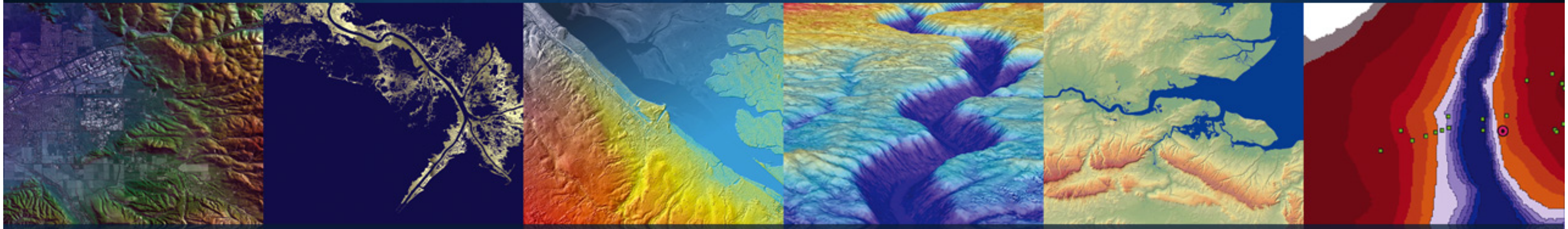
INTERMAP™ TECHNOLOGIES



Country-Wide 3D Mapping by Airborne InSAR

CEOS 2009, Pasadena

Bryan Mercer, Intermap Technologies

Contents

- Introduction
- The NEXTMap Program
  - Status
  - How it has been accomplished
  - Validation
  - Some applications and derived products
- Single-Pass L-Band PolInSAR
  - Background
  - Forest height and bare earth test results

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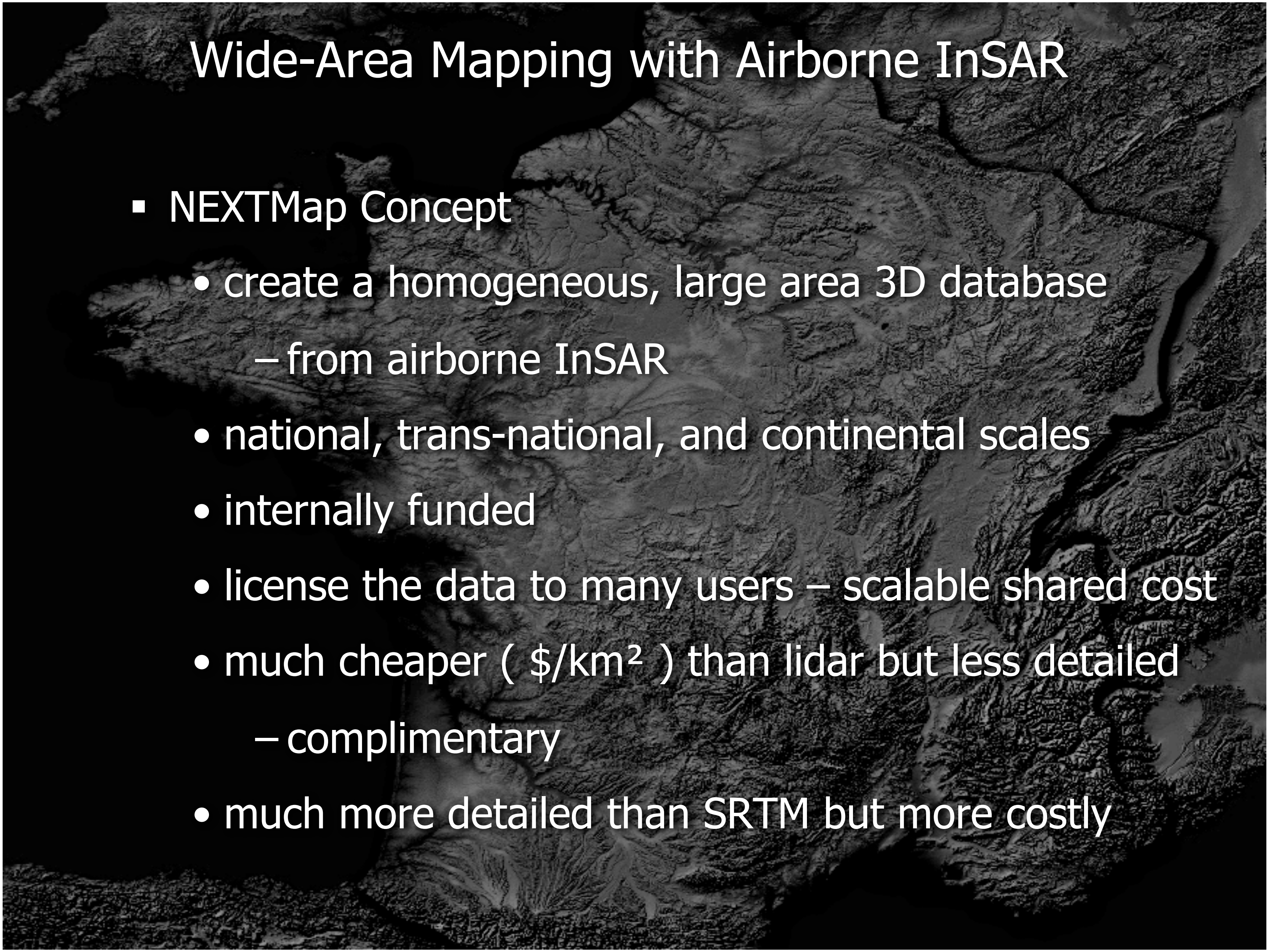
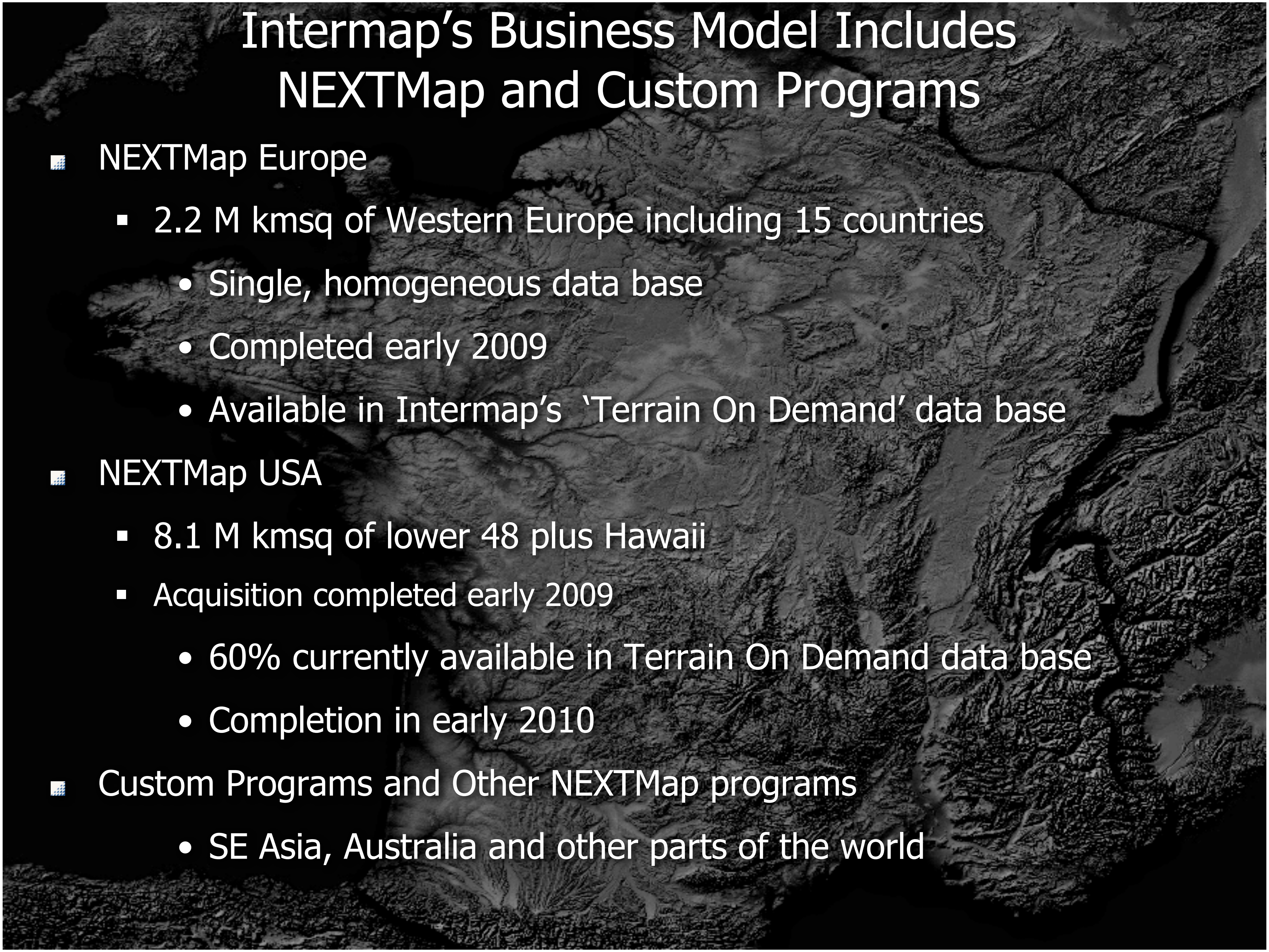


Wide-Area Mapping with Airborne InSAR

- NEXTMap Concept
  - create a homogeneous, large area 3D database
    - from airborne InSAR
  - national, trans-national, and continental scales
  - internally funded
  - license the data to many users – scalable shared cost
  - much cheaper (\$/km^2) than lidar but less detailed
    - complimentary
  - much more detailed than SRTM but more costly

Intermap’s Business Model Includes NEXTMap and Custom Programs



- NEXTMap Europe
  - 2.2 M kmsq of Western Europe including 15 countries
    - Single, homogeneous data base
    - Completed early 2009
    - Available in Intermap’s ‘Terrain On Demand’ data base
- NEXTMap USA
  - 8.1 M kmsq of lower 48 plus Hawaii
  - Acquisition completed early 2009
    - 60% currently available in Terrain On Demand data base
    - Completion in early 2010
- Custom Programs and Other NEXTMap programs
    - SE Asia, Australia and other parts of the world

STAR InSAR: ORI

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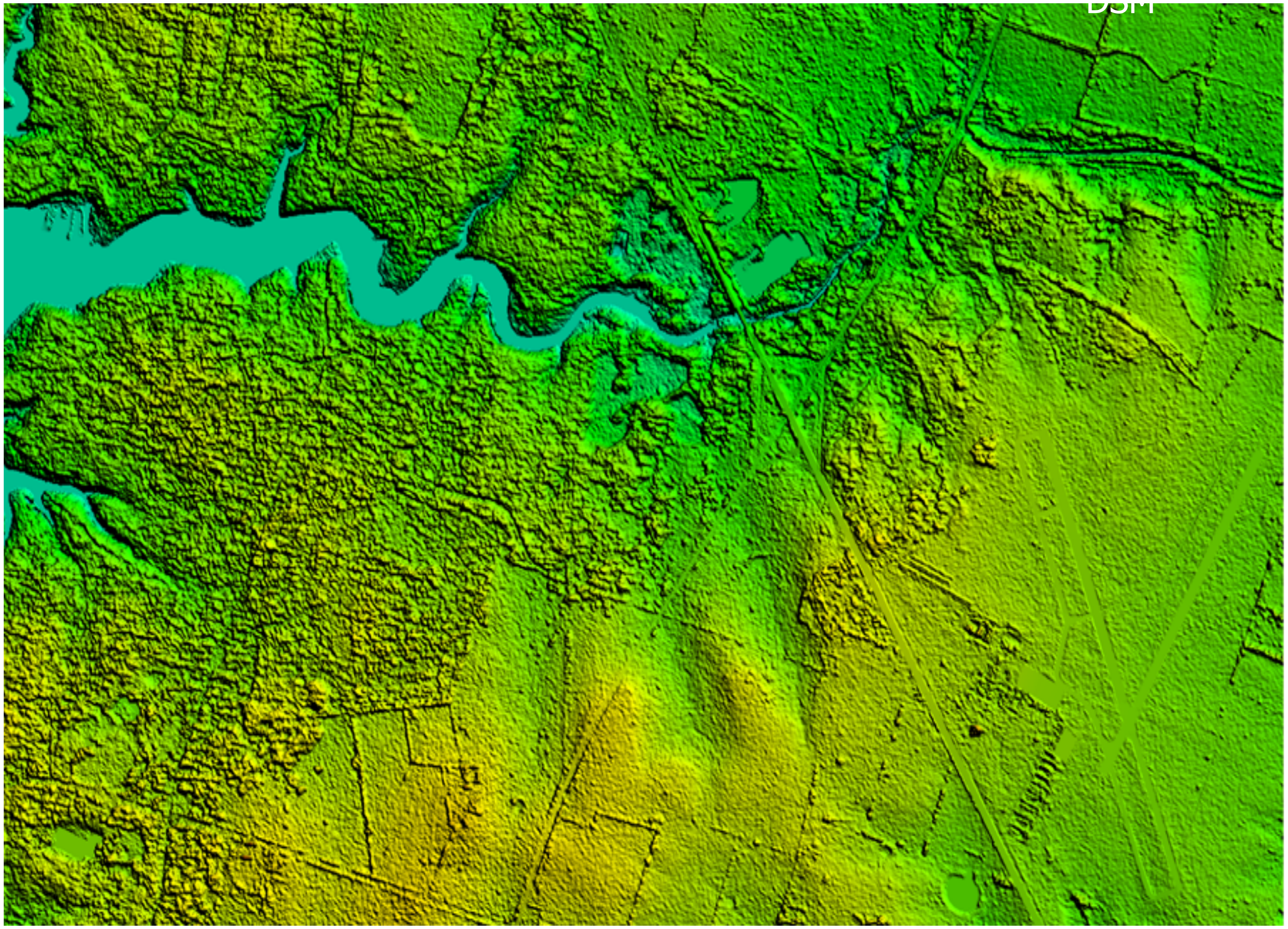
STAR InSAR: DSM



