Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Pol-InSAR Forest Height Inversion by means of L-band F-SAR Data
- Forest Monitoring & Vertical Structure

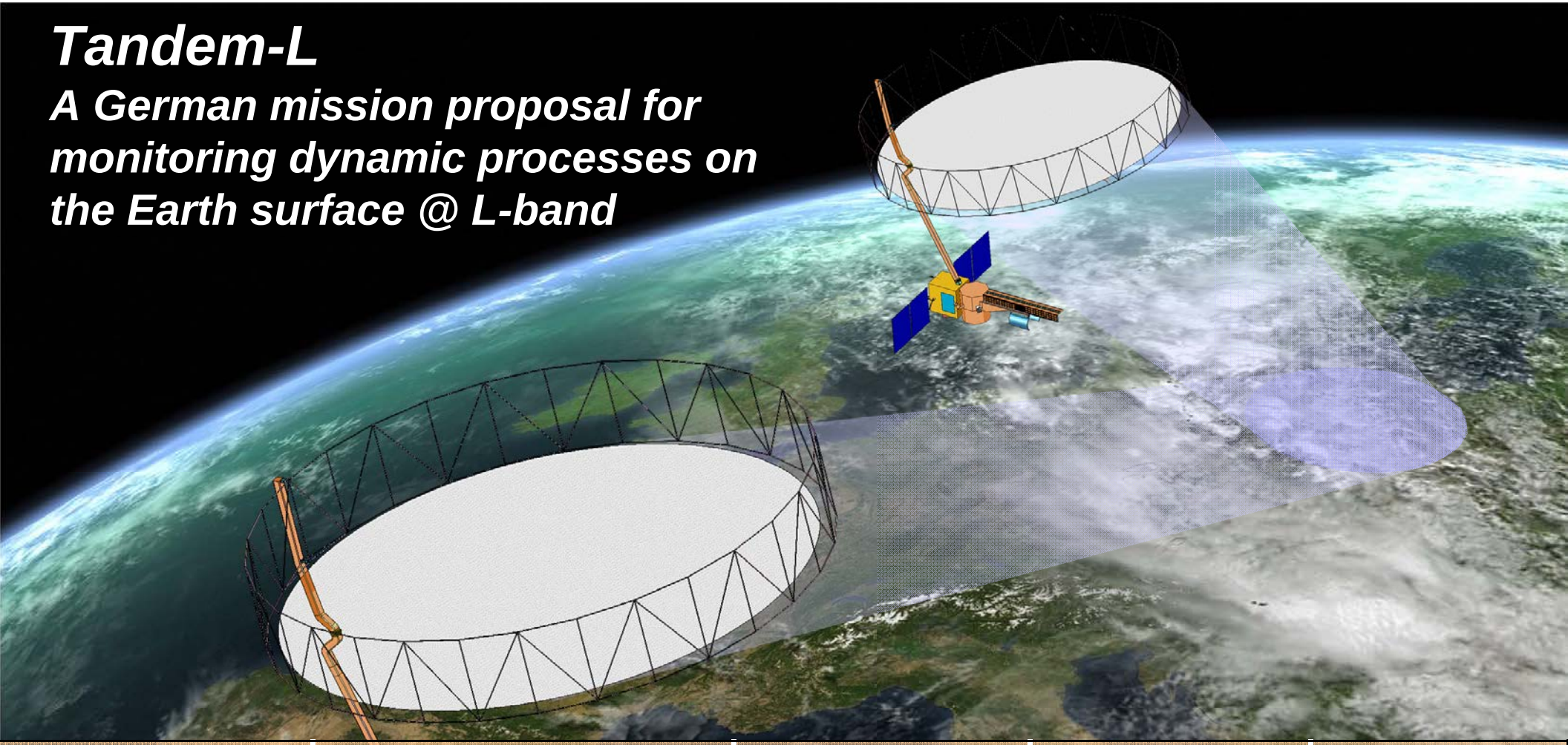
Seung-Kuk Lee[2][1], Matteo Pardini[1], Florian Kugler[1], Kostas Papathanassiou[1], & Irena Hajnsek[2][1]

1) Microwaves and Radar Institute, German Aerospace Center (DLR), Germany
2) Institute of Environmental Engineering, ETH Zurich, Switzerland

DLR

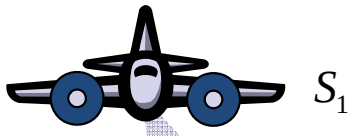
Tandem-L

A German mission proposal for monitoring dynamic processes on the Earth surface @ L-band

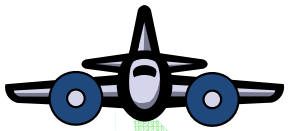


	Science Product	Coverage	Product Resolution	Product Accuracy
Biosphere	Forest Height	All forest areas (Height ≥ 8 m)	50 m (global) 20 m (local)	~ 10 %
	Above Ground Biomass		100 m (global) ≤ 50 m (regional)	~ 20 % (or 20 t/ha)
	Vertical Forest Structure		50 m (global) 20 m (local)	3 layers
	Underlying Topography		50 m	< 4 m

Polarimetric SAR Interferometry



S_1 S_2

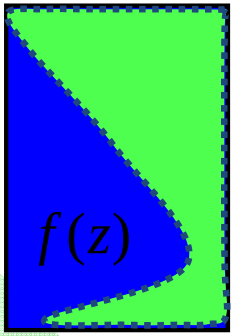


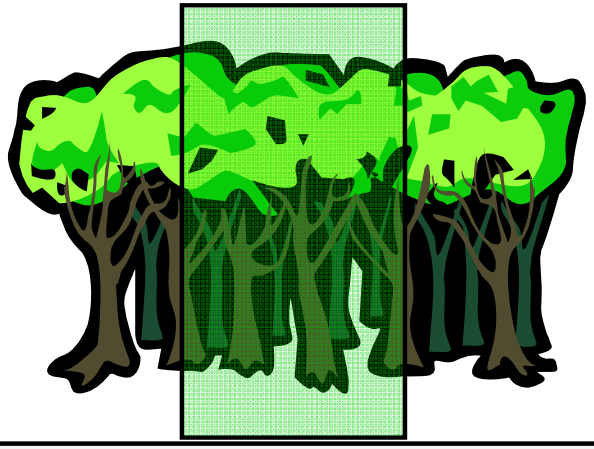
Interferometric Coherence

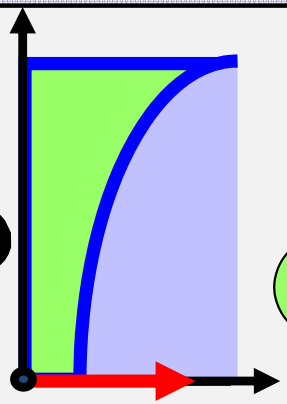
$$\tilde{\gamma}(S_1\ S_2) = \frac{< S_1\ S_2^* >}{\sqrt{< S_1\ S_1^* >< S_2\ S_2^* >}}$$

Volume Coherence

$$\tilde{\gamma}_V(f(z)) = e^{i\kappa_z z_o} \frac{\int_o^{h_v} f(z)\, e^{i\kappa_z z}\, dz}{\int_o^{h_v} f(z)\, dz}$$







Random Volume over Ground (RVoG) Model (Two-layer scattering model)

$$f(z) = \tilde{m}_V e^{\frac{2\sigma}{\cos\theta_0} z} + m'_G\, \delta(z - z_0)$$

Volume ***Ground layer***

$$\tilde{\gamma}(\vec{w}) = e^{i\phi_0} \frac{\tilde{\gamma}_V + m(\vec{w})}{1 + m(\vec{w})}$$

Volume Coherence

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

$$I = \int_0^{h_v} e^{i\kappa_z z'} e^{\frac{2\sigma z'}{\cos\theta_0}} dz'$$

$$I_0 = \int_0^{h_v} e^{\frac{2\sigma z'}{\cos\theta_0}} dz'$$

G/V Ratio: $m(\vec{w}) = \frac{m_G(\vec{w})}{m_V(\vec{w}) I_0}$

Vertical Wavenumber: $\kappa_z = \frac{4\pi}{\lambda} \frac{\Delta\theta}{\sin(\theta_0)}$

