Flood Mapping from Satellite SAR Data

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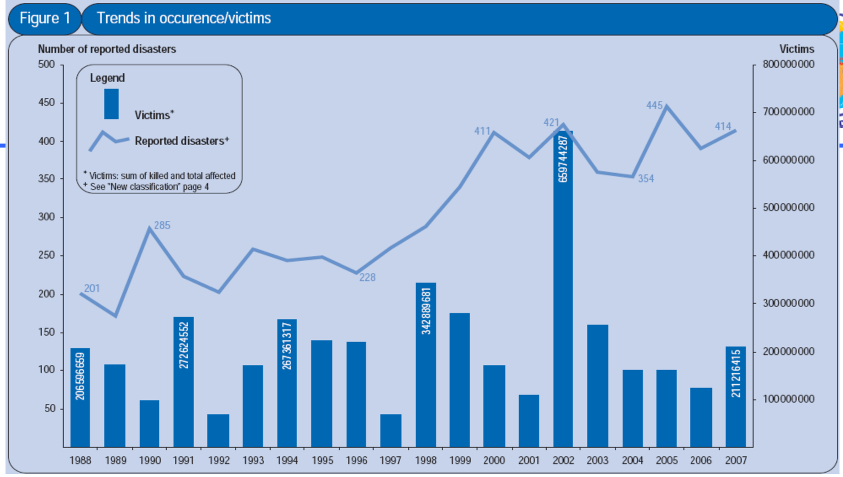
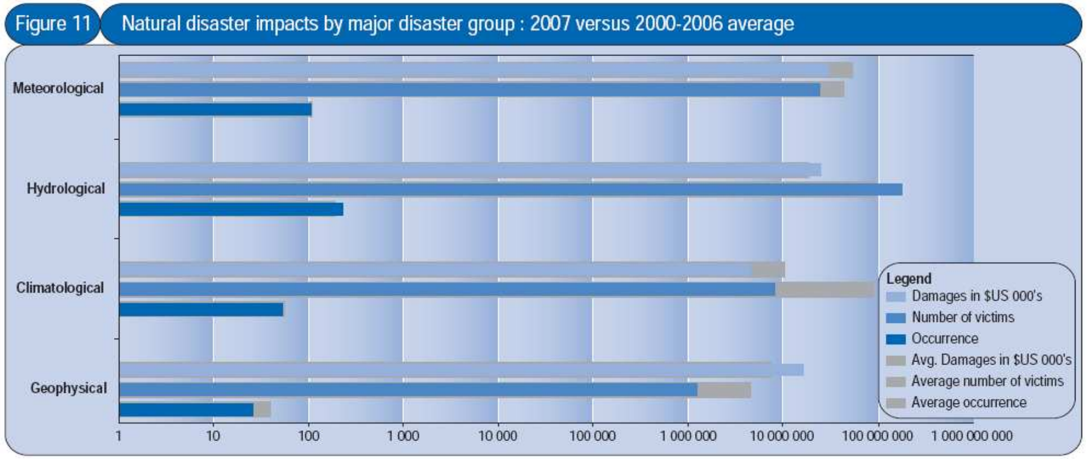
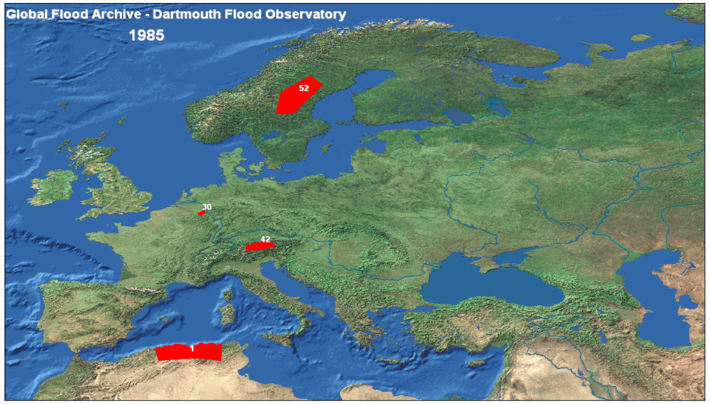
Disasters

- Disasters
  - 2000 to 2007: an average annual growth rate of **8.4%**
  - Hydrological disasters
    - incl. floods, wet mass movements
    - represent **55%** of the overall disasters reported in 2007
    - impact: **177 million victims** and economic damages **24.5 billion USD**





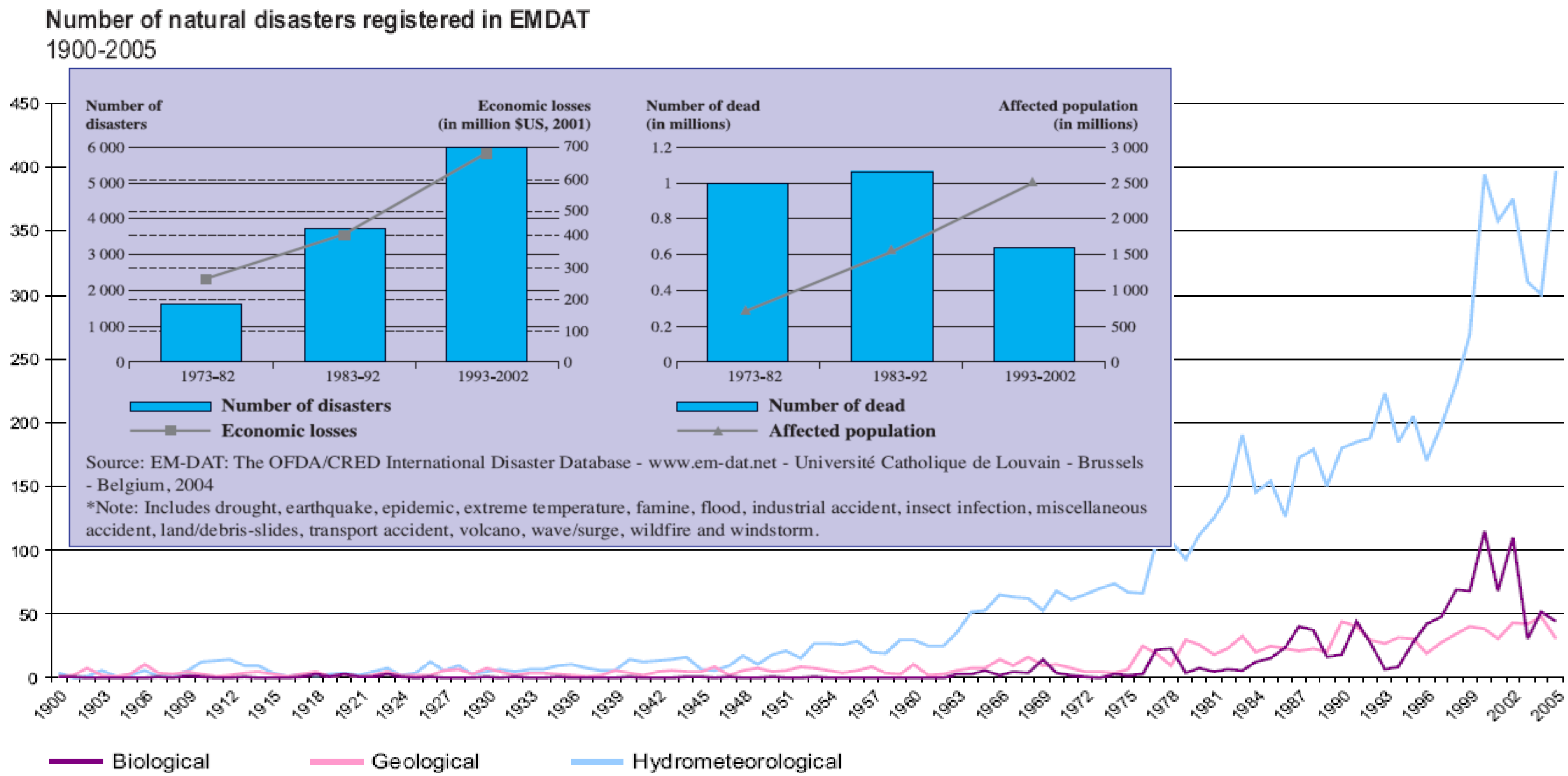


[Source: Annual Disaster Statistical Review – The Number and Trends 2007]

[Source: http://www.dartmouth.edu/~floods]

