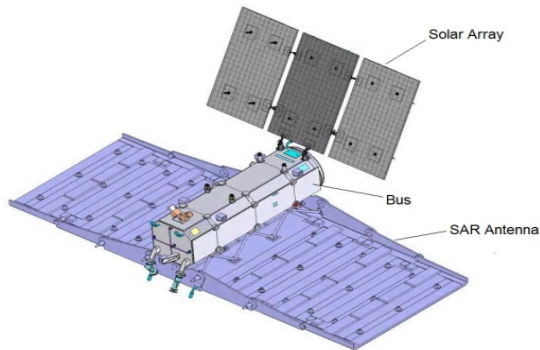


Business from technology



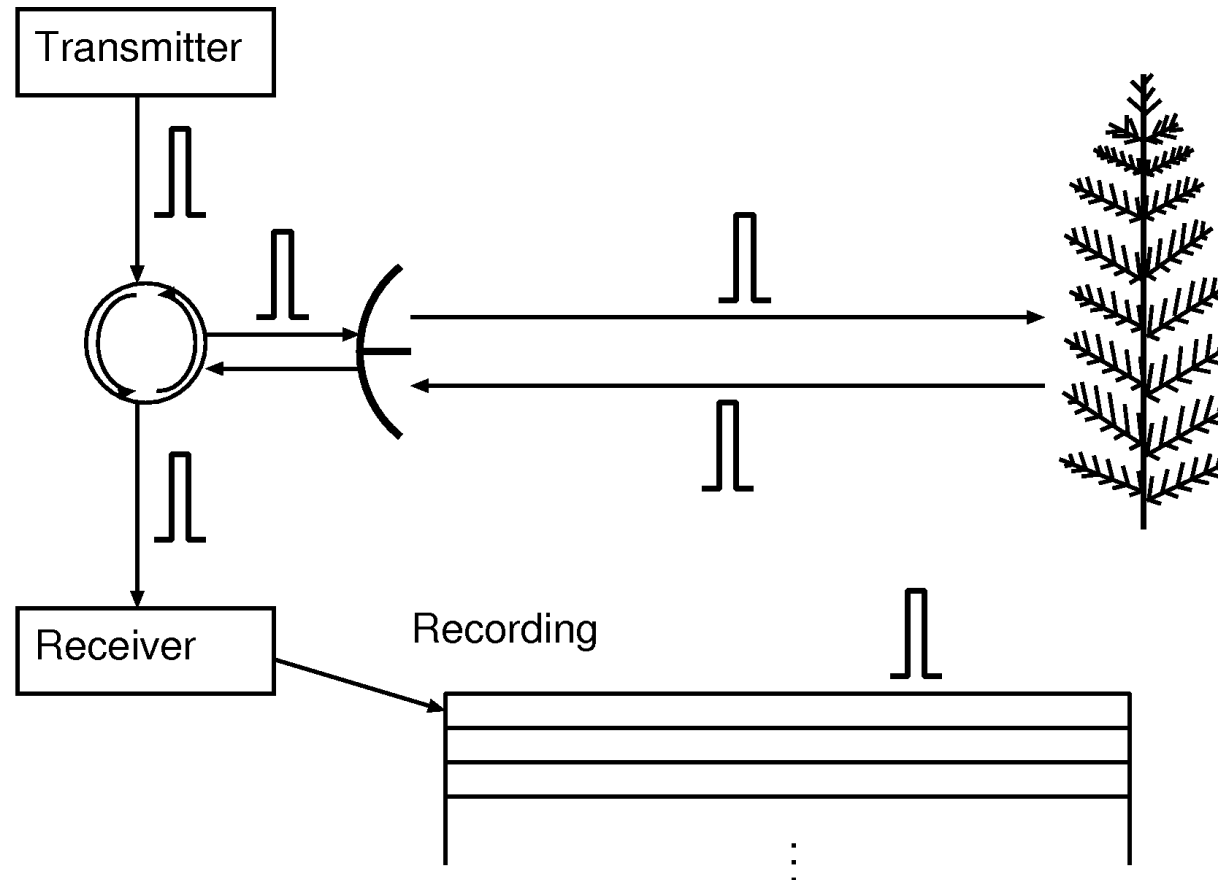
SAOCOM Companion Satellite (CS)

Compiled by Tuomas Häme

Oct 30, 2014

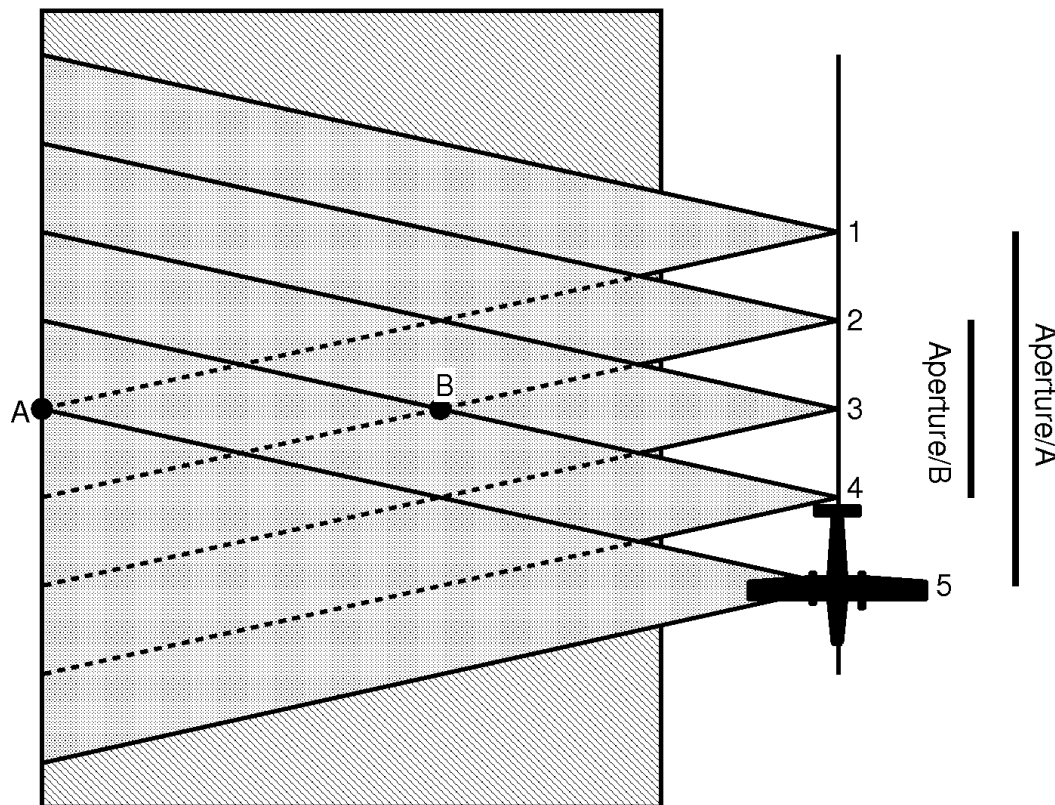
VTT Technical Research Centre of Finland

What is Radar



- Acronym from words "RADio Detection And Ranging"
- Implies measurement from the sensor to the target
- A pulse is sent
- The return signal recorded as a function of time
- Intensity of the signal = power, P
- Square root of P = amplitude

