Global Remote Sensing – The Digital Revolution: Twenty Years On

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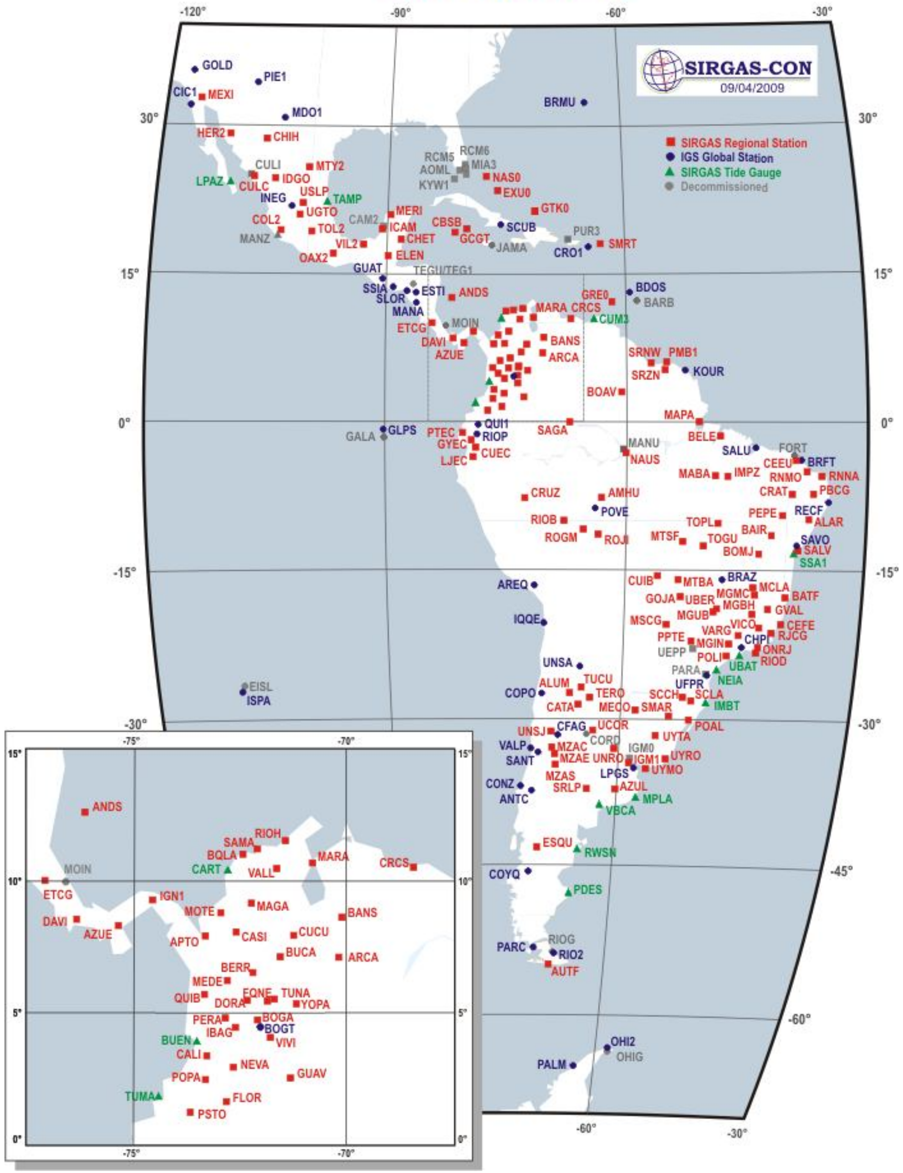
Contents

- Enabling technologies
- Development of photogrammetry and remote sensing
- New applications
- Future directions

Underpinning technology – GNSS/INS

- GNSS makes it possible for better and more widespread use of satellite positioning systems
- Enables direct georeferencing to take place
- Essential for Lidar and IfSAR
- Uniform coordinate reference system is fundamental to any development project, application, or service requiring some form of geo-referencing
- Traditional national reference frames are inadequate for regional, continental, or global initiatives

SIRGAS-CON



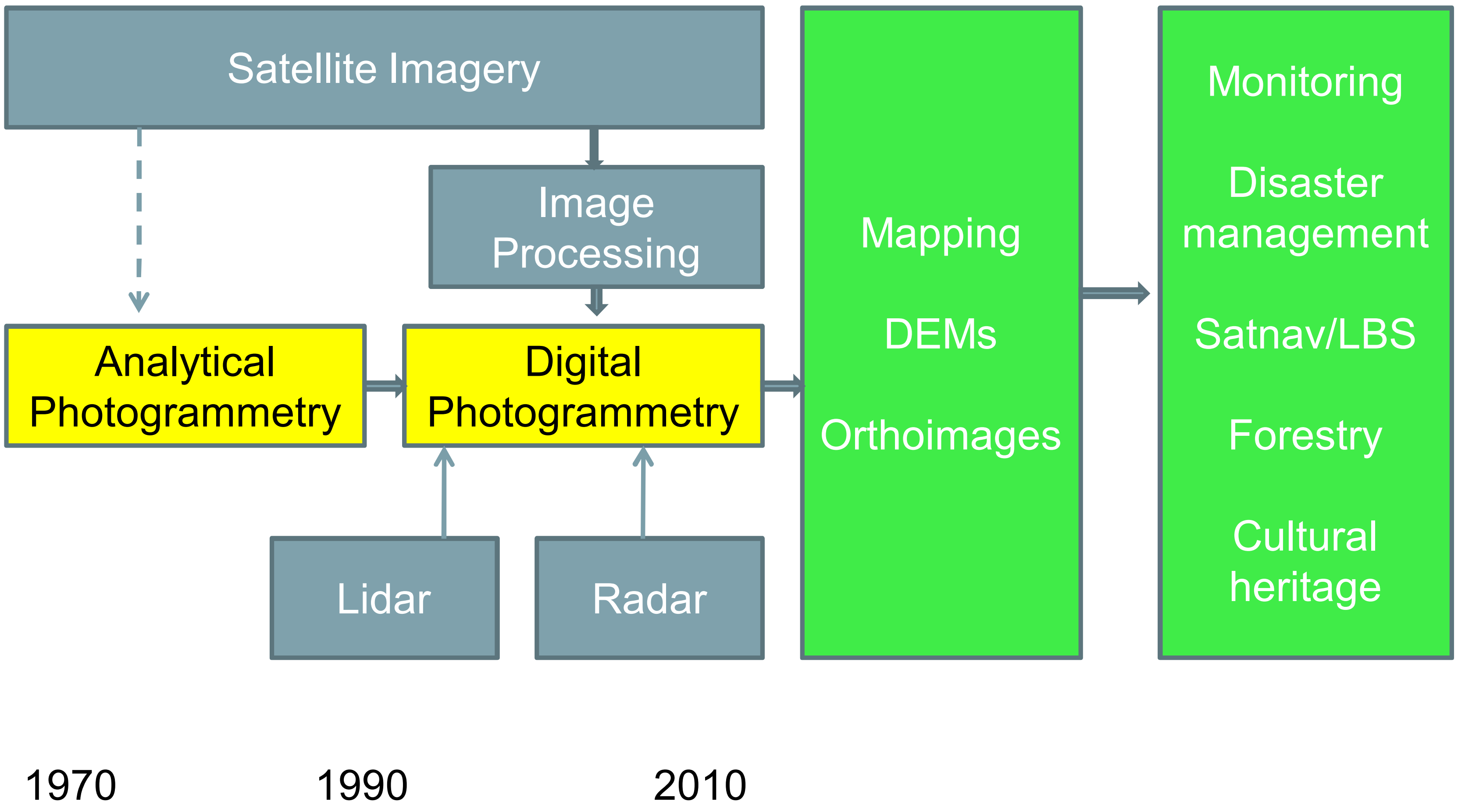
Latin America SIRGAS

200 permanently operating GNSS sites, 50 of them from the global IGS network

Underpinning technology: Communications and Spatial Data Infrastructure

- **Harmonisation** of image, topographic, physical data
- **Standardisation** of geospatial information and distributed architecture for geospatial services and analysis.
- Services need to be adaptive to different computing environment, e.g., web-based, mobile/wireless and LBS.
- Efficient data dissemination essential for many applications

The evolution of digital photogrammetry



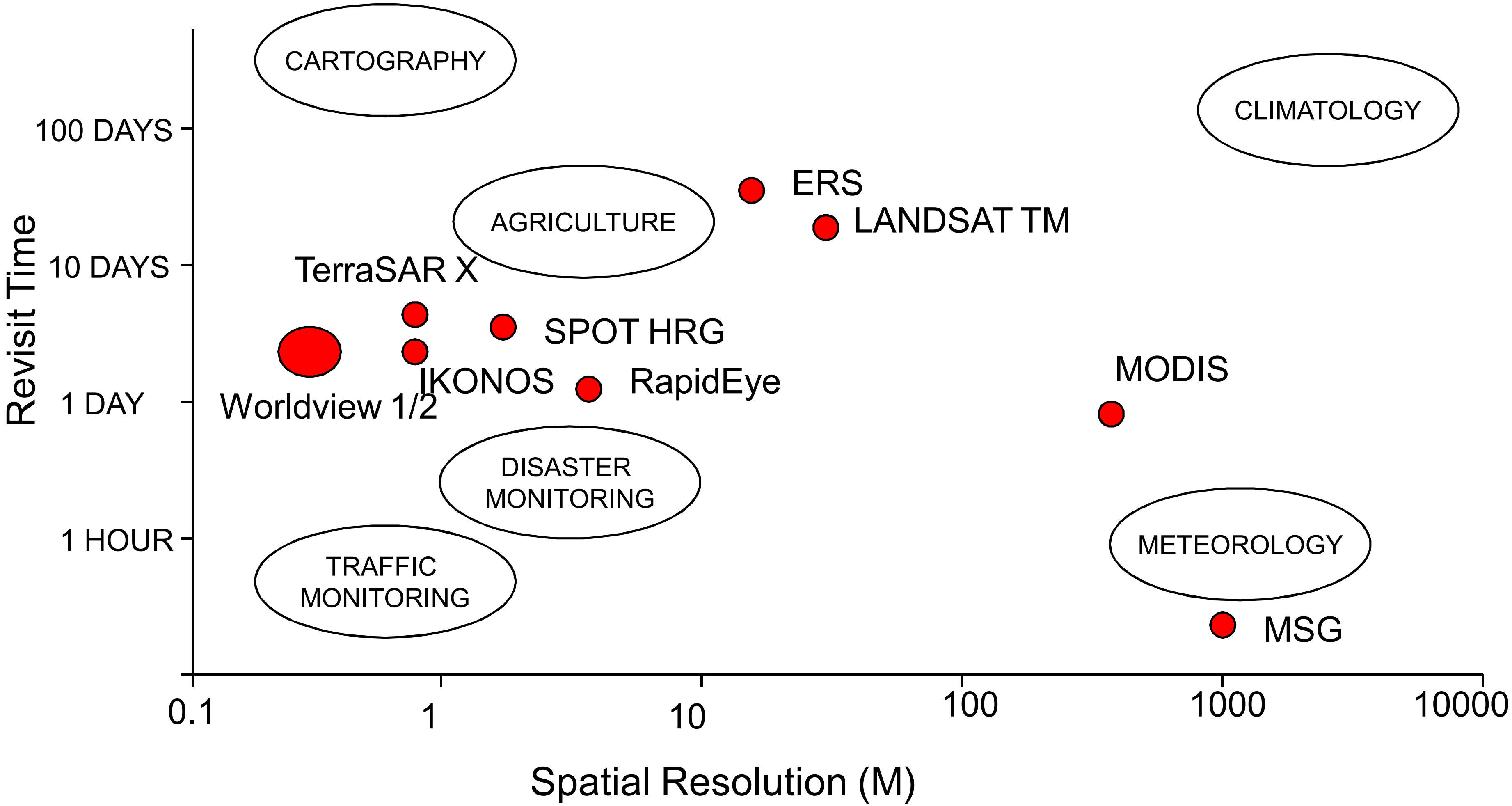
Chronology of Key Stages in Earth Observation