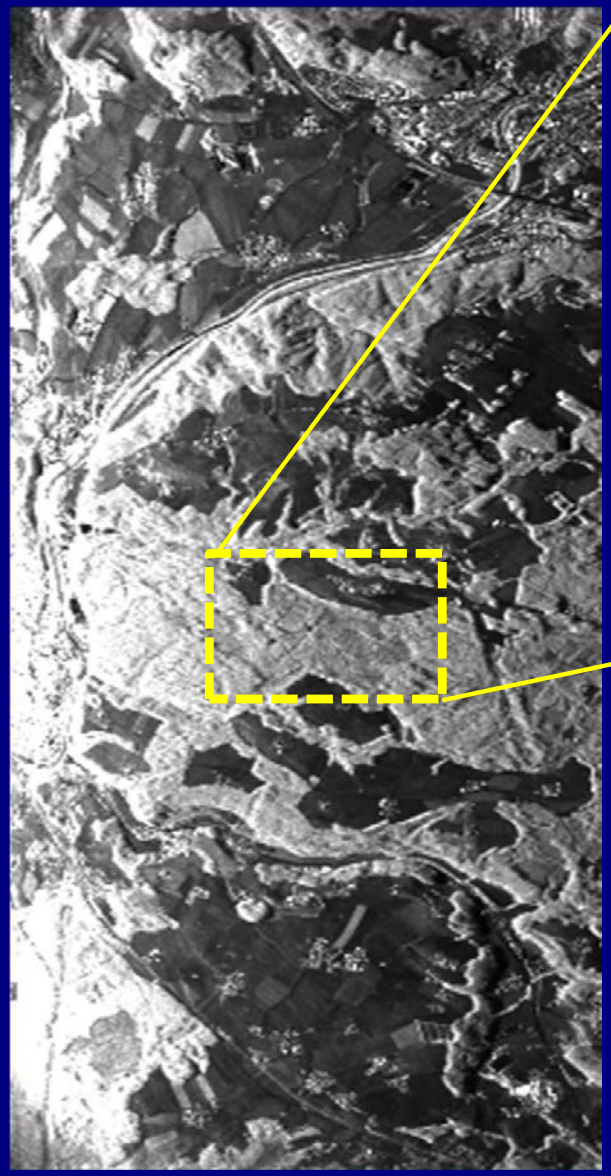
Volume Height h_V

Extinction σ

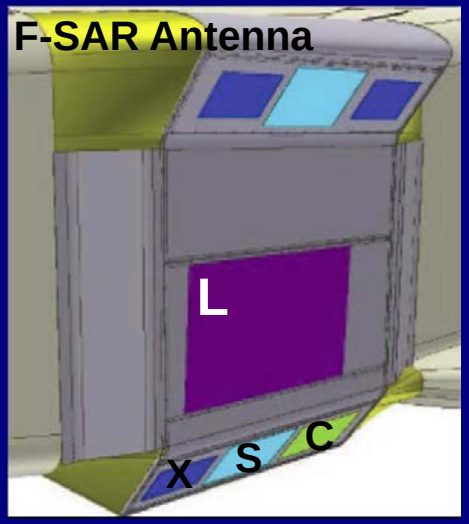
Topography ϕ_0

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

L-band F-SAR System



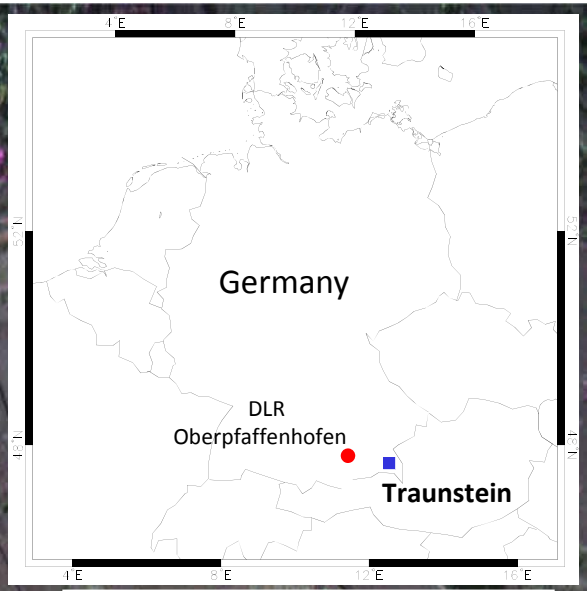
Parameters	F-SAR	E-SAR
Incidence angle (°)	25 – 60	
Platform velocity (m/s)	≈ 90	
Polarizations	HH, HV, VV, VH	
Altitude above ground	≈ 3100	
Center frequency (MHz)	1325	1300
Wavelength (m)	0.226	0.23
Chirp bandwidth (MHz)	150	94
Range resolution	1.00	1.49



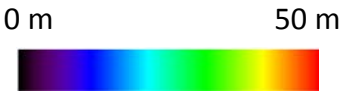
DLR

Traunstein Test Site

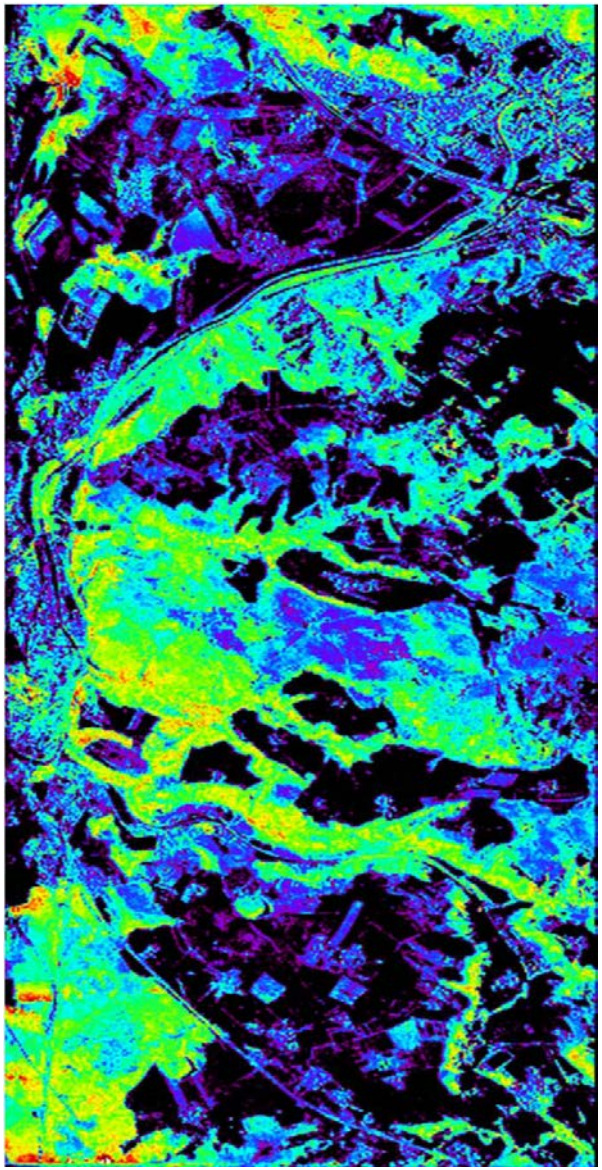
Sensor	F-SAR
Frequency	L-band (1325 MHz)
Test site	Traunstein (Germany)
Forest type	Temperate
Topography	Moderate slopes
Height	25 ~ 30m
Species	N. Spruce, E. Beech, White Fir
Biomass	40 ~ 450 t/ha
Acquisition	17th June 2011 (6 tracks) 13th November 2012 (6 tracks) 23rd November 2012 (5 tracks)



