Synthetic Aperture Radar (SAR) for Agriculture

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With inputs from the CSIR DPSS SAR team

August 2018

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Contents

Goal Of Presentation

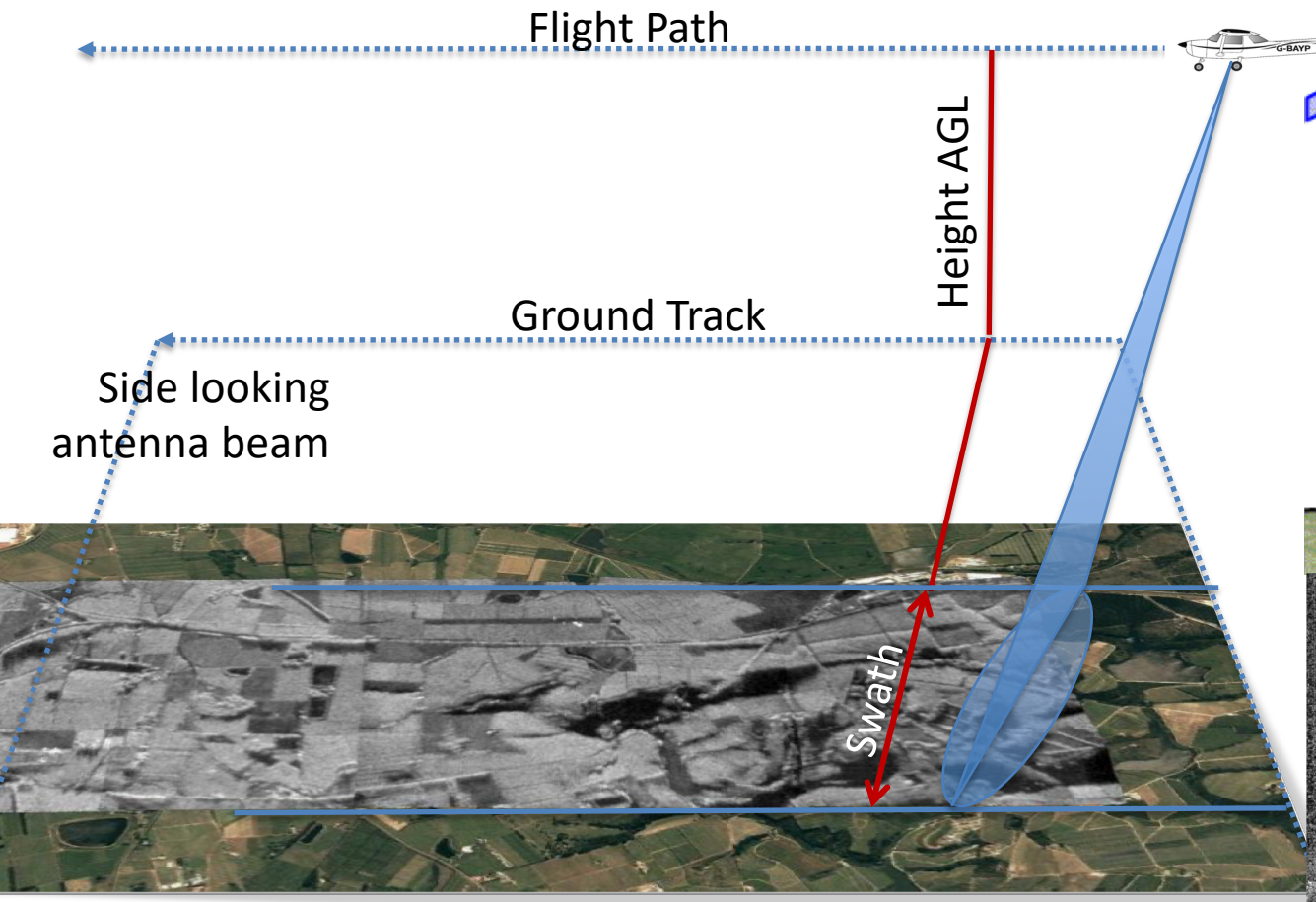
- Introduce the CSIR TCBI Airborne Synthetic Aperture Radar (SAR) Facility
- Role in investigating and promoting the use of SAR in South Africa
- Seeking partnerships to explore this

- What is Synthetic Aperture Radar (SAR) ?
- Applications of SAR in SA context
- Role of SAR in agriculture applications
- The CSIR airborne SAR facility and its capabilities
- Road forward

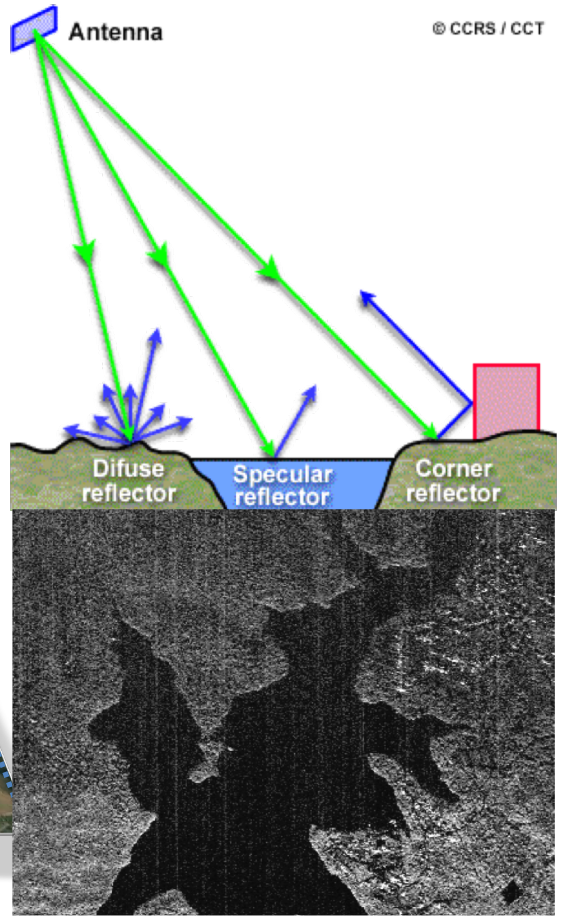
CSIR Mandate

" … through directed and multi-disciplinary research and technological innovation, …
… foster scientific and industrial research … with private and public sector …"

What is SAR? – An Earth Observation Sensor



Farming Area close to Bredasdorp
L-Band Clutter measurement facility SAR 2012

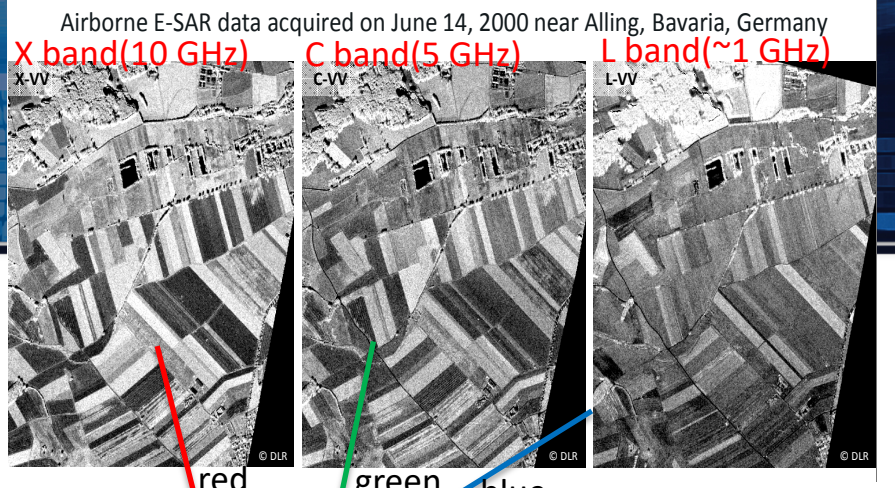


Roodeplaat Area –
TCCBI C Band SAR
2017

Image formed through clouds, day & night

Some important SAR characteristics

- **Wide area coverage**
- **Resolution is independent of range**
- Imagery is **independent of sun illumination!** (SAR Sensor provides own illumination)
- Imagery can be **produced at different wavelengths/frequencies** – increased information for agricultural data!
- All weather, day and night operation
- Ability to **sense with polarization** can add even further information to the scene
- Coherent sensor can measure very fine changes in the scene (wavelength type differences)



