WMB-LAPAN-Novel-Approaches = Equatorially Orbiting Sensors

Trend on Polarimetric Synthetic Aperture Radar Techniques:

Assessment of fully polarimetric POLSAR Environmental Remote Sensing & Geophysical Stress-change Monitoring for implementing Equatorially ORBITING Satellites over Indonesia

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Wooil Moon & Duk-Jin Kim
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Abstract-1

With the un-abating global population increase our natural resources are stressed as never before, and the global day/night monitoring of the terrestrial covers from the mesosphere to the litho-sphere becomes all the more urgent. Microwave radar sensors are ideally suited for space imaging because those are almost weather independent, and microwaves propagate through the atmosphere with little deteriorating effects due to clouds, storms, rain, fog aerosol and haze. Globally humidity, haze and aerosols next to cloudiness are increasing at a rather rapid pace, whereas only 20 years ago all of those covered 48% of the globe, today those have increased to about 62% and within another 20 years may exceed 80% for irreversible reasons. Thus, optical remote sensing from space especially in the tropical and sub-tropical vegetated belts is already and will become ever more ineffective, and microwave remote sensing technology must now be advanced strongly and most rapidly hand in hand with digital communications technology because operationally it is more rapidly available especially for disaster mitigation assistance.

Abstract-2

Separate international multi-modal fully polarimetric airborne SAR developmental efforts culminated in a well coordinated group effort of three independent teams eventually launching and operating Fully Polarimetric Satellite SAR Sensors at L-Band (ALOS-PALSAR launched by JAXA/Japan in 2006 January – and to be followed by ALOS-PALSAR-2 &3); at C-Band (RADARSAT-2 launched by CSA-MDA in 2007 December – to be followed by independent RADARSAT-3&4) and at X-Band (TerraSAR-X launched by DLR-Astrium in 2007 July with the follow-on tandem mission TanDEM-X launched in June 2010) . Thus, international collaboration on advancing day & night global monitoring of the terrestrial covers was demonstrated with the launch of the three fully polarimetric multi-modal SAR Satellites at L-, C-, X-Band and its first tandem satellite-pair update of the DLR TanDEM-X. All of these efforts will be topped by the near-future joint DLR-JPL DESDynI/Tandem-L wide-swath, high-resolution fully polarimetric sensor implementation. Of specific relevance is the replacement of DLR E-SAR by the multi-band fully polarimetric F-SAR airborne POLSAR sensor platform.

OUTLINE

1. Recent most pertinent POLinSAR Workshops

- 1. POLinSAR 2003 January 14 - 16: No space-borne SAR, participants: 80
  http://earth.esa.int/workshops/polinsar2003

- 2. POLinSAR 2005 January 17 - 21: No space-borne SAR, participants: 120
  http://earth.esa.int/workshops/polinsar2005

- 3. POLinSAR 2007 January 22 - 26 : ALOS-PALSAR, participants: 160+
  http://earth.esa.int/workshops/polinsar2007

- 4. POLinSAR 2009 January 26 - 30: 3 space-borne SAR, participants: 180+
  http://earth.esa.int/workshops/polinsar2009

- 5. POLinSAR 2011 January 24 - 28: 3 space-borne SAR, participants: 150+62
  http://earth.esa.int/workshops/polinsar2009

2. Advent of Fully Polarimetric Space-borne & Multi-band airborne SAR sensorss

- ALOS-PALSAR	L-Band: January 2006
- RADARSAT-2	C-Band: December 2007
- TerraSAR-X	X-Band: June 2007 **& TanDEM-X June 2010**
- **Multi-band F-SAR**	**P, L, S, C, X, K_a, (K, Ku, W)**

Recent Textbooks on Radar Polarimetry & Polarimetric Interferometry

Mott, Boerner, Yamaguchi, Souyris,
Jin, Jin - Xu, Pottier - Lee, Cloude,
Cumming-Wong, van Zyl-Kim

Recent Books on Polarimetric Radar & SAR, Polarimetric Interferometry

Harold MOTT*, *Remote Sensing with Polarimetric Radar, Wiley-IEEE Press, 1st ed., January 2007, pp309 , ISBN: 978-0470074763 {also see previous books by late Harold Mott, 1986 & 1992}

Boerner, Wolfgang-Martin, *Introduction to Synthetic Aperture Radar (SAR) Polarimetry*, Wexford Press (reprinted *without permission* from W-M. Boerner (April 2007), Basics of SAR Polarimetry 1, *In Radar Polarimetry and Interferometry (pp. 3.1- 3-40)*, Educational Notes RTO-EN-SET-081bis, Paper 3, Neuilly-sur-Seine, France RTO, available from: http://www.rto.nato.int/abstracts.asp

Yamaguchi, Yoshio, *Radar Polarimetry from Basics to Applications: Radar Remote Sensing using Polarimetric Information (in Japanese),* IEICE Press, Dec. 2007, (soft cover), ISBN: 978-4-88552-227-7, http://www.ieicepress.com/

Masonnett Didier & Souyris Jean-Claude*, Imaging with Synthetic Aperture Radar*, EPFL/CRC-Press, Engineering Sciences/Electrical Engineering, Taylor & Francis Group, 2008, (hard-cover), ISBN 978-0-8493-8239-4; http://www.crcpress.com

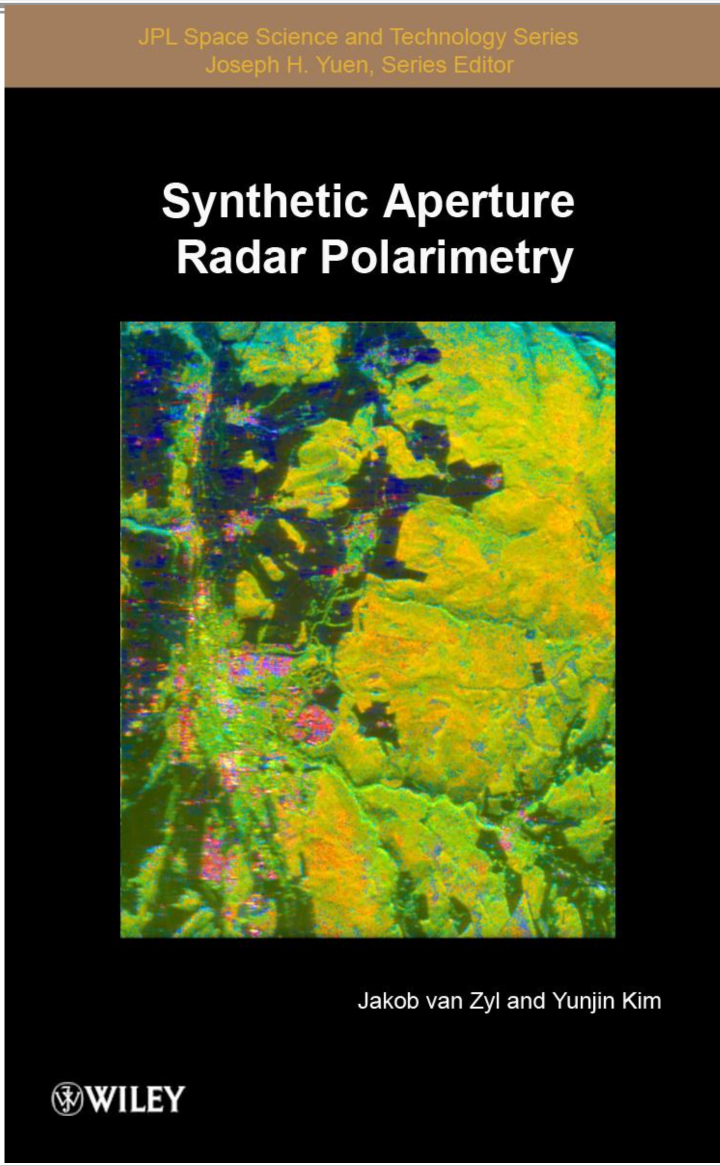
Ya-Qiu JIN & Feng XU, *Theory and Approach for Polarimetric Scattering and Information Retrieval of SAR Remote Sensing (In Modern Chinese)*, Beijing: Science Press, 2008, (hard cover), ISBN978-7-03-022649-5; http://www.sciencep.com

Lee Jong-Sen & Pottier, Eric, *Polarimetric Radar Imaging – from basics to applications*, CRC Press – Taylor & Francis Group, January 2009, ISBN 978-1-4200-5497-2 (hard-cover), TK6580.L424.2009, 621.3848- -dc22; http://www.crcpress.com {Chinese version to be published by 2009 October}

Cloude, Shane Robert, *Polarisation: Applications in Remote Sensing,* Oxford University Press, UK & EU, August 2009, ISBN 978 -0-19-9569731-1 (352p, 260 line-ill: hard-copy), http://www.oup.com.contact/

vanZyl Jakob-Johannes & Kim Yun-Jin, Introduction *to SAR Polarimetry* – in progress and to be completed by 2009 December: To be published with the JPL Series, John Wiley.

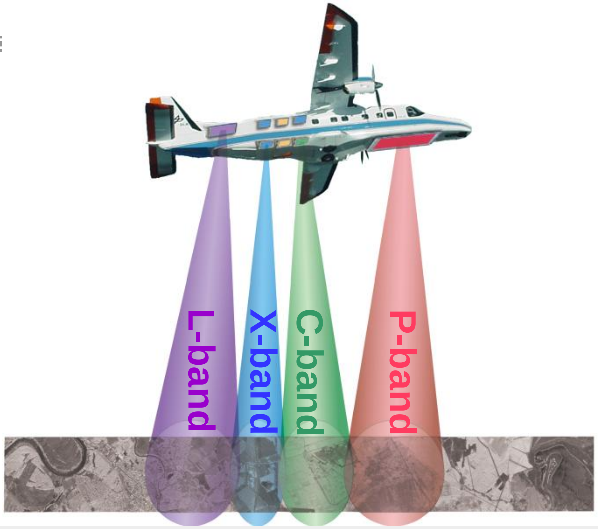
Cumming, I. G. and F. W. Wong, "*Digital Processing of Synthetic Aperture Radar Data".* Artech House, 653-pages, January 2005. (Published in Chinese, October 2007).



Contents List

To appear in 2010 July
John Wiley & Sons, Inc.
ISBN:

Multi-Band Airborne E- SAR => **F-SAR**



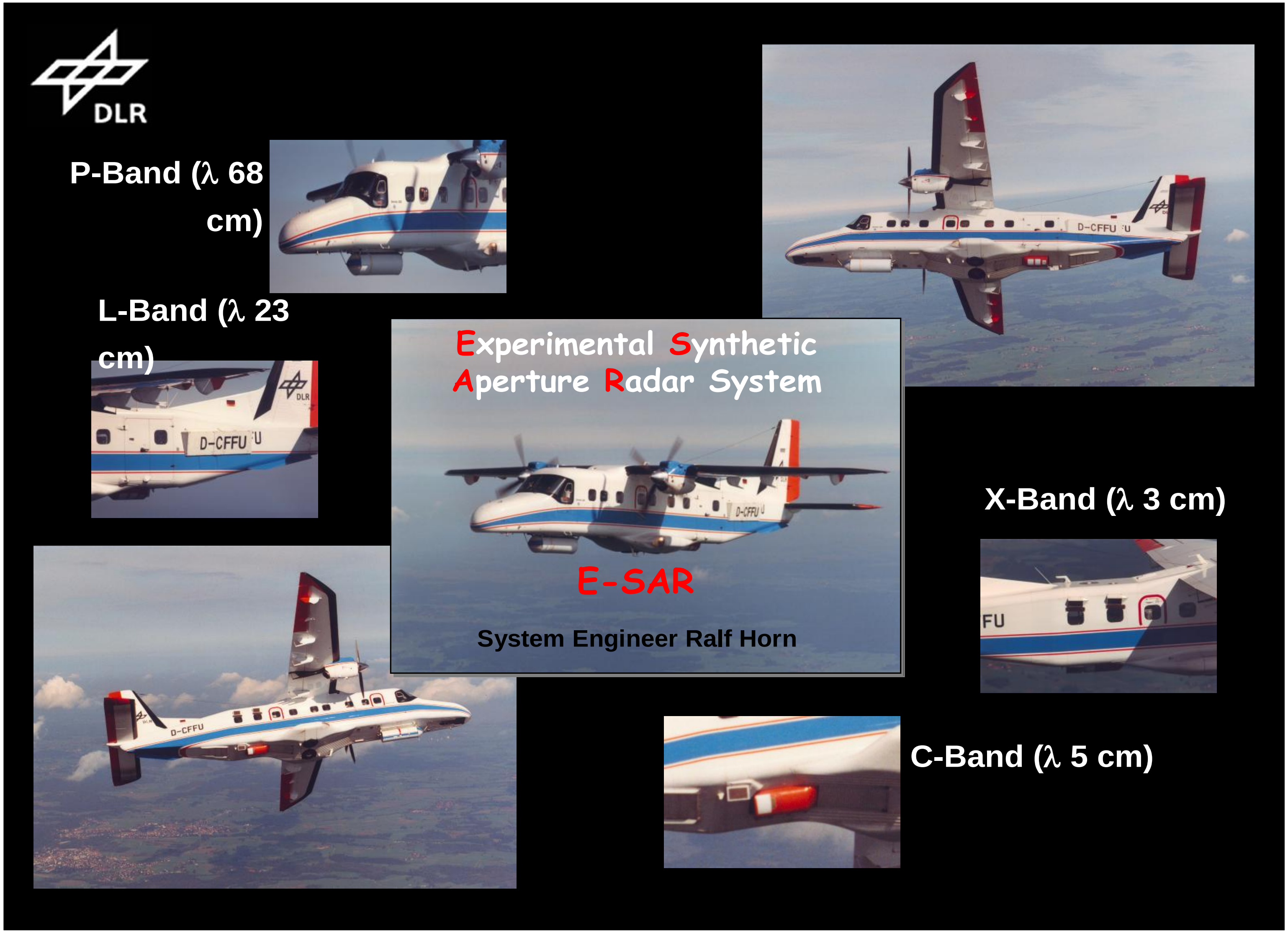
New features:
- significantly enhanced resolution and image quality
- simultaneous data recording in up to four frequency bands
- modular design for easy reconfiguration
- single-pass polarimetric interferometry in X- and S-band
- fully polarimetric capability in all frequencies

E-SAR technical characteristics

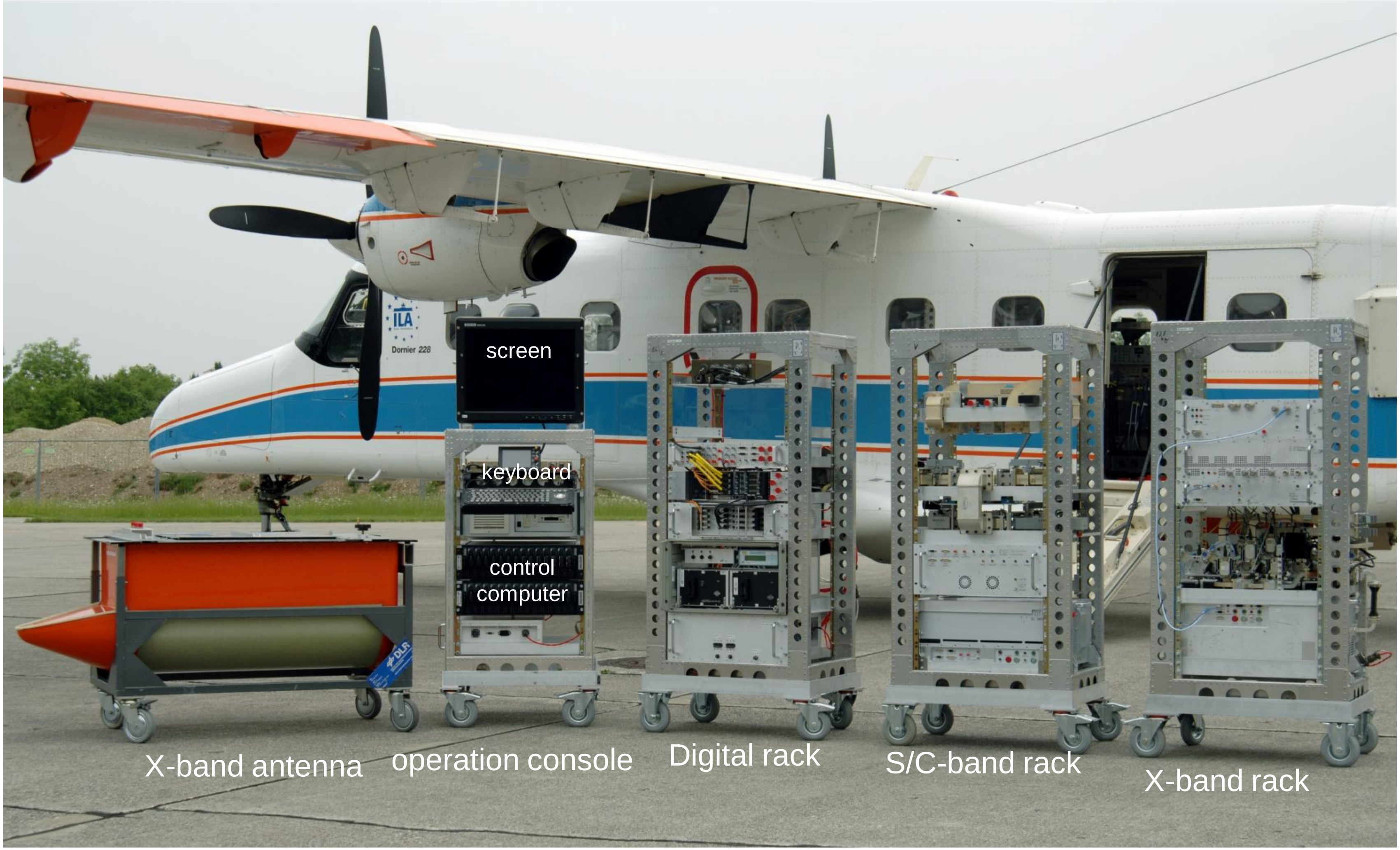
	X	C	L	P
RF [GHz]	9.6	5.3	1.3	0.35
BW [MHz]	50-100 (selectable)			
PRF [kHz]	up to 2			
Rg res. [m]	1.5	1.5	2.0	3.0
Az res. [m]	0.2	0.3	0.4	1.5
Pol/InSAR	-/+	-/-	+/o	+/o
Rg cov [km]	3-5			
Sampling	6-8 Bit complex; 100MHz; max number of samples 4 K per range line; 1 recording channel.			

F-SAR technical characteristics

	X	C	S	L	P
RF [GHz]	9.6	5.3	3.2	1.3	0.35
BW [MHz]	800	400	300	150	100
PRF [kHz]	up to 12				
Rg res. [m]	0.3	0.6	0.75	1.5	2.25
Az res. [m]	0.2	0.3	0.35	0.4	1.5
Pol/InSAR	+/+	+/o	+/+	+/o	+/o
Rg cov [km]	12.5 (at max.bandwith)				
Sampling	8 Bit real; 1000MHz; max number of samples 64 K per range line; 4 recording channels.				

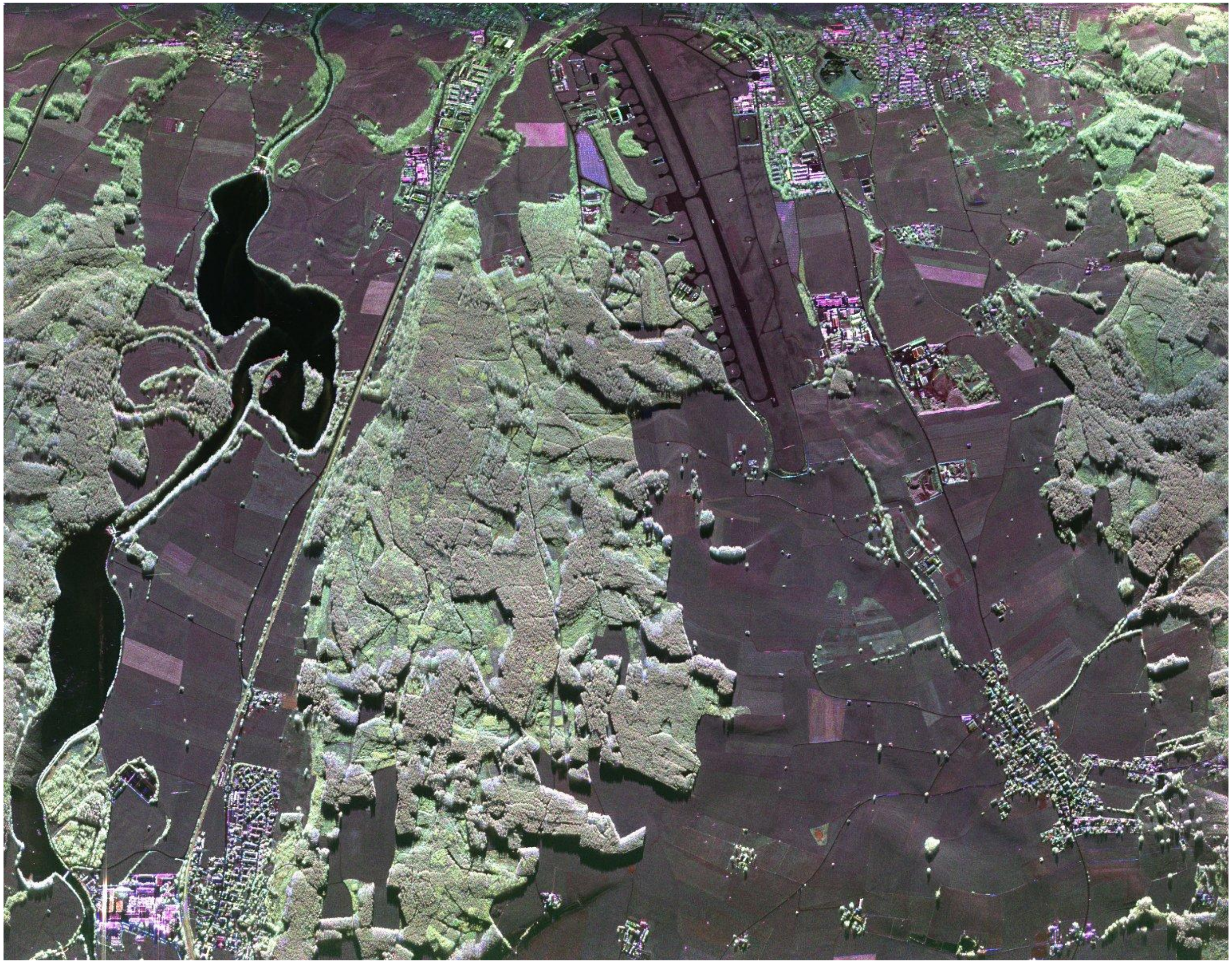

DLR
P-Band (λ 68 cm)
L-Band (λ 23 cm)
Experimental Synthetic Aperture Radar System
E-SAR
System Engineer Ralf Horn
X-Band (λ 3 cm)
C-Band (λ 5 cm)
D-CFFU