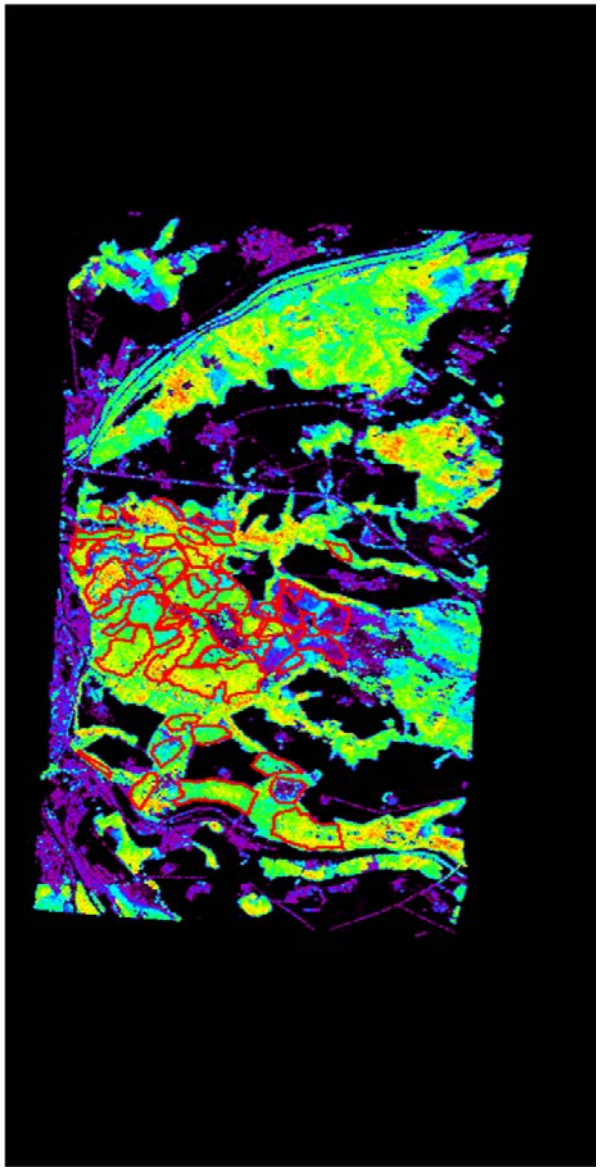
L-band F-SAR Forest Height Map

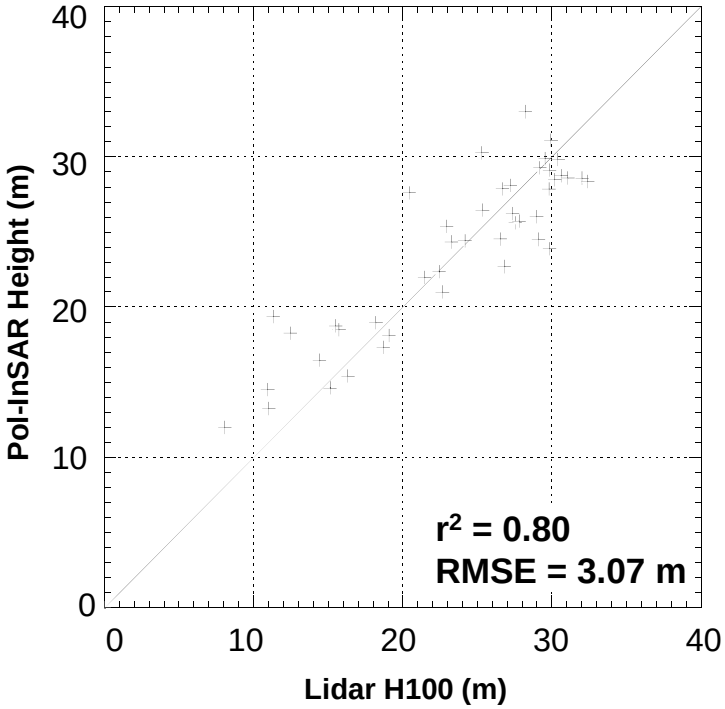


Pol-InSAR Inversion



Lidar H100





- **L-band F-SAR Pol-InSAR inversion was successfully performed.**

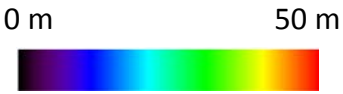
DLR

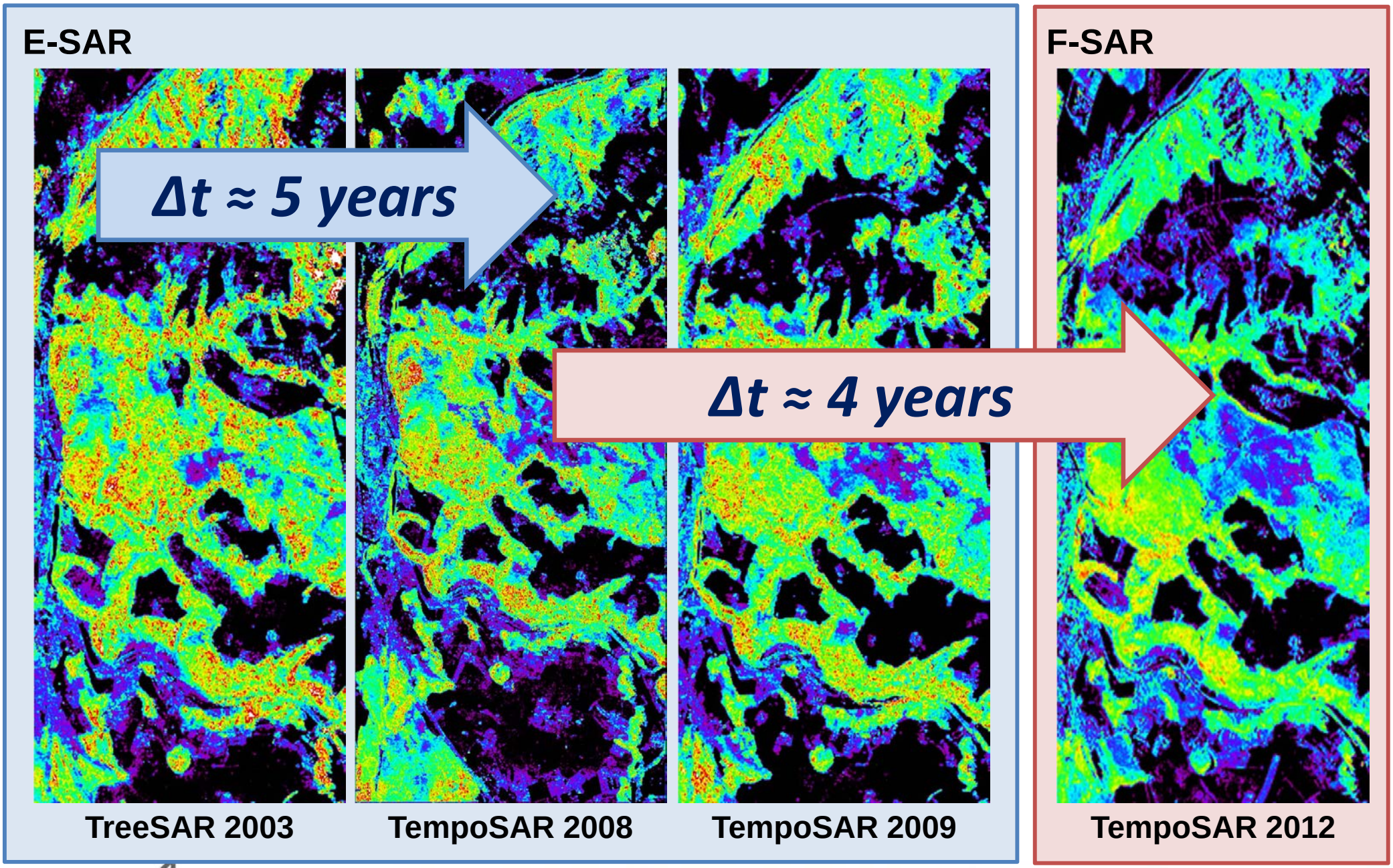
TreeSAR & TempoSAR Campaigns; Traunstein Test Site

- Collect L-band Pol-InSAR data sets with a variety of spatial and temporal baselines
  - ✓ Multi-baseline Pol-InSAR Inversion / Impact of temporal decorrelation
  - ✓ Above Ground Biomass
  - ✓ Forest monitoring
  - ✓ Tomography …

System	Campaign	Date	Acquisition	Temporal Baseline	Pol-InSAR	Lidar
E-SAR	TreeSAR 2003	Oct.	2	15 days	O	×
	TempoSAR 2008	June	5	1 - 13 days	O	O
	TempoSAR 2009	Apr. - May	5	1 - 15 days	O	×
		Oct. - Nov.	3	1 - 9 days	O	×
F-SAR	TempoSAR 2011	June	1	X	×	×
	TempoSAR 2012	Nov.	2	10 days	Δ	O