Combined Multi-Frequency Image

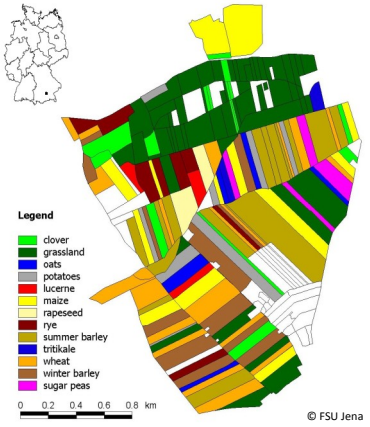
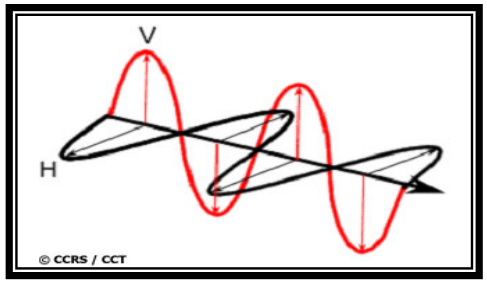
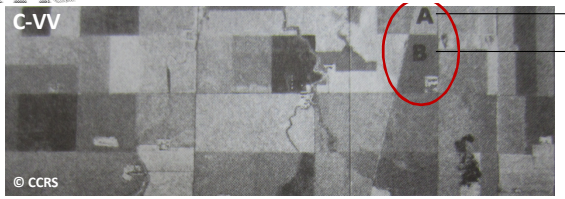


Fig.: X-VV / C-VV / L-VV composite (left) and crop type map (right)





barley

wheat

- VV-polarisation: stronger interaction with vegetation structure

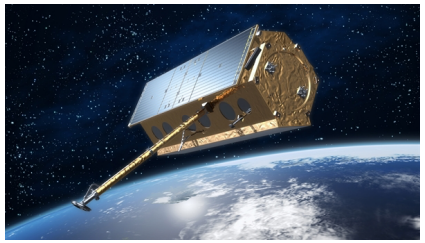
- HH-polarisation: stronger soil contribution – similar roughness and moisture

Fig.: C-VV and C-HH SAR images acquired on July 13, 1989 over an agricultural area near Melfort, Saskatchewan (Brisco & Brown, 1998)

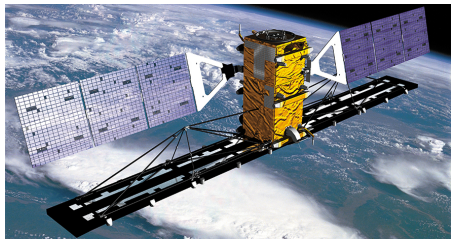
Imagery created by: DLR (Germany)
Source: Biosphere SAR Tutorial 2014 (ESA)

Typical SAR Systems

Satellite SAR Systems



European TerraSAR-X from DLR and EADS Astrium



Canadian RadarSat-2 from MDA

Airborne SAR Systems

DLR E-SAR installed on Dornier DO228-212 aircraft

CSIR TCBI SAR installed on Atlas Angel aircraft

Characteristics of Satellite System

- Wider swath widths
- Resolutions down to 1 m
- Revisit every 12-24 days
- Single Frequency
- Often Single Polarisation

Characteristics of Airborne System

- Resolutions down to better than 1 m
- Better Signal to Noise
- Revisit as often as required
- Multiple frequency
- Multiple polarisations
- Configurable

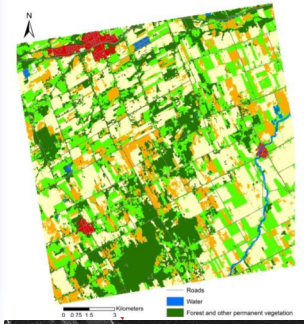
Use of and Number of SAR Systems is Exploding

Relevant Applications of SAR in South Africa

Food Security and Agriculture Monitoring

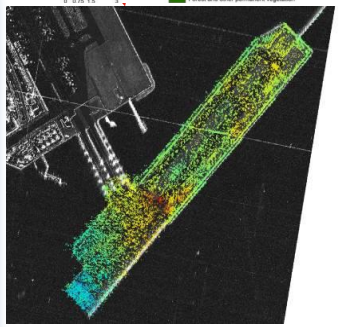
- Annual Crop Monitoring
- Crop yield and production status
- Soil moisture
- Precision Agriculture (Drones)
- Crop health

Early season crop identification



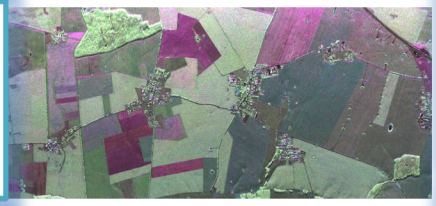
Infrastructure monitoring and Urban Monitoring

- Bridges, Dams, Roads
- City Planning
- Monitoring of government investment in infrastructure development



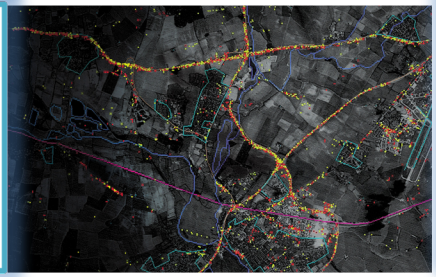
Cartography

- Automated mapping
- Terrain elevation measurement
- Land Use / Land Cover



Security

- Surveillance
- Border Security
- Targeting
- Damage Assessment
- Terrain Negotiability



Disaster Management

- Predict and prevent disasters
- Situational awareness during the disaster time, including:
  - Flood monitoring (even through the storm)
  - Fire detection and monitoring
  - Earthquake prediction and subsidence monitoring

Maritime Safety + Security

- Detecting Oil Slicks
- Ship detection and classification
- Ship traffic monitoring
- Monitoring Protected Zones
- Search and Rescue

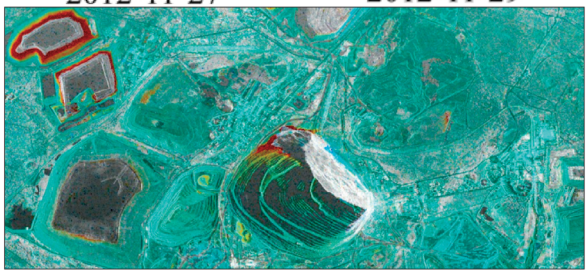
Mining

- Safety (subsidence)
- Operations
- Stockpile monitoring
- Geological Survey

Oceanography

- Due to our location at the southern tip of Africa, South Africa plays an important role in monitoring of the oceans, and at present SAR is being used to monitor several aspects of ocean currents and ocean health.