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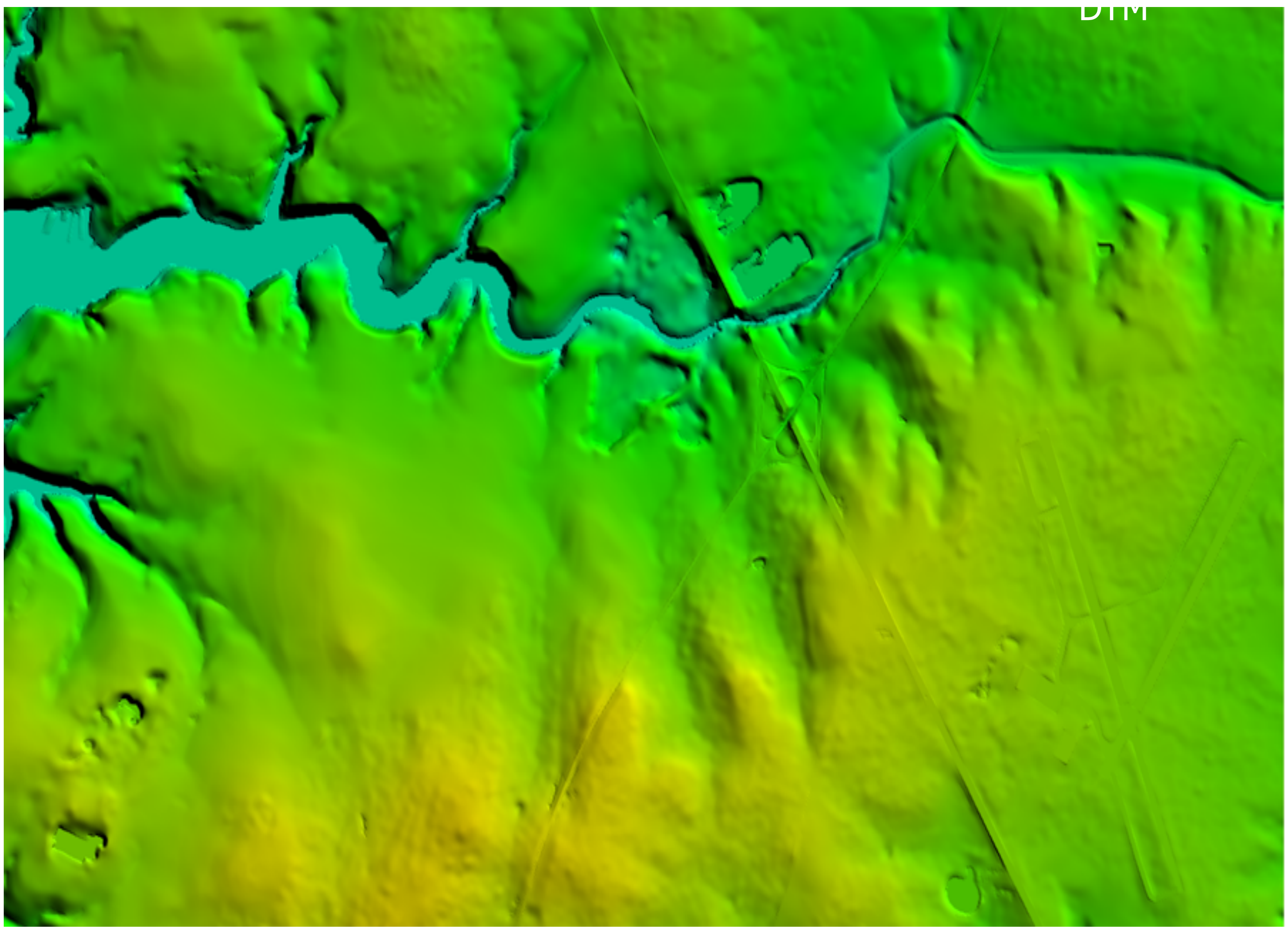
DTM (derived from DSM)



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InSAR Product Types and Specifications

	DSM (m)		DTM (m)		ORI (m)	
	RMSE	Spacing	RMSE	Spacing	RMSE	Pixel
Type I+	0.5	5	0.7	5	<2	0.625
Type I	0.5	5	0.7	5	2	1.25
Type II	1	5	1	5	2	1.25
Type III	3	5	-	-	-	1.25

Notes:

- **NEXTMap Europe is Type II**
  - **except for Ireland (Type I+) and SE England (Type I)**

- **Vertical accuracy specifications apply only to bare, unobstructed terrain with slopes <10°**

- **ORI:**
  - **RMSE refers to horizontal (circular) error**
  - **Pixel refers to pixel spacing which is close to the resolution**

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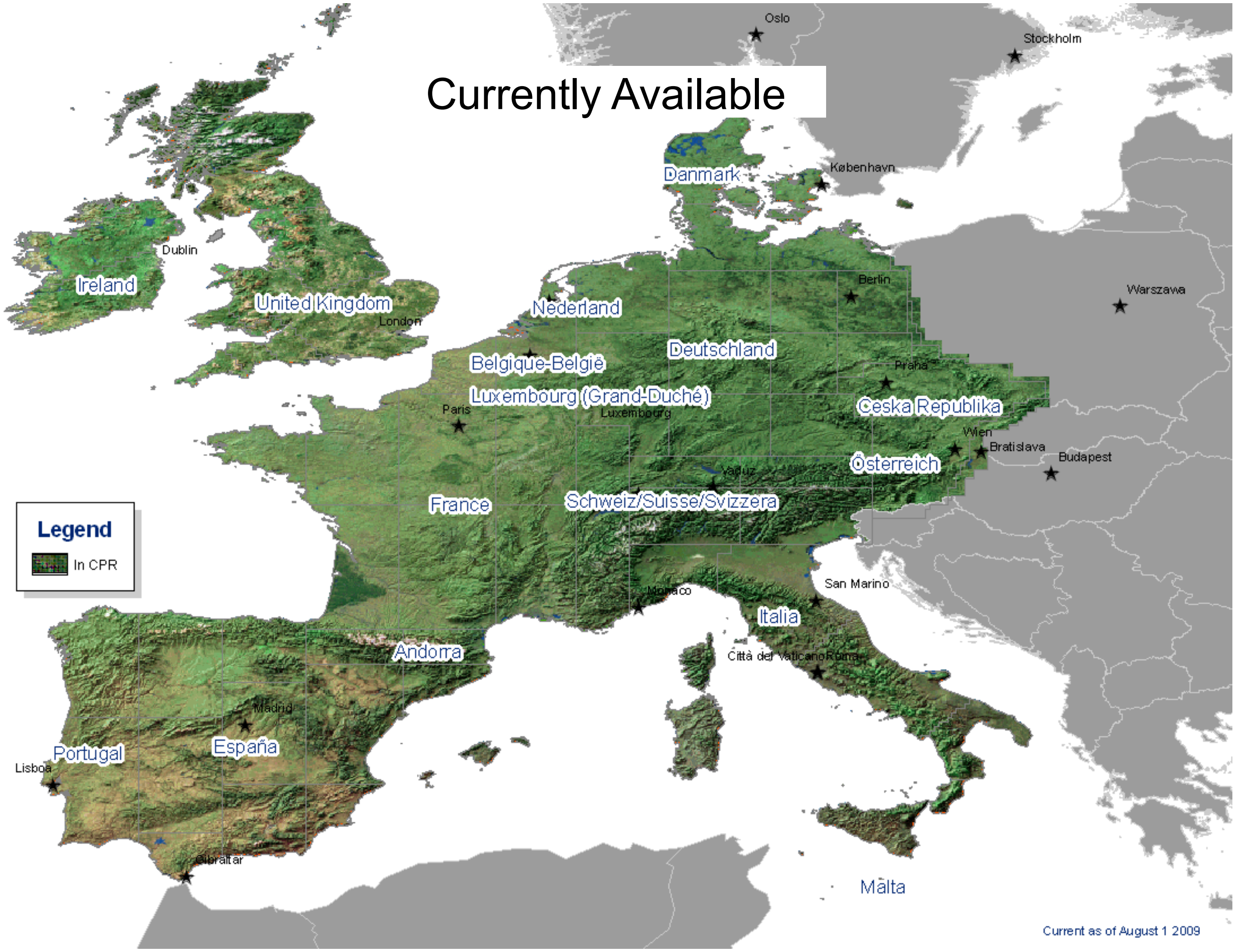
NEXTMap Europe Coverage



The fifteen countries currently in the NEXTMap Europe data-set include:

Austria,
Belgium,
Czech Republic,
Denmark,
France,
Germany,
Ireland,
Italy,
Luxembourg,
Malta,
Netherlands,
Portugal,
Spain,
Switzerland,
United Kingdom.

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Data Acquisition Complete

- 8 million km^2
- 57% complete & in the library
- Complete and commercially available early 2010

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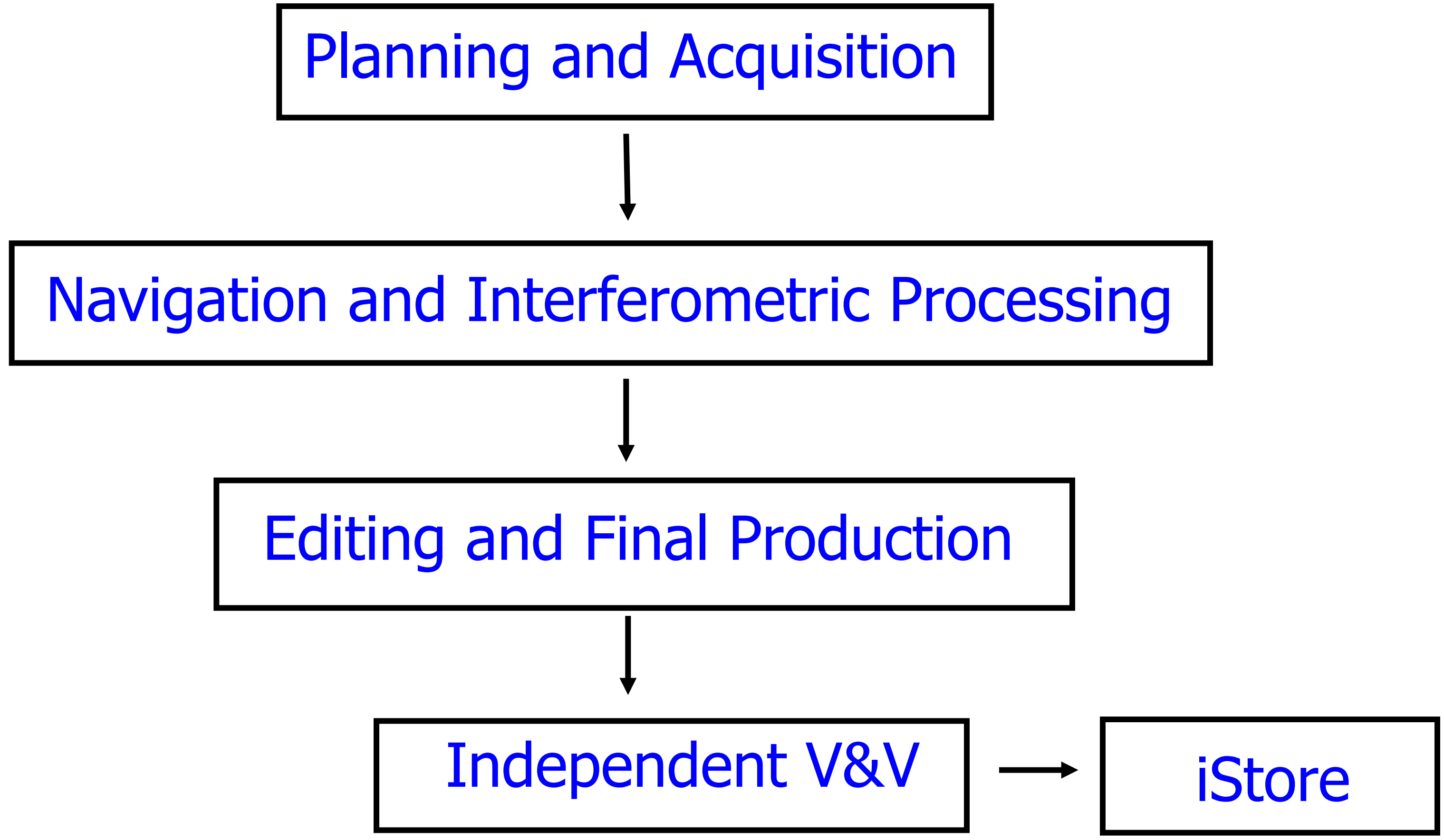
How is this accomplished?