E-SAR & F-SAR Pol-InSAR Inversion Results



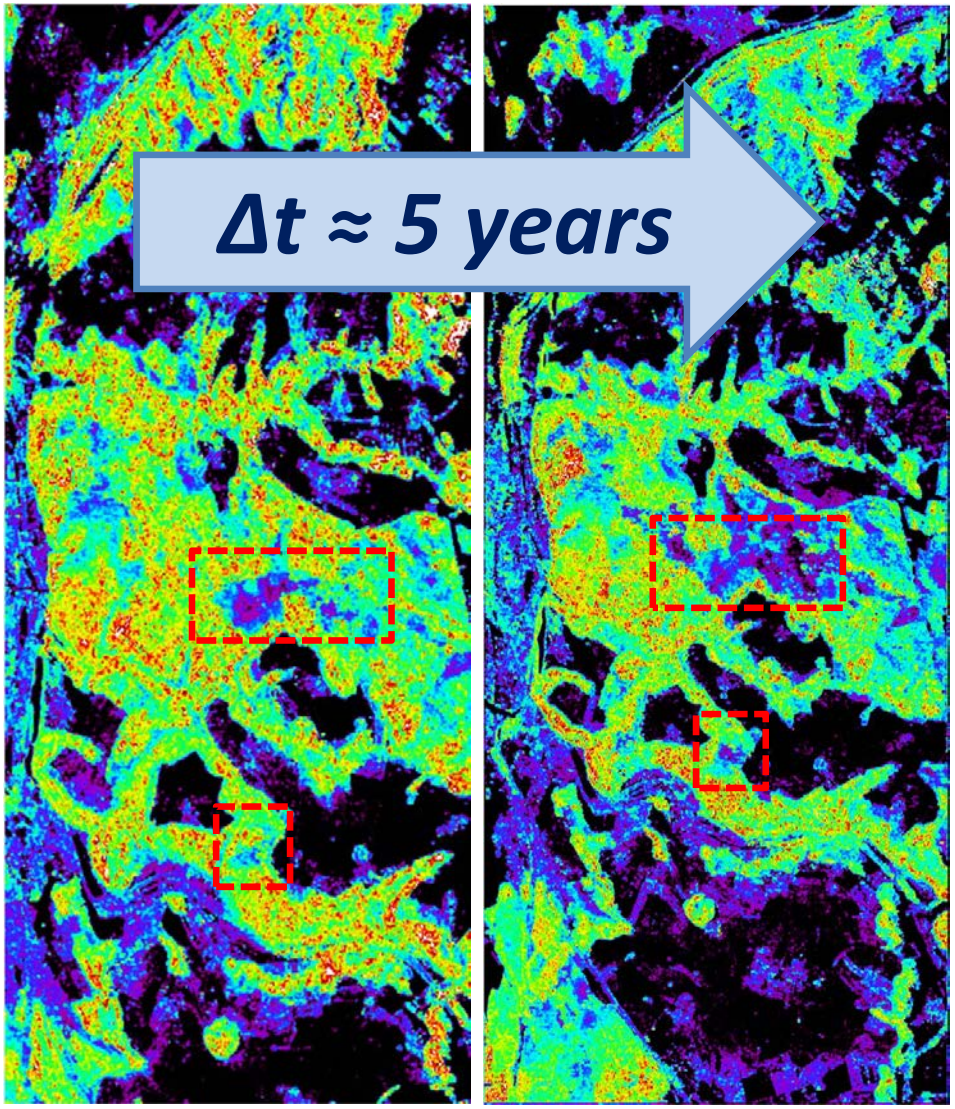


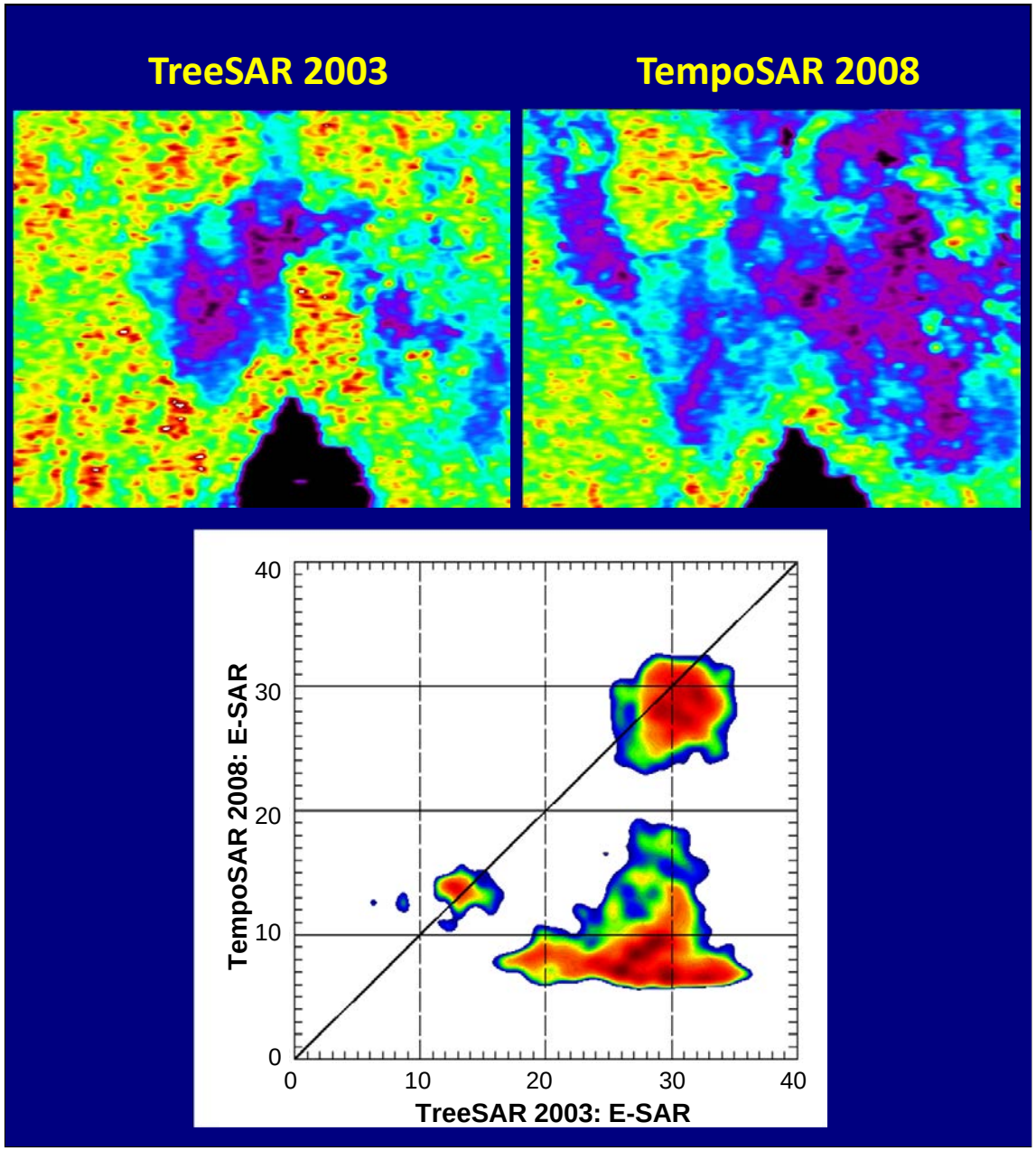
DLR

Delta Forest (ΔF) Traunstein: 2003 → 2008

0 m 50 m

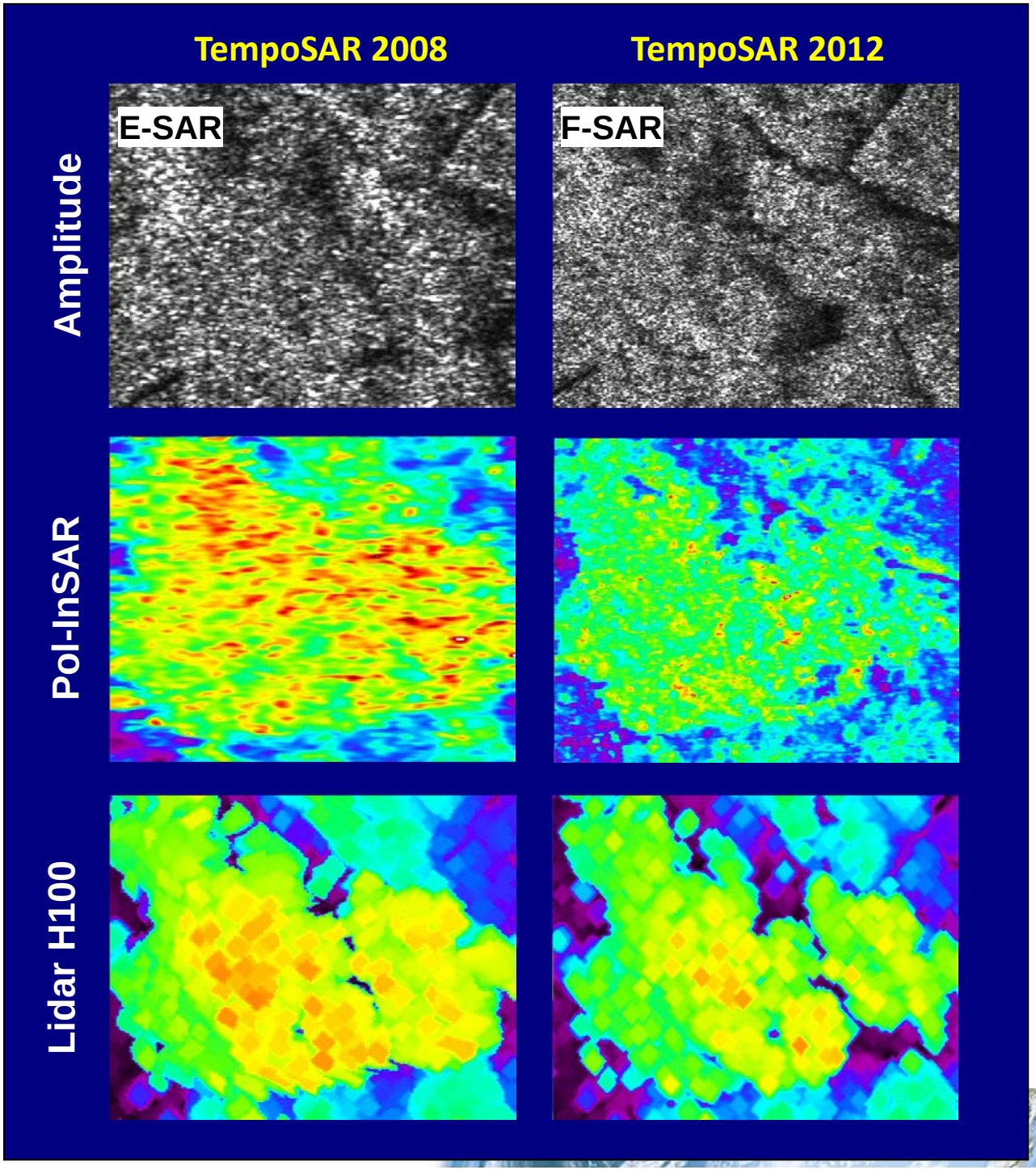
TreeSAR 2003 TempoSAR 2008

