# Polarimetric L-Band Imaging Scatterometer Data Processing

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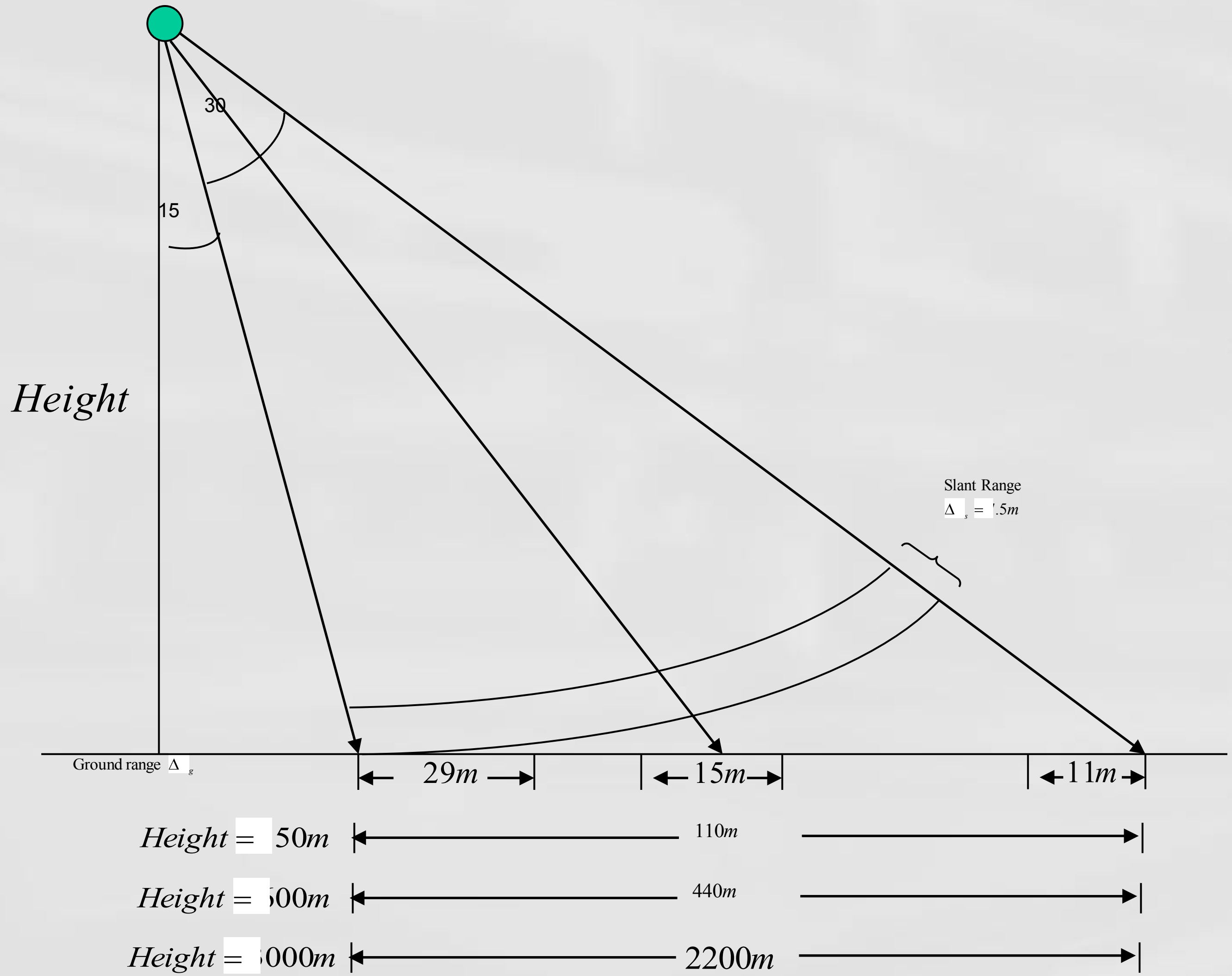
# Overview

- Radar Parameters
- Imaging Geometry
- Imaging Algorithm
- Gamma Remote Sensing
  - Modular SAR Processor (MSP)
  - Motion Compensation (MoCom)
- Calibration
  - Polarimetric Active Radar Calibrators (PARCs)
  - Triangular trihedrals