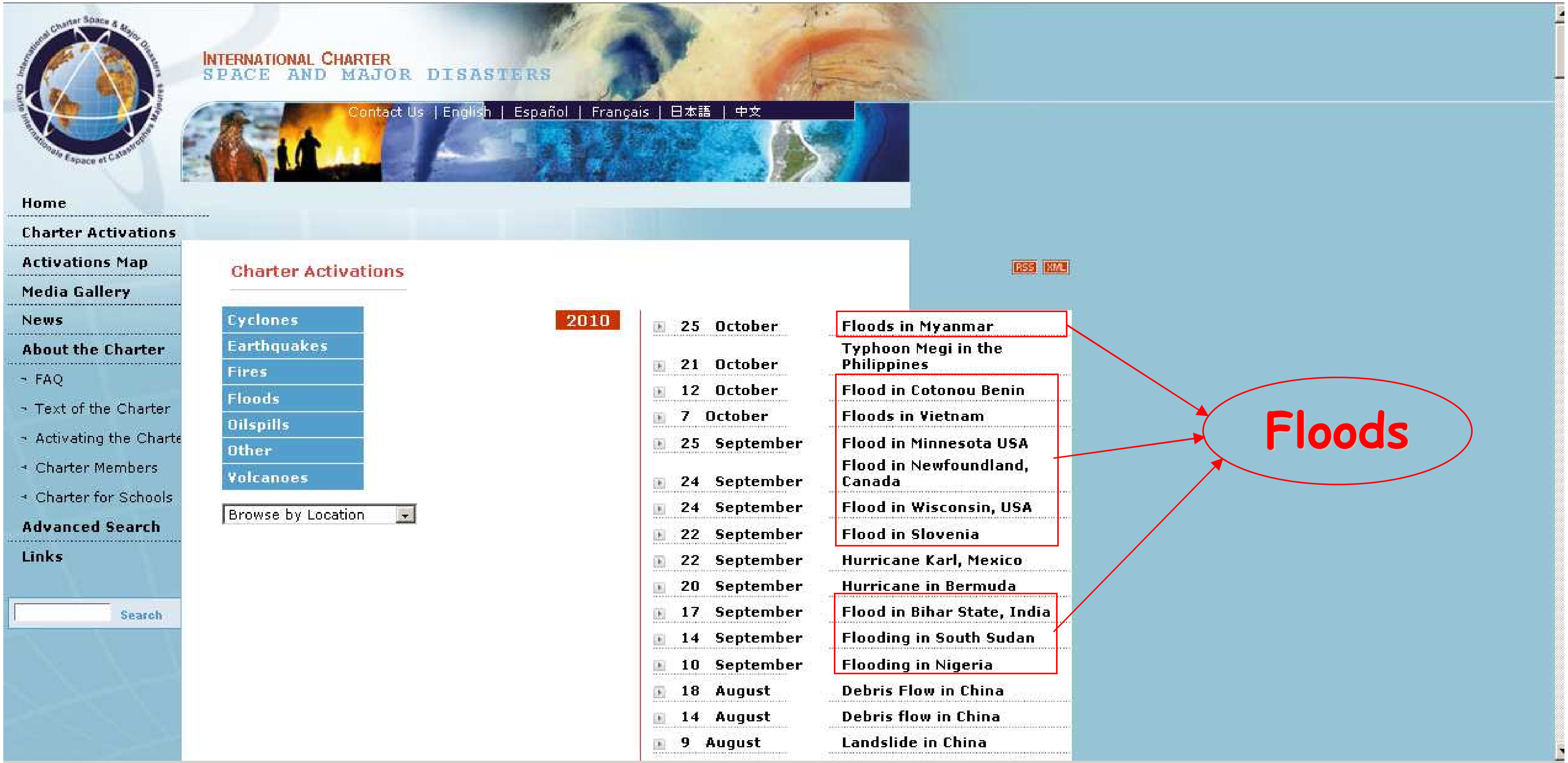
Actuality

- **A flood can be defined as any relatively high water flow that overtops the natural or artificial banks in any portion of a river or stream**



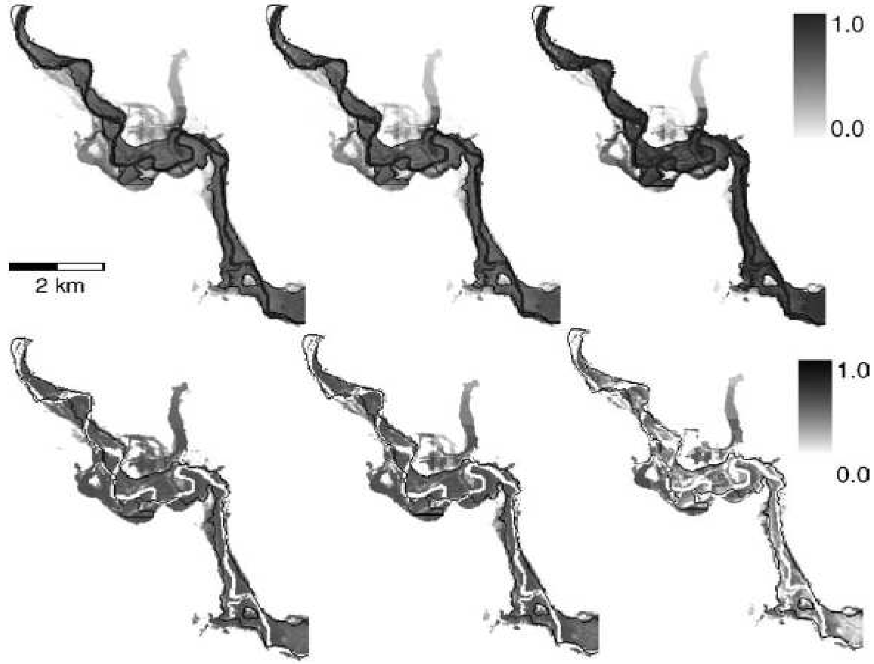
Source: http://www.unisdr.org/disaster-statistics/pdf/isdr-disaster-statistics-occurrence.pdf

Actuality (cont') – Latest Charter activations



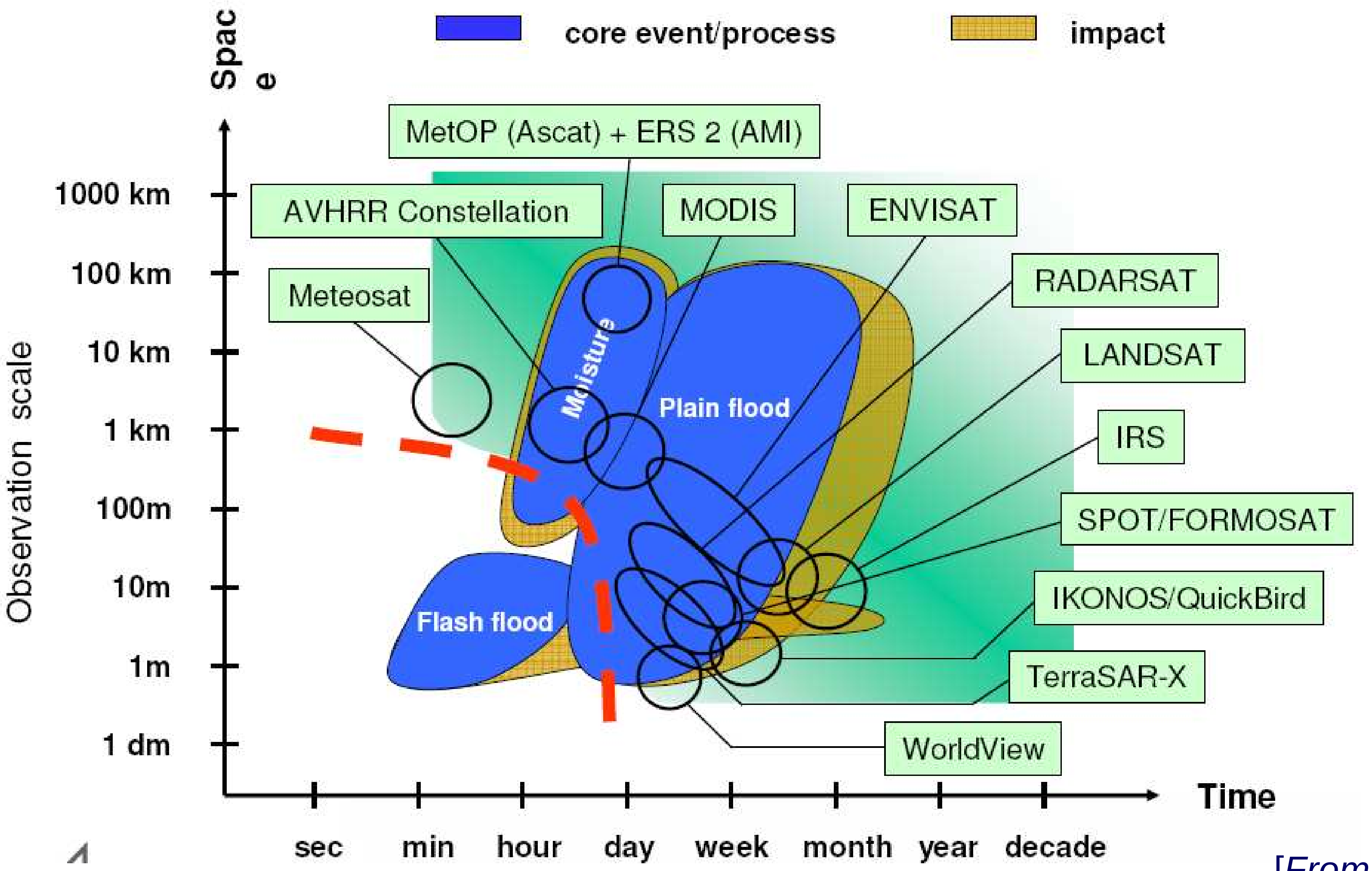
Application of Flood Maps

- It is impractical to acquire the flood area through field observations
- Hydraulic models
  - to reconstruct what happened during the flood and determine what caused the water to go where it did
- Damage assessment and risk management
- Benefit to rescuers during flooding
  - Flood extent with GIS basemaps



[*From: Horritt 2006*]

Spatial and temporal scales in flood monitoring



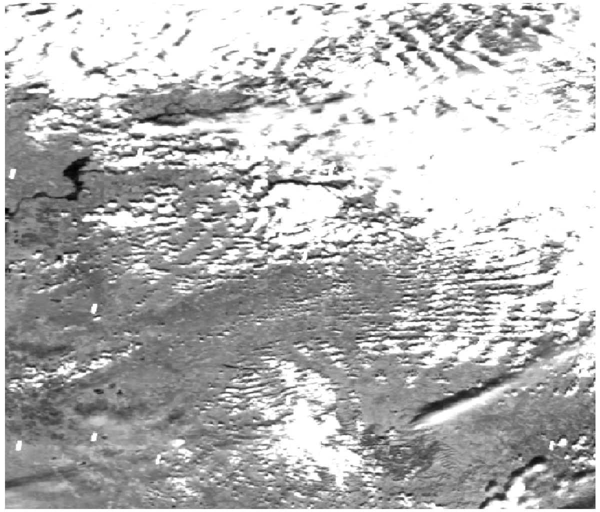
[*From: S. Voigt, DLR*]