- **Landsat 1972**: Global covergage in 18 days; Multi spectral data at 30m
- **AVHRR 1978**: Global coverage twice daily; With 1km resolution
- **SPOT 1986**: Stereoscopic coverage > 3D
- **ERS 1 1991**: RADAR
- **ERS Tandem/SRTM**: Interferometric SAR
- **IKONOS 1999**: High resolution sensors
- **MODIS, 2003**: Med resolution global sensors
- **Constellations**: Greater coverage

Plenty of data - but there are challenges…

- Handling large volumes of data
- Filling gaps in the observations
- Co-ordination of data collection
- Data distribution
- Calibration of the data
- Integrating data from multiple sources
- Analysis and modelling of data
- Data quality

Spatial and temporal resolution

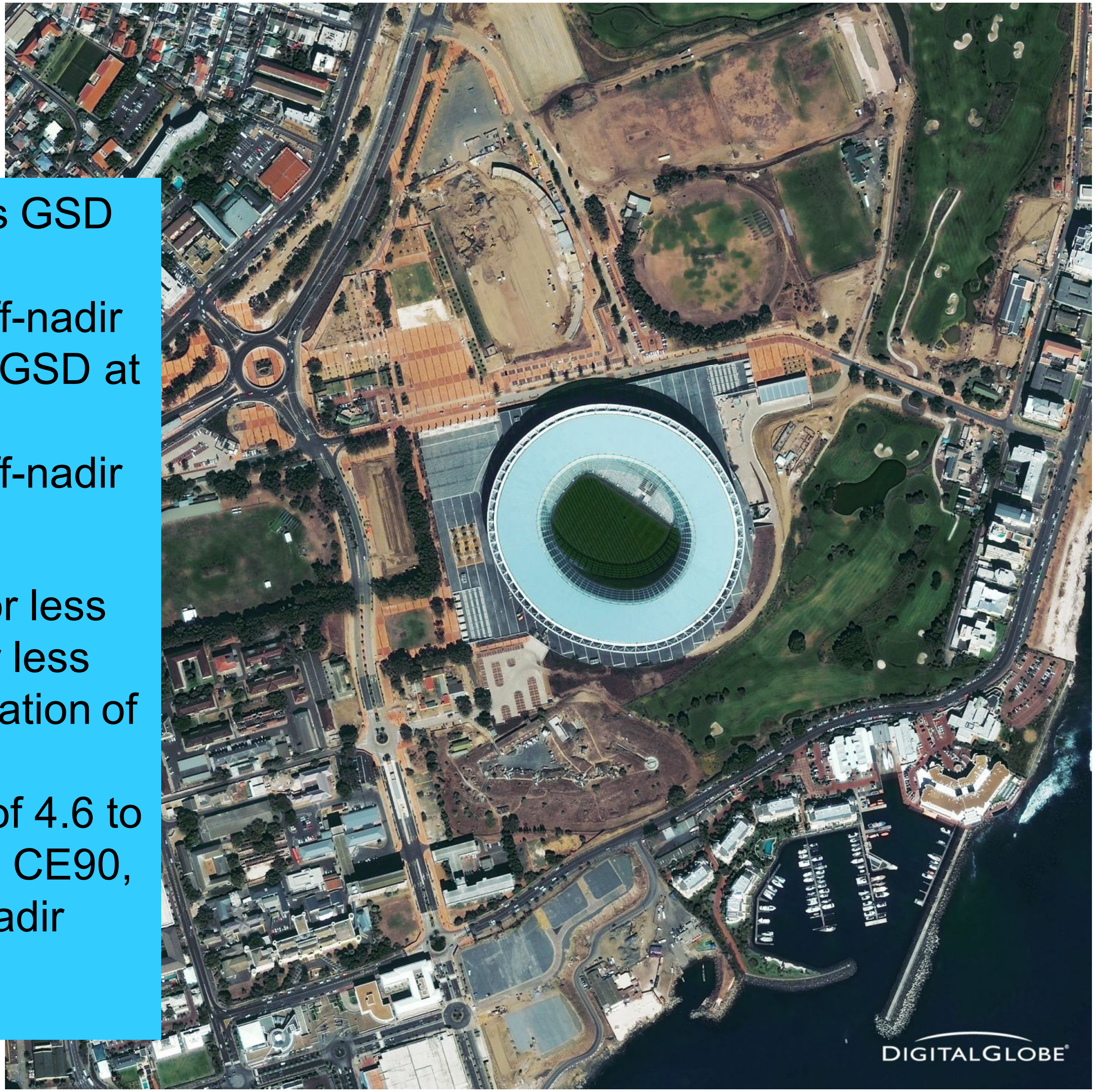


‘High Resolution’ Satellite Sensors

- High resolution optical sensors
  - <10m pixel size, panchromatic and multispectral
  - ‘Agile’ sensors with flexible pointing
  - Stereo capability providing Digital Elevation Models
- Small optical sensors
  - Emphasis on multispectral
  - Serving national requirements
  - Use of constellations provides frequent revisit
- Microwave (Radar) sensors
  - All weather capability
  - Improving resolution
  - Interferometry for measuring small displacements

Worldview-2

- Panchromatic: 0.46 meters GSD at nadir
  0.52 meters GSD at 20° off-nadir
  Multispectral: 1.84 meters GSD at nadir
  2.08 meters GSD at 20° off-nadir
- 11-bits per pixel
- 1.1 days at 1 meter GSD or less
  3.7 days at 20° off-nadir or less (0.52 meter GSD) Specification of 6.5m CE90, with predicted performance in the range of 4.6 to 10.7 meters (15 to 35 feet) CE90, excluding terrain and off-nadir effects



Worldview-2 image CapeTown, Courtesy Digital Globe

Radar

EO Missions

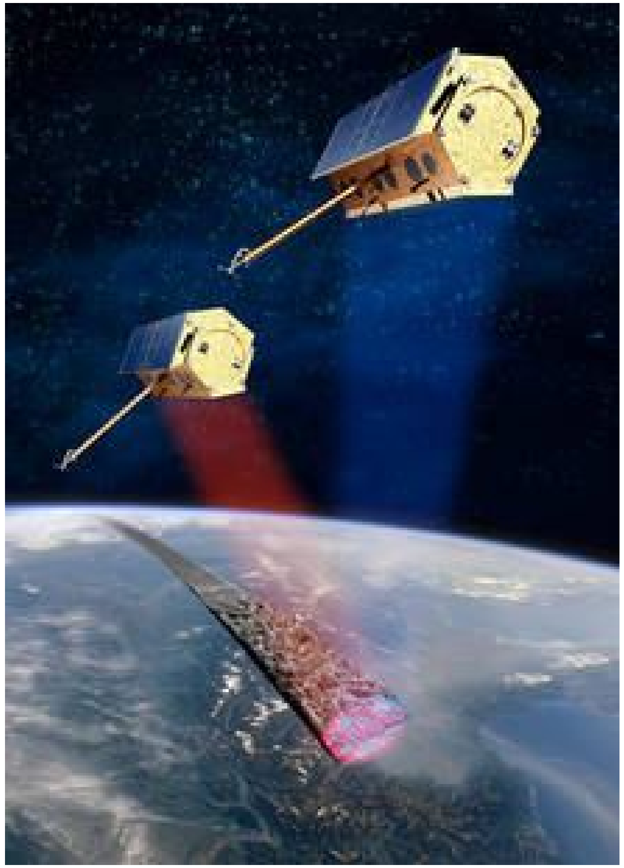
- Envisat
- Radarsat
- TerraSAR X

Interferometry Missions

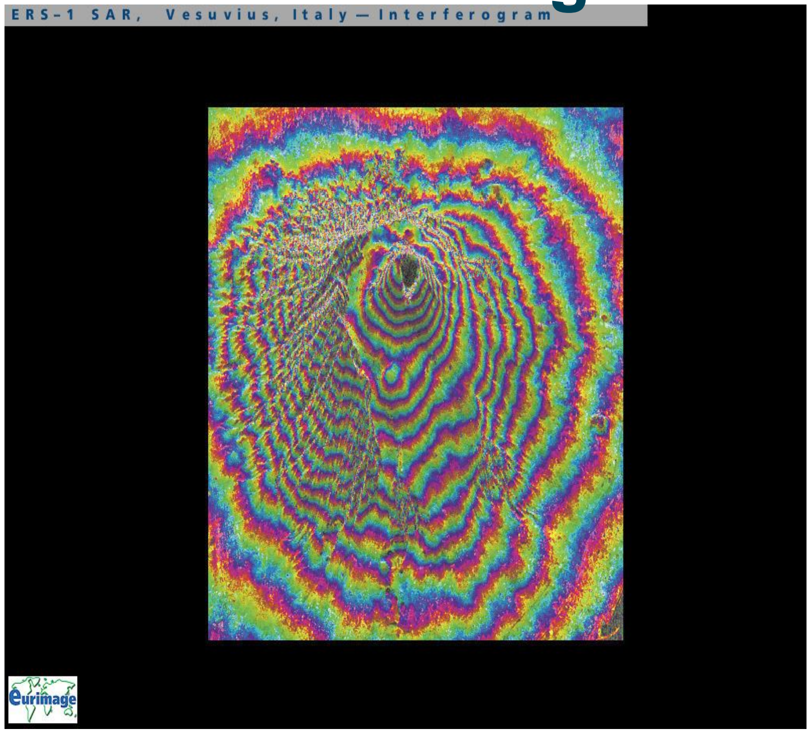
- SRTM
- Intermap Airborne SAR
- TanDem-X

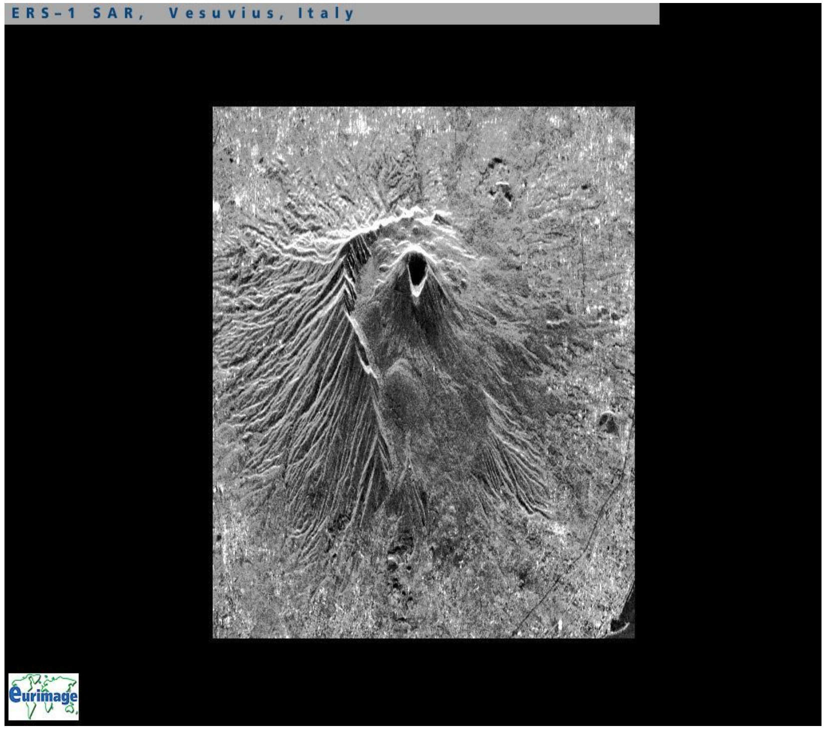
TanDEM-X

- TanDEM-X is a second, very similar spacecraft that orbits in a close formation flight with TerraSAR-X
- This unique twin satellite constellation will allow the generation of global digital elevation models (DEMs) at an unprecedented accuracy, coverage and quality – a consistent DEM of the Earth's land surface is envisaged to be acquired and generated within three years after launch.