Synthetic Aperture Radar

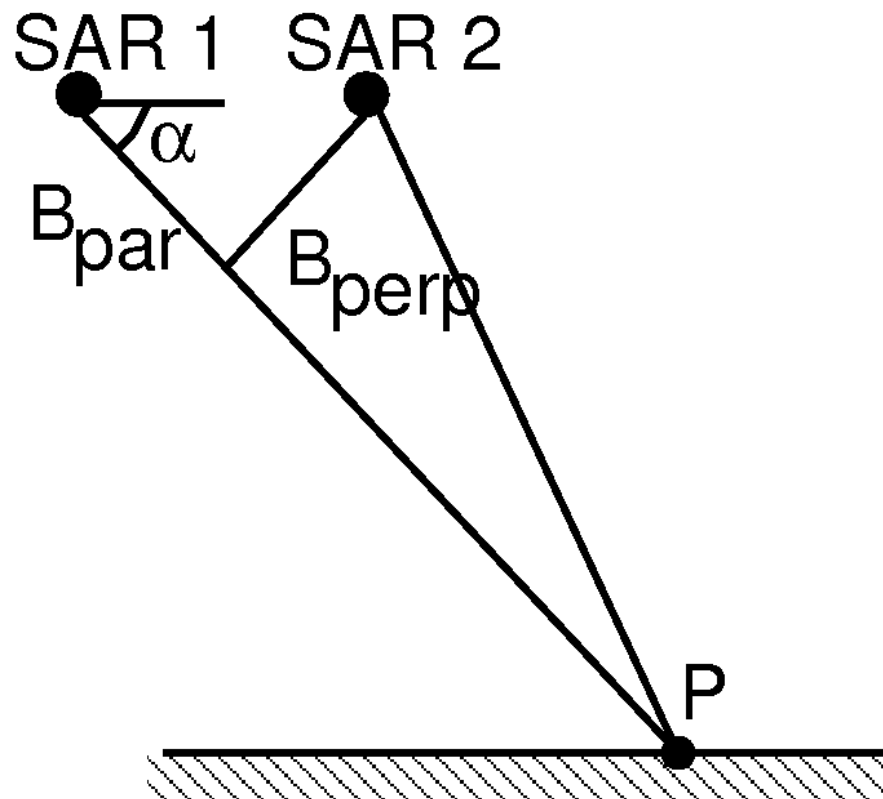


- In real aperture radar, the resolution along track is the better the longer antenna is used
- In synthetic aperture radar (SAR) a long synthetic aperture is constructed by combining the registered echoes from several pulses along the track
- Matched filtering in SAR processing
- Raw data (level 0) is useless without a SAR processor

Radar Frequencies

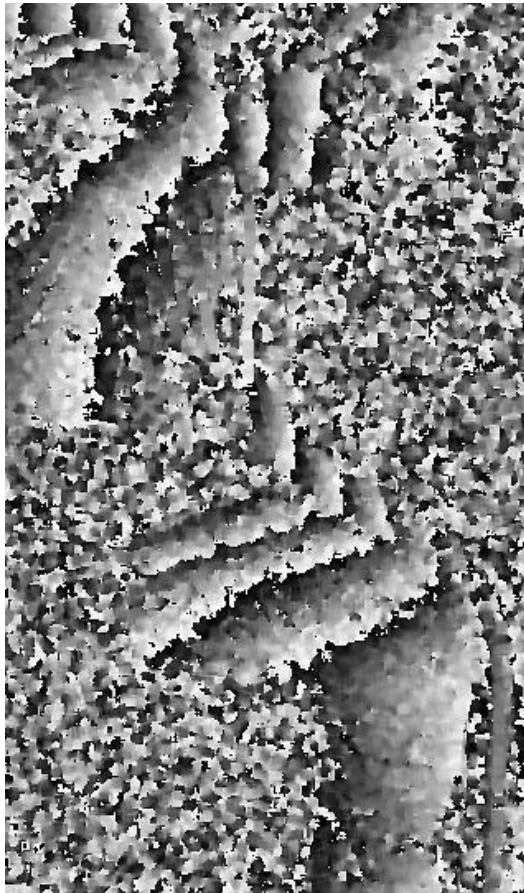
- For historical reasons (military secrecy, allocation of frequency bands in the electromagnetic spectrum), a common practice to refer to radar frequencies is by "radar band":
- X-band: wavelength approximately 3 cm, frequency approximately 10 GHz (Giga Herz)
- C-band: 6 cm, 5 GHz
- **L-band: 23 cm, 1.3 GHz - SAOCOM**
- P-band: 63 cm, 0.5 GHz
- K_u-band: 2 cm, 15 GHz (in some old real-aperture radars)

SAR Interferometry

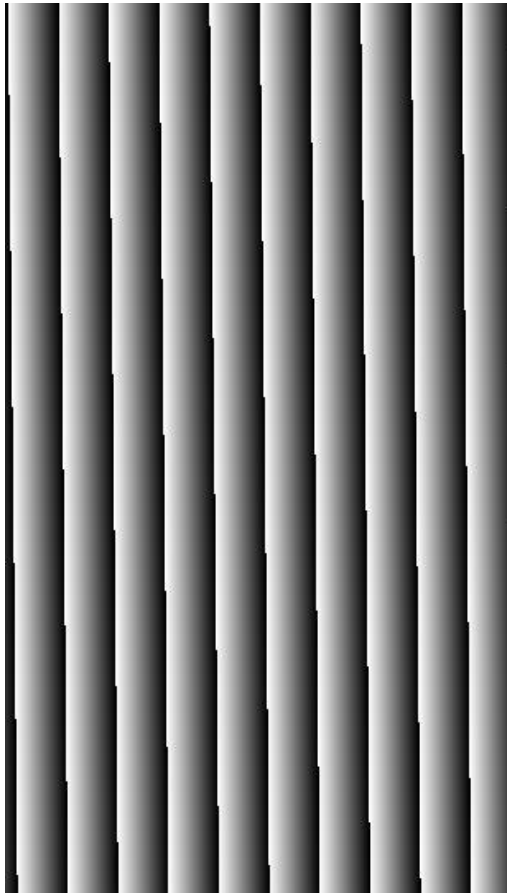


- The change in orbit positions between two over-flights forms a baseline
- The perpendicular baseline component B_{perp} causes a phase shift between the SAR scenes as a function of pixel elevation

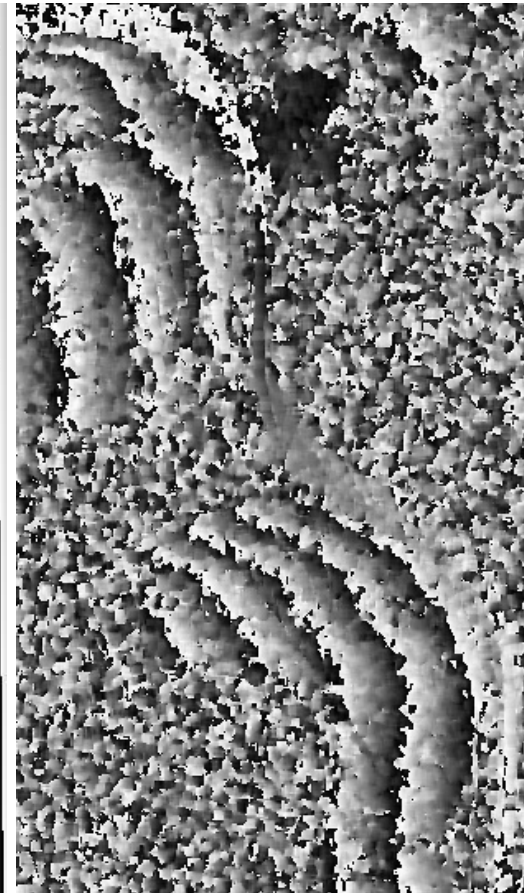
Interferometry/Example on Elevation Mapping



Without flattening



Phase computed for
ellipsoid

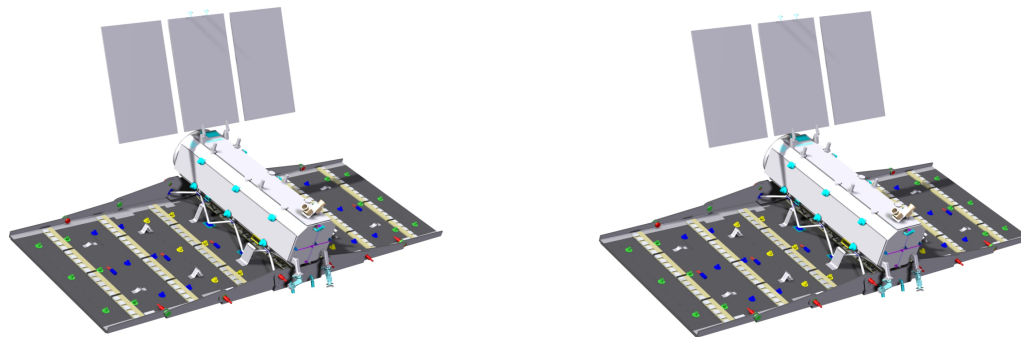


Ellipsoid-flattened

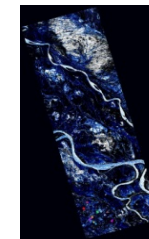
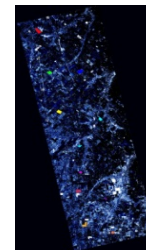
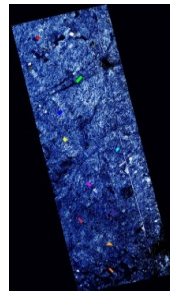
- Effects of the changes on interferogram phase caused by an ellipsoidal earth are computed and then corrected
- Fringes separated by $H_{2\pi}$ (in this case 12.65 m) in elevation