DLR-HR's new SAR sensor



F-SAR X-Band Quad-Pol

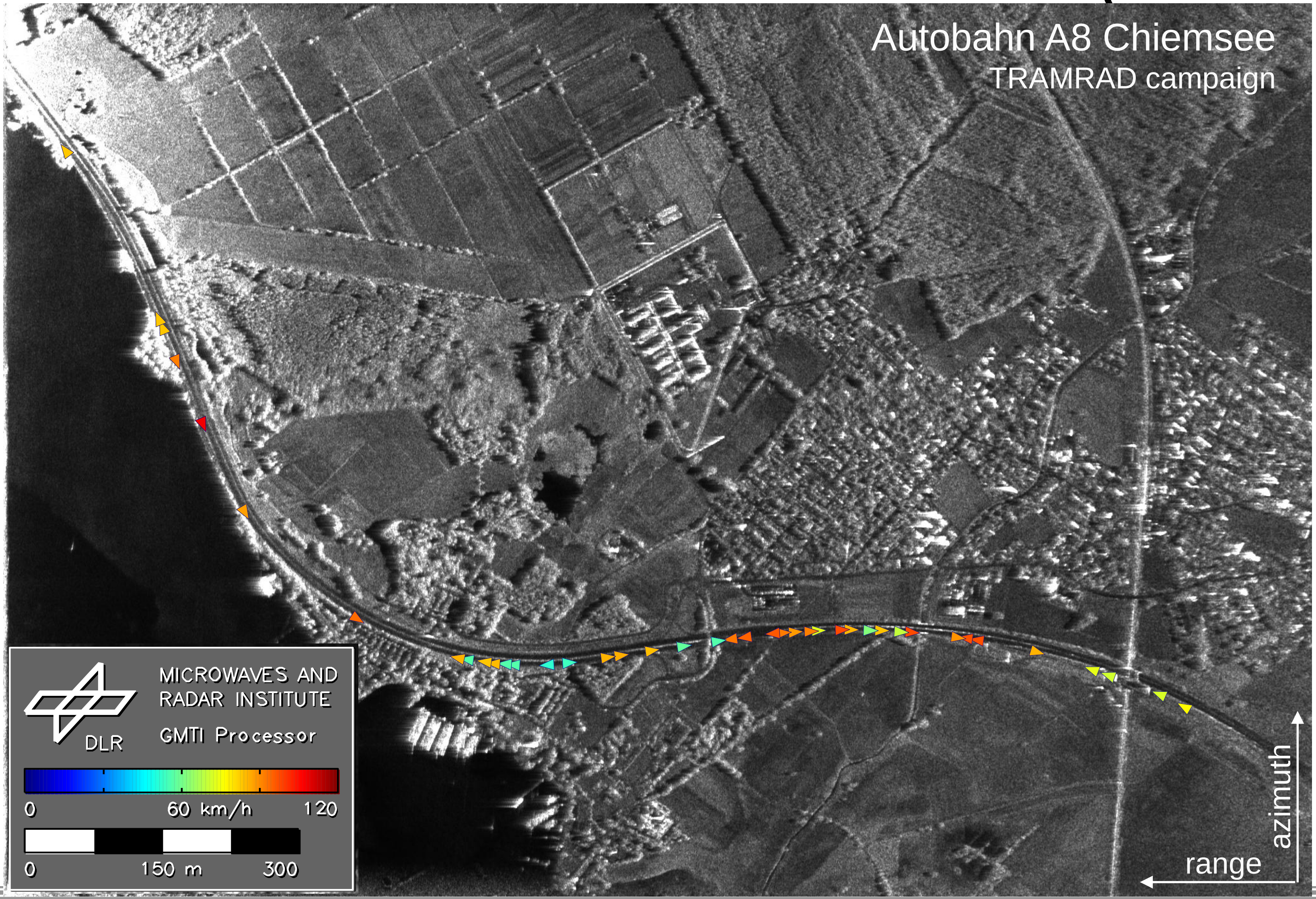
DLR
F-SAR
S-band
Quad-Pol

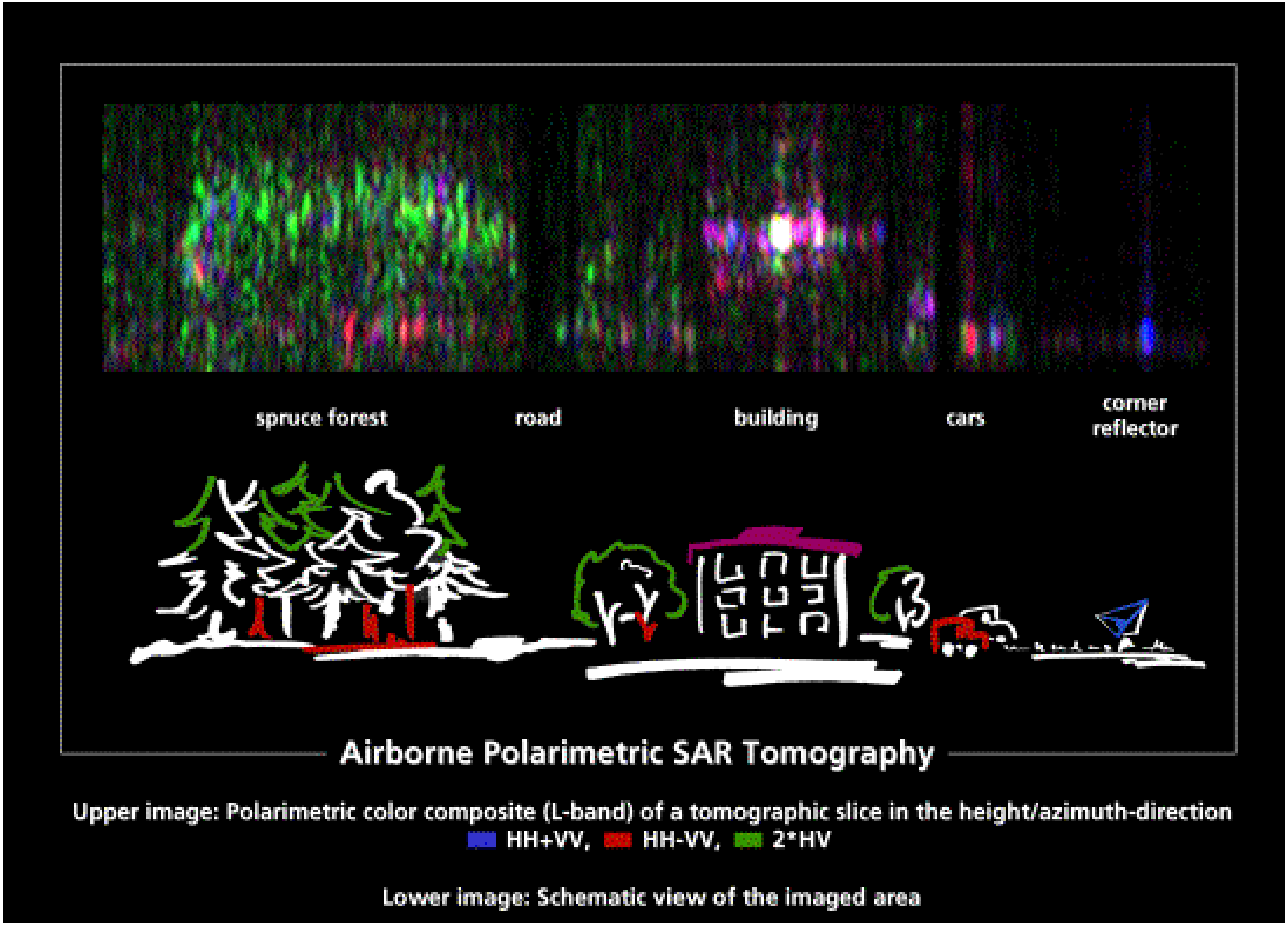


DLR
F-SAR
S-band
Quad-Pol

Zoom

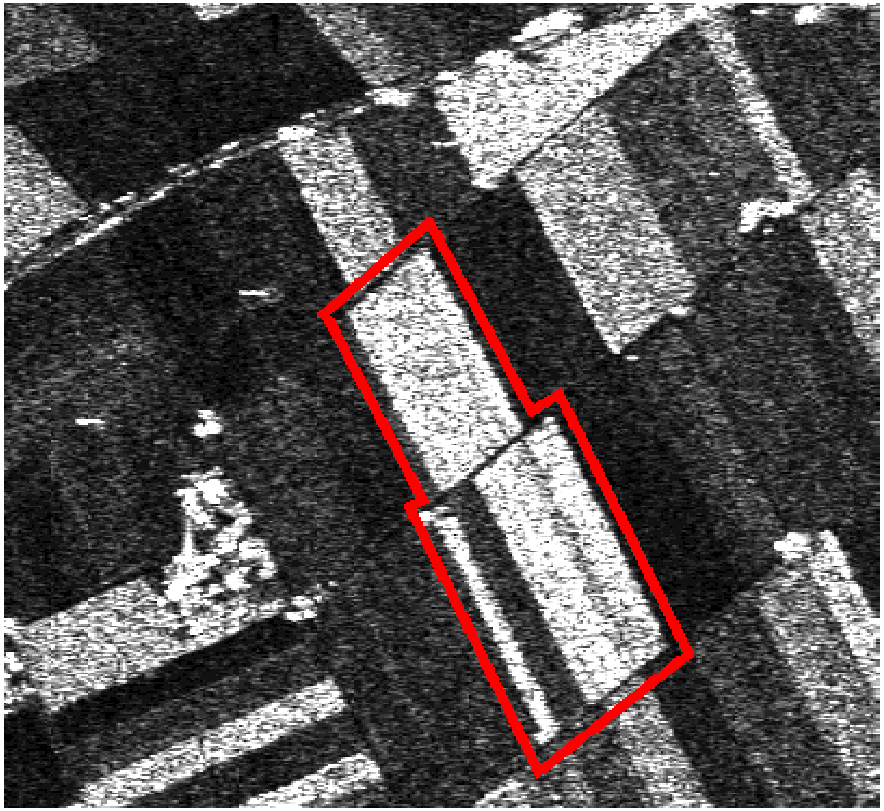
Measurement of car velocities with F-SAR X-band (ATI mode)



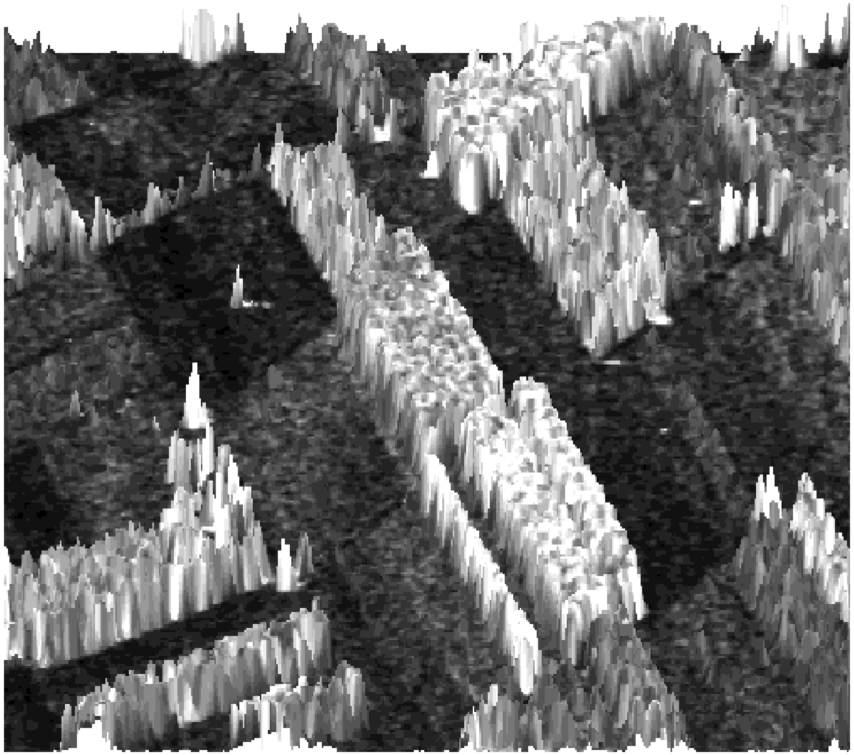

spruce forest
road
building
cars
corner reflector
Airborne Polarimetric SAR Tomography
Upper image: Polarimetric color composite (L-band) of a tomographic slice in the height/azimuth-direction
HH+VV, HH-VV, 2*HV
Lower image: Schematic view of the imaged area

Random-Volume-over-Ground Model Inversion Results

ESAR / Test Site: Kuettighoffen, Switzerland

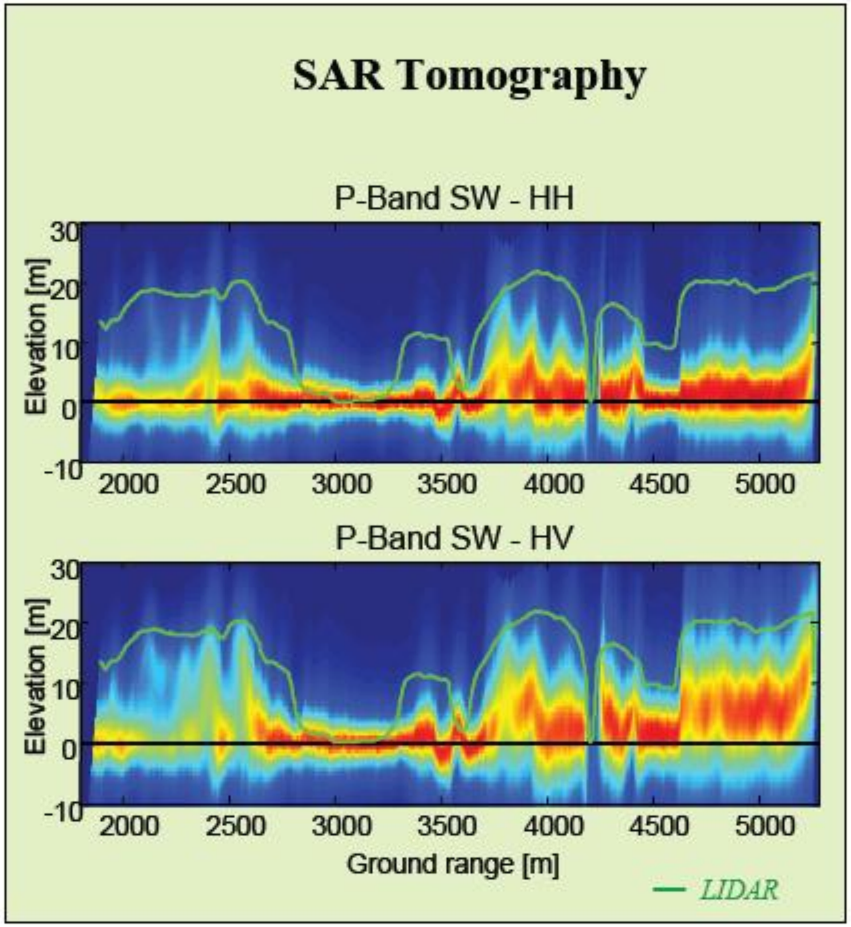


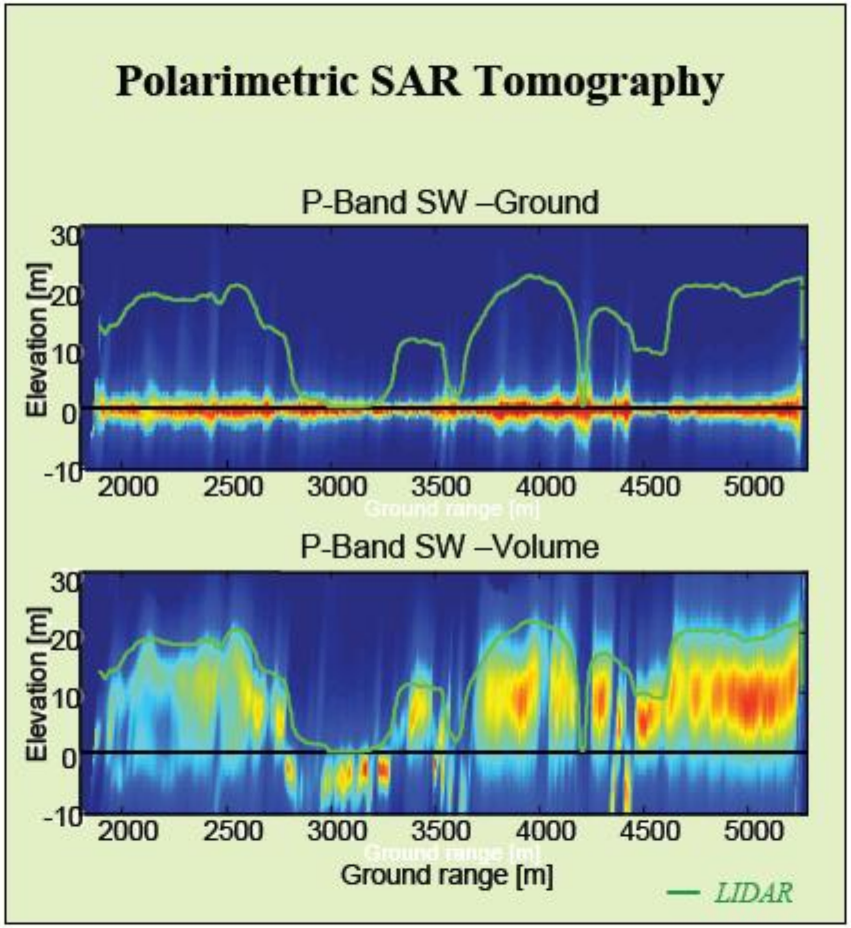
SAR Image L-band



Corn Height Map

Polarimetric SAR Tomography





Goal: Separation Of the backscattered power profiles associated with ground and volume scattering

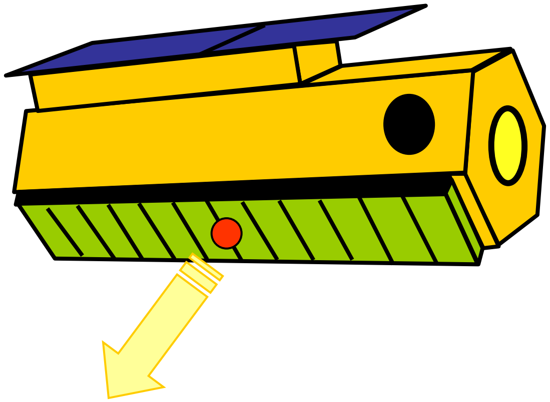
The TerraSAR-X satellite bus claims heritage from the successful Champ and Grace Missions. The spacecraft bus features a primary structure with a hexagonal cross section. The active phased array SAR antenna is attached on the Earth-facing panel in the figure. The solar array is body-mounted, a satisfactory scheme for the sun-synchronous orbit plan. The X-Band down link antenna is mounted on a 3.3 m long deployable boom in order to prevent interference with the X-Band SAR instrument. This concept enables simultaneous data acquisition and data down link.

Table 1. Selected Mode Parameters

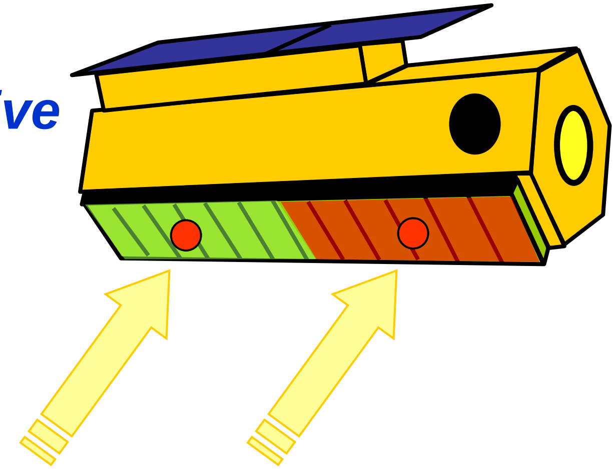
Mode (selected)	Resolution (m)	Swath (km)	Looks	Polarization
Standard, stripmap	3	30	1	HH or VV
High-resolution Spotlight	1	10	1	HH or VV
ScanSAR	16	100	1	HH or VV
Quad-pol (experimental)	3	15	1	Full polarization

Dual Receive Antenna Mode (DRA Mode)

Transmit



Receive



Principle

- For <u>transmit</u> the full antenna is used
- For <u>receive</u> the antenna is ‚electrically' divided into two sections in azimuth direction ➔ two independent receive channels are available

New Experimental Modes

- **Along-Track Interferometry (ATI)**
  (Moving Target Indication, Widespread Traffic Control, Ocean Current Measurement)
- **Quad polarization**
  (Sea/Ice, Snow Cover, Urban Environment)

Quadpol switching scheme

TX:	V	H	V	H	…
RX_1:	V	V	V	V	…
RX_2:	H	H	H	H	…
CH_1:	VV	HV	VV	HV	…
CH_2:	VH	HH	VH	HH	…

Polarization Modes

Single Polarization

- 1 polarization channel, {HH, VV}
- stripmap, spotlight, ScanSAR

Dual Polarization

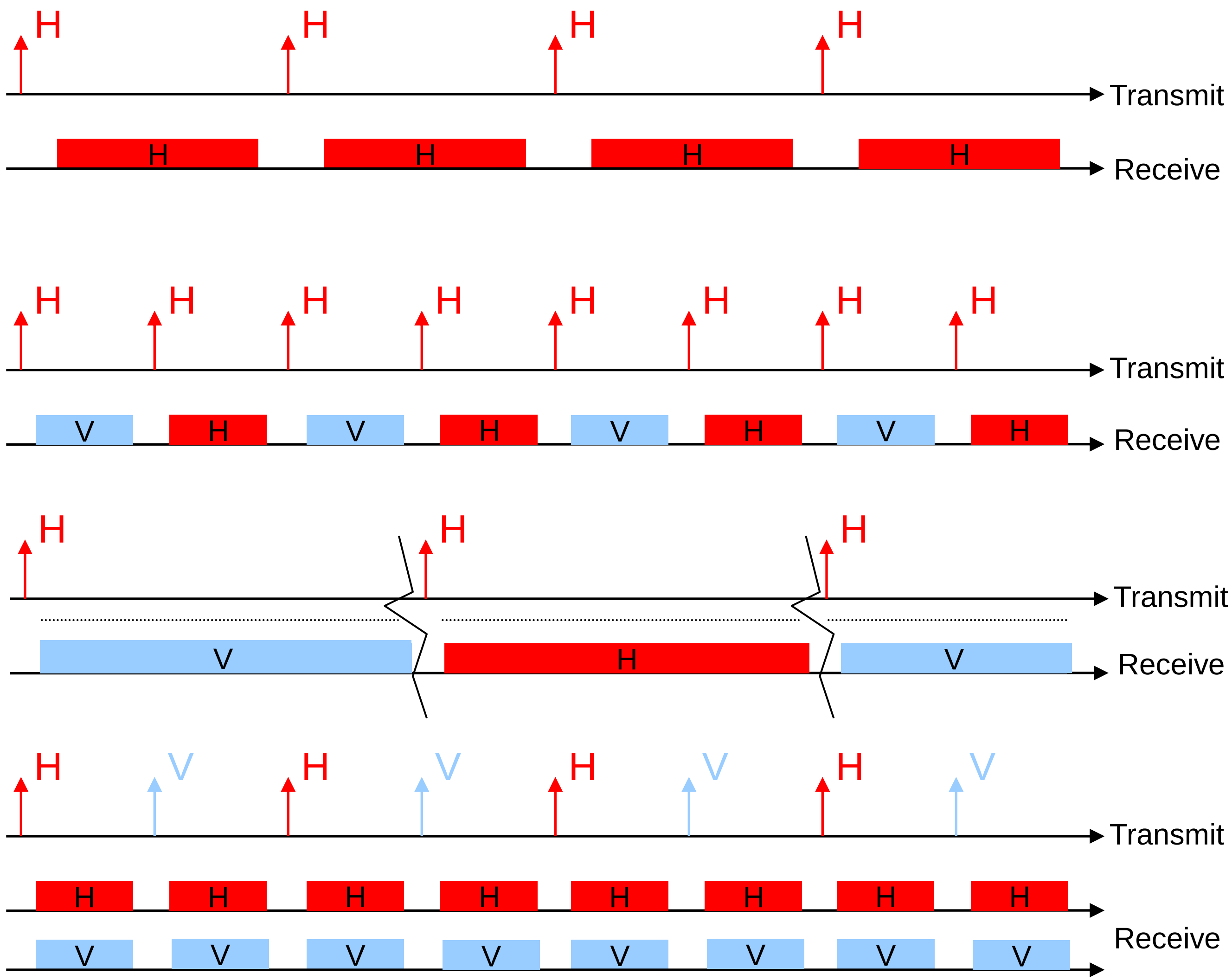
- 2 polarization channels, {HH/VV, HH/HV, VV/VH}
- stripmap, spotlight
- coherent pol. phase
- smaller elevation beam