Remote Sensing for Flood Mapping

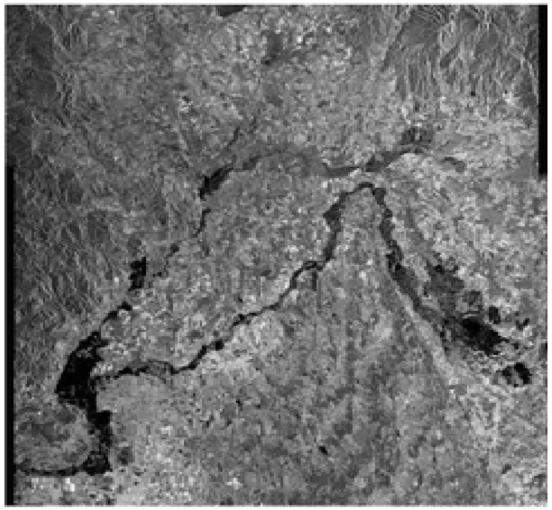
- The use of **optical imagery** for flood mapping is limited by severe weather conditions, in particular **presence of clouds**

Terra/MODIS

2001-03-10



- **SAR (synthetic aperture radar)** measurements from space are independent of daytime and weather conditions

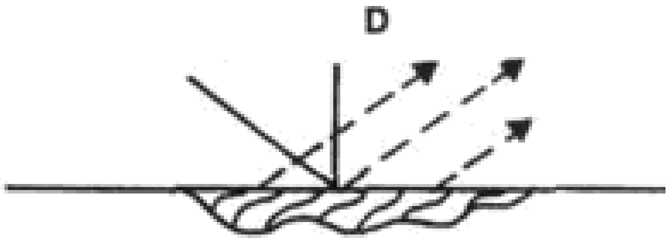


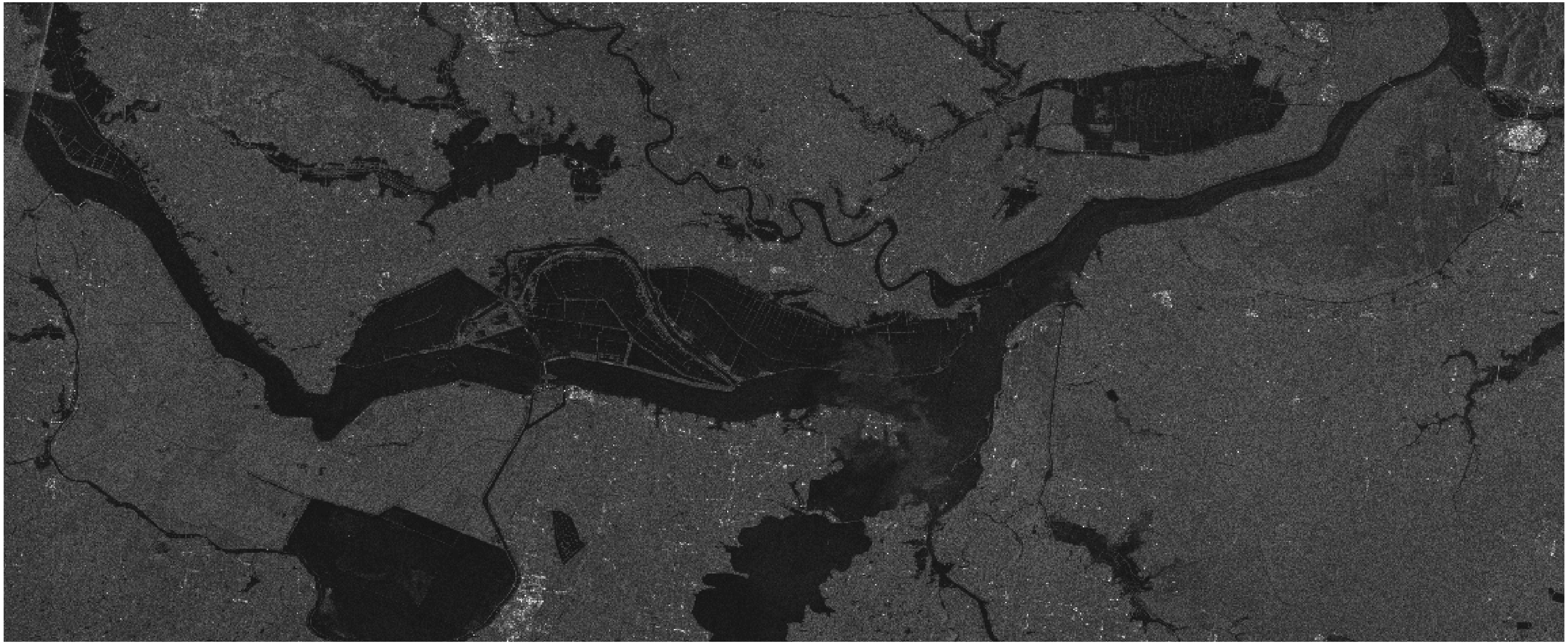
ERS-2/SAR

2001-03-10

Flood mapping using SAR

- Smooth water surface provides no return to antenna in microwave spectrum and appears black in SAR imagery





Flood mapping using SAR

Aspects of Flood Mapping from SAR data

Verification
- topographic maps
- airborne imagery
- in-situ data
- DEM

Water / Flood Features
- wind, roughness
- vegetation (double bounce)
- flood type (e.g. flash flood)

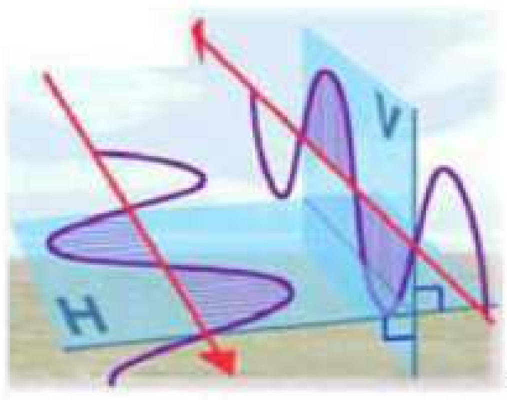
Scale
- temporal
- spatial

Sensor Parameters
- repetition rate
- spatial resolution
- incidence angle
- wavelength
- polarization

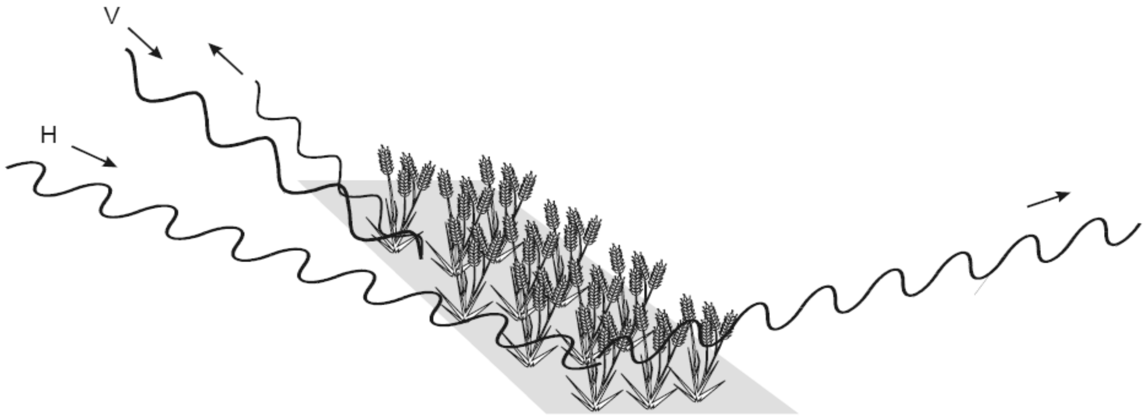
Classification Approach
- object- pixel-based
- supervised/unsupervised
- thresholding
- snake/region growing algorithms

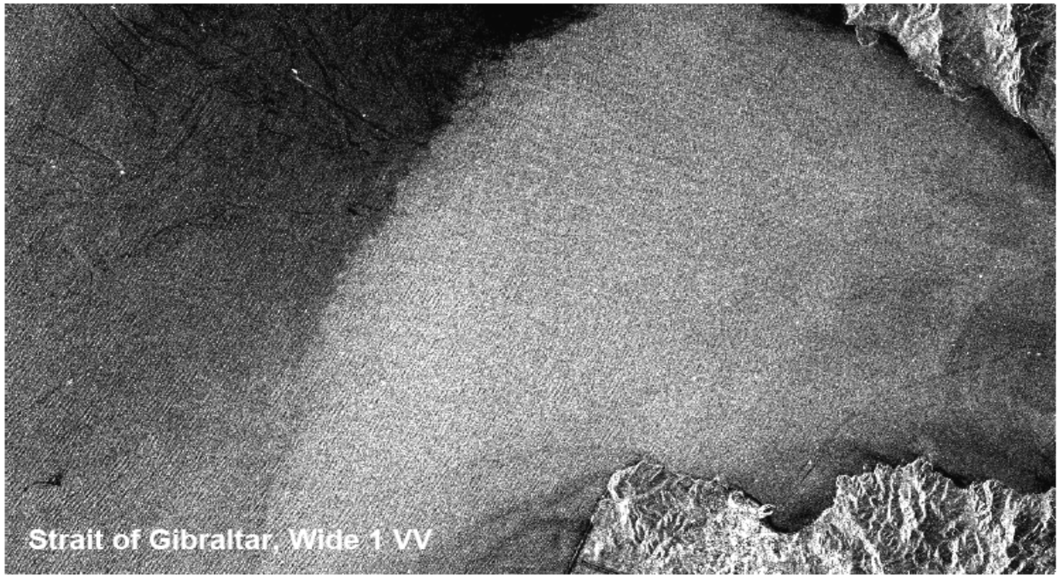
[*From: S. Voigt, DLR*]