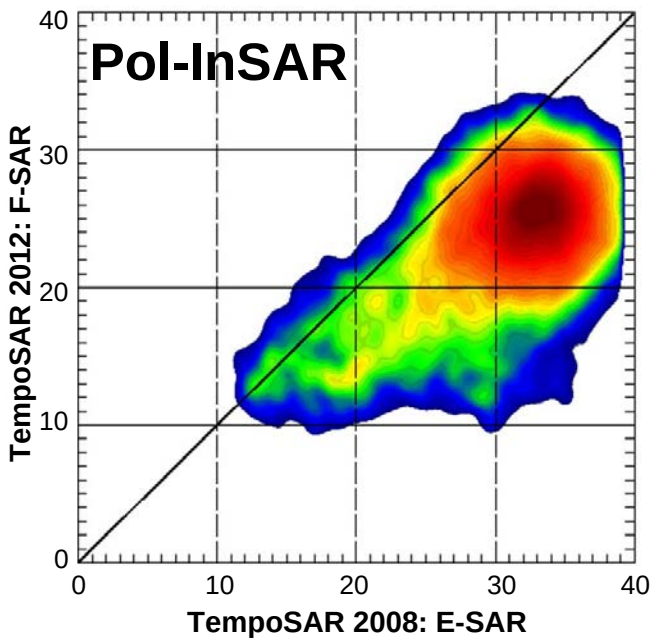


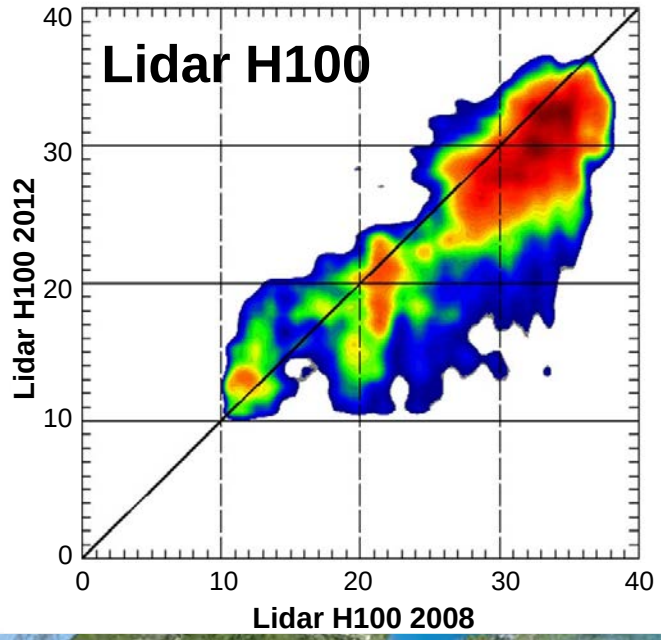


- **The mean forest height in Traunstein has been reduced from 2003 to 2008**

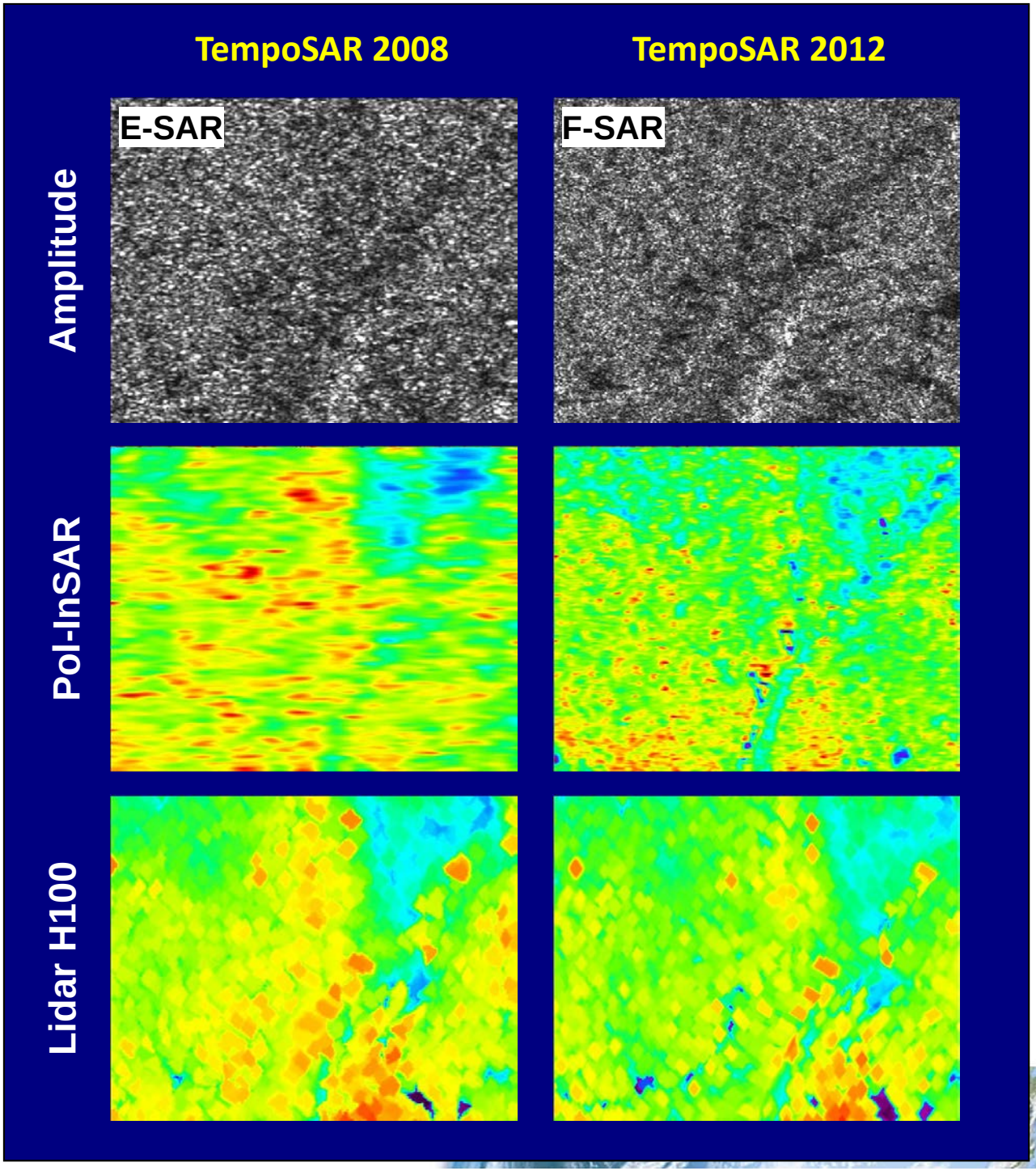
Delta Forest (ΔF) Traunstein: 2008 → 2012