Twin Polarization

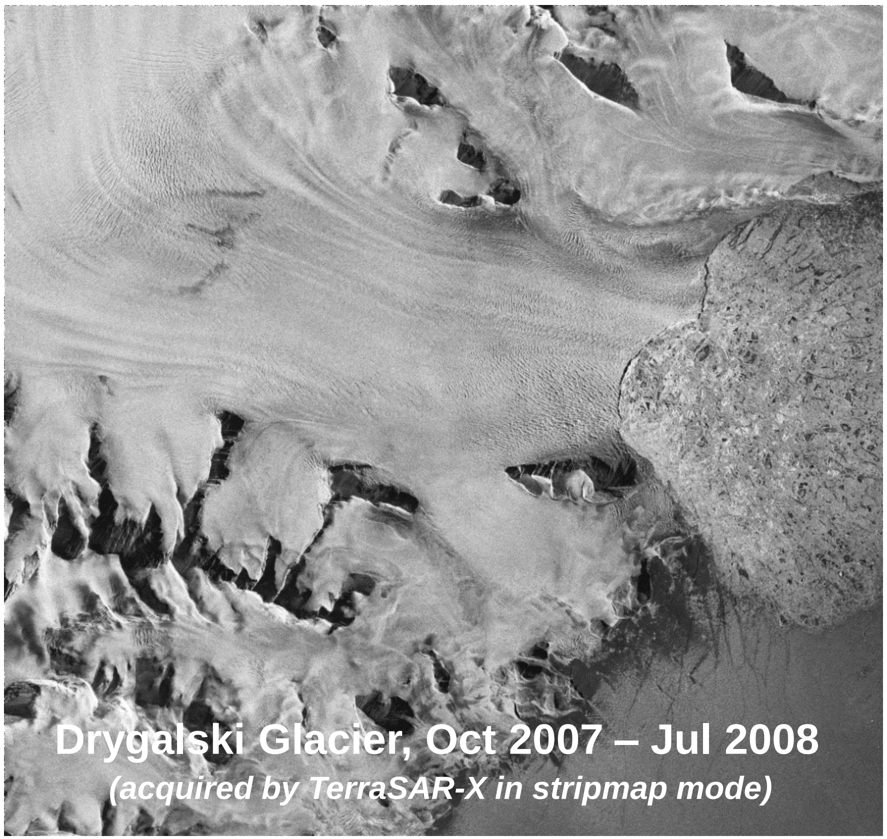
- 2 polarization channels, {HH/VV, HH/HV, VV/HV}
- Stripmap, incoherent pol-phase, full el beam

Quad Polarization

- All 4 pol. channels
- Stripmap
- coherent pol. Phase
- smaller elevation beam
- Experimental product

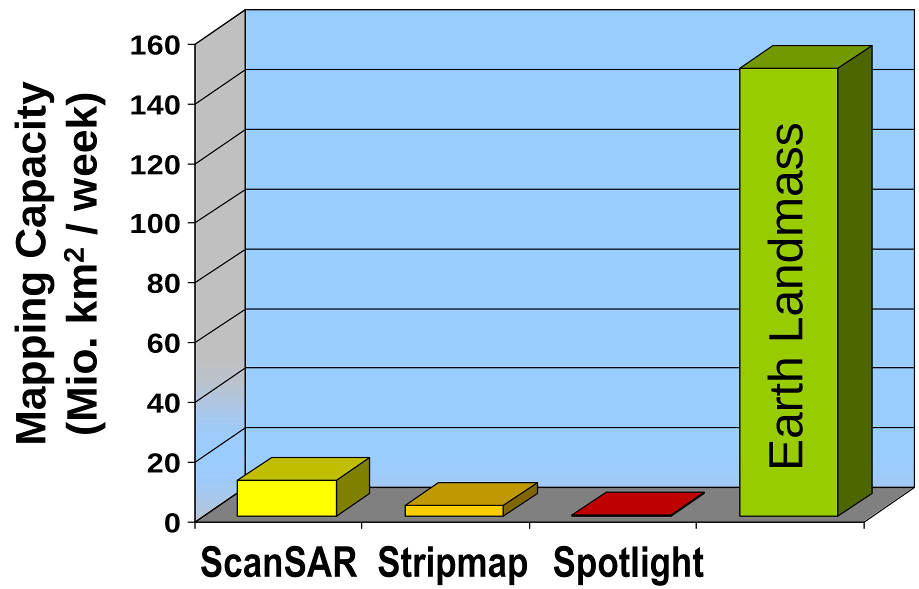


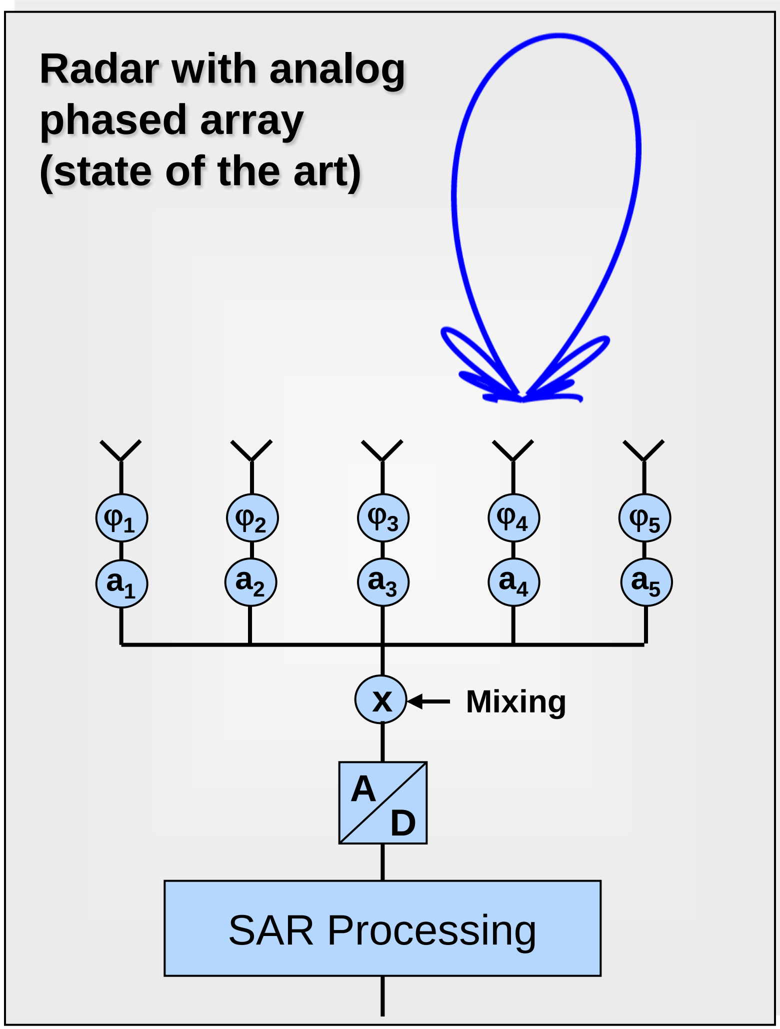
SAR is the ideal sensor for the observation of dynamic processes on the Earth surface, but ...

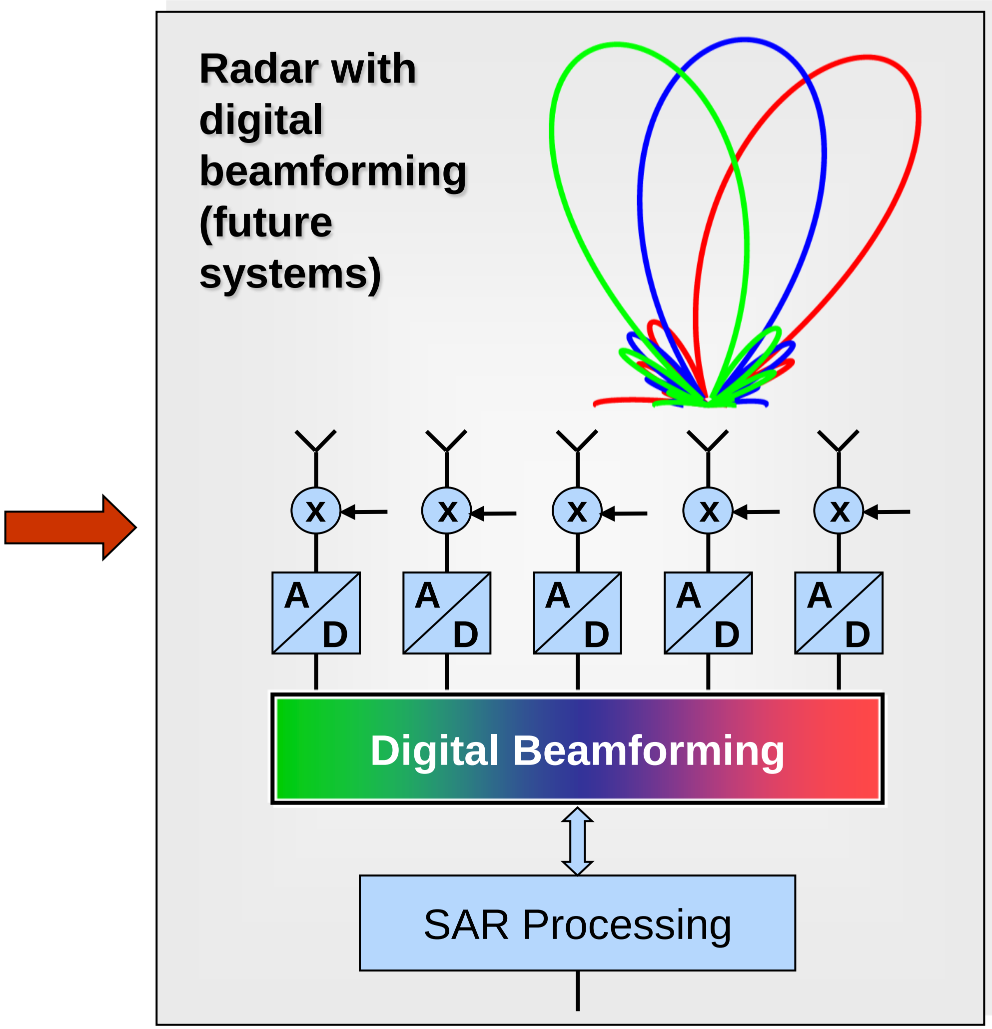


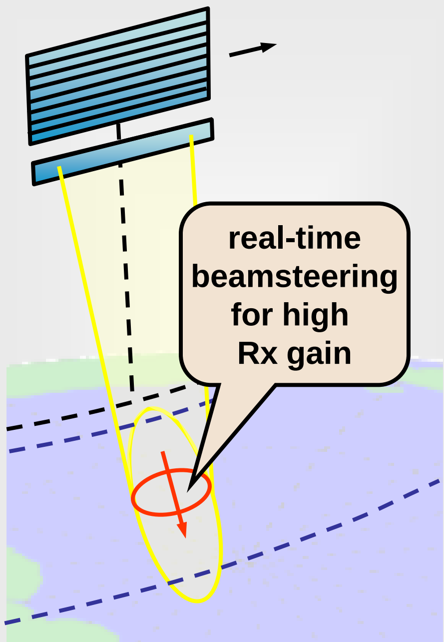
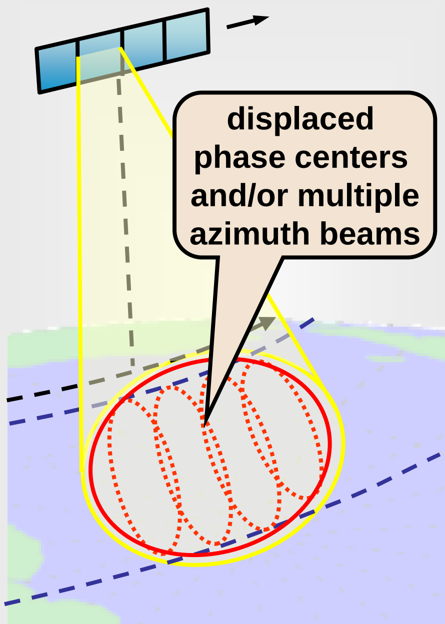
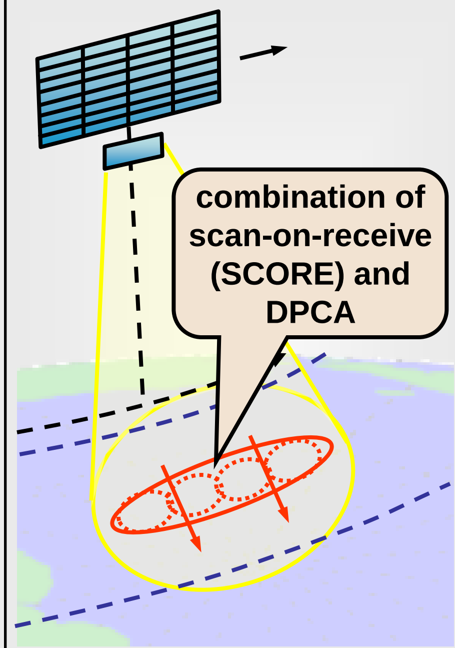
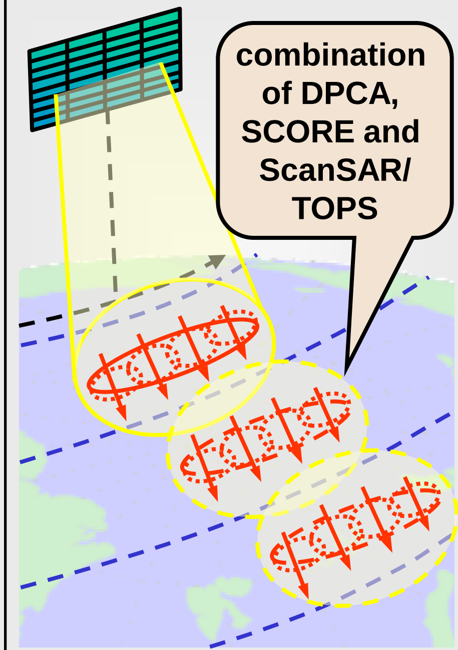
Drygalski Glacier, Oct 2007 – Jul 2008
(acquired by TerraSAR-X in stripmap mode)

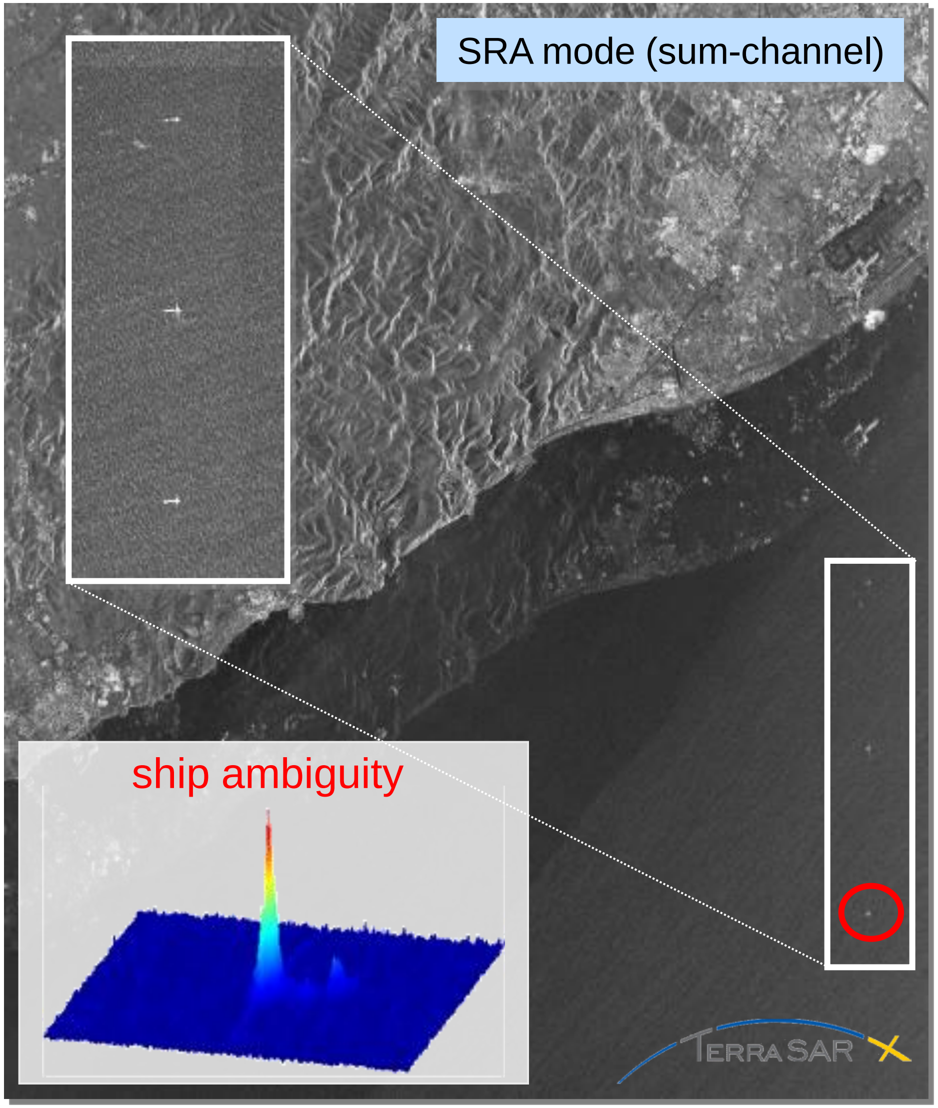
	Imaging Mode (Single Pol.)		
	ScanSAR	Stripmap	Spotlight
Resolution	16 m	3 m	1 m
Swath Width	100 km	30 km	10 km
Duty Cycle	3 minutes / orbit		

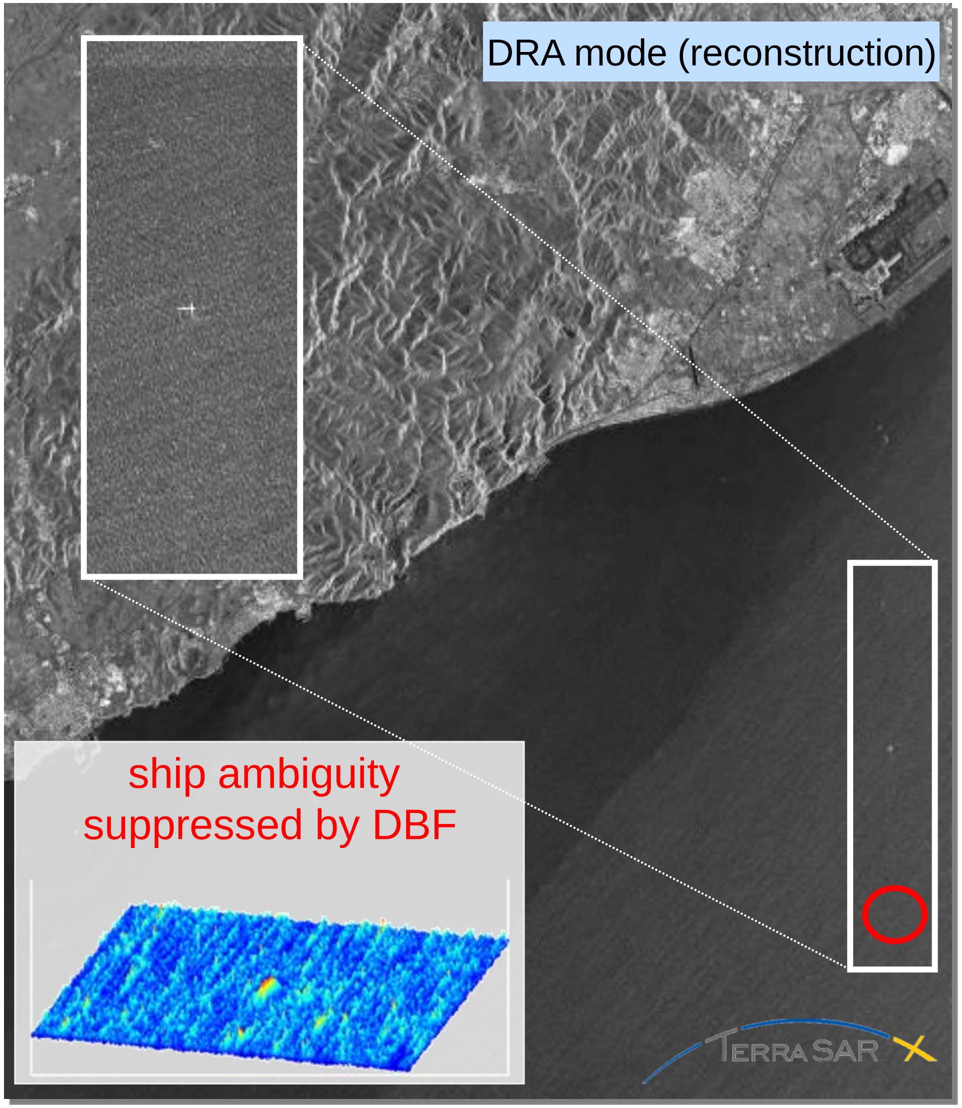


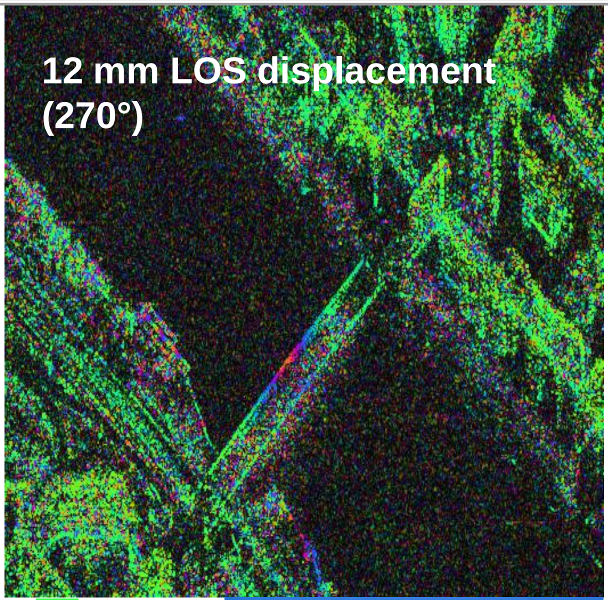

Radar with analog phased array (state of the art)
φ1
φ2
φ3
φ4
φ5
a1
a2
a3
a4
a5
X
Mixing
A
D
SAR Processing

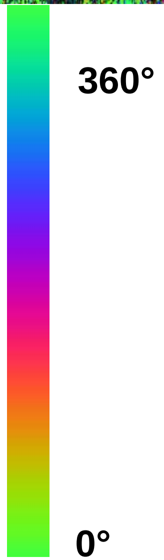

Radar with digital beamforming (future systems)
X
X
X
X
X
A
D
Digital Beamforming
SAR Processing

Scan-On-Receive	DPCA	HRWS	Burst-DBF-SAR
			
▪ high sensitivity and less pattern losses at swath border ▪ improved range ambiguity suppression	▪ enables high azimuth resolution and wide swath ▪ requires dedicated multichannel SAR processing	▪ high resolution combined with high sensitivity ▪ antenna length limits swath width	▪ enables mapping of ultra-wide swaths with high resolution ▪ suggested as Sentinel-1 successor system