SAOCOM Mission

The SAOCOM 1 Mission is composed of two satellites, SAOCOM 1A and SAOCOM 1B, presently under development. Both satellites are equally designed and each one carries a full polarimetric L-band SAR instrument



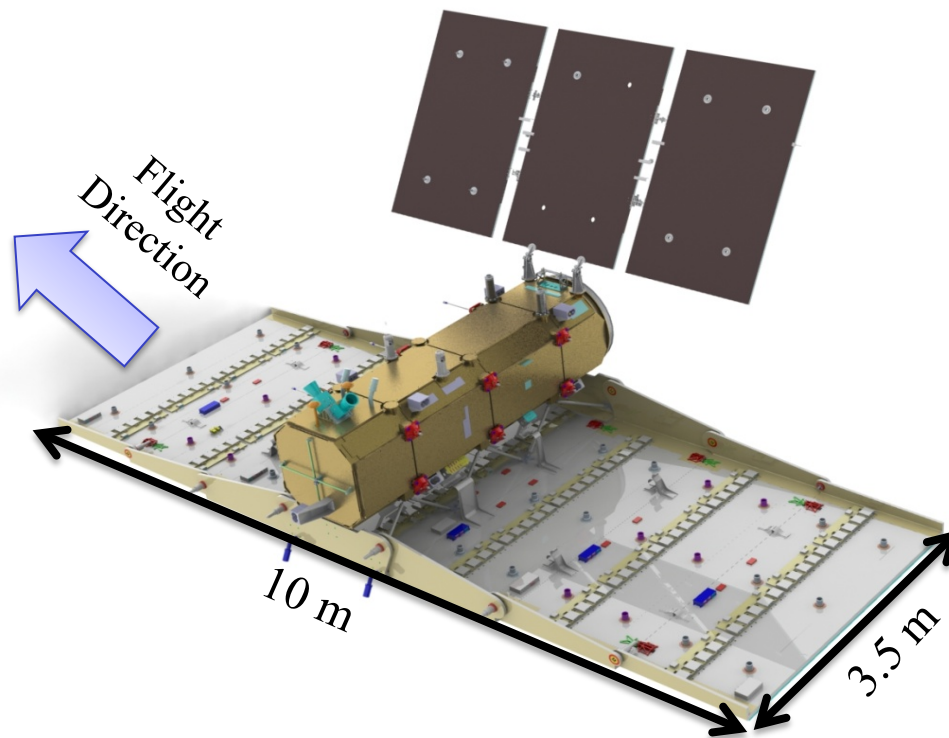
This mission has as main driver the generation of Soil Moisture Maps over the Pampas Region in **Argentina**, with the aim of providing an essential quantitative input of the soil moisture content for giving support to agricultural and hydrological applications (SAOCOM Strategic Applications).



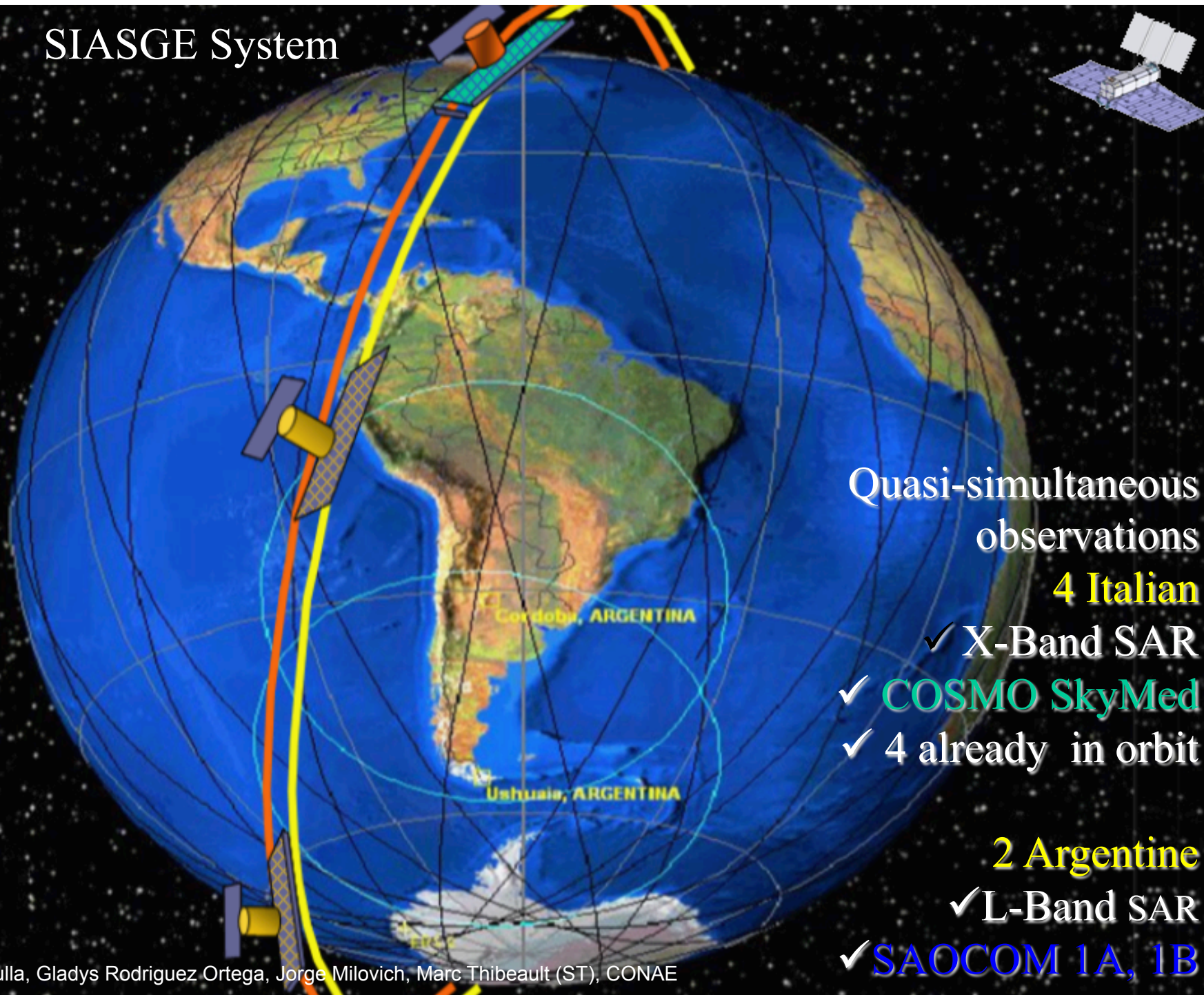
SAOCOM SAR Instrument

MAIN CHARACTERISTICS

- L-Band SAR
- Right looking SAR
- Left looking capability
- 10m x 3.5m active phased array antenna with 140 TRMs
- TOPSAR & Stripmap acquisition modes
- Single, dual and quad polarization operative modes
- More than 2600 beams
- Satellite Weight: **~3 tons**
- Solar Array area: $\sim 13 \text{ m}^2$