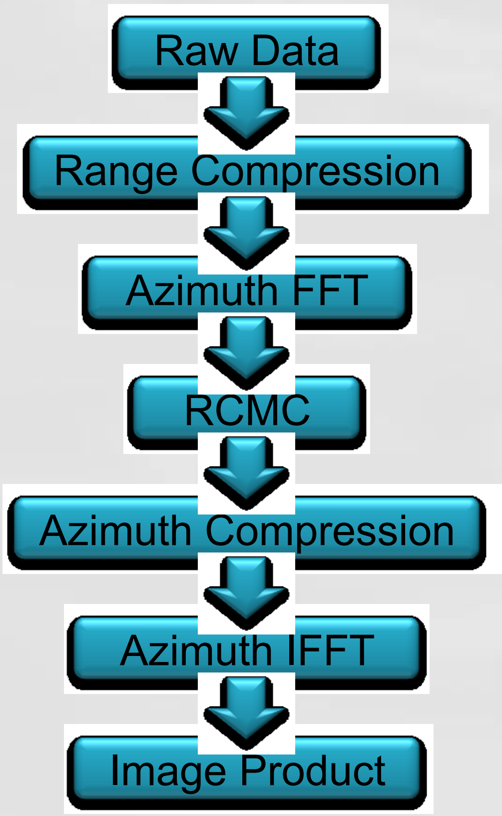
# Radar Parameters

| | |
|---|---|
| Frequency | 1.26GHz |
| Power | 25W |
| Maximum Duty Cycle | 4% |
| Bandwidth | 30MHz |
| Pulse Length | 100ns-10us |
| Pulse Repetition Frequency Maximum | 20kHz |
| Transmit Polarisation | Interleaved H/V |
| Receive Polarisation | Simultaneous H/V |
| Look Direction | Interleaved L/R |
| Antenna Type / Gain | 2x2 Patch Array / 9dBi |

# Imaging Geometry

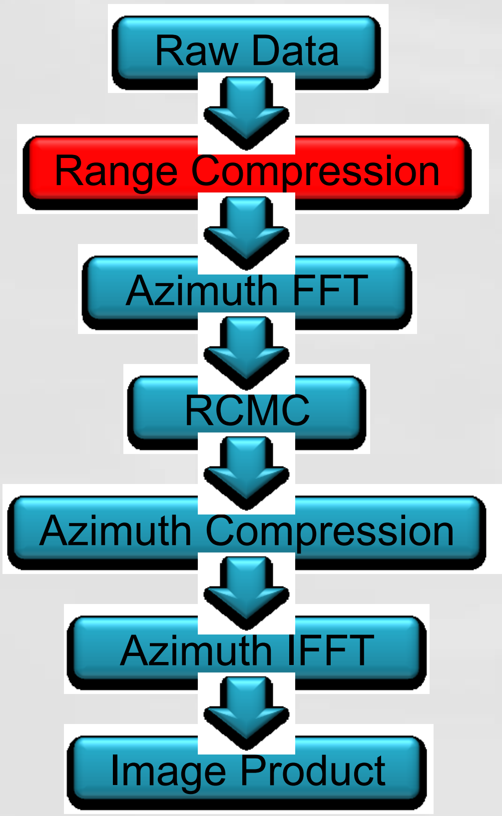


# Range-Doppler Imaging Algorithm




- Good Accuracy
- Efficiency gained by using the Fast Fourier Transform
- Assumes two independent dimensions (Range-Doppler)
- Processes Range Dimension with a matched filter using Fast Convolution
- Processes Azimuth Dimension with a matched filter in Doppler domain