Planning and Acquisition

Navigation and Interferometric Processing

Editing and Final Production

Independent V&V

iStore

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Acquisition: Four Platforms Provided Capacity and Redundancy


1


2


3


4

Intermap Platforms:

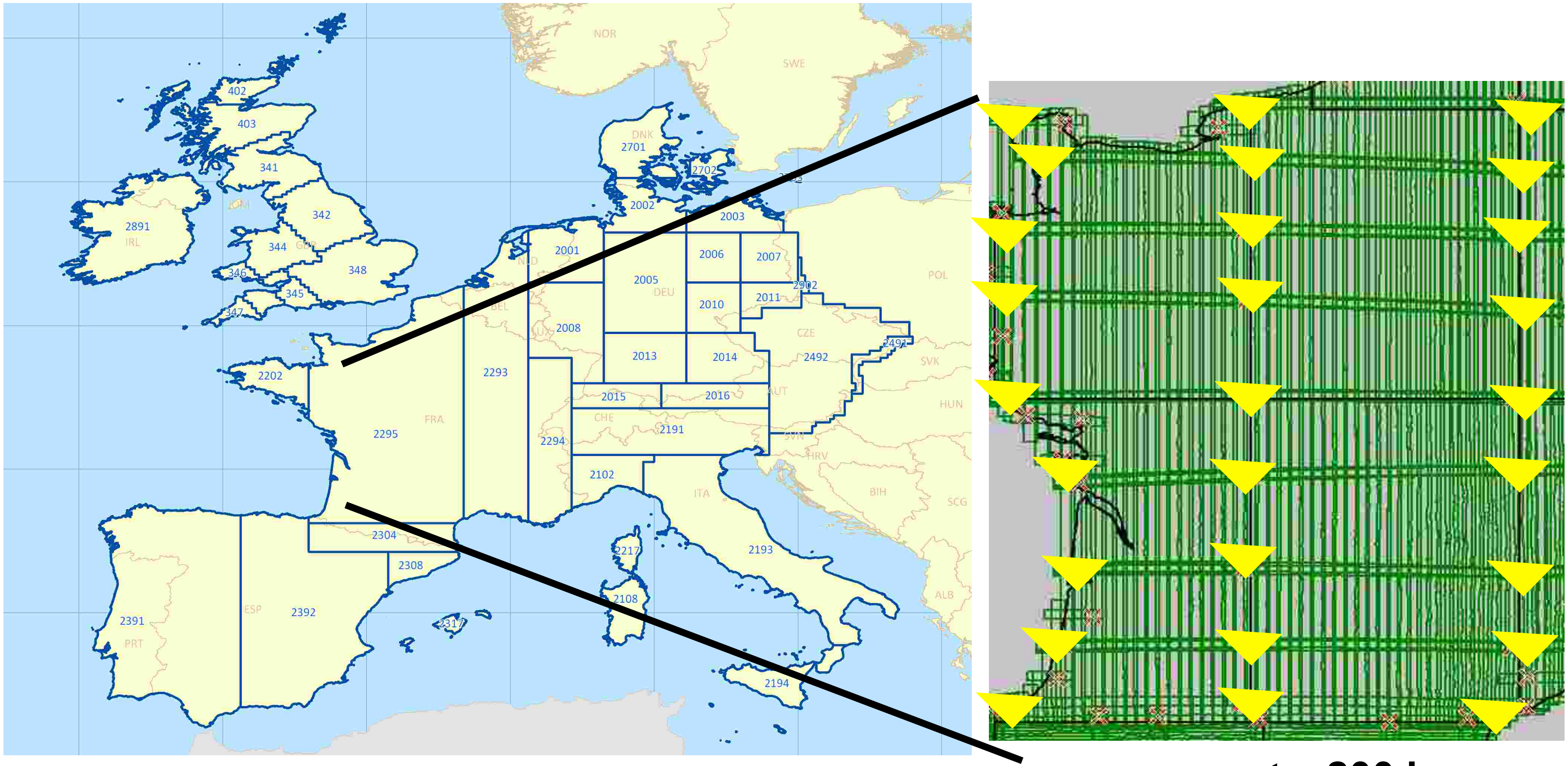
1. STAR-3 (upgraded in 2002)
2. STAR-4 (developed in 2004)
3. STAR-5 (added in 2006)
4. STAR-6 (added in 2007)

Characteristics (LearJet Platforms):

- Altitude 9 - 10 km
- Swath 8.5 – 10.5 km
- Speed 700 km/hr

Combined acquisition capacity has grown from 300,000 km^2/yr to 5,000,000 km^2/yr

Planning and Acquisition: Block Structure, Tie Lines and Reflectors



- Swath width approx 10 km,
- Sidelap varies depending on terrain
- Vertical lines are the primary data
- Horizontal lines are tie lines
- Yellow triangles are GPS surveyed 'corner reflectors'

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Navigation and Interferometric Processing

- Navigation Solution (from Kalman Filtered GPS/INU)
- Interferometric Processing
  - Motion compensation
  - SAR processing
  - Interferometric processing
  - Block adjustment (tie lines, absolute reflector coordinates)
  - Geocoding, mosaicking, tiling >> ORI, DSM (unedited)
    - Ready to go to editing
- Automated
- Scalable (can keep up with acquisition)
- Current capacity 5 million kmsq/year

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Editing and Production

- Stereo viewing environment
  - Editing tools (internally developed)
- DSM feature editing
  - Hydrology: Lakes, rivers, ocean
  - Transportation Features: Highways, Railways, Airports, Docks
  - Radar Anomalies
- DTM Editing
  - First stage automated
    - Removes buildings, power poles, clusters of trees
  - Streams
  - Supported by Ancillary data, particularly in difficult areas
- Output format

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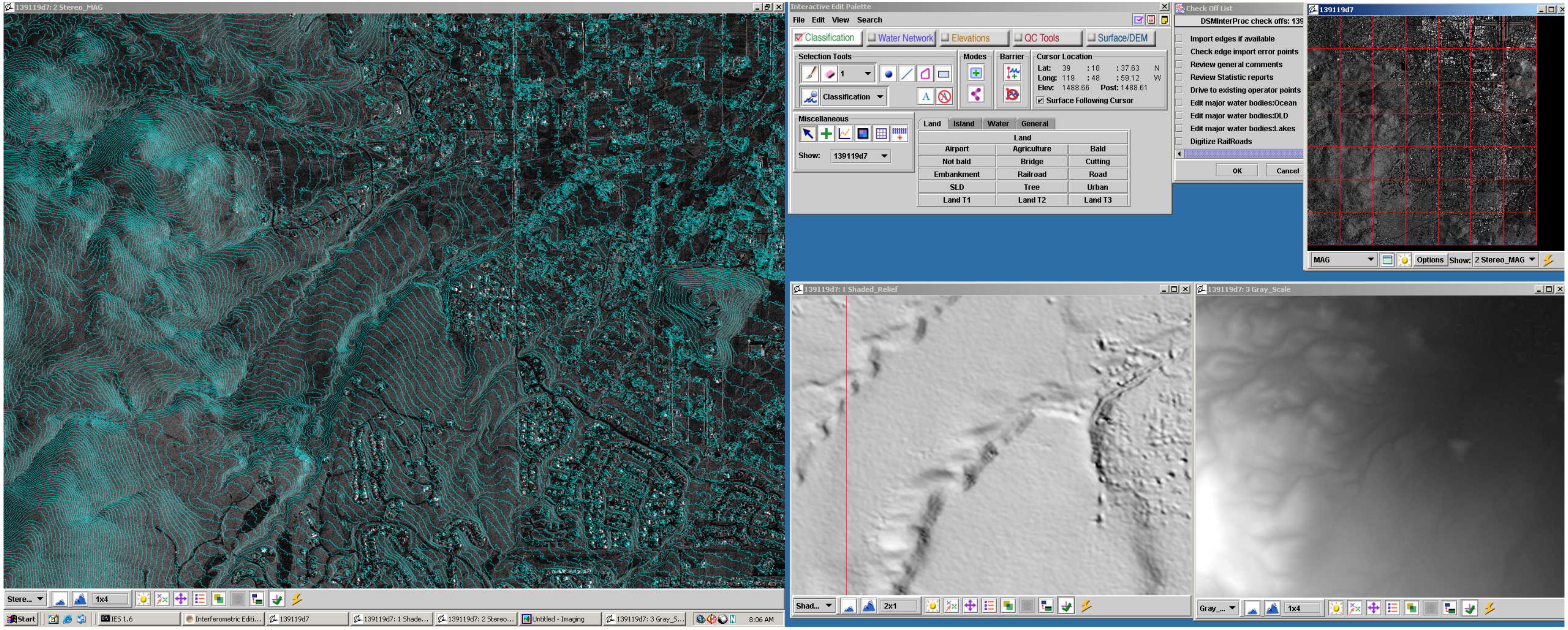
DSM and DTM Editing

- Proprietary Interferometric Editing System (IES) software used to edit DEM data.
  - Takes place in a 3D environment.
  - Semi-automated for consistency.
  - Work off a well defined set of editing rules.
- Currently 150 workstations



Lat: 39 :18 :37.63 N
Long: 119 :48 :59.12 W
Elev: 1488.66 Post: 1488.61
☑ Surface Following Cursor

Land		
Airport	Agriculture	Bald
Not bald	Bridge	Cutting
Embankment	Railroad	Road
SLD	Tree	Urban
Land T1	Land T2	Land T3

DSMInterProc check offs: 139

- ☐ Import edges if available
- ☐ Check edge import error points
- ☐ Review general comments
- ☐ Review Statistic reports
- ☐ Drive to existing operator points
- ☐ Edit major water bodies:Ocean
- ☐ Edit major water bodies:DLD
- ☐ Edit major water bodies:Lakes
- ☐ Digitize RailRoads

OK Cancel

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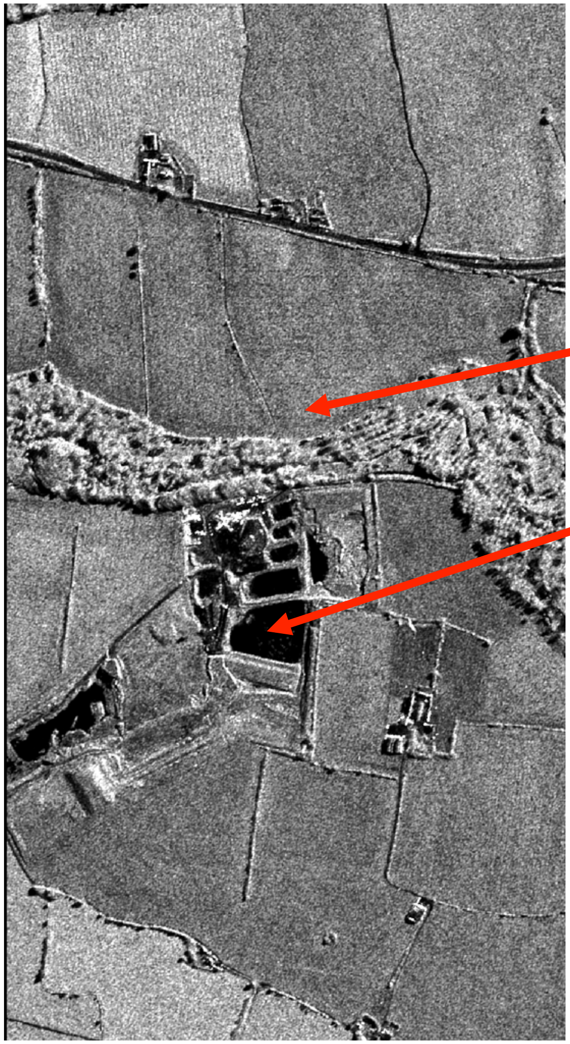
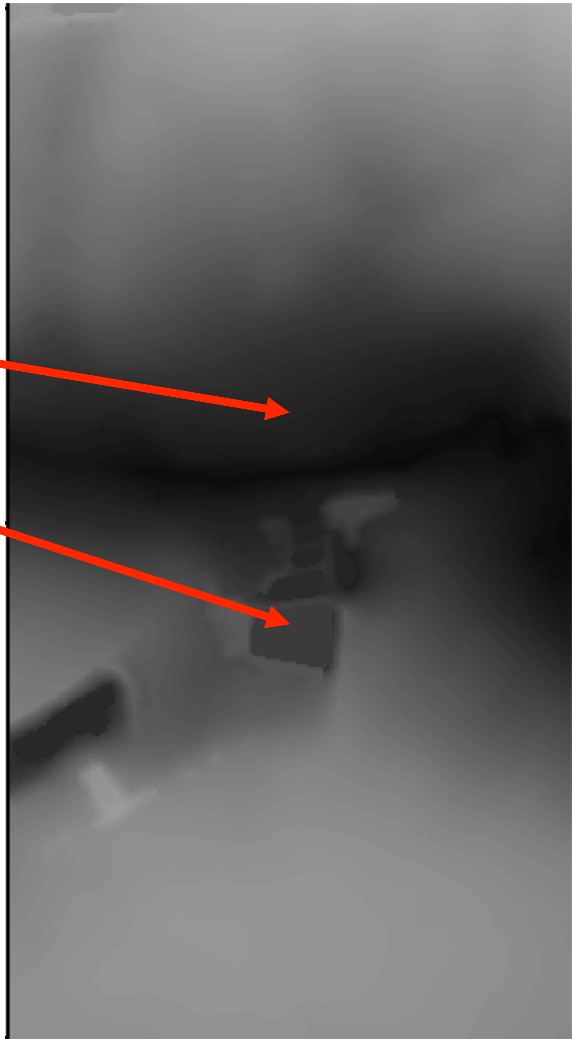
For example editing water bodies



