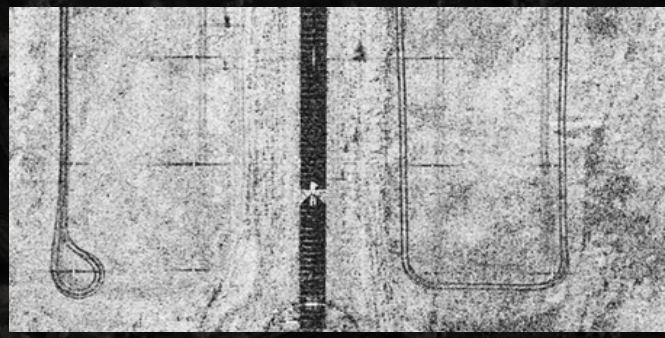
SAND2016-9827PE

Exceptional service in the national interest

Sandia National Laboratories





Overview of Synthetic Aperture Radar at Sandia National Laboratories

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Sandia National Laboratories
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Sandia Airborne ISR: www.sandia.gov/radar/

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2014-XXXXP

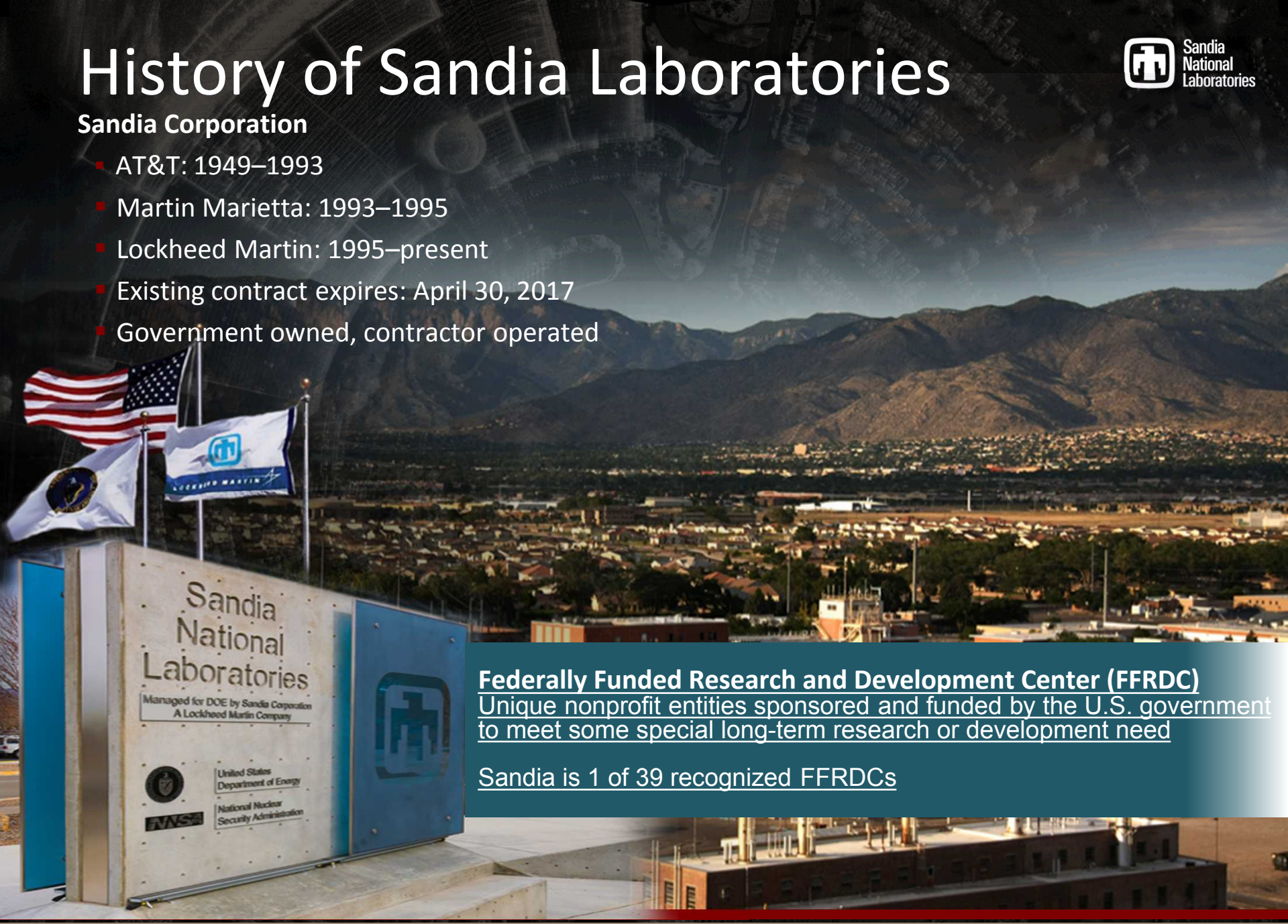
U.S. DEPARTMENT OF ENERGY | NNSA

History of Sandia Laboratories

Sandia National Laboratories

Sandia Corporation

- AT&T: 1949–1993
- Martin Marietta: 1993–1995
- Lockheed Martin: 1995–present
- Existing contract expires: April 30, 2017
- Government owned, contractor operated



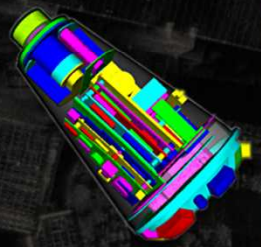
Federally Funded Research and Development Center (FFRDC)
Unique nonprofit entities sponsored and funded by the U.S. government to meet some special long-term research or development need

Sandia is 1 of 39 recognized FFRDCs

NW Mission & Sandia SAR Evolution

Sandia National Laboratories

NW Radar Fuze Tech Base



Advanced radar fuzing technology

Radar tech base originated with Nuclear Weapons

Strengthened through SAR development

Applied advanced technology to NW systems

Synthetic Aperture Radar

SNL SAR Overview

Sandia National Laboratories

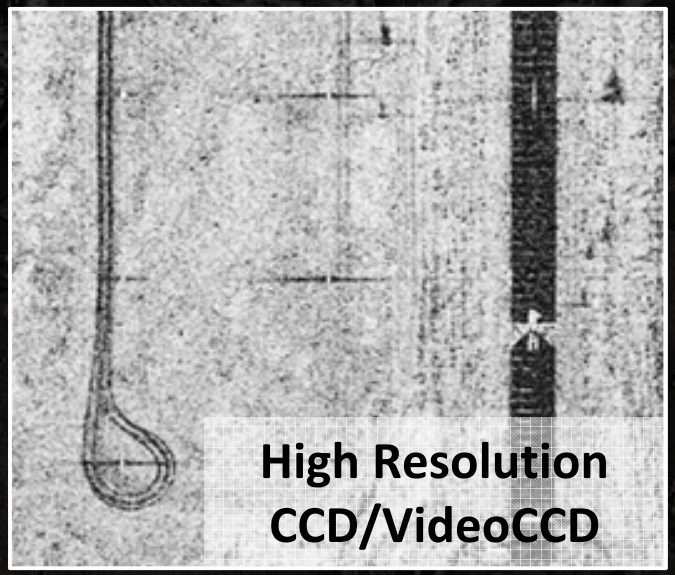
- Pathfinder Airborne ISR Solutions
- Real World Applications
- Complete Mission Solutions
- Multi-Mode Functionality
- SAR Resolution Matters
- Radar Change Product Image: Coherent Change Detection
- Video SAR Vehicles Example
- Advanced Capabilities
- SAR R&D Testbed
- Rethinking Search
- Human Factors
- SAR Training
  - What can SAR Measure?
  - Syllabus
  - Mini-Tutorial on Range Layover and Shadows
- Working with Sandia
- Summary

Pathfinder Airborne ISR Solutions

Sandia National Laboratories

3+ decades of experience delivering pathfinder SAR solutions for complex, critical and urgent national security problems (FFRDC)

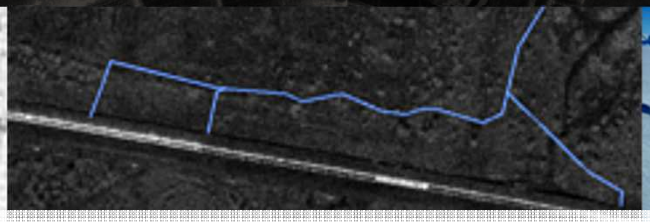
- All Weather, Day or Night
- High Resolution, Optical-like
- On-board and Real-time Processing
- Flexible platform and TPED configuration



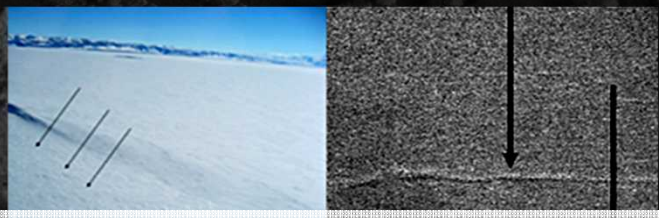
Real World Applications

Sandia National Laboratories

Coherent Change Detection

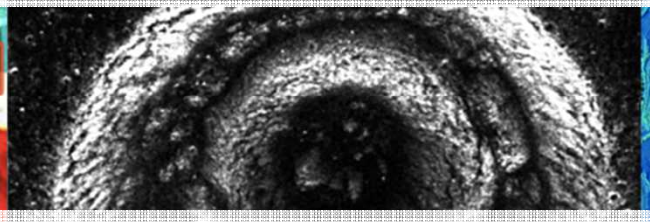


Facilities and Border Protection

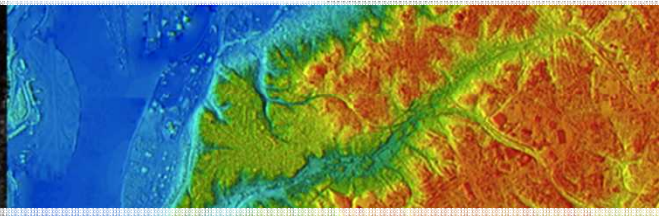


Crevasse Detection

Environmental Monitoring



Earth Sciences

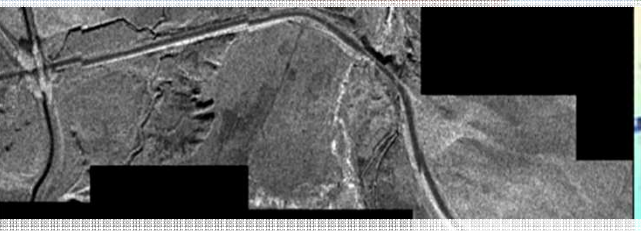


High Res. Terrain Elevation Mapping

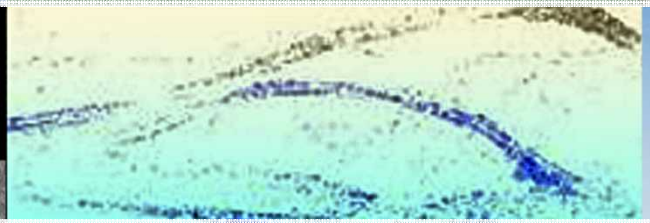
Maritime & Littoral

Tracking

S&R and Targeting



C-IED & Route Reconnaissance



Patterns of Life

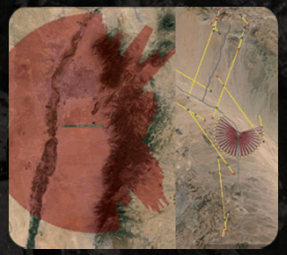
Precision Guidance

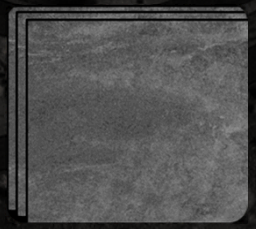
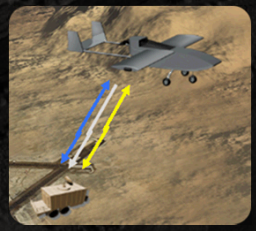
Since 1997, Sandia radars have been used to address critical problems in all geographic areas

Complete Mission Solutions

Sandia National Laboratories

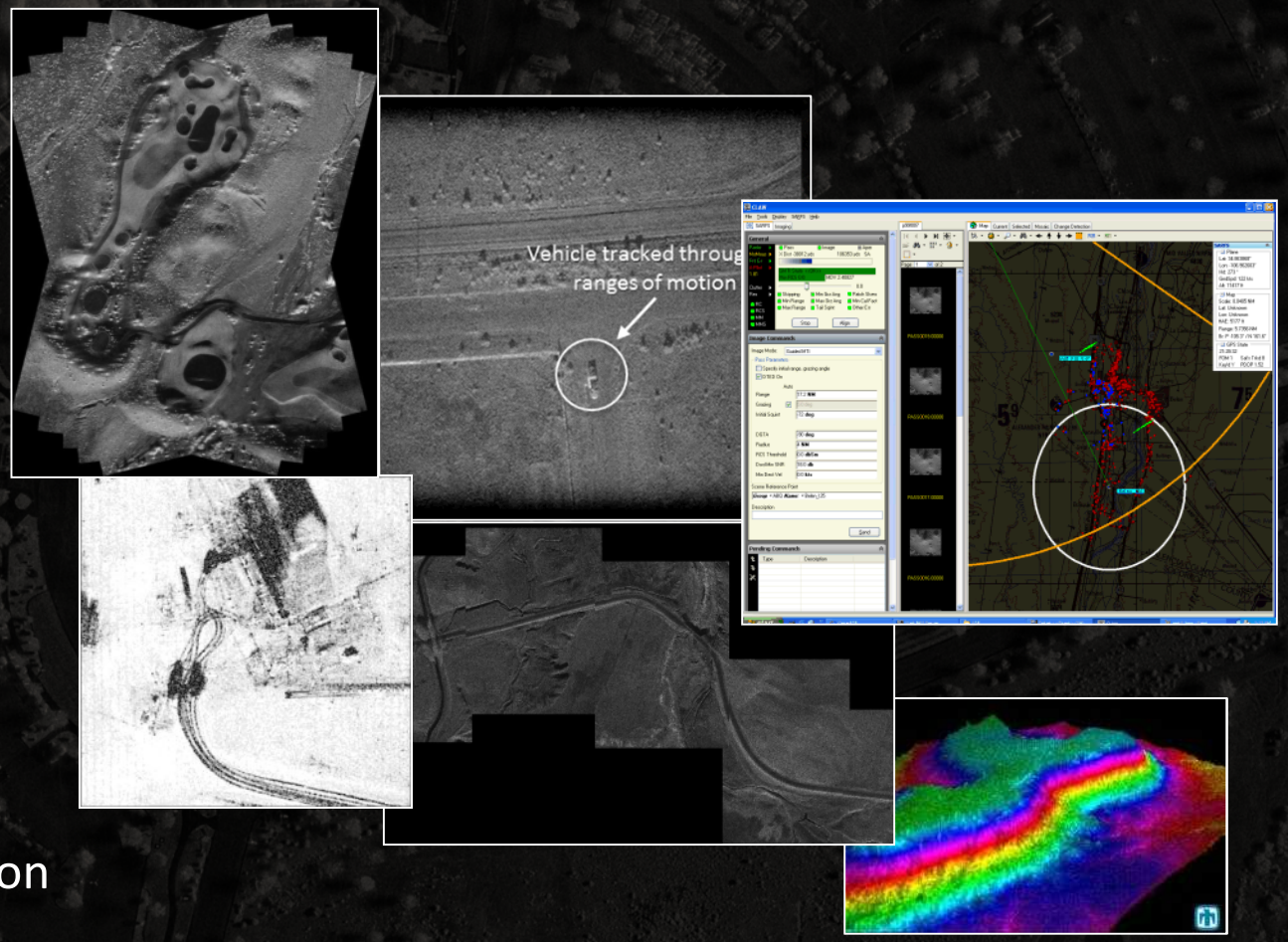
- Provider of end-to-end solutions that leverage physics, engineering, and data and information science to support national security decision making
  - **Mission Engineering**
    - Pre-Mission Analysis & Flight Planning
    - Highly customized TTPs and CONOPs
    - Continuous performance assessments
    - Analyst Training in SAR phenomenology
  - **Real-time Processing**
    - Real-time Delivery of Multiple Image Products to Analysts
    - Image Formation
    - Change Detection Products
    - Transmission of Real-time Products
  - **Advanced Sensor Exploitation**
    - Predictive Intelligence
    - Human Factors
    - Advanced Exploitation Techniques
  - Analyst Training



