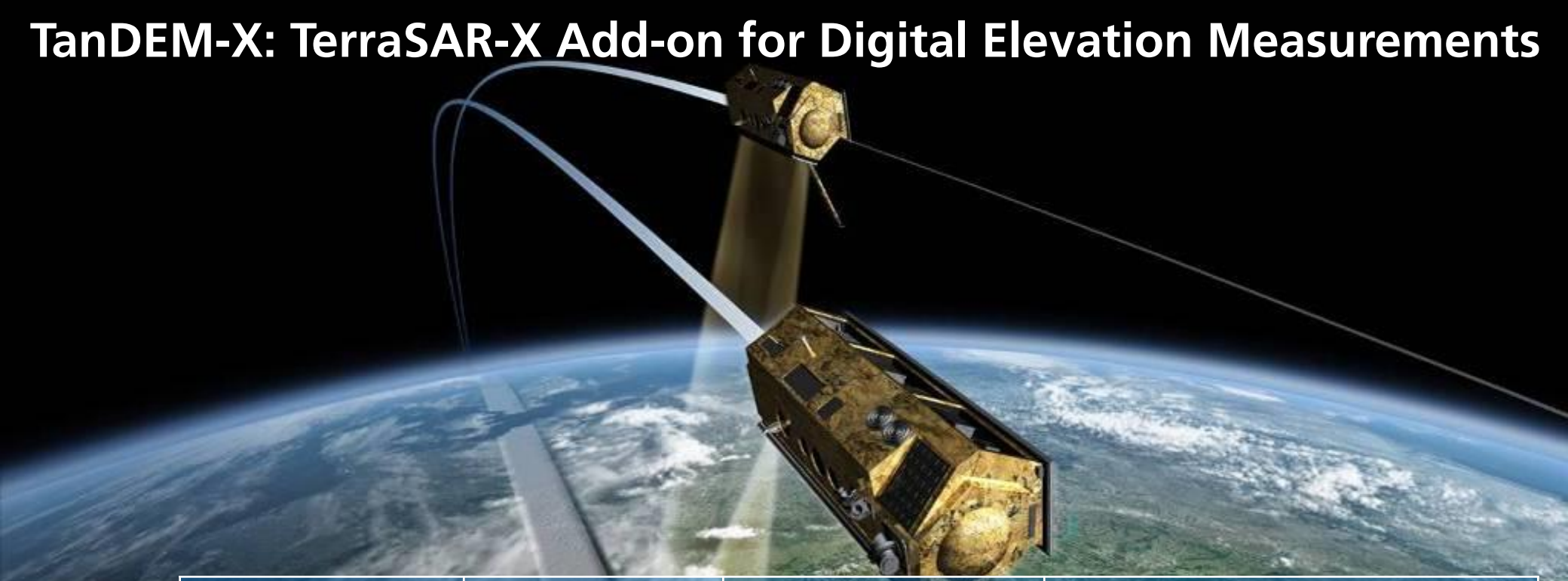
Tandem-L



	Tandem-L Science Products	Resolution	Revisit
Biosphere	Forest height	20 - 50 m	16 days - seasonal
	Above ground biomass		
	Vertical forest structure		
Geo-/ Lithosphere	Plate tectonics	5 - 100 m	weekly
	Volcanoes		
	Landslides		
	Deformation		
Cryo- & Hydrosphere	Glacier flow	50 - 500 m	weekly
	Soil moisture		weekly
	Water level change		on demand
	Snow water equivalent		seasonal
	Ice structure Change		seasonal
	Ocean Currents		weekly
Global	Digital Terrain and surface model	20 - 50 m	yearly