- ORI and DTM
- river valley and trees
- water bodies are edited to a constant elevation



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Independent Verification & Validation

- Utilize 3rd party data for validation
  - Typically survey markers from government agencies
- Re-process control survey data
- Examination of final products versus stated specifications

- Release to iStore

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Country-based Validation Statistics

- 'Validation Check Points' (VCPs) from national survey data bases used as reference
- All survey reports checked for suitability before validation process
  - Where possible, also checked on airphoto
  - Excluded from validation process if obstructed or on slope >10°
- Reports created for each country
  - First 5 NEXTMap Europe country validation results shown below
    - mean spacing of VCPs ~5 km (but variable)
  - Similar results for USA state reports
- Results well within Type II spec (1.0 m)

Difference Statistics (meters)	Belgium		France		Germany		Italy		Spain	
	DSM	DTM	DSM	DTM	DSM	DTM	DSM	DTM	DSM	DTM
Mean	0.23	0.12	0.01	-0.22	0.01	-0.16	-0.11	-0.38	0.22	-0.27
Standard Dev'n	0.57	0.58	0.53	0.59	0.68	0.68	0.60	0.78	0.67	0.73
RMSE	0.61	0.58	0.53	0.63	0.68	0.69	0.61	0.87	0.70	0.78
95 Percentile	1.18	1.10	1.06	1.33	1.42	1.47	1.13	1.85	1.38	1.59
No. Check Pts.	53	53	987	987	690	690	703	703	2619	2619

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Applications and Products: A Few Examples Follow

- **Mapping Services:**
  - **Image Orthorectification and Merging with Optical**
  - Base Mapping
  - Topographic Mapping
  - Geological Mapping
  - Vegetation Mapping
  - Urban Mapping
  - Land Cover Classification
- **Products:**
  - Contour Maps
  - **3D Roads for Automotive**
  - **3D Visualization**
  - **Off-road Recreational (PND, iPhone)**
  - Hybrid Hill Shader

- **Flight Simulation**
- Automotive Safety, Energy Savings, Mapping Convenience
- Infrastructure Design
- Environmental Planning
- Engineering Planning
- Telecommunications
- Land Slip Risk Assessment
- Biomass Study
- **Flood Risk Analysis**
- Hydrology
- Seismic Hazards
- Situational Awareness
- Change Detection

bmercer@intermap.com

Orthorectification of Optical Images

- NEXTMap ORI as source of GCPs (and CPs)
  - 1.25 m (or 0.625 m) pixel (GSD)
  - Fundamental accuracy limited by DSM accuracy
  - Large numbers available - robust
- NEXTMap DSM
- Applicable to
  - high or med resolution satellite images
  - air photo
- Demonstrated in 2001 with early Ikonos and subsequently with Quickbird and air photo
  - Following summer/winter Ikonos scenes totally different geometries

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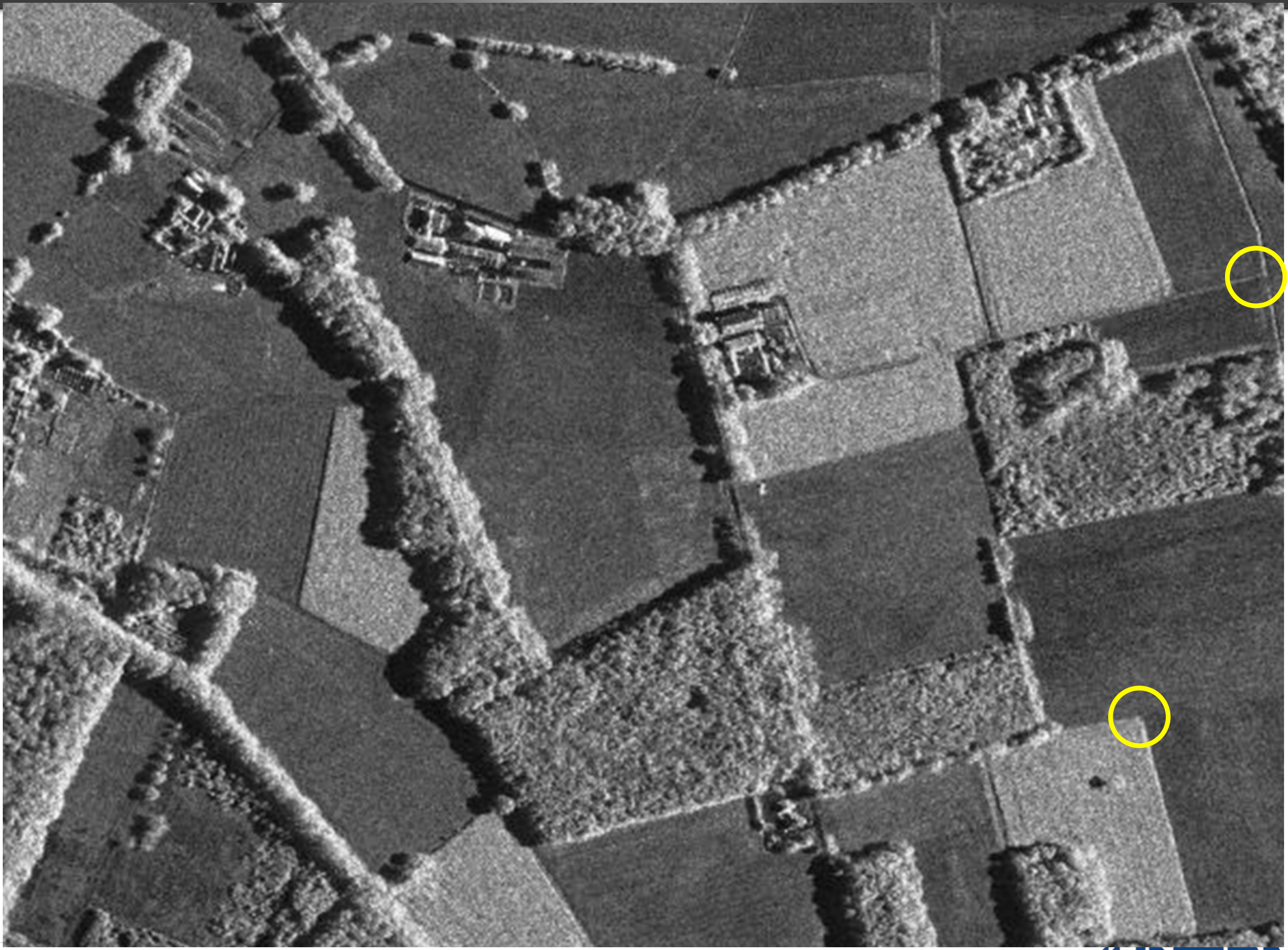
ORI as source of GCPs for optical ortho-rectification



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Winter Ikonos Scenes (orthorectified using ‘old’ STAR-3 data)

Derived RPCs from ORI/Ikonos match. Approx 2 m RMSE (abs)

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Summer Ikonos Scenes (orthorectified using 'old' STAR-3 data)

Derived RPCs from ORI/Ikonos match. Approx 2 m RMSE (abs)

bmercer@intermap.com

Visualization (various examples and applications)

- 2001 Ikonos scene – orthorectified (as shown previously) and draped over STAR-3i DSM in Denver, USA area

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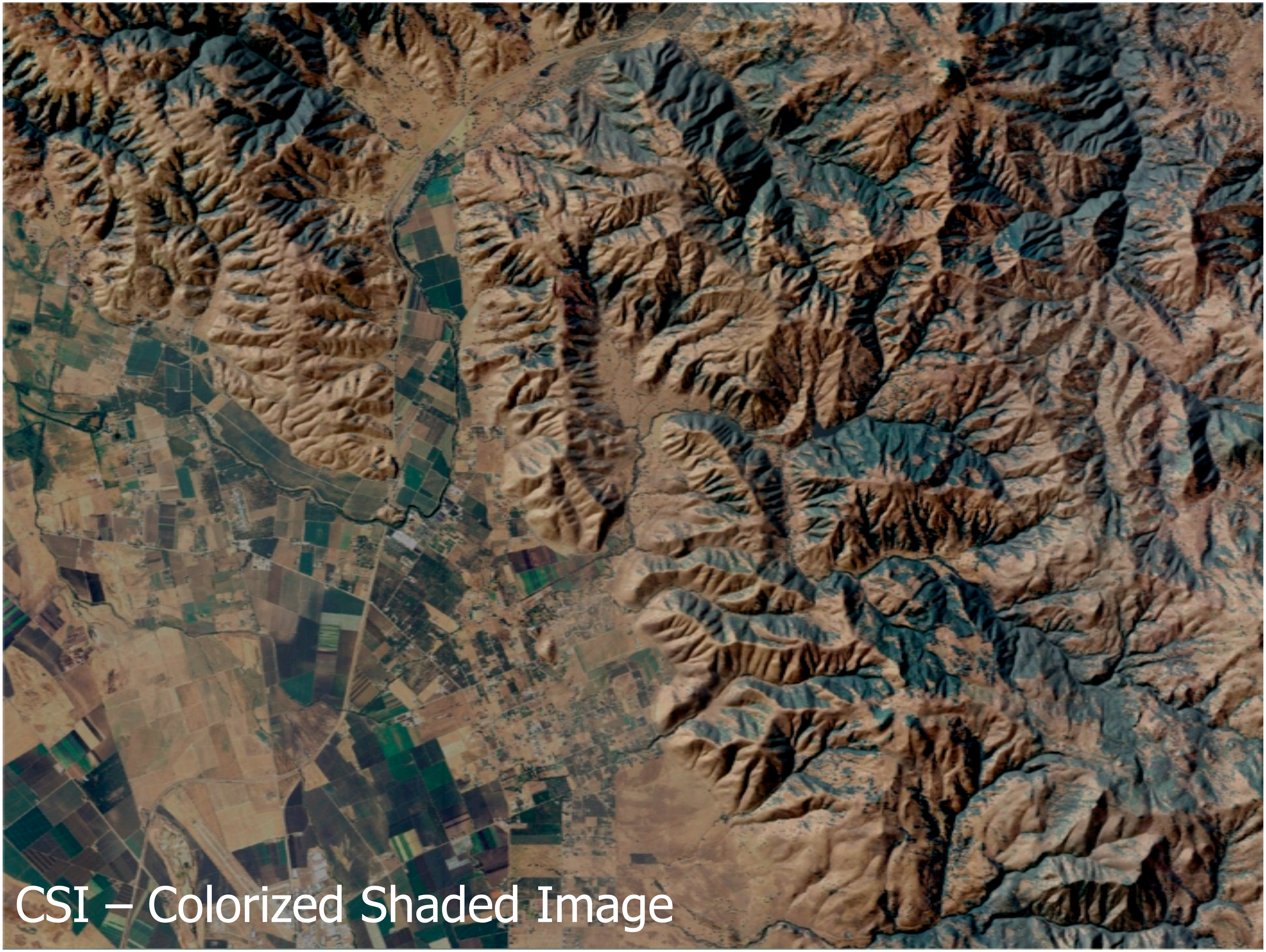

CSI – Colorized Shaded Image

Flight Simulation

Microsoft Flight Simulator: NEXTMap® *ProMesh*™ and FS Dreamscapes

Moving Map Displays

☑ ARPT
☑ VOR
☐ PROHIB
☑ TERR

☑ CLASS C
☑ NDB
☐ RESTR
☐ RIVERS

☑ TCA
☐ FIX
☐ FIR
☐ LAKES

From This

To THIS!