Multi-Mode Functionality

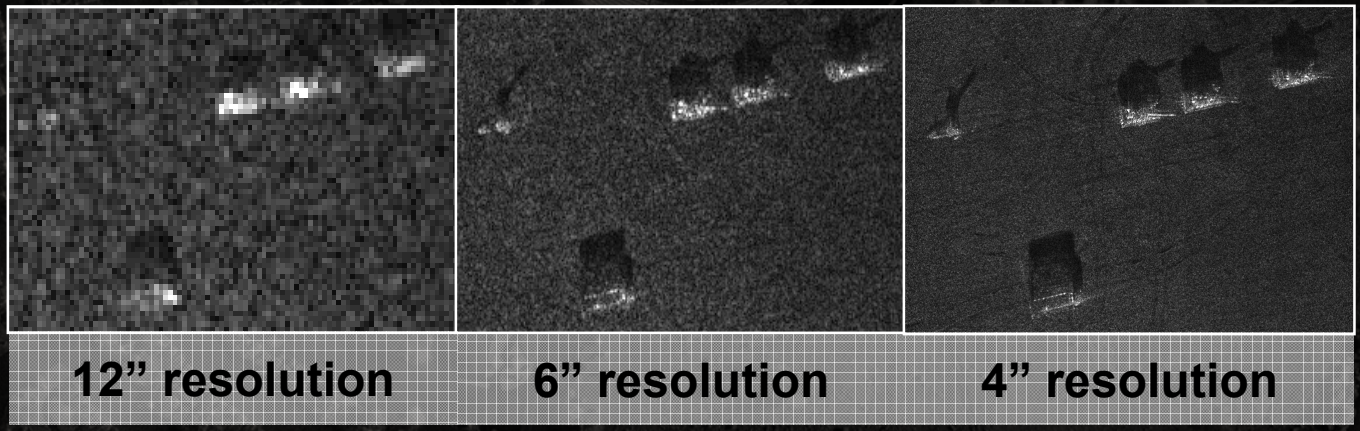
- Spotlight
- SpotDwell
- Circle
- Stripmap
- Arbitrary Stripmap
- CCD/NCP
- IFSAR
- VideoSAR/VICTR
- GMTI/DMTI
- Wide Area Search
- High Range Resolution



As new radar modes are developed they can be integrated into existing Sandia radars during product improvement phases without redeveloping the entire system

SAR Resolution Matters

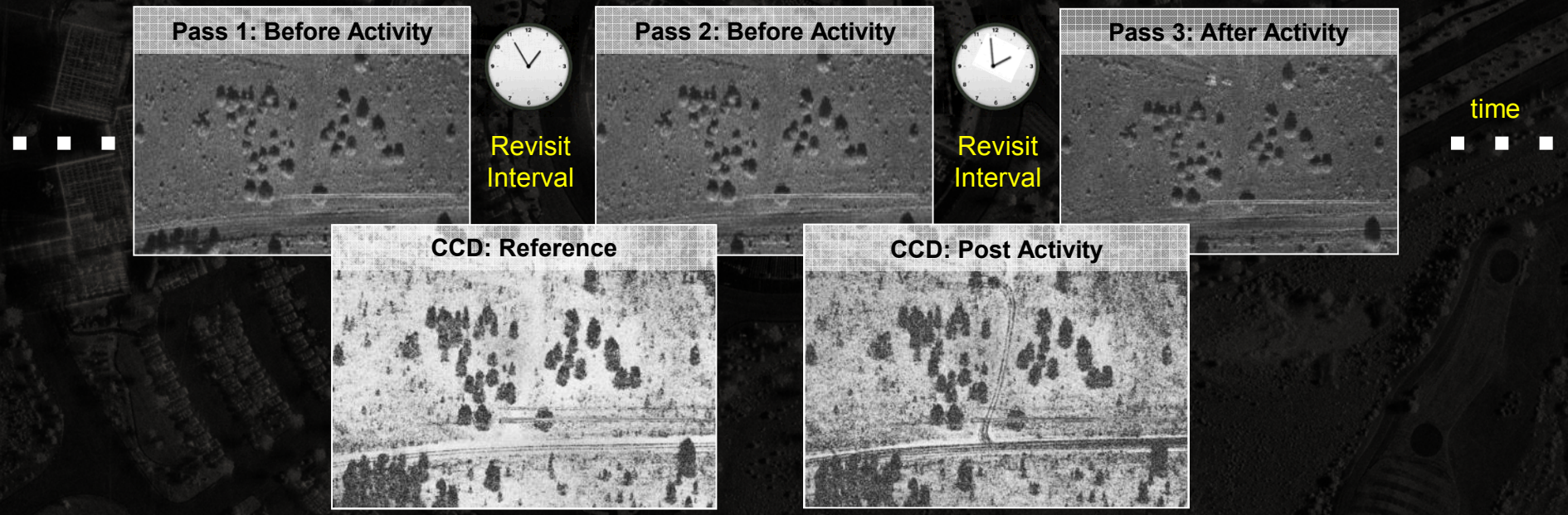
- More “pixels on target” results in a more optically literate image for analysis
- Better facilitates accurate target identification
- Further improves capability of modes such as Coherent Change Detection (CCD) that exploit phase change



Radar Change Product Image: Coherent Change Detection (CCD)

Coherent change detection (CCD) is a sensitive technique for identifying subtle differences that occur in a ground scene between two SAR passes

- Can highlight arrival of new objects, removal of objects, agricultural activity and other changes
- Widely used for non-persistent surveillance, maintains a history of change



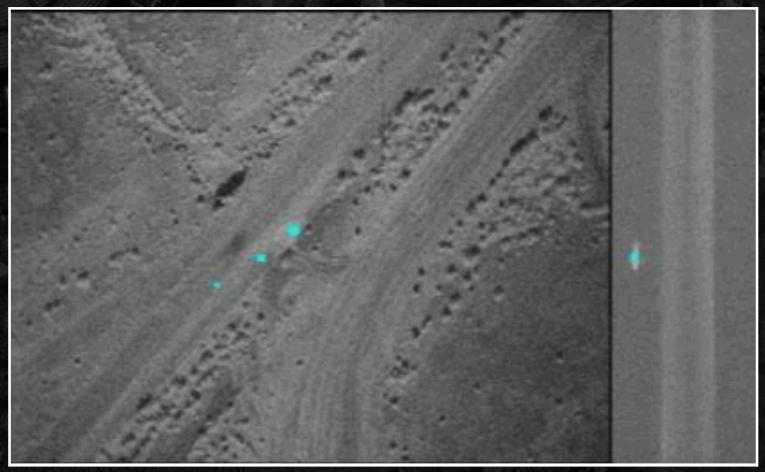
WHITE = high coherence
BLACK = low coherence

VideoSAR Vehicles Example

This is VideoSAR footage of a gate at a facility. The video shows vehicle traffic moving through the gate. As the vehicles are in motion their location is indicated by a shadow. As the vehicles stop the reflected energy of the vehicles fall on top of the shadow. Once the vehicle continues in motion the shadow is again visible. The lines moving across the screen are Doppler shifts caused by the moving vehicles.

Advanced Capabilities

- Multiple channels with the same instantaneous bandwidth.
- Multiple phase centers – sum and difference yield clutter suppression and increased ability to track targets.
- Polarimetric (HH, VV, HV, VH) yields additional information around scattering phenomena.



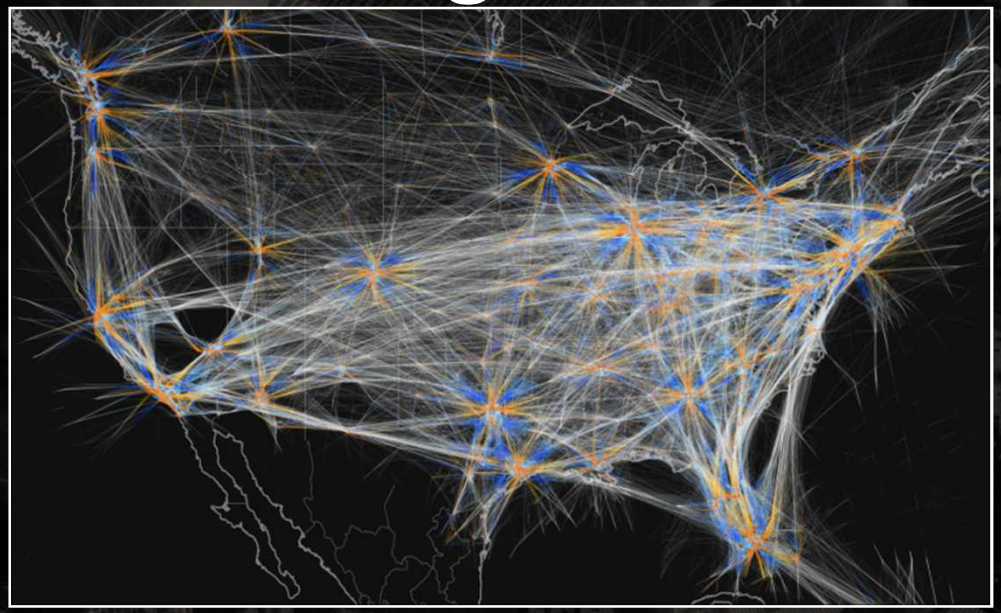
SAR R&D Testbed

Sandia National Laboratories

- An in-house, high-performance, multi-mode airborne radar capability for the continued advancement of SAR ISR capabilities
- Works in accord with R&D efforts, both internal and external, to provide advanced radar airborne data collection and exploitation assets to facilitate specific research goals
- Provides a “testbed laboratory”/research tool set that can be widely utilized in support of internal R&D, new program development, and collection of nationally-important data products.

DeHavilland DHC-6 “Twin Otter” research aircraft operated for Sandia by Twin Otter International

Rethinking Search

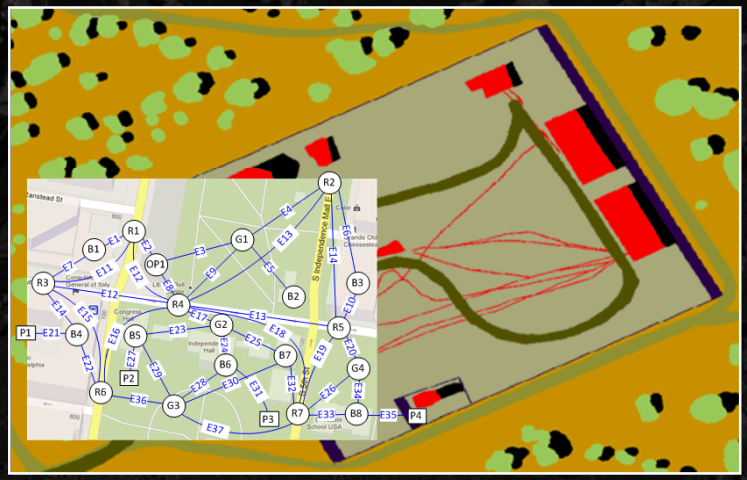


Rethinking traditional GIS and geospatial search.

- Compact, efficient representations of features extracted from sensor data
- Sensor agnostic capability for multi-INT feature relationships in time and space
- Predictive and forensic analysis

Rethinking patterns in motion.

- Geometric and temporal trajectory analyses – changing dots to tracks to *trajectories*.
- Geospatial-temporal relationships – i.e., identifying things like co-travelers.



Decision Makers and Analysts care about "what", "where", and "when".
Where is it going? Where has it been? What's the relationship? What's changed?

Human Factors Issues Permeate ISR

Sandia National Laboratories

- Human-system integration remains the weakest link in the analytics research-development-deployment process
  - Human factors requirements may not be adequately addressed in acquisitions process.
  - As a result, situation awareness and general ergonomics may not be optimal for the TCPED cycle
  - Sandia is investing in its understanding of the Human-Machine Interface (HMI) in efforts to deliver optimal PED solutions.