# Range-Doppler Imaging Algorithm

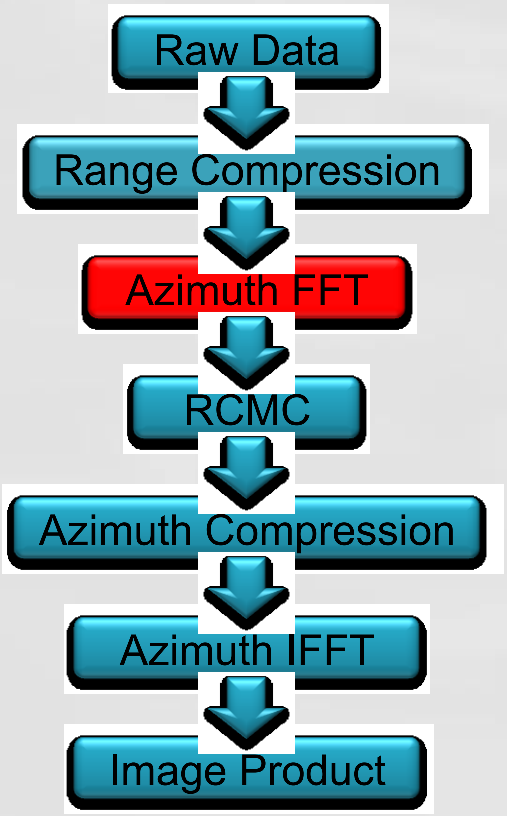



- Matched Filter using Fast Convolution in range dimension

$$s_{rc}(\tau,\eta) = IFFT\{FFT\{s_{raw}(\tau,\eta)\} \times G(f_\tau)\}$$

- G is a filter matched to the transmit waveform usually with a window function applied
- FFT/IFFT are forward and reverse fast Fourier transforms
- $\tau$ is range time
- $\eta$ is azimuth time

# Range-Doppler Imaging Algorithm

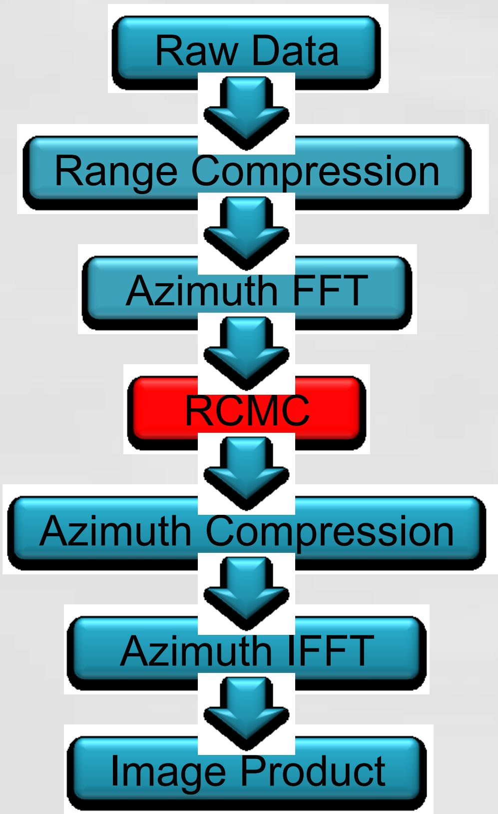



- Take Azimuth Fast Fourier Transform

$$S_{rd}(\tau, f_\eta) = FFT_\eta\{s_{rd}(\tau, \eta)\}$$

- Allows for block processing

# Range-Doppler Imaging Algorithm

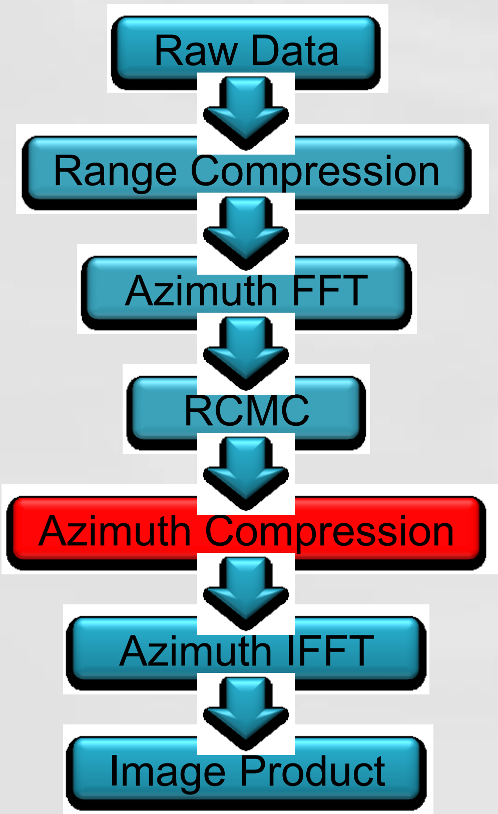



- Interpolate in range for each azimuth frequency

$$R_{rd}(f_\eta) = \frac{R_o}{D(f_\eta, V_r)} \qquad D(f_\eta, V_r) = \sqrt{1 - \frac{\lambda^2 f_\eta^2}{4V_r^2}}$$