SIASGE System



Quasi-simultaneous
observations

4 Italian

- ✓ X-Band SAR
- ✓ COSMO SkyMed
- ✓ 4 already in orbit

2 Argentine

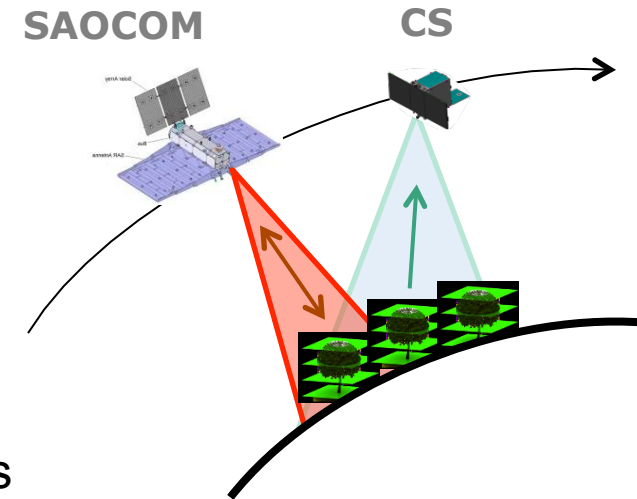
- ✓ L-Band SAR
- ✓ SAOCOM 1A, 1B

Nominal Modes Features

acquisition mode	polarization mode	swath width	spatial resolution	minimum incidence angle range
StripMap	SP: HH or HV or VH or VV	> 40 km	< 10 m	21° - 50°
	DP: HH/HV or VV/VH	> 40 km	< 10 m	21° - 50°
	QP: HH/HV/VH/VV	> 20 km	< 10 m	20° - 35°
TOPSAR Narrow	SP: HH or HV or VH or VV	> 150 km	< 30 m	25° - 45°
	DP: HH/HV or VV/VH	> 150 km	< 30 m	25° - 45°
	QP: HH/HV/VH/VV	> 100 km	< 50 m	20° - 35°
TOPSAR Wide	SP: HH or HV or VH or VV	> 350 km	< 50 m	25° - 45°
	DP: HH/HV or VV/VH	> 350 km	< 50 m	25° - 45°
	QP ⁽¹⁾ : HH/HV/VH/VV	> 220 km	< 100 m	20° - 35°
	CL-POL: RH/RV or LH/LV	> 350 km	< 50 m	25° - 45°

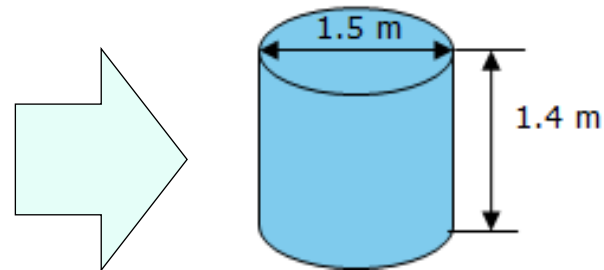
Development of a companion to SAOCOM Mission - overview

- TangoSat “Companion Satellite” (“SAOCOM-CS”)
 - ✓ **receive-only**, dual-pol L-band SAR satellite
 - ✓ (close) formation with SAOCOM
 - ✓ SAOCOM as illuminator
- Complement science return of SAOCOM
 - ✓ new radar science: tomography, bistatic measurements
 - ✓ **mapping of biomass and structure of boreal forests by SAR tomography**
 - ✓ several imaging geometries (baselines and angles) for **experimental** applications
 - ✓ detailed studies by POLIMI, DLR and CSL confirmed preliminary mission science program
- Launcher & schedule constraints
 - ✓ Falcon-9, available volume: cylinder, 1.5 m diameter x 1.4 m height
 - ✓ max. total launch mass: **ca. 400 kg**
 - ✓ tight schedule imposes maximum reuse of existing equipment / high TRL



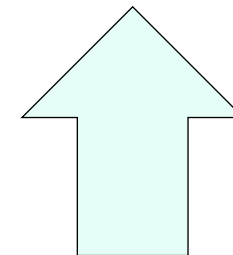
System Definition

Launch with Falcon-9 as
secondary payload.
MAS-5 launcher adapter.



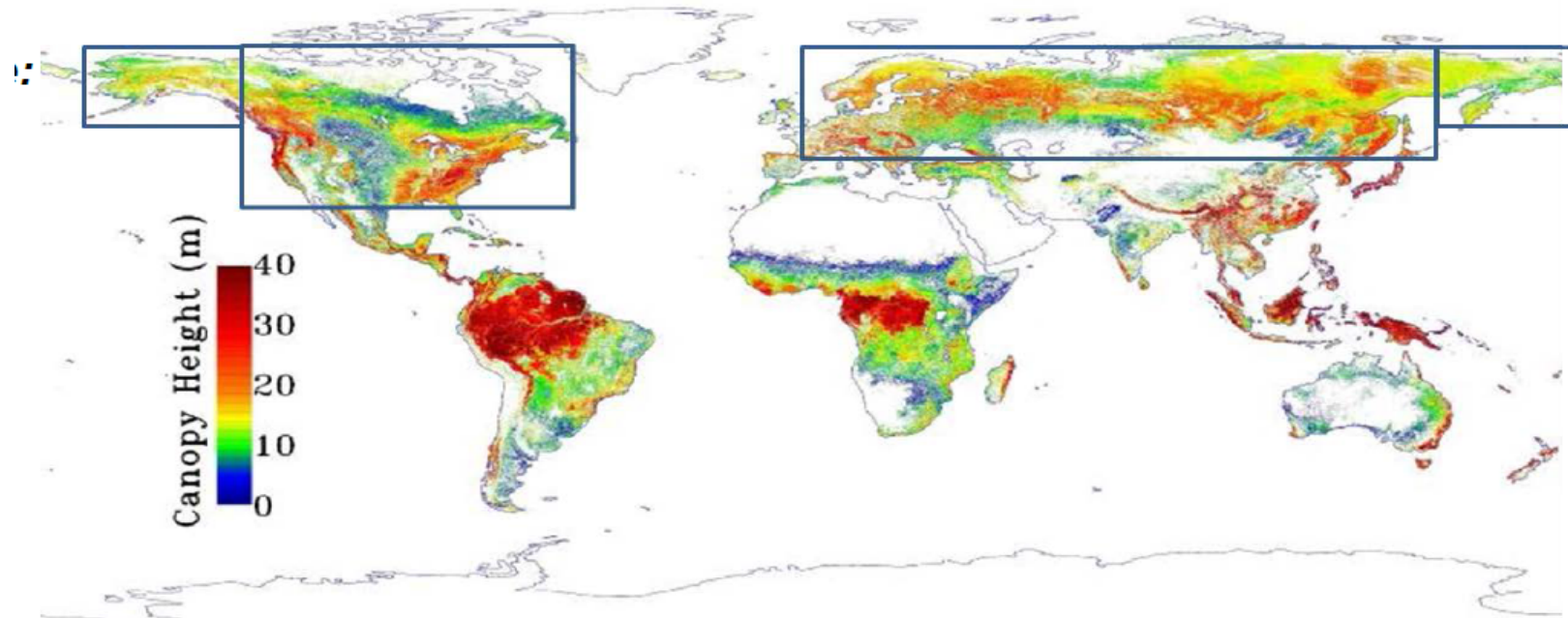
Dynamic envelope
Max mass: ca 400 kg

- Small platform
- Planar deployable antenna
- Reuse/Adaptation of Central electrons