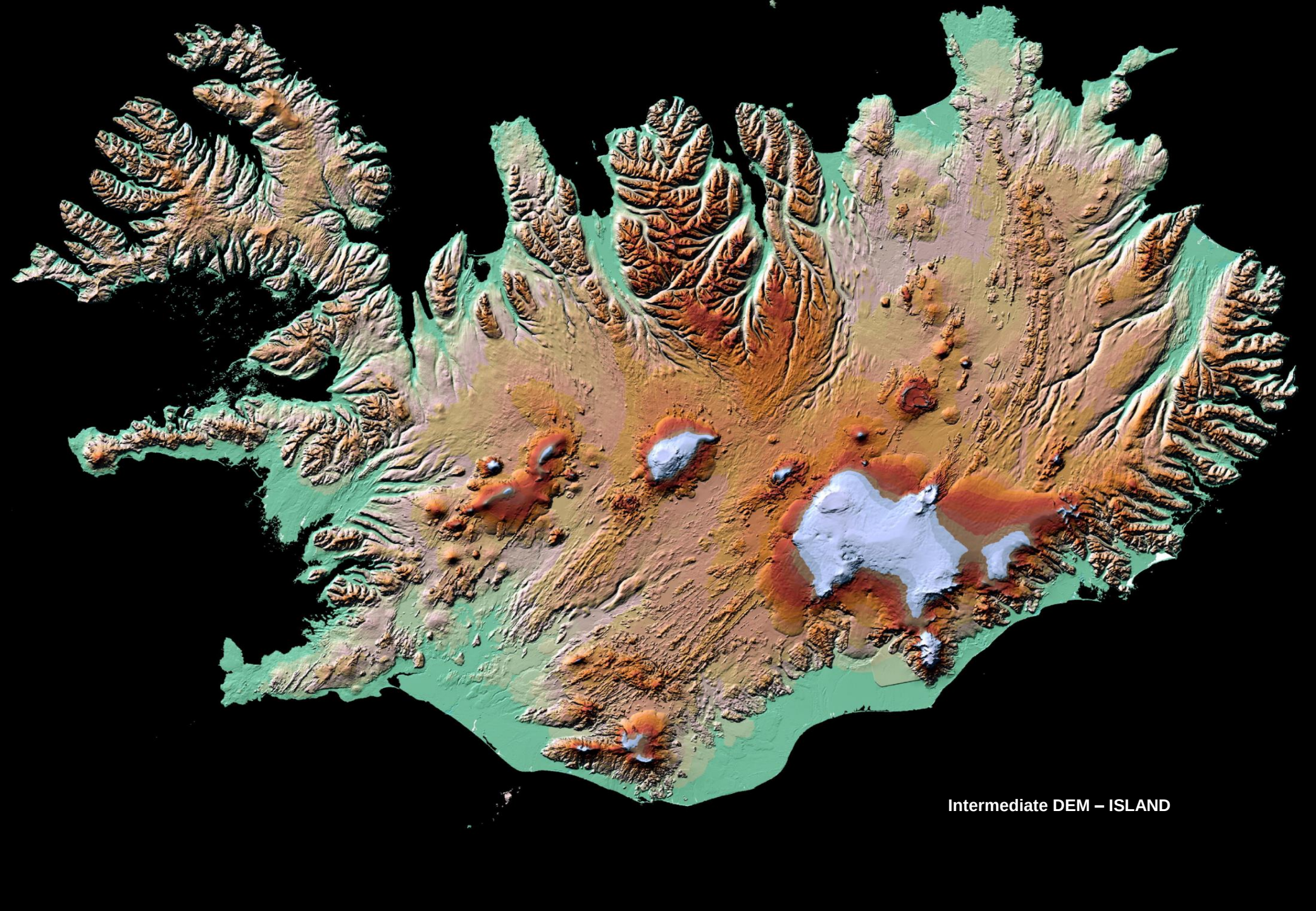
DLR

TanDEM-X: TerraSAR-X Add-on for Digital Elevation Measurements

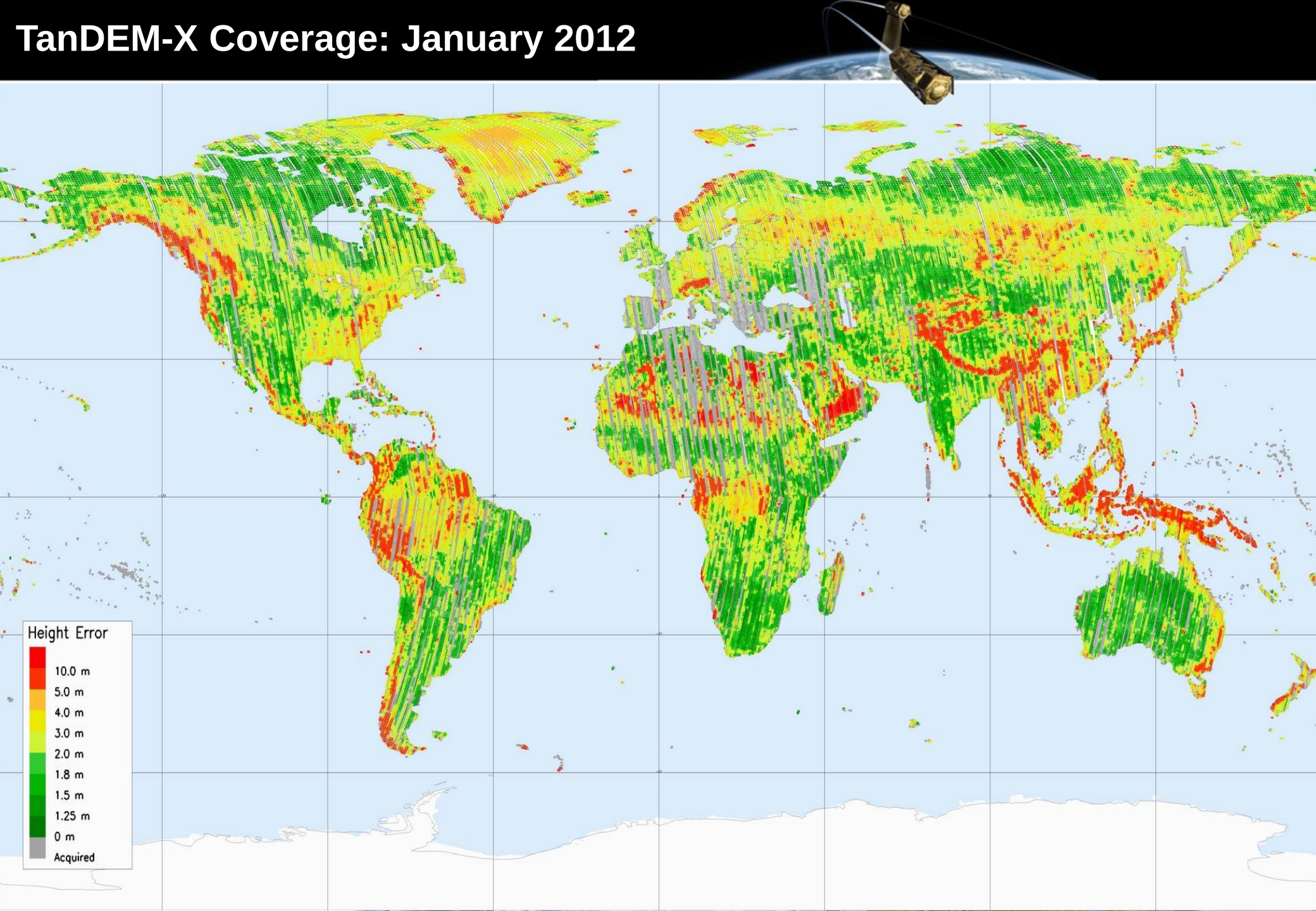


DEMs	Spatial Resolution	Absolute Vertical Accuracy (90%)	Relative Vertical Accuracy (point-to-point in 1° cell, 90%
DTED-1	90m x 90m	< 30m	< 20m
DTED-2	30m x 30m	< 18m	< 12m
TanDEM-X DEM	12m x 12m	< 10m	< 2m
HDEM	6m x 6m	< 5m	< 0.8m

DLR ASTRIUM infoterra

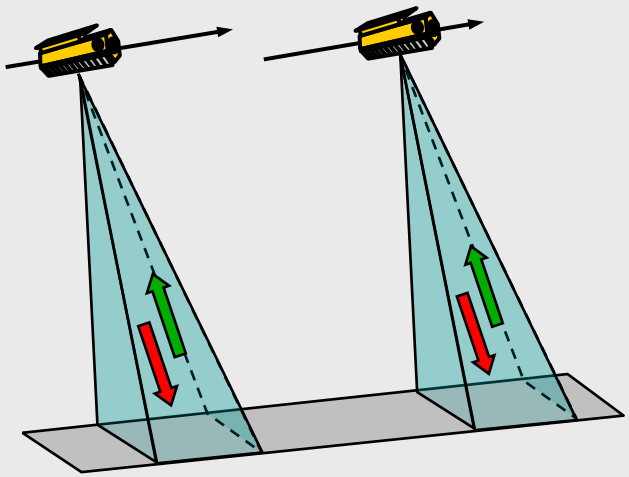

Intermediate DEM – ISLAND

TanDEM-X Coverage: January 2012



TanDEM-X Data Acquisition Modes

Pursuit Monostatic



- **both satellites transmit and receive independently**
- susceptible to temporal decorrelation & atmospheric disturbances
- no PRF and phase synchronisation required (backup solution)

July until October 2010

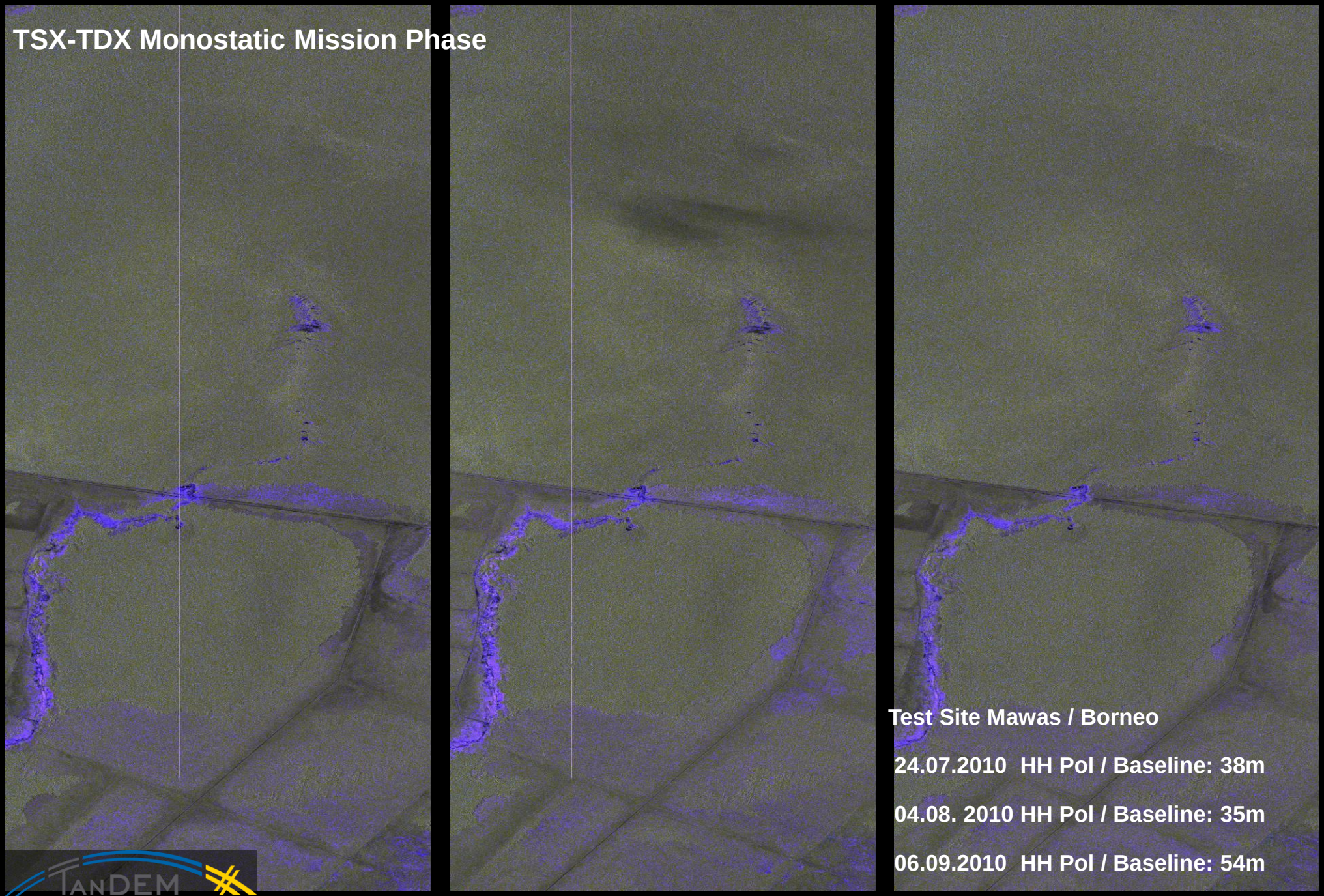
- **one satellite transmits and both satellites receive simultaneously**
- small along-track displacement required for Doppler spectra overlap
- requires PRF and phase synchronisation

Alternating Bistatic

- **transmitter alternates between PRF pulses**
- provides three interferograms with two baselines in a single pass
- enables precise phase synchronisation, calibration & verification

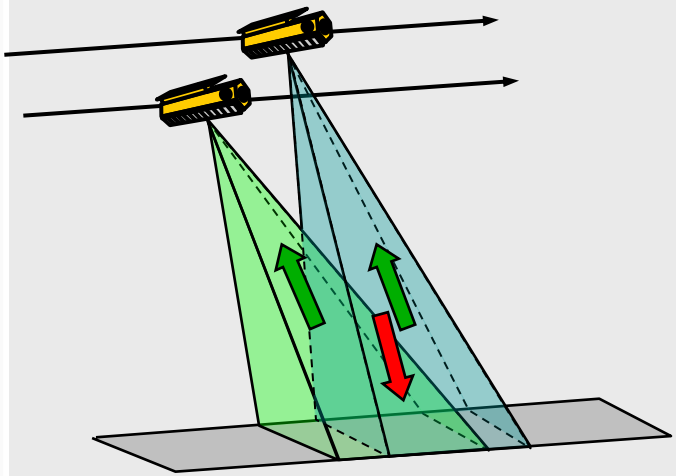
Standard DEM Mode

Temporal baseline: 2-3 sec (20-30Km Across Track separation)