- λ is radar wavelength
- $V_r$ is platform speed
- $R_o$ is imaging range
- Usually use truncated Sinc function interpolation
- Sinc length 8-16

# Range-Doppler Imaging Algorithm

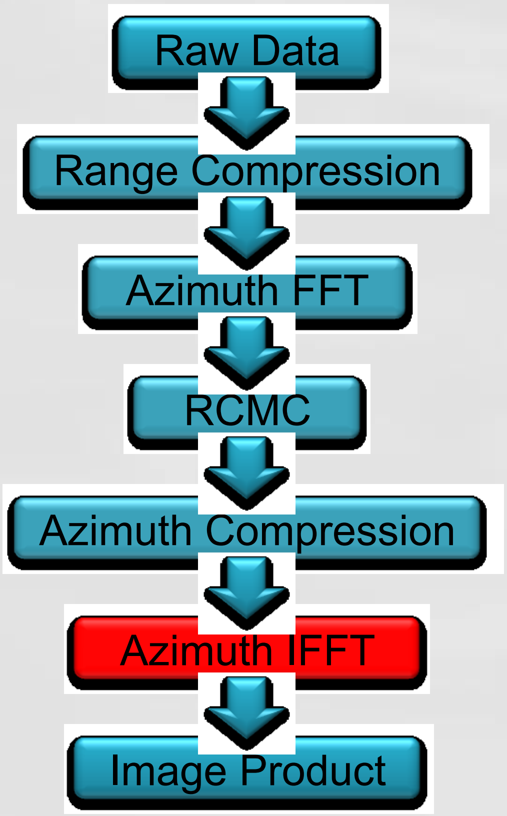



- Matched filter in the azimuth dimension for each range

$$H_{az}(f_\eta) = exp\left\{j\frac{4\pi R_o D(f_\eta, V_r) f_o}{c}\right\}$$

- $f_o$ is the radar frequency
- c is the speed of light
- Notice the filter changes for each range, R
- Dependence on platform dynamics

# Range-Doppler Imaging Algorithm




- Complete processing with an azimuth inverse fast Fourier transform

$$s_{slc}(\tau,\eta) = IFFT_{\eta}\{S_{rd}(\tau,f_{\eta})\}$$

- Repeat process along the range compressed data sequence

# Gamma Remote Sensing

- Modular SAR Processor (MSP)
  - Implements the Range-Doppler Algorithm
  - Each processing stage is executed on an intermediate binary file with an associated parameter file
  - All polarisation combinations and look directions are processed separately
- Image Products
  - Single Look Complex (SLC) – 32bit floating point
  - Multi Look Intensity (MLI) – 32bit floating point
  - Scaled raster – 8bit integer