☑ ARPT
☑ VOR
☐ PROHIB
☑ TERR

☑ CLASS C
☑ NDB
☐ RESTR
☐ RIVERS

☑ TCA
☐ FIX
☐ FIR
☐ LAKES

Consumer Markets & Devices

3 Market Segments

Dedicated GPS

Off-road & Recreation Markets

Personal Navigation Device (PND)

Add 3D Terrain Views & Elevation Shaded Image layers

iPhone / SmartPhone

Launch additional platforms

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2D/3D Road Vectors for ADAS and Fuel Efficiency

- Scalable high volume collection of 3D road vectors

- Requirements:
  - CORE Products
    - DSM/DTM
  - 3D Work Station
  - Road Vector Collection Software

- Outputs:
  - 2D Road Vectors
  - 3D Road Vectors
  - 3D Drapes

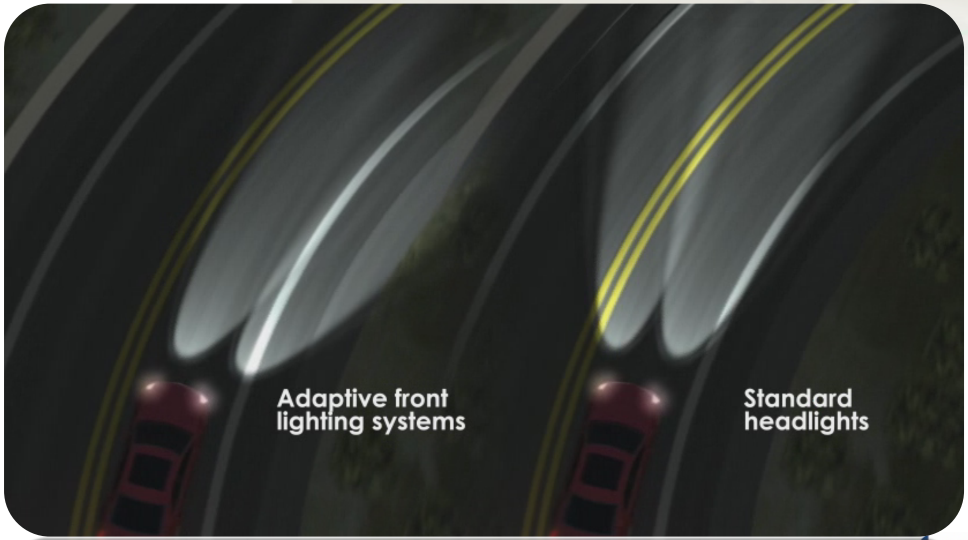
bmercer@intermap.com

Terrain View In-dash Navigation Systems

- Elevation data coupled with color image improves the display and makes it more intuitive for the driver

Automotive ADAS (Advanced Driver Assist Systems) and Powertrain Management for Trucks

Require 3D road vectors



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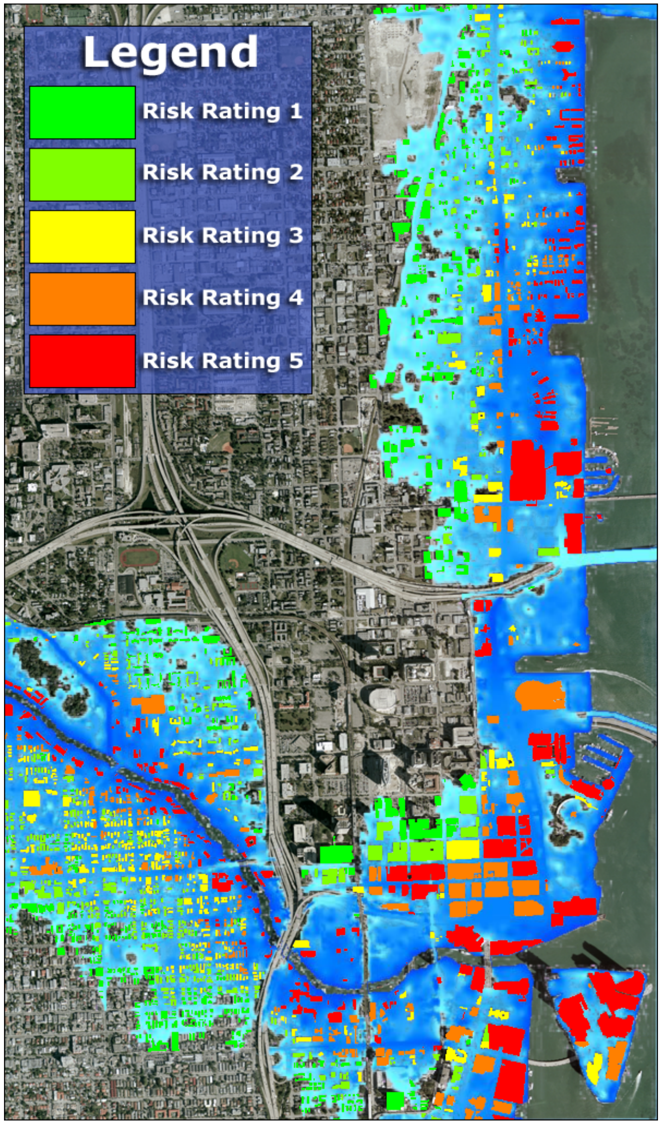
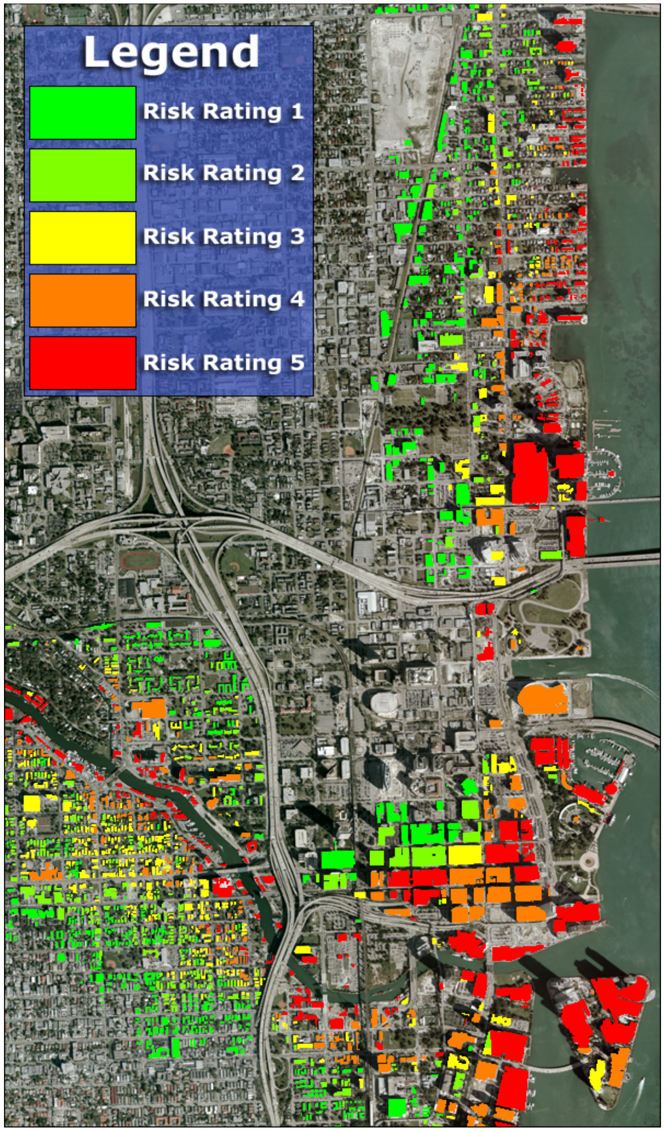
Flood Risk Assessment Product

Miami Beach: Category 5 Hurricane Storm Surge Model





Flythrough Demonstration: Snowdonia National Park, U.K.

Production by Horizon Simulation Ltd.
DSM by Intermap Inc.
Air Photos by Getmapping PLC

Summary

- We have provided an update regarding NEXTMap: the creation of trans-national, regional and continental scale 3D data-bases using airborne InSAR
    - NEXTMap Europe is now available for 15 + countries covering 2.2 million kmsq of western Europe through ‘Terrain-on-Demand’
    - NEXTMap USA will be completed in early 2010
- The vertical accuracy of DSM and DTM has been tested against several thousand independent check points distributed across each of the countries with RMSE values well under the 1.0 m Type II specification.
- A number of applications related to emerging markets were demonstrated (most were not)

bmercer@intermap.com

L-Band Single-Pass PolInSAR Demonstrated for Canopy and Ground Extraction

- A few slides from our IGARSS2009 presentation

bmercer@intermap.com

Single-Pass L-Band PolInSAR System: Design Philosophy

- Objectives of L-Band Test Program:
  - Build a single-pass, quad-pol InSAR system for test purposes
    - To remove temporal de-correlation issues
  - Demonstrate DEM and tree height extraction performance in several sets of forest / topography conditions
    - Learn enough to make sound recommendation for an operational follow-on system
- Constraints:
  - Inexpensive
  - Rapid turn-around: one-year design / build / test window

Design Approach (continued)

- Modify existing X/P airborne system (TopoSAR)
  - Take advantage of flexible digital architecture
- Maintain S/N performance (NESZ = -40 db)
  - Low power, low gain antennas
  - Fly low (1km), sacrifice swath (1km)

bmercer@intermap.com

The 2007 Demo System

- Gulfstream Commander platform
- Radar hardware based on TopoSAR system
  - originally X- and P-band
- Antennas:
  - H and V polarizations
  - Mounted on rigid beam passing through the un-pressurized part of the fuselage
  - 3.5 m baseline
- Single Tx/Rx chain
  - Pulse sequential switching between polarizations and antennas
- 135 MHz digitally programmable

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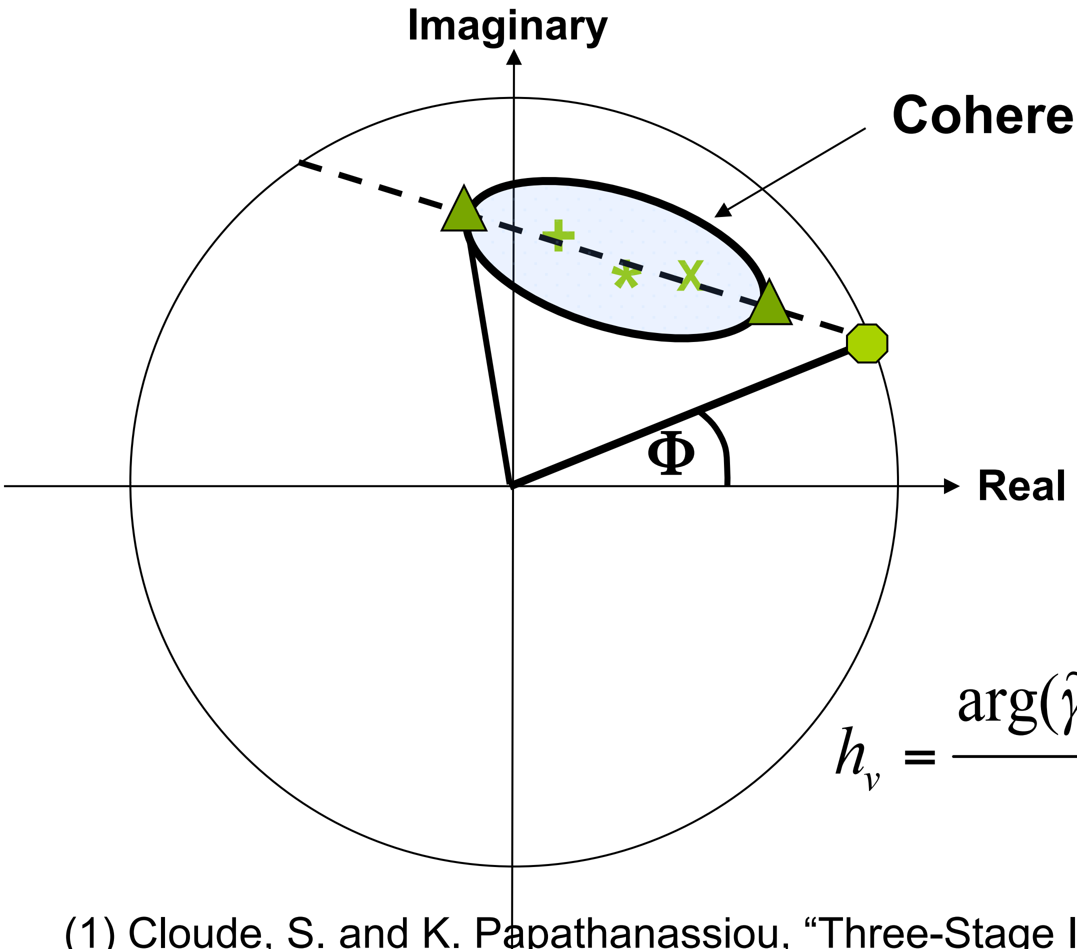
Extraction of Ground Phase and Canopy Height



To obtain ground phase, use:

- **Coherence Mag. Optimization(1)**
  - **for low vegetation**
- **Phase Optimization(2)**
  - **for high vegetation**

To obtain h_v:

- **use the inversion expression(3)**

$$h_v = \frac{\arg(\tilde{\gamma}_{w_v}) - \hat{\phi}}{k_z} + \varepsilon \frac{2 \sin c^{-1}(|\tilde{\gamma}_{w_v}|)}{k_z}$$

(1) Cloude, S. and K. Papathanassiou, “Three-Stage Inversion Process for Polarimetric SAR Interferometry”, IEEE Proc.-Radar Sonar Navig. (2003)