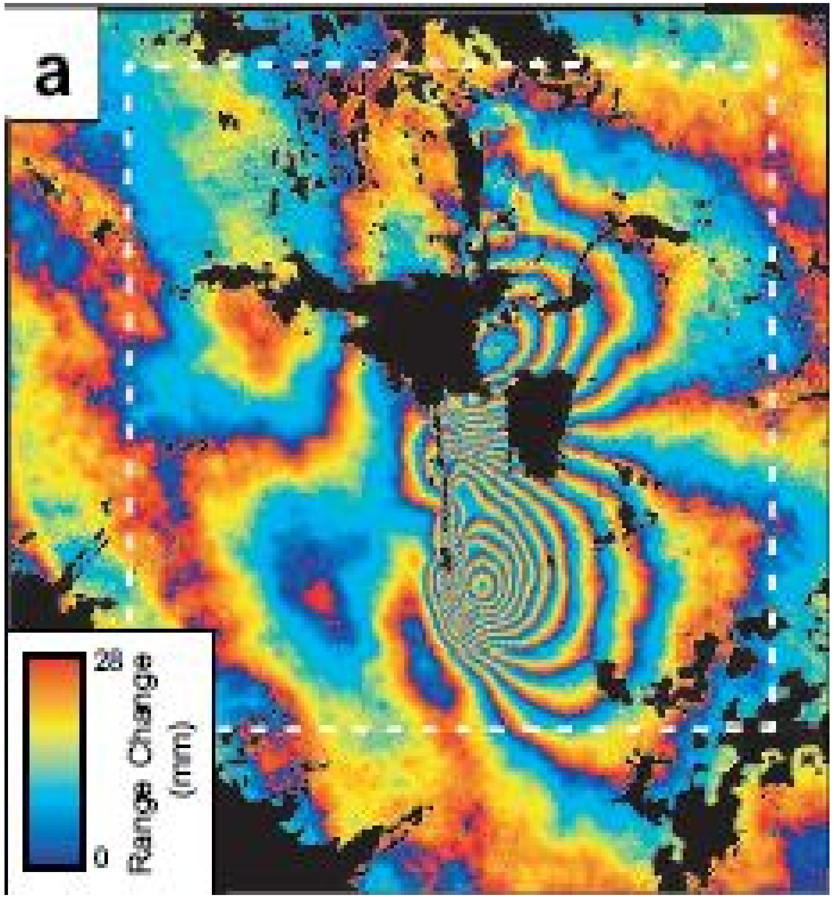
Interferometric SAR
Production of Digital Elevation Models





Interferogram and DEM of Mount Vesuvius

Differential Interferometric SAR
Measuring displacement and subsidence



Envisat Interferogram of Bam Eathquake showing displacement and faultline

Small Satellites
Surrey Satellites (SSTL) and the DMC

- Used in the Disaster Monitoring Constellation.
- AISAT-1, NigeriaSat-1 and UK-DMC2
  - with 32m resolution.
- UK-DMC2 and Deimos-1 launched 29th July 2009.
  - 22-metre resolution imaging capability.
- 5-satellite RapidEye constellation
  - 6.5-metre resolution imaging capability.
- Future projects
  - 1m optical sensor
  - Small SAR system

Constellations

- DMC
- RapidEye
- COSMO SkyMed
- CEOS Virtual Constellation Concept
  - To satisfy the 10 year implementation plan for GEOSS
  - Co-ordination of space agency activities whilst still allowing priority for national interests
  - Based on user requirements (GEOSS)
  - Design based on a series of standards
    - Performance requirements
    - Inter calibration
    - Data format and interoperability
    - Data policy

Geometric Modeling

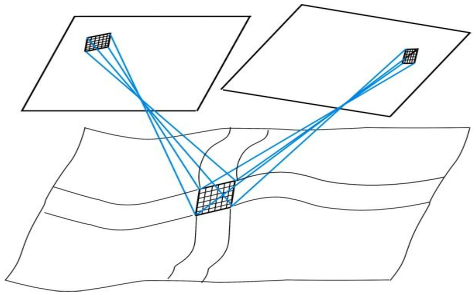
- Rational Polynomial Coefficients (RPCs) are now used for orientation but physical models could give best results
- Automatic and real-time orientation methods
- Use of linear features as tie objects (rather than points) in bundle adjustment opens a new venue for using old archived photographs, combined with newly acquired remotely sensed spectral data for change detection and temporal research in urbanization, desertification and cryospheric studies.
- Use of multi-image matching for DEM generation

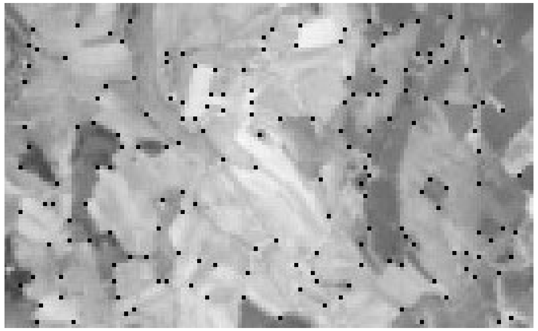
Image matching

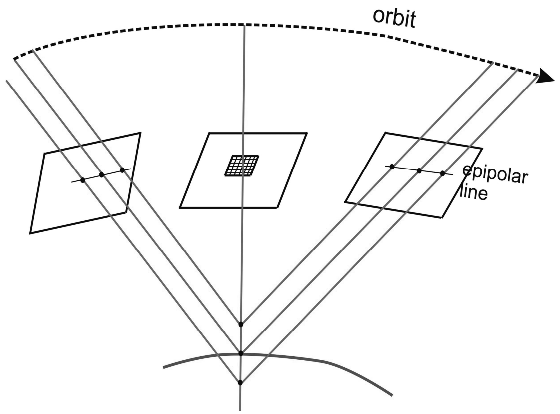
- Image matching should be one of the major advantages of digital photogrammetry.
- DEM generation over open terrain with good texture works well (see below)
- DEM generation over urban areas does not work so well
- Techniques are still developing

Matching techniques

- Intensity based (area based)
  - Cross correlation
  - Least squares matching
- Feature based
- Relational
- Multi point matching







Results from matching in urban areas

Least squares matching. b. Dynamic programming. c. Semiglobal matching

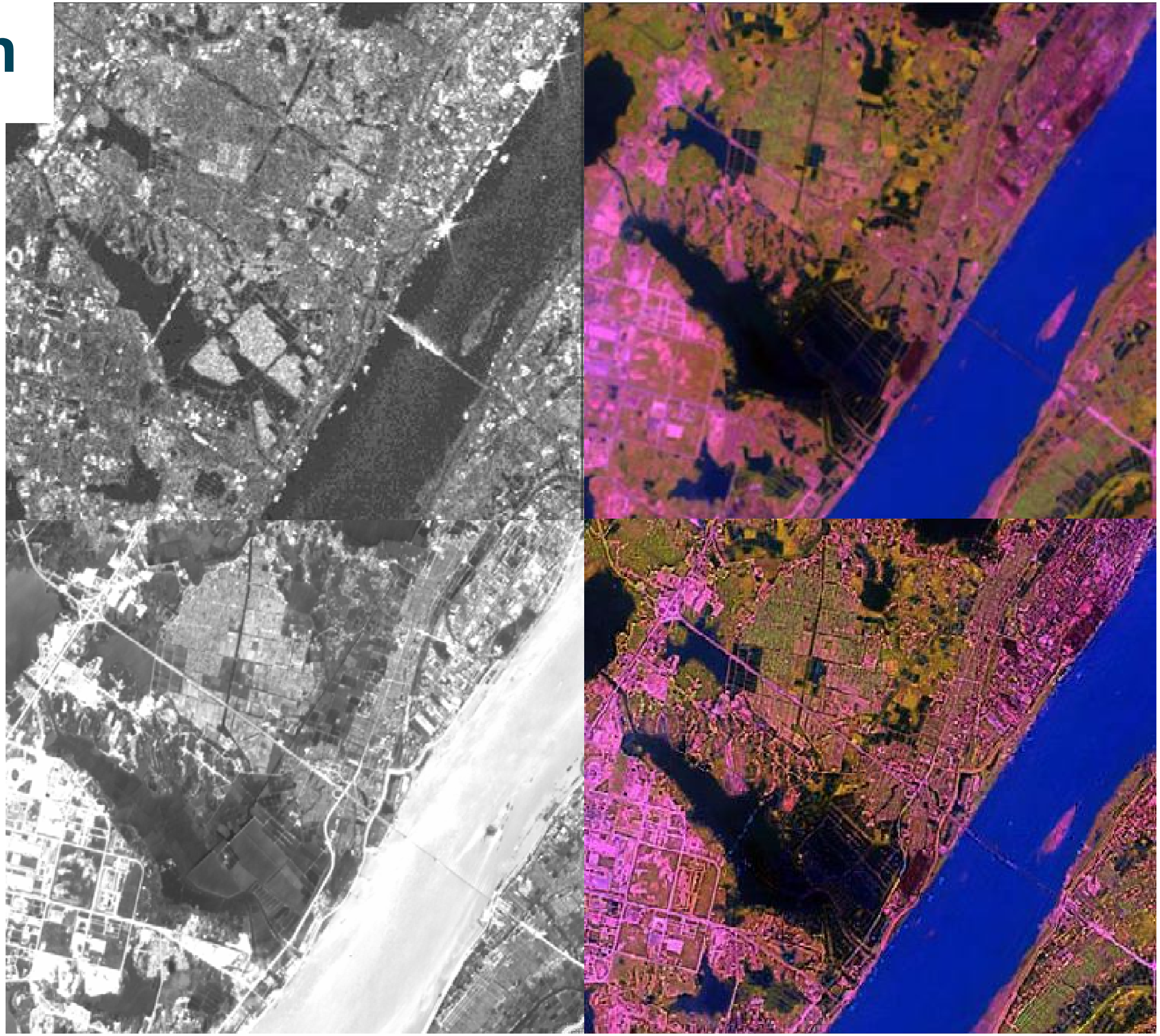
Bing Maps – mapping the world with UltraCam images

- Process
  - Automated dense matching
  - Extremely robust due to high redundancy
- Result
  - High res. DSM
  - > 50 „points/sqm“
  - << 10cm accuracy

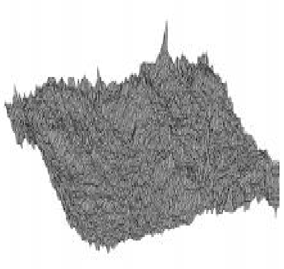
Downtown Denver is represented by three dimensional building model with photo realistic texture.