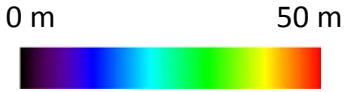


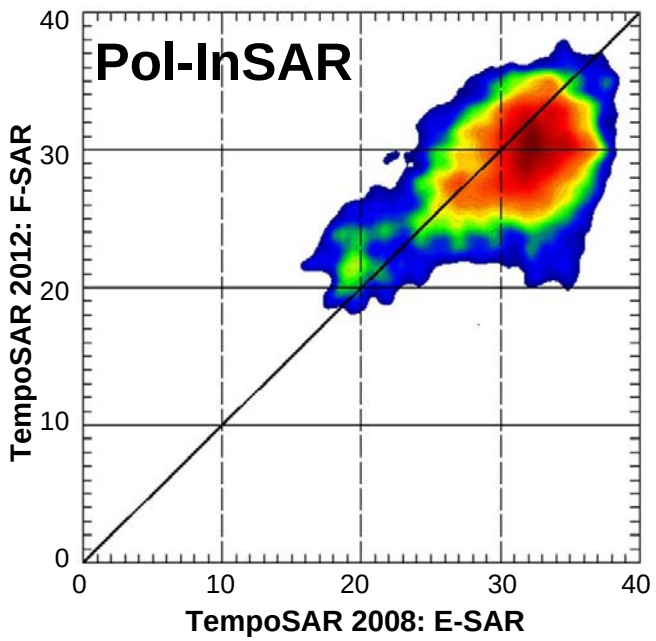


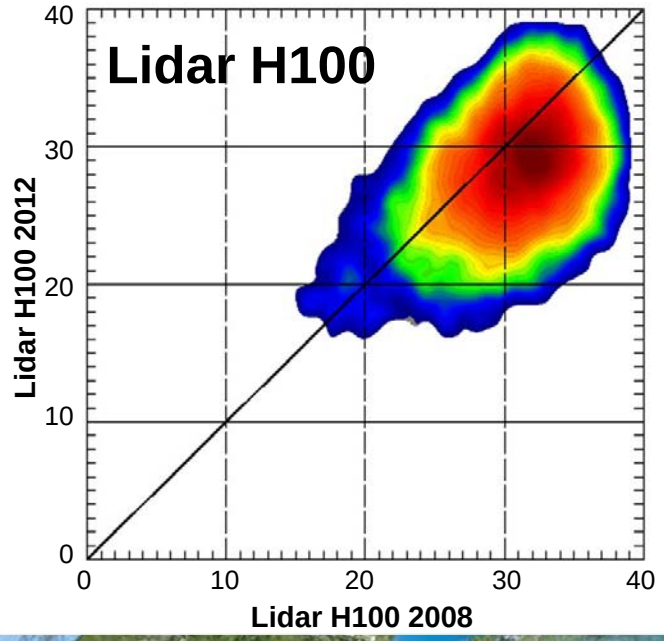


Delta Forest (ΔF) Traunstein: 2008 → 2012

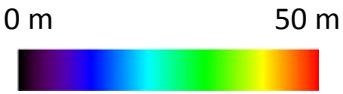


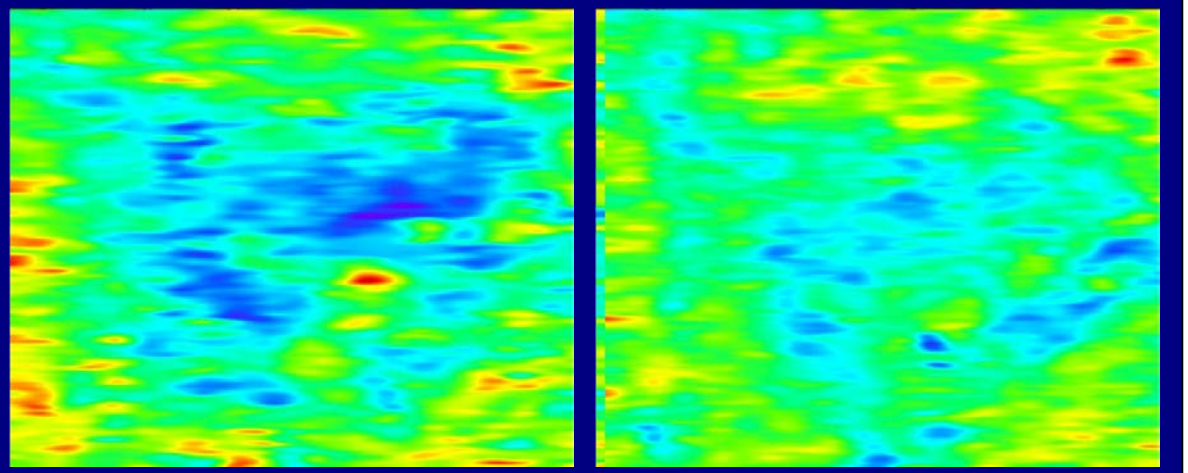


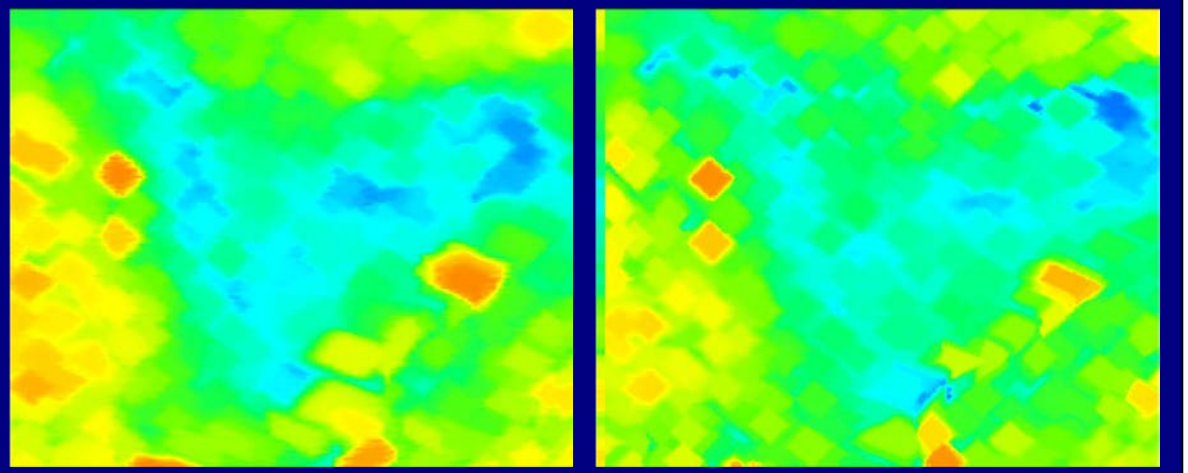


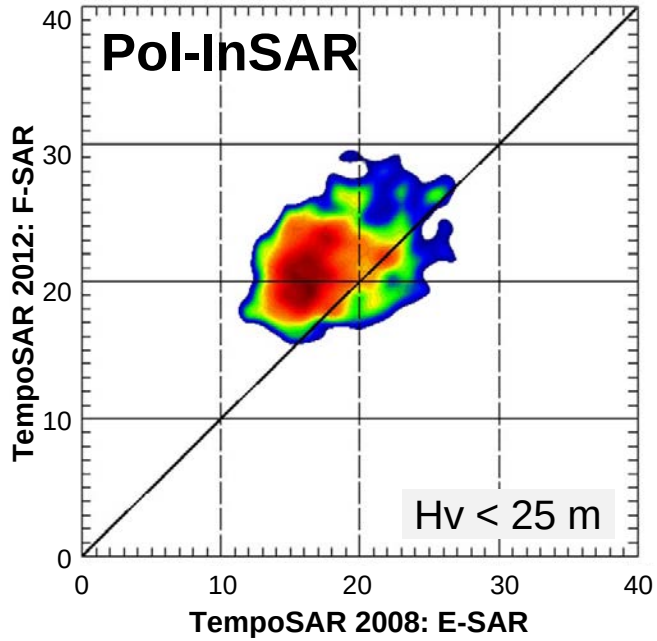


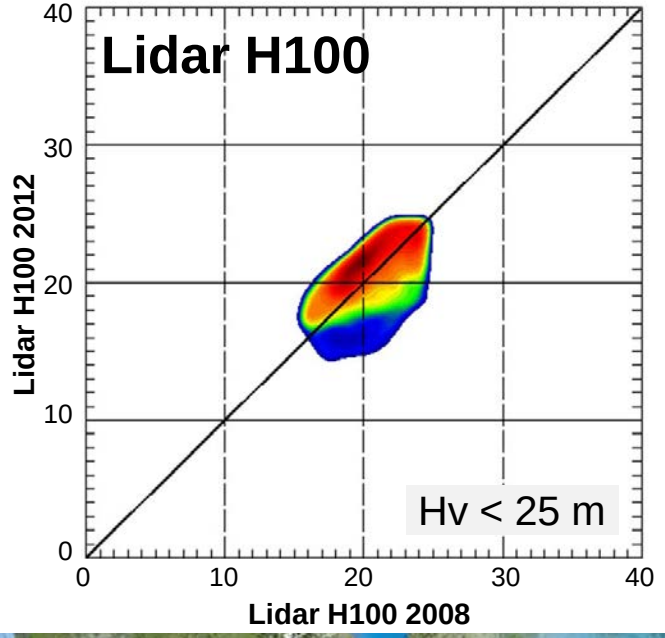
Delta Forest (ΔF) Traunstein: 2008 → 2012







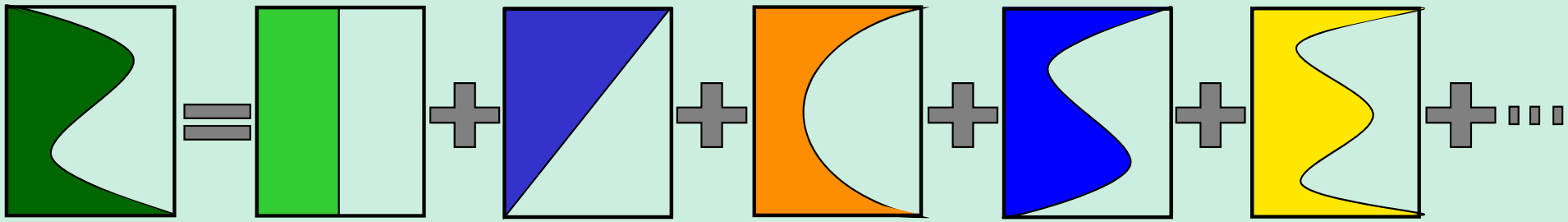




- **A growth of between 3 m and 5 m could be observed over a period of four years.**

MB-Pol-InSAR Data for Vertical Structure

"Model-based" approaches: Polarization Coherence Tomography

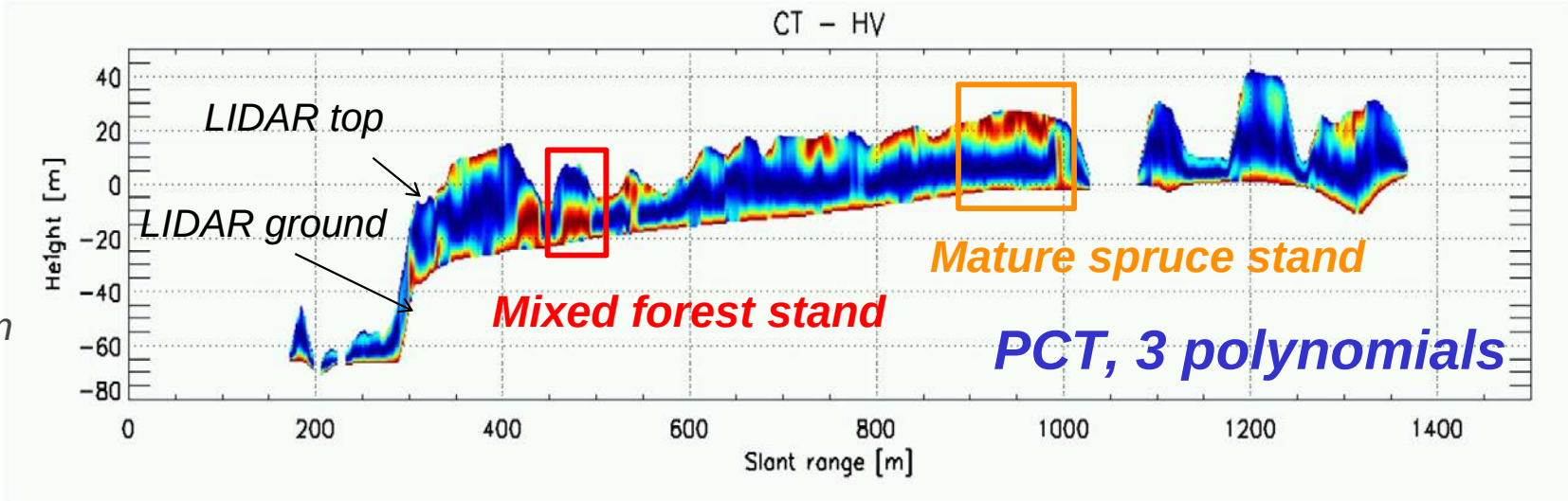


$$f(z) = \sum_n a_n P_n(z)$$

- **Vertical structure representable with a small amount of coefficients!!**
- **Coefficients can be calculated easily with a linear fitting**
- **Here: Legendre polynomials**