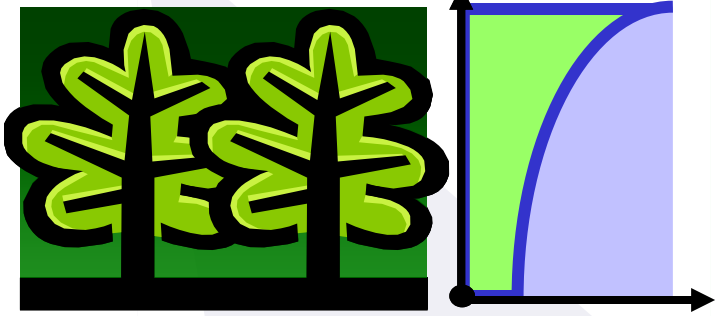

TSX-TDX Monostatic Mission Phase
Test Site Mawas / Borneo
24.07.2010 HH Pol / Baseline: 38m
04.08. 2010 HH Pol / Baseline: 35m
06.09.2010 HH Pol / Baseline: 54m
TanDEM


TSX-TDX Monostatic Mission Phase
Test Site Mawas / Borneo
24.07.2010 HH Pol Baseline: 38m
04.08. 2010 HH Pol Baseline: 35m
06.09.2010 HH Pol Baseline: 54m

TanDEM-X Data Acquisition Modes

Pursuit Monostatic	Bistatic	Alternating Bistatic
		
• **both satellites transmit and receive independently** • susceptible to temporal decorrelation & atmospheric disturbances • no PRF and phase synchronisation required (backup solution)	• **one satellite transmits and both satellites receive simultaneously** • small along-track displacement required for Doppler spectra overlap • requires PRF and phase synchronisation	• **transmitter alternates between PRF pulses** • provides three interferograms with two baselines in a single pass • enables precise phase synchronisation, calibration & verification

Standard DEM Mode



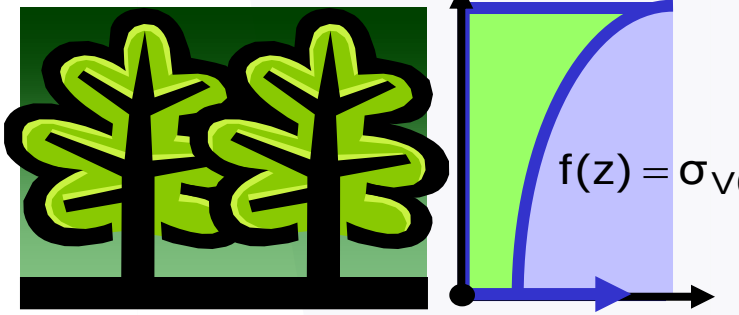
Single-Pol: 1 Layer Scattering Model

$$f(z) = \sigma_{V0} \exp\left(\frac{2\ \sigma\ z}{\cos\theta_0}\right)$$

$$\tilde{\gamma}(\vec{w}) = \exp(i\phi_0)\,\tilde{\gamma}_V$$

DEM ► Topography ϕ_0

Volume Height h_V **Extinction** σ



Dual-Pol: 2 Layer Scattering Model

$$f(z) = \sigma_{V0} \exp\left(\frac{2\ \sigma\ z}{\cos\theta_0}\right) + m'_G \delta(z - z_0)$$

$$\tilde{\gamma}(\vec{w}) = \exp(i\varphi_0)\,\frac{\tilde{\gamma}_V + m(\vec{w})}{1 + m(\vec{w})}$$

Volume Height h_V **Extinction** σ

Topography ϕ_0 **G/V Ratio** $m(\vec{w})$

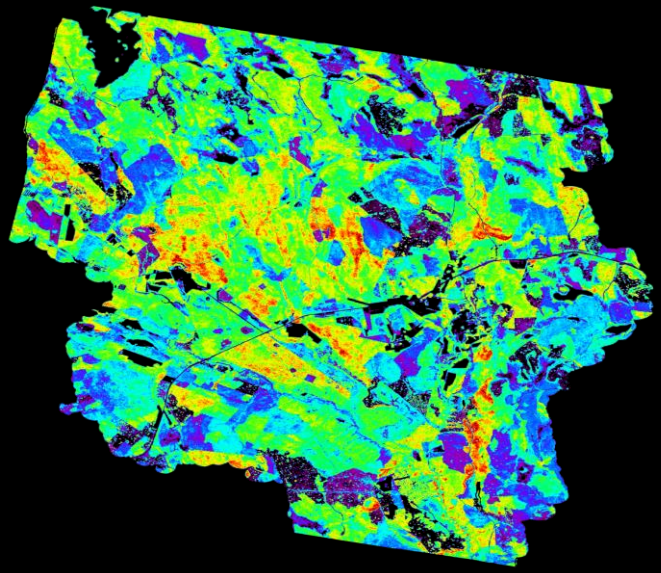
$$\tilde{\gamma}_V = \frac{I}{I_0}$$

$$I = \int_0^{h_V} \exp(i\kappa_z z') \exp\left(\frac{2\ \sigma\ z'}{\cos\theta_0}\right) dz'$$

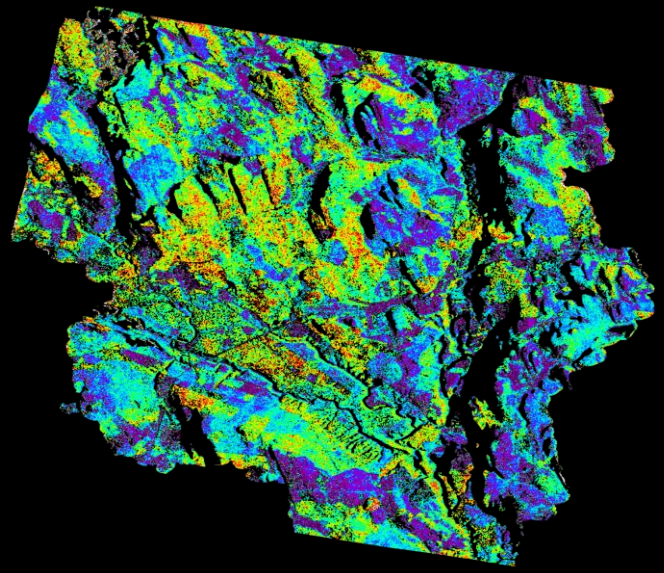
$$I_0 = \int_0^{h_V} \exp\left(\frac{2\ \sigma\ z'}{\cos\theta_0}\right) dz'$$

G/V Ratio: $m(\vec{w}) = \frac{m_G(\vec{w})}{m_V(\vec{w}) I_0}$ **Vertical Wavenumber:** $\kappa_z = \frac{\kappa \Delta\theta}{\sin(\theta_0)}$