SAR Training Overview

Sandia National Laboratories

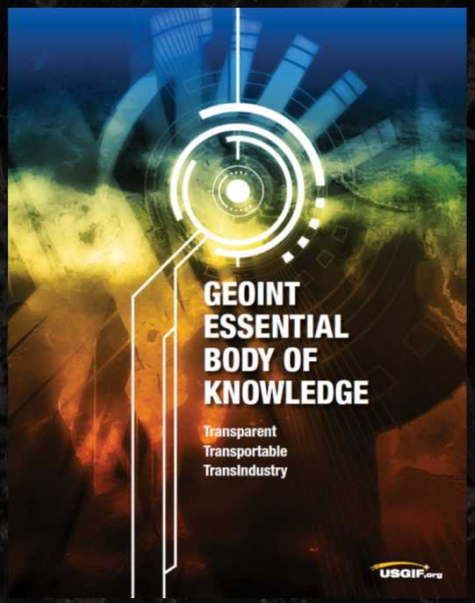
- Program-specific SAR Training
  - Sandia designed and delivered operational training packages as early as 1999.
  - Since 2008 SNL has been training radar operators and analysts in support of real-world operations
    - Current training programs consist of:
      - SAR Fundamentals: 3-day session
      - SAR Fundamentals and exploitation: 1 week of classroom instruction and 2 weeks of hands-on ground school
      - Executive Overview: ½-day briefing
  - >500 military, government, and civilian personnel trained in support of 4 specific programs and general SAR education

- SNL's SAR Syllabus aligns with USGIF EBK Compentency II: Remote Sensing Fundamentals + Radar Imagery Analysis
  - SAR topics not covered
    - Imagery formats and metadata standards (NTIF, SICD) for SAR
    - GMTI processing and exploitation

- Other
  - Classified Signature Catalog

USGIF EBK Competency II

Sandia National Laboratories



COMPETENCY II: Remote Sensing & Imagery Analysis

Remote Sensing & Imagery Analysis generates products and/or presentations of any natural or man-made feature or related object or activity through satellites, airborne platforms, unmanned aerial vehicles, or other similar means. This competency area contains the knowledge necessary to synthesize technical, geographic, and intelligence information derived through the interpretation or analysis of imagery and collateral materials as well as the processes, uses, interpretations, and manipulations of imagery for dissemination. Remote Sensing & Imagery Analysis includes:

Remote Sensing Fundamentals

- Image Target Elements (e.g., tone, shape, size, pattern, texture, shadow, association)
- Types of Resolution (e.g., spatial, spectral, radiometric, temporal, extent)
- Analog and Digital Imagery Formats
- Imagery Sensors for Remotely Sensed Data (e.g., LiDAR, airborne, electro-optical, radar, infrared, full-motion video)
- Airborne vs. Satellite Imagery
- Active and Passive Sensor Considerations
- Relationship Between Sensors, Resolution, and Electromagnetic Spectrum
- Combinations of Sensors and/or Resolutions to Generate End Product
- Common Challenges Associated with Remotely Sensed Imagery Data (e.g., atmospheric/weather, ground effects/dust, camouflage)
- Image Evaluation (e.g., sources of systematic and unsystematic errors, accuracy, precision, National Imagery Interpretation Ratings Scales)
- Image Metadata
- Other Sensors (e.g., unattended ground sensors, supervisory control and data acquisition, relationship with materials identification and analysis)

Imagery Preprocessing

- Geometric Correction
- Radiometric Corrections
- Mosaicking
- Geometric Registration

Imagery Enhancement

- 1st and 2nd Generation Orthorectification
- Georeferencing
- Dynamic Range Adjustments
- Spatial Filtering
- Image Histogram
- Stereoscopic Visualization
- Imagery Mensuration Techniques

Imagery Transformation

- Principal Components Analysis
- Spectral Ratioing
- Multi-Resolution Integration

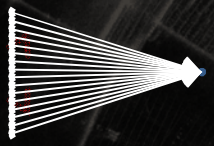
Imagery Classification

- Supervised Image Classification
- Unsupervised Image Classification
- Classification Accuracy Assessment and Error Analysis
- Information Classes and Spectral Classes
- Automated Feature Extraction

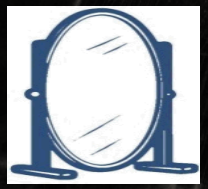
Imagery Analysis

- Radar Imagery Analysis
- LiDAR Imagery Analysis
- Multispectral Imagery Analysis
- Hyperspectral Imagery Analysis
- Pan Sharpening
- Change Detection Techniques
- Geographic Object-Based Imagery Analysis
- Time Series Imagery Exploitation
- Analysis of Polarized Imagery

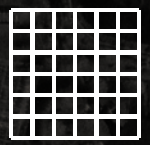
What SAR Can Measure?



Range: distance to the target or targets

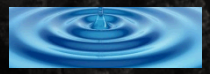


Reflectivity: magnitude, brightness, or strength of echo

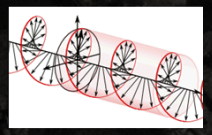


Direction: azimuth and/or elevation of target

Doppler Shift: relative velocity between radar and target



Phase: relative delay of echo, measured in wavelengths



Polarization: the orientation or plane of the electric field

Measurement and processing of physical parameters enables an analyst to detect and contextualize features and signatures such as:

- **Distance**
- **Height/Elevation**
- **Overlay**
- **Shadows**
- **Terrain**
- **Indicator of material, size, clutter, landcover**
- **Coherence**
- **Motion**

Syllabus – Part 1

Sandia National Laboratories

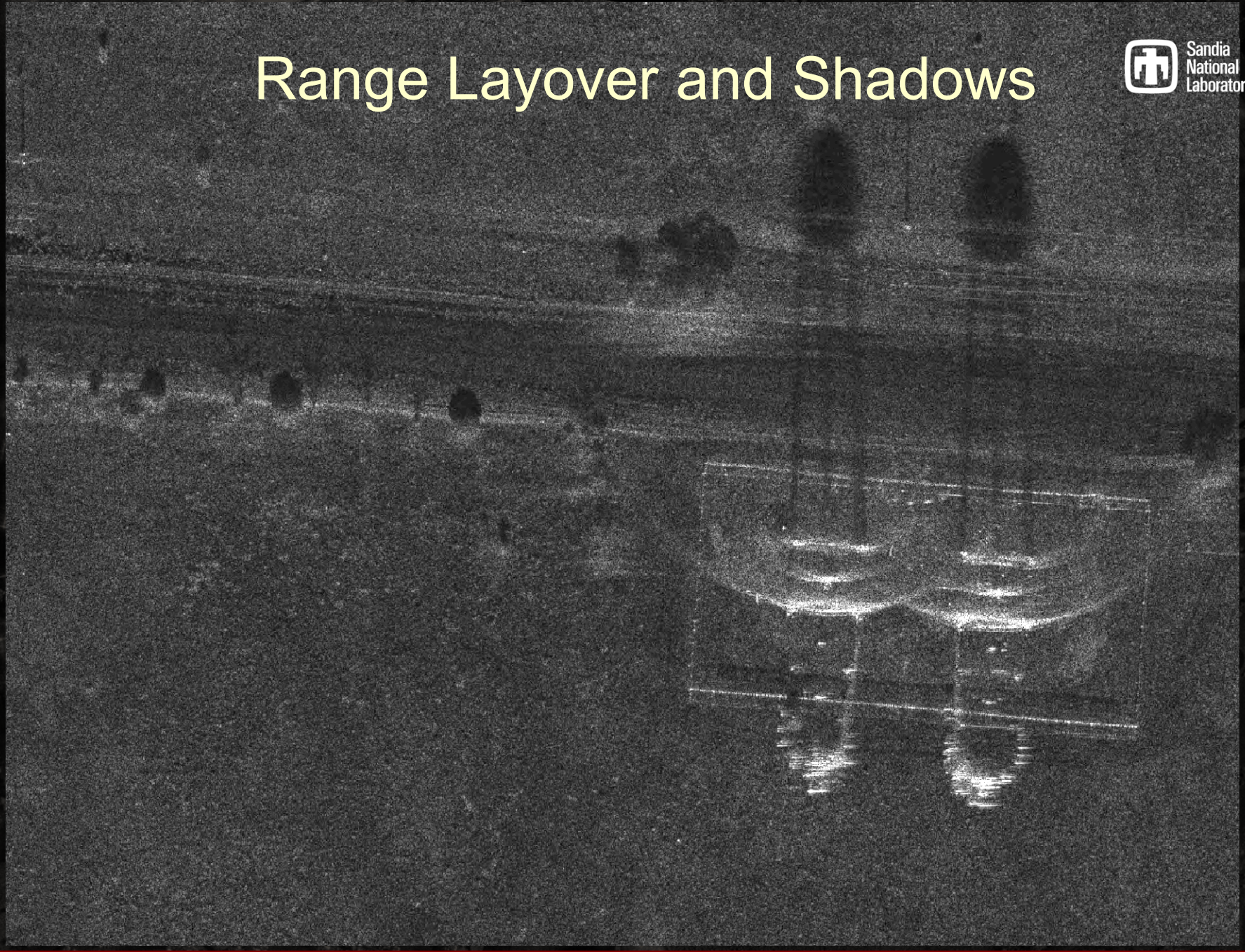
- Introduction to Radar Basics (146 slides)
  - What can Radar measure
    - Range
    - Reflectivity
      - Discrete targets
      - Distributed targets
      - Specular *vs*. diffuse targets
    - Direction
    - Doppler Shift
    - Phase
    - Polarization
- Introduction to SAR (221 slides)
  - How does a SAR Form an Image
    - Range
    - Reflectivity
    - Direction (SAR Antenna)
    - Doppler Shift
  - SAR image formation
    - Determination of range bin
    - Determination of azimuth bin
    - Image intensity as grayscale
    - Relationship between geometry and performance
    - Differences between radar and optical imagery
  - SAR Imaging Modes
    - Stripmap
    - Circle
    - Spotlight

Syllabus – Part 2

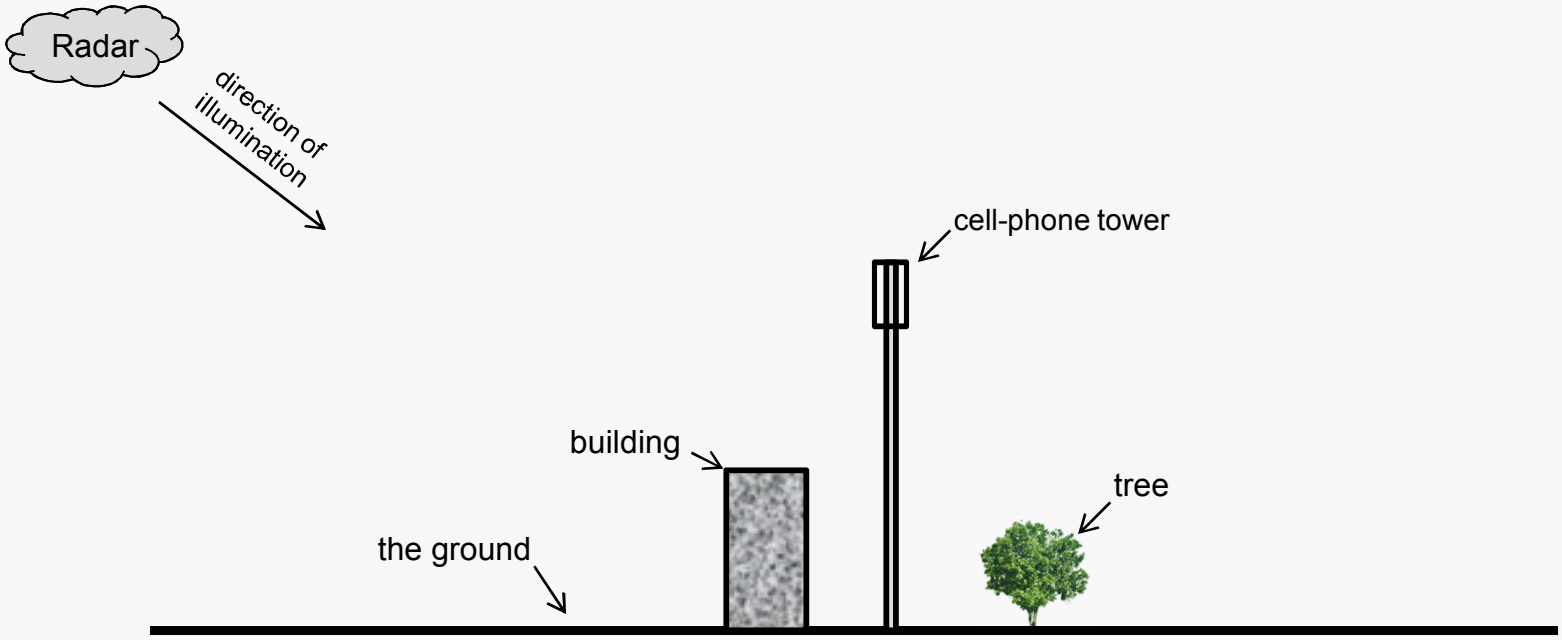
Sandia National Laboratories

- SAR Phenomenology (202 slides)
  - Resolution
  - Shadows And Range Layover
  - Multipath
  - Radar cross section and image intensity
  - Moving objects
- Introduction to Change-detection
  - Magnitude-change detection (MCD) and Amplitude Change detection ACD (27 slides)
  - Coherent-change detection (CCD) (143 slides)
- Change-detection Phenomenology
  - Magnitude-change detection (MCD) and Amplitude Change detection ACD Phenomenology (52 slides)
  - Coherent-change detection Phenomenology (CCD) (39 slides)
- Image interpretation and analysis
- SAR System Overview: Hardware, Software, People (9 slides)
- SNL Specific CONOPS & Mission Execution (123 sllides)
  - Applications