2012-11-27 2012-11-29



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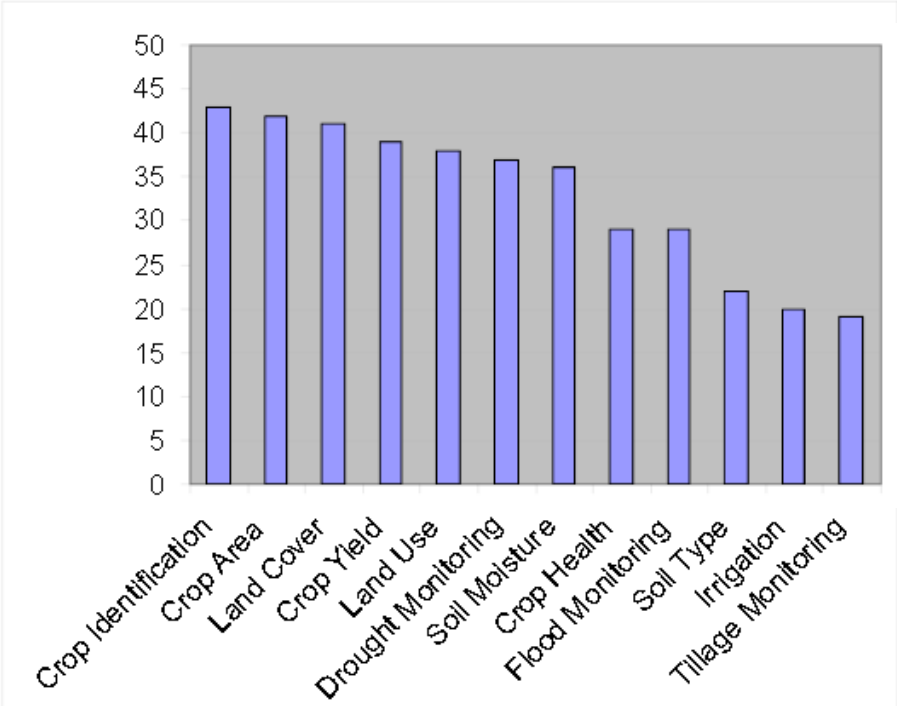
Applications of SAR in Agriculture

Most frequent applications of EO-data in agriculture

(Findings of the pre-workshop survey of the International GEO Workshop on S Aperture Radar (SAR) to support agricultural monitoring, Canada, 2009)



Top Twelve EO Applications of Agricultural EO Data (Government of Canada, 2010)

Prominent Players in ***SAR for Agriculture***

Europe

DLR Earth Observation Center

esa

Canada

Agriculture and Agri-Food Canada

MDA

Japan

JAXA

*SAR FOR AGRICULTURE- Research and Development at AAFC by Science and Technology Branch, Agriculture and Agri-Food Canada

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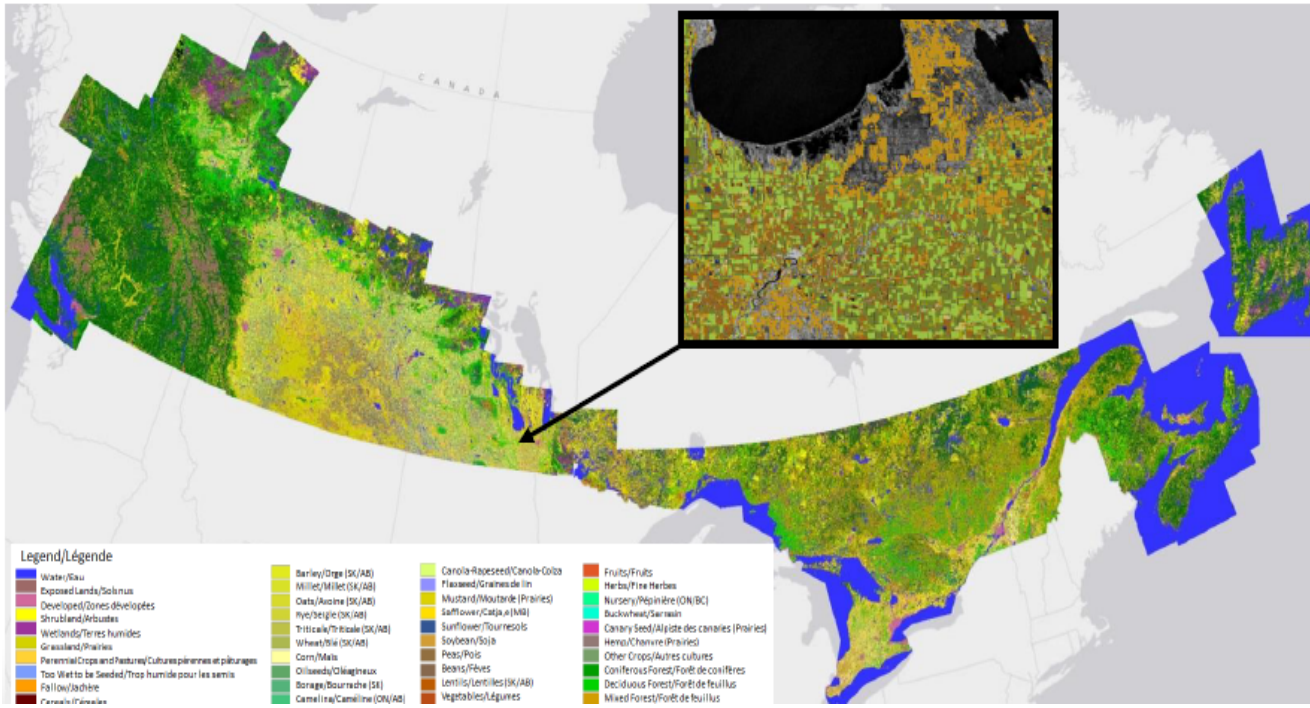
Example from Literature: Crop Inventory – Conclusions from Research out of Canada

Decades of R&D

Advantages of ***multi-frequency*** SAR include:

- It eliminates **operational challenge of removing cloud**
- Risks in the resulting products due to **cloud cover interference are mitigated**
- There's a possibility of the **automation of ortho-rectification** of SAR through using satellite ephemeris data
- **Automation of pre-classification** image processing of SAR is simple
- **Polarization diversity has proven to be crucial** - best results were observed through full and compact polarimetry.



Plant parameters

- Phenology
- Plant height
- Leaf Area Index (LAI)
- Plant Biomass
- Water content

Status

- Annual Crop Inventory (production)
- Crop Condition Assessment
  - Research
- Soil Moisture
  - Pilot