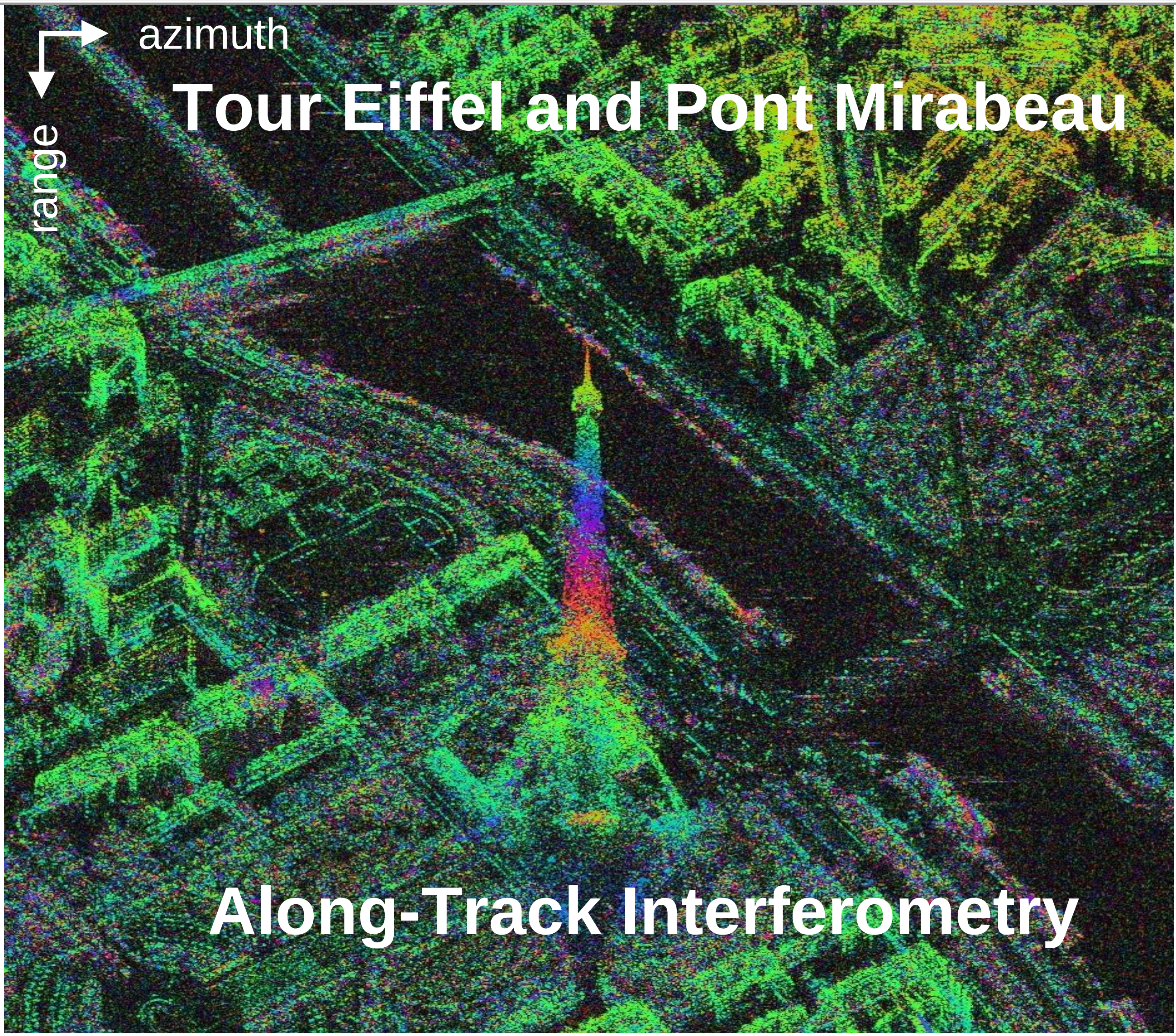

SRA mode (sum-channel)
ship ambiguity
TERRASAR X


DRA mode (reconstruction)
ship ambiguity
suppressed by DBF
TERRASAR X


12 mm LOS displacement
(270°)


360°
0°


325 m


azimuth
range
Tour Eiffel and Pont Mirabeau
Along-Track Interferometry

TanDEM-X: Mission Status & Scientific Contribution

Irena Hajnsek[1/2], Gerhard Krieger[1], Kostas Papathanassiou[1], Stefan Baumgartner[1], Marc Rodriguez-Cassola[1], Pau Prats[1], Maria Sanjuan Ferrer[1], Florian Kugler[1] & TanDEM-X Team

[1]Microwaves and Radar Institute & [2]Institute of Environmental Engineering, ETH Zurich

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

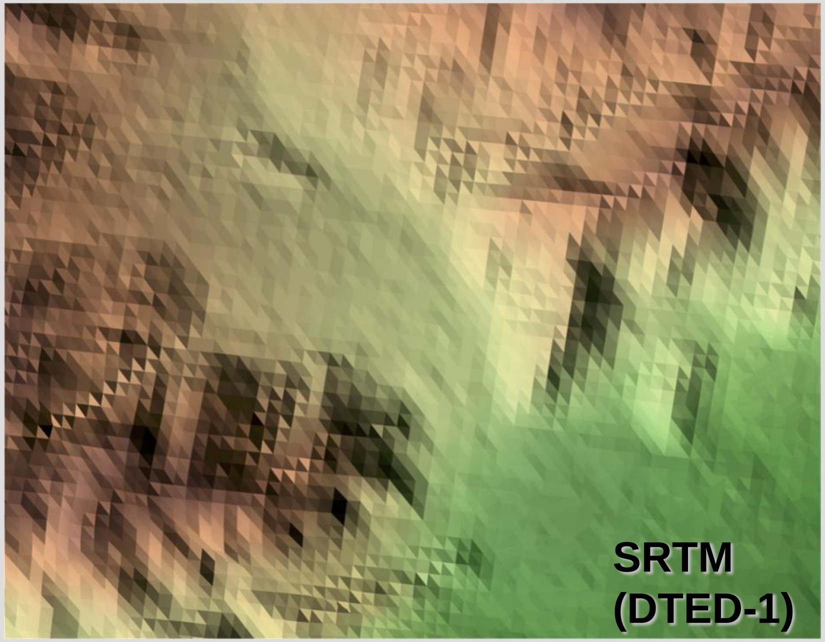
TanDEM

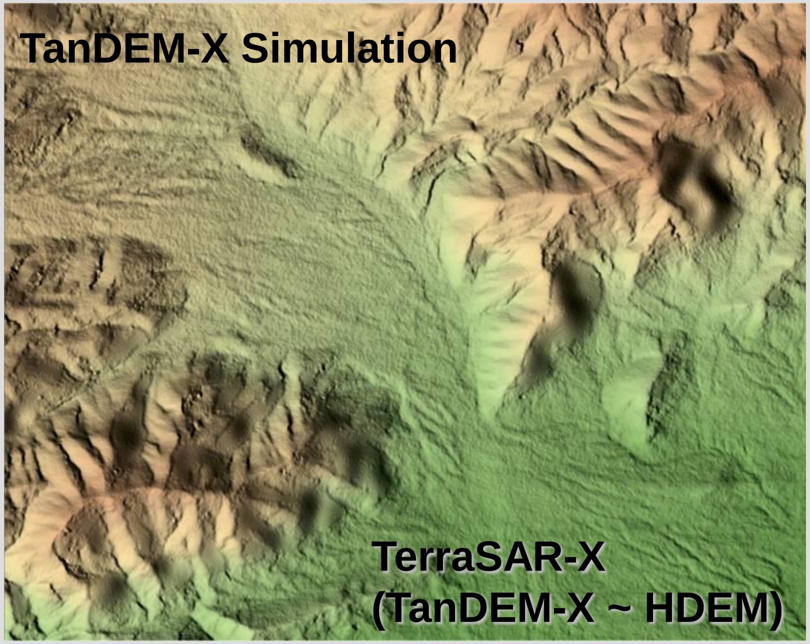
29-July-2010


TanDEM-X: TerraSAR-X-Add-on for
Digital Elevation Measurements
TanDEM
Launch: 21.June 2010 (38 days ago)
from Baikonor (first signal arrived
after 15min from the ground station
Troll in the Antarctic)
DLR
EADS ASTRIUM
infoterra

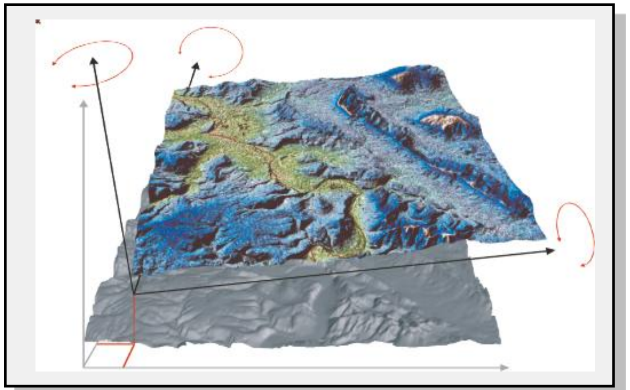
Standards for Digital Elevation Models (DEM)

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

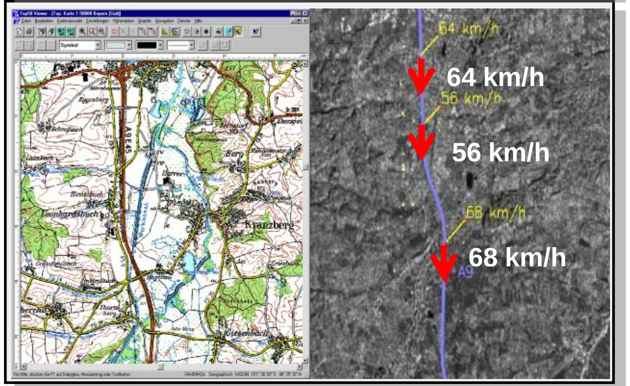




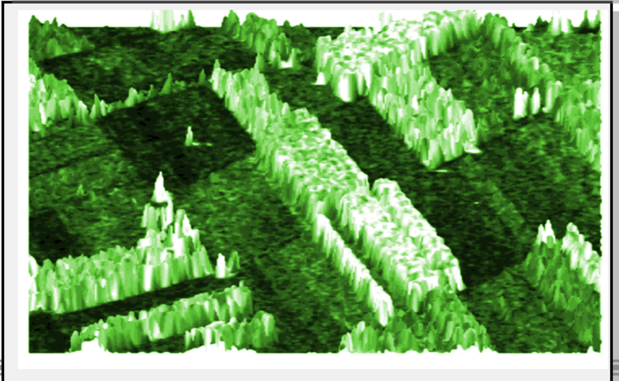
- **Across track InSAR (Digital Elevation Model)**
  - ***Development & improvement of algorithm for validation of heights derived from InSAR; Input parameter for a variety of different applications***
  - ***Added values and generation of scientific products***



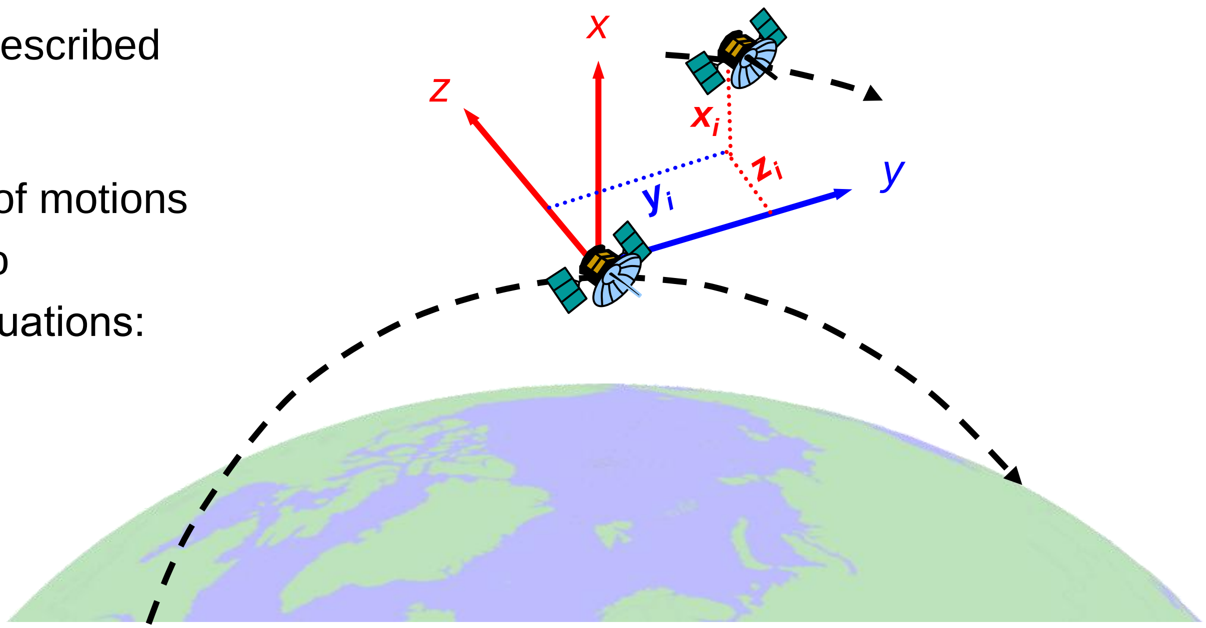
- **Along track InSAR (Velocity Measurements)**
  - ***Exploitation of innovative applications and development of algorithm***
  - ***New application and scientific product development***



- **New SAR Techniques (First Technical Demo.)**
  - ***Demonstration and exploitation of new SAR techniques***
  - ***New perspectives for future SAR systems and development of new applications***



- Relative satellite movement is described in a ***rotating reference frame***
- ***Linearization*** of the equations of motions in a circular Kepler orbit leads to Clohessy-Wiltshire (or Hill's) Equations:



$$\ddot{x} - 2n\dot{y} - 3n^2 x = 0$$
$$\ddot{y} + 2n\dot{x} = 0$$
$$\ddot{z} + n^2 z = 0$$

with $n = \sqrt{\frac{GM_\oplus}{a_{sat}^3}}$

- Solution to Clohessy-Wiltshire Equations :

$$x_i(t) = A_i \sin\left(\frac{2\pi}{T_0} t + \alpha_i\right)$$

vertical (radial) baseline

$$y_i(t) = 2A_i \cos\left(\frac{2\pi}{T_0} t + \alpha_i\right) + \Delta y_i$$

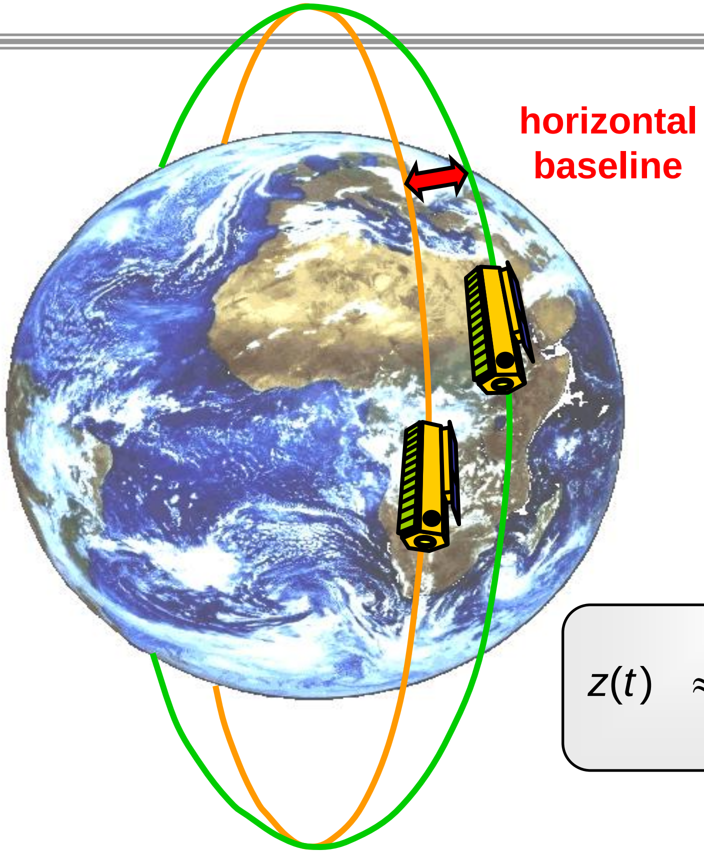
along-track displacement

$$z_i(t) = B_i \sin\left(\frac{2\pi}{T_0} t + \beta_i\right)$$

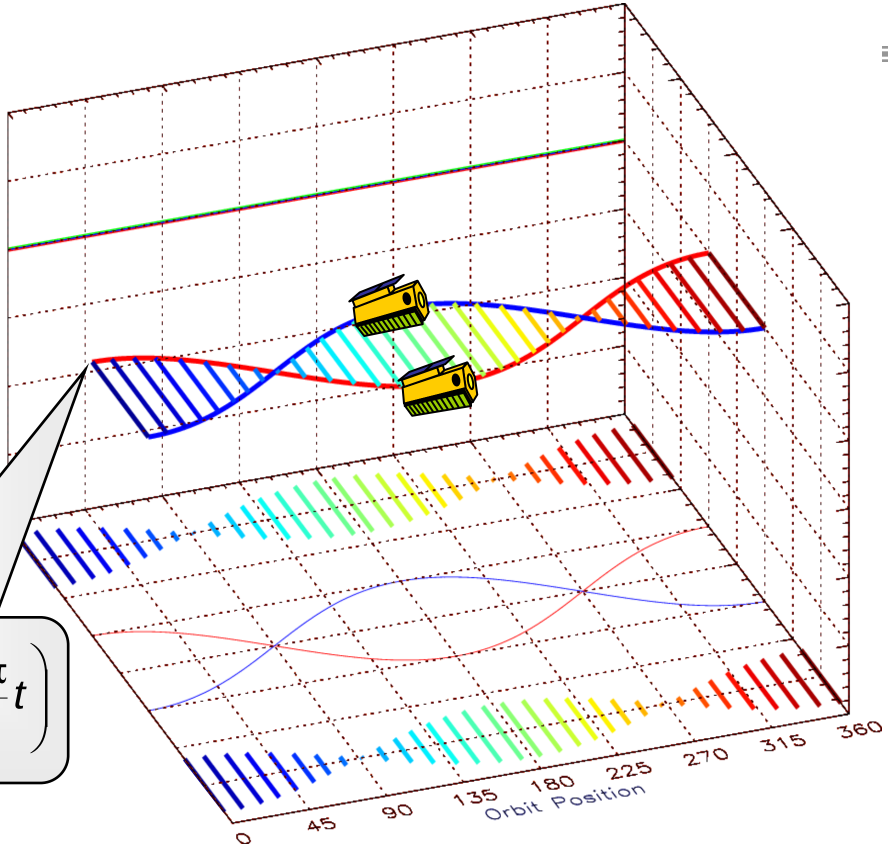
horizontal cross-track baseline

with $T_0 = 2\pi\sqrt{\frac{a_{sat}^3}{GM_\oplus}}$

2-SAT Pendulum



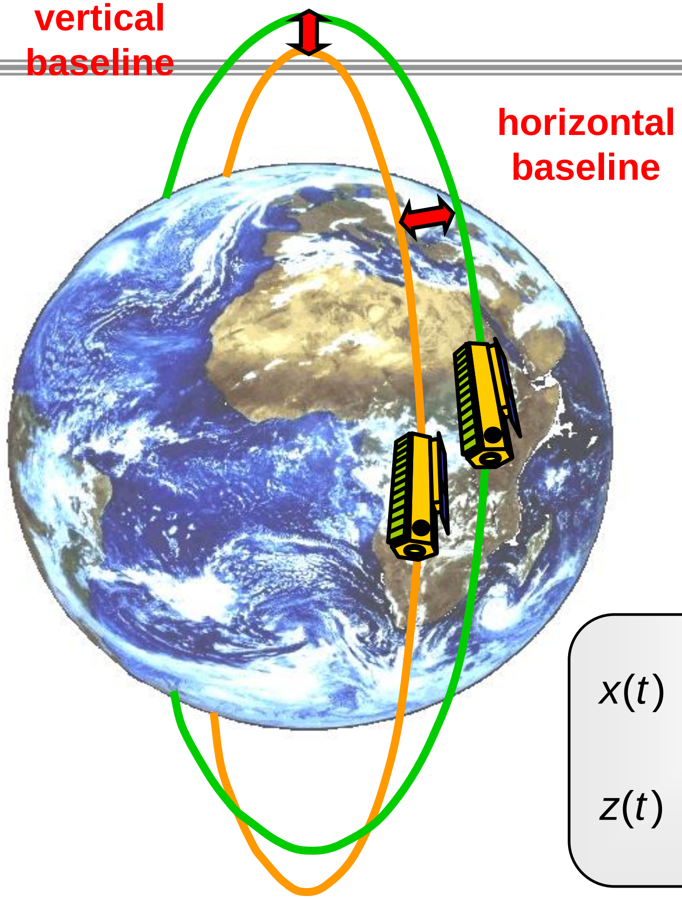
$$z(t) \approx A \cdot \cos\left(\frac{2\pi}{T_0} t\right)$$

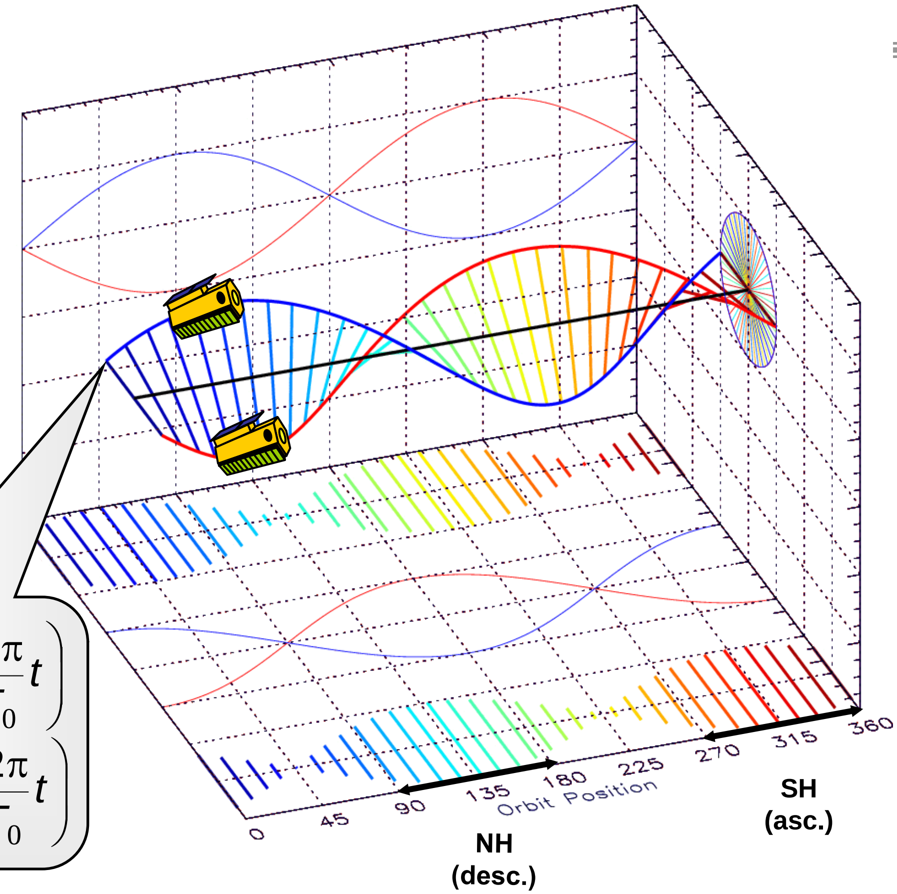


2-SAT Pendulum (Hartl 1989, Zebker, 1992)