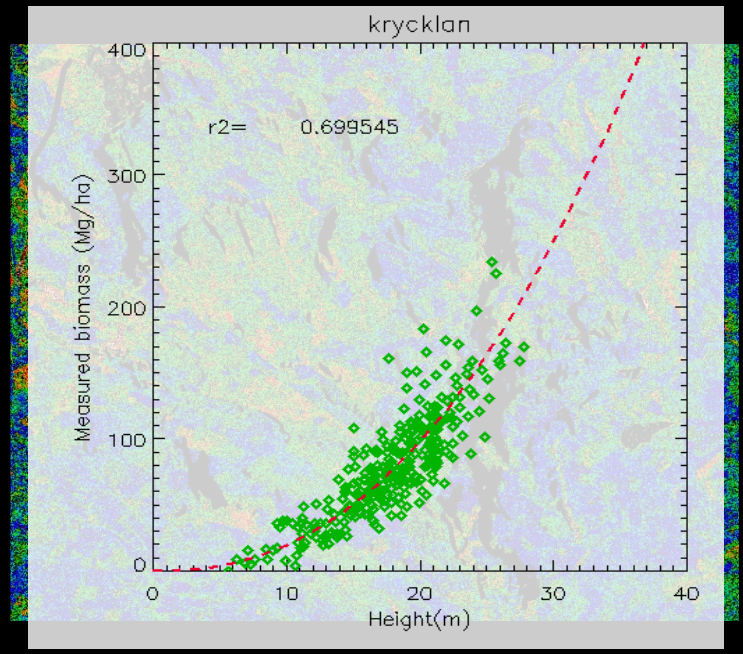
Test Site: Krycklan, Sweden



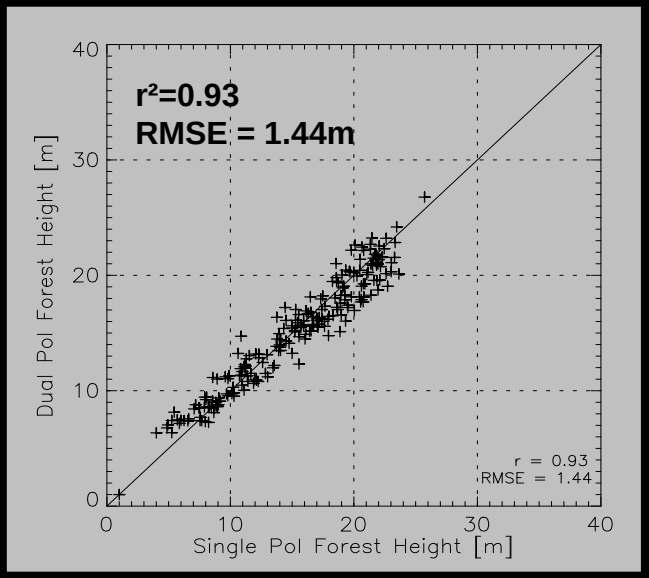
Lidar H100

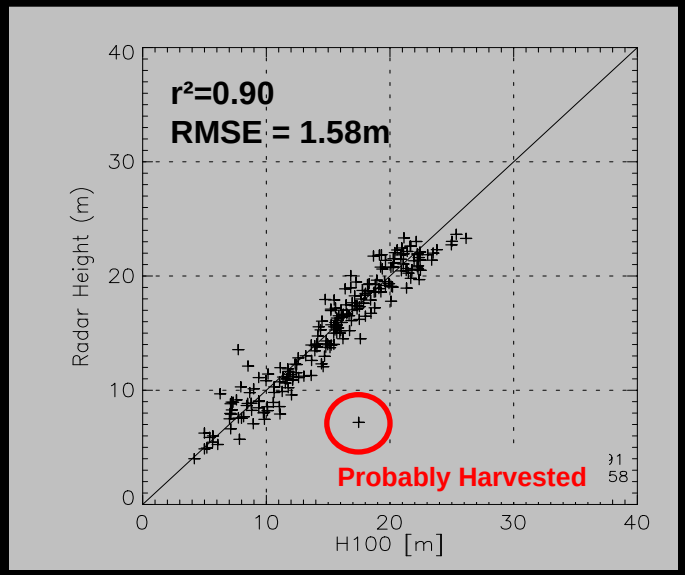


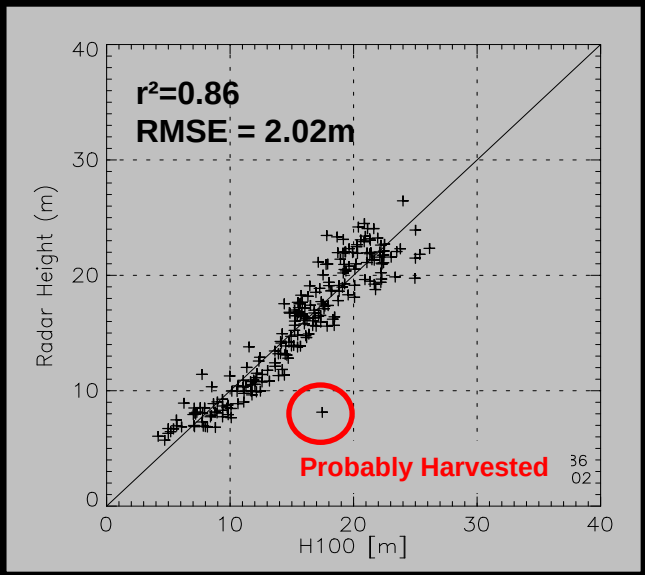
Single-Pol + DEM H100



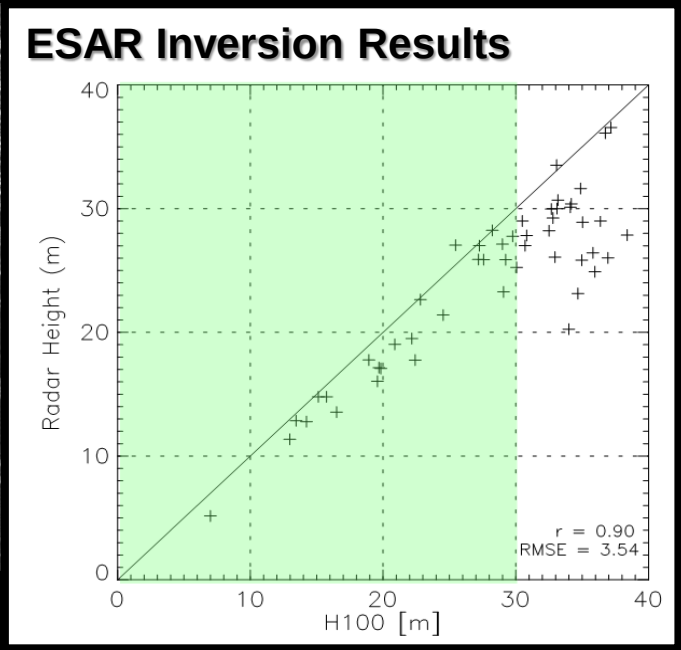
Dual-Pol H100

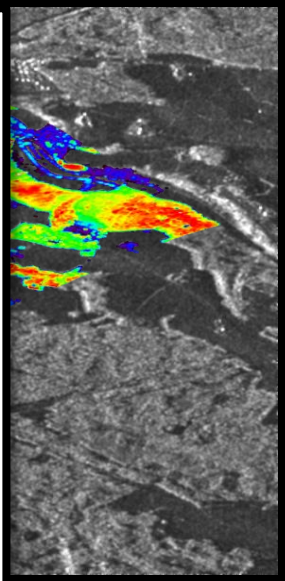


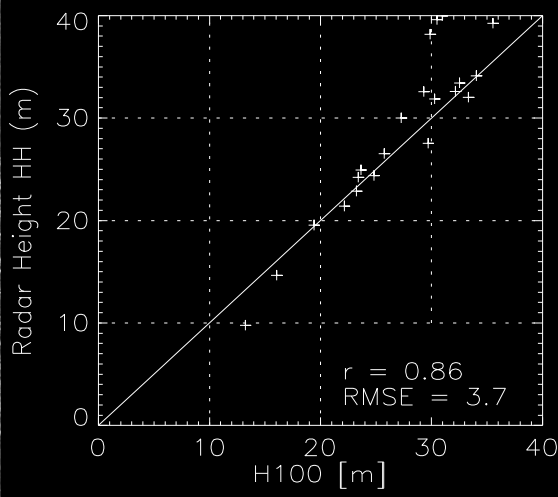