Data fusion

Fusion of ENVISAT, LANDSAT and SPOT images

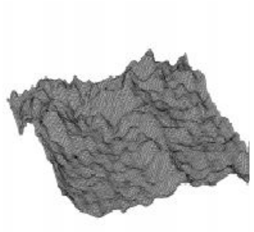


Fusion of SPOT and ERS DEMs (after Honikel)



SPOT DEM

ERS IfSAR DEM



Fused DEM

Results from data fusion of DEMs, (From Honikel, 2002)

	SPOT	ERS	Fused
Σ posts	514,635	514,635	451,837
μ (m)	0.7	0.23	-0.15
σ, rmse (m)	9.6, 9.5	11.9, 11.9	5.5, 5.5
ΔH_{min}, ΔH_{max} (m) $\mid \Delta H \mid$>40m(%)	-118, 158 5.2%	-79, 72 0.01%	-36, 40 0%

GEOSS


THE GLOBAL EARTH OBSERVATION SYSTEM OF SYSTEMS
INFORMATION FOR THE BENEFIT OF SOCIETY
Disasters
Health
Energy
Climate
Agriculture
Ecosystems
Biodiversity
Water
Weather

GEOSS Task DA-09-02c

Sub-task Title: Global Geodetic Reference Frames

- Ensure the availability of accurate, homogeneous, long-term, stable, global geodetic reference frames as a mandatory framework and the metrological basis for Earth observation.
- Identify steps towards such consistent high-accuracy global geodetic reference frames for Earth observation and the observing systems contributing to GEOSS.

GEOSS Task DI-09-01a

Sub-task Title: Vulnerability Mapping and Risk Assessment

- Facilitate access to the remote-sensing & in-situ data required to perform systematic geohazards vulnerability mapping and risk assessment.
- Related activities will include:
  - Retrieval, integration and systematic access to remote sensing & in-situ data in selected regional areas exposed to geological threats (“Supersites”);
  - Development, testing and application of global seismic vulnerability mapping to “Supersites” areas.

Case studies

- DEM generation
- Monitoring Tectonic movement and subsidence
- Forestry
- Agriculture

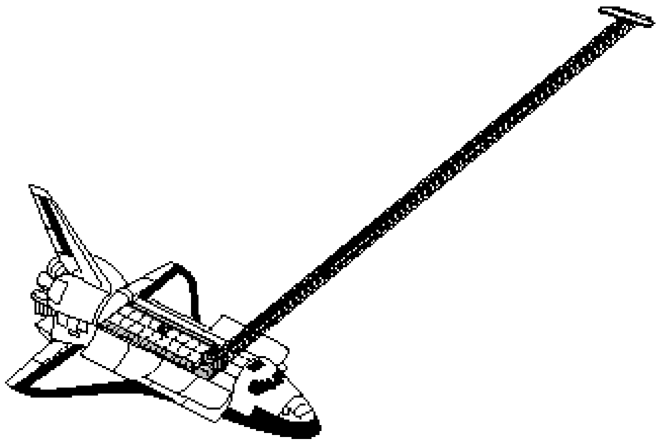
SRTM - Shuttle Radar Topography Mission

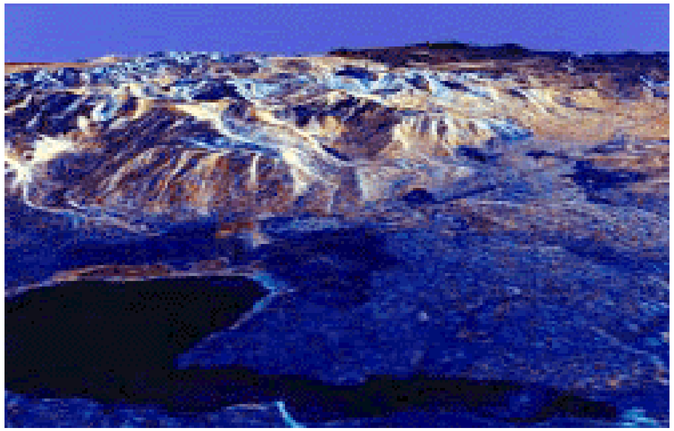
For data between the equator to 50 degrees latitude, the postings are spaced at 1" (one arcsecond) latitude by 1" longitude. (At the equator, these are spacings of approximately 30 meters by 30 meters.)

The absolute horizontal accuracy (90% Circular Error) is 20 meters.

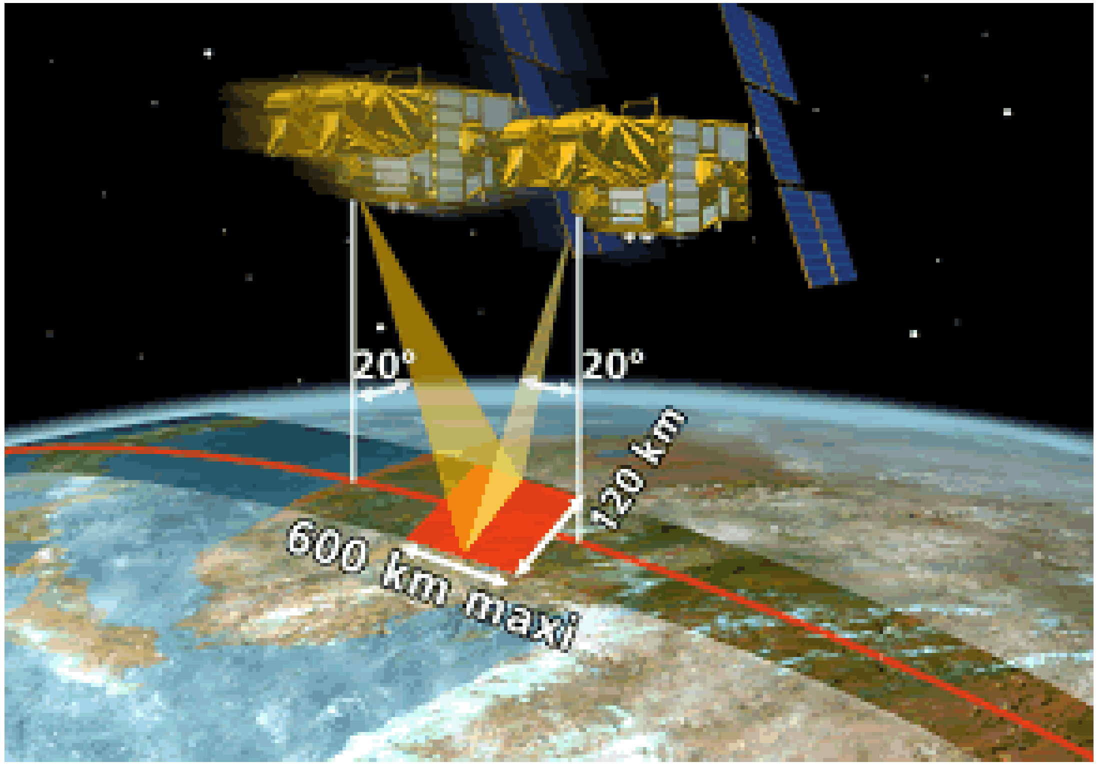
The absolute vertical accuracy (90% Linear Error) is 16 meters.

*





SPOT5 – HRS Global Mission



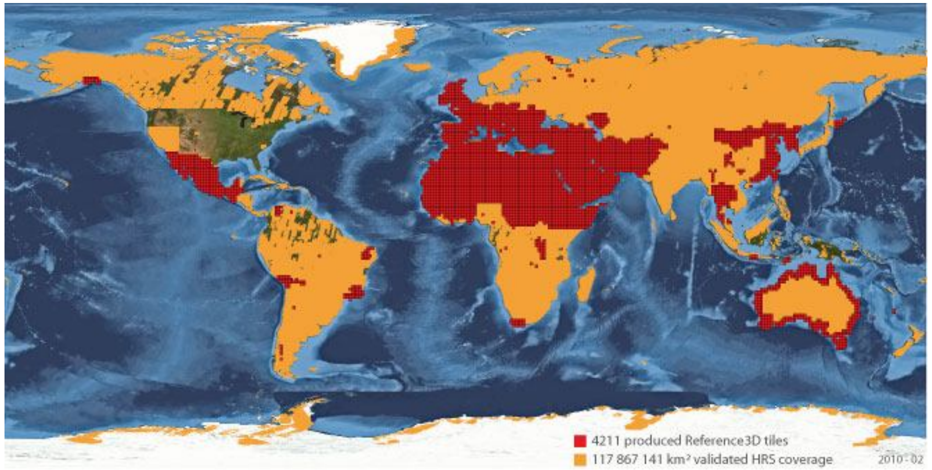
Reference3D is a geocoded database containing three layers of information:

- a DTED level 2 HRS DEM
- GPS-compatible HRS Orthoimage
- quality and traceability metadata

HRS instrument 10m pixel size
Fore and aft pointing, ±20˚
DORIS gives 5m orbit determination 50m positional accuracy

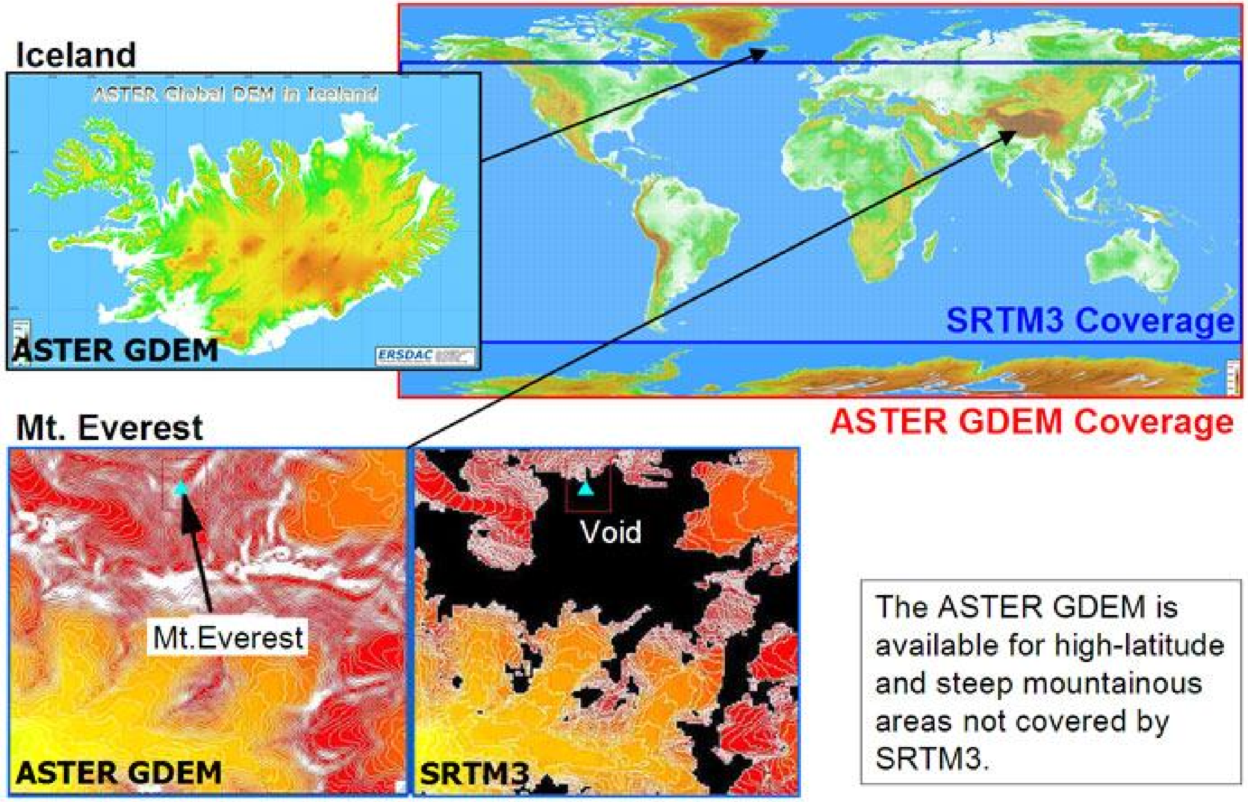
SPOT Reference 3D - DEM

- Files contain a uniform grid of terrain elevation values of an area of interest and are obtained through automatic correlation of SPOT HRS stereopairs.
- Sampling step: **1 second of arc** (~ 30 m at the equator, varying according to latitude)
- Absolute elevation accuracy: **10 m** @ 90% for a slope < 20°
- Absolute planimetric accuracy: **15 m** @ 90%