Range Layover and Shadows

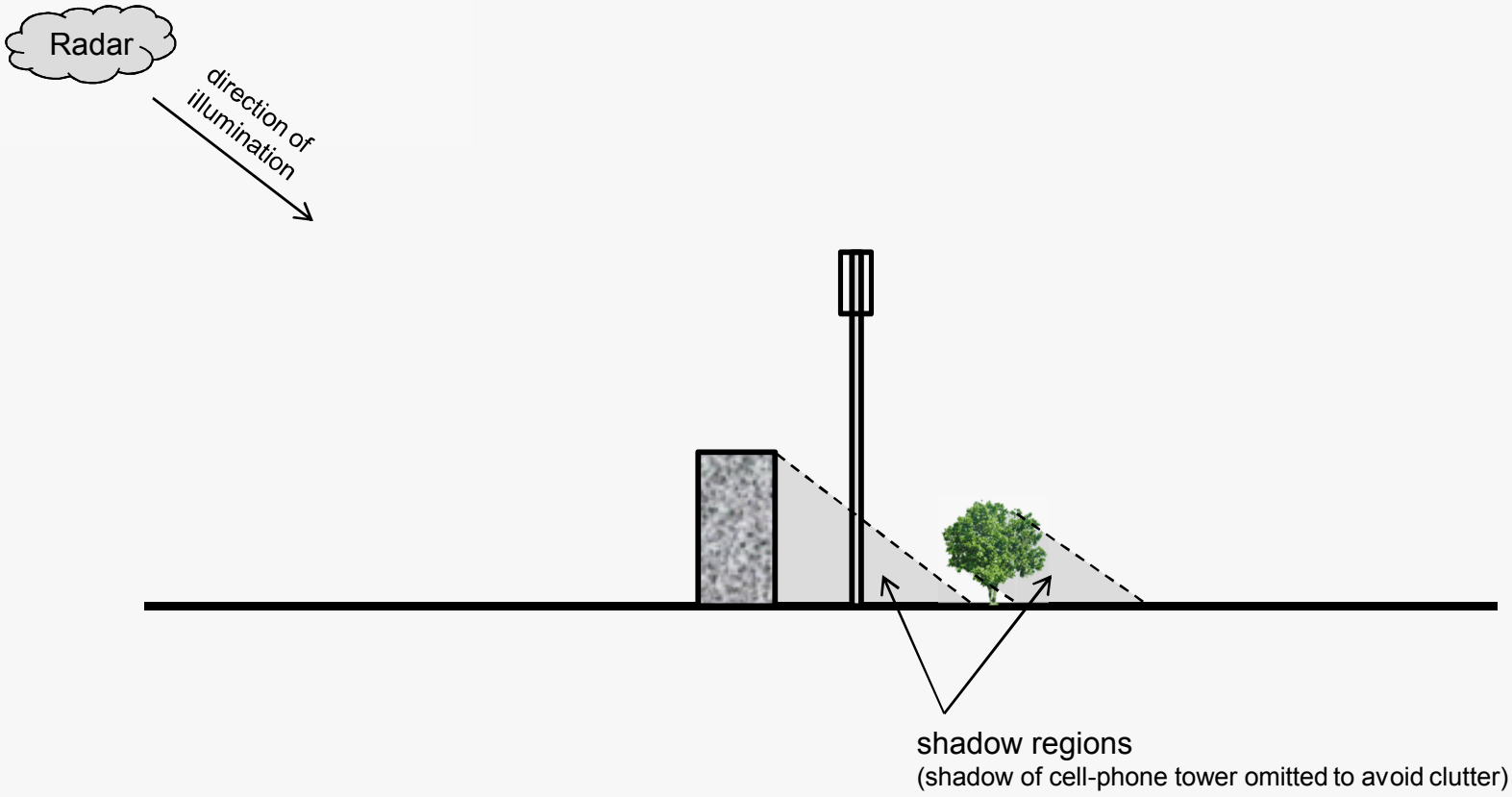


Range Layover



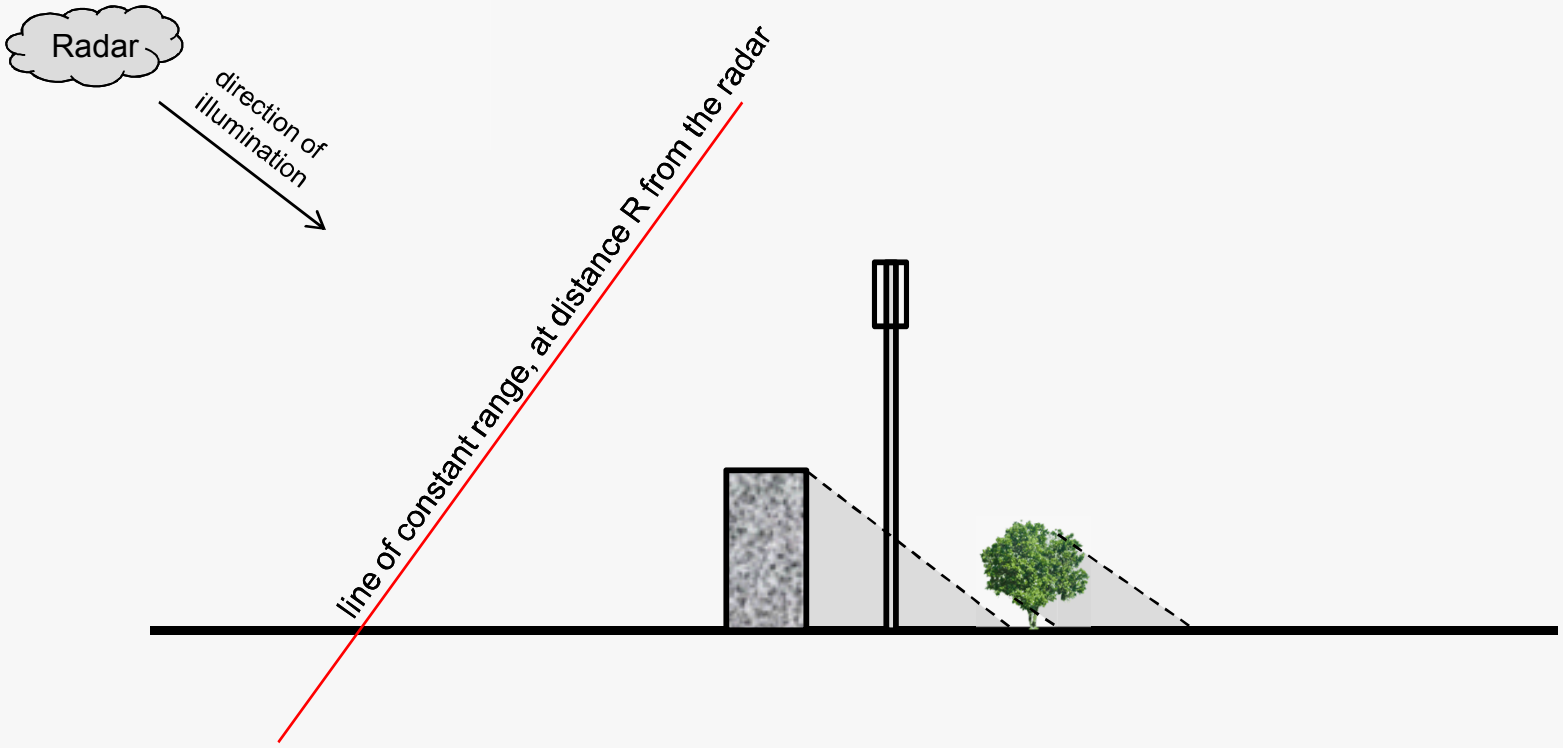
BACK LAYOVER & SHADOWS

Range Layover



BACK LAYOVER & SHADOWS

Range Layover



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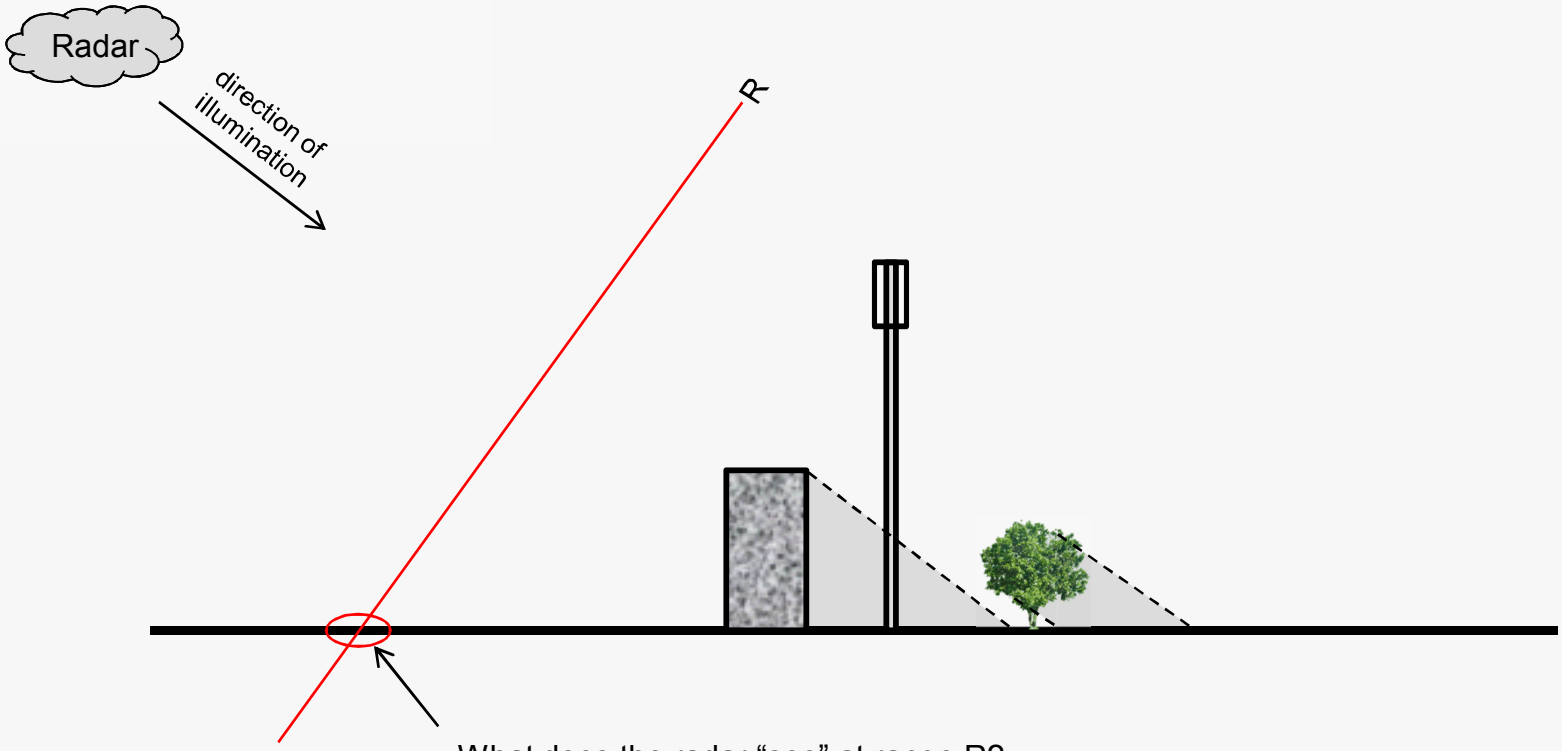
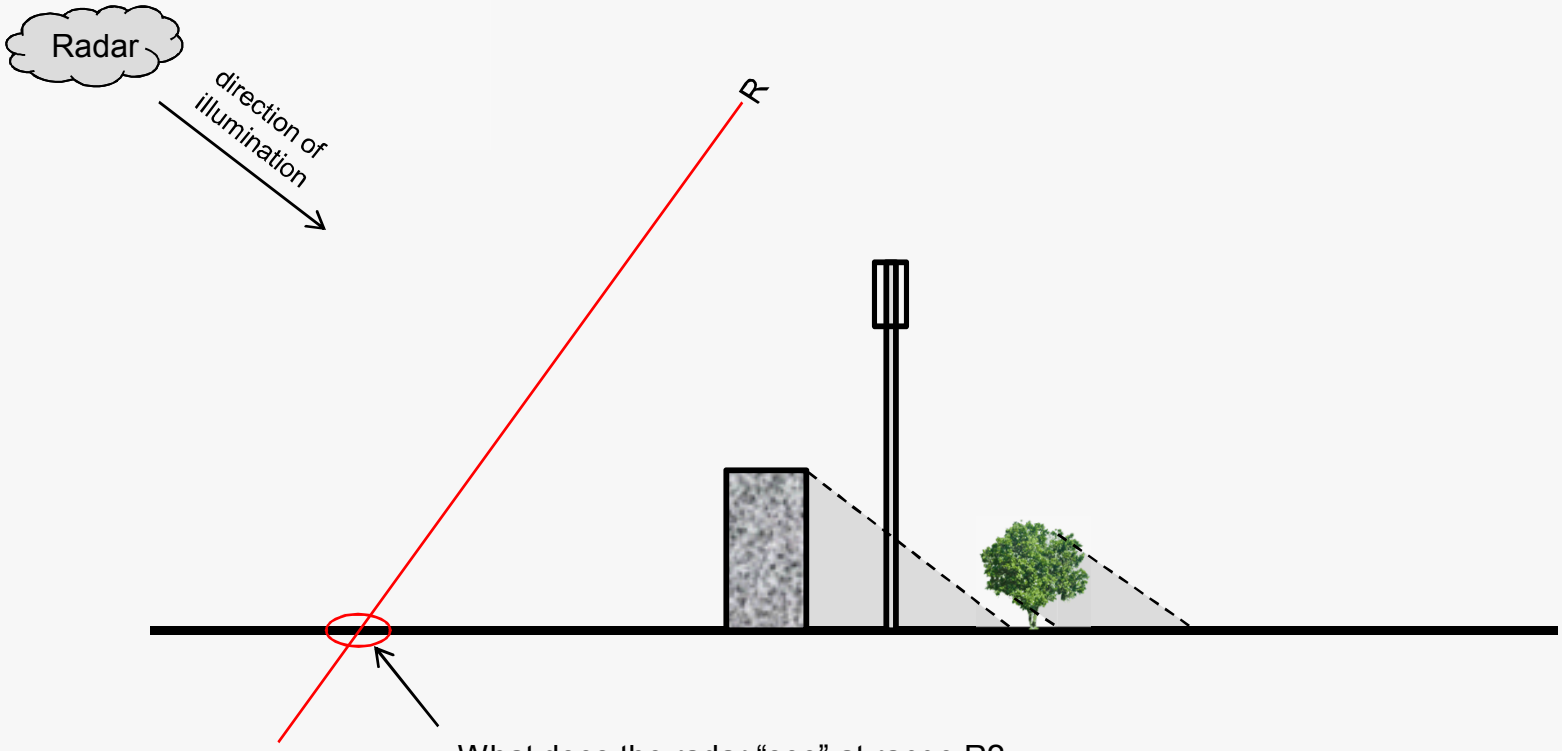
Range Layover



BACK LAYOVER & SHADOWS

Range Layover

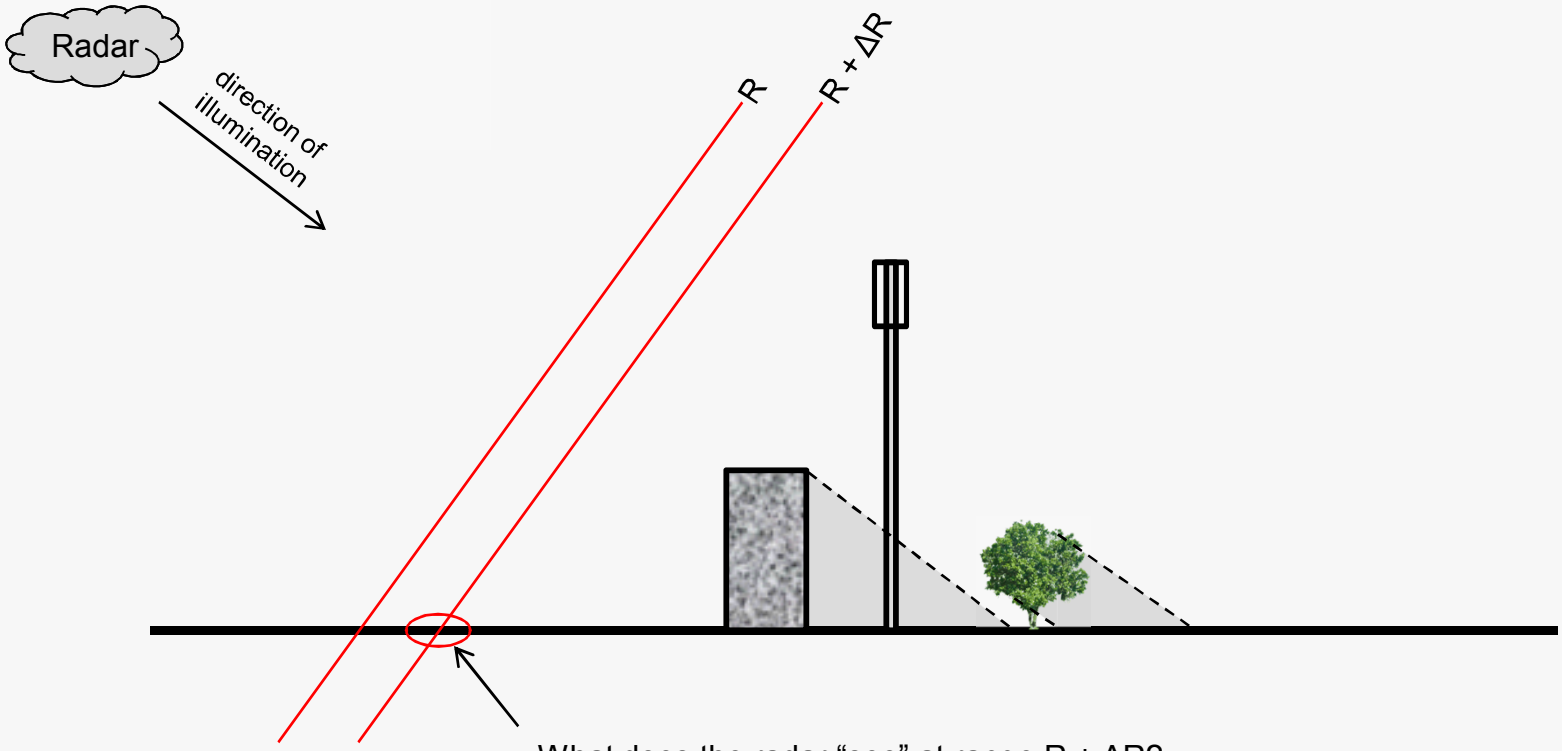


What does the radar “see” at range R?