Source: SAR for Agriculture – R&D at AAFC, Heather McNairn

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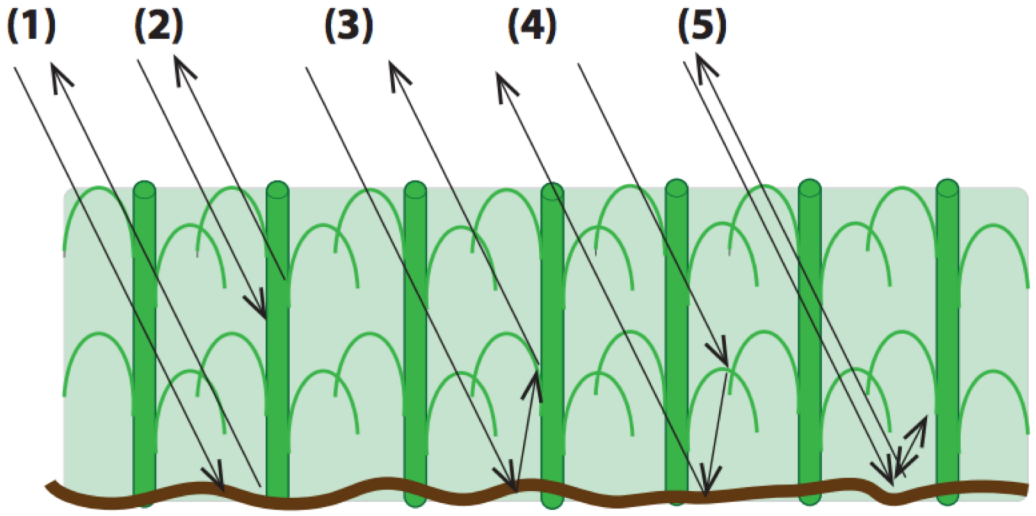
Backscatter in the context of agriculture

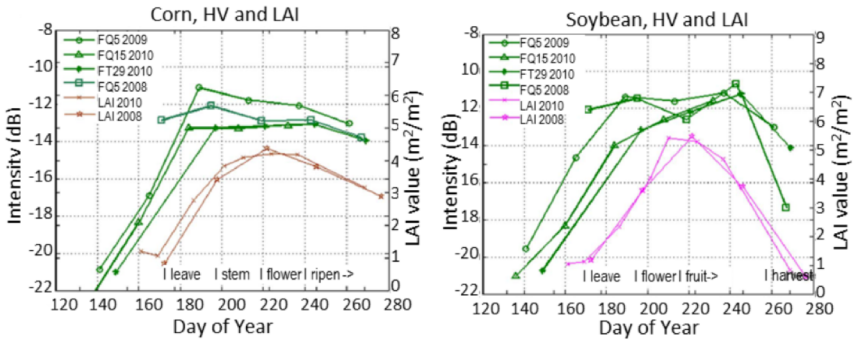


Source: Radar Remote Sensing of Agricultural Canopies: A Review
Susan C. Steele-Dunne, Heather McNairn, et al
IEEE Journal of Selected Topics in Applied EO and RS 2017

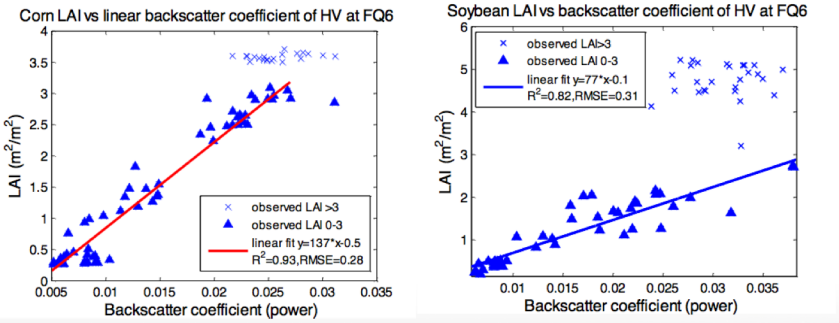
Fig. 2. Scattering mechanisms considered in the first-order models for both energy and wave based approaches: (1) direct ground (2) direct vegetation (3) ground-vegetation (4) vegetation-ground (5) ground-vegetation-ground

- Backscatter can be broken into 5 components
- Backscatter is dependent on various factors including: Frequency, Polarisation, Incidence Angle, Soil Moisture, Underlying terrain undulation angles, Crop structure (orientation, row distance)
- Longer wavelengths (lower frequency) tend to penetrate deeper and scatter more from soil
- Certain frequencies & polarization are sensitive to volume of plant

Example from Literature: RADARSAT-2 Example: Leaf Area Index for Corn and Soybean



RADARSAT-2 response to LAI of corn and soybeans over growing season



Correlation between RADARSAT-2 backscatter and LAI of corn and soybeans

- LAI is a strong indicator of crop productivity and is linked through crop process models to yield and biomass
- LAI from optical data have been assimilated into yield models and have improved model estimates
- Gaps in access to optical data, especially early in the season when growth accelerates, is problematic
- SAR parameters sensitive to volume scattering (HV intensity, entropy and F-D volume component) have all proven to be highly correlated with LAI
- Track LAI until reproductive phase begins, then use SAR to determine phenology changes
- HV is very sensitive to LAI, but are advantages in using FP or CP configurations

Liu, C., Shang, J., Vachon, P., and McNairn, H. 2013. Multi-year crop monitoring using polarimetric RADARSAT-2 in IEEE Transactions on Geoscience and Remote Sensing, 51(4): 2227-2240.

Jiao, X., McNairn, H., Shang, J., Pattey, E., Liu, J., and Champagne, C. 2011. The Sensitivity of RADARSAT-2 Polarimetric SAR Data to Corn and Soybean Leaf Area Index in Canadian Journal of Remote Sensing, 37:69-81.

Source: SAR for Agriculture – R&D at AAFC, Heather McNairn

Example from Literature: Scattering behavior example

Scattering behaviour of selected crop types

Corn

- Grain with the highest production worldwide in 2012 (FAO, 2013)
- Important staple food and feed crop
- Cultivated throughout the world (40% in United States)

Fig.: Example of a corn canopy, test site Nordhausen, Thuringia, Germany (© FSU)

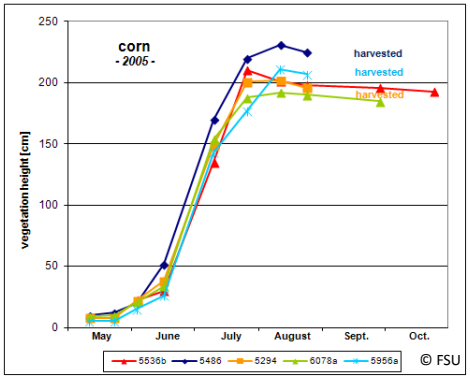


Fig.: Seasonal development of vegetation height for single corn fields, test site Nordhausen, Thuringia, Germany (© FSU)

Growth rate: up to 15 cm/day

Corn – C-band

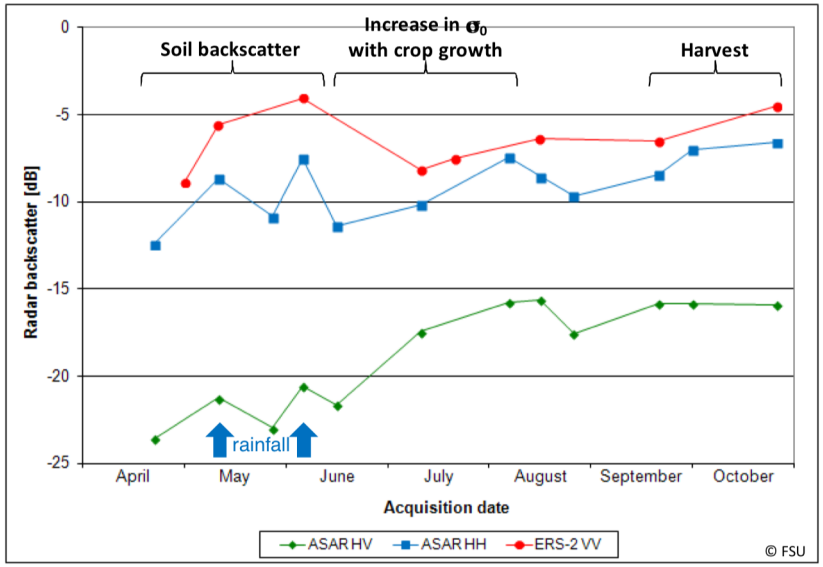


Fig.: C-band temporal signatures of corn in 2005 (regional mean values), test site Nordhausen, Thuringia, Germany (© FSU)