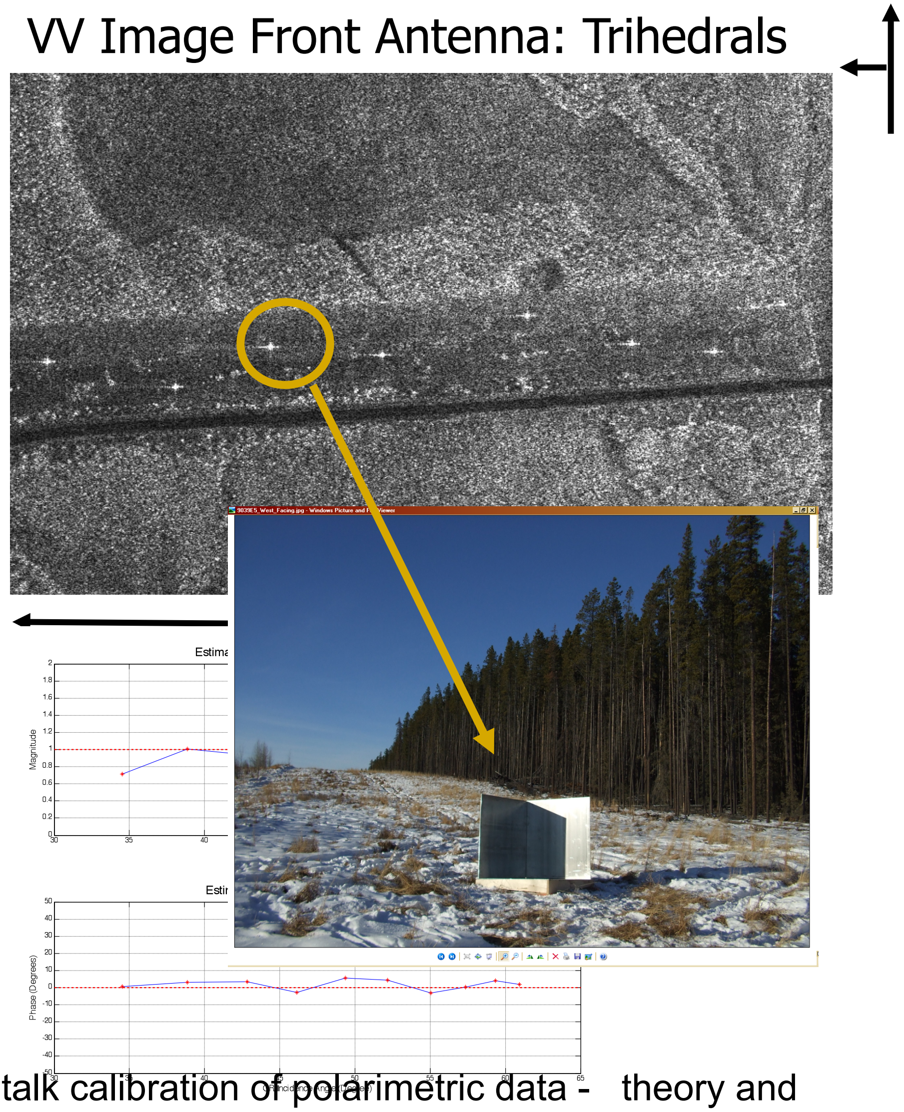
(2) Tabb, M., et. al., “Phase Diversity: A Decomposition for Vegetation Parameter Estimation using Polarimetric SAR Interferometry”, EUSAR2002

(3) Cloude, S., “Polarization Coherence Tomography”, Radio Science, Vol 41 (2006)

Calibration

- Geometric and polarimetric calibration components
- Polarimetric calibration based on Quegan method(1)
  - Range-dependant cross-talk and imbalance correction terms calculated using:
    - Trihedrals (10) placed across swath
    - Forest (flat, relatively homogeneous, extensive)
  - Cross-talk (observed) less than -25 d
  - HH/VV imbalance corrected across swath to
    - Amplitude 1.0 +/- 0.05
    - Phase 0.0 +/- 5 degrees

VV Image Front Antenna: Trihedrals



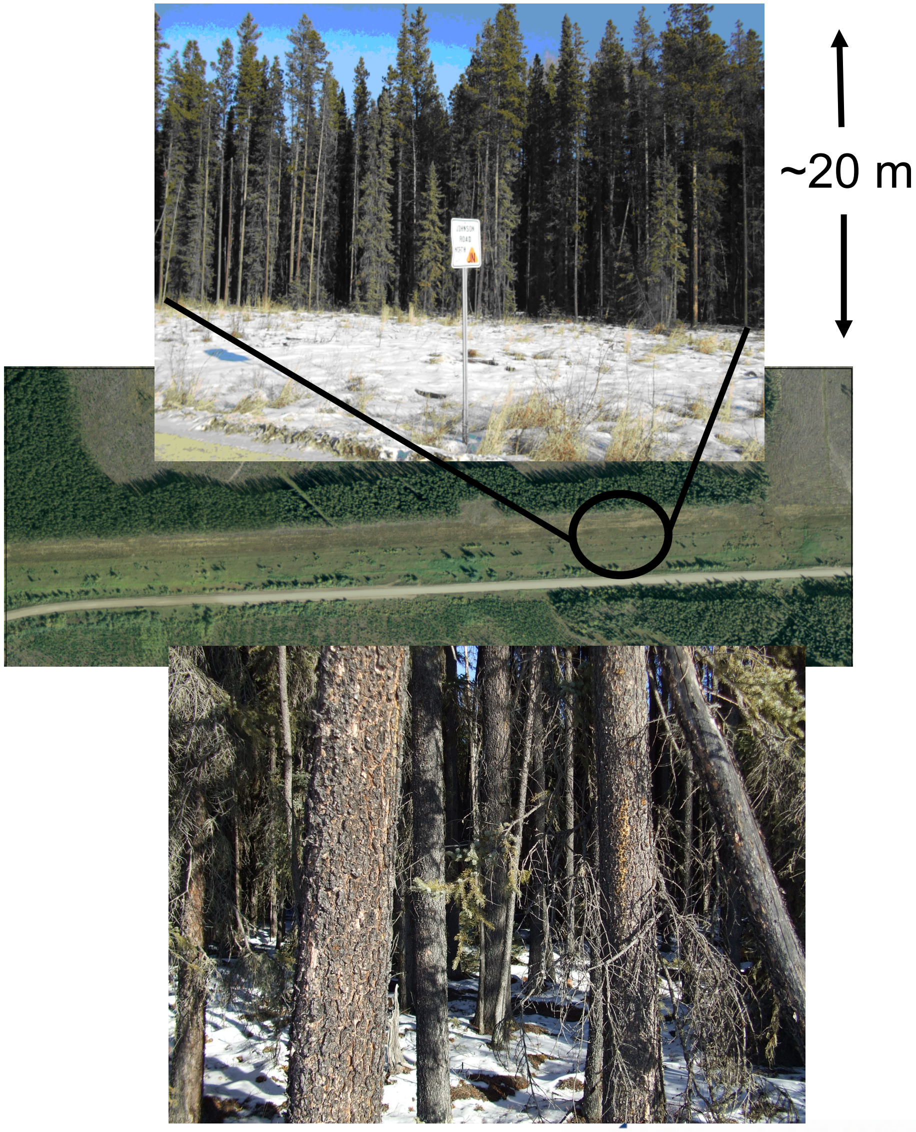
(1) (1) S. Quegan, "A unified algorithm for phase and crosstalk calibration of polarimetric data -   theory and

(2) Observations", *IEEE Trans. on Geoscience and Remote Sensing*, vol. 32, no. 1, pp. 89–99, 1994.

bmercer@intermap.com

2007 Test of L-Band PolInSAR Tree Height Retrieval

- Test area near Edson: a forested region of Alberta, Canada
  - Patchwork of lodgepole pine forest and clearcut areas
  - Clearcuts may have been re-planted and in a regrowth phase
  - Typically 15-30 m high
  - L-Band data acquired in Nov. 2007 and again in June 2008
- Ancillary data
  - X-Band DSM (from 2006)
  - Lidar ground elevations and point cloud (courtesy Terrapoint 2007)
  - Color air photo (Valtus 2007)



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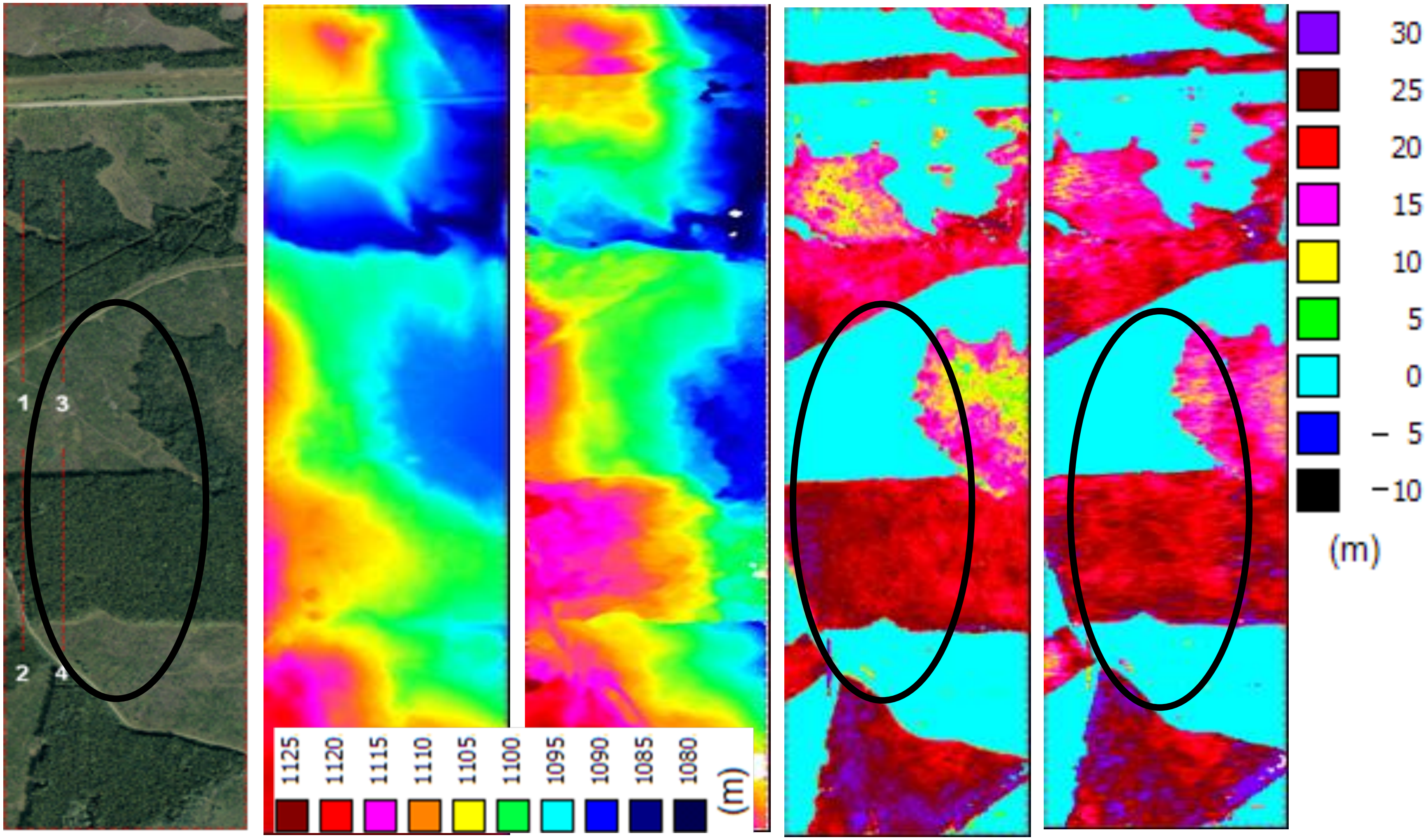
Edson Test Site: Tree Height Results