GEO Task DA-09-03d : Global DEM

ASTER GDEMASTER GDEM is an easy-to-use, highly accurate DEM covering all the land on earth, and available to all users regardless of size or location of their target areas.



http://www.ersdac.or.jp/GDEM/E/1.html

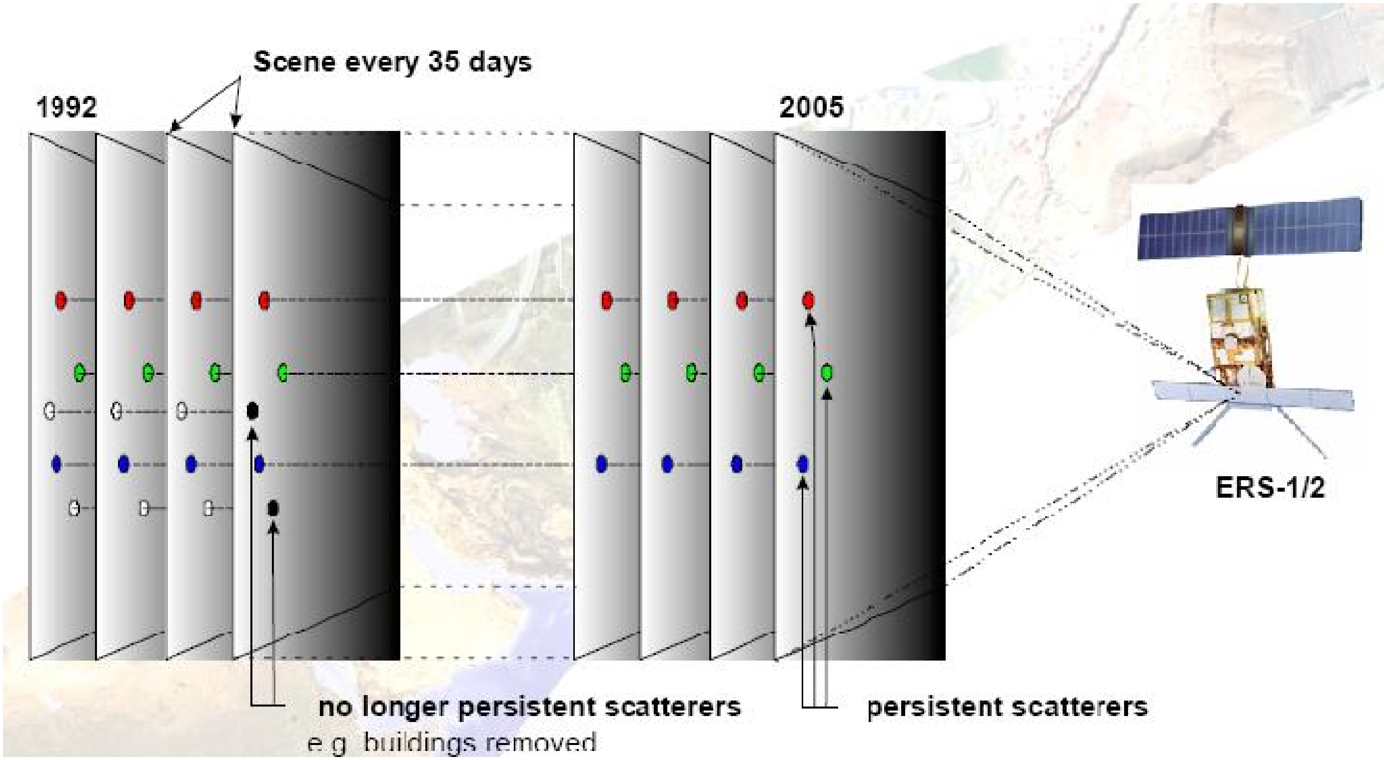
ASTER GDEM vs other DEMs

	ASTER GDEM	SRTM3*	GTOPO30**	10 m mesh
Data source	ASTER	Space shuttle radar	varied	1:25,000 map
interval	30m	90m	1000m	~10m
Accuracy (stdev.)	7~14m	10m	30m	5m
DEM coverage	83 degrees north ~ 83 degrees south	60 degrees north ~ 56 degrees south	Global	Japan only
Area of Missing data	Areas with no ASTER data due to constant cloud cover (supplied by other DEM)	Topographically steep area (due to radar characteristics)	None	None

Case study – Measuring Subsidence with persistent scatterers (PS IfSAR)

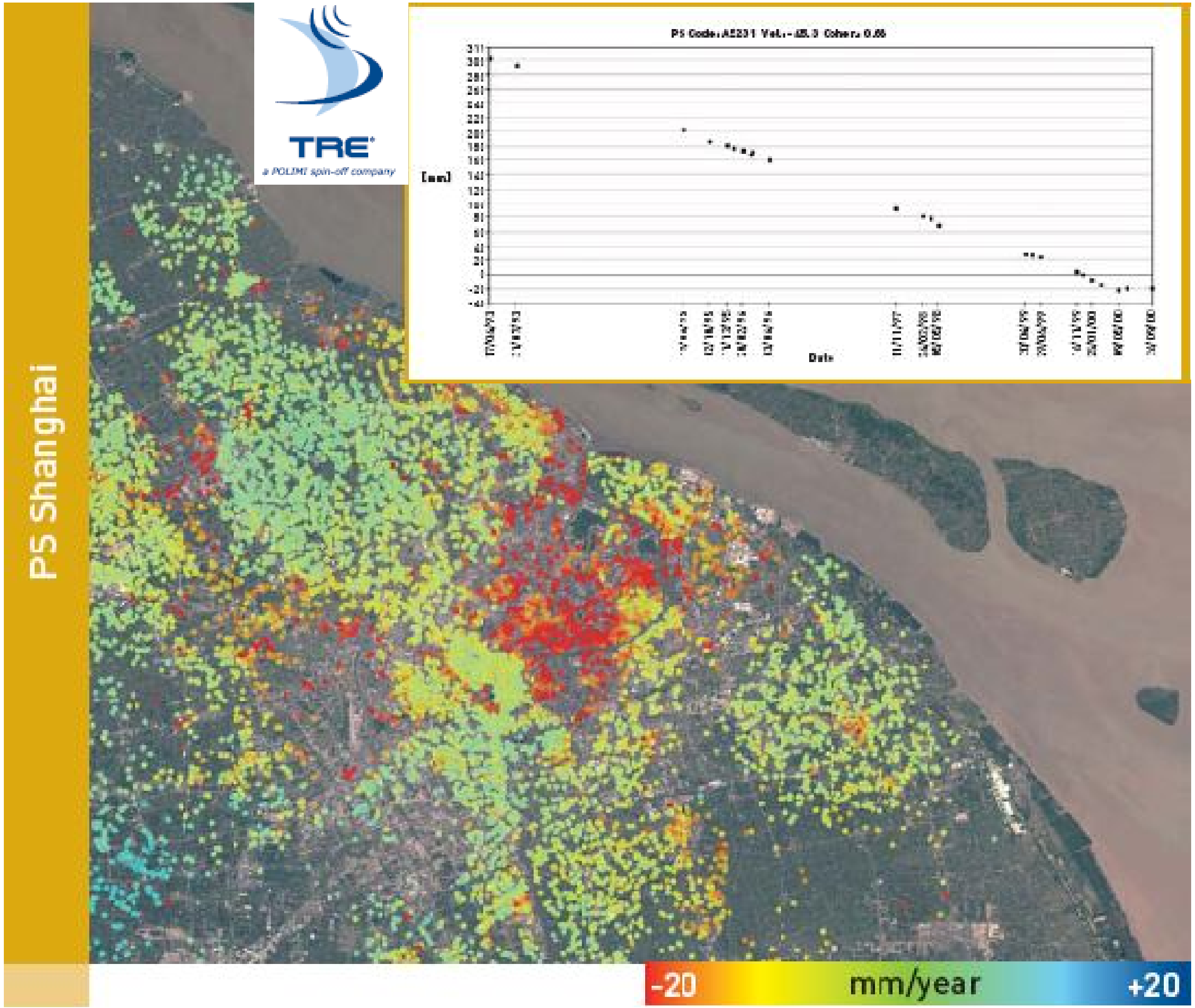
- The PS technique identifies single coherent benchmarks, known as **Permanent Scatterers** or **PS**, and reconstructs their displacement history.
- PS typically correspond to objects on man-made structures such as buildings, bridges, antennae, as well as to stable natural reflectors (e.g. exposed rocks)
- Steps:
  - Establish their geographic coordinates)
  - Estimate their displacement rate for which the precision can be as good as 0.1 mm/year, depending on the amount of available data and the PS density;
  - Reconstruct the displacement history of an individual PS where the precision can be as good as 1 mm on a single measurements.

PSI Data Stack



Case study: Shanghai

Average displacement rates (along the satellite line of sight) of radar targets (PS) identified.
PS time series, at top right.



ESA data © 1993 - 2000.