The only thing illuminated by the radar at range R is the ground!

BACK LAYOVER & SHADOWS

Range Layover

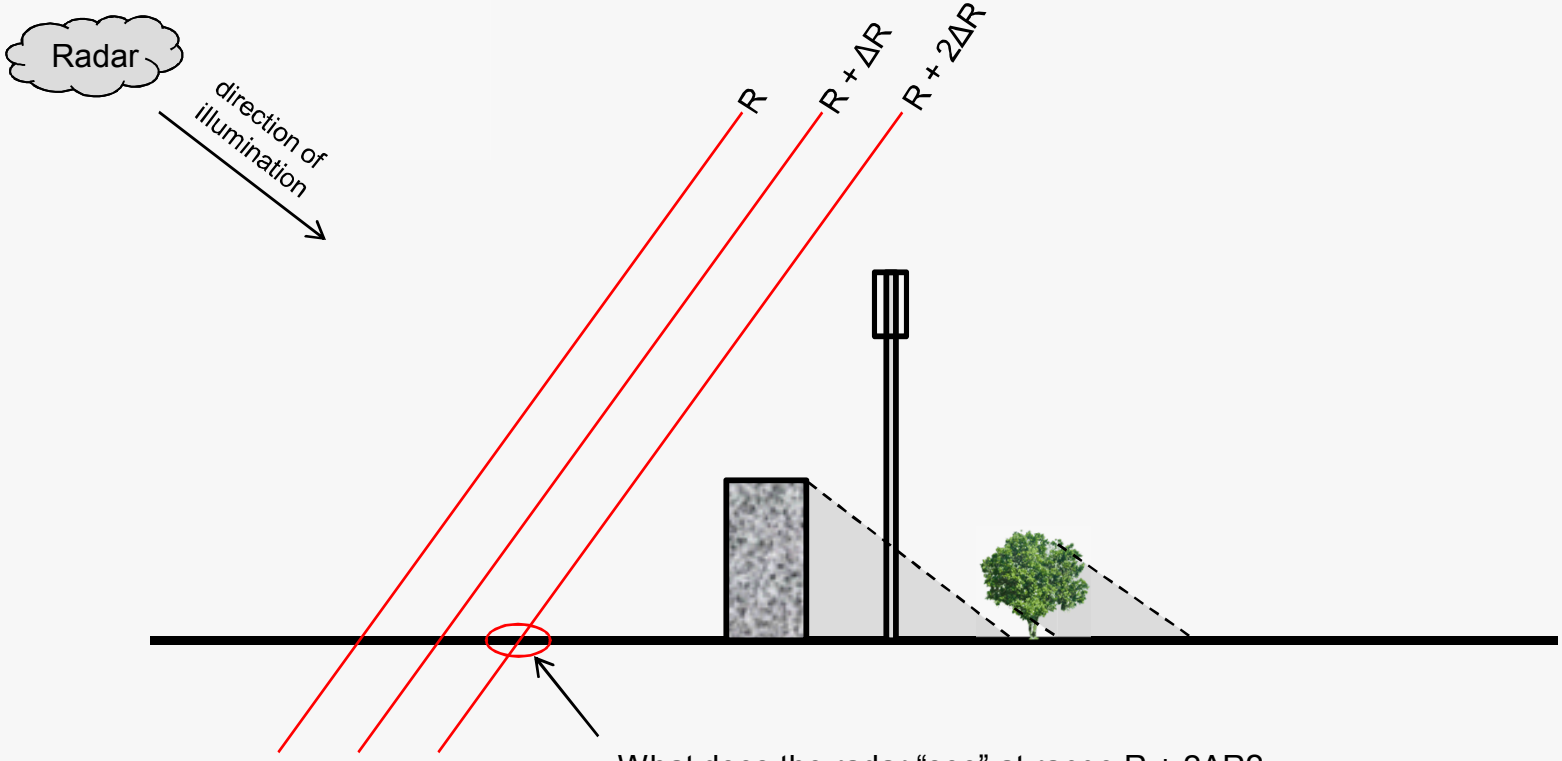


What does the radar “see” at range R + ΔR?

The only thing illuminated by the radar at range R + ΔR is the ground!

BACK LAYOVER & SHADOWS

Range Layover

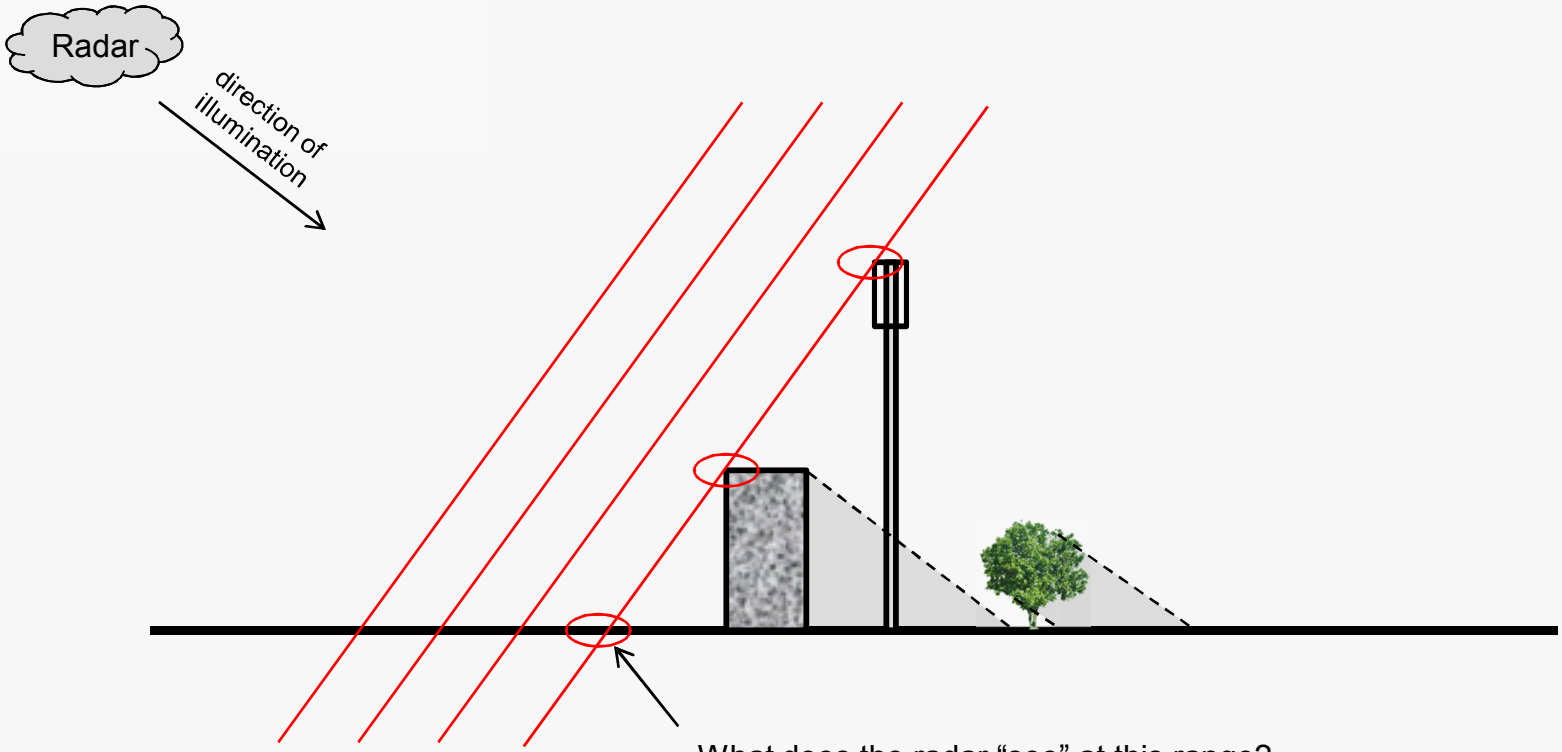


What does the radar "see" at range R + 2ΔR?

Again, the only thing illuminated by the radar at range R + 2ΔR is the ground!

BACK LAYOVER & SHADOWS

Range Layover

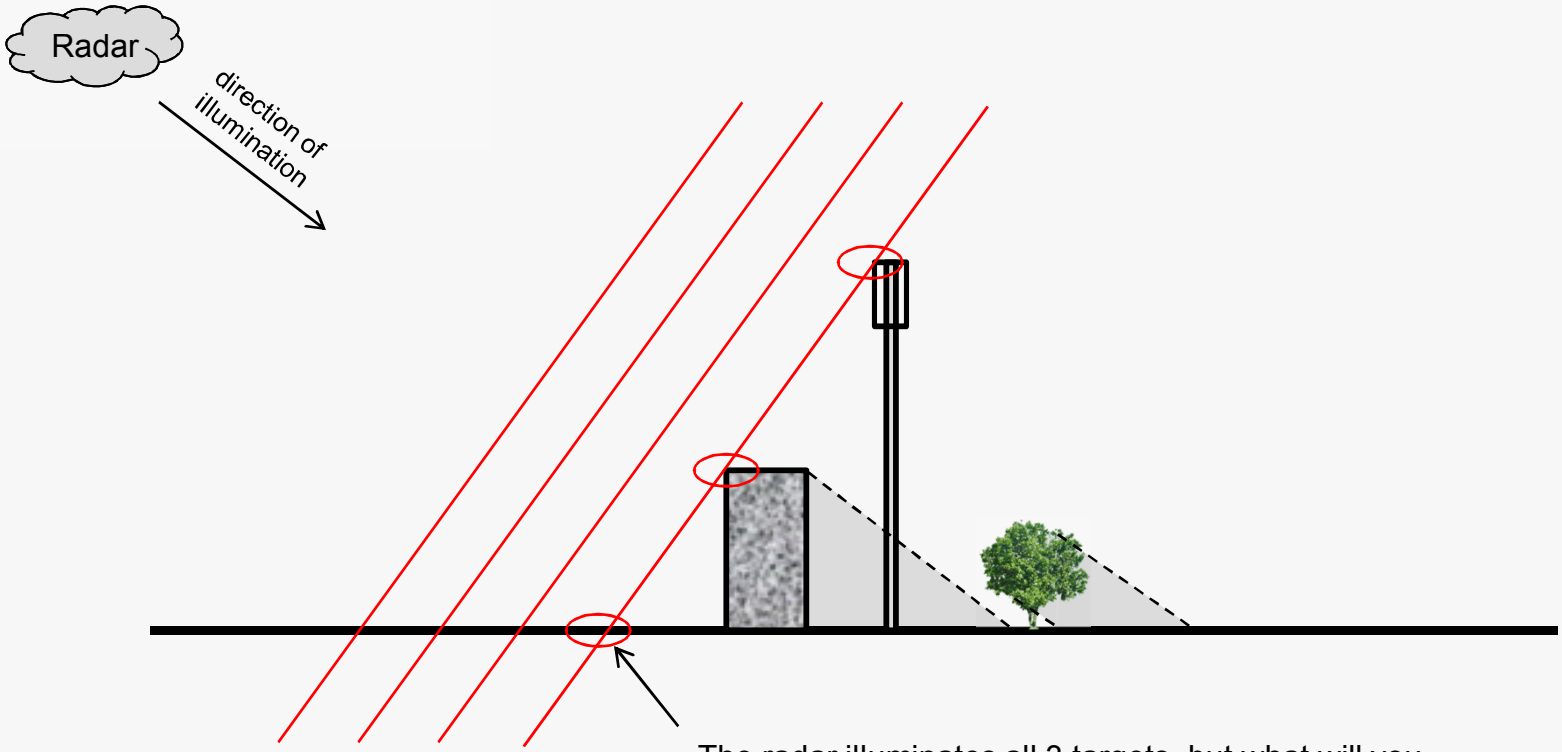


What does the radar “see” at this range?

Here, the radar is illuminating the ground, the building, and the cell-phone tower! As a result, all 3 returns will appear in the same range bin.

BACK LAYOVER & SHADOWS

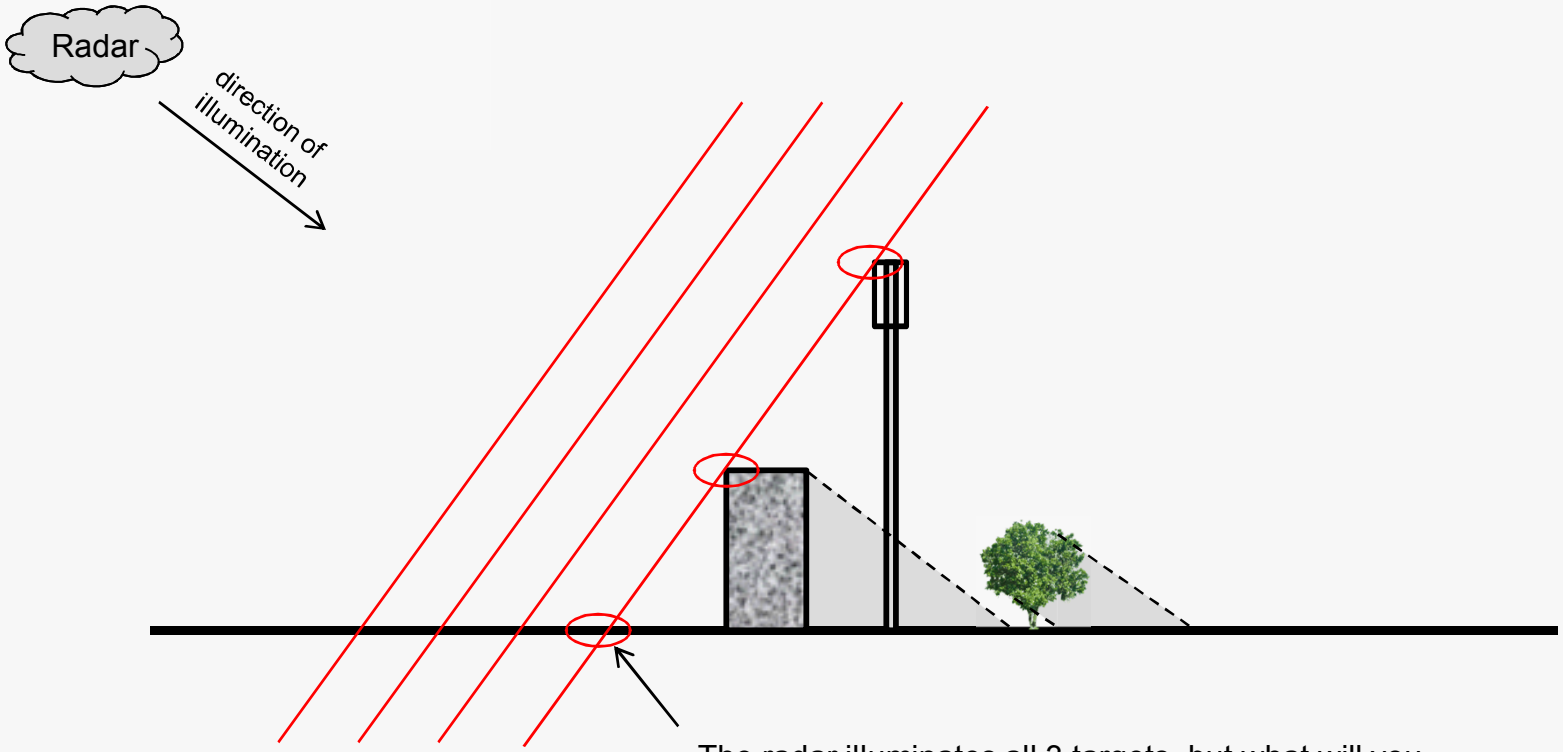
Range Layover



The radar illuminates all 3 targets, but what will you see in the final image?