Air Photo **Lidar DTM** **L-Band DTM** **Lidar h_{100}** **L-Band h_v**

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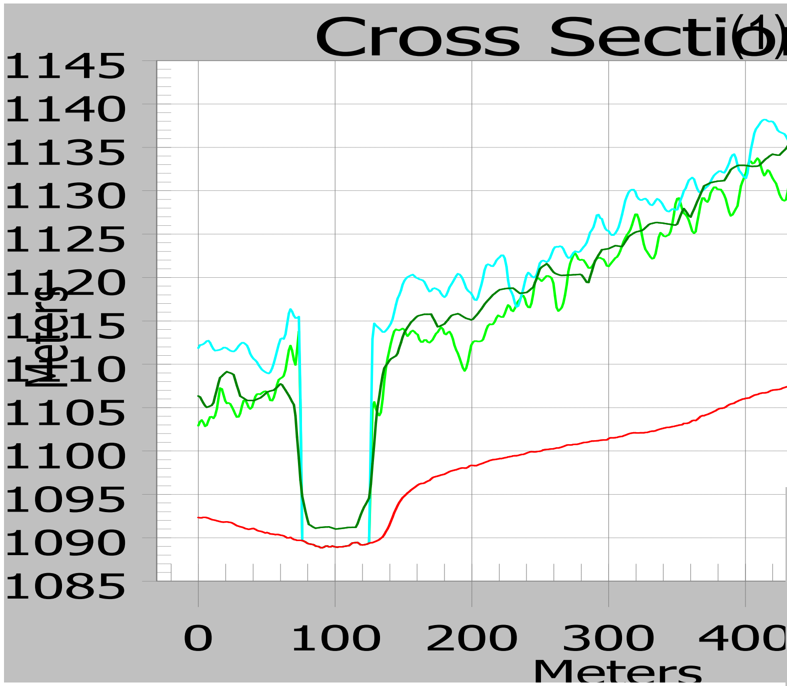
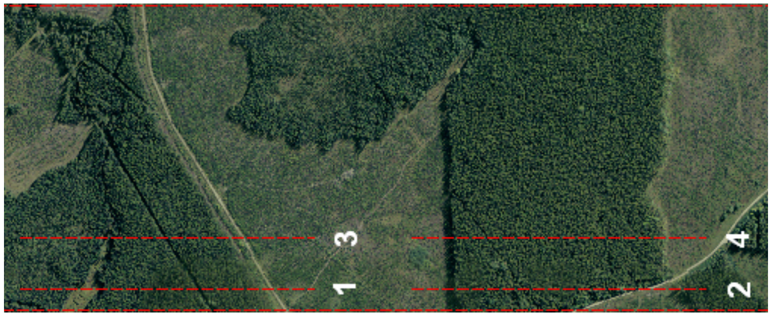
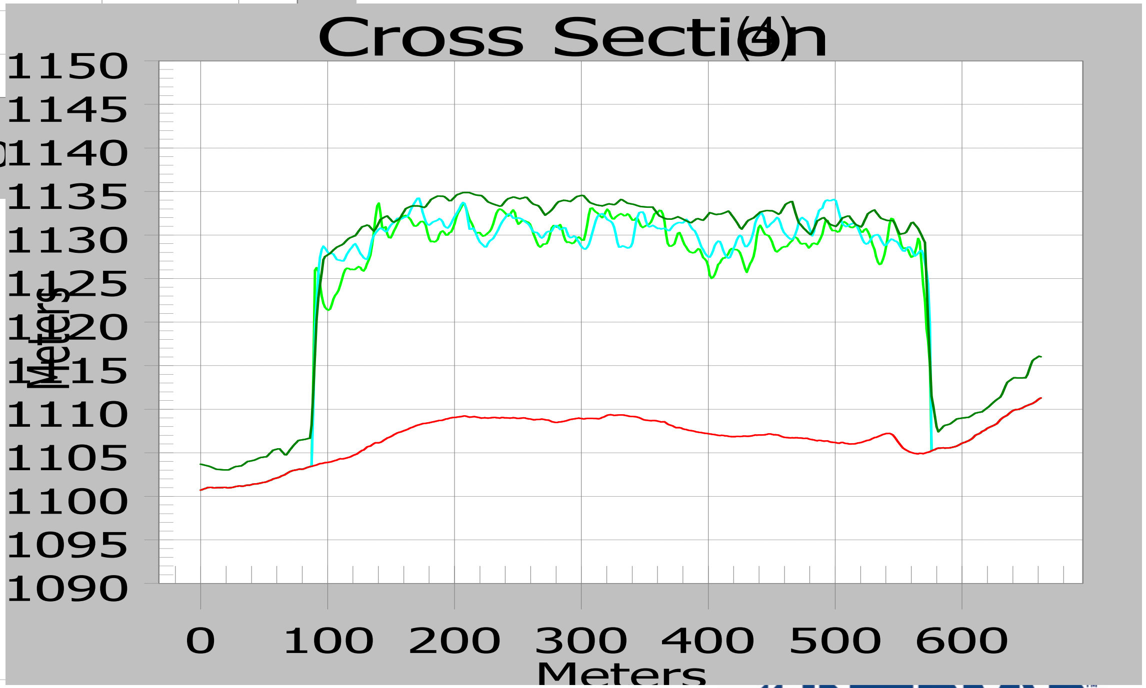
Canopy Height Profiles 1 & 4



Lidar DTM
Lidar Canopy Height
L-Bnd h_v (Summer)
L-Band h_v (Winter)

20-30 m canopy





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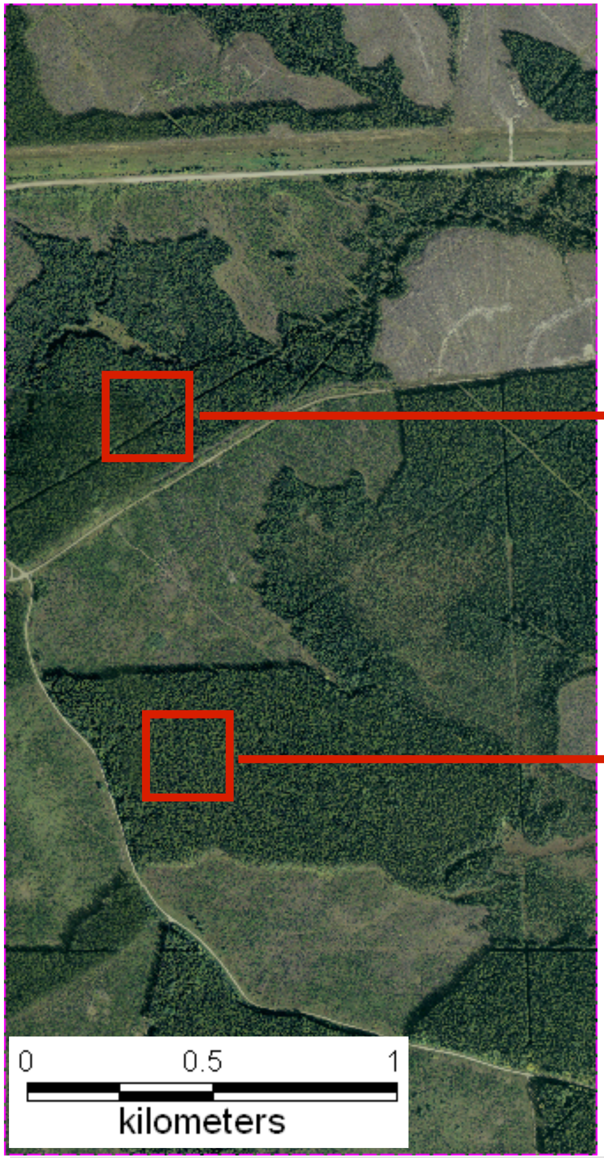
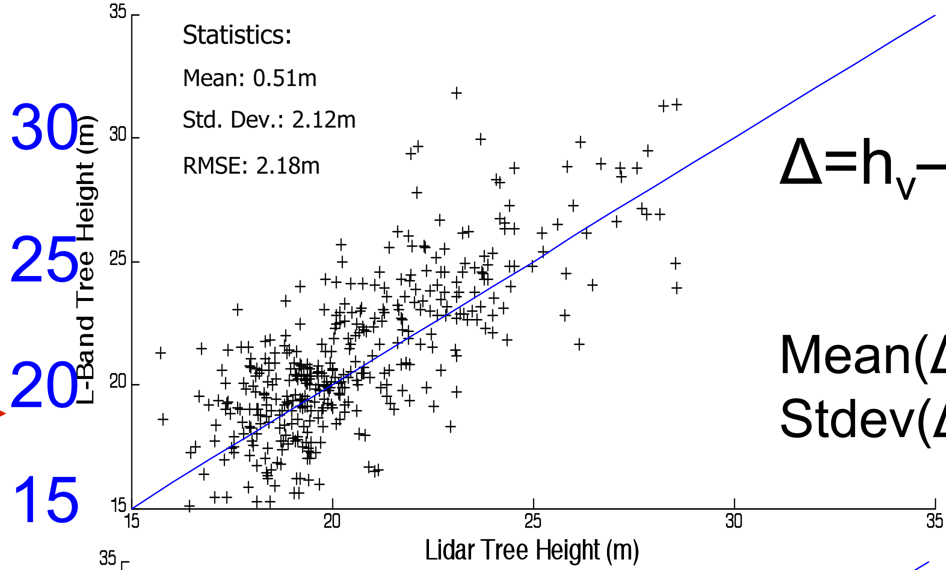
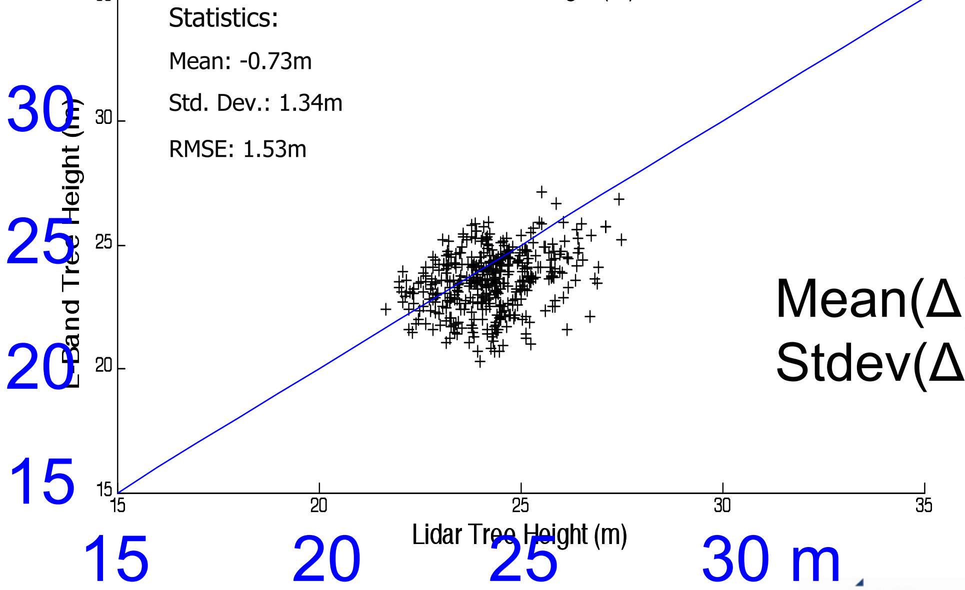
L-Band h_v vs Lidar Canopy Heights ($K_z \sim 0.1$)





$\Delta = h_v - h(\text{lidar})$

Mean(Δ)= 0.5m
Stdev(Δ)=±2.1m

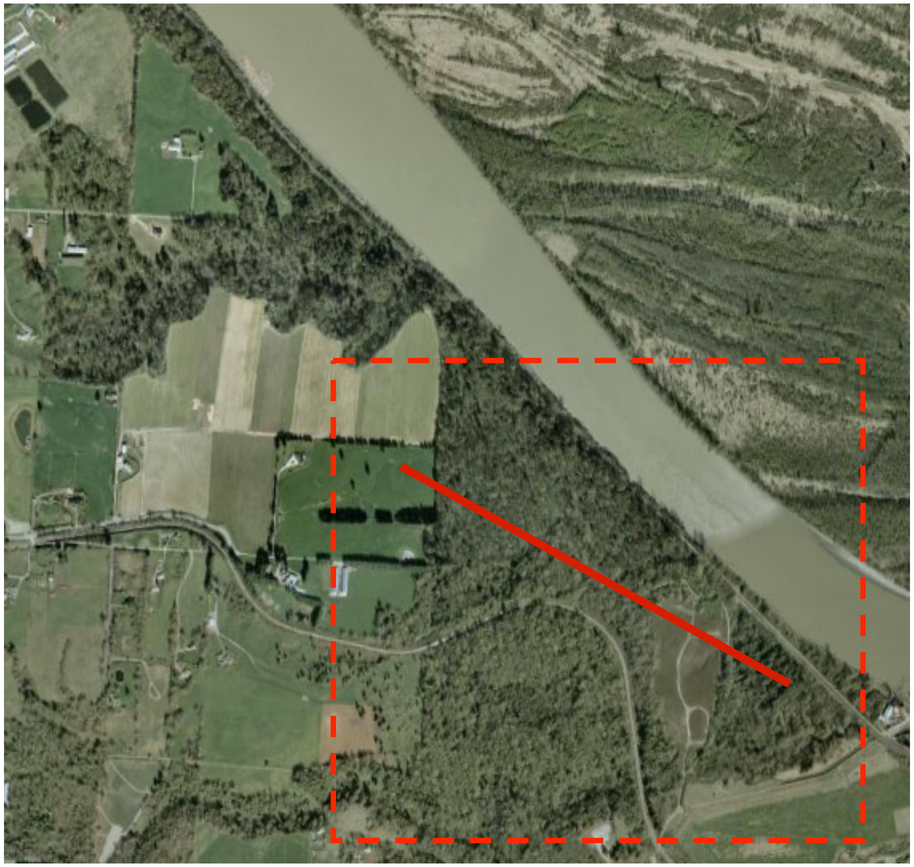


Mean(Δ)= - 0.7m
Stdev(Δ)= ±1.3m

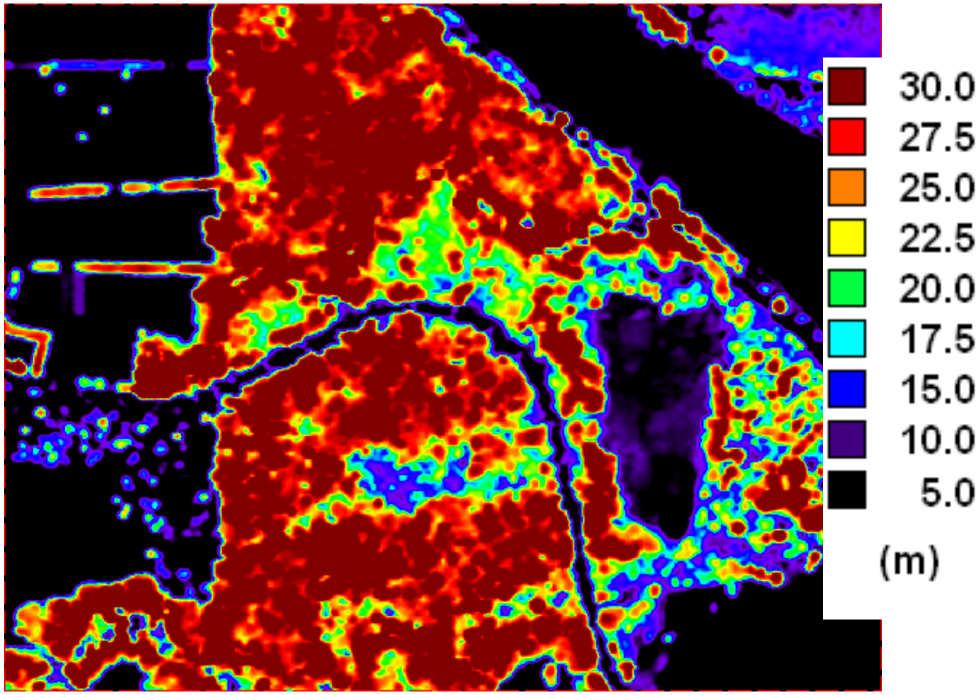
bmercer@intermap.com

Fraser Delta Test Site: Ancillary Data

- no direct ground truth
- from forestry reports
  - 30 - 70 year-old hardwoods
  - high biomass ?
- spacing of visible crowns ~ 20 meters