- Available technology
- High TRL
- Design heritage

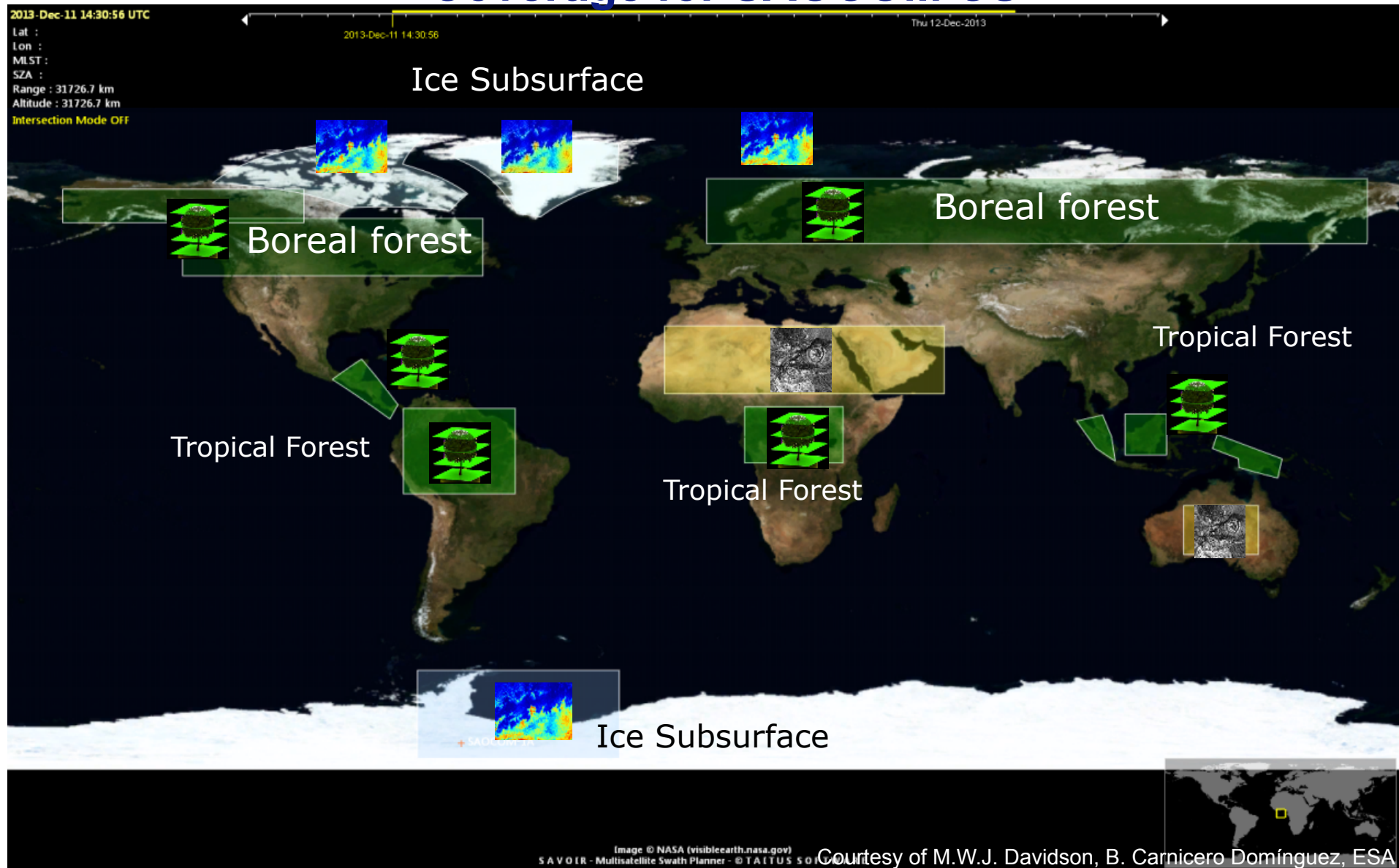
SAOCOM CS Science Mission Driver: Boreal forest structure



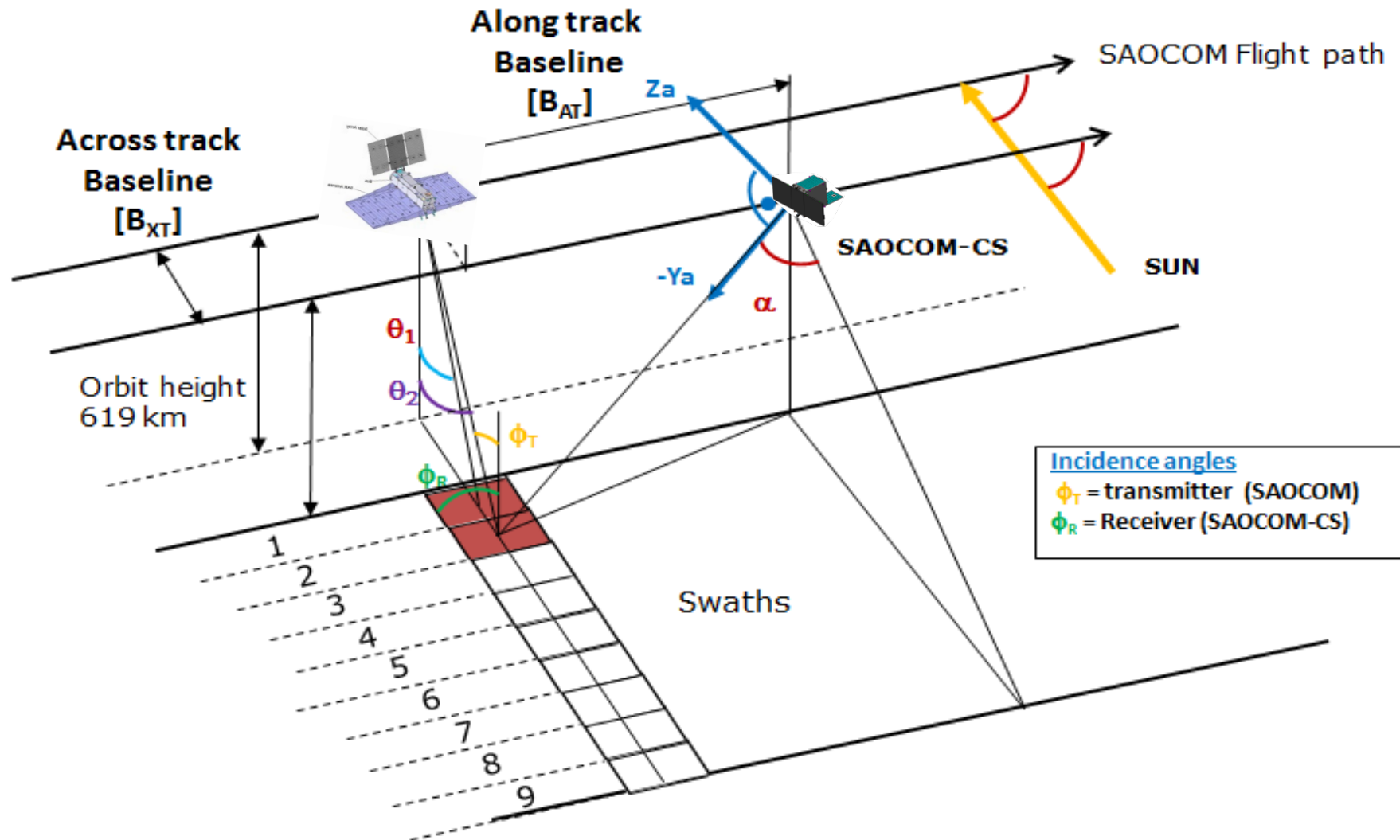
Attractive science goal for SAOCOM CS mission

- Forest structure provides valuable information including forest biomass/carbon resources
- Fill in SOTR restricted areas
- Complements ESA BIOMASS Explorer Mission and other mission concepts NASA L-band SAR/JAXA PaISAR/DLR Tandem-L

Tomographic Science Applications and Coverage for SAOCOM CS



Observation Geometry



Science and Observation Geometry

- Four configurations w.r.t baselines and viewing geometry
- Three science mission phases: tomographic, bistatic, specular