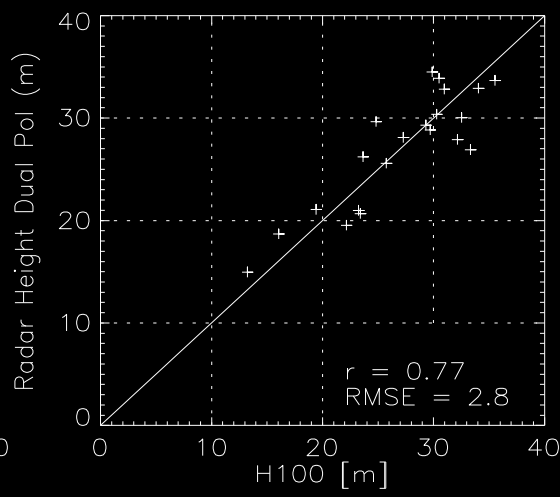


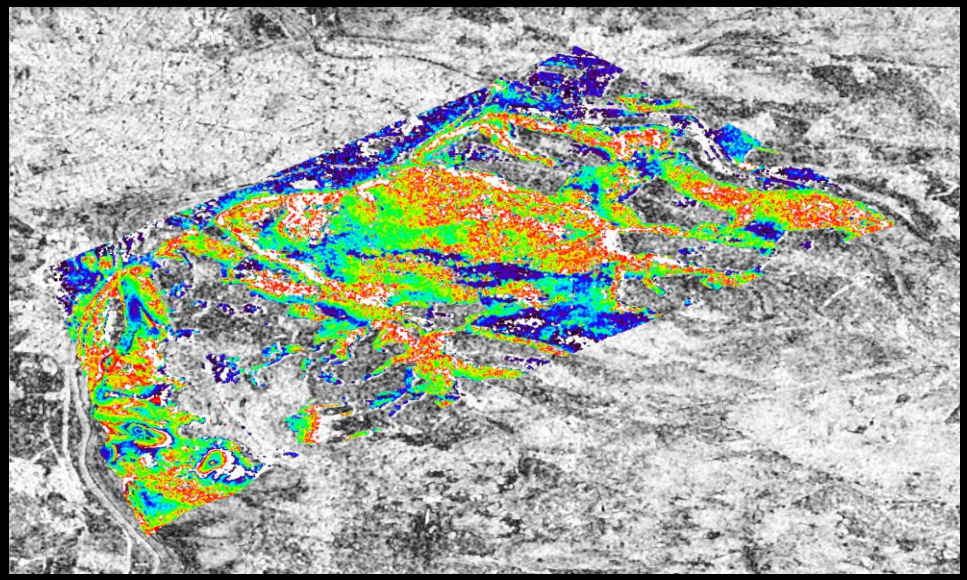
Test Site: Traunstein, Germany



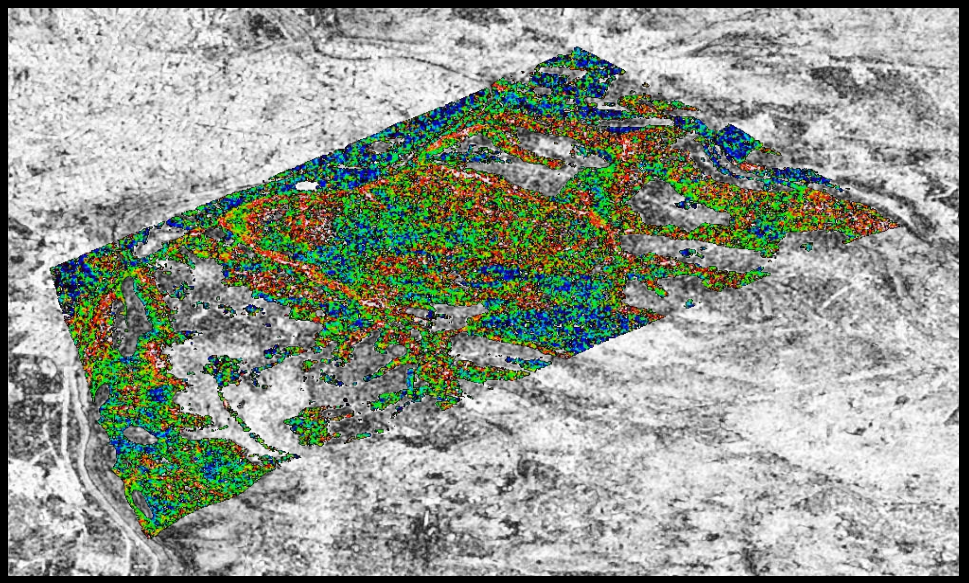






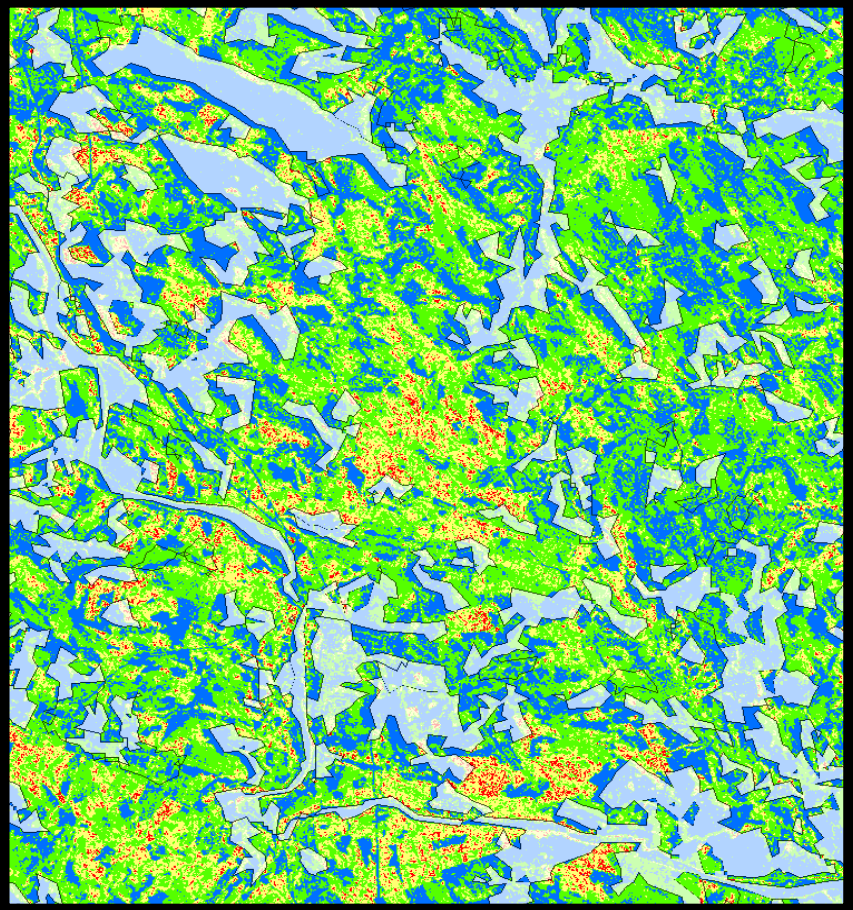


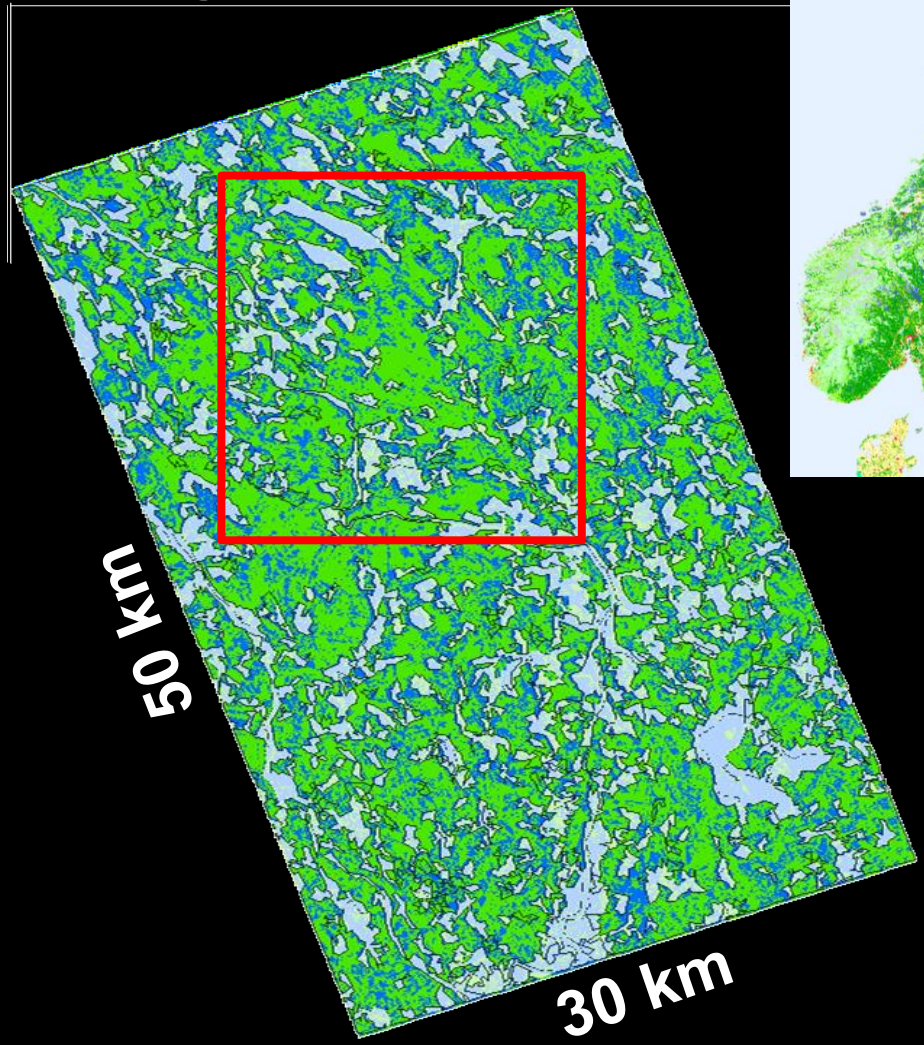
Single-Pol (HH) + DEM H100

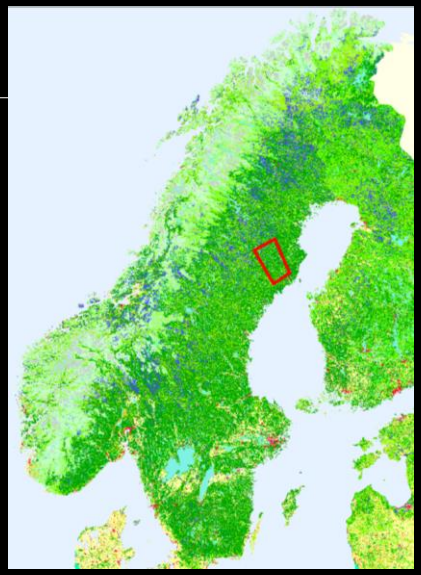


Dual-Pol H100

CORINE Land Cover Classes - Krycklan