- *horizontal cross-track separation at equator by different ascending nodes*
- *requires along-track displacement to avoid satellite collision at orbit crossing*
- *insufficient baselines for cross-track interferometry in polar regions*

HELIX Formation





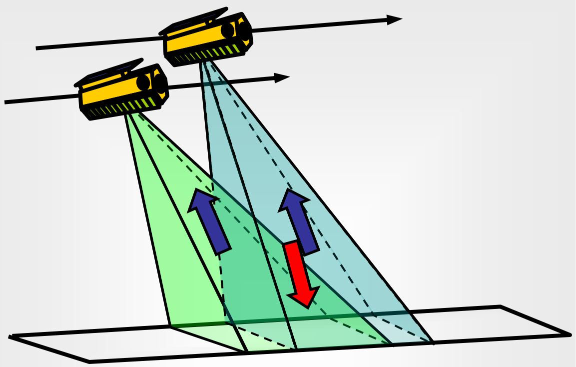
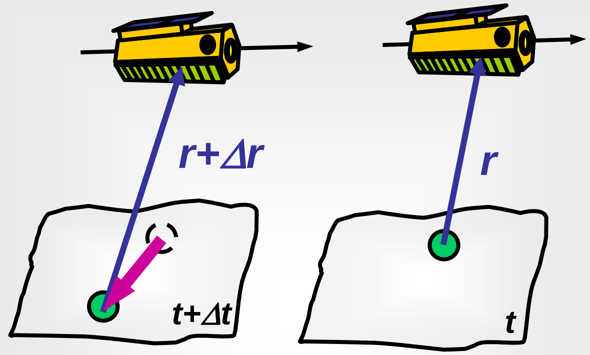
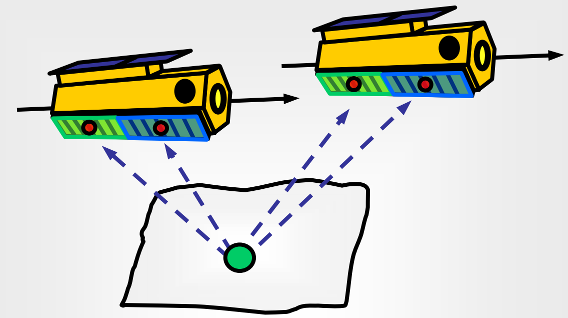
$$x(t) \approx A \cdot \sin\left(\frac{2\pi}{T_0} t\right)$$

$$z(t) \approx B \cdot \cos\left(\frac{2\pi}{T_0} t\right)$$

HELIX satellite formation enables safe operation

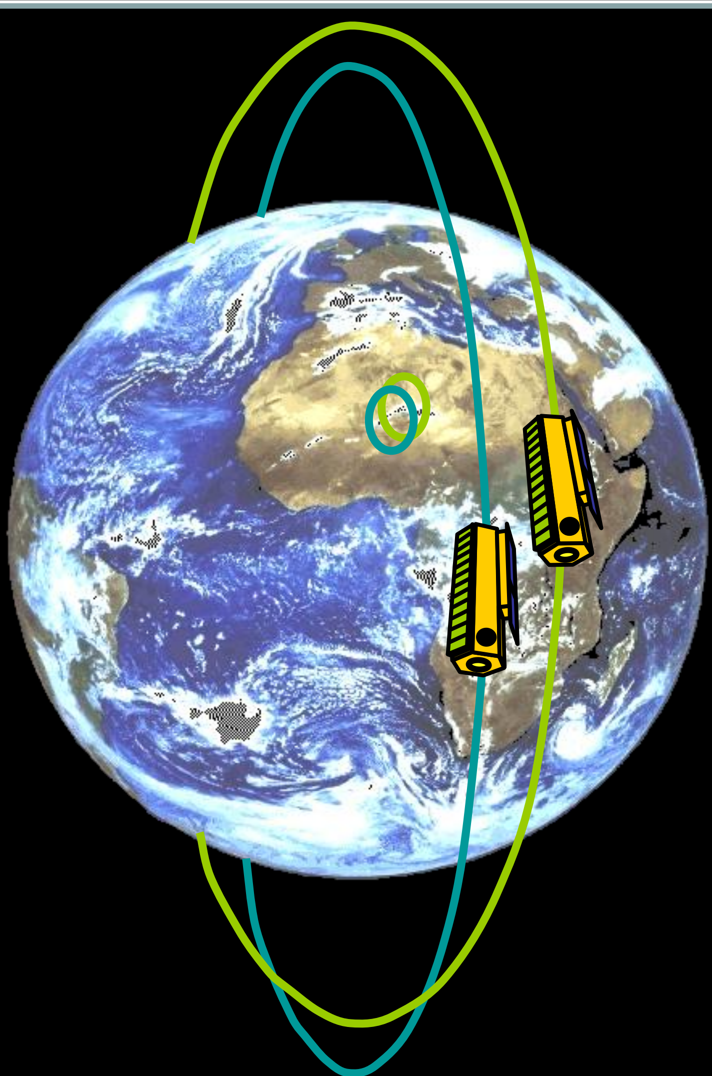
- *horizontal cross-track separation at equator by different ascending nodes*
- *vertical (radial) separation at poles by orbits with different eccentricity vectors (periodic motion of libration has to be compensated by regular manoeuvres)*

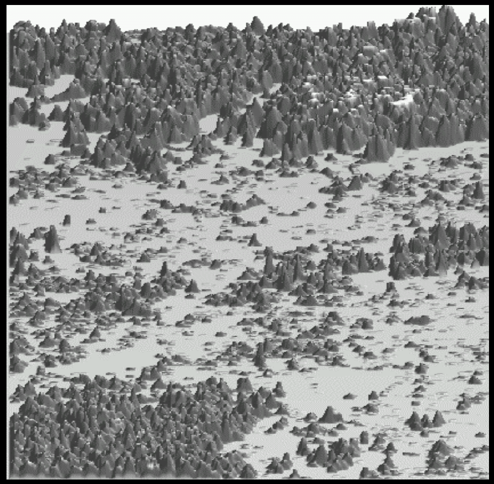
Capabilities of TanDEM-X

Cross-Track Interferometry	Along-Track Interferometry	New Techniques
		
→ **Digital Elevation Models** → **Spatial Coherence** (forest, …) → **Double DInSAR** (change maps, ..) → **High Resolution SAR Images**	→ **Large Scale Velocity Fields** (ocean currents, ice drift, …) → **Moving Object Detection** → **Temporal Coherence Maps**	→ **4 Phase Center MTI** (traffic, …) → **PolInSAR** (vegetation height, …) → **Digital Beamforming** (HRWS, …) → **Bistatic Imaging** (classification, ..)

TanDEM-X is a highly flexible sensor enabling multiple powerful imaging modes

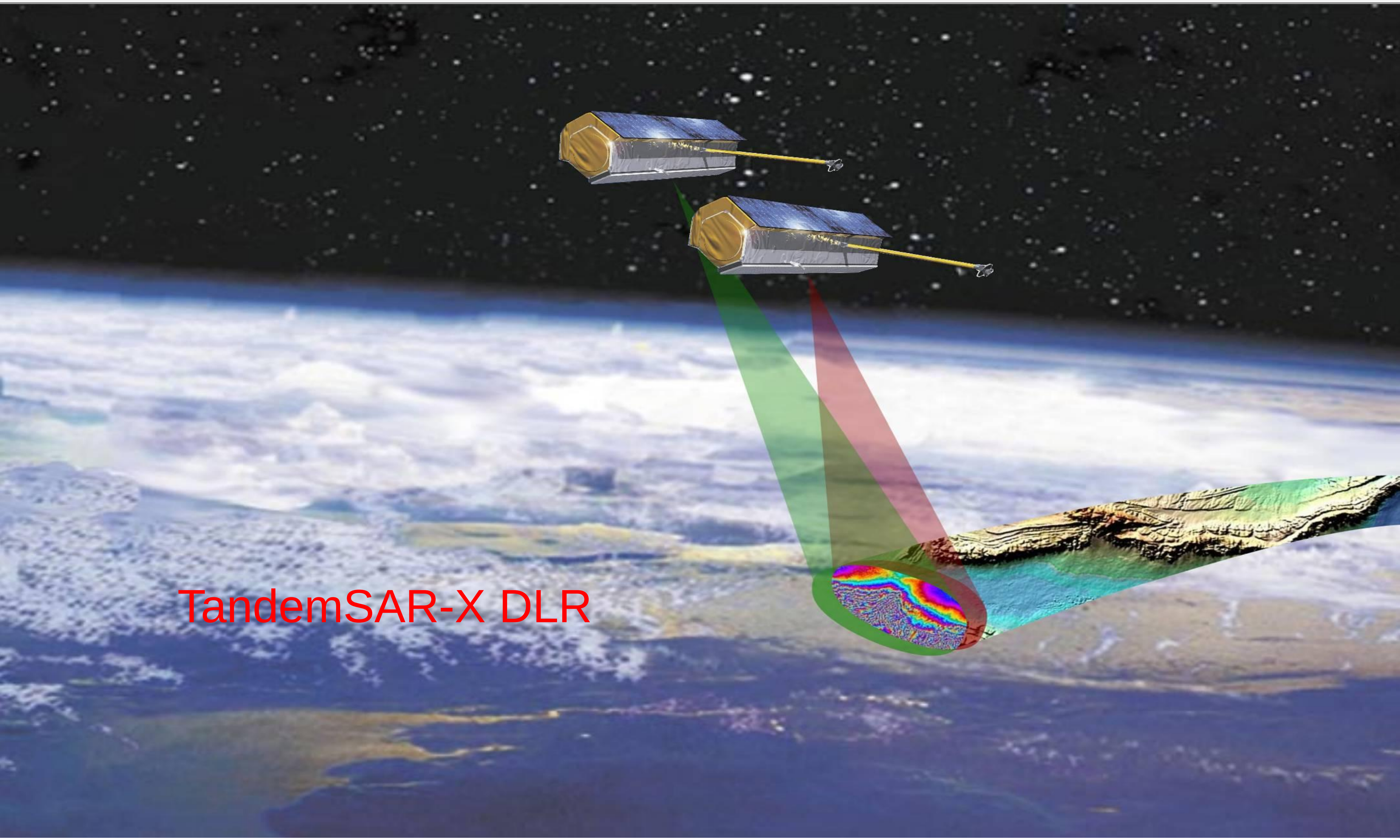
▪cross-track baselines (0 km to several km) ▪along-track baselines (0 km to several 100 km)	▪interferometric modes (bistatic, alternating, monostatic) ▪SAR modes (ScanSAR, Stripmap, …)	▪bandwidth / resolution (0 ... 150/300 MHz) ▪incident angles (20° ... 55°)	▪polarisations (single, dual, quad) ▪…

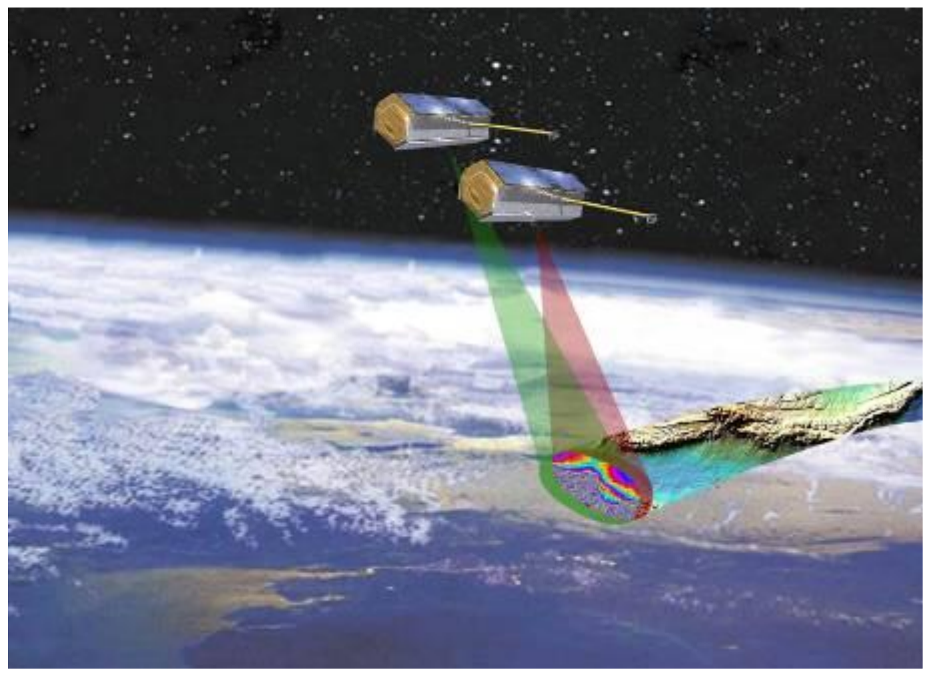


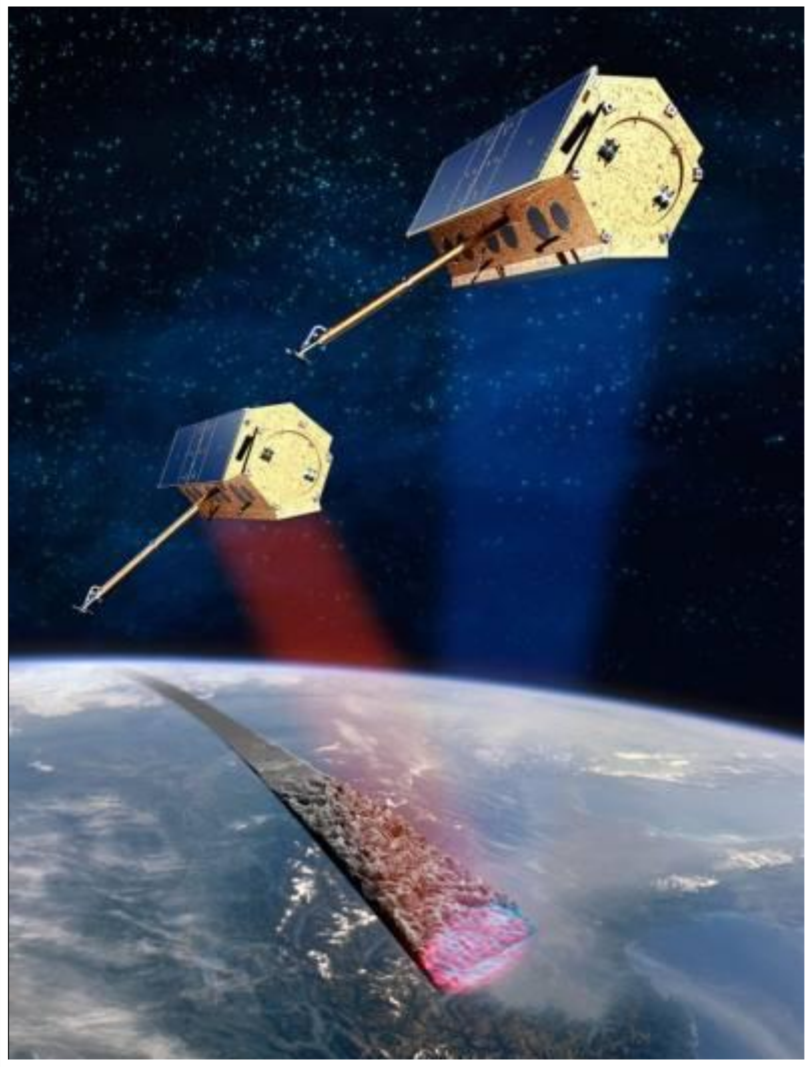


Global Monitoring of Bio-, Geo-, Cryo- and Hydrosphere processes with hith temporal and spatial resolution.
(Prof. A. Moreira – POLINSAR09)

Radar Interferometry


TandemSAR-X DLR



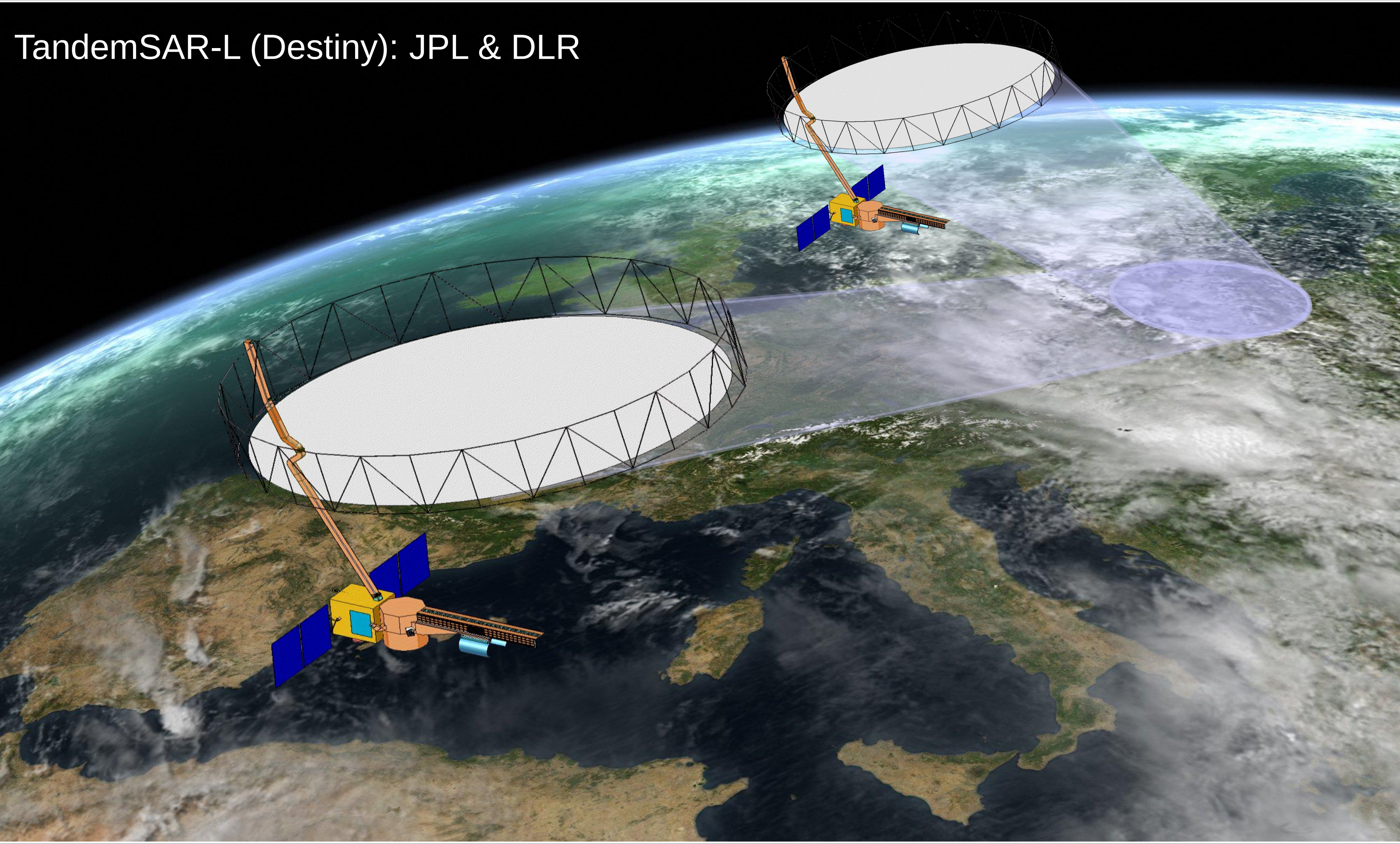


TerraSAR – X (1 & 2)
(2010)