Tomographic phase

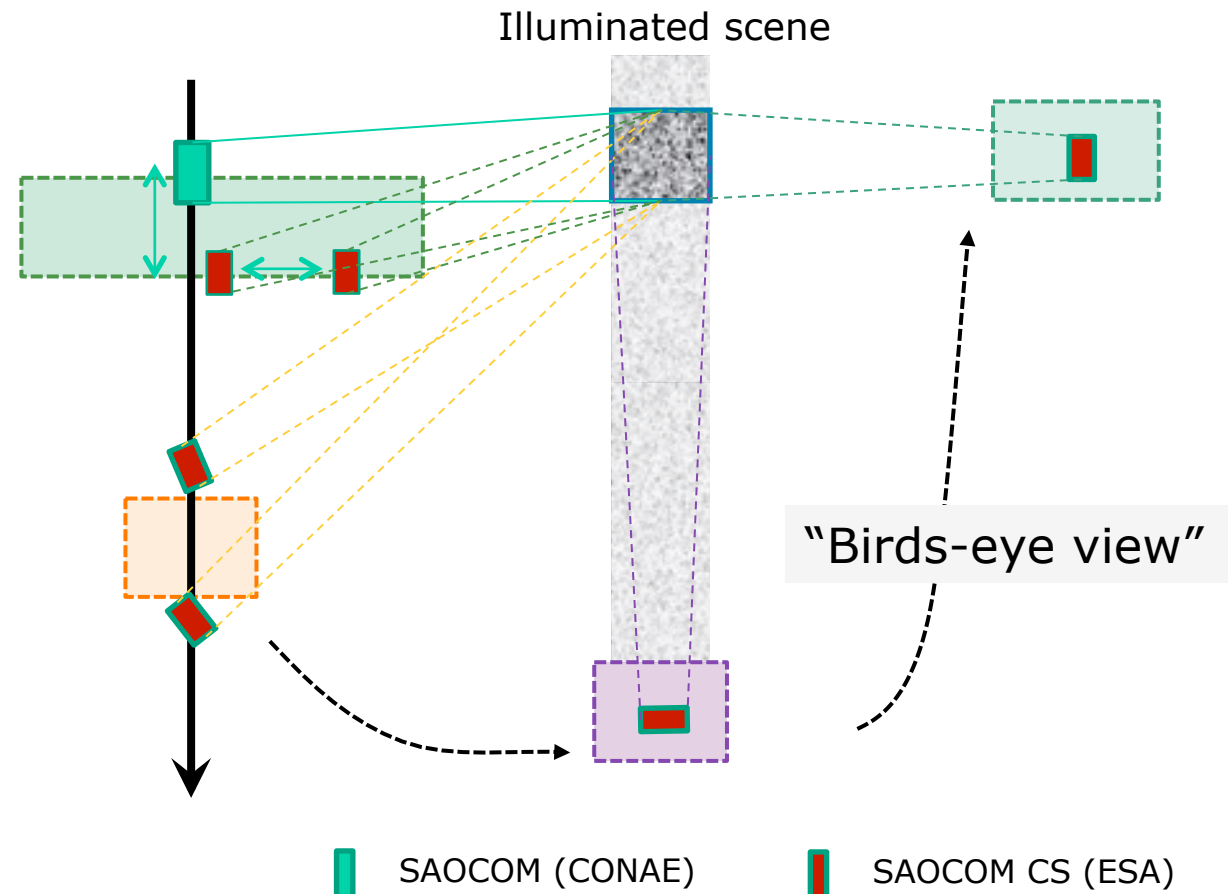
- ✓ **AT baseline** < 6 km
- ✓ **XT baseline** varies ~1–6 km
- ✓ **Science mission driver**
- ✓ **Duration** ~2.5 years

Bistatic 1, Bistatic 2

- ✓ **AT baseline** < 250 km
- ✓ **Small XT baseline (phase 1)**
- ✓ **Large XT baseline (phase 2)**
- ✓ **Duration** ~2 years

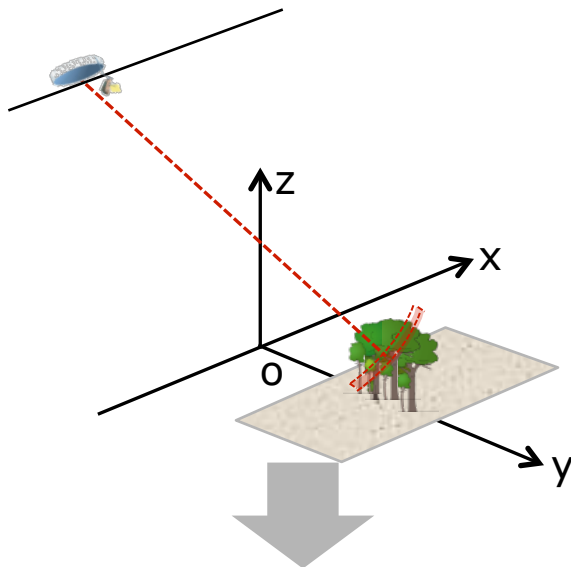
Specular phase

- ✓ **Experimental**
- ✓ **Short duration**

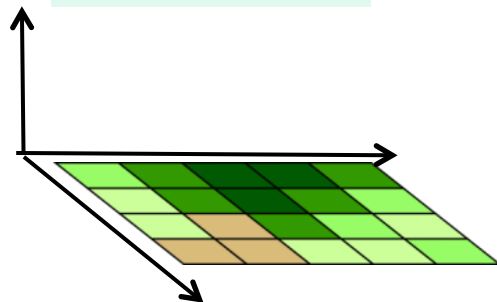


SAOCOM + SAOCOM CS - 3 independent types of information depending on geometry & baselines

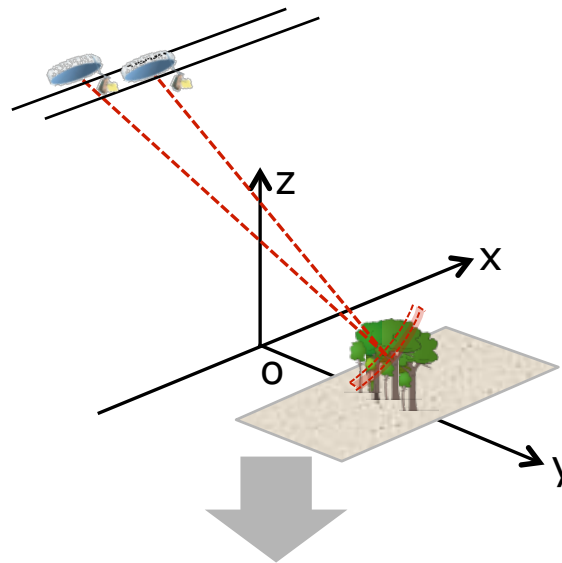
PolSAR
(SAR Polarimetry)



SAOCOM only

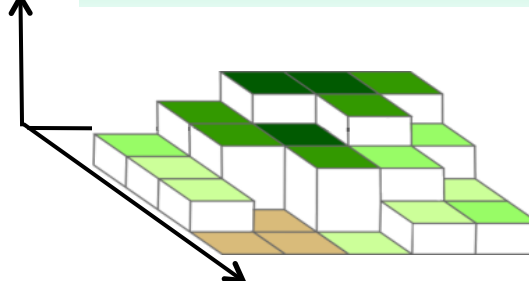


PolInSAR
(Polarimetric SAR Interferometry)

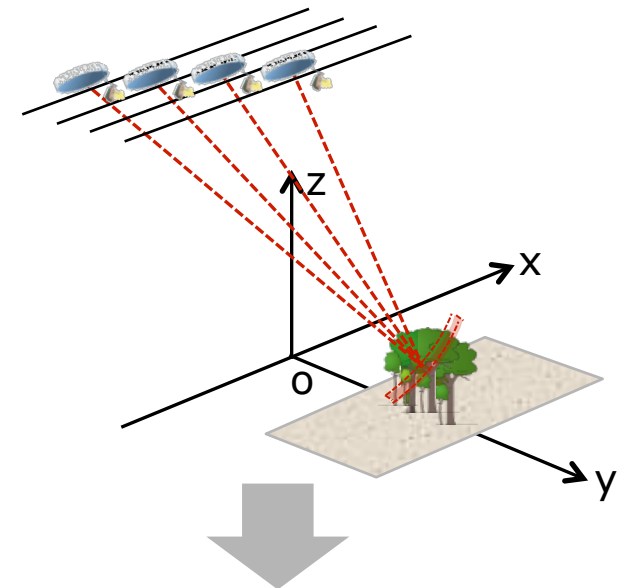


Height

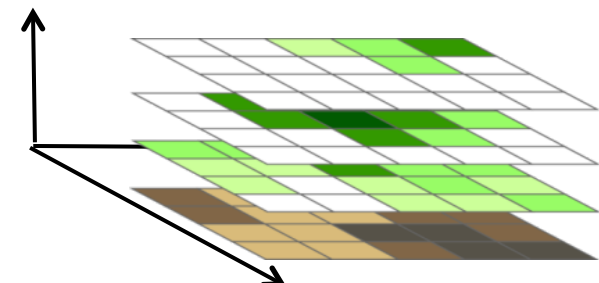
SAOCOM+CS (1 pass)