BACK LAYOVER & SHADOWS

Range Layover

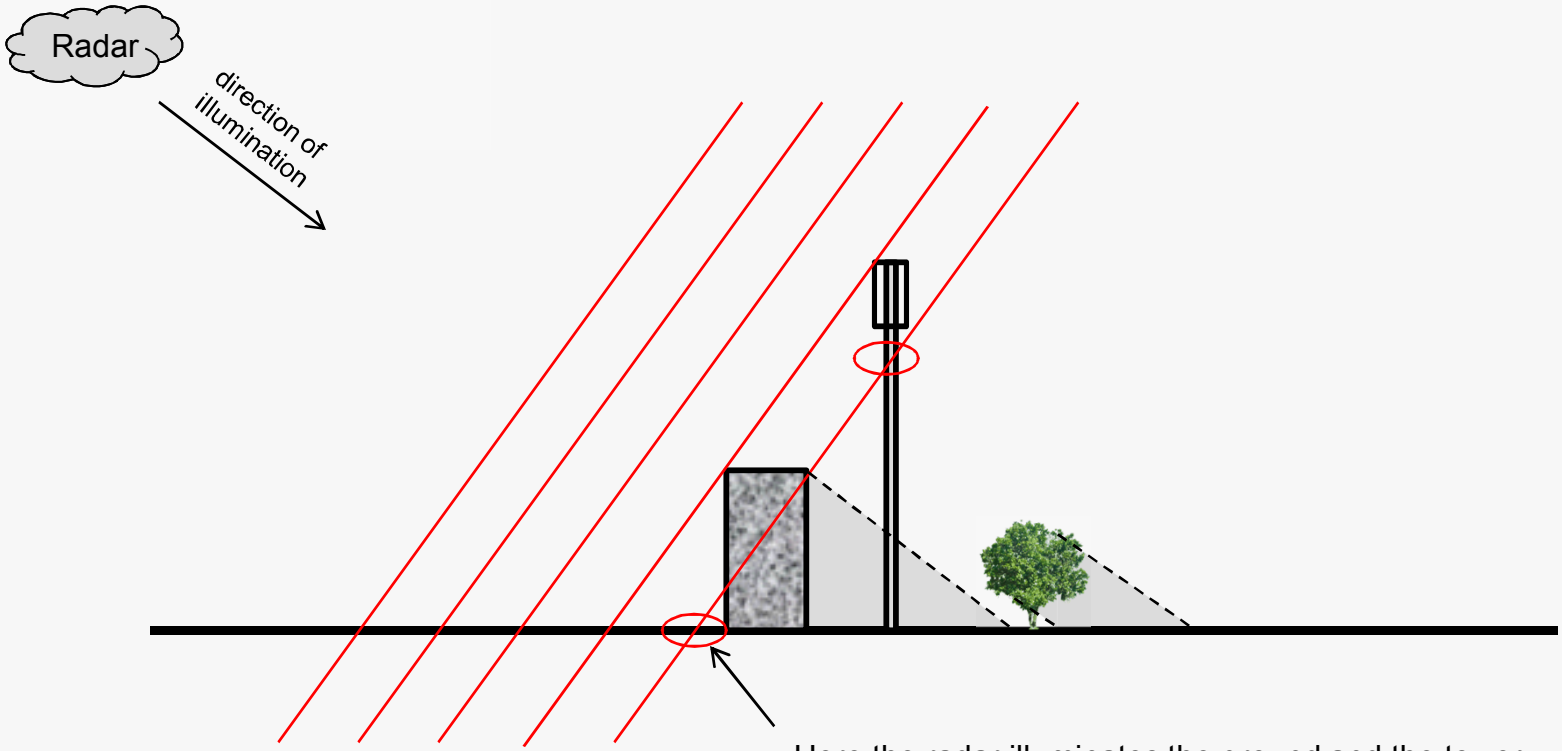


The radar illuminates all 3 targets, but what will you see in the final image?

If these 3 targets appear at the same azimuth position, and thus in the same range-azimuth bin (pixel), you will see the sum of their gray-level values (often only the brightest one).