< 10 Mg/ha

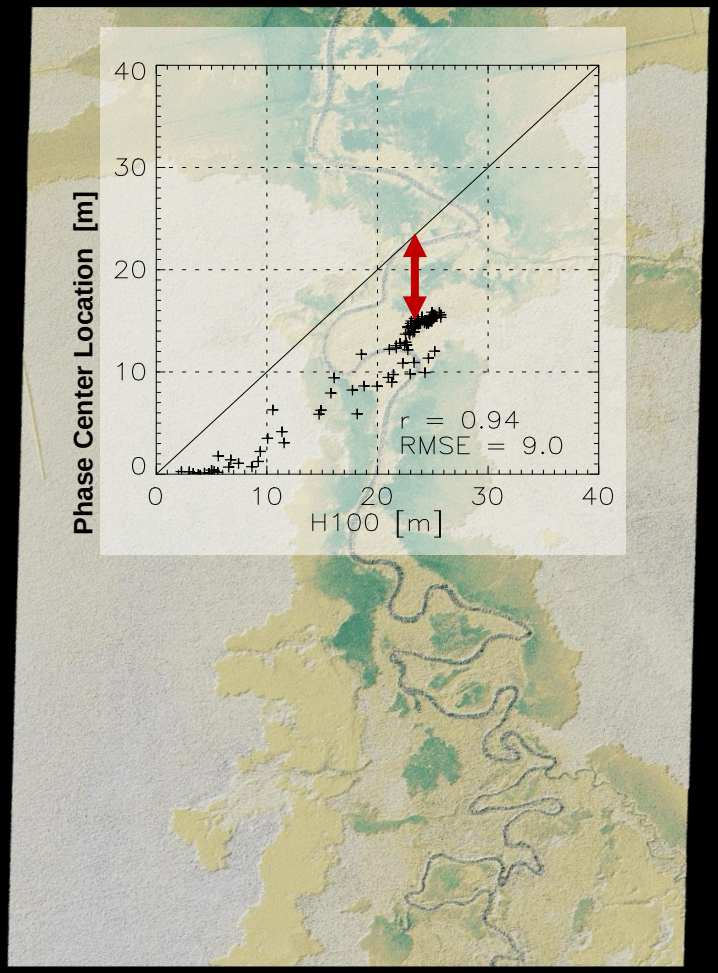
10 - 50 Mg/ha

50 - 150 Mg/ha

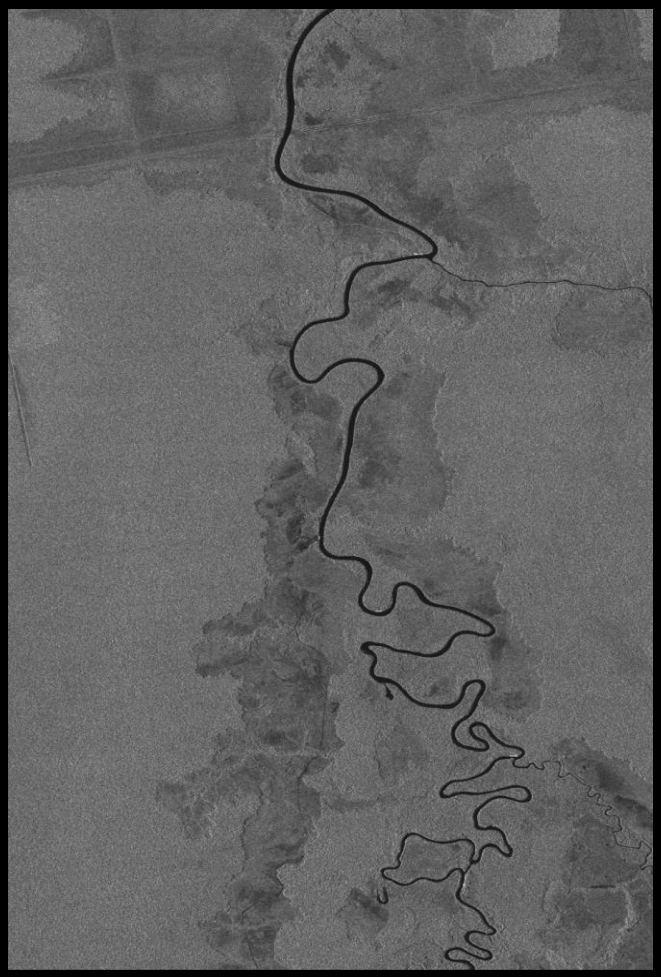
> 150 Mg/ha

TanDEM

Test Site: Mawas, Indonesia

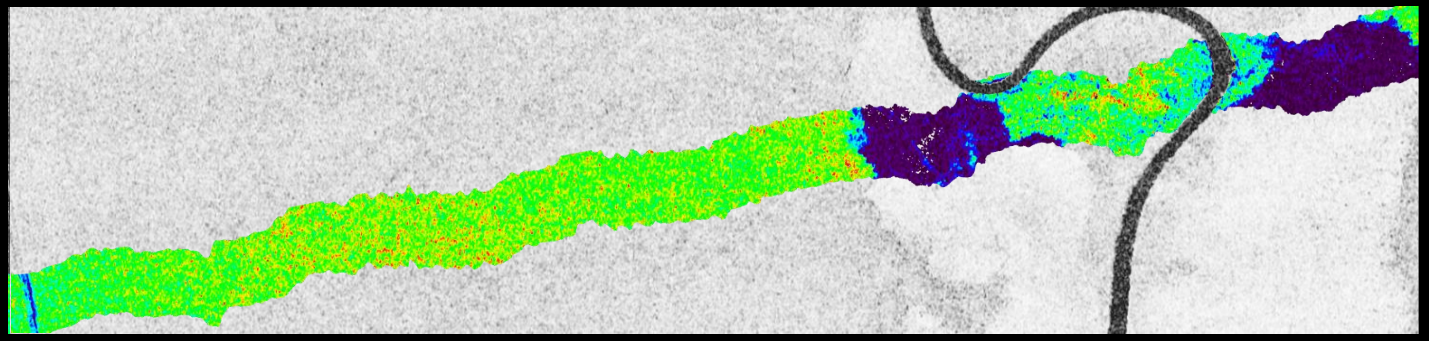


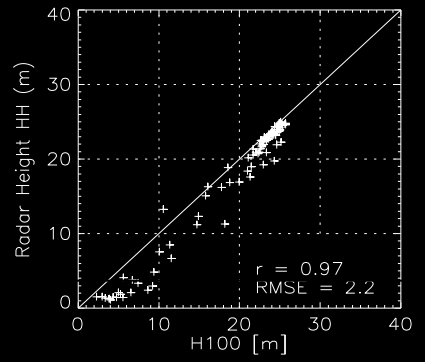
Tandem DEM



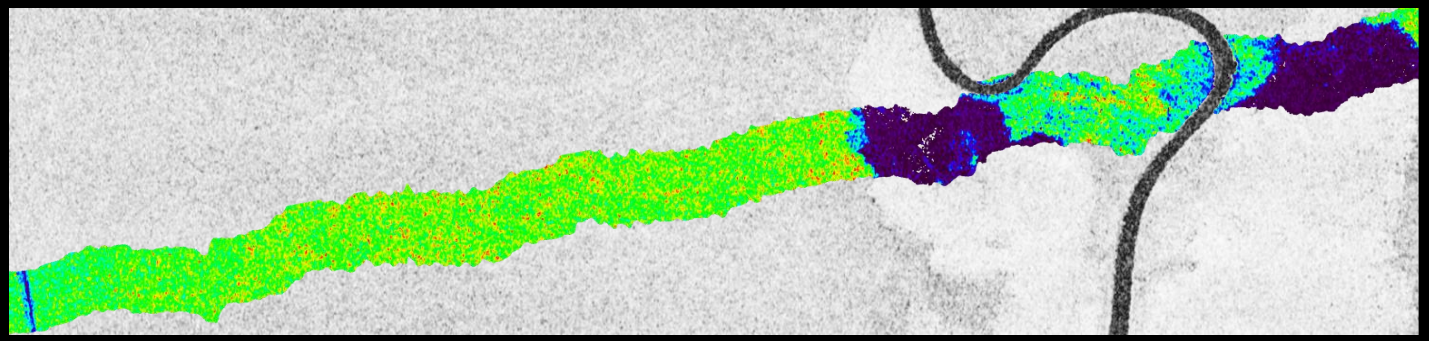
Amplitude HH

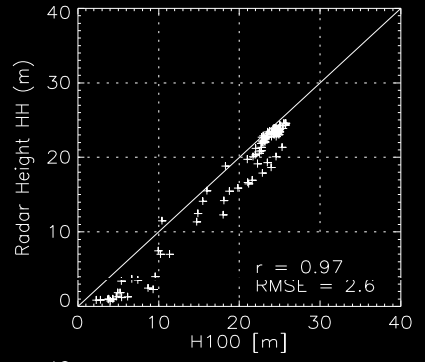