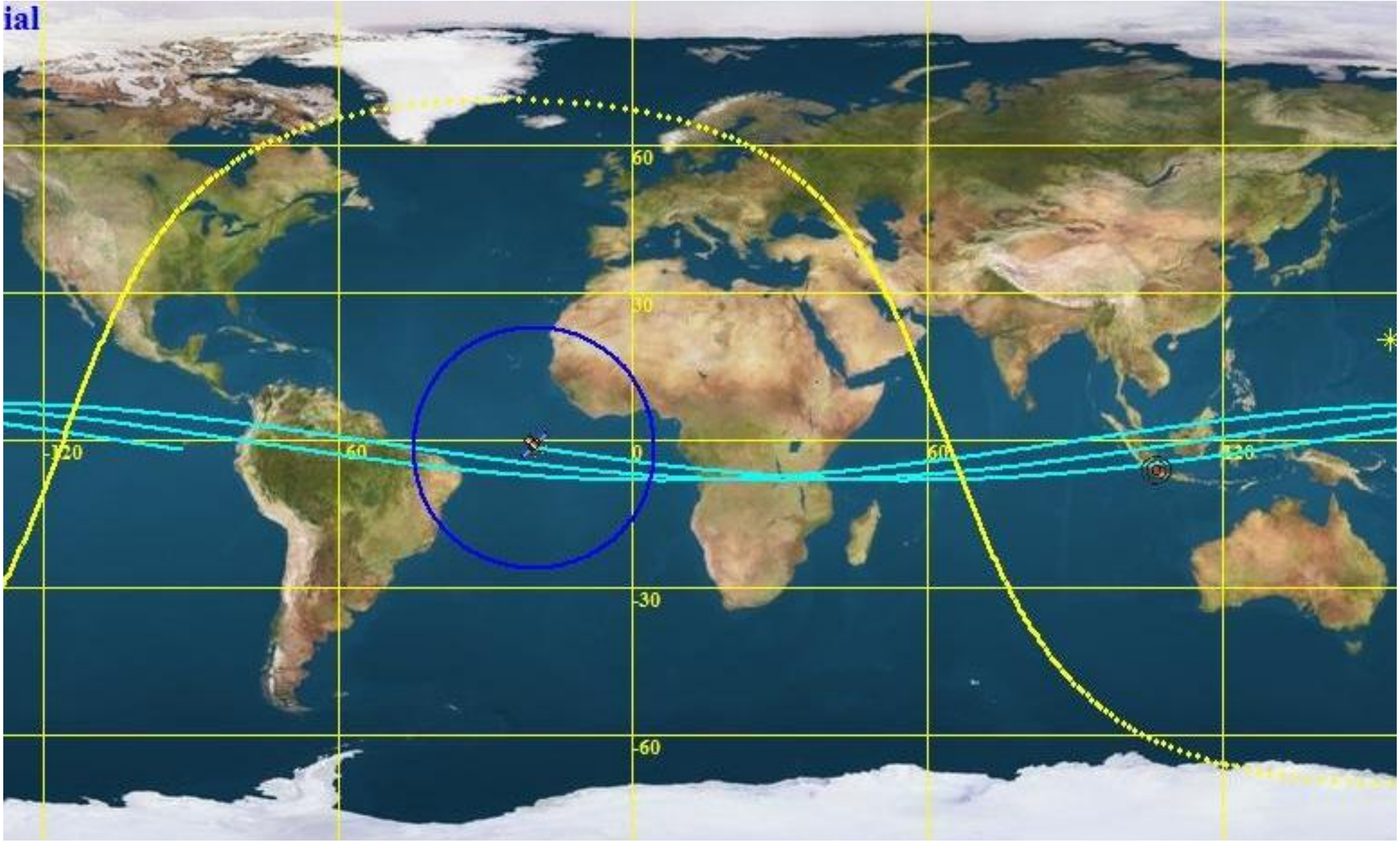
Pol – InSAR Sensors

TanDEM-X

TandemSAR-L (Destiny): JPL & DLR

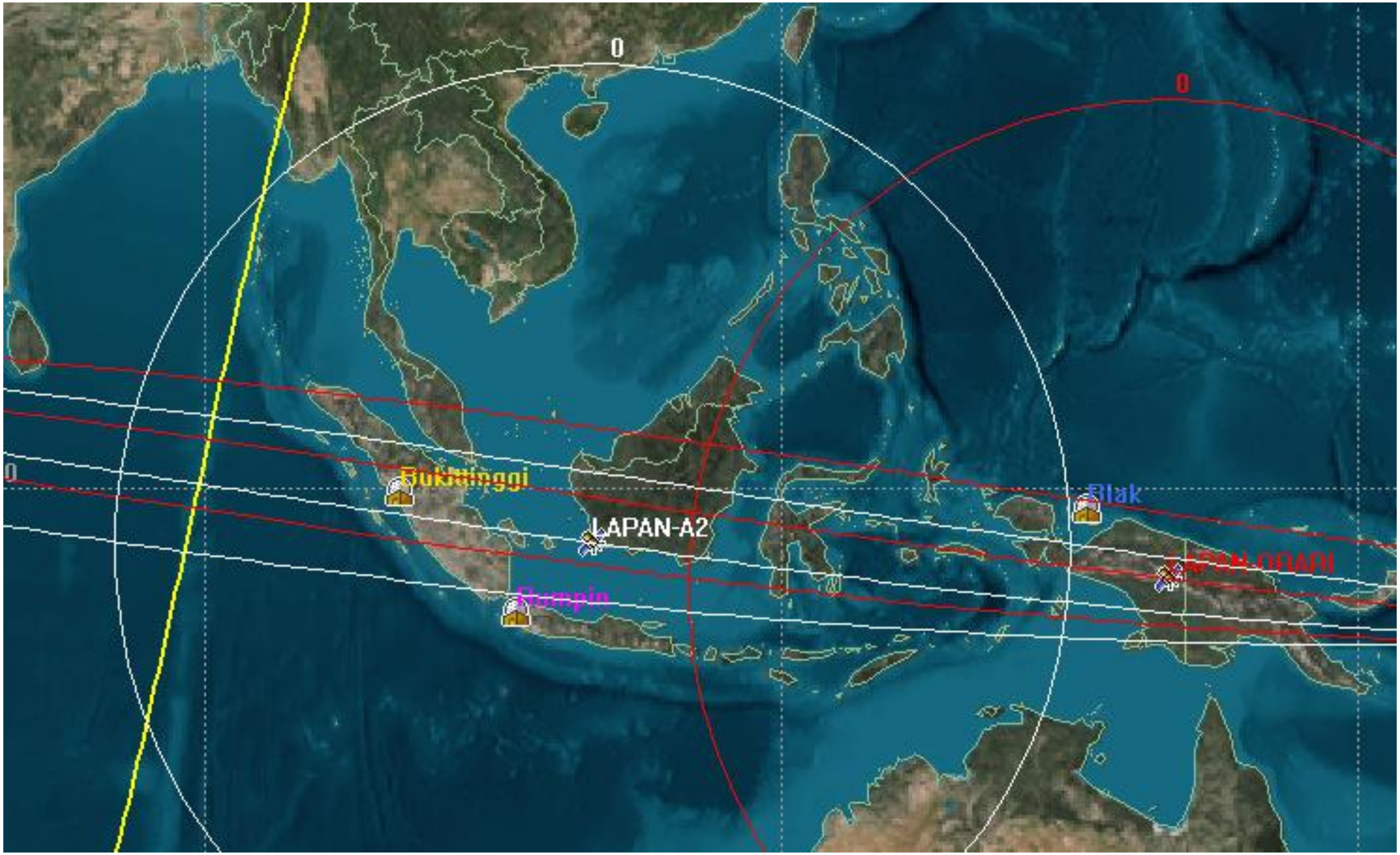


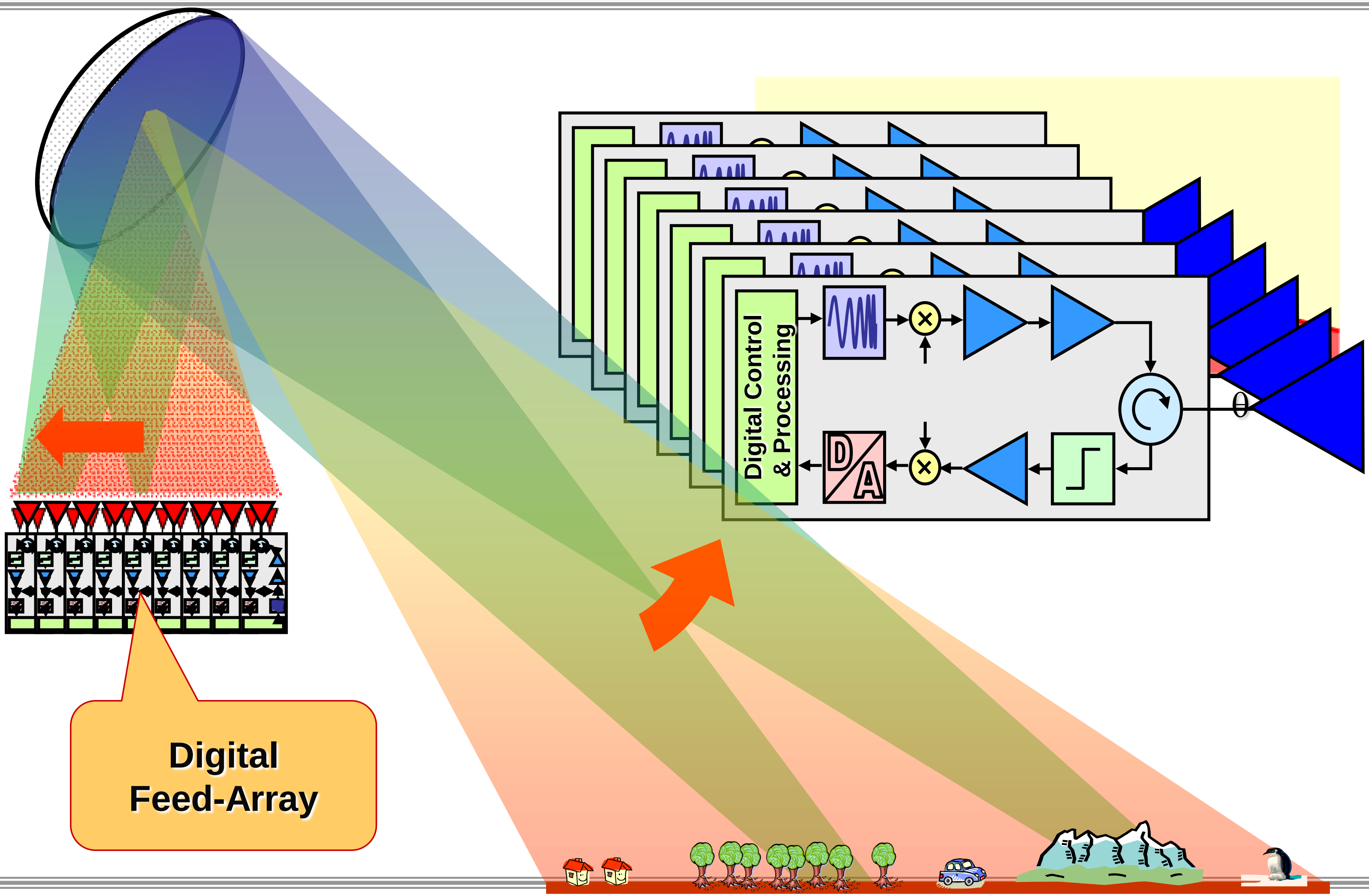
LAPAN-A2 ORBIT PROFILE
(14 pass per 24 hr / orbit time 100 minutes and stay above horizon at about 10 minutes)



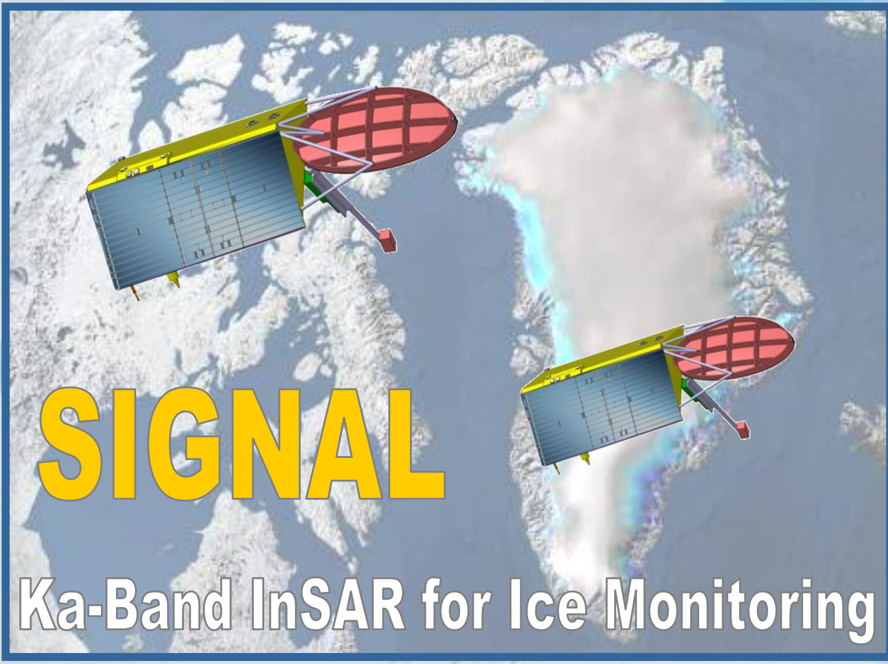
TUB-LAPAN-ORARI ORBIT PROFILE

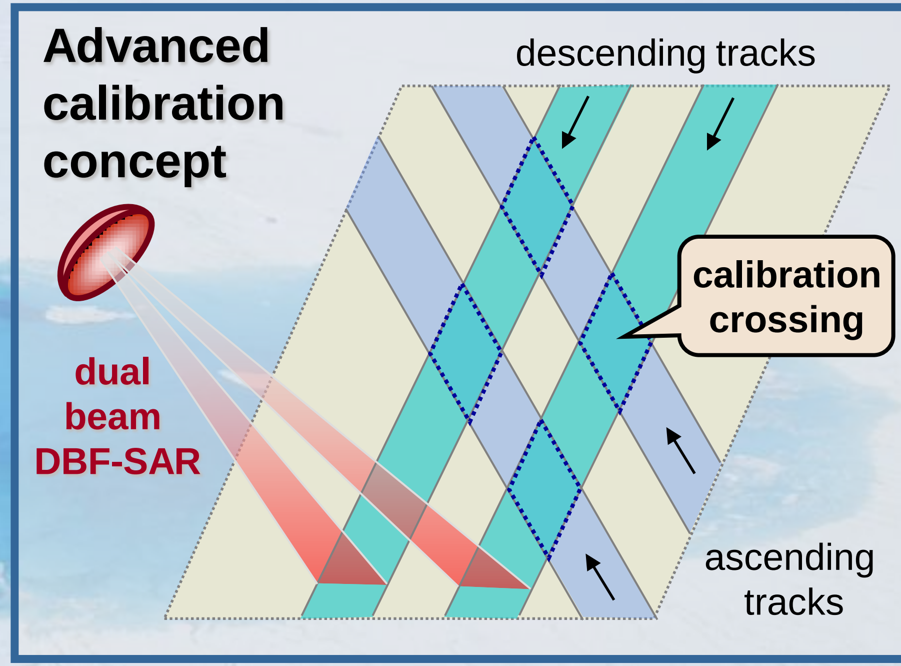
(14 pass per 24 hr / orbit time 100 minutes and stay above horizon at about 10 minutes)



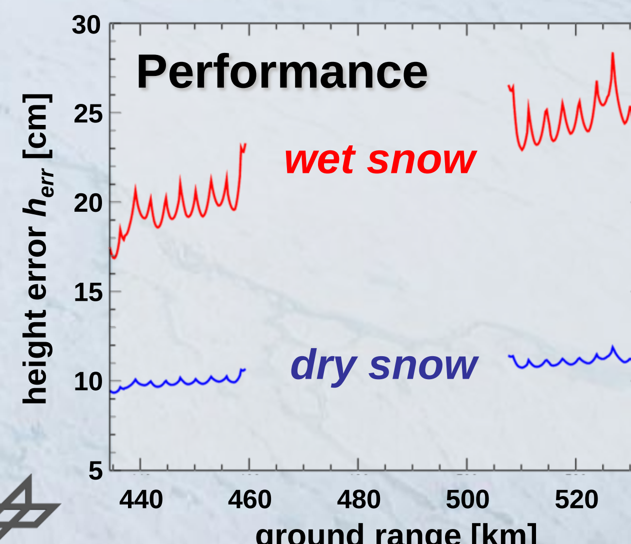

Digital Control & Processing
D/A
θ
Digital Feed-Array

SIGNAL Mission Proposal





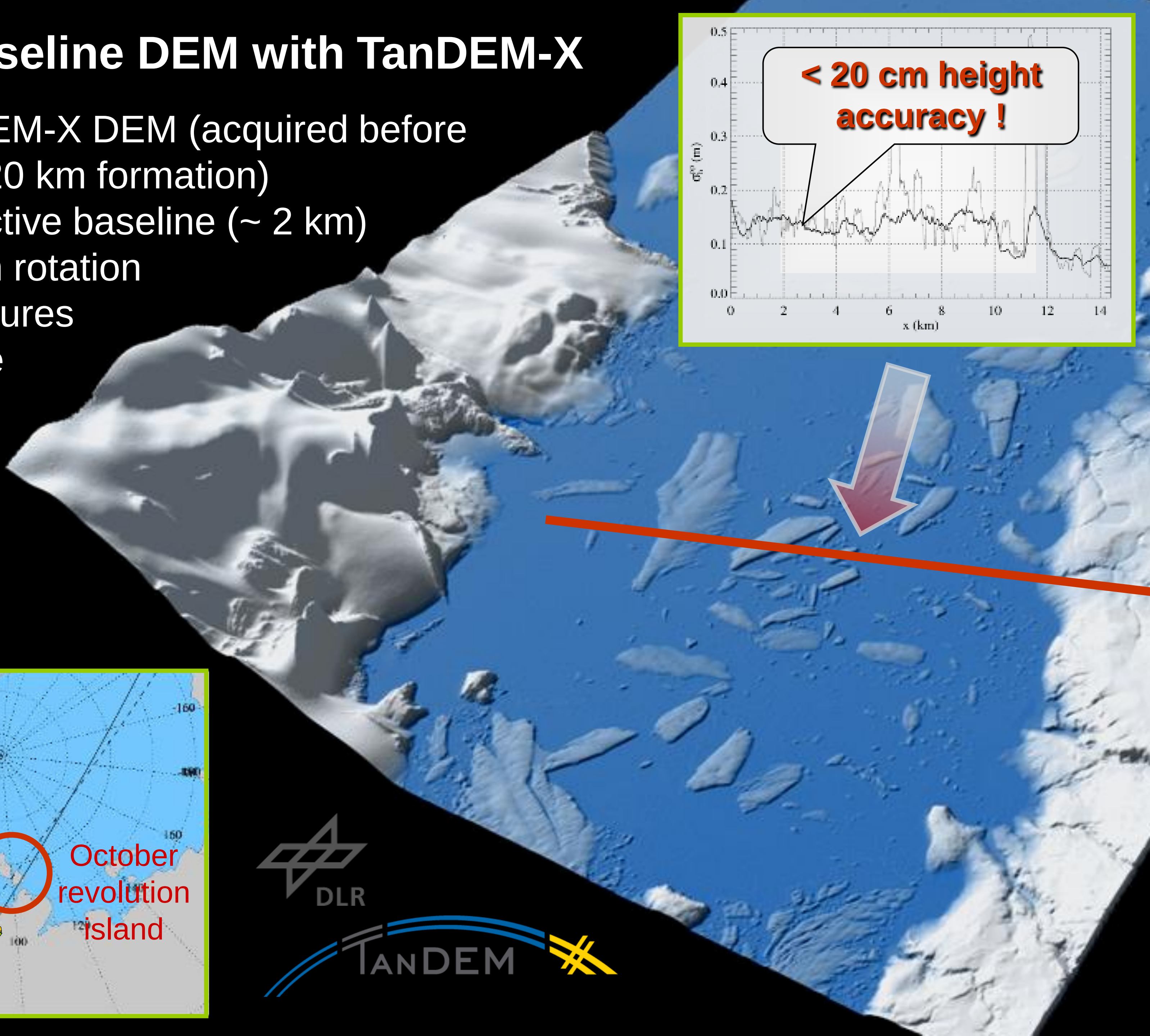
- High uncertainty about future sea level rise
  - IPCC’07 height increase 28 - 43 cm, now 1.4 m
  - major uncertainty: stability of polar ice sheets
- Large baseline satellite formation
  - innovative dual beam InSAR concept
  - avoids gaps of laser & radar altimetry systems
  - submitted to ESA Earth Explorer Opportunity call

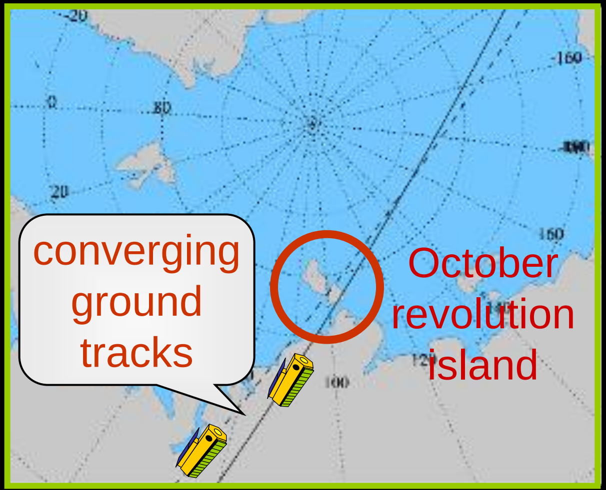


universität innsbruck AWI enveo ASTRIUM AN EADS COMPANY ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich DLR

Large Baseline DEM with TanDEM-X

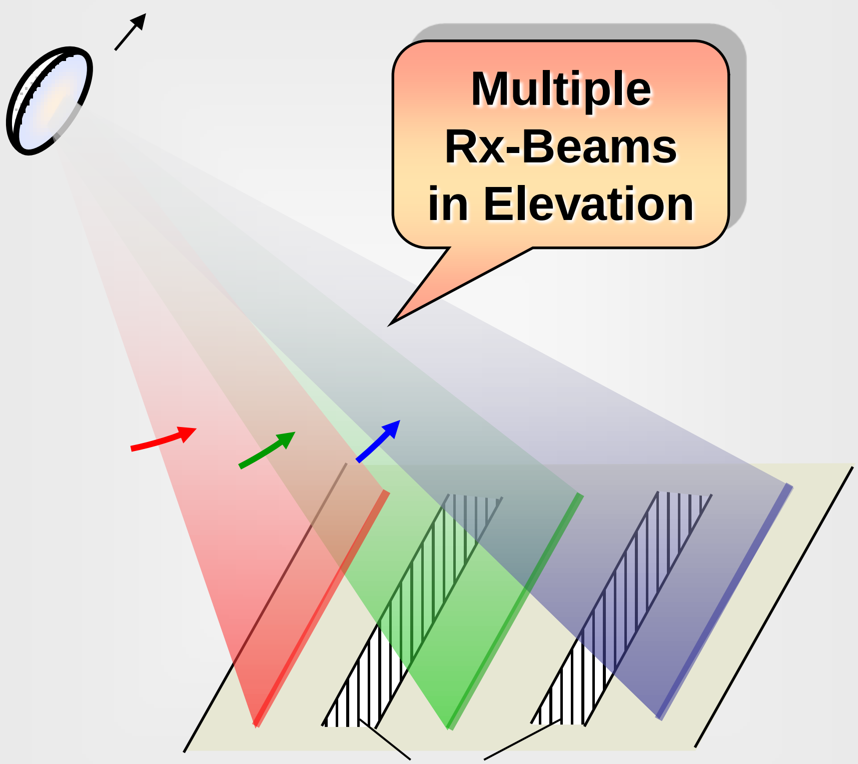
- first TanDEM-X DEM (acquired before reaching 20 km formation)
- large effective baseline (~ 2 km) from Earth rotation
- squint ensures coherence