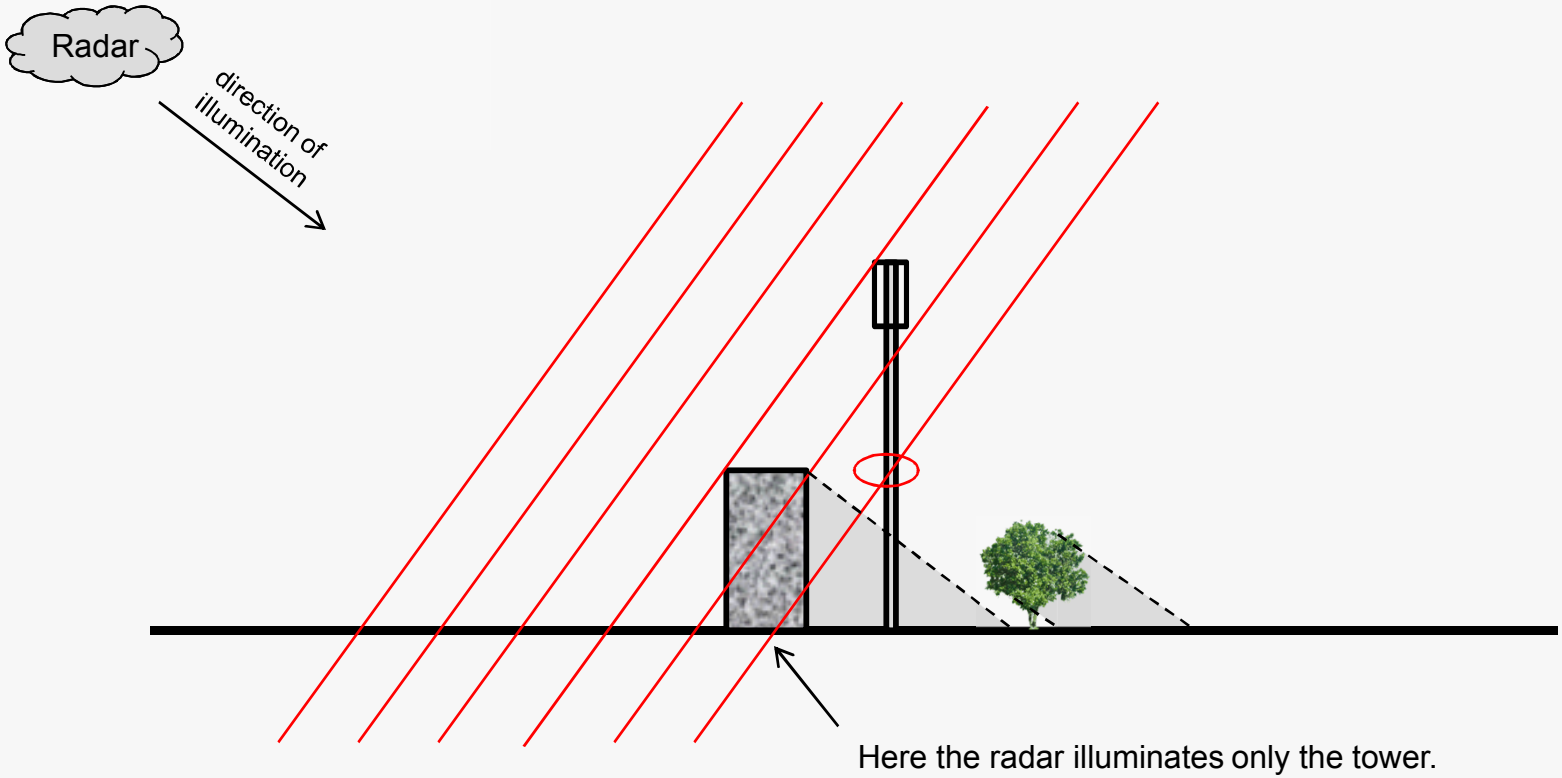
BACK LAYOVER & SHADOWS

Range Layover



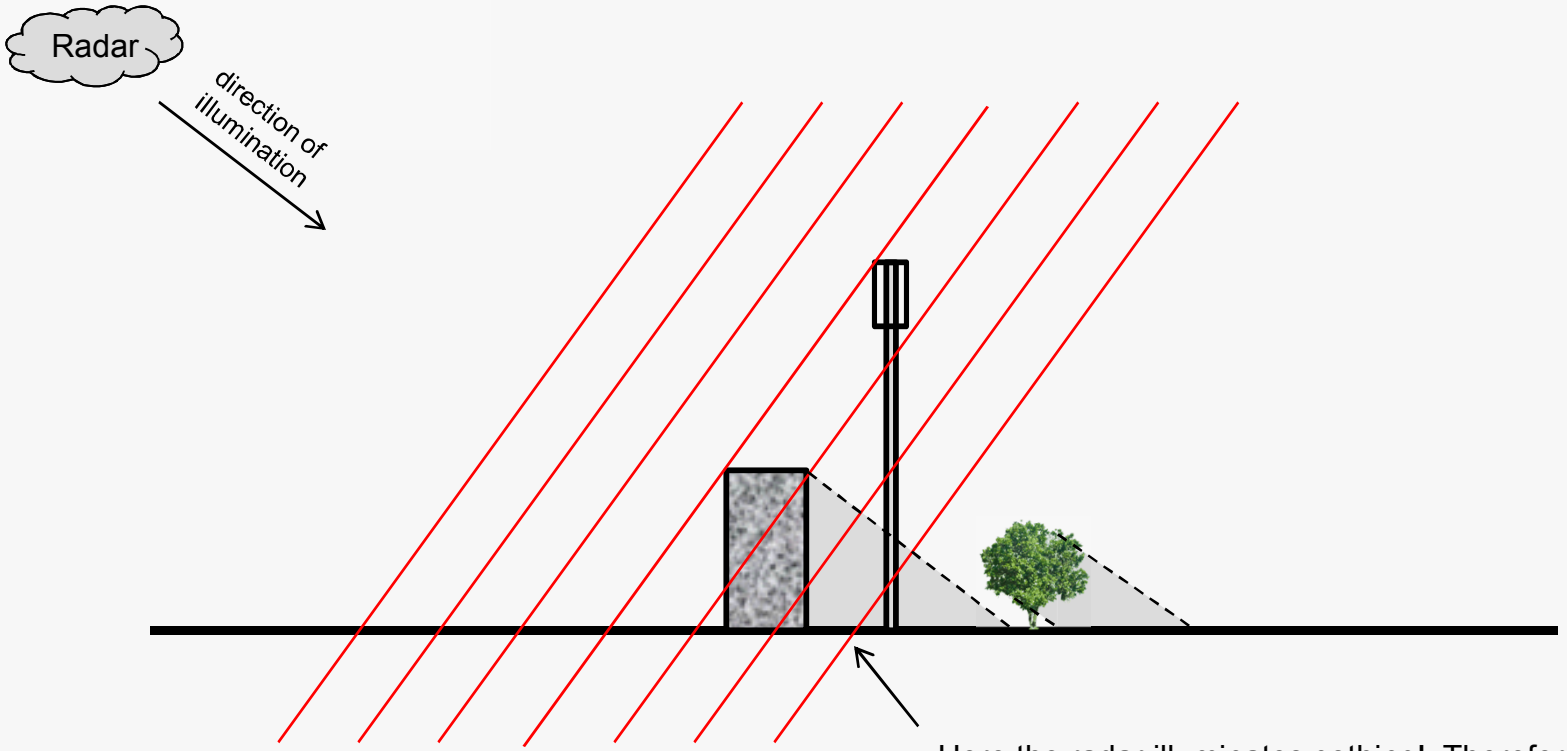
BACK LAYOVER & SHADOWS

Range Layover



BACK LAYOVER & SHADOWS

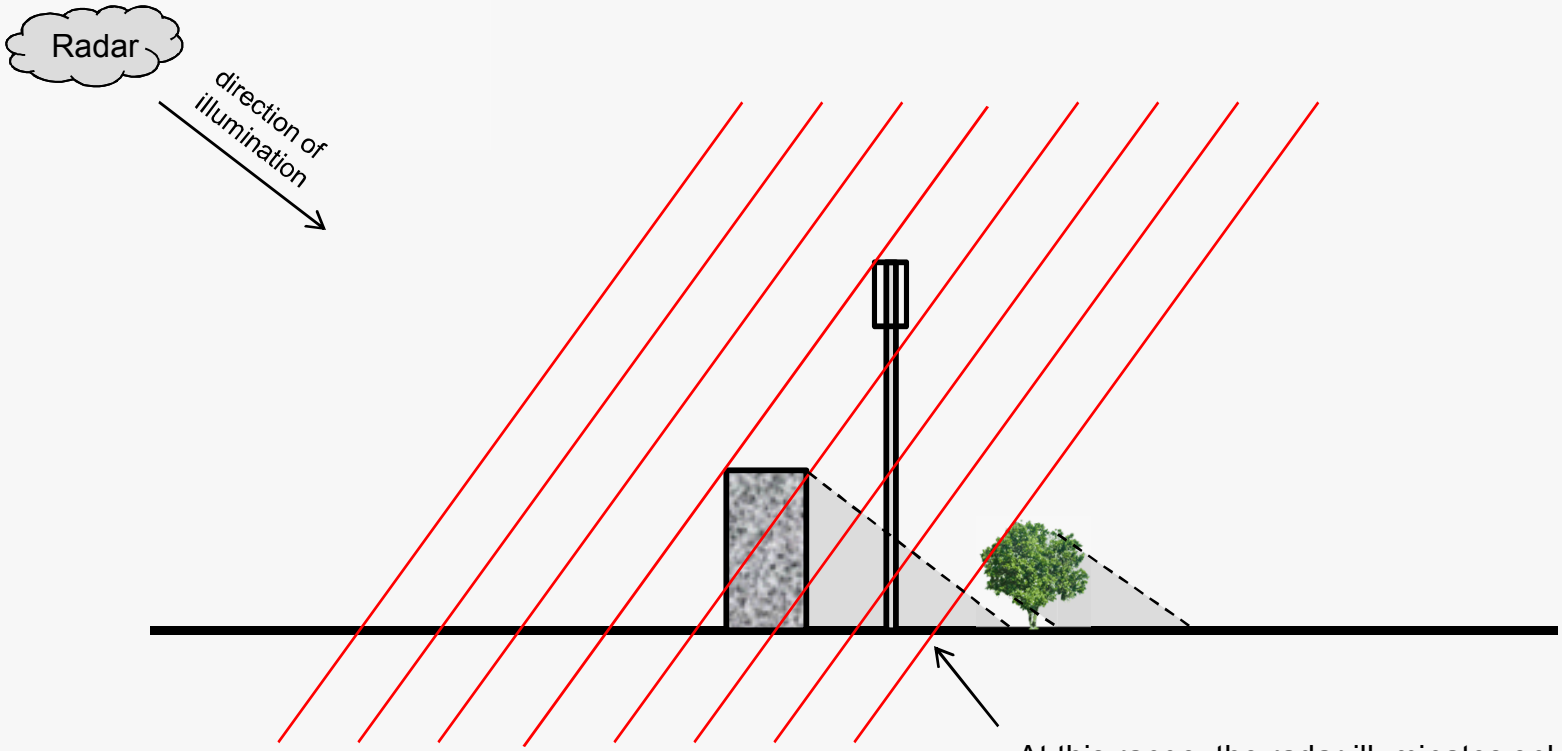
Range Layover



Here the radar illuminates nothing! Therefore only a shadow appears in the corresponding range-azimuth bin (pixel).

BACK LAYOVER & SHADOWS

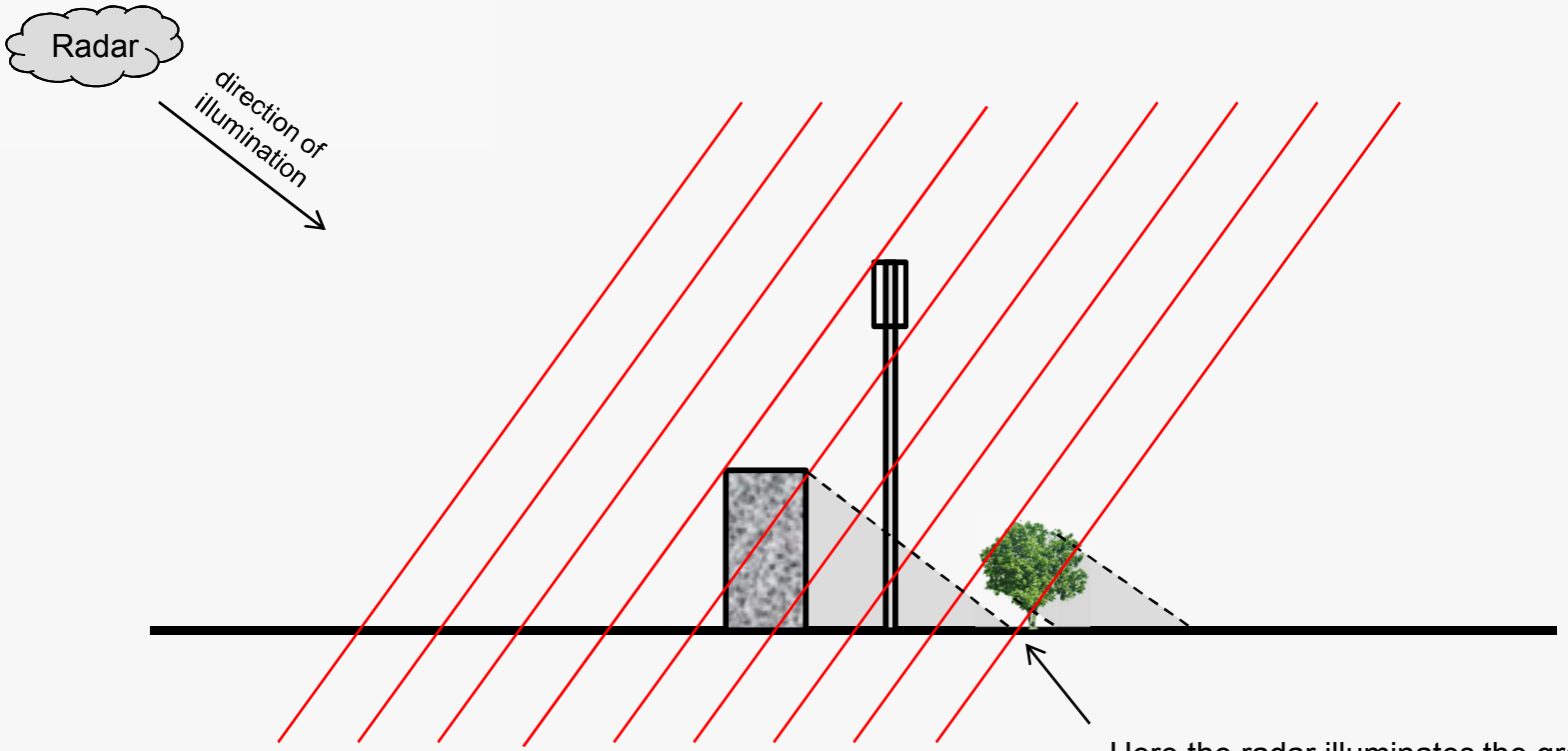
Range Layover



At this range, the radar illuminates only the tree. Note that the image of the tree appears at the same range as the shadow of the building (it “lays over” onto the image of the shadow).

BACK LAYOVER & SHADOWS

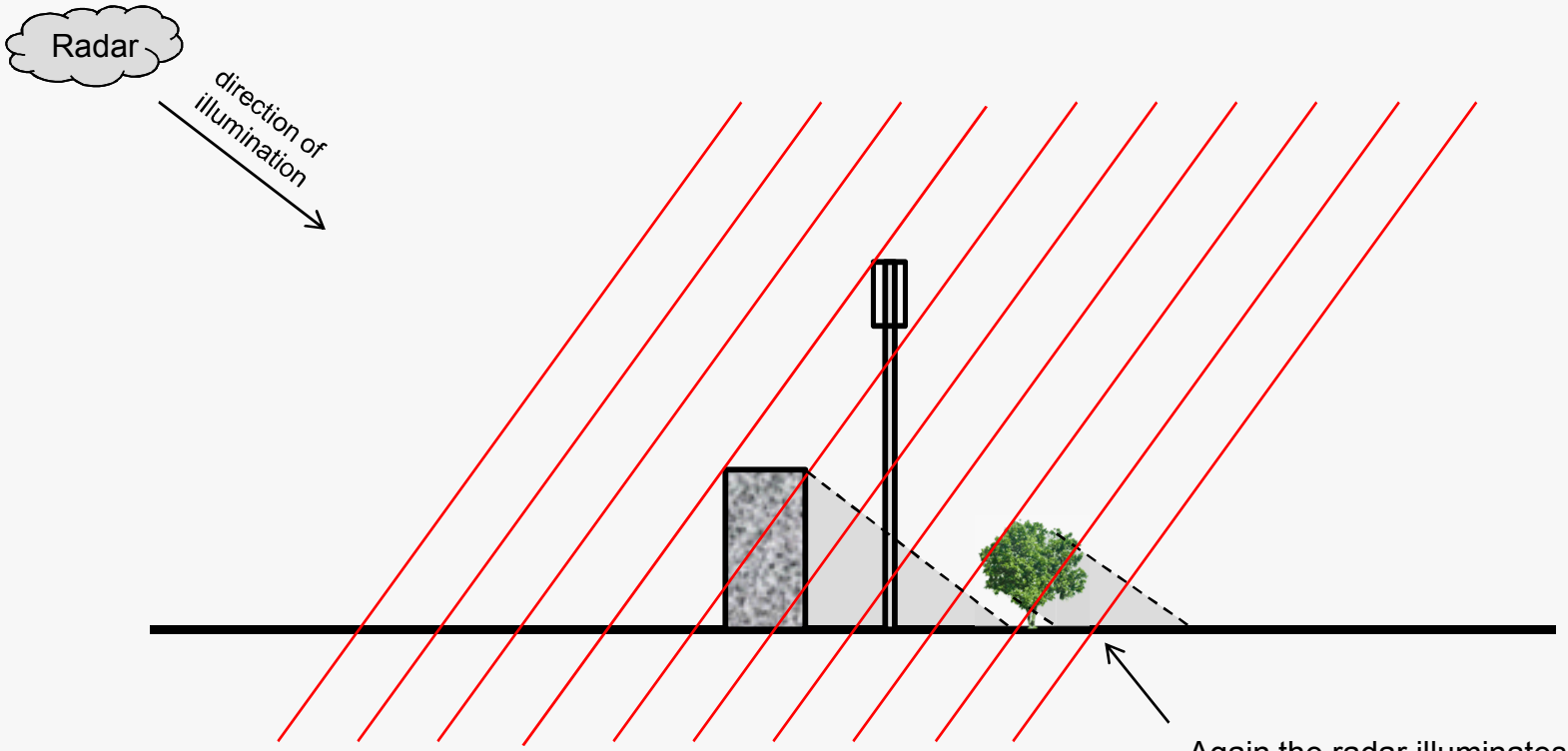
Range Layover



Here the radar illuminates the ground just ahead of the tree trunk. This gives the appearance, in the radar image, that you can see “under” the tree!

BACK LAYOVER & SHADOWS

Range Layover

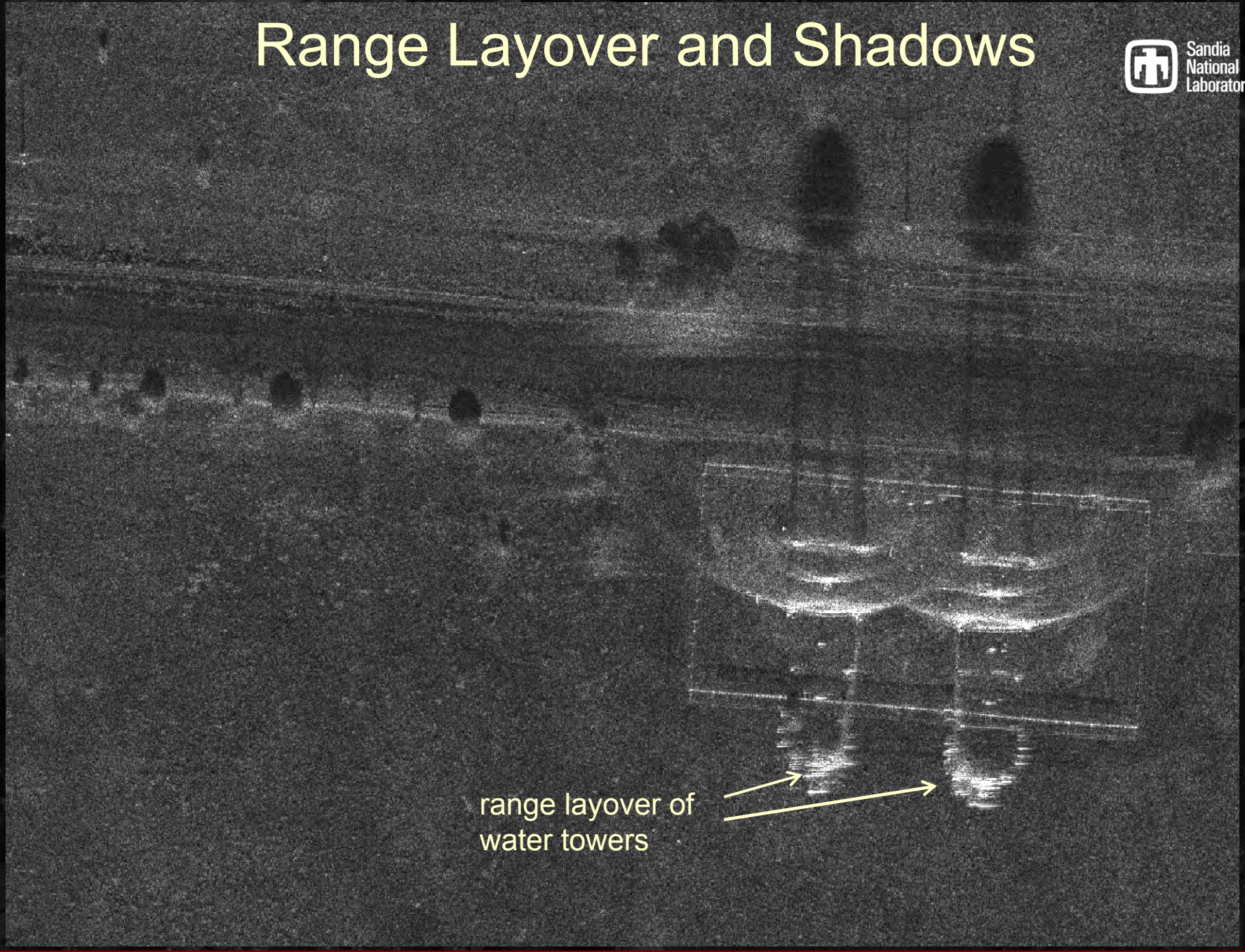


Again the radar illuminates nothing, so only shadow appears in the image.