- HV vs. HH: higher range of variation with increasing vegetation height (see figure previous slide) / biomass
- VV: missing data for mid of June

Example from Literature
Scattering behavior example - wheat

- Grain with the third-highest production worldwide in 2012 (FAO, 2013b)

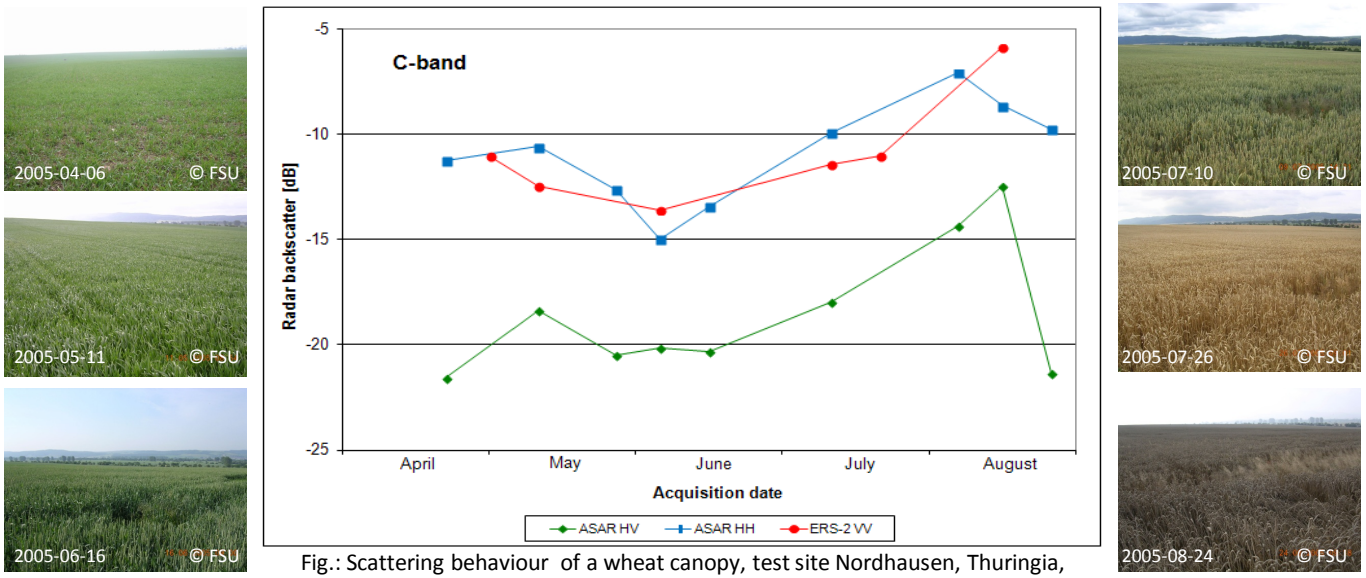


Fig.: Scattering behaviour of a wheat canopy, test site Nordhausen, Thuringia, Germany (© FSU)

C-band, HH & VV polarisation:

- Crop growth → decrease in σ_0 → attenuated soil backscatter
- Ripening → decrease in canopy moisture → canopy becomes more transparent → increase in σ_0

C-Band, HV polarisation: strong impact of ear bending on σ_0 (Ferrazzoli, 2001)

Conclusions up to this point

SAR can be a useful sensor for large-scale and regional scale monitoring of agriculture

- Can measure (either directly or inferred) useful crop parameters such as crop height and crop condition
- Can provide these measurements over large swath areas with high resolution

Unique benefits, particularly due to ability to sense even during cloud cover

To be useful it would seem the sensor should be multi-frequency (at least C and L band) and also multi-polarization

Airborne sensors has benefits of allowing regional measurement at lower-cost and higher update rates than spaceborne sensors

- Can measure all frequencies simultaneously
- Can measure with high update rates since sensor is not bound by satellite orbital geometries

Spaceborne sensors might be better suited to national scale monitoring

TCCBI SAR Facility

A highly configurable SAR sensor for:

- Airborne SAR campaigns,
- Mission requirement analysis
- Flight testing of SAR sensor subsystems

Dual frequency (L and C-band)

Modes

- Full polarisation on both bands
- 4 Simultaneous receive channels
- Single Pass Interferometry

Key Specs

- Swath width up to 12 km
- NESZ as low as -40dBsm/sm
- Resolutions down to .25m

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Developed over the last 2.5 years

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Airborne SAR Facility – Phase 1

Advanced Navigation Spatial Dual IMU

GPS antennas

IMU

Short range Wifi

Control Laptop
Dell XPS 13"