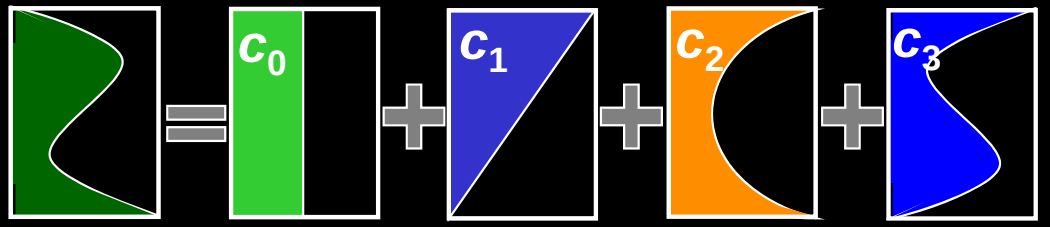
Traunstein TempoSAR '08
DLR's E-SAR

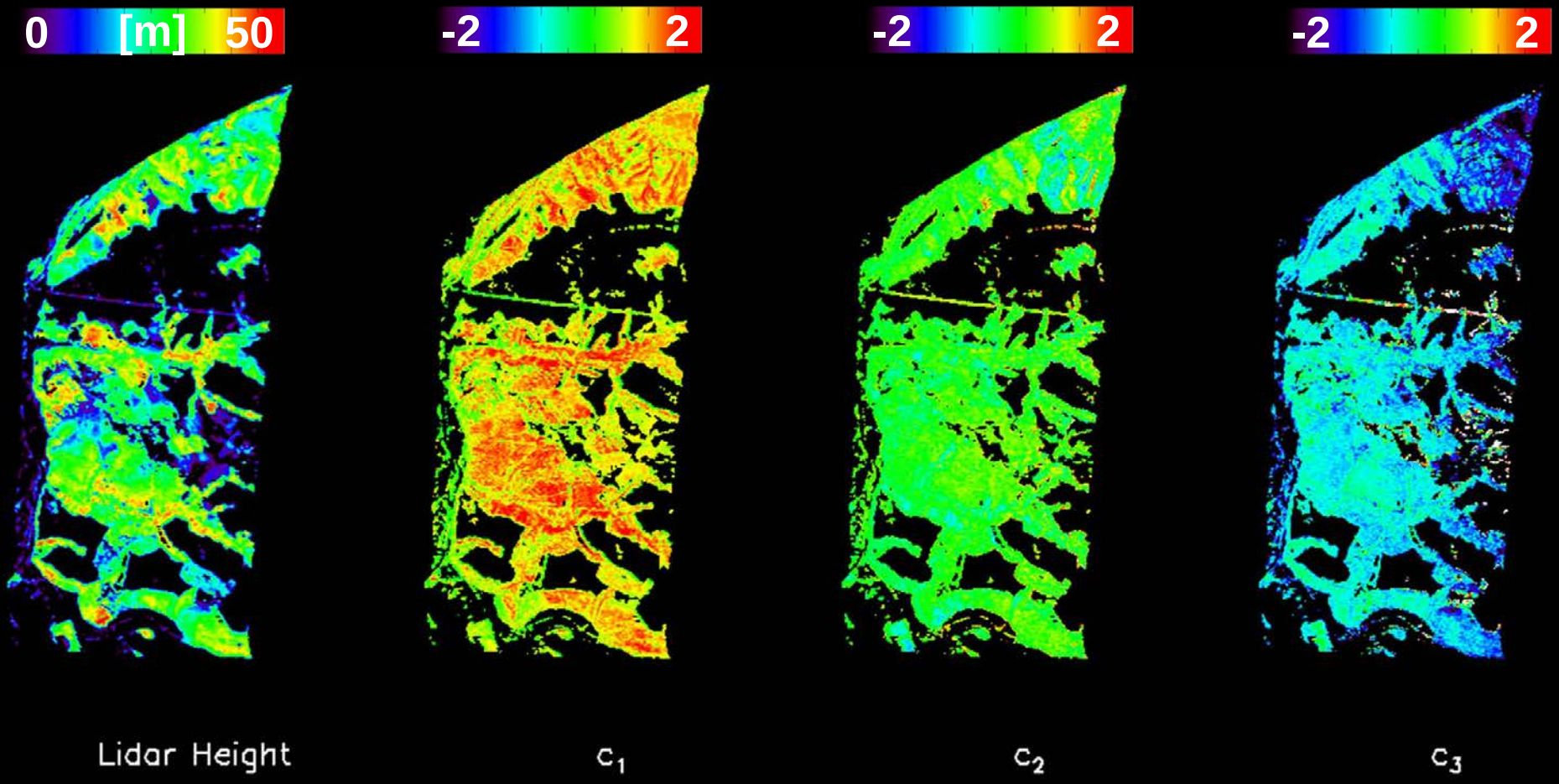
5 images
Max hor. baseline 25m
Height res. variable with range



DLR

PCT coefficients; HV pol.





- Different forest areas have different coefficients
- Considering 3 coefficients allows for a better distinction

DLR

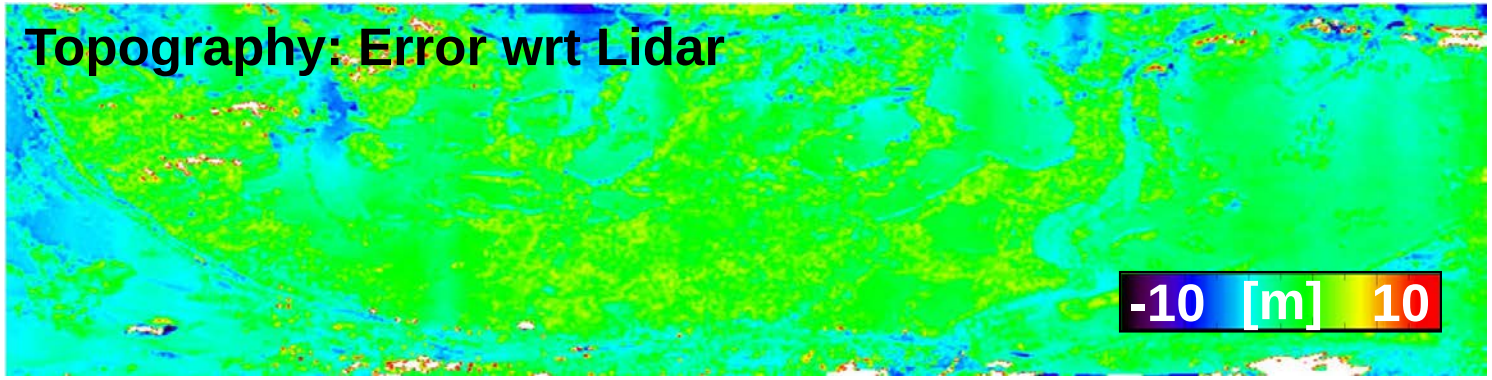
Removal of Ground Scattering

Traunstein
TempoSAR '08
DLR's E-SAR

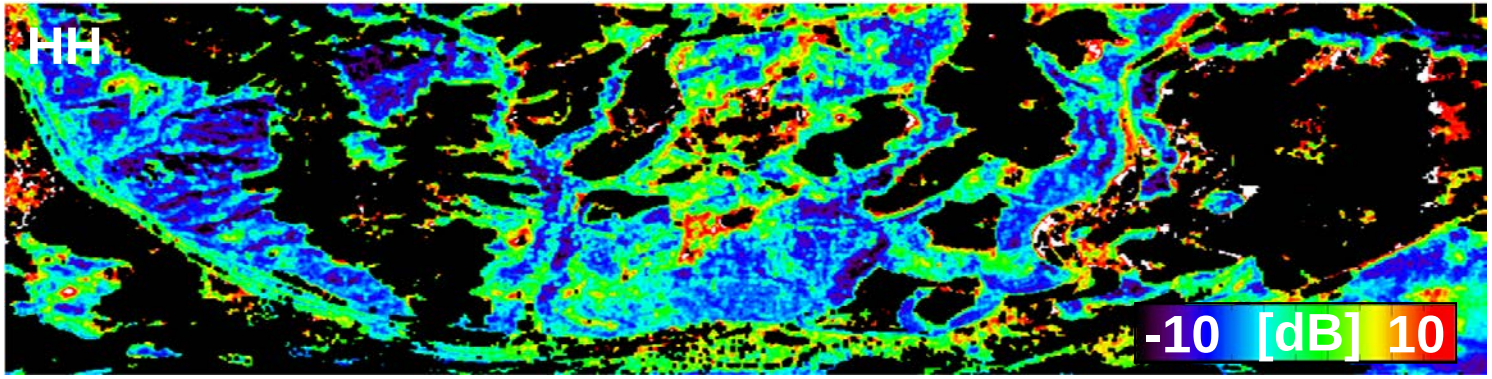
Baselines + polarizations *can be used to estimate* ***ground topography and ground to volume ratio (in each polarization)***

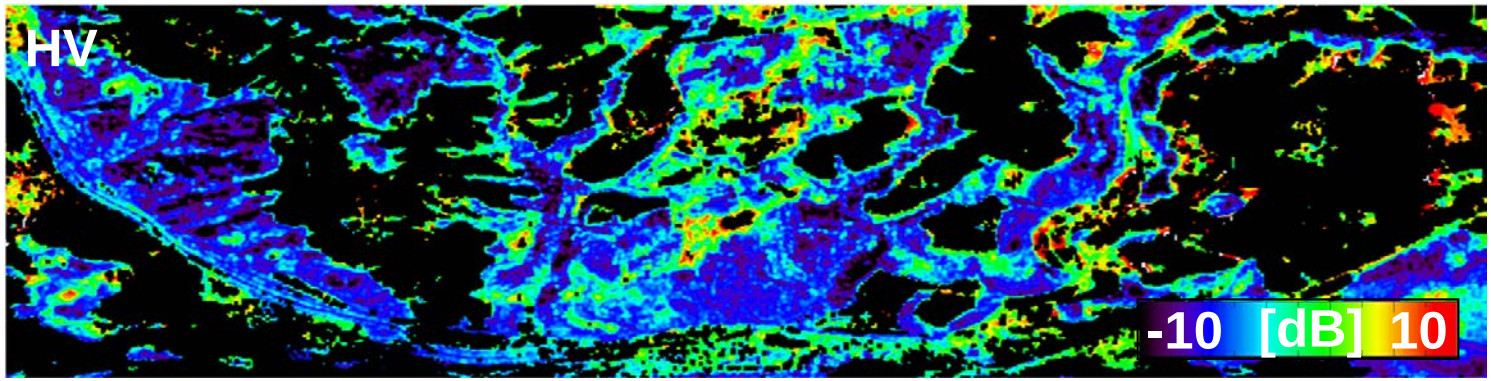
Ground height estimation, full-pol ***M-RELAX***