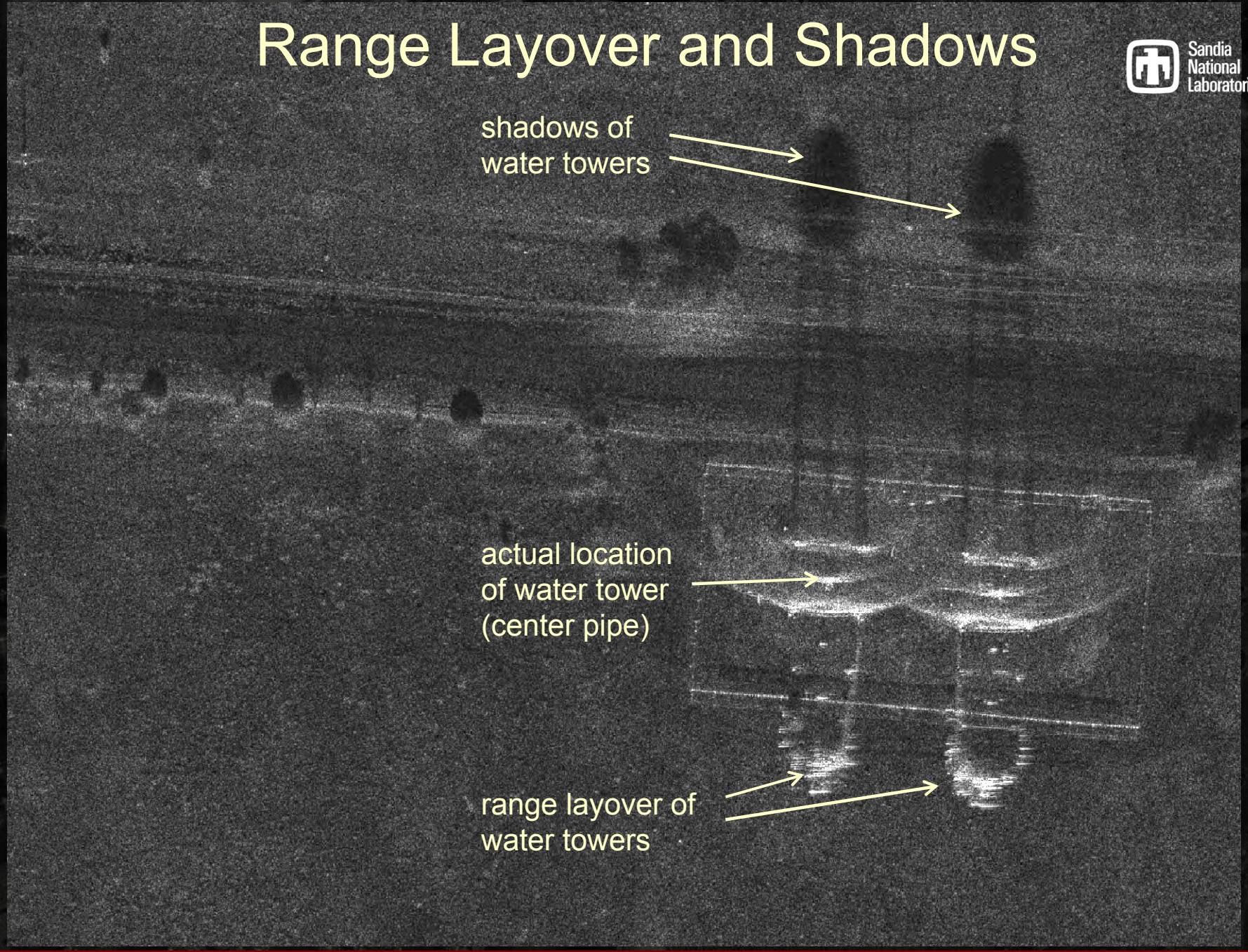
BACK LAYOVER & SHADOWS

Range Layover and Shadows

Range Layover and Shadows



Range Layover and Shadows



Range Layover and Shadows

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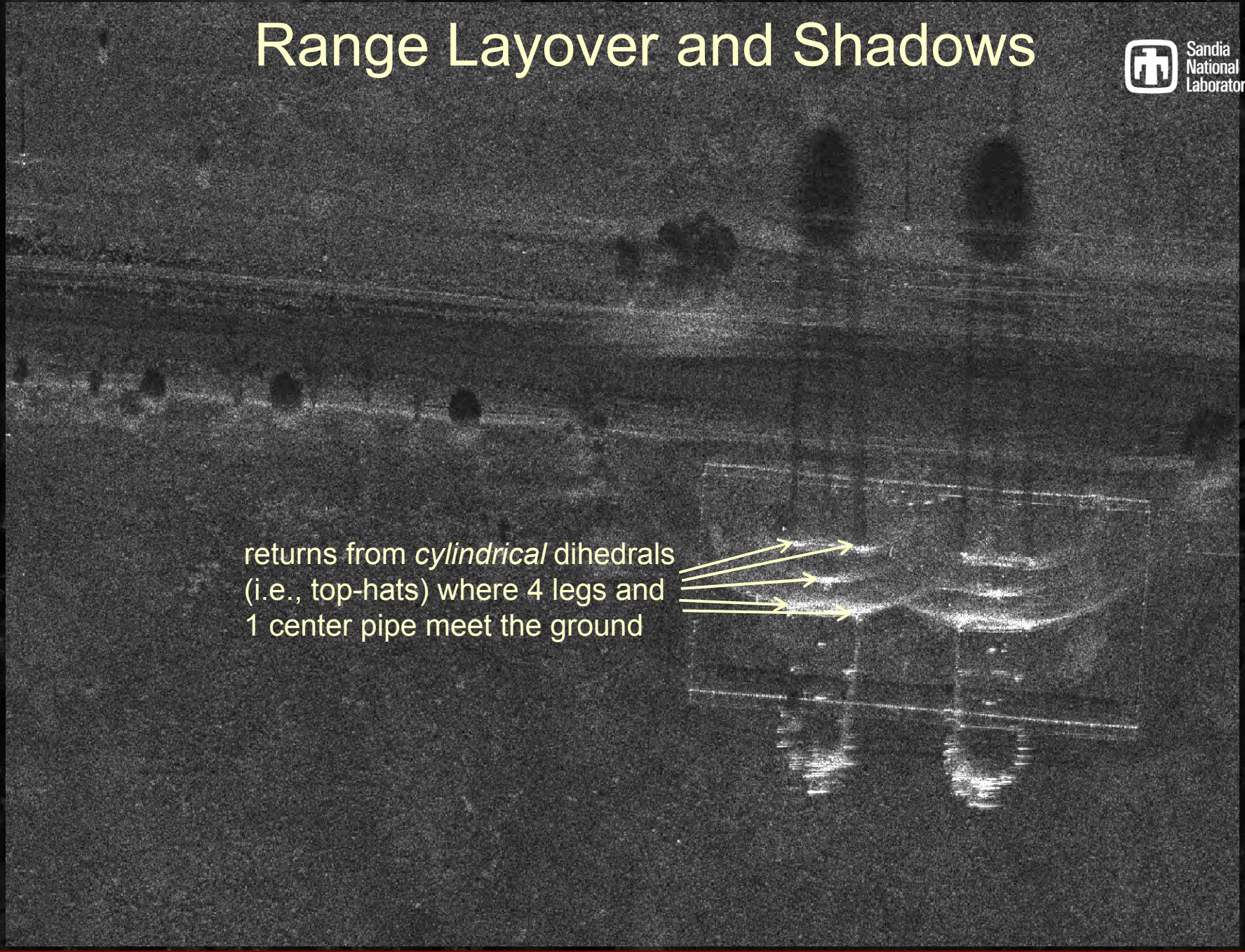
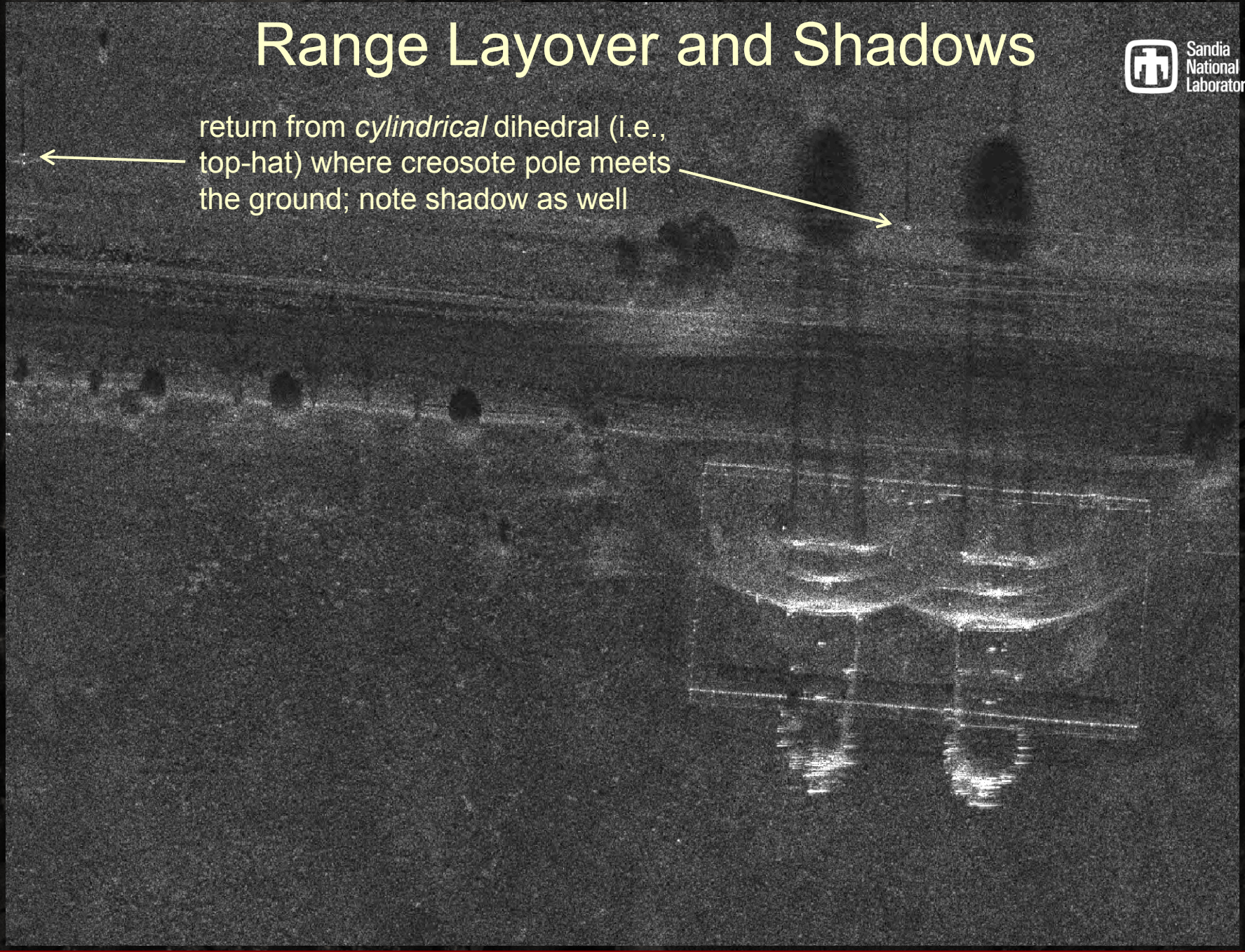


Range Layover and Shadows



Range Layover and Shadows

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Airborne ISR at Sandia

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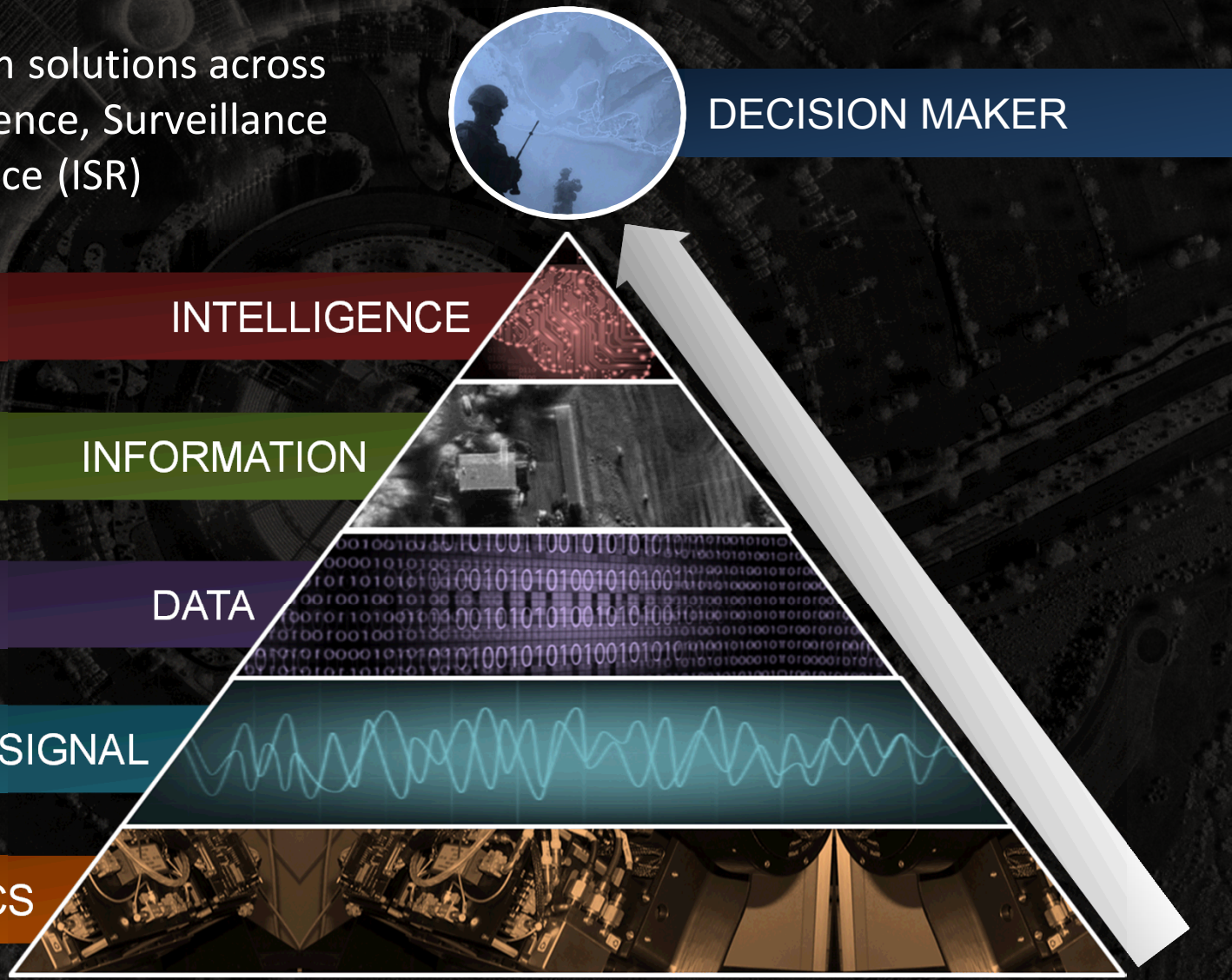
Provider of system solutions across the entire Intelligence, Surveillance and Reconnaissance (ISR) architecture



Working with Sandia

Sandia National Laboratories

- Collaborations through USGIF
- In process: access to high resolution SAR datasets
- University Partnerships
  - http://www.sandia.gov/working_with_sandia/technology_partnerships/universities/index.html
- Careers/internships
  - http://www.sandia.gov/careers/students_postdocs/index.html

SUMMARY

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SANDIA VIDEOS

- Sandia's presentation at 2016 USGIF Symposium: https://vimeo.com/169916541
- Sandia's YouTube Channel
- Sandia's Remote Sensing and Surveillance Technologies: https://www.youtube.com/watch?v=7L_L6CmFPg4&feature=youtu.be

Thank You!

www.sandia.gov/radar/