XMC

PCIe

Sensor hardware

ADCs

Data recorder

SATA III

Storage

Connectorised Receiver Exciter techology

Innovative integration X6 250M

SSD

4 Core i7 CPU
16 GB RAM

Standard gain Horn antenna technology

Acromag ARCX-4121
Conduction Cooled Solution

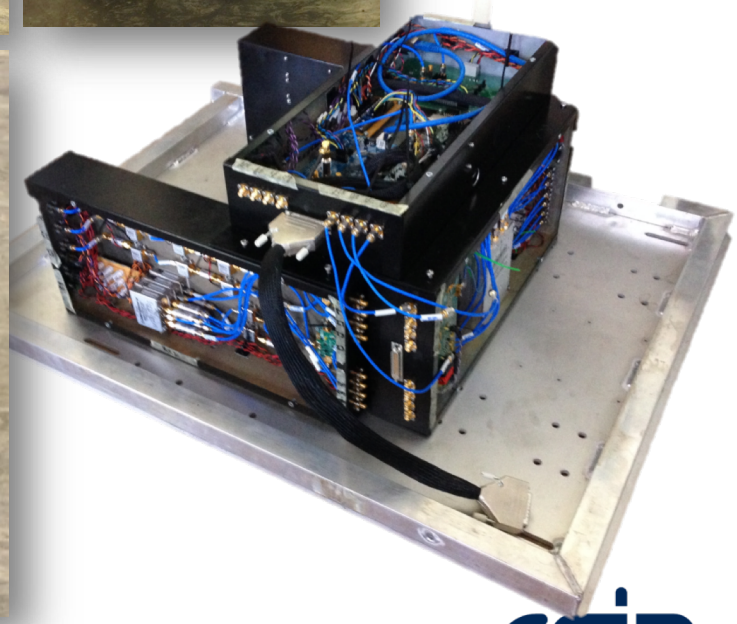
132mm

220mm

210mm

science

Phase 1
Transmit Receive System Hardware



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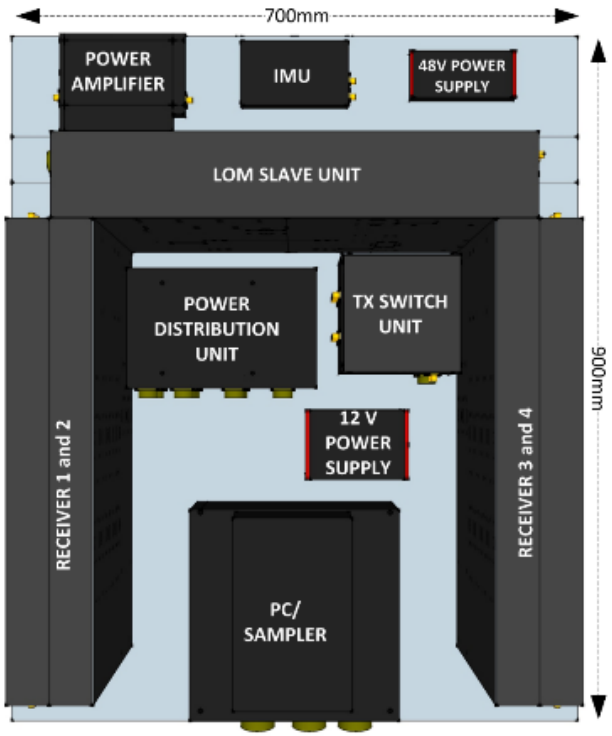
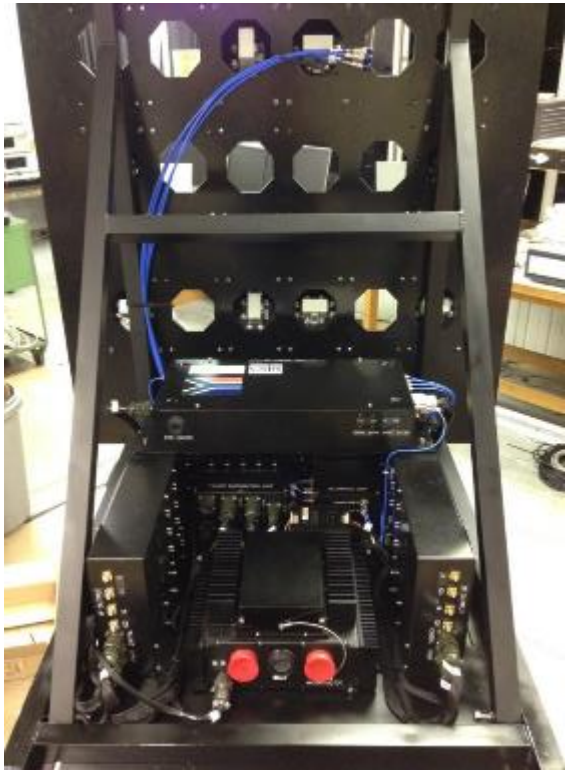
Sensor hardware





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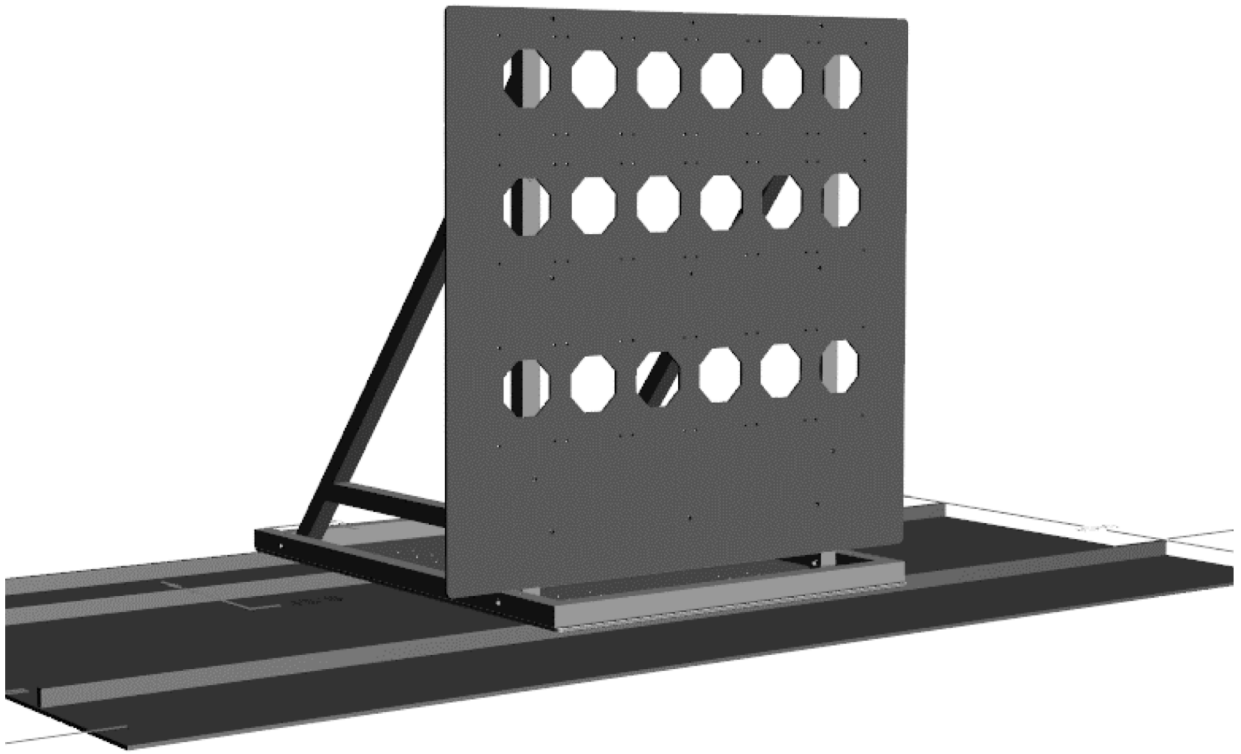
Sensor overview - flexibility

Reconfigurable antenna mount, enabling the following modes:



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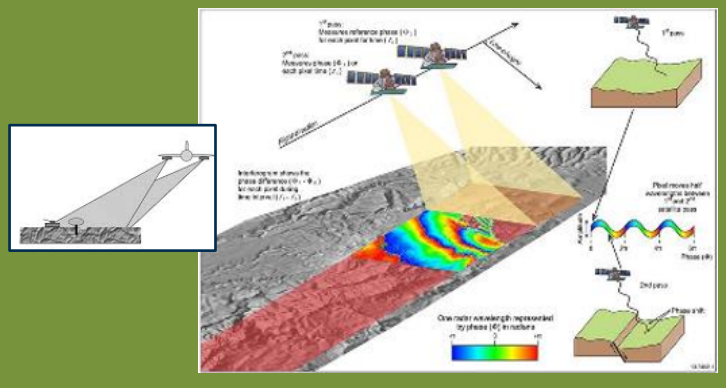
Sensor overview - flexibility