Tomo SAR
(SAR Tomography)



SAOCOM+CS (>1 passes)



Courtesy of M.W.J. Davidson, B. Carnicero Domínguez, ESA

Overview: Mission Timeline and Baselines

Tomographic
Phase
(880 days)

Bistatic Phase
(720 days)

Specular
Phase
(160 days)

Science Cycle	Science Target	Days	RC	SAOCOM Inst. mode	AT Baseline	XT Baseline
TC1	Boreal forest/Tomography	160	10	SM/DP/Swath2	<= 6km	<= 1200m (RC1), <=6km (RC2-9), <= 1200m (RC10)
TC2	Boreal forest/Tomography	160	10	SM/DP/Swath2	<= 6km	<= 1200 at 55N (RC1), <=6 km (RC2-9), <= 1200m (RC10)
TC3	Tropical Forest Structure/Height	320	20	SM/DP/Swath2	<= 6km	<= 600m at 0N (RC1) <= 12km (RC2-RC19) <= 600m (RC20)
TC4	Ice subsurface structure	160	10	SM/FP	<= 6km	<= 1km at 70N (RC1) <= 6km (RC2-9) <=1km (RC10)
TC5	Desert subsurface structure/super resolution	80	5	SM/FP	<= 6km	<=800m at 10N (RC1) <= 2km (RC2-4) <=800m (RC5)
BS2	Dense PS interferometry	480	30	SM/DP/Swath2	50km	0km
BS3	Ocean currents	80	5	SM/DP/Swath2	9km	<= 300m
BS4	Bistatic Interferometry	160	10	SM/FP	50-250km	0km
BS5	Bistatic Interferometry	80	5	TBC	250km	260km
SP	Specular	80	5	TBC	Close to 0km	520km at SAOCOM height (specular)

Science Days: 1760
Science Years: 4.82

Courtesy of M.W.J. Davidson, B. Carnicero Domínguez, ESA

Imaging Modes & L1b performance

- small antenna height limits access to near range swaths
 - ✓ 2 swaths in quad-pol mode
 - ✓ 2 nominal (+2 experimental) swaths in dual-pol mode
- stripmap mode selected due to best geometric resolution (single look)
Resolution (az x rg): 6 x 10 m² (quad-pol) and 5 x 10 m² (dual-pol)

Swath	Q1	Q2	D1	D2	D3	D4
PRF (Hz)	3479	3434	1839	1796	2150	1856
Start (°)	17.6	19.5	20.7	24.9	29.1	33.7
End (°)	19.6	21.5	25.1	29.2	33.9	38.4
Chirp (MHz)	44.7	40.5	38.3	32.2	27.9	24.4
B _{dop} (Hz)	> 1050		> 1250			

625 km
altitude

- full range of altitudes considered
- radiated peak power 3.1 kW, RF losses 4.2 dB
- calculations limited to tomographic phase (small AT baselines)

Conclusions

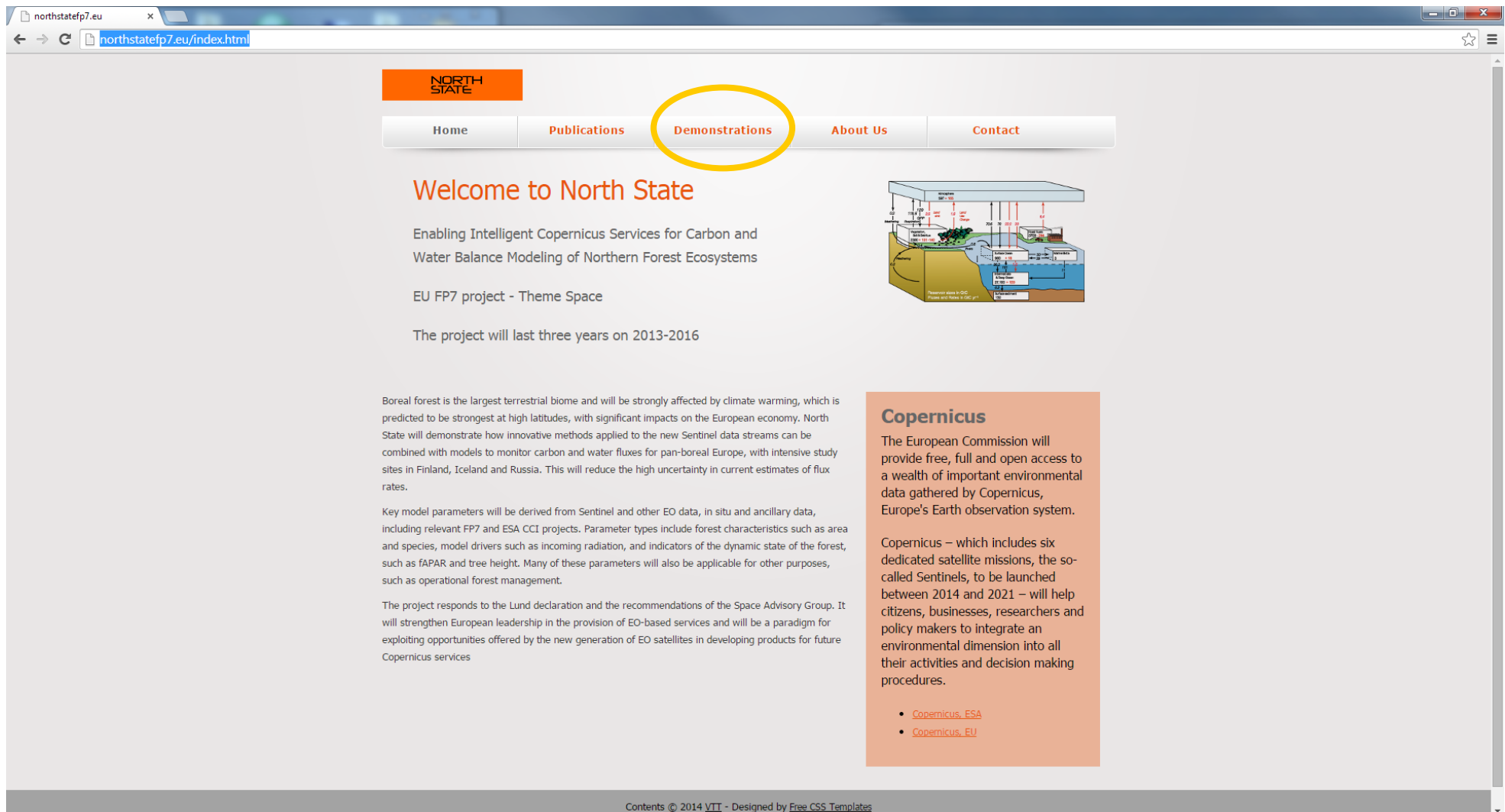
- SAOCOM-CS represents a new mission concept with attractive elements
 - ✓ high degree of R&D with respect to novel radar measurements (tomography, bistatic, specular) and processing techniques
 - ✓ short development schedule (ready for launch by 2018)
 - ✓ Demonstrator for more operational-oriented - but still cost-effective - SAR convoy missions e.g. with Cosmo or Sentinel-1
 - ✓ collaboration between Agencies and with the science community
- Studies have demonstrated principle mission feasibility and science return
- Investigations are on-going, follow-on activities initiated:
 - ✓ Phase A/B1 system (platform, accommodation of payload and in launcher) studies (kicked-off July 2014)
 - ✓ Parallel activities on payload, science, processing, and operations on-going or planned to start
 - ✓ Confirmation of mission by ESA member states expected early 2015

ADD-on:

SENTINEL-1 MOSAIC FROM FINLAND

Sentinel-1 mosaic from Finland

<http://northstatefp7.eu/index.html>



The screenshot shows a web browser window with the URL northstatefp7.eu/index.html. The website has a navigation bar with links: Home, Publications, Demonstrations (highlighted with a yellow circle), About Us, and Contact. The main content area features a 'Welcome to North State' section with the text: 'Enabling Intelligent Copernicus Services for Carbon and Water Balance Modeling of Northern Forest Ecosystems', 'EU FP7 project - Theme Space', and 'The project will last three years on 2013-2016'. To the right of this text is a diagram of a forest ecosystem showing various layers and data inputs. Below the welcome section, there is a paragraph about boreal forest and its impact on climate warming, followed by a paragraph about key model parameters derived from Sentinel and other EO data. At the bottom, a paragraph describes the project's response to the Lund declaration and its goal to strengthen European leadership in EO-based services. On the right side of the page, there is a 'Copernicus' section with a description of the European Commission's role in providing free, full and open access to environmental data, and a list of links to 'Copernicus, ESA' and 'Copernicus, EU'.