# Gamma RS – SMAPex 1

Left Side VV

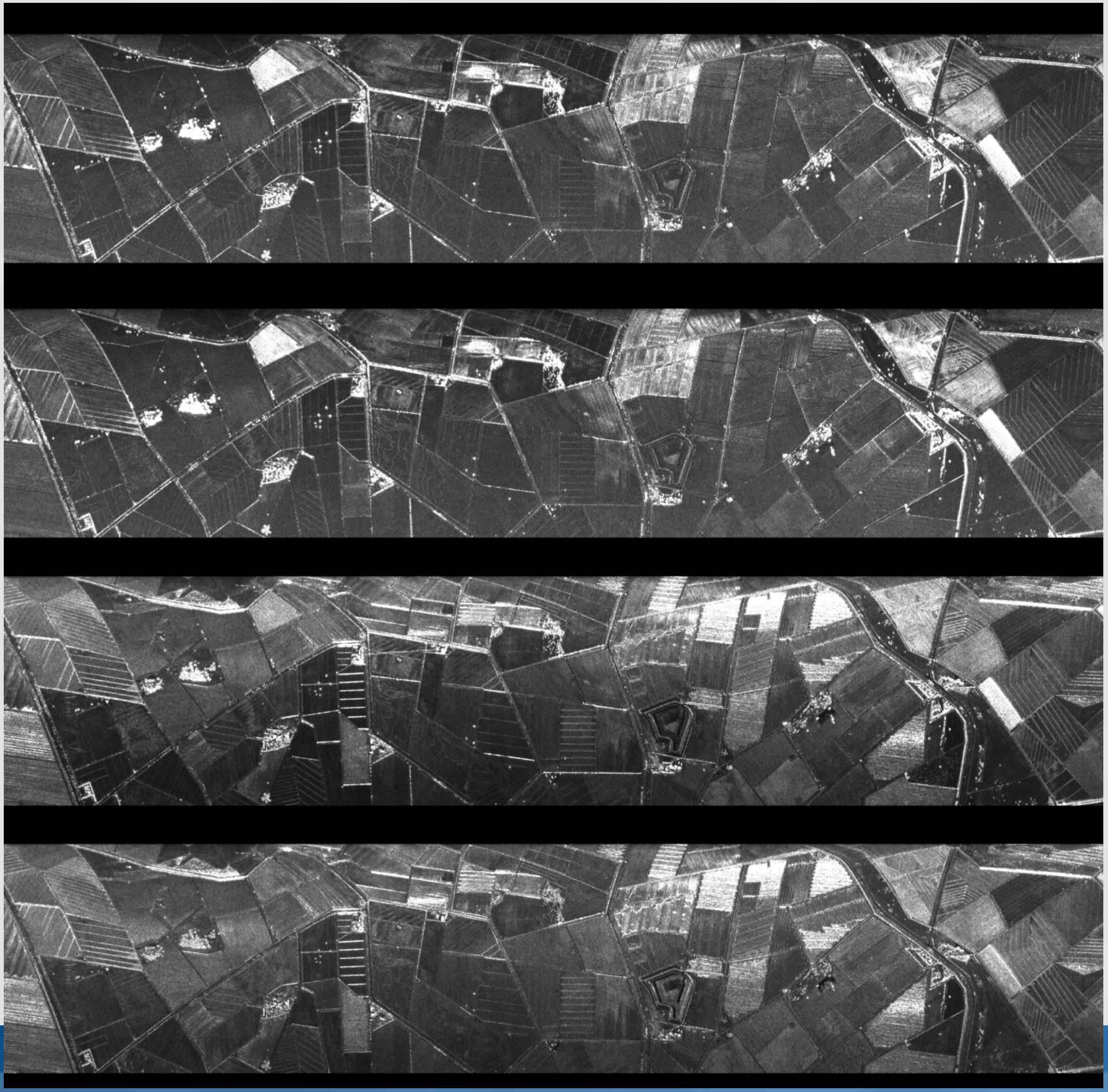
Left Side HH

$dR = 6.0m$

$dAz = 4.2m$

Left Side VH