Google Earth Image



Lidar Canopy Height

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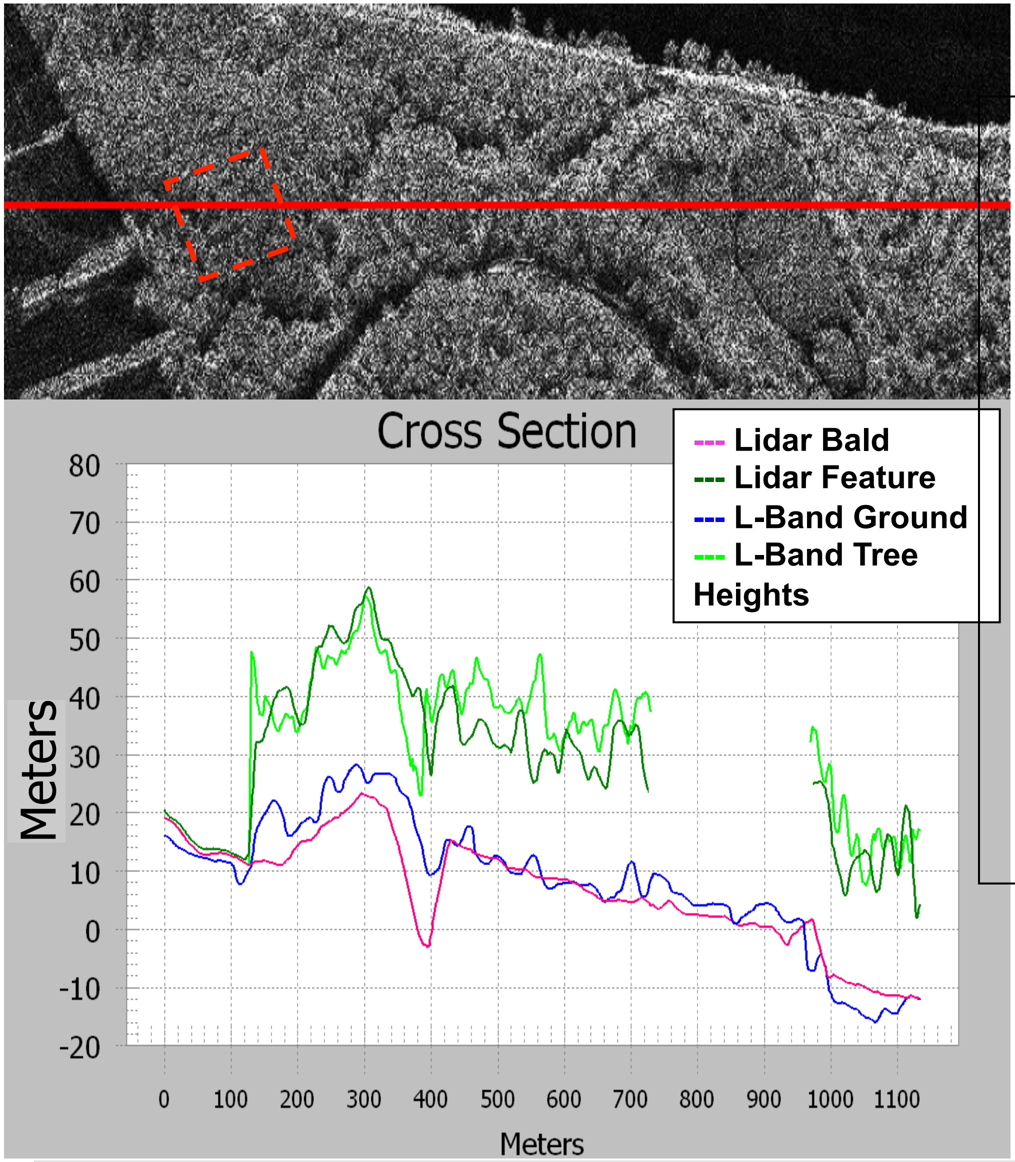
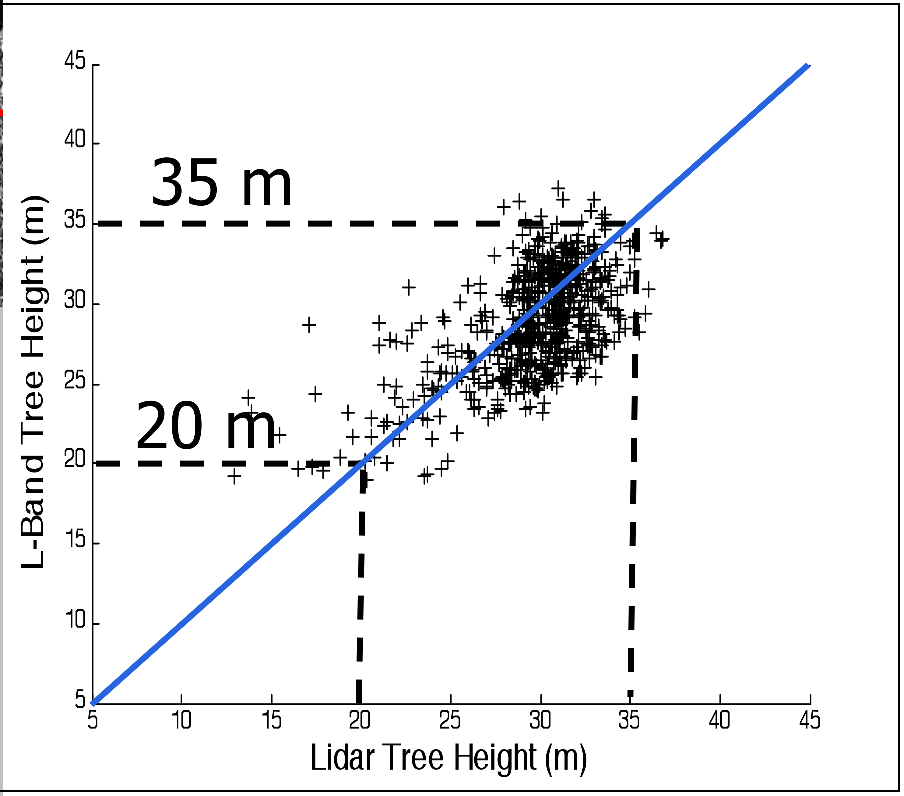
Fraser Delta Test Site: Results





Δ=hv–h(lidar)

Mean(Δ)= - 0.8m

Stdev(Δ)= ±3.0m

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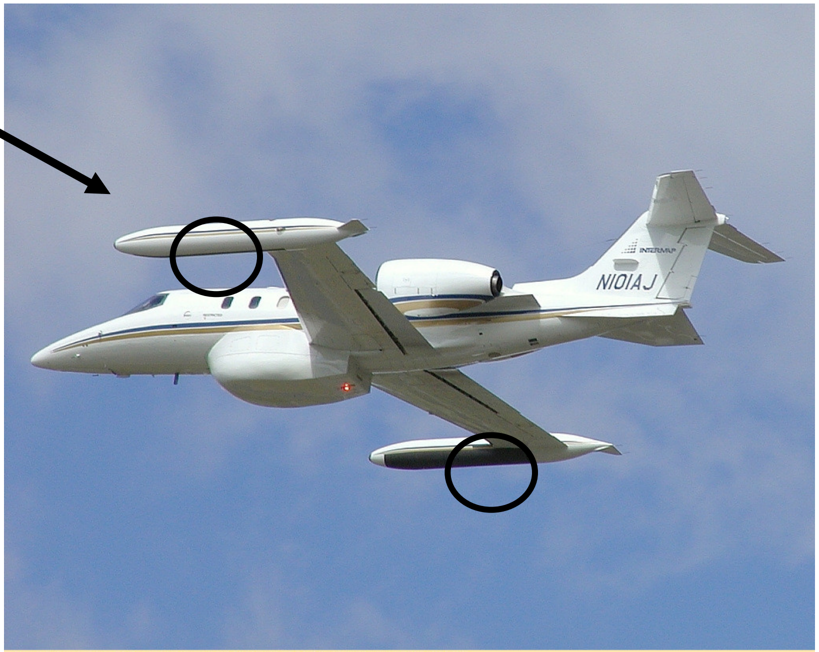
Where we want to go:

From this



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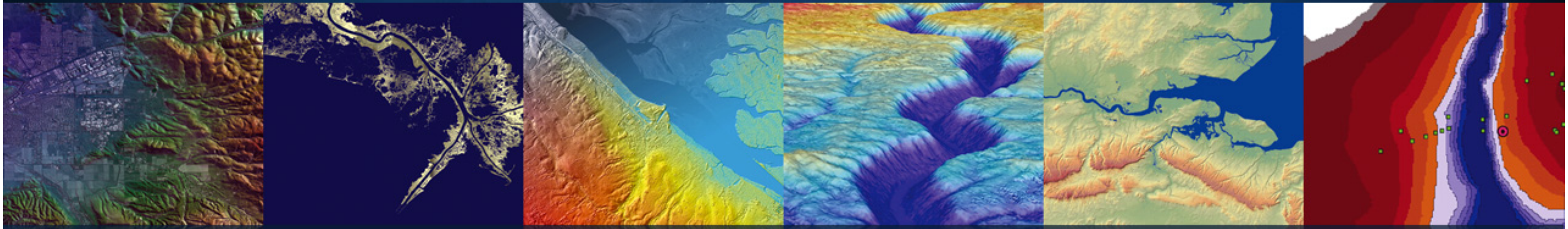

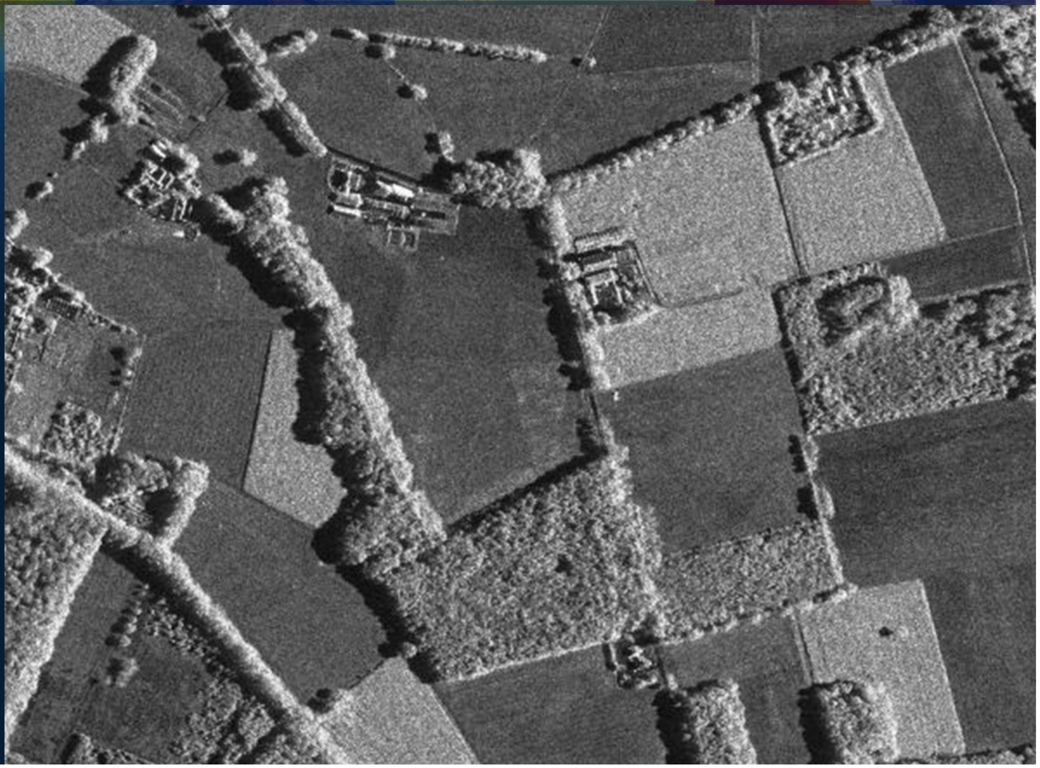

Thank you!

bmercer@intermap.com

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