NORTH STATE

Home Publications **Demonstrations** About Us Contact

Welcome to North State

Enabling Intelligent Copernicus Services for Carbon and Water Balance Modeling of Northern Forest Ecosystems

EU FP7 project - Theme Space

The project will last three years on 2013-2016

Boreal forest is the largest terrestrial biome and will be strongly affected by climate warming, which is predicted to be strongest at high latitudes, with significant impacts on the European economy. North State will demonstrate how innovative methods applied to the new Sentinel data streams can be combined with models to monitor carbon and water fluxes for pan-boreal Europe, with intensive study sites in Finland, Iceland and Russia. This will reduce the high uncertainty in current estimates of flux rates.

Key model parameters will be derived from Sentinel and other EO data, in situ and ancillary data, including relevant FP7 and ESA CCI projects. Parameter types include forest characteristics such as area and species, model drivers such as incoming radiation, and indicators of the dynamic state of the forest, such as fAPAR and tree height. Many of these parameters will also be applicable for other purposes, such as operational forest management.

The project responds to the Lund declaration and the recommendations of the Space Advisory Group. It will strengthen European leadership in the provision of EO-based services and will be a paradigm for exploiting opportunities offered by the new generation of EO satellites in developing products for future Copernicus services

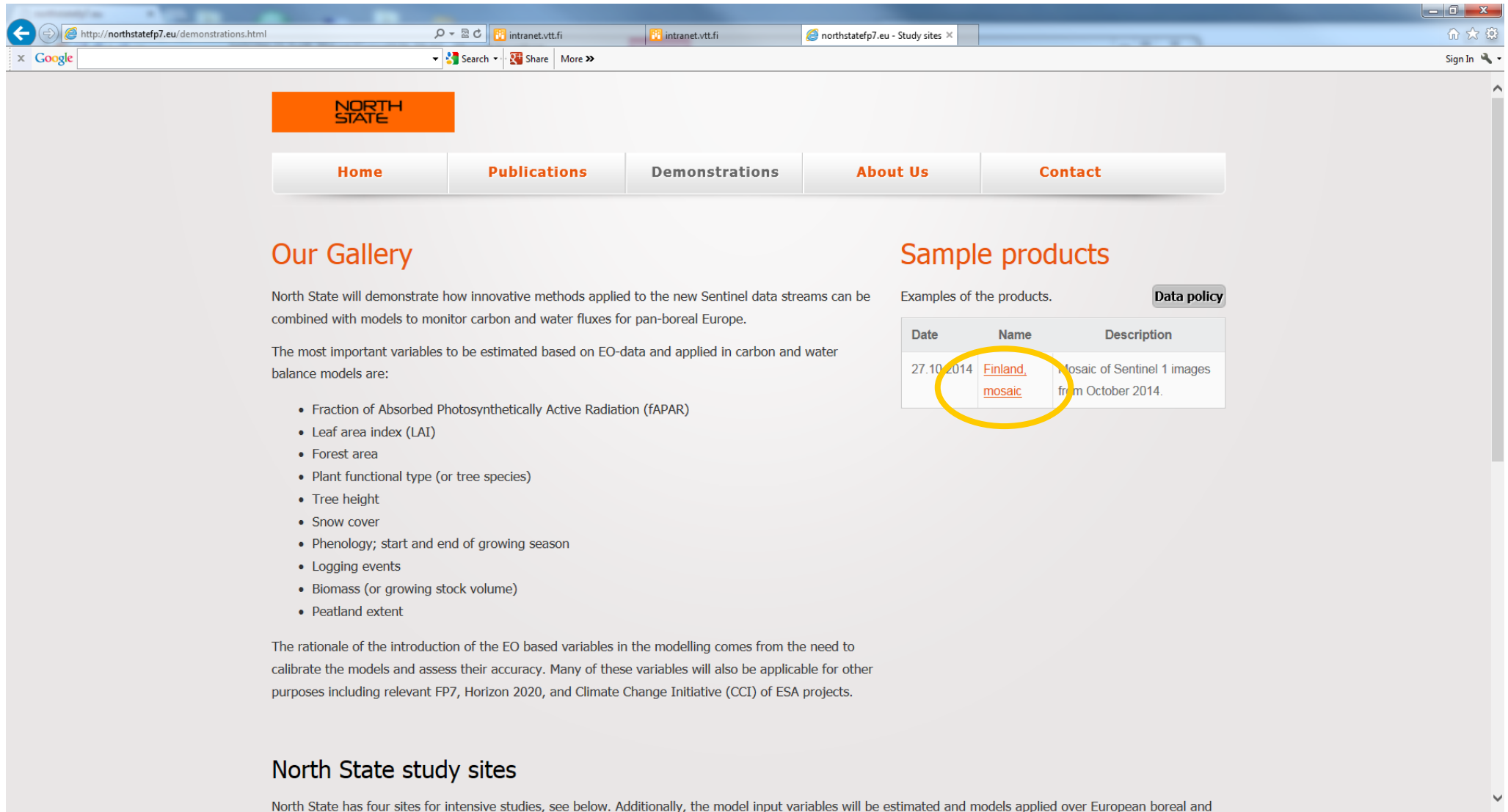
Copernicus

The European Commission will provide free, full and open access to a wealth of important environmental data gathered by Copernicus, Europe's Earth observation system.

Copernicus – which includes six dedicated satellite missions, the so-called Sentinels, to be launched between 2014 and 2021 – will help citizens, businesses, researchers and policy makers to integrate an environmental dimension into all their activities and decision making procedures.

- [Copernicus, ESA](#)
- [Copernicus, EU](#)

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The screenshot shows a web browser window with the URL <http://northstatefp7.eu/demonstrations.html>. The page features a navigation bar with links: Home, Publications, Demonstrations, About Us, and Contact. The main content area is divided into two columns. The left column, titled 'Our Gallery', contains a paragraph about innovative methods for monitoring carbon and water fluxes, a list of variables to be estimated, and a paragraph about the rationale for EO-based variables. The right column, titled 'Sample products', includes a 'Data policy' link and a table of product examples. A yellow circle highlights the 'Finland_mosaic' entry in the table.

Our Gallery

North State will demonstrate how innovative methods applied to the new Sentinel data streams can be combined with models to monitor carbon and water fluxes for pan-boreal Europe.

The most important variables to be estimated based on EO-data and applied in carbon and water balance models are:

- Fraction of Absorbed Photosynthetically Active Radiation (fAPAR)
- Leaf area index (LAI)
- Forest area
- Plant functional type (or tree species)
- Tree height
- Snow cover
- Phenology; start and end of growing season
- Logging events
- Biomass (or growing stock volume)
- Peatland extent

The rationale of the introduction of the EO based variables in the modelling comes from the need to calibrate the models and assess their accuracy. Many of these variables will also be applicable for other purposes including relevant FP7, Horizon 2020, and Climate Change Initiative (CCI) of ESA projects.

Sample products

Examples of the products. [Data policy](#)

Date	Name	Description
27.10.2014	Finland_mosaic	Mosaic of Sentinel 1 images from October 2014.

North State study sites

North State has four sites for intensive studies, see below. Additionally, the model input variables will be estimated and models applied over European boreal and