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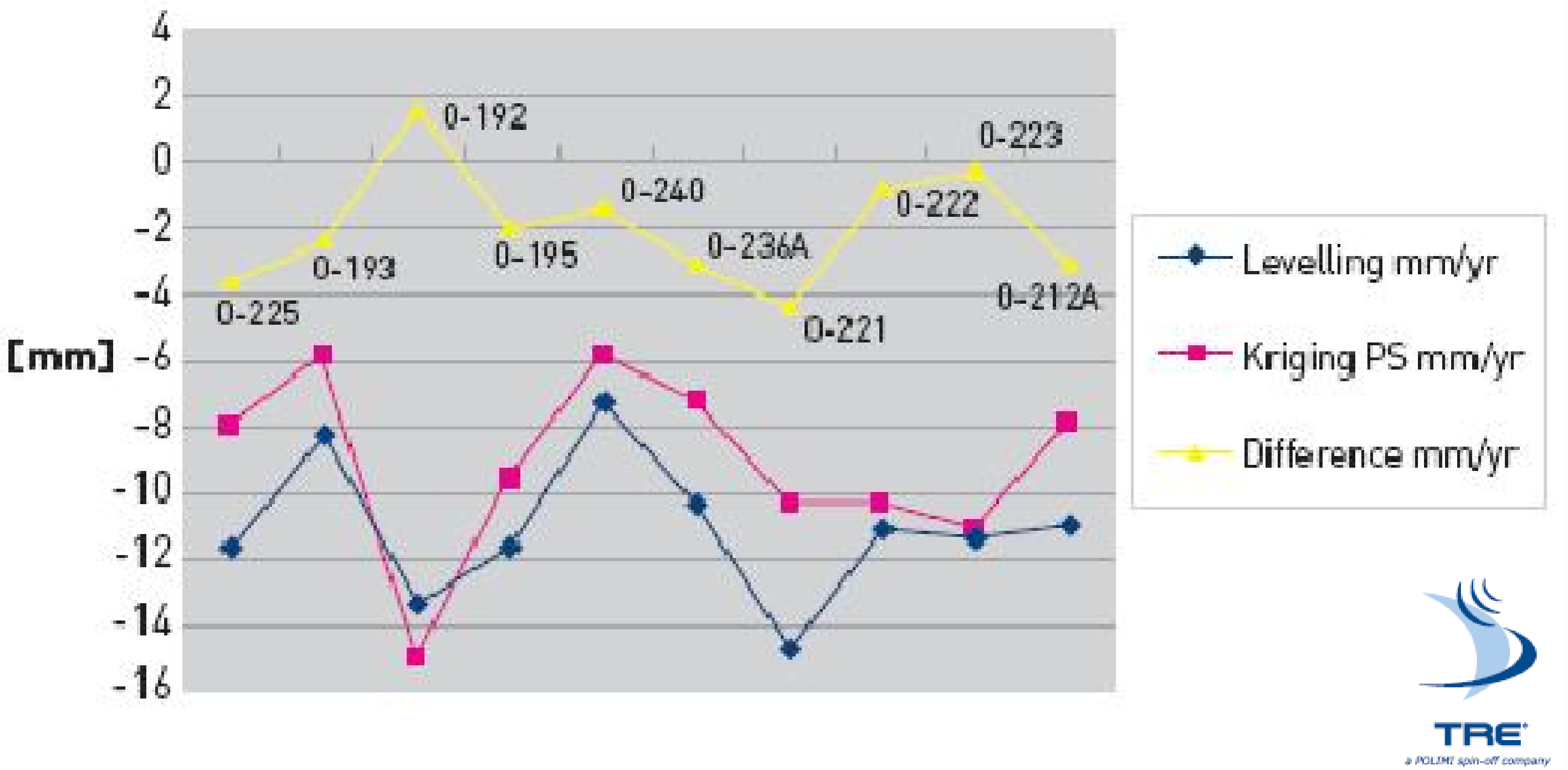
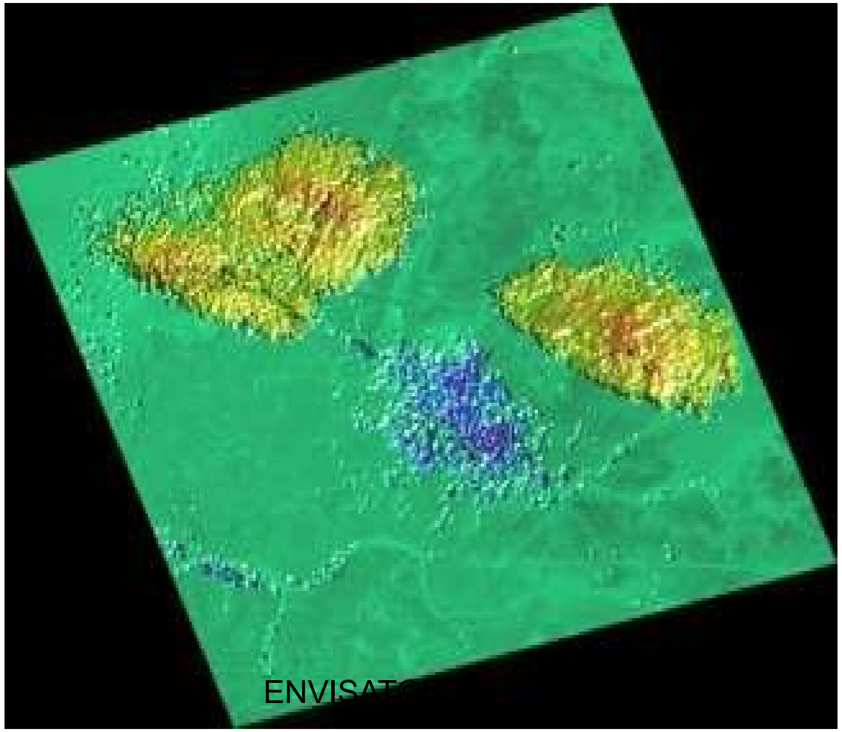
Comparison of PS with levelling data



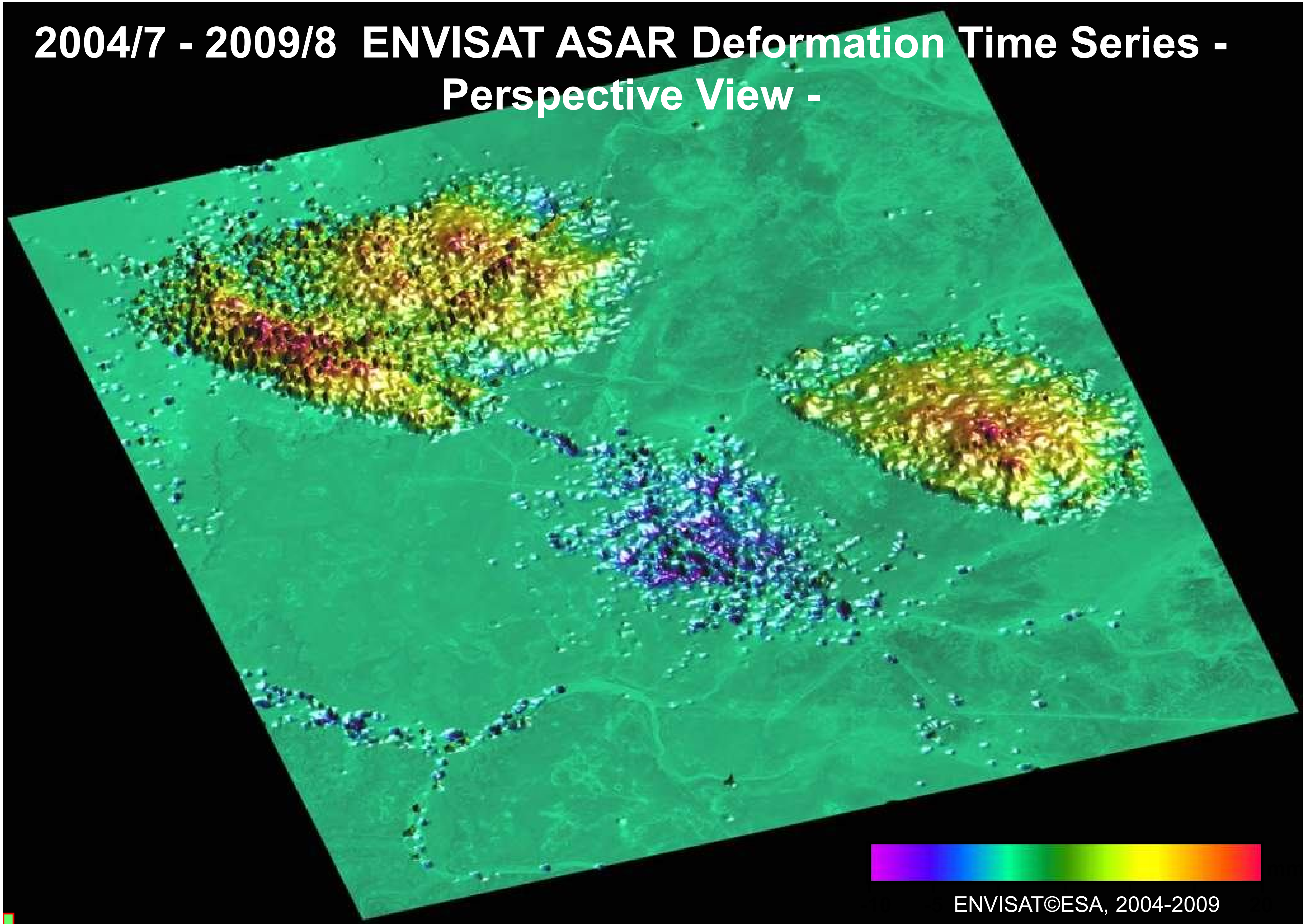
DInSAR Demonstration Case

- The DInSAR analyses using ENVISAT ASAR has successfully revealed the surface deformation related with CO_2 injection.
- Accuracy: 1/10~1/20 of wavelength: ~3 mm in case of ENVISAT ASAR.