Interferometric Coherence HH



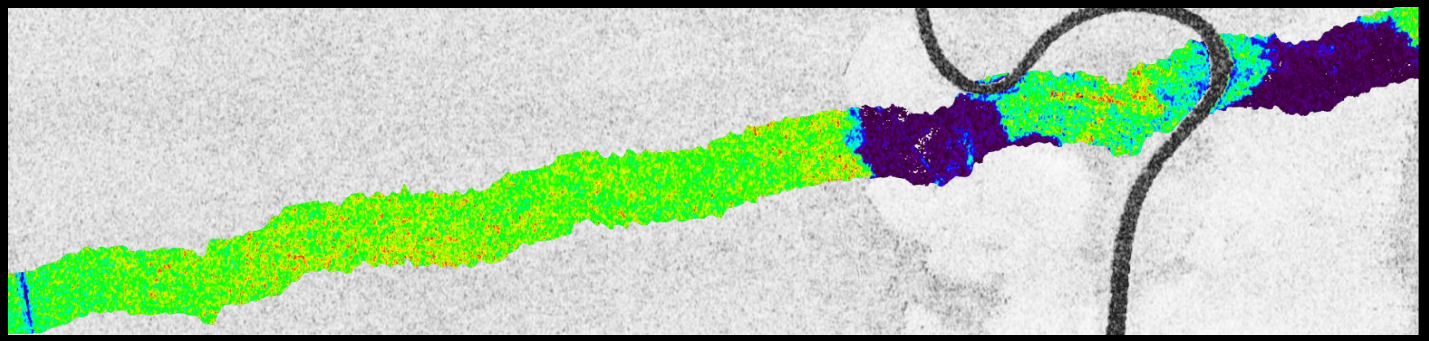


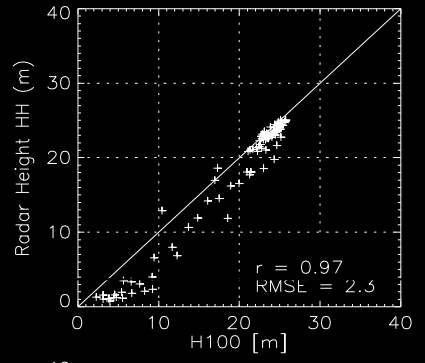
04.01.2011



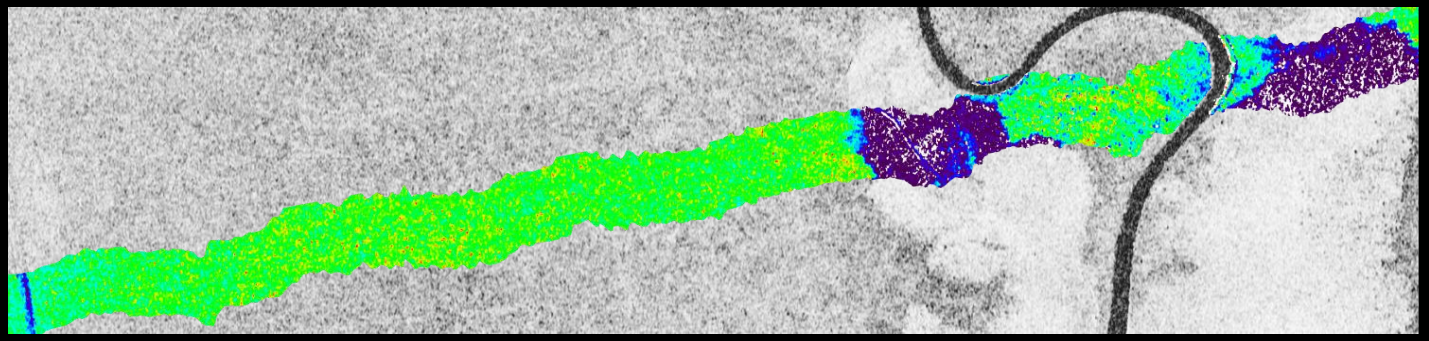


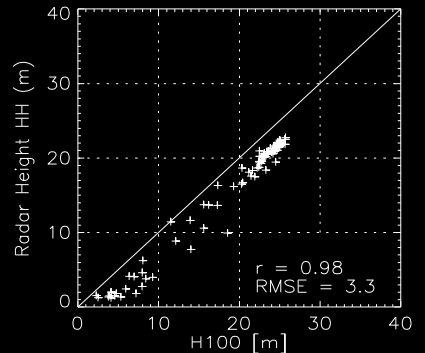
24.12.2011





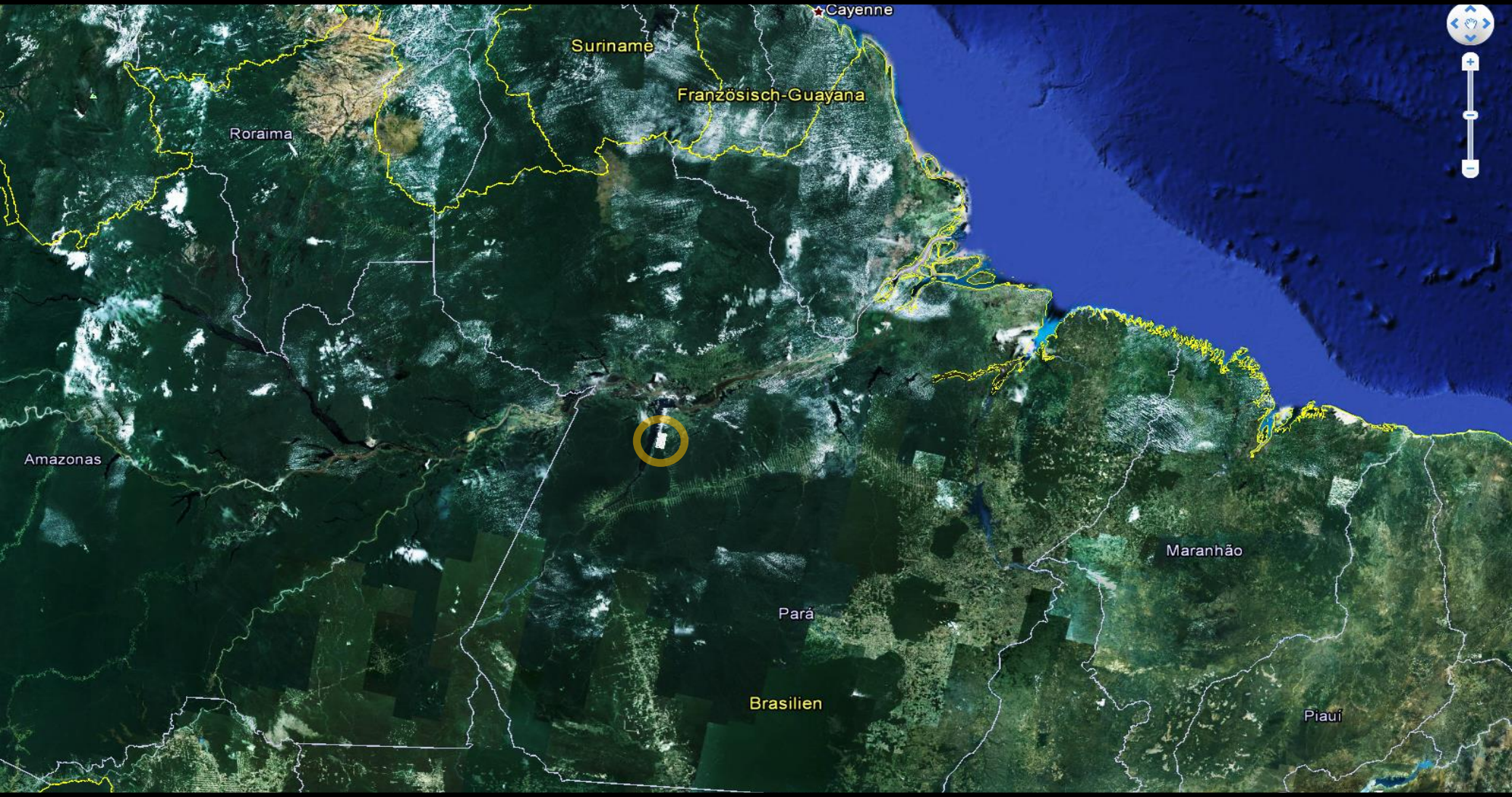
13.12.2011



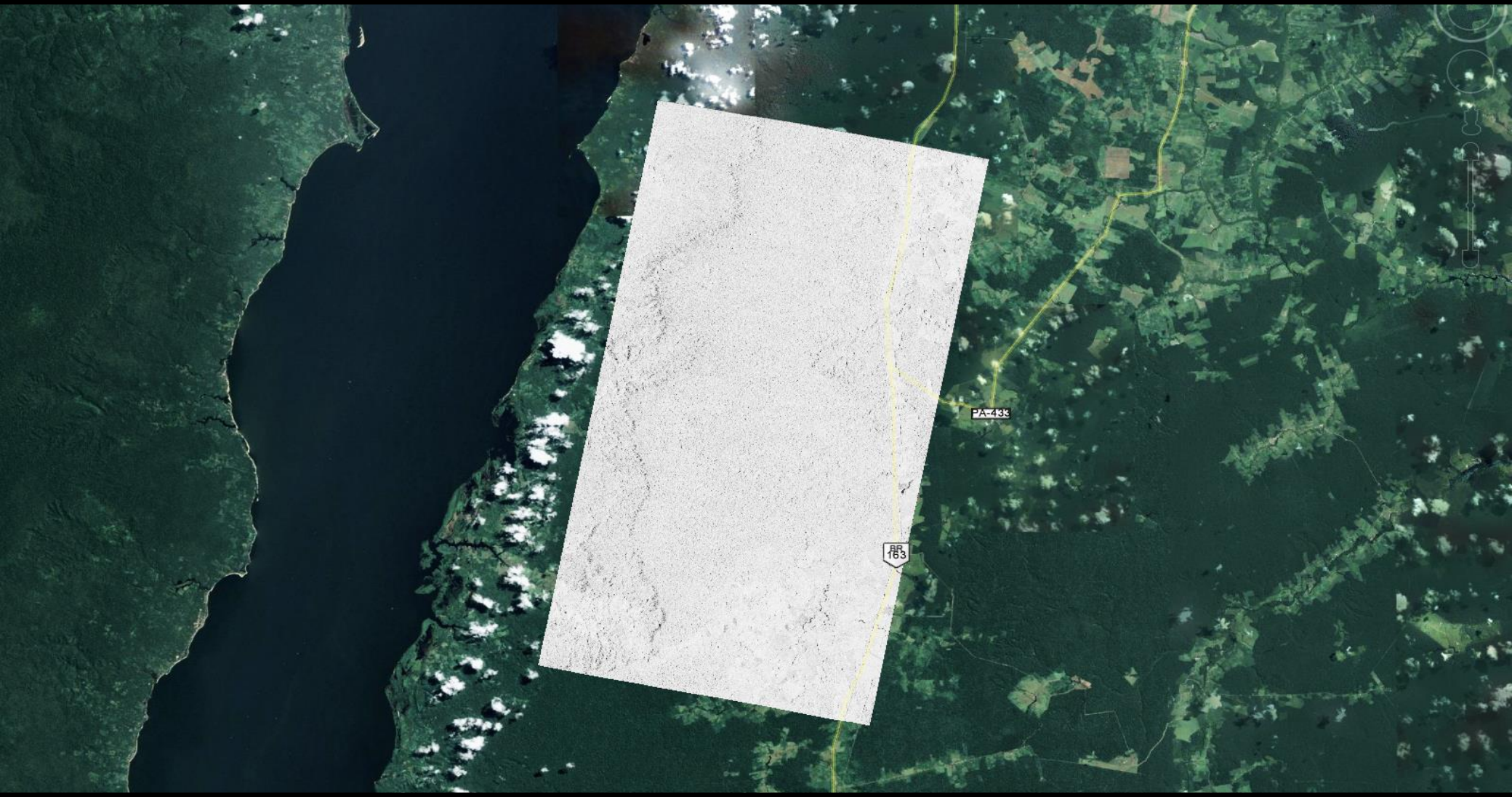


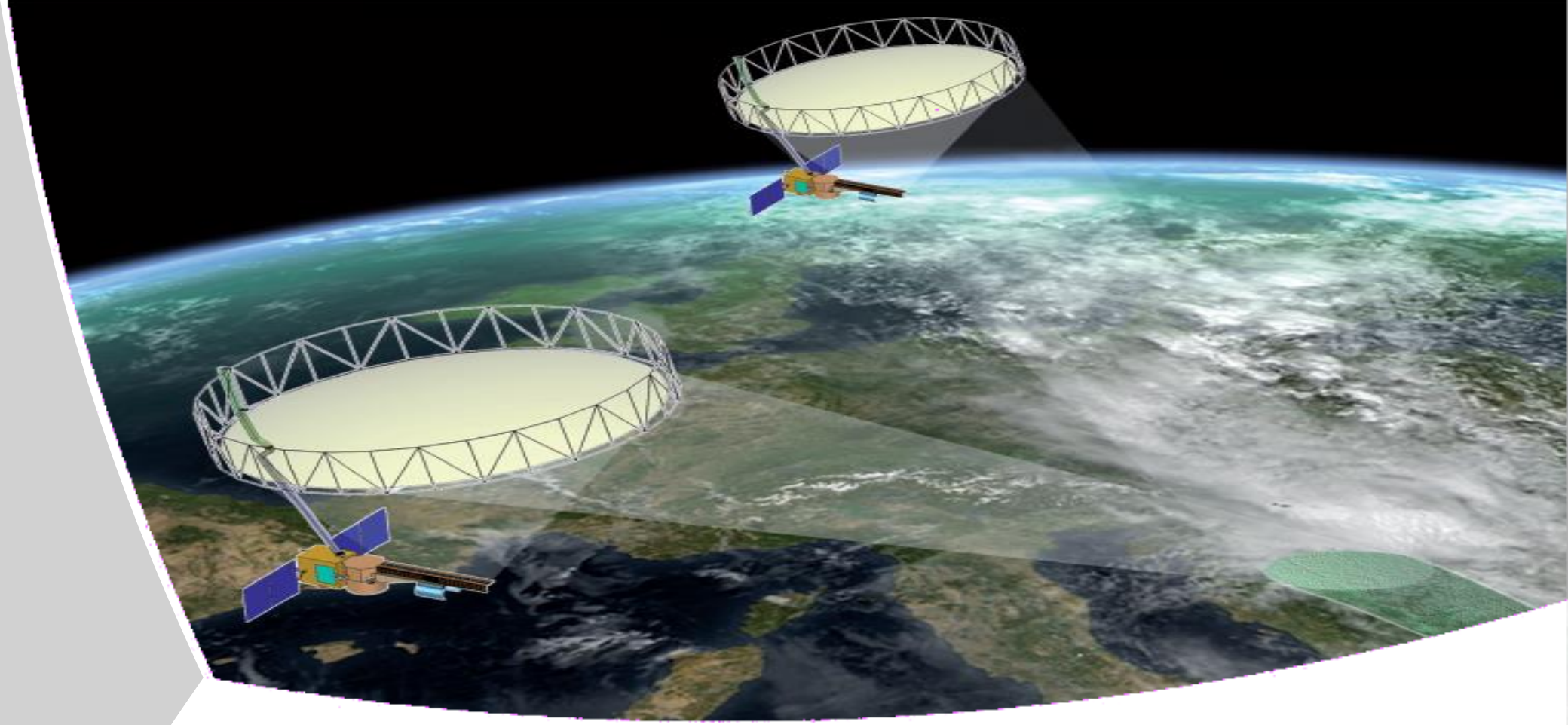