Left Side HV



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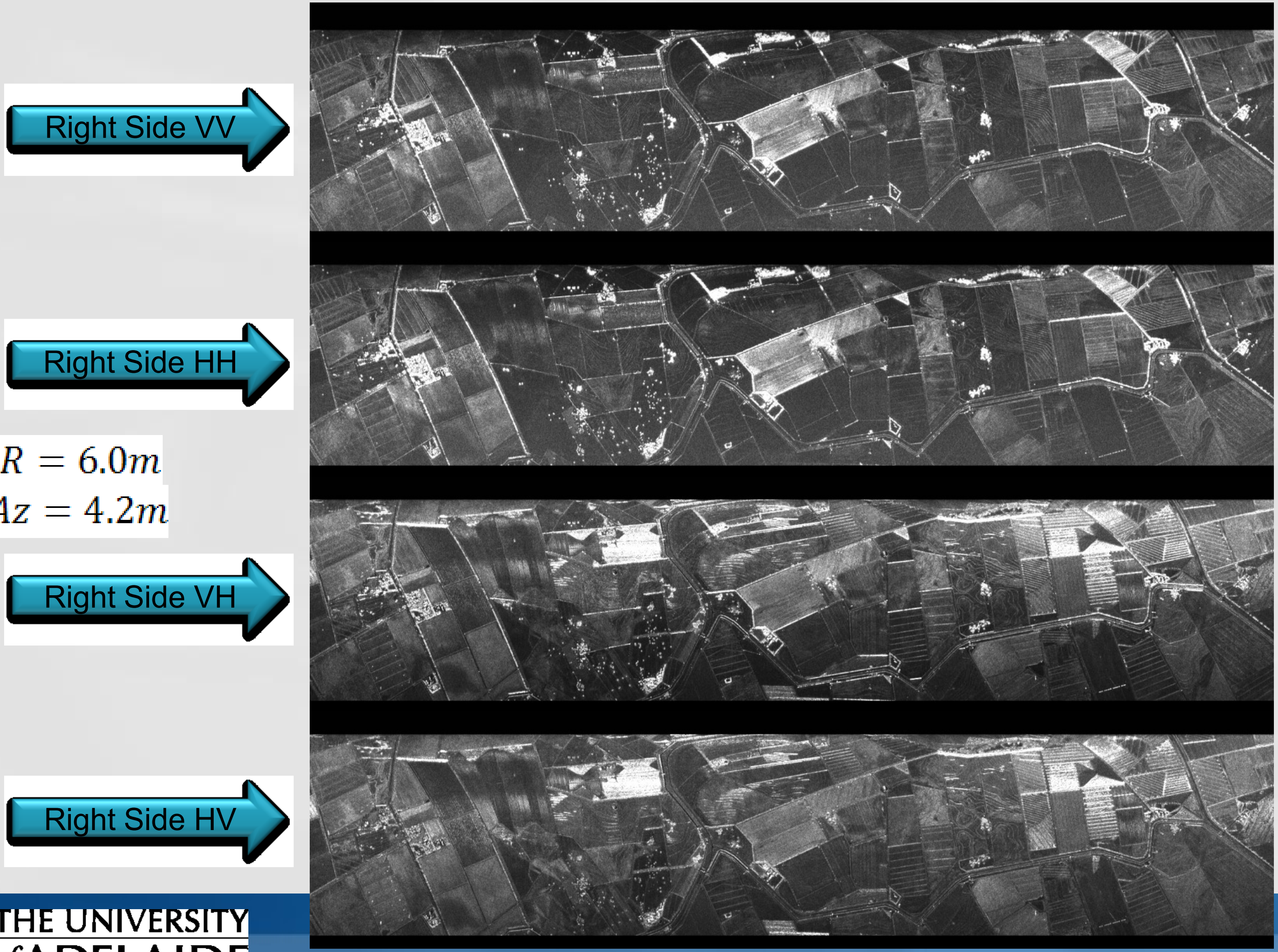
# Gamma RS – SMAPex 1