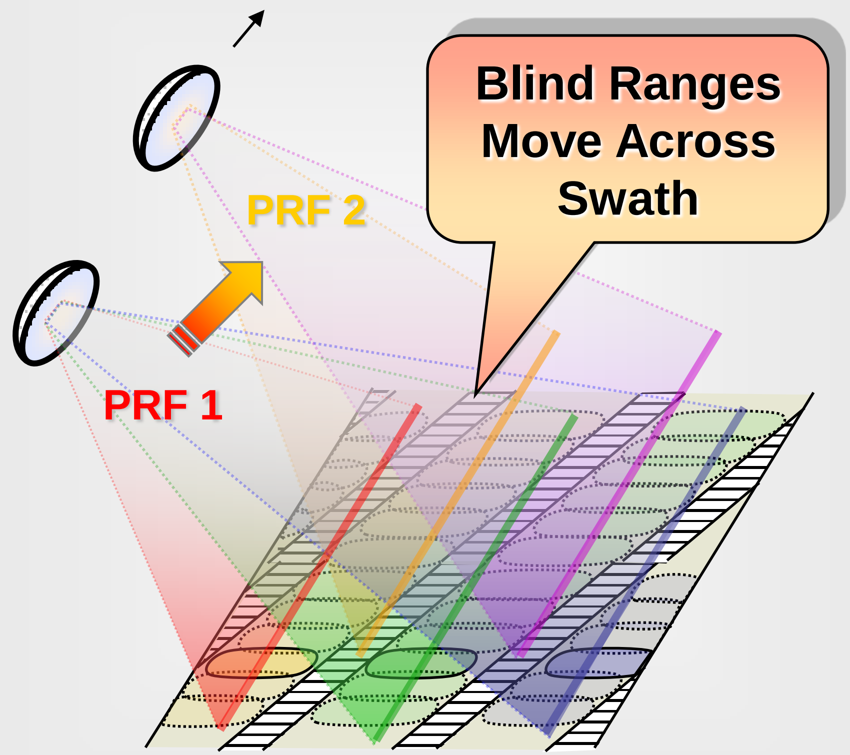
Ultra-Wide-Swath SAR Imaging

Multiple-Beam Stripmap

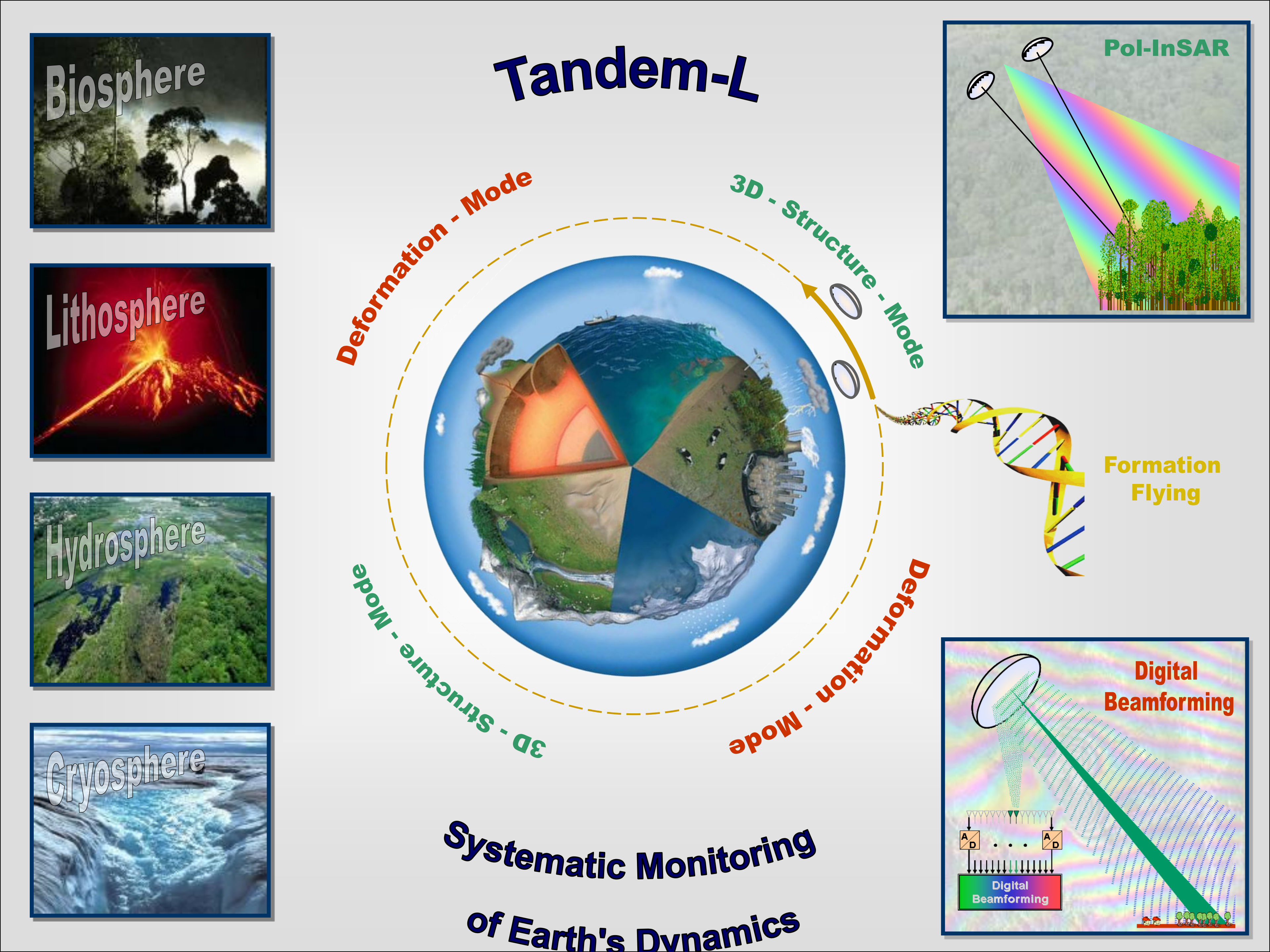


blind ranges for given PRF

Continuous PRI Variation

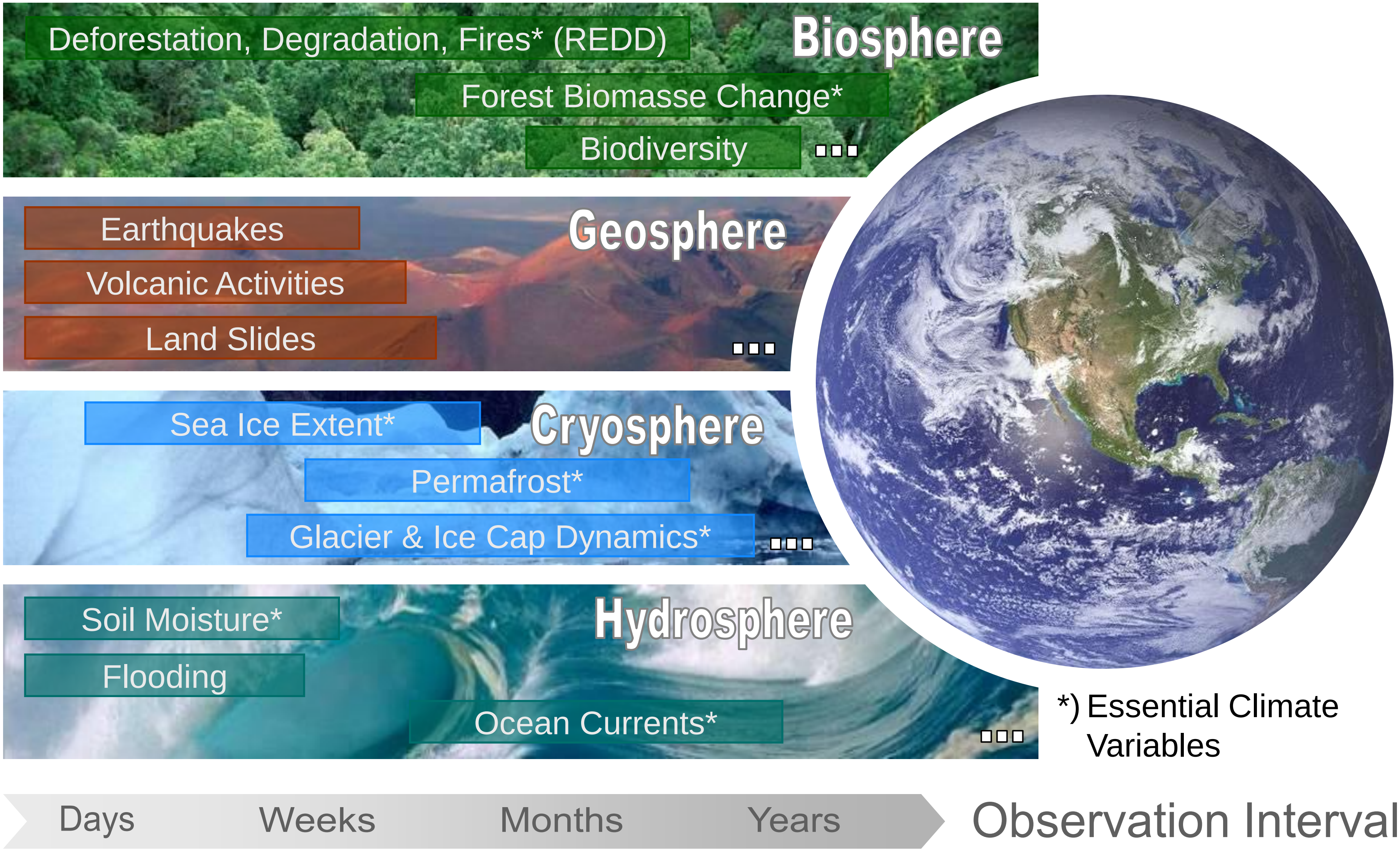


gaps eliminated



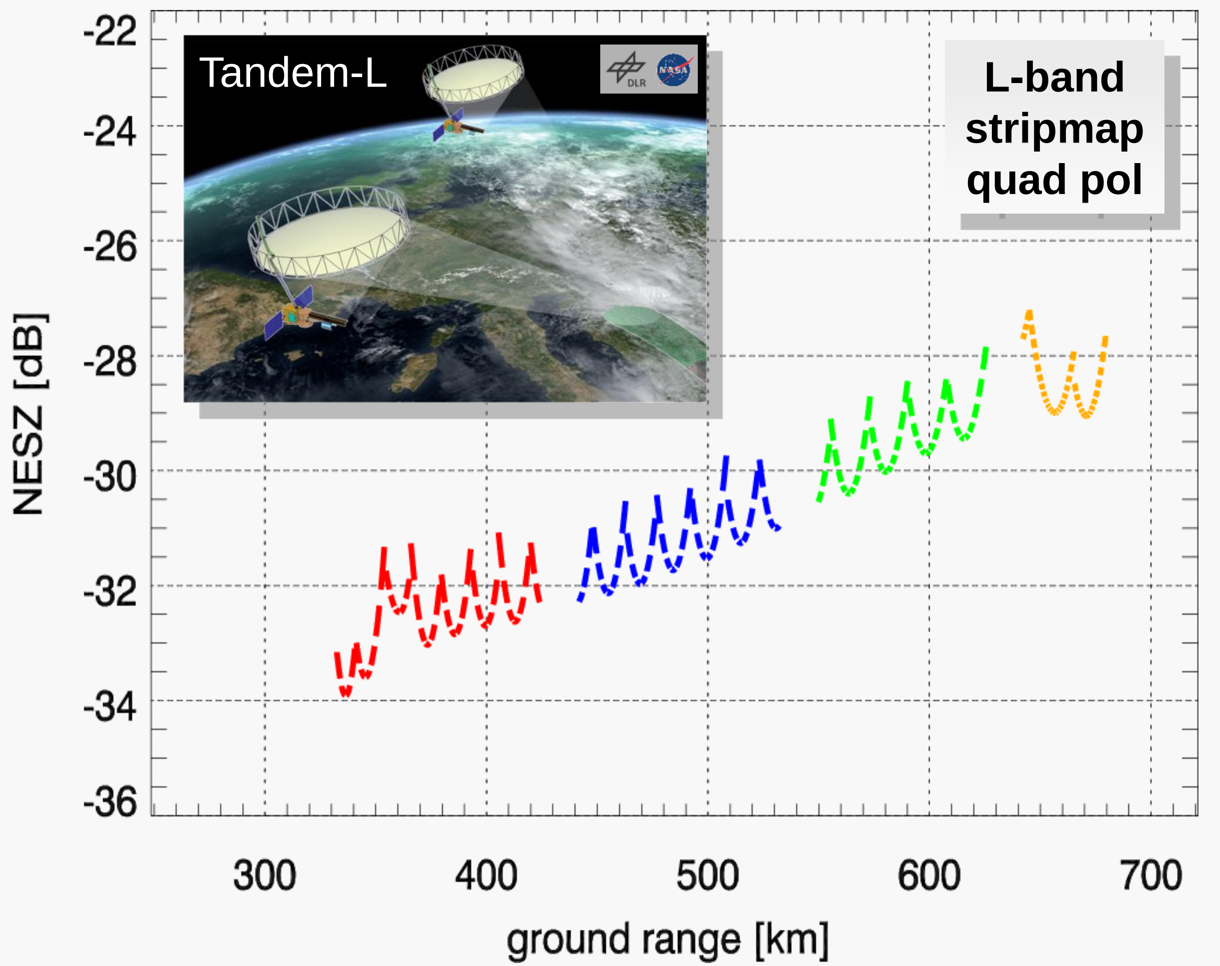
Tandem-L
Biosphere
Lithosphere
Hydrosphere
Cryosphere
Deformation - Mode
3D - Structure - Mode
3D - Structure - Mode
Deformation - Mode
Pol-InSAR
Formation Flying
Digital Beamforming
A D
A D
Digital Beamforming
Systematic Monitoring of Earth's Dynamics

Dynamic Processes on the Earth Surface



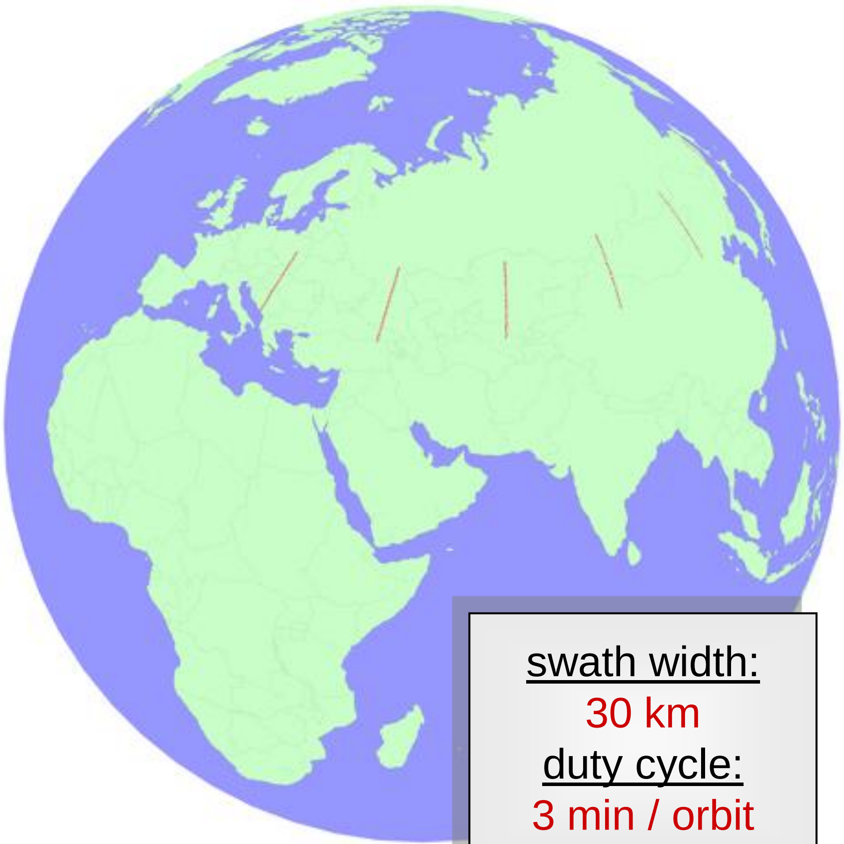
Parameter	Value
Orbit Height	760 km
Repeat Cycle	8 days
Swath Width	349 km
Incident Angle	26.3° - 46.6°
Ground Range	331 – 680 km
Tx Power (avg.)	**96 W**
Duty Cycle	4 %
Bandwidth	85 MHz
Polarization	Quad (linear)
Reflector Size	**15 m (diameter)**
Focal Length	10 m
Feed Location	centre
Feed Elements	24
Feed Length	3.43 m
Tilt Angle	31.9°
System Loss	1 dB
Rx Noise Temp.	420 K
PRF	2365 Hz

Noise Equivalent Sigma Zero



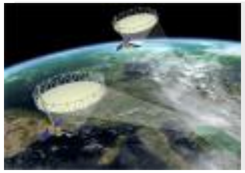
TanDEM-X

1 global coverage / year



Tandem-L

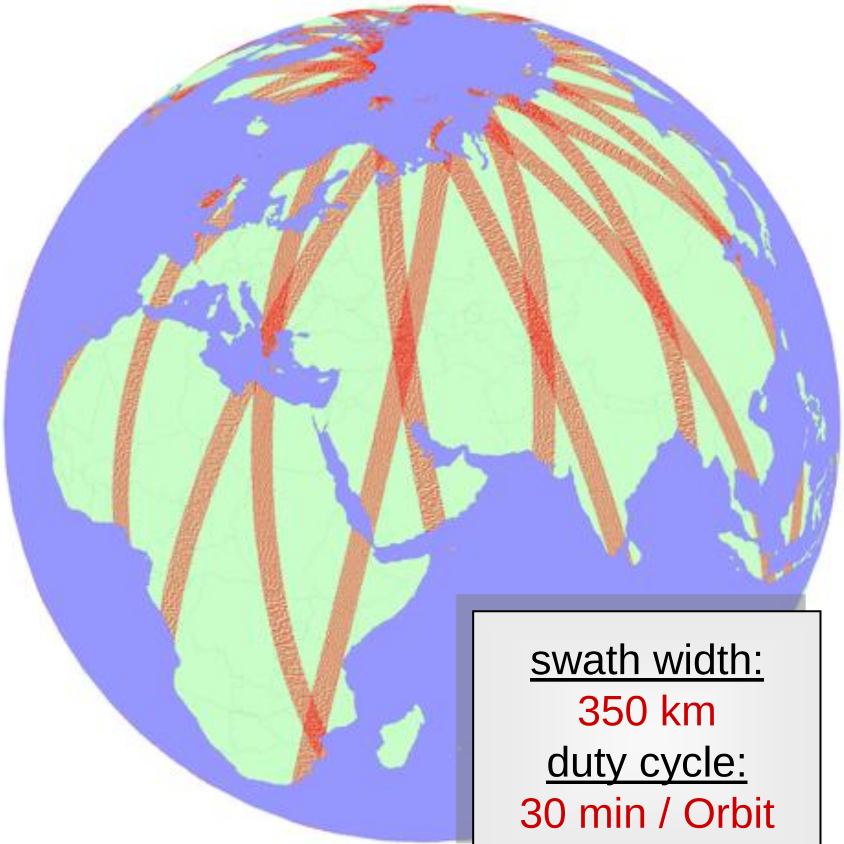
2 global coverages / week



swath width:
30 km
duty cycle:
3 min / orbit

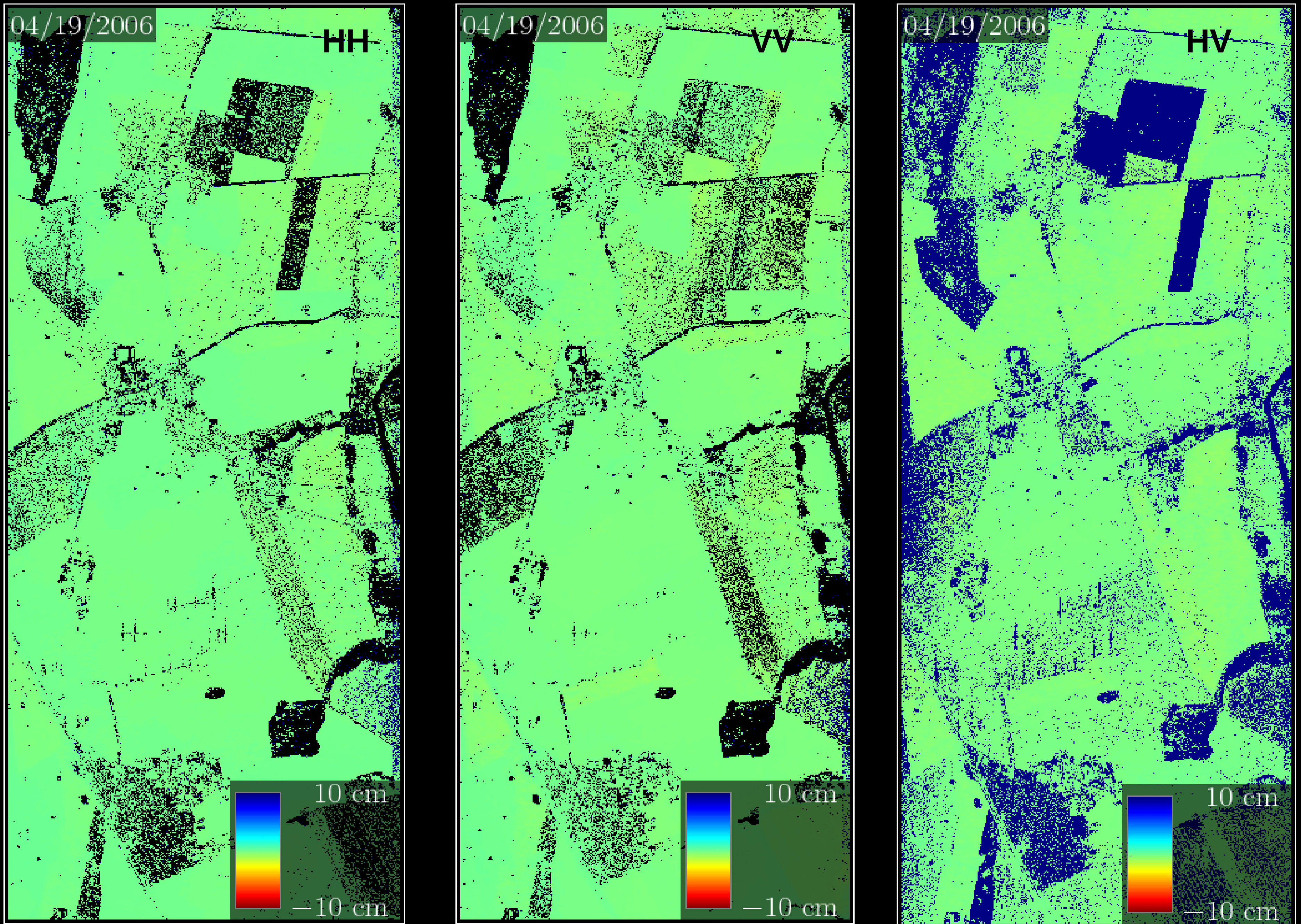
Day

1



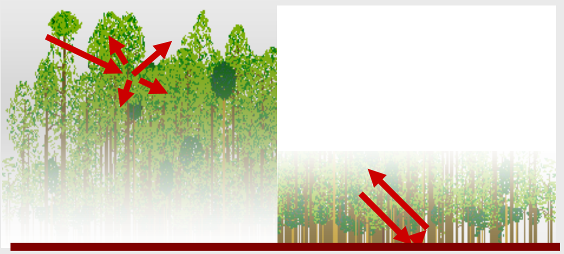
swath width:
350 km
duty cycle:
30 min / Orbit