25.08.2012

Test Site: Tapajos, Brasil



Test Site: Tapajos, Brasil



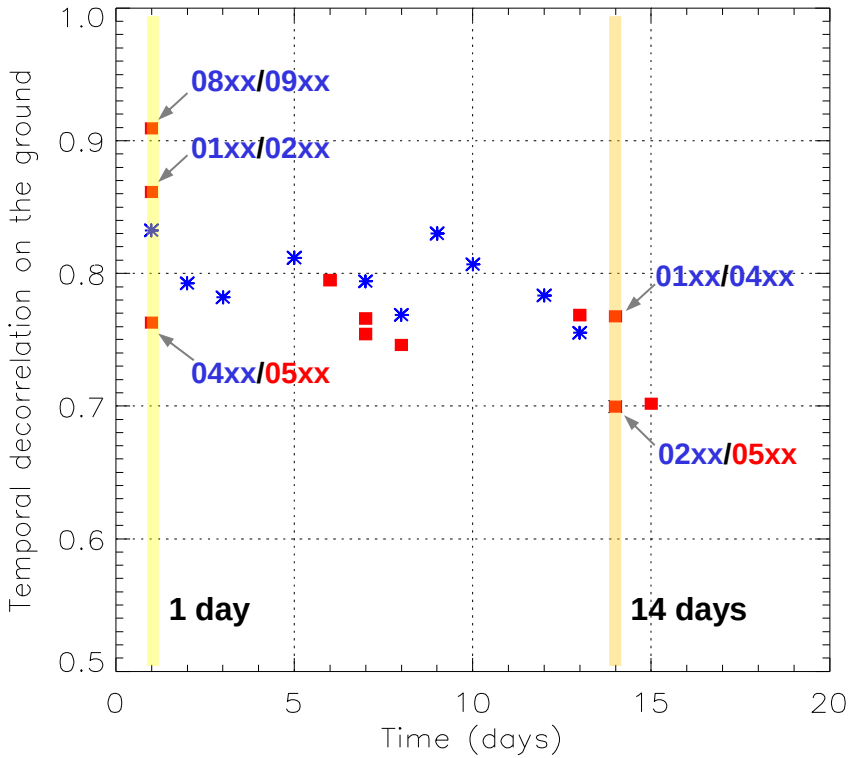


Tandem-L

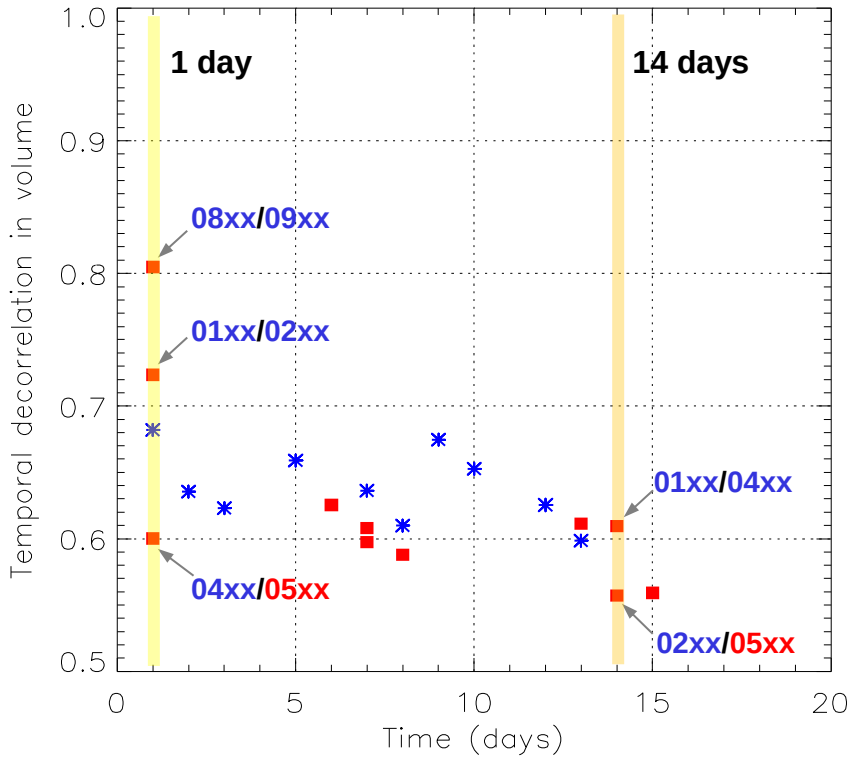
Microwaves and Radar Institute

Temporal Decorrelation Estimation

γ_{TG} Temporal decorrelation on the ground layer



γ_{TV} Temporal decorrelation in volume



TempoSAR 2008

TempoSAR 2009