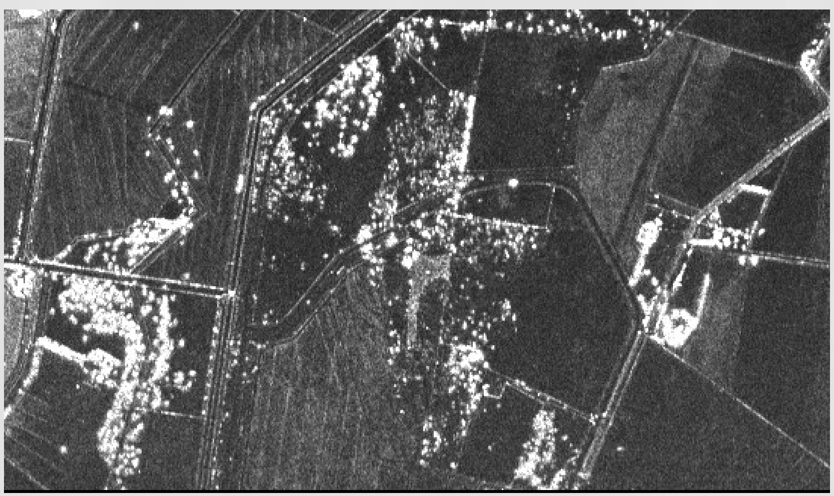

$dR = 6.0m$

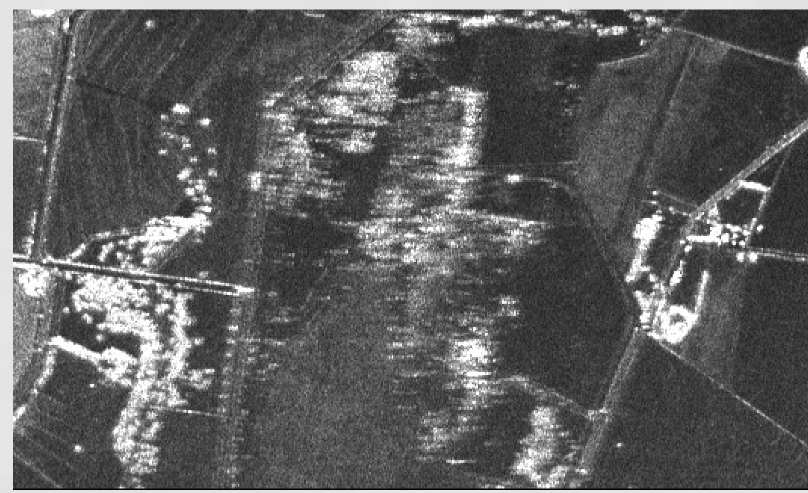
$dAz = 4.2m$

# Gamma Remote Sensing

- Motion Compensation (MoCom)
  - Interpolates the range compressed data using navigation information from the platform
  - Corrects for deviations from the reference platform track
  - Corrects for mismatches in the data compared to that expected by the azimuth matched filter
  - Sharpens the image focus

$$dR = 6.0m$$
$$dAz = 4.2m$$





# SAR Calibration

- Scattering Matrix - *S*
- System model (receiver voltage) - *L*
- Variables $\psi_t, \psi_r$ are relative phase inside a range cell
- N is complex additive white Gausian noise
- Cross talk terms - $\delta_1, \delta_2, \delta_3, \delta_4$
- Channel imbalance - $f_1, f_2$
- Amplitude factors due to range to target and back as well as antenna pattern asymmetry - $A_r, A_t$
- Need to estimate scattering calibration matrix parameters
- This formulation includes cross coupling between the various polarisation combinations due to antenna imperfections and system leakage

$$S = \begin{bmatrix} s_{hh} & s_{hv} \\ s_{vh} & s_{vv} \end{bmatrix}$$

$$L = \begin{bmatrix} z_{hh} & z_{hv} \\ z_{vh} & z_{vv} \end{bmatrix} = R^H S T + N$$

$$R = A_r e^{j\psi_r} \begin{bmatrix} 1 & \delta_2 \\ \delta_1 & f_1 \end{bmatrix}$$

$$T = A_t e^{j\psi_t} \begin{bmatrix} 1 & \delta_3 \\ \delta_4 & f_2 \end{bmatrix}$$

# Calibration – Point Targets

- Polarimetric Active Radar Calibrators (PARCs)
  - Fixed known Radar Cross Section - $A_1, A_2, A_3$
  - Combination of three gives response in all polarisation combinations
  - Direct method for scattering calibration matrix parameters although not as simple as it appears