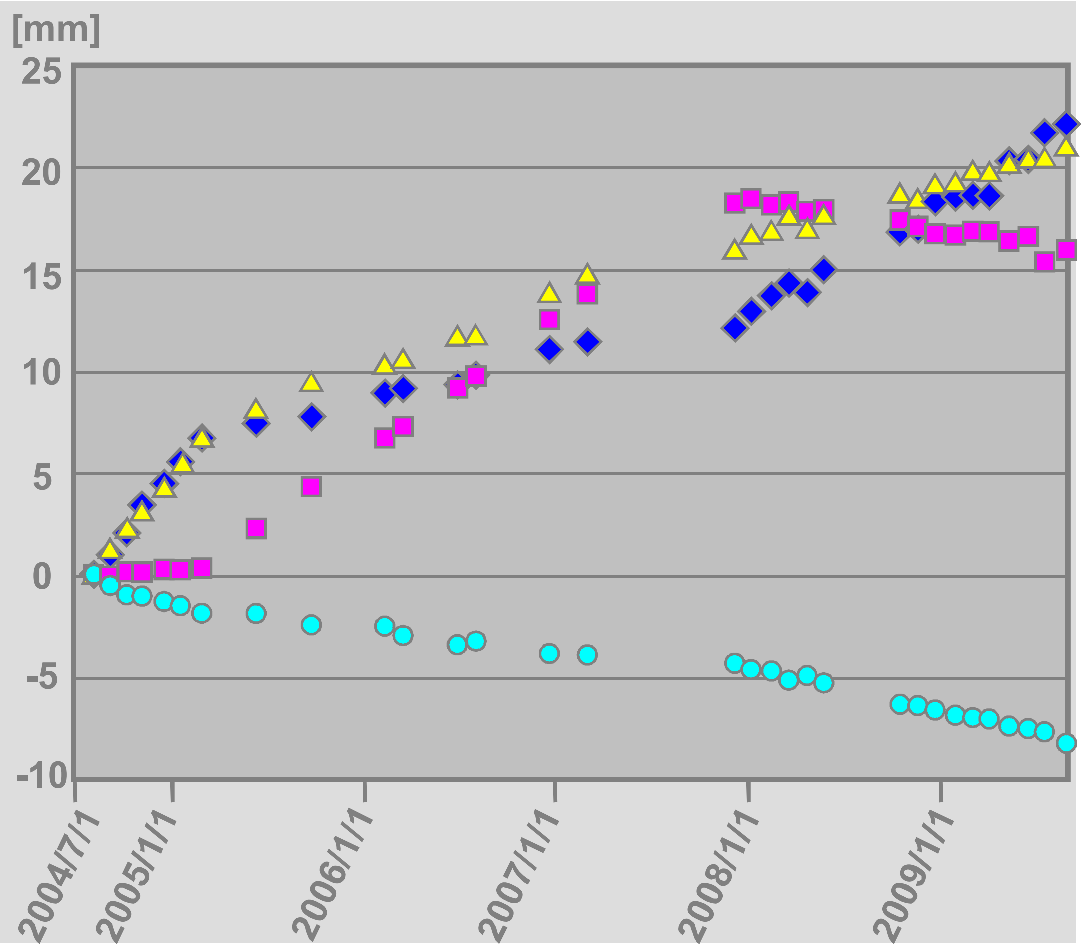


T. Onuma, et al, Applied Geoscience Department, JGI, Inc.

2004/7 - 2009/8 ENVISAT ASAR Deformation Time Series - Perspective View -

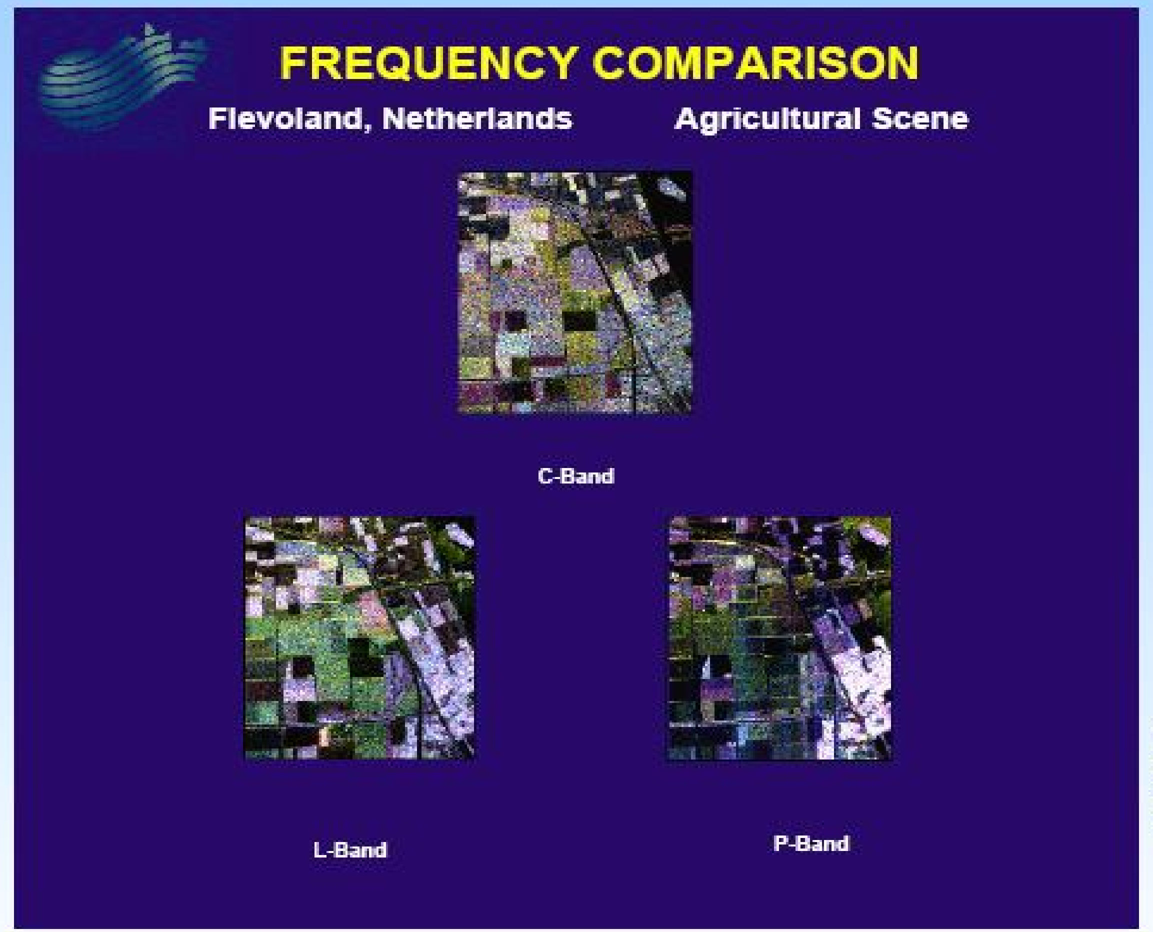


Perpendicular Deformation Histories



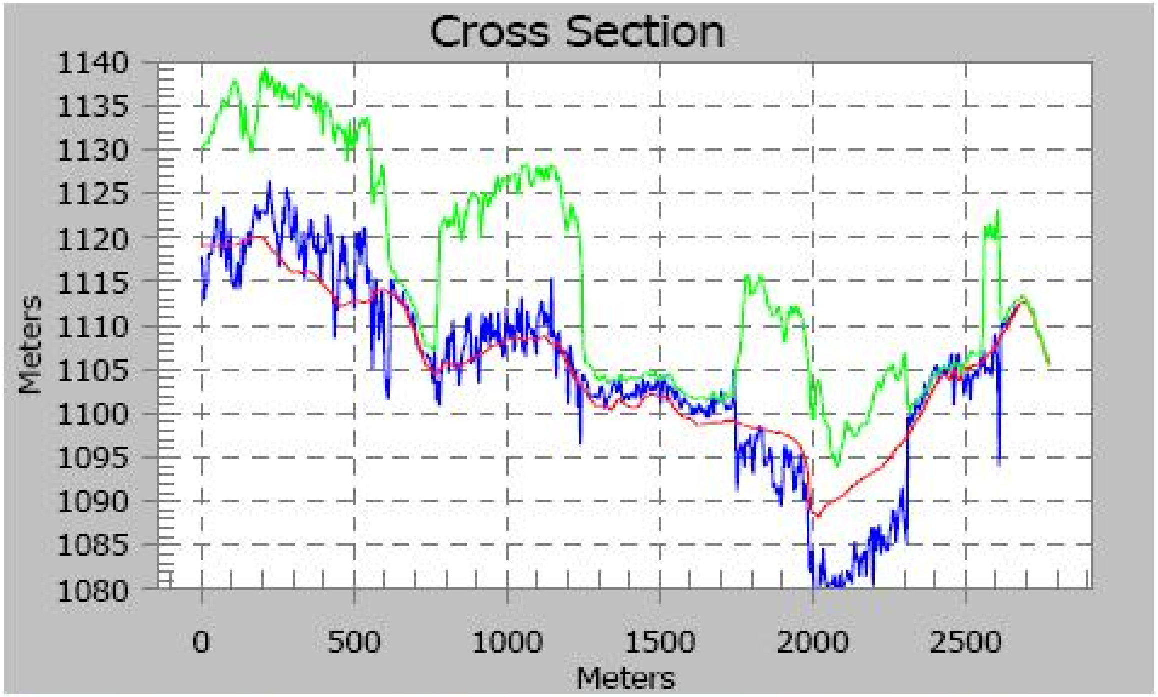
Forestry Applications

Frequency Comparison: C-, L-, and P-Bands



Multipolarization colour composites courtesy of JPL

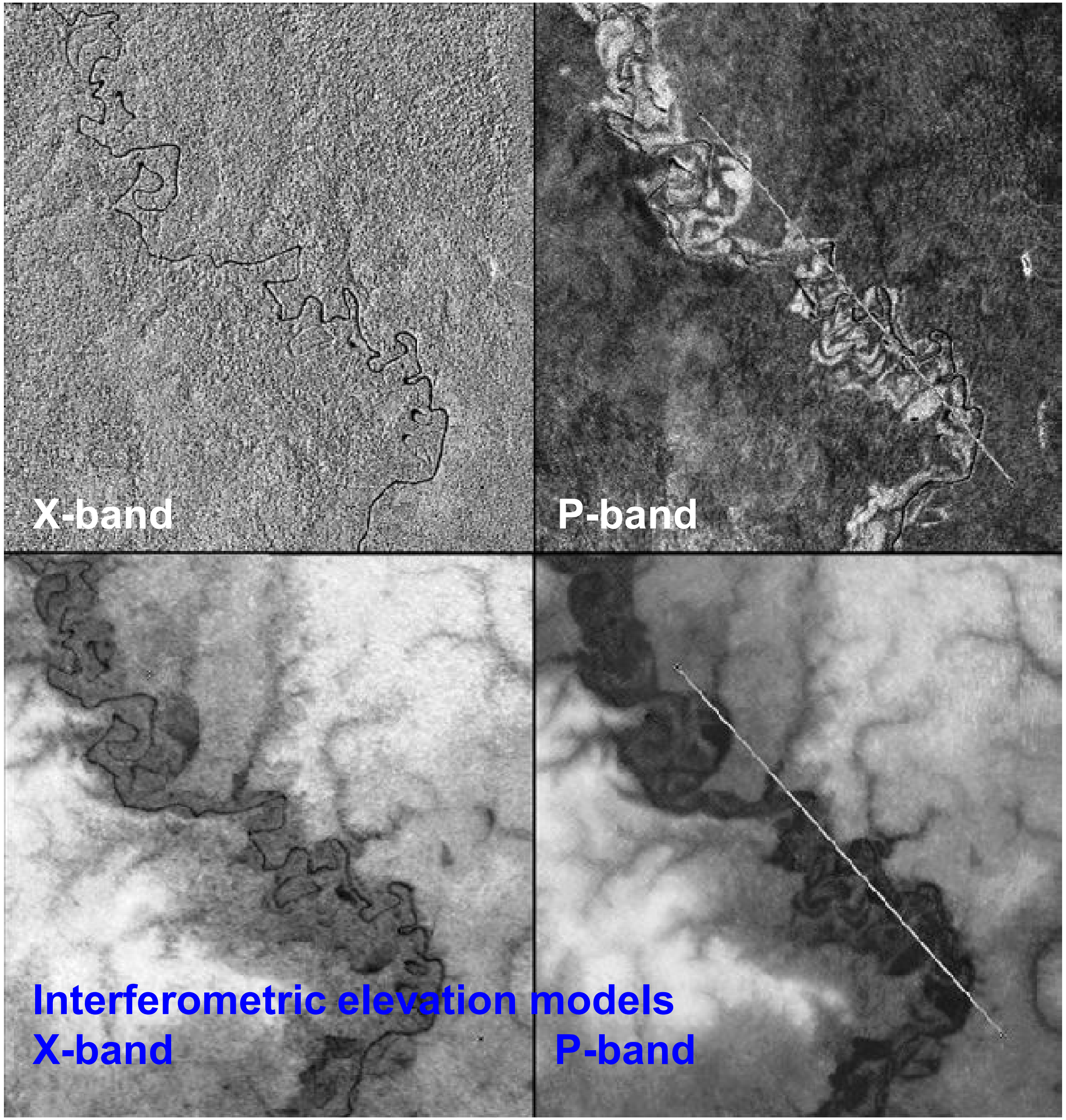
X band and L band over forest



Elevation cross-profile of lidar bald-earth (Red), X-Band DSM (data acquired in April 2006, Green), L-Band ground elevation (blue). Bottom: Location of the profile line is overlaid on a color airphoto

An area of the Amazon Basin

The P-band image shows brighter returns commonly associated with flooded understory. These bright returns are well correlated with dark (flat) areas in the P-band digital elevation model. [Carson, 2008]



Precision agriculture

Precision agriculture is the ability to manage land by the square meter instead of the square mile