Further details @ poster session



Forested areas: Bias 0.35m, Std 1.6m





DLR

Removal of Ground Scattering

Fundamental assumption: RVoG model

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

Ground –to-volume ratio

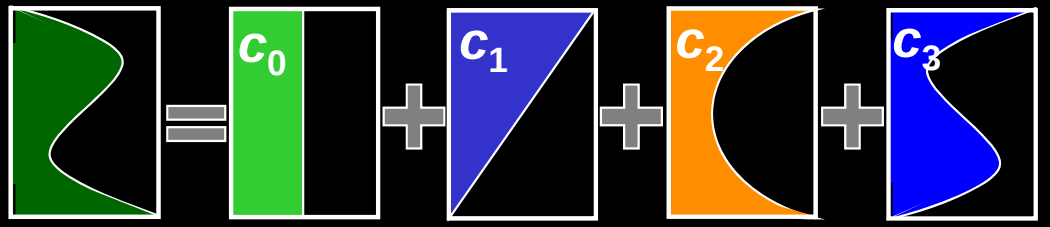
Ground phase

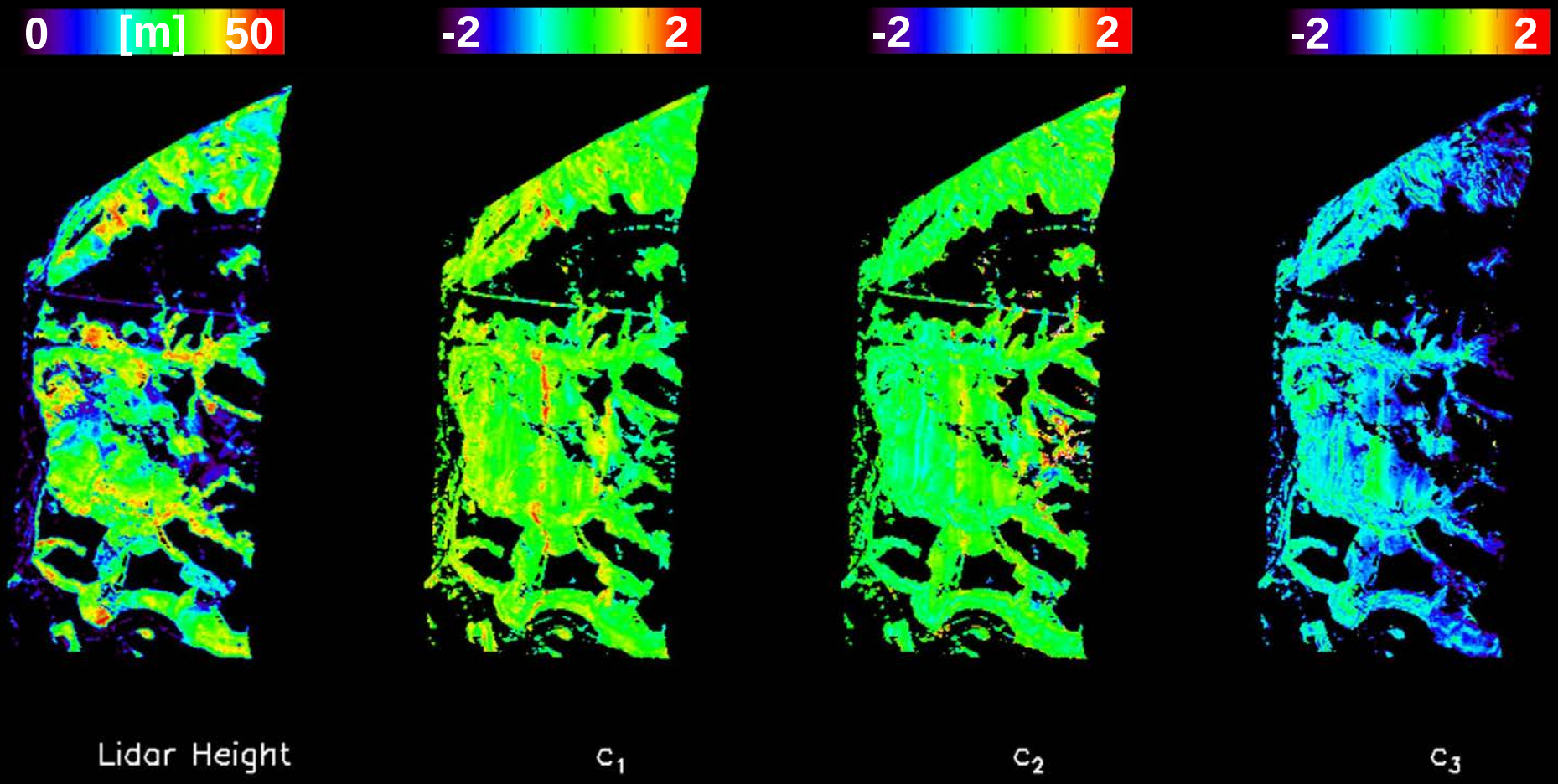
$m(w)$ and φ_0 can be estimated accurately with multibaseline-multipol techniques

$\Rightarrow$ An estimate of γ_V can then be obtained for each polarization channel

As the volume scattering is assumed independent from channel to channel, the PCT coefficients can be estimated from the average volume coherences in the available polarization channels

PCT Coefficients After Ground Removal Full-pol Processing



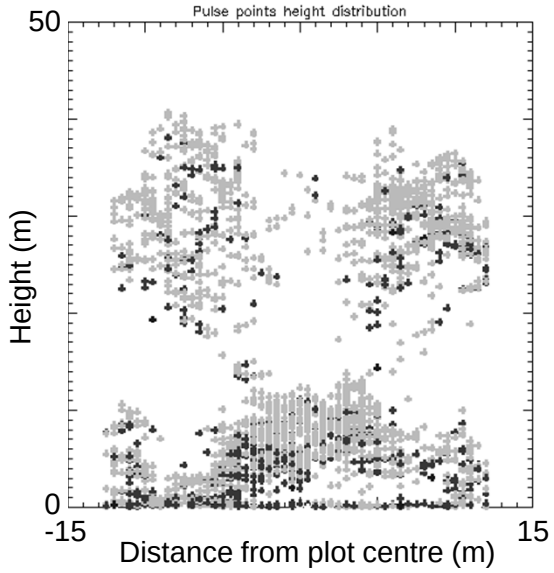


- Higher distinction between different forest areas

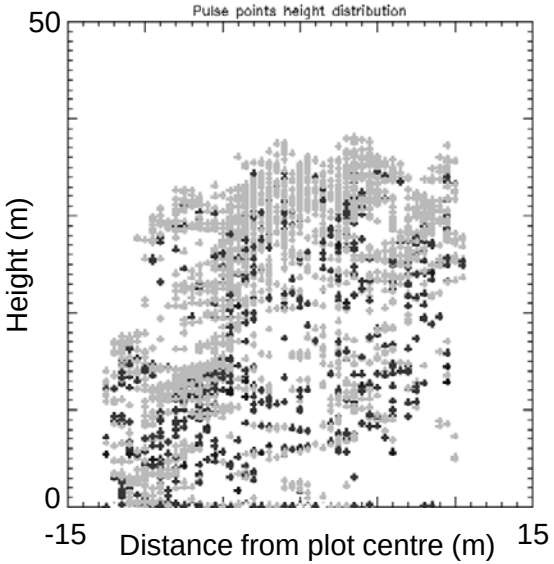
DLR

Examples of Estimated Vertical Profiles

Airborne Lidar returns

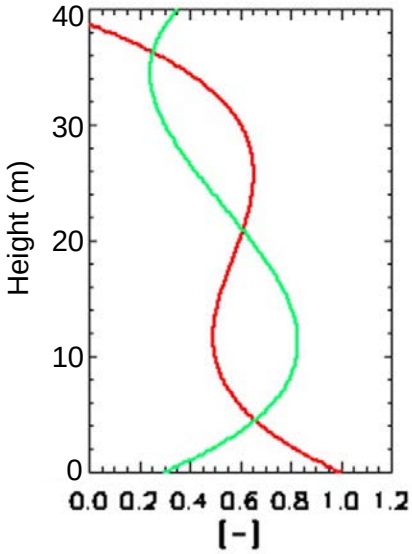


Forest plot with **understory until 10m** and a **not very dense canopy**



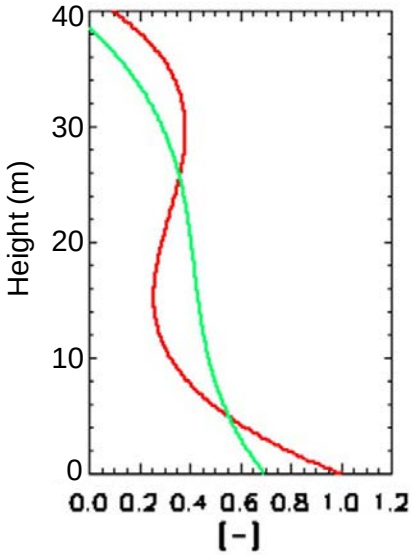
Forest plot with **rather homogeneous vegetation** from top to ground

Radar profiles, PCT



Total signal

Volume only



Total signal

Volume only

DLR

Conclusions

❑ L-band F-SAR Pol-InSAR Inversion

- L-band F-SAR Pol-InSAR forest height shows good estimation performance.
- Validation (against Lidar H100) shows a good correlation coefficient (0.80) and an RMS error of about 3 m.

❑ Forest Changes (∆F)

- Time-series Pol-InSAR forest height maps can monitor forest changes; clear cut, logging, deforest, growth and so on.
- ∆Pol-InSAR inversion results are compared with ∆Lidar H100.
- ∆F will be quantitatively estimated and validated with reference forest information (Lidar H100, field measurement…).

❑ Forest Vertical Structure

- Vertical structure of vegetation free of ground scattering has been derived by combining multi-baseline/full-pol data; a first validation has shown encouraging results.
- Further experiments are ongoing in order to interpret the radar profiles and to relate them to the 3-D biomass distribution.

DLR


Thank you very much for your attention!