$$A_i = G_e \frac{G_A^2 \lambda^2}{4\pi}, i = 1,2,3$$

$$S_1 = A_1 \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}$$

$$S_2 = A_2 \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}$$

$$S_3 = A_3 \begin{bmatrix} -1 & -1 \\ 1 & 1 \end{bmatrix}$$

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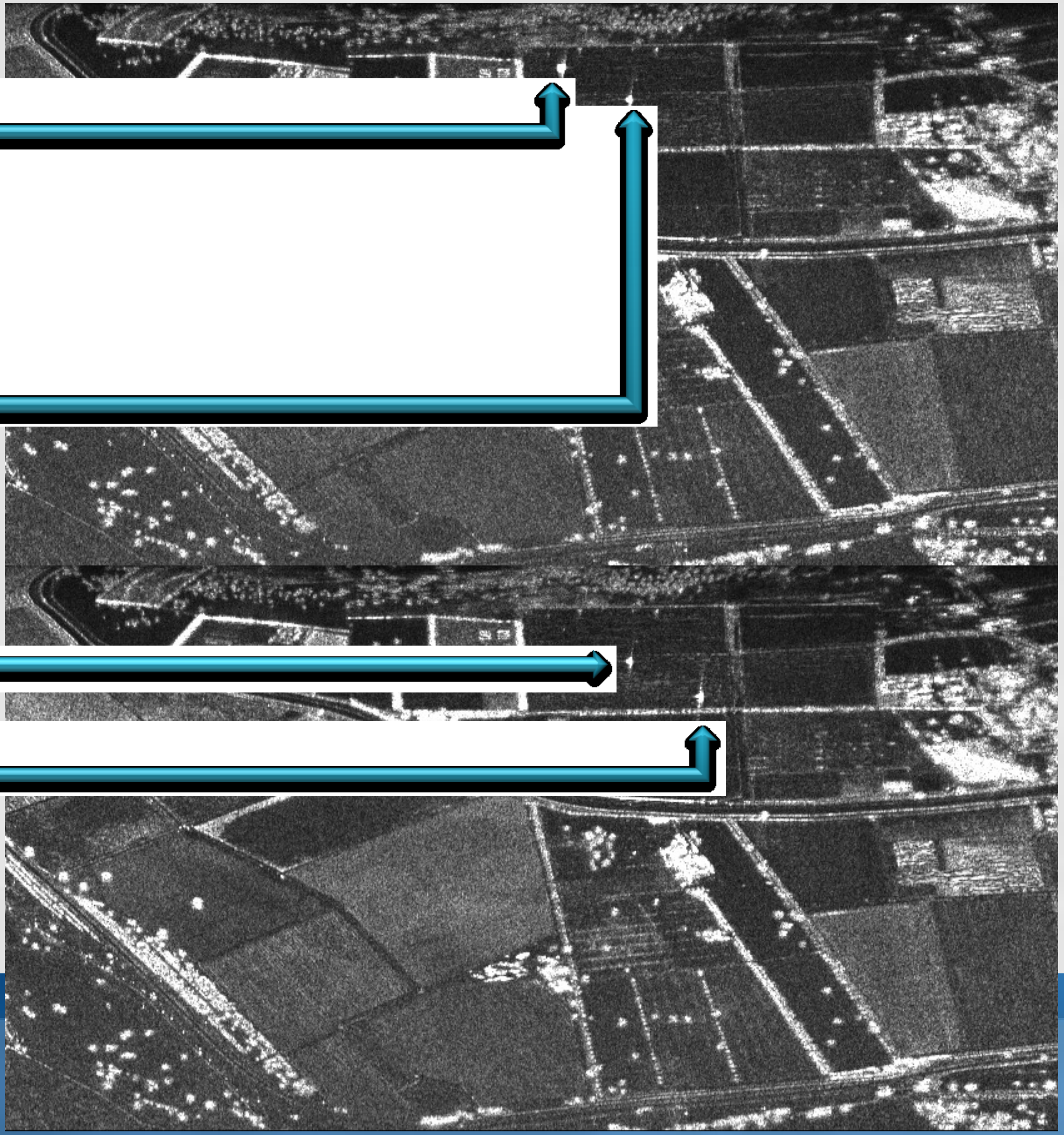
# Calibration – Point Targets

- Triangular Trihedral
  - Fixed known Radar Cross Section
  - Gives response in co-polarised channels only
  - Direct method for scattering calibration matrix parameters also non trivial

$$A_T = \frac{4\pi a^3}{3\lambda^2}$$

$$S_T = A_T \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

# Calibration – Image Example




$$dR = 6.0m$$
$$dAz = 4.2m$$

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# Summary

- Range-Doppler imaging algorithm focuses raw radar data
- Gamma RS is proprietary modular software implementing the range-Doppler algorithm
- Motion compensation must be applied for sharp imagery
- Calibration is a non trivial stage in producing useful backscatter measurements