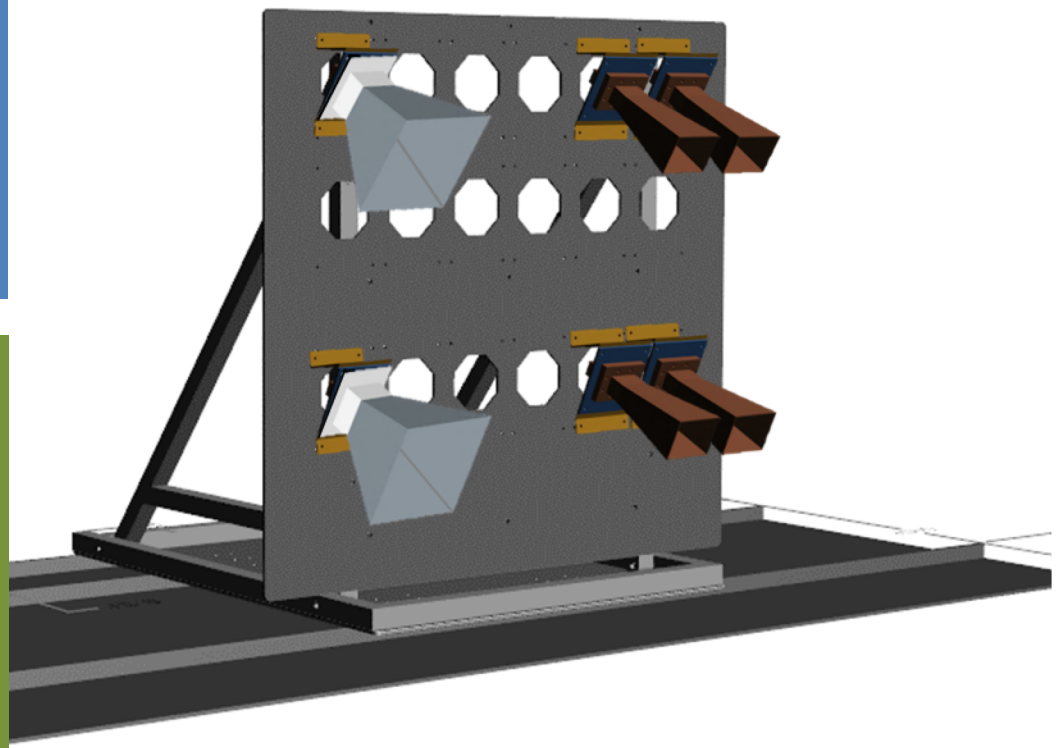
Reconfigurable antenna mount, enabling the following modes:

Full polarisation (L or C-band)

and

Interferometric SAR (L or C-band)



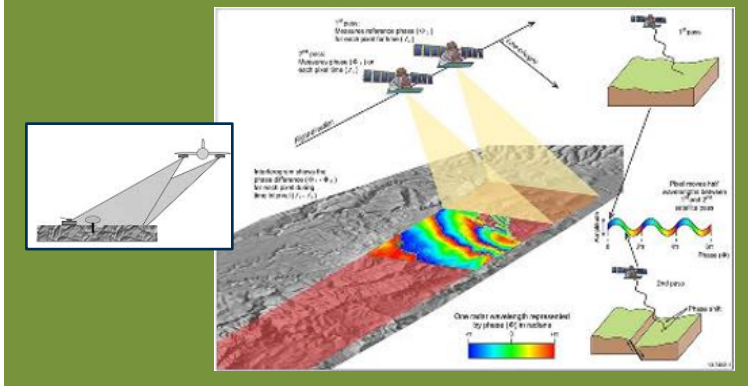


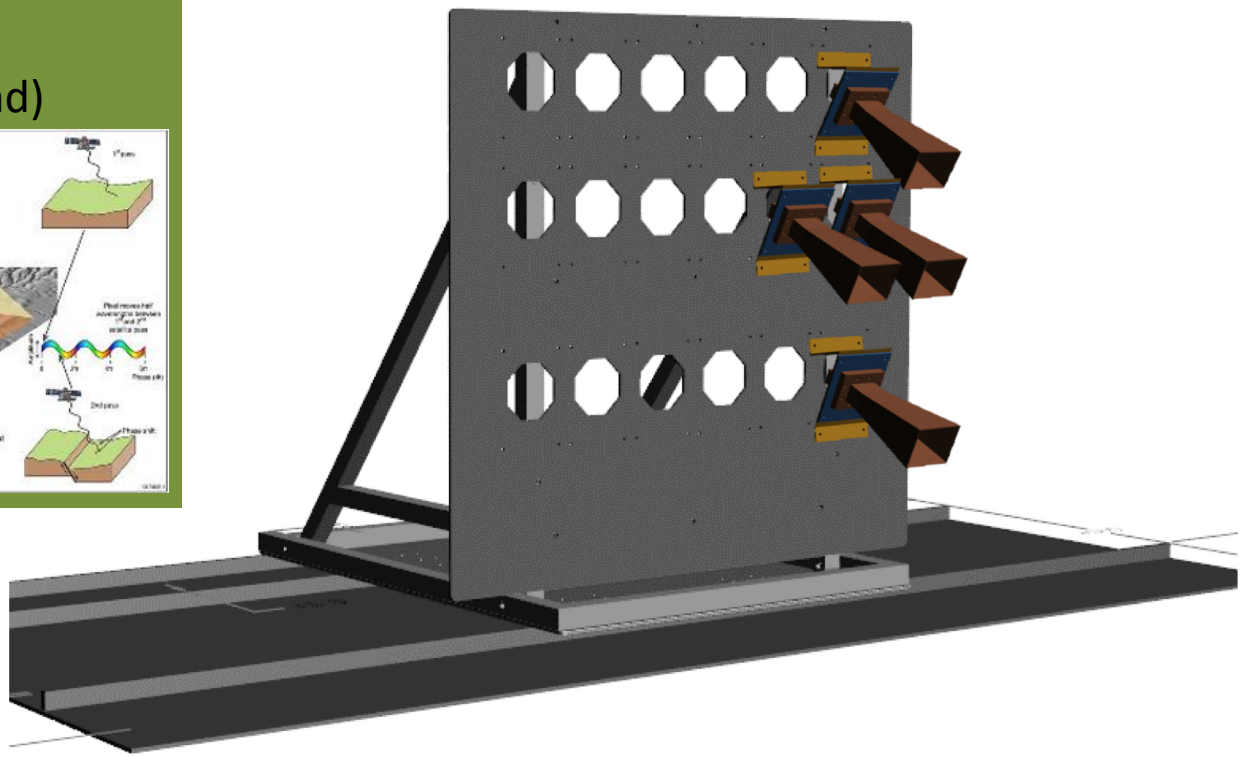
DST SAR TCCBI

Sensor overview - flexibility

Reconfigurable antenna mount, enabling the following modes:

Single polarisation,
multiple baseline
Interferometric SAR (C-band)





TCCBI SAR Facility

DST SAR TCCBI C-Band Results
First Flight Trial Hartebeespoort

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Example Image over Farmlands Hartbeespoort dam area

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Example Image over Farmlands Hartbeespoort dam area

Comparison between **TCCBI airborne and** *free* **Sentinel 1 C-band Spaceborne SAR imagery**