Fully Polarimetric Soil Mapping with High Spatial Resolution @ L-band

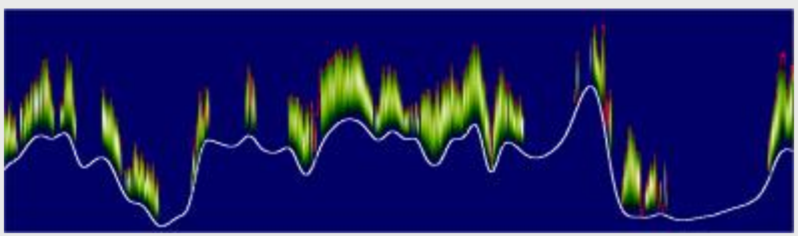


3-D Structure Mode

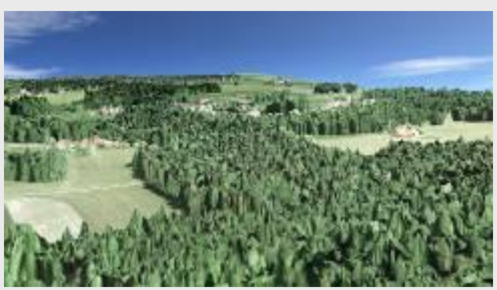
Polarimetric Backscattering



3-D Forest Structure

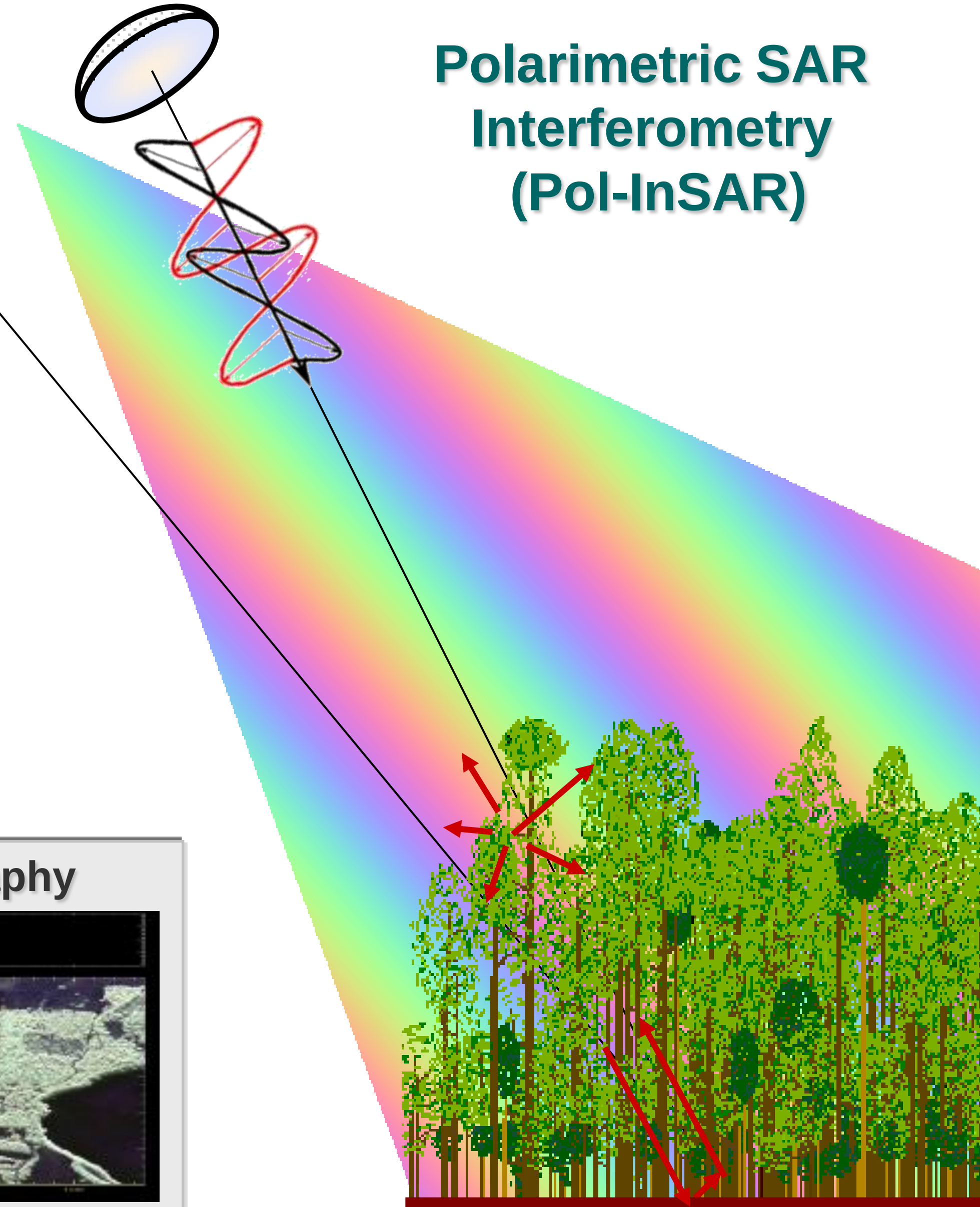


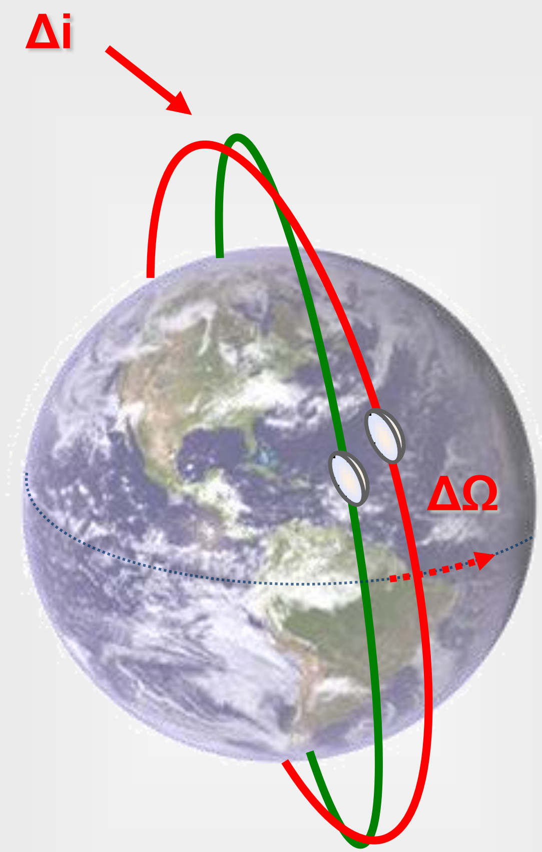
Forest height and Biomass



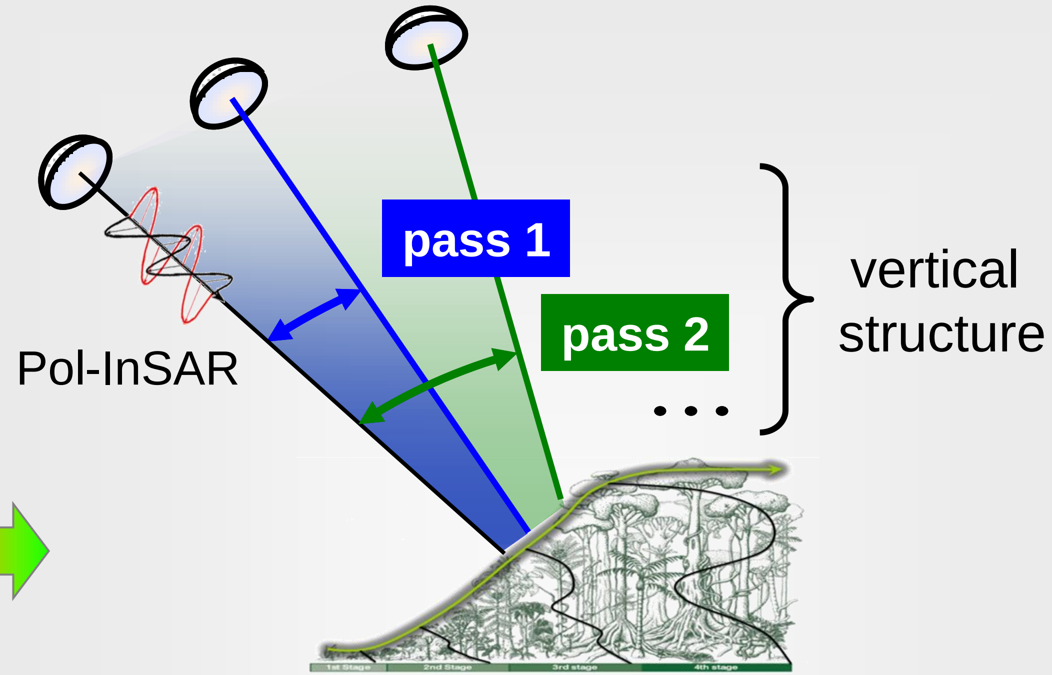
Tomography

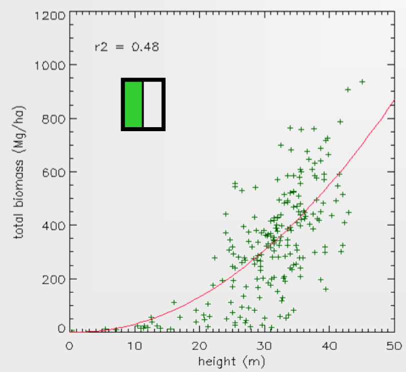
Polarimetric SAR Interferometry (Pol-InSAR)



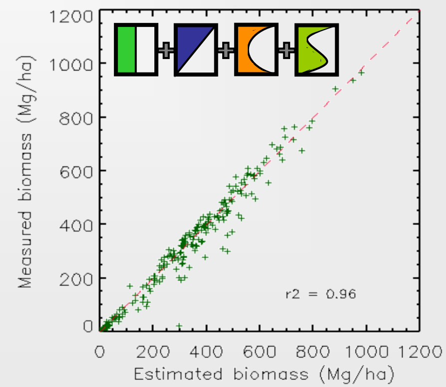


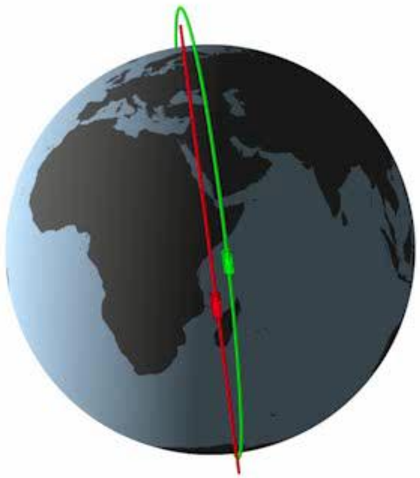
systematic mapping
with varying baselines

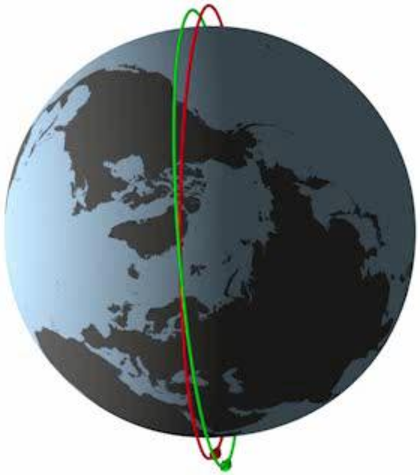


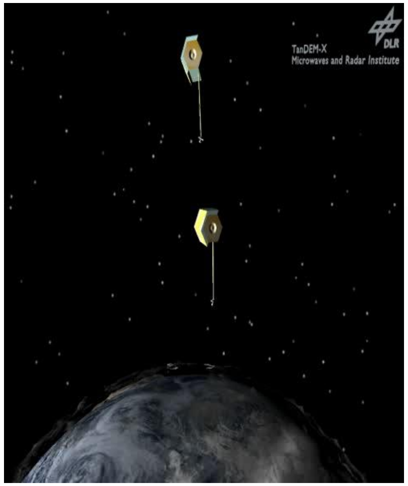


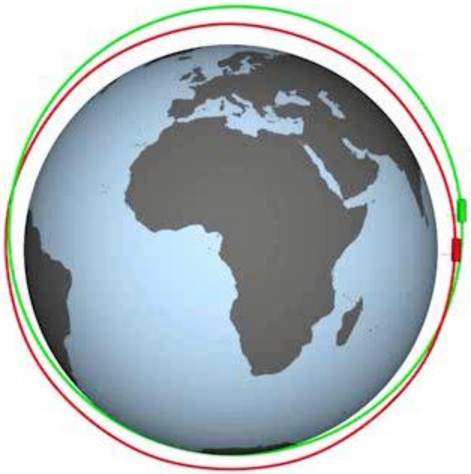
accurate
biomass
retrieval

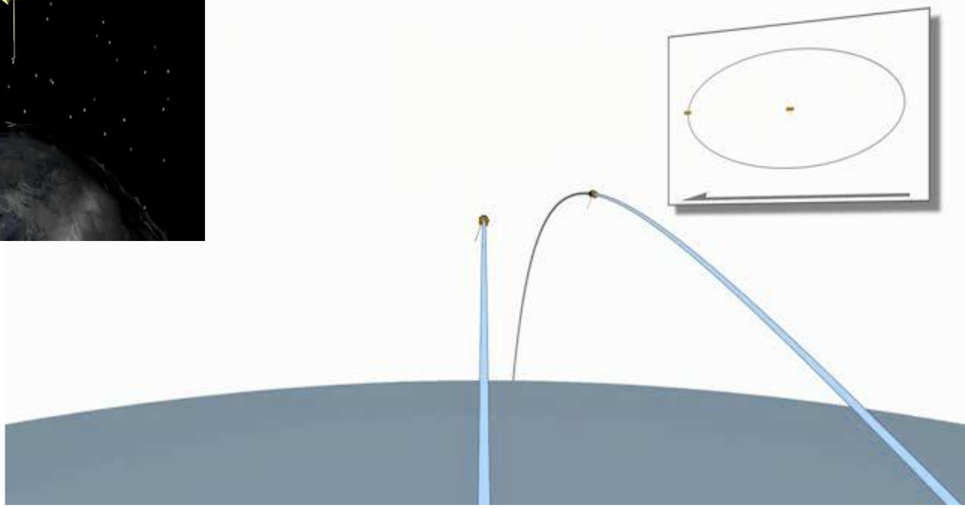




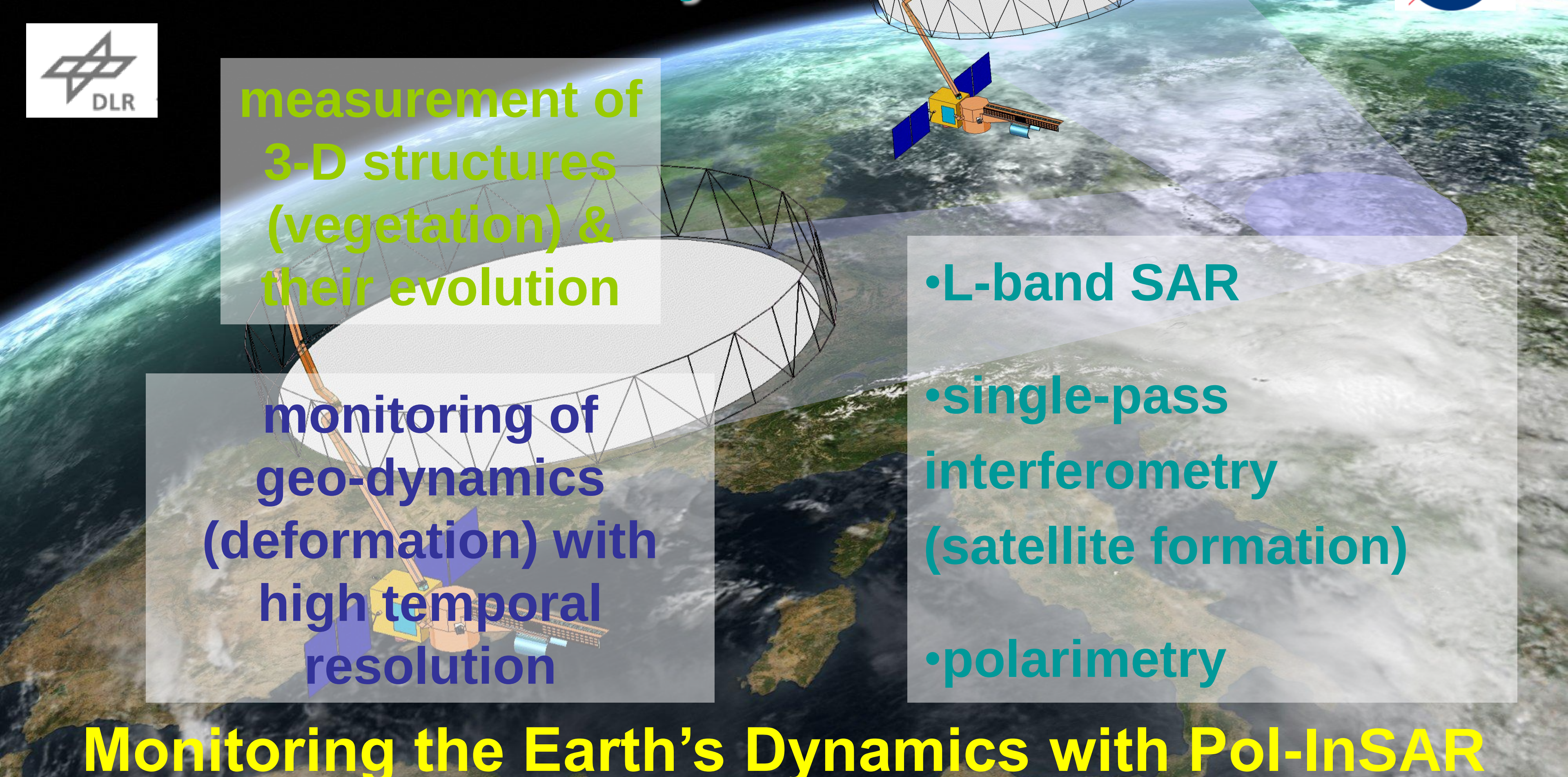



TanDEM-X
Microwaves and Radar Institute
DLR





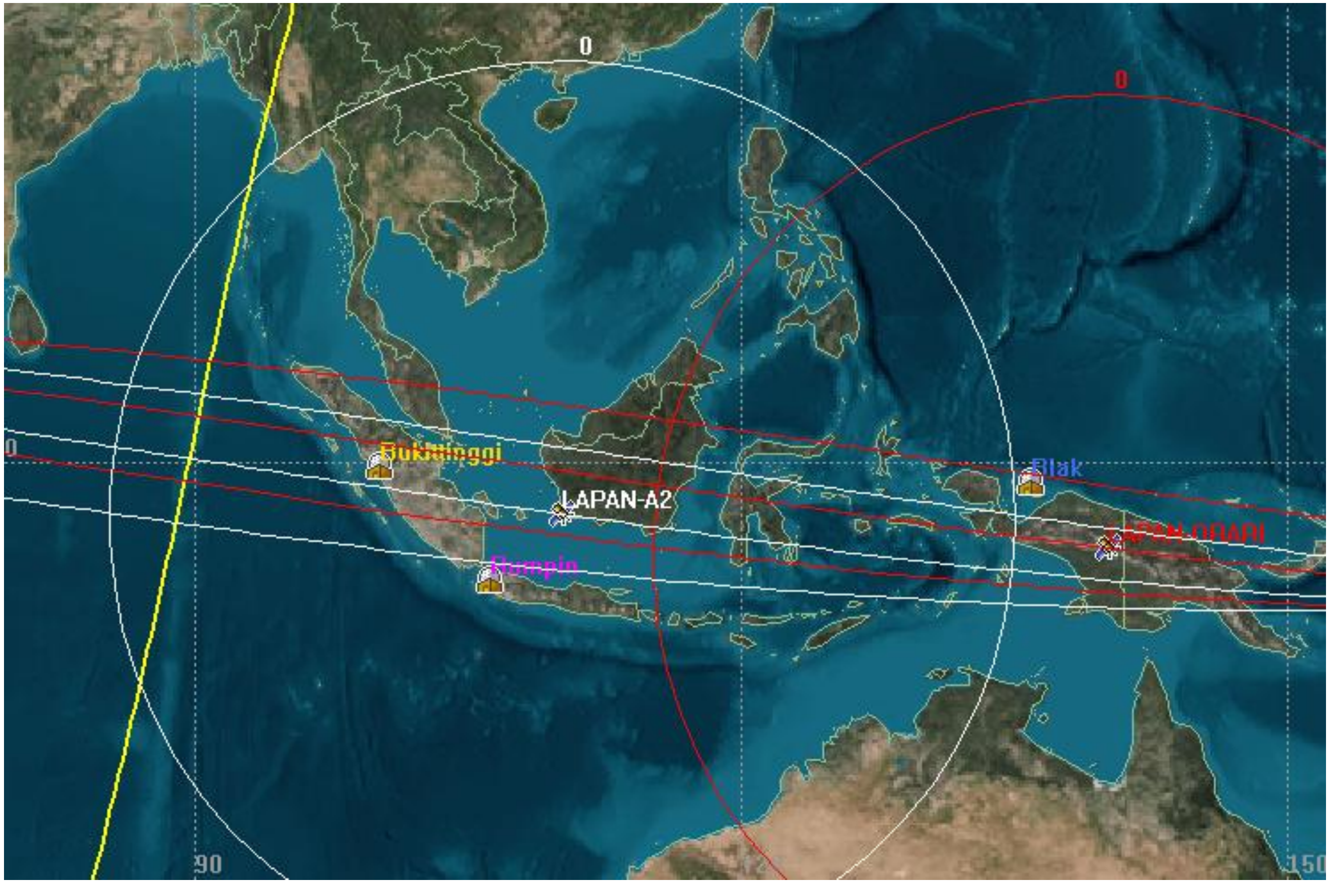
TanDEM-L – DESDynI



Courtesy of Pr. A. Moreira – POLINSAR09

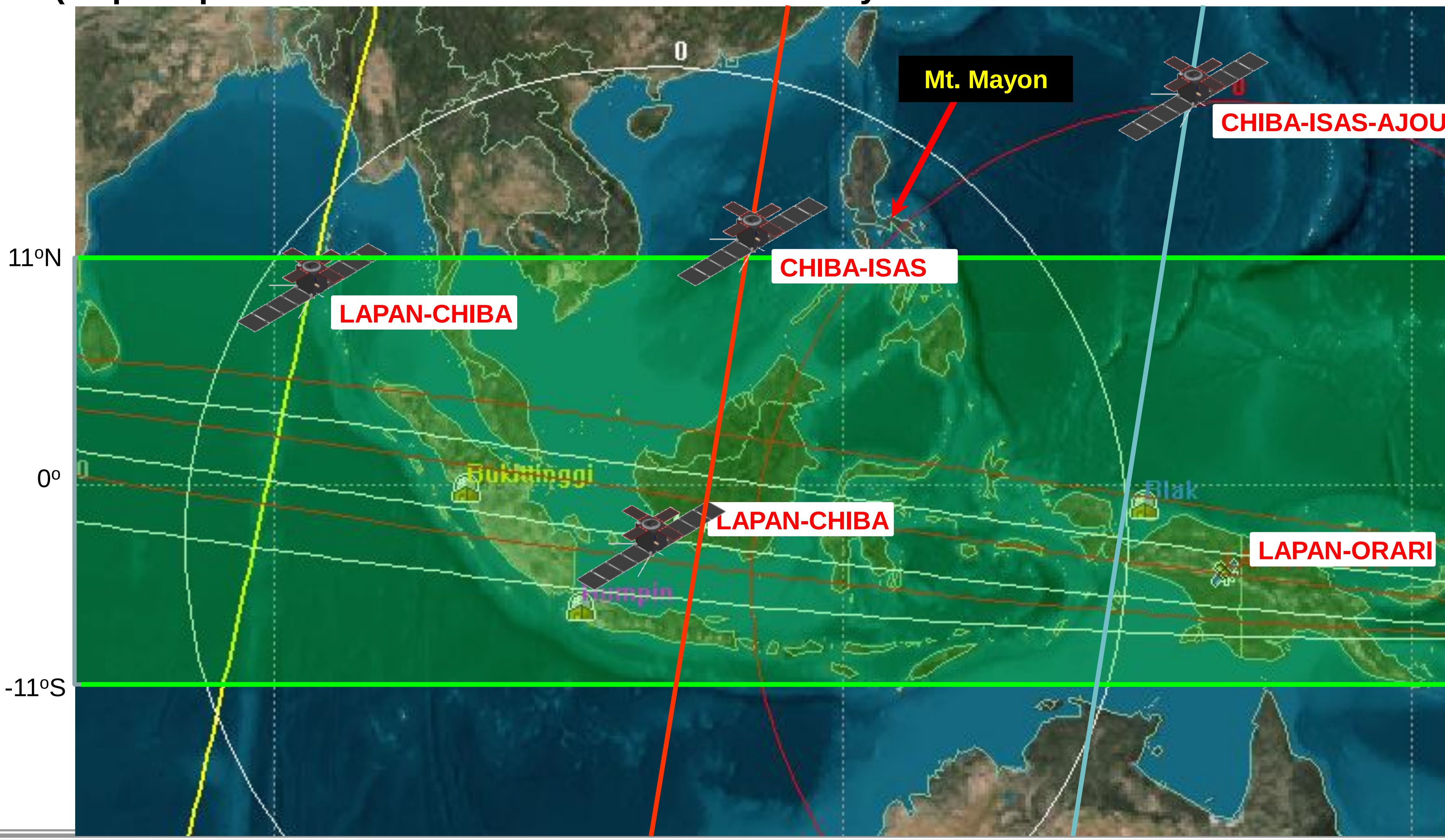
TUB-LAPAN-ORARI ORBIT PROFILE

(14 pass per 24 hr / orbit time 100 minutes and stay above horizon at about 10 minutes)



SATELLITES ORBIT PROFILES

(14 pass per 24 hr / orbit time 100 minutes and stay above horizon at about 10 minutes)



Major Paradigm for Remote Sensing from Air and Space of the Terrestrial Covers:

“Natural hazards are inevitable! Natural disasters are not & how can we reduce aftereffects?”

Accomplished with fully Polarimetric POLinSAR Sensors at all pertinent frequency bands at tandem orbital formation with wide swath-widths – at all weather, at day and night:

ACQUISITION OF NEW BANDS FOR ROTHPASSIVE & ACTIVE SENSING

• **Deep earth sounding**	**ULF - LF**
• **Ground penetrating radar**	**LF - VHF**
• **Mineral resource exploration**	**HF - UHF**
• **Biomass and vegetative cover estimation**	**HF – EHF (P/L/C-Band)**
• **Man made surface structure monitoring**	**HF – EHF (C/X/K-Band)**
• **Atmospheric passive remote sensing**	**cm – sub-mm**

◊ **We need to put our act together as the global remote sensing community and request from ITU/WMO the protection of the "fundamental natural resource: the e-m spectrum", and for providing the spectral bands for us to fulfill our professional duties as**

"The Remote Sensing Pathologists and Radiologists of Earth and Planetary Covers"

Recent Advances in Fully Polarimetric Space SAR Development and Its Applications

Conclusions:

The Vector (Polarization) Electromagnetic Spectrum:
A Natural Global Treasure

Terrestrial Remote Sensing with PolSAR **:**
The *Diagnostics of the Health of the Earth*
at all weather and volcanic conditions
and at day and night