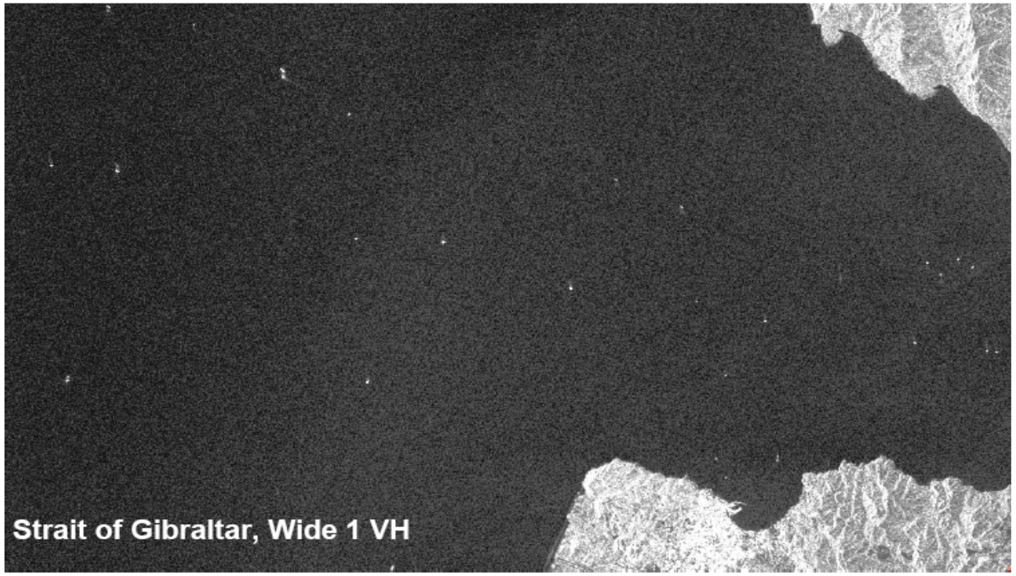
Polarization



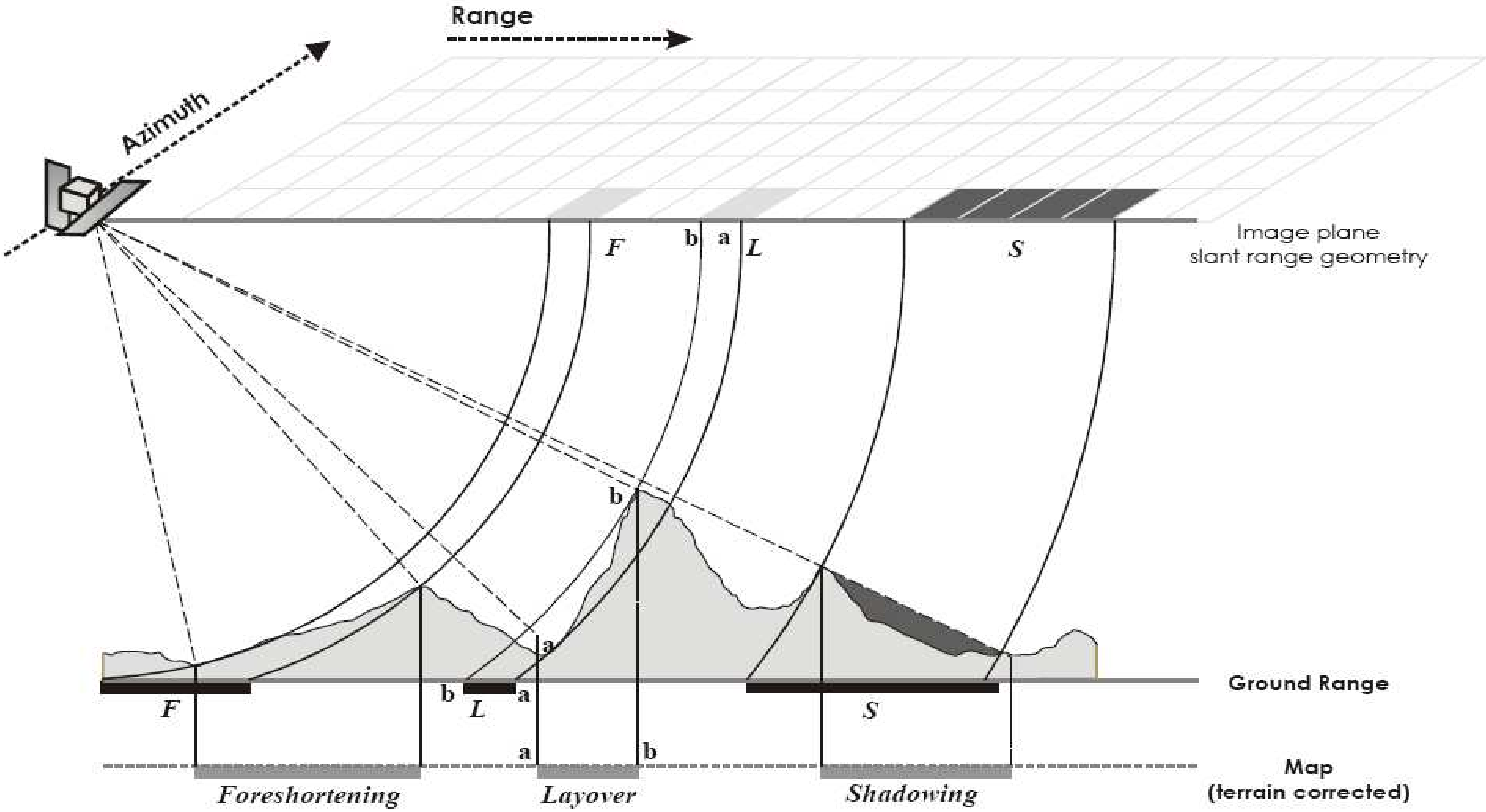
HV polarization







Geometric and radiometric relief distortions

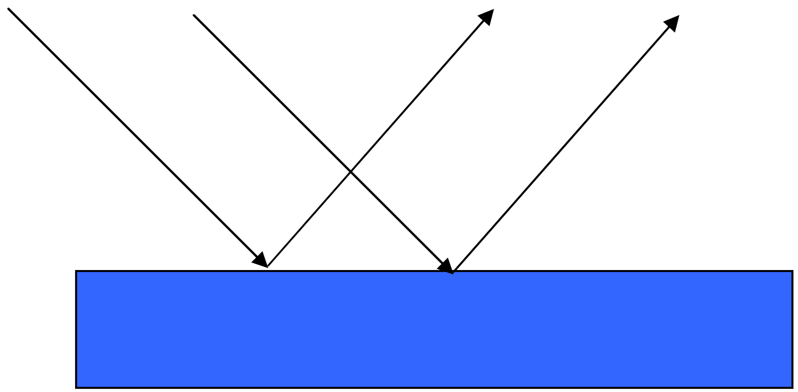


Difficulties in image analysis and interpretation

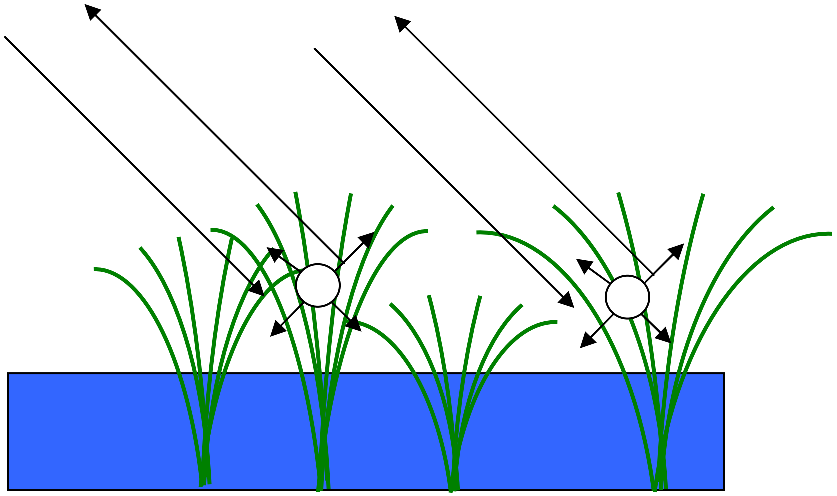
- Flooded vegetation
- Sand
- Roads

Flooded vegetation

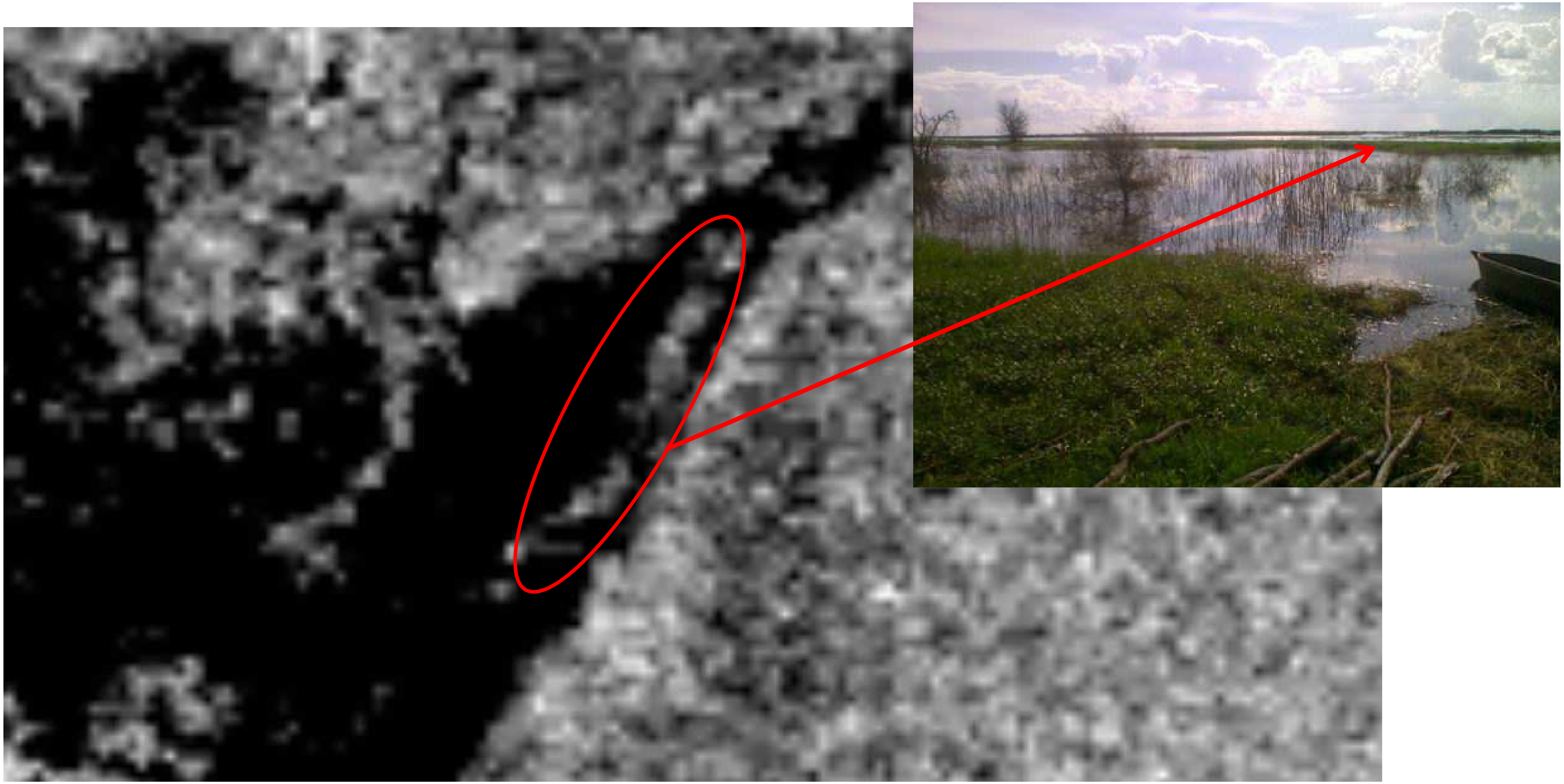
Low backscatter



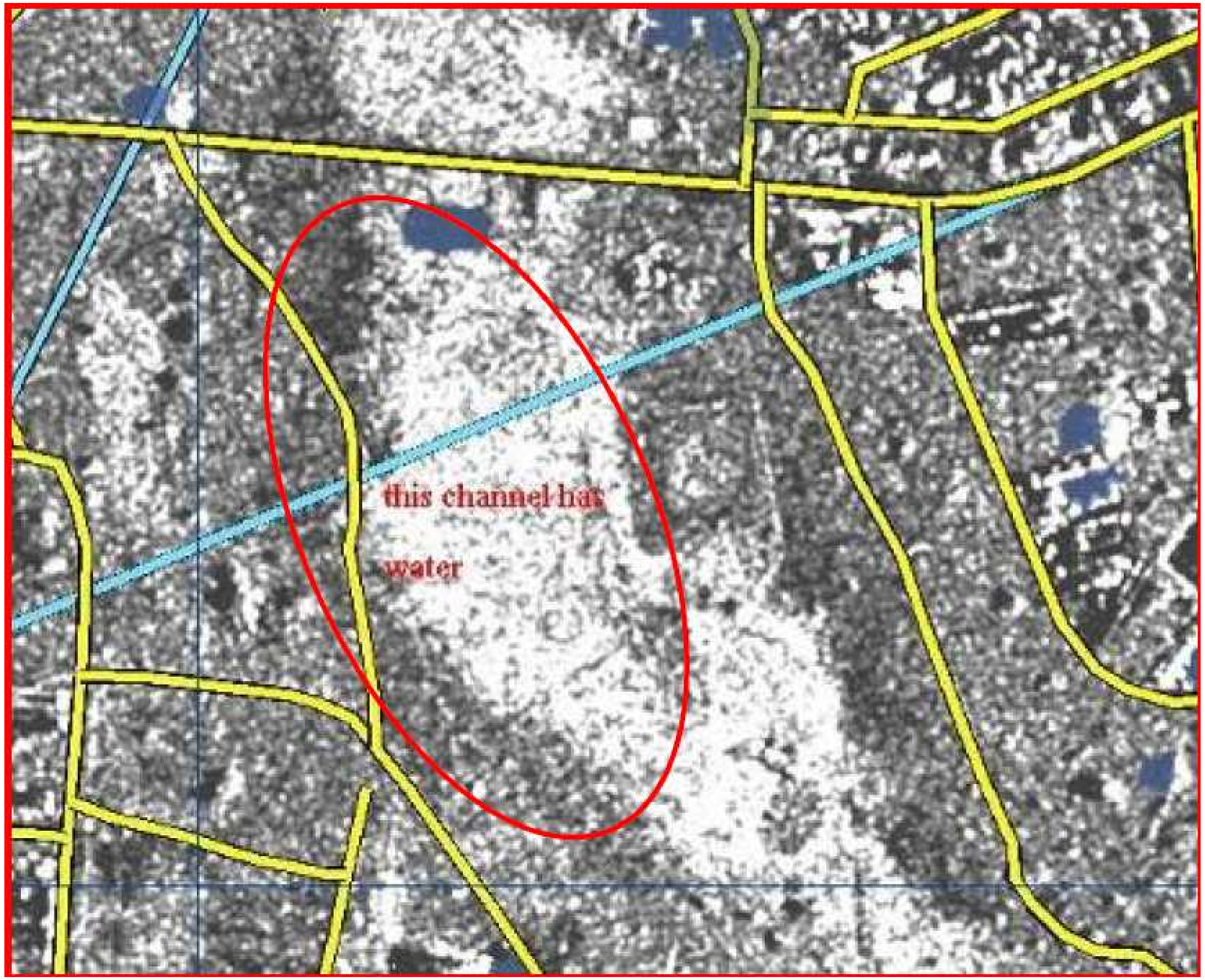
Higher backscatter



Flooded vegetation (cont')



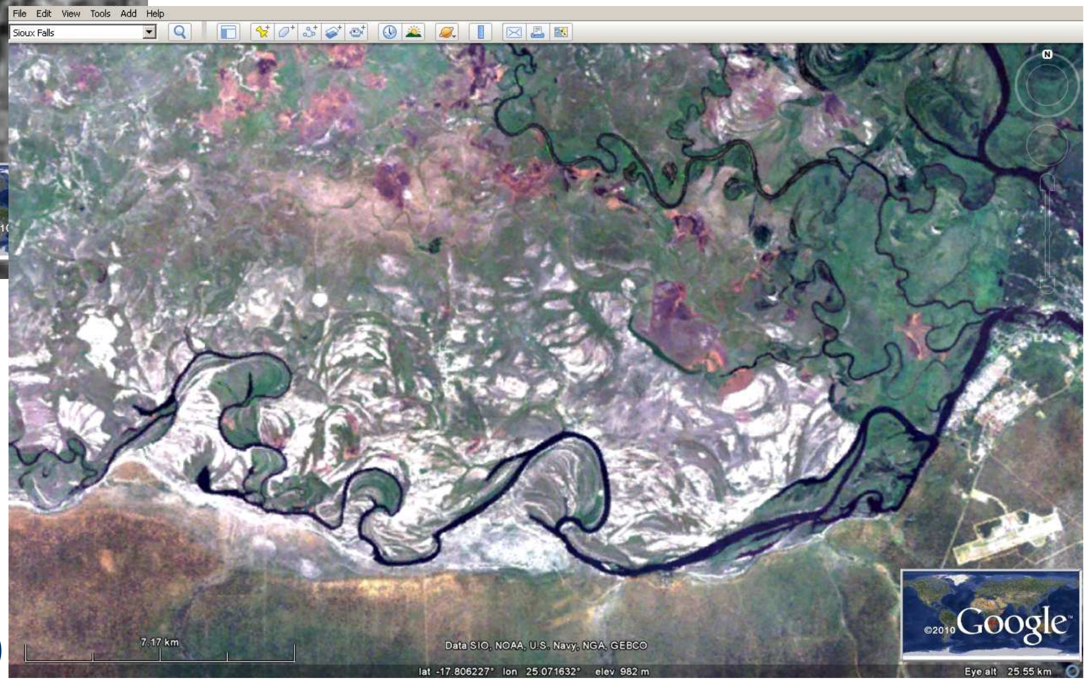
Flooded vegetation (cont')



[*From: S. Voigt, DLR*]

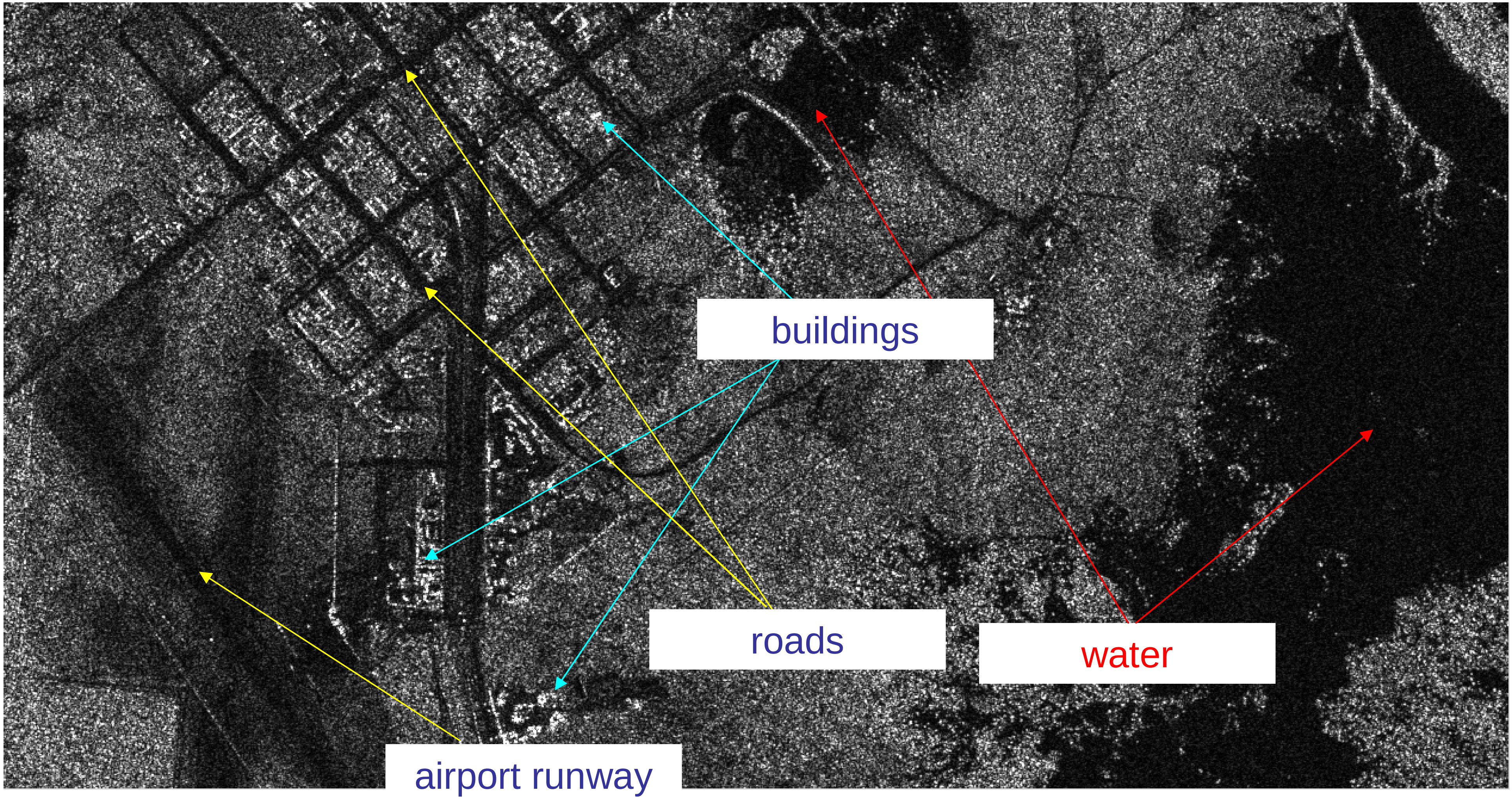
Sand

Envisat/ASAR 30-Jan-2010



Landsat-5/TM 26-Jan-2010

Roads

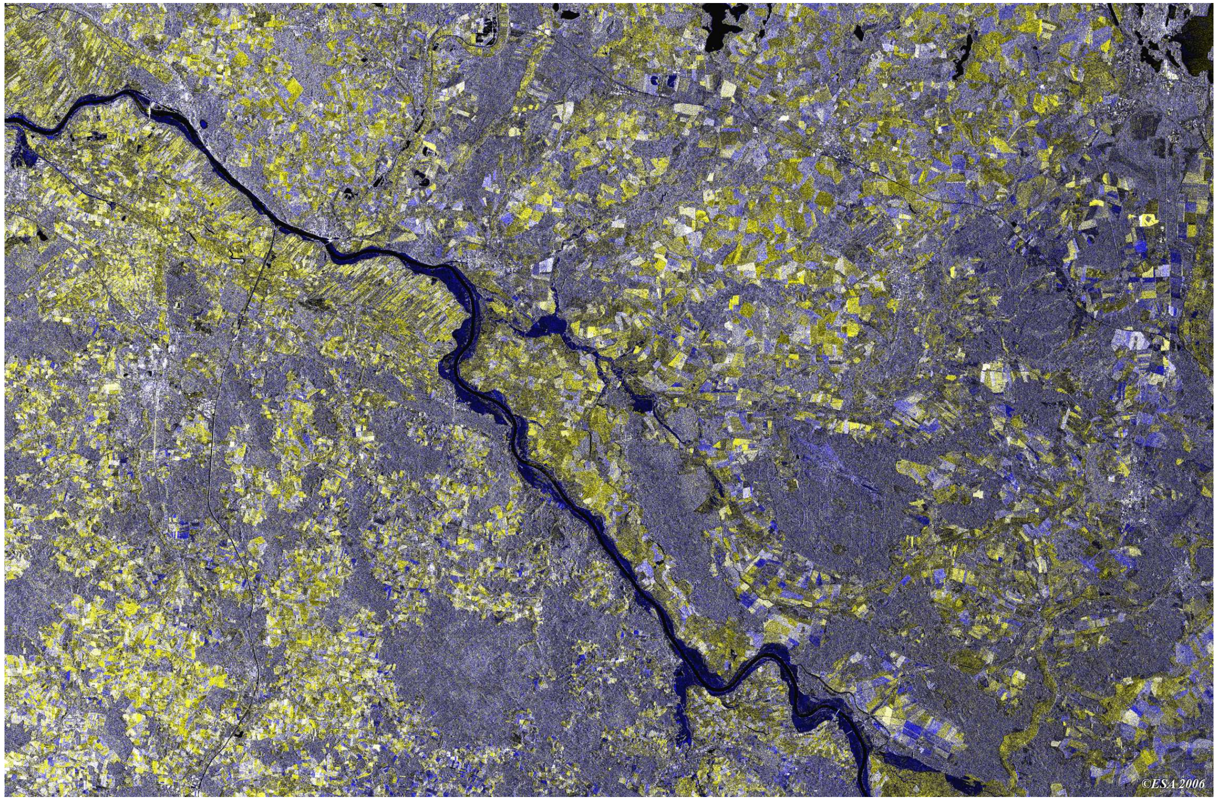


Existing Approaches

- **Multi-temporal technique**
  – Uses SAR images of the same area taken on different dates (one image is acquired during flooding and the second one in “normal” conditions)
  – Implemented as operational service in ESA’s Grid Processing on Demand (G-POD, http://eogrid.esrin.esa.int)

Existing Approaches

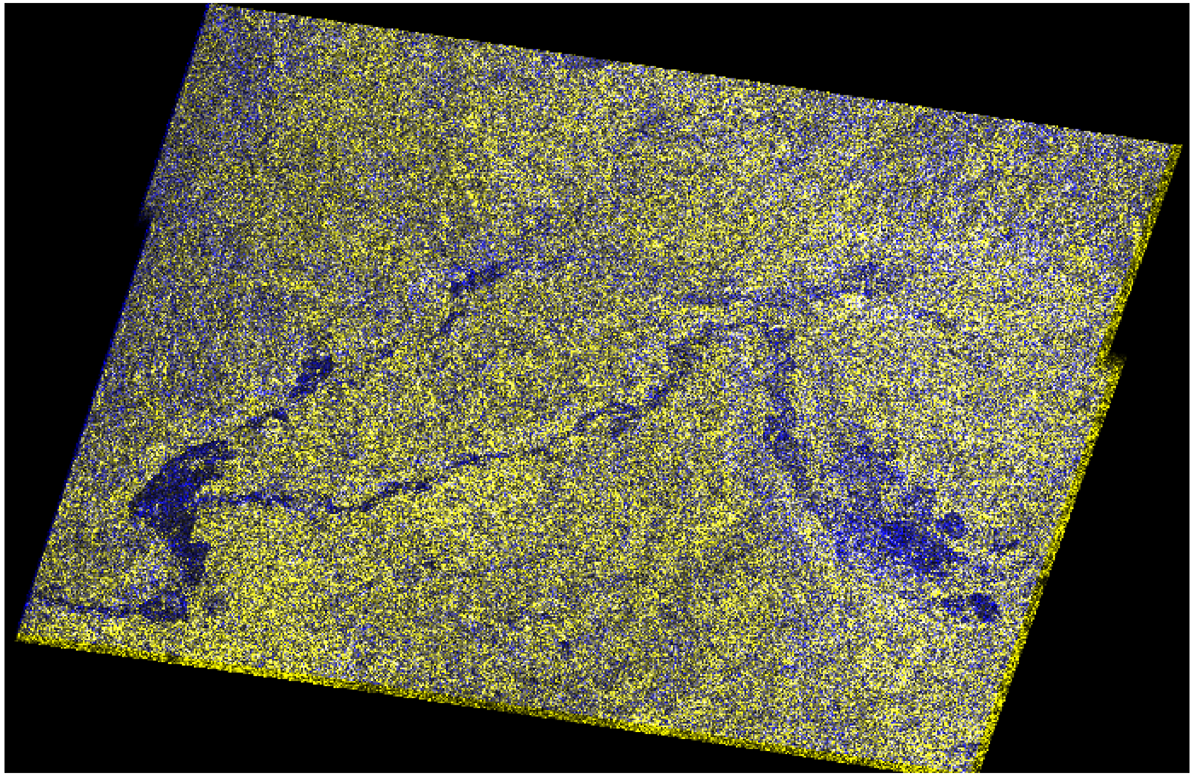
- **Multi-temporal technique**



The image upon acquired by ERS-2 radar, showing the flood extent of the Elbe River in the area around Hitzacker in Lower Saxony, Germany. This is a multitemporal image composed of an ERS-2 image acquired before flooding (1 July 2005) and an ERS-2 image acquired during flooding (7 April 2006). *Source: ESA*

Existing Approaches

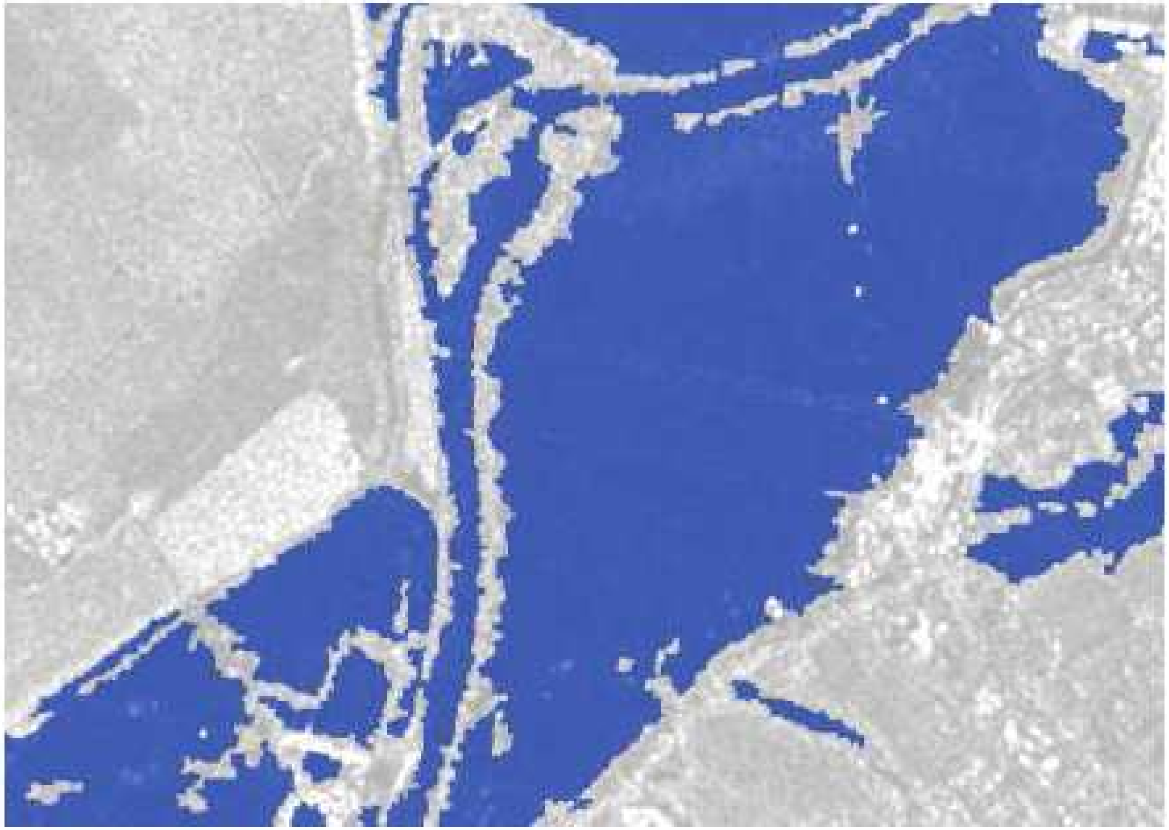
- **Multi-temporal technique**



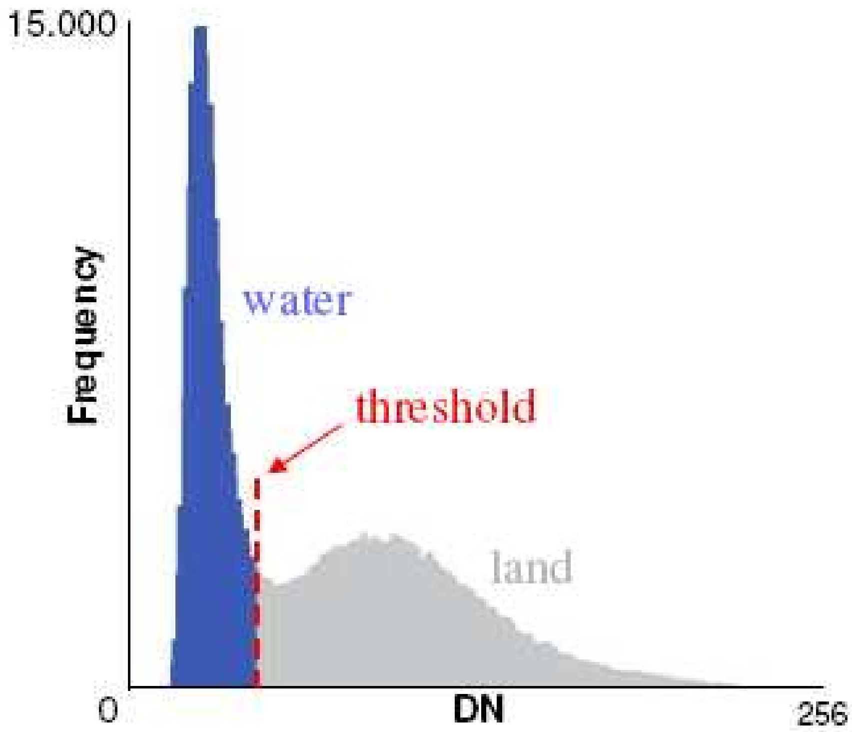
Multitemporal image composed of two ERS-2 images acquired during flooding on Tisza River (10 March, 2001) and after flooding (14 April, 2001). R, G: March, 10, 2001; B: April,14,2001. Blue areas indicate flood extent.

Existing Approaches

- **Threshold segmentation**



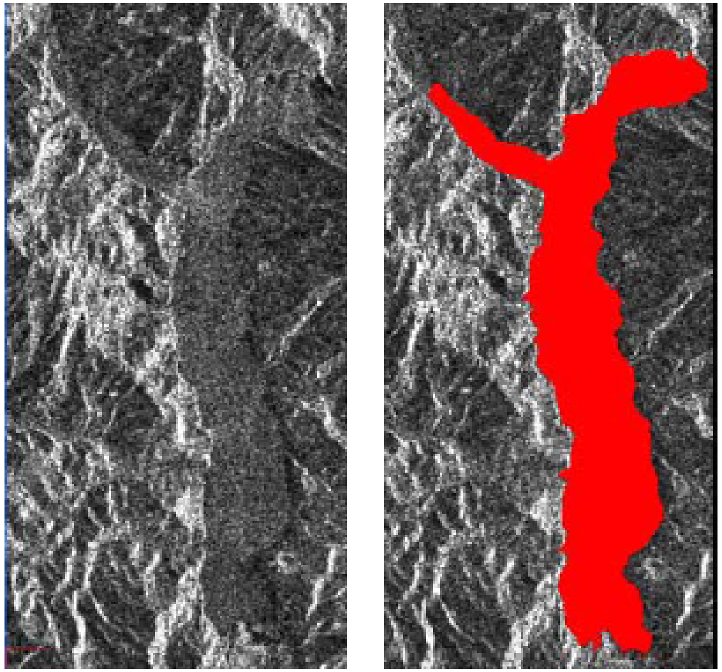
TerraSAR-X Stripmap scene



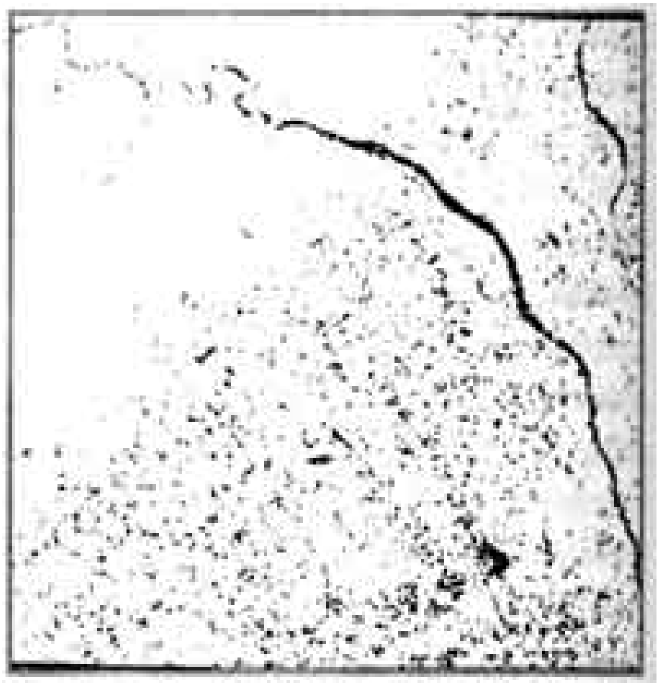
Grey level histogram

Existing Approaches

- **Pixel processing – using threshold**
  - DN < K is flood extent
    DN>=K is not flood extent



De Chiara G., Bovolin V., P., Migliaccio M. "Remote sensing technique to estimate the water surface of artificial reservoirs Villani - Problems and potential solutions" //IEEE GOLD Remote Sensing Conference 2006.



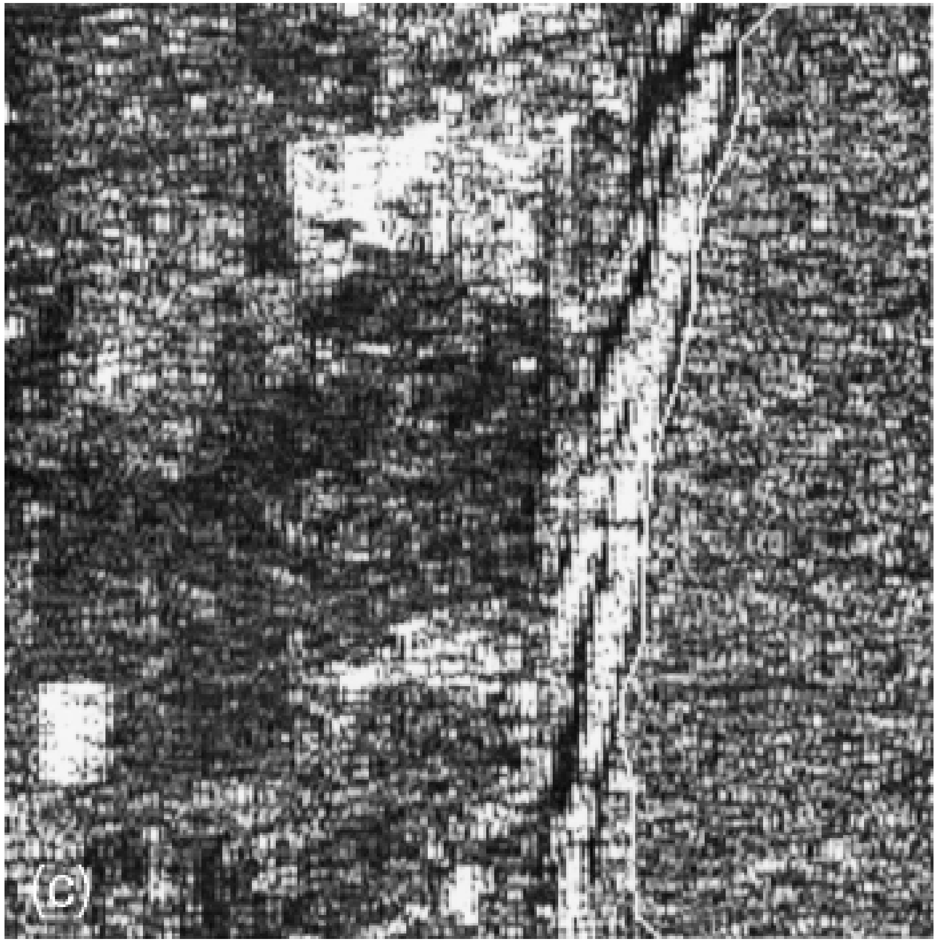
Yang Cunjian Zhou Chenghu Wan Qing. "Deciding the Flood Extent with RADARSAT SAR Data and Image Fusion" // 20th Asian Conference on Remote Sensing, 1999

Existing Approaches

- **Statistical active contour model** [Horritt 1999]
  - accuracy is within 1 pixel of segment boundaries
  - difficulties: stuck in local minima, poor modelling of long concavities, inaccurate results when the initial contour is chosen simple or far from the object boundary, need of a priori knowledge of image statistical properties

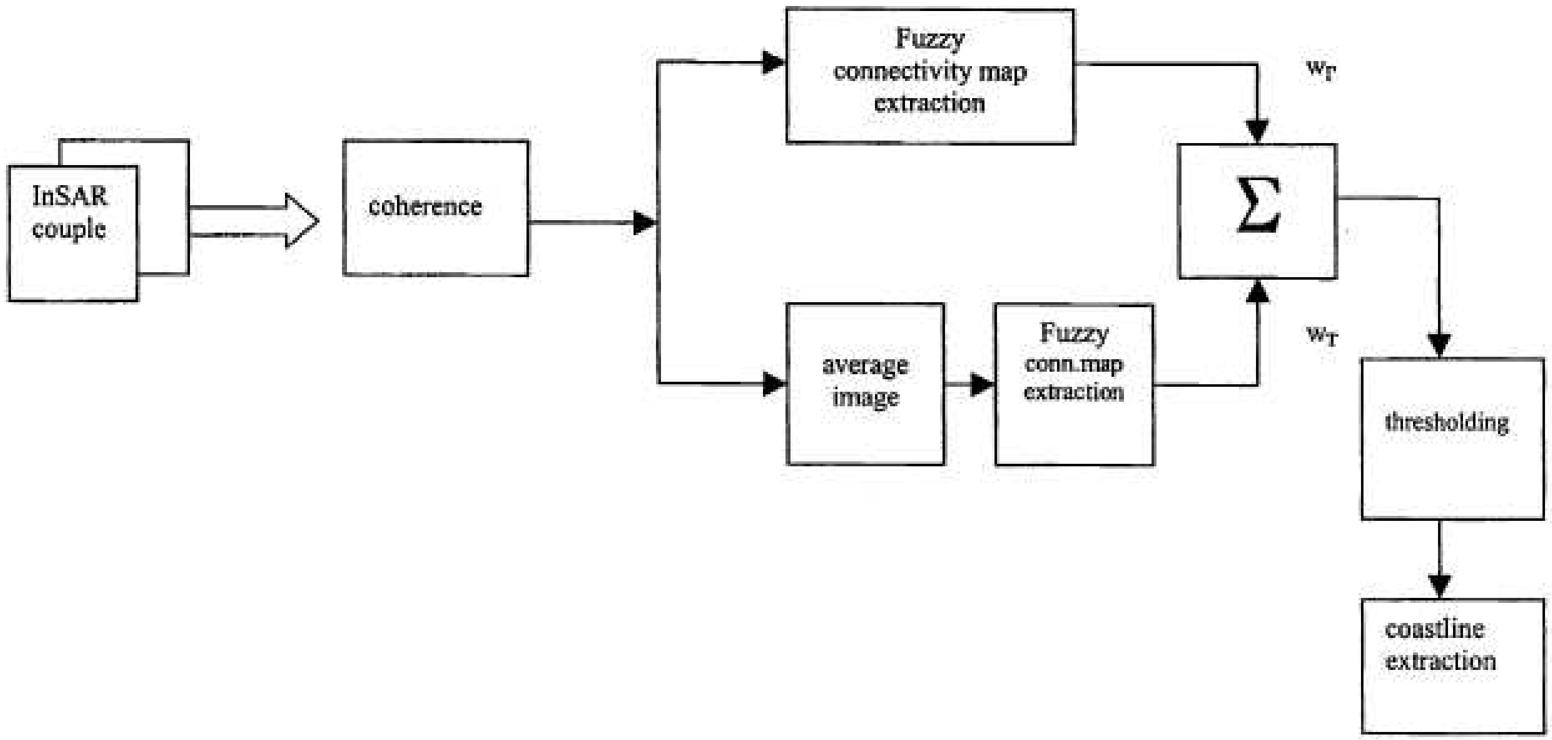
Existing Approaches

- **Statistical active contour model** [Horritt 1999]



Existing Approaches (cont.)

- **Fuzzy concept and InSAR** [Dellepiane et al. 2004]
  - innovative algorithm being able to discriminate water and land areas
  - incl. fuzzy connectivity concepts and coherence measure extracted from an InSAR



Existing Approaches (cont.)

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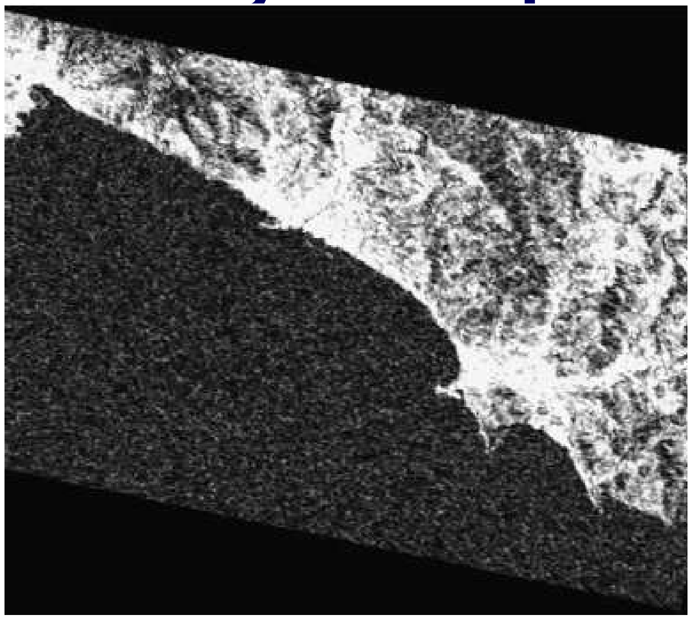