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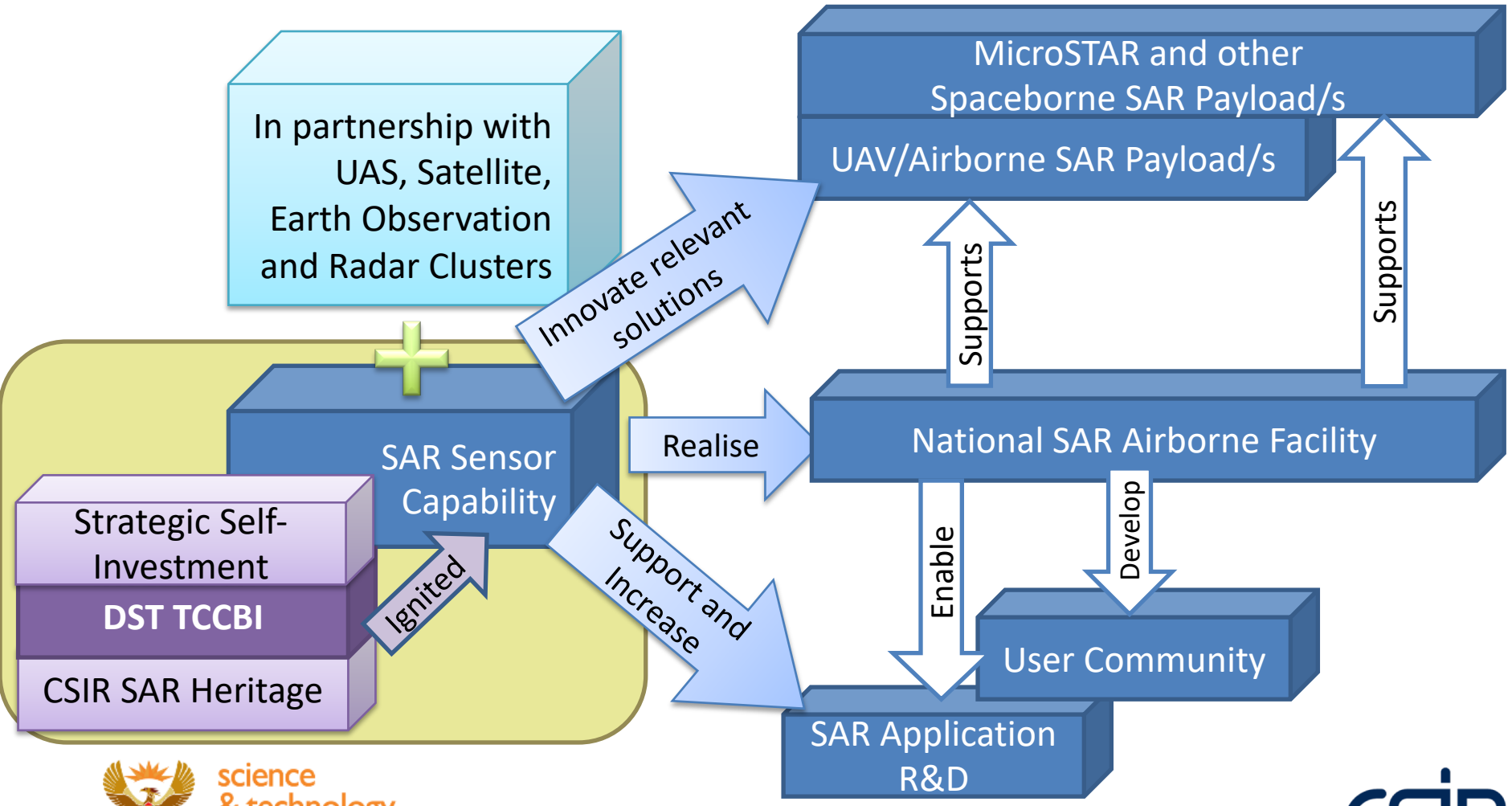
Is it cost effective / affordable?
Airborne vs Spaceborne Data (normalised)

SAR Sensor	Image resolution (m)	Band	Polarisation	Normalised Annual cost to provide imagery	Judgement of Value Proposition (for application)
TCCBI Airborne SAR	*<1*	*L+C*	*Full*	*1*	*1*
ALOS	3	L	Full	0.6	2
TerraSAR-X HS	1	X	Single[1]	8.2	6
TerraSAR-X SL	2	X	Single[2]	3.1	4
RadarSAT spotlight	1	C	Single[2]	0.7	3
RadarSAT ultrafine	3	C	Single[2]	0.4	5

Monthly Acquisitions of a Similar Coverage

L/C Band data most applicable to agricultural monitoring

SAR Sensor (and user community) Development Roadmap



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Road ahead

- Utilise the CSIR SAR National Facility to explore the benefit of SAR in the use of Agriculture
  - Experiment based investigation – ground truth
  - Operational experiments
  - Operationalise
- Continue to enhance facility capability
  - Multiple frequency
  - Multi polarisation
- Looking for partners to investigate, validate and productise SAR utilisation
  - Scientists who understand agriculture
  - Test sights and ground truth
  - Assess business case and prioritise applications
- Support accessing R&D funding
  - Real partnerships to unlock value
  - Engineer – scientist – farmer
- Funding required
  - Regular flight campaigns
  - Scientific analysis
  - Operational experiments

The SAR Facility Development Team

Summary of outputs achieved in the **2 year** program

- SAR capability re-established at CSIR
- SAR technology demonstrator developed and tested during flight trials
- SAR processor developed and validated on measured data
- HCD

– 7 CSIR DPSS Engineers upskilled on SAR sensor development and processing

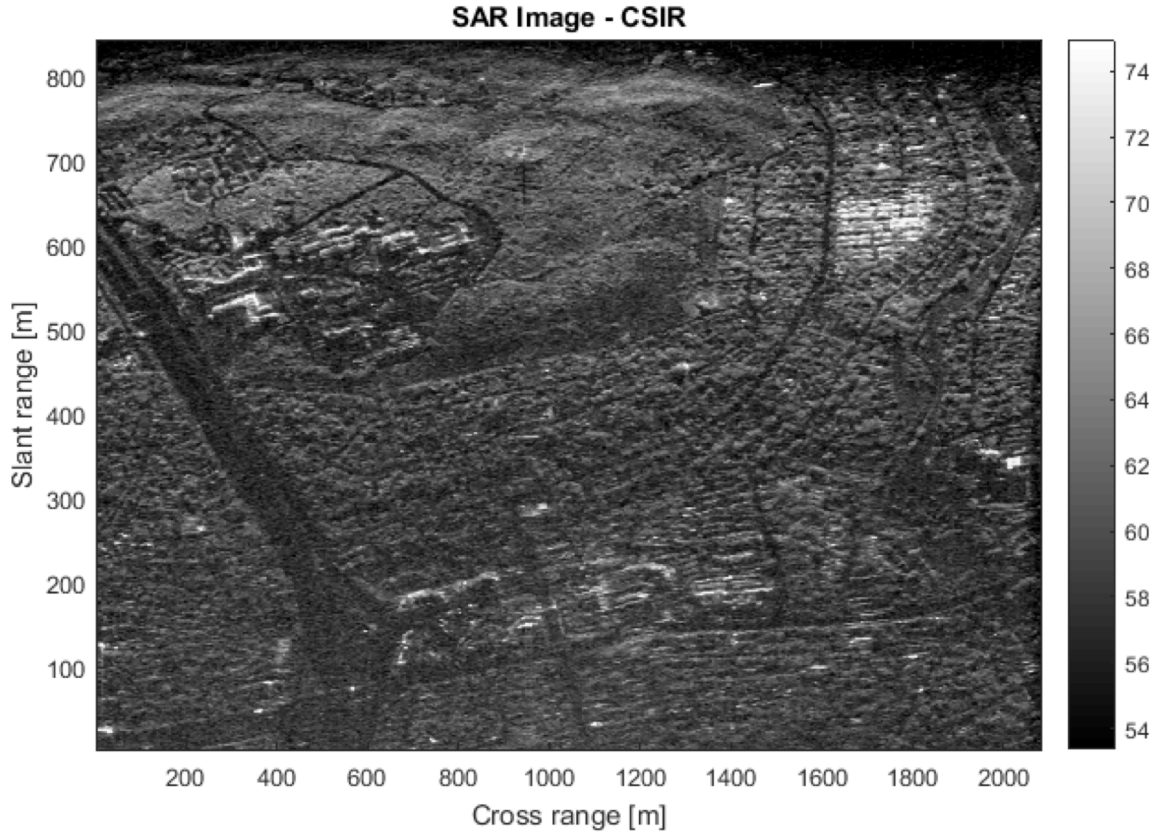
– 4 students with Masters topics on SAR

SAR Masters Students at DPSS

Upskilled SAR engineers

SAR Masters Students at DPSS

Thank you



SAR image over CSIR

TCCBI SAR 2017

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