Mobile Mapping for precision Agriculture

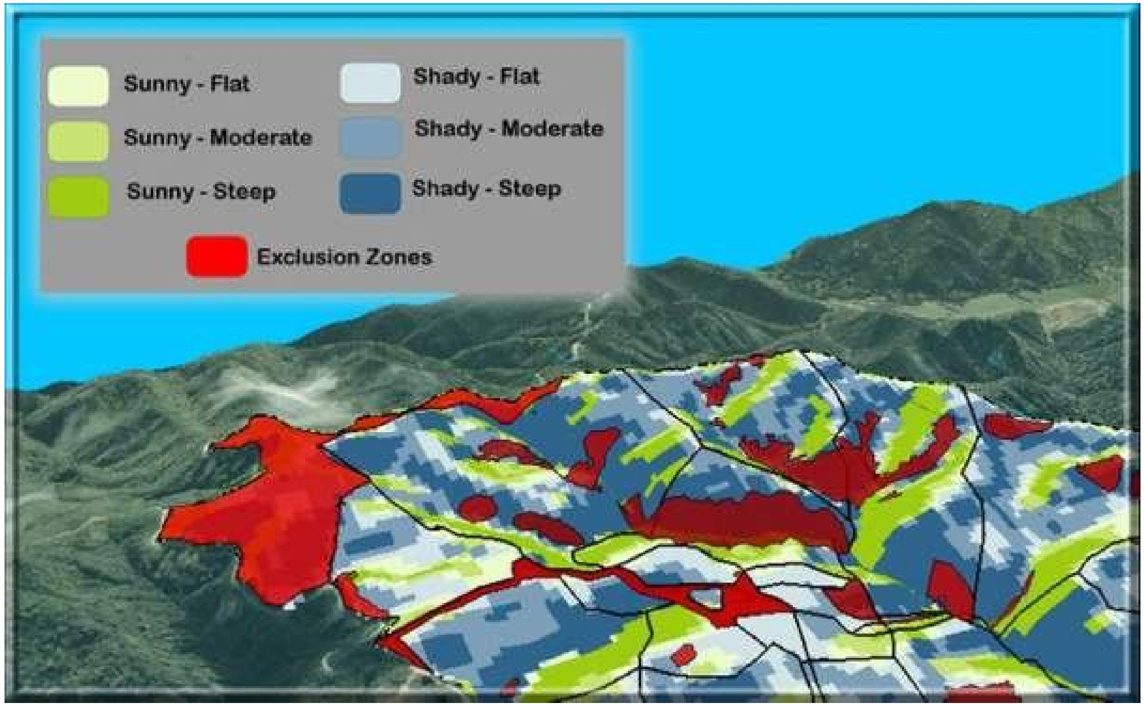
http://www.gisdevelopment.net/application/agriculture/overview/agrio0011.htm

- Data Collection:
  - "Free Form" (notation)
  - "Choice List" selection, (predefined)
  - Editing existing attributes
- Data Entry:
  - Pen stylist selection
  - Hand writing recognition
  - Voice recorder Import from other sources.
- Expandable Memory and Storage
- Modem Connectivity
- Wireless Applications
  - Digital phone
  - Web based email
  - Web Browser

Ruggedized Handheld Personal Computer (HPC)

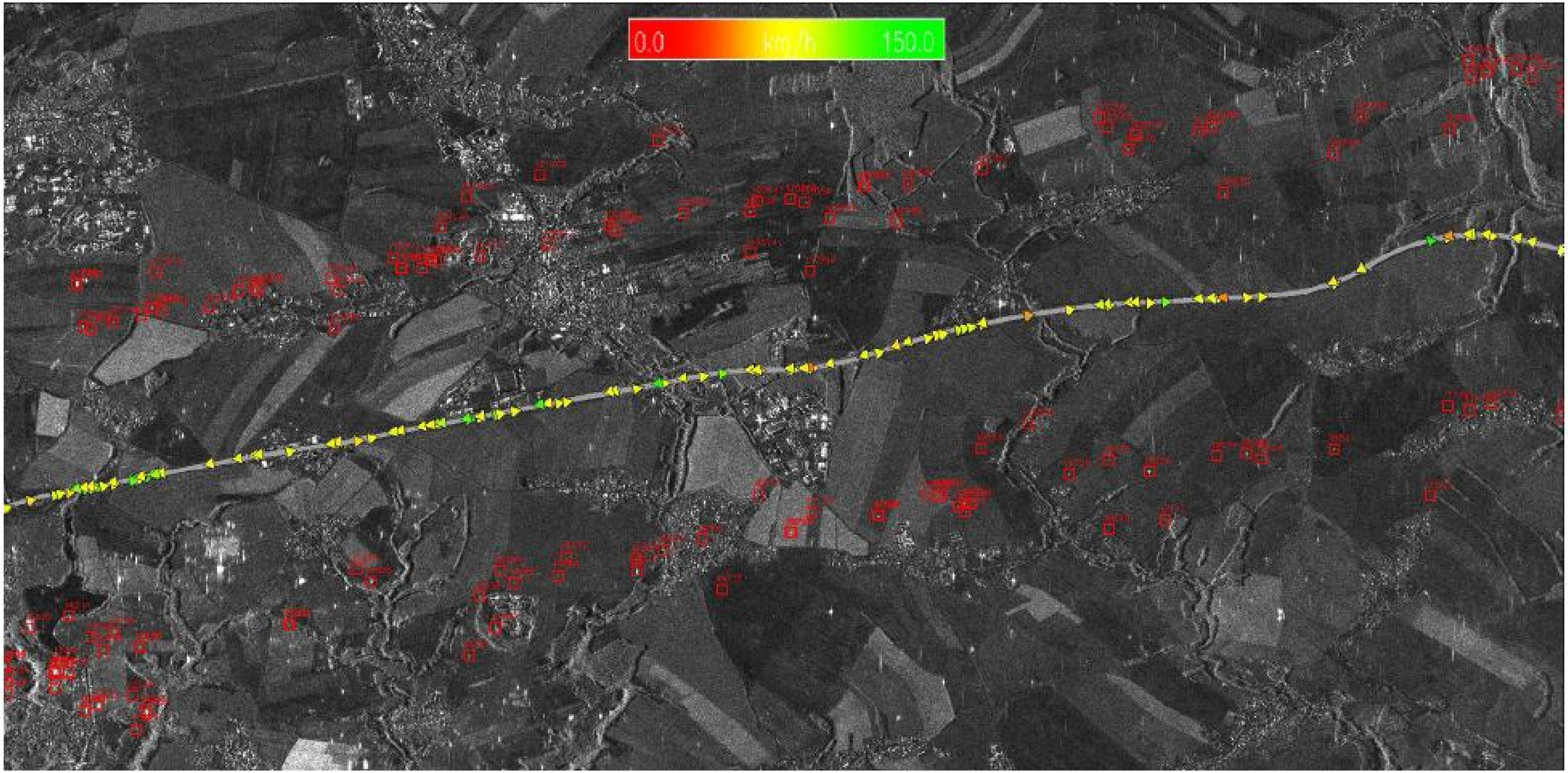
Maps
Photographs
Topography
Field observations
Testing results
Climatic data
Previous agronomic data

Prescription map – for variable rate application



- Incorporates aspect, slope and exclusion layers
- Ready for direct input to the fertiliser control system
- Total fertiliser required and amount per zone is calculated

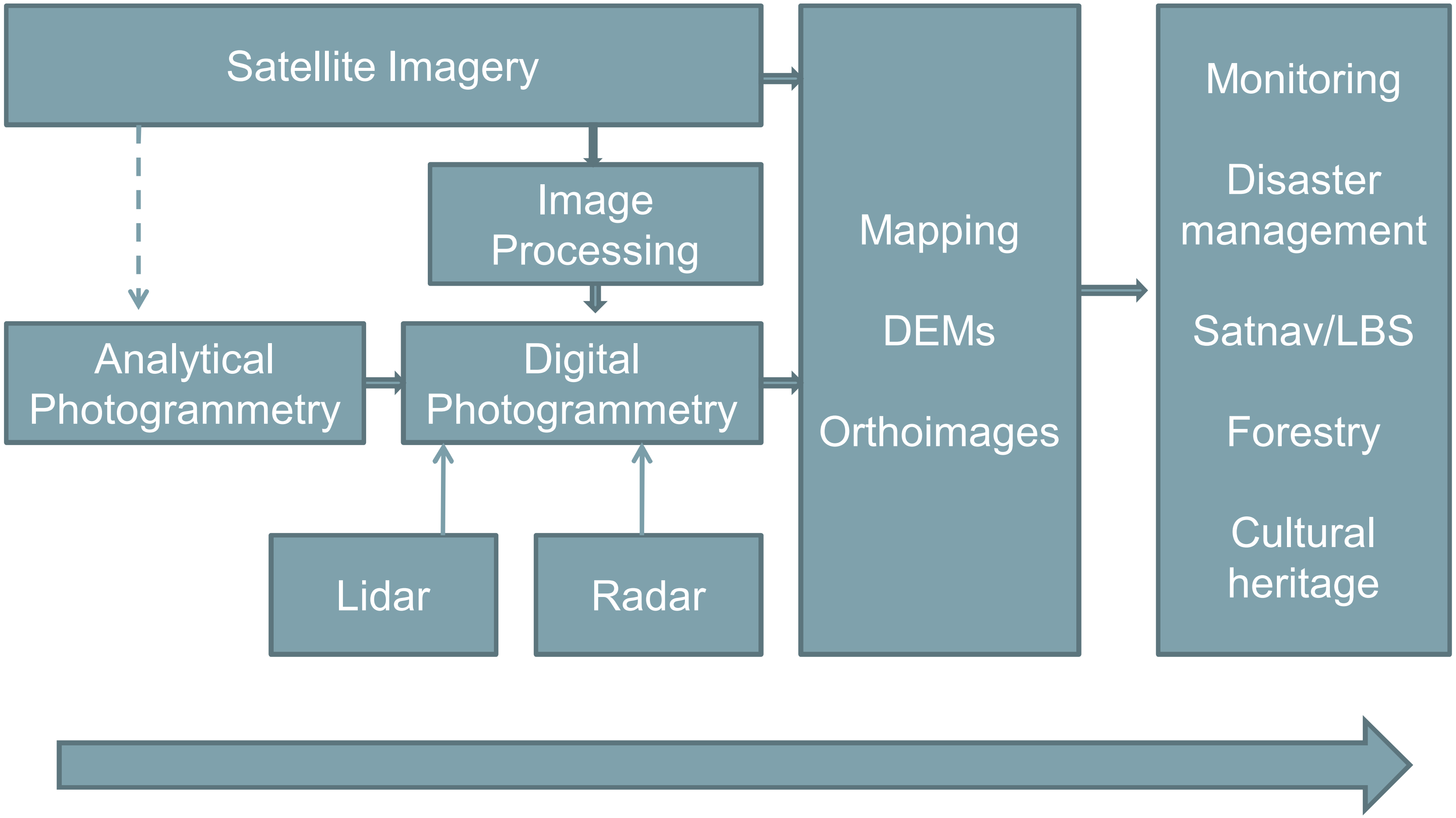
Traffic detection with TerraSAR-X



Issues with applications

- Understand the user requirements
- Ensure that the user needs the product and can use it (education and training)
- Provide the right equipment

The evolution of digital photogrammetry



Convergence of techniques and expansion of applications

Conclusions

- Remote sensing and photogrammery have converged
- Digital photogrammetry has realised the potential of automation
- Digital Elevation Models are finding applications in many areas
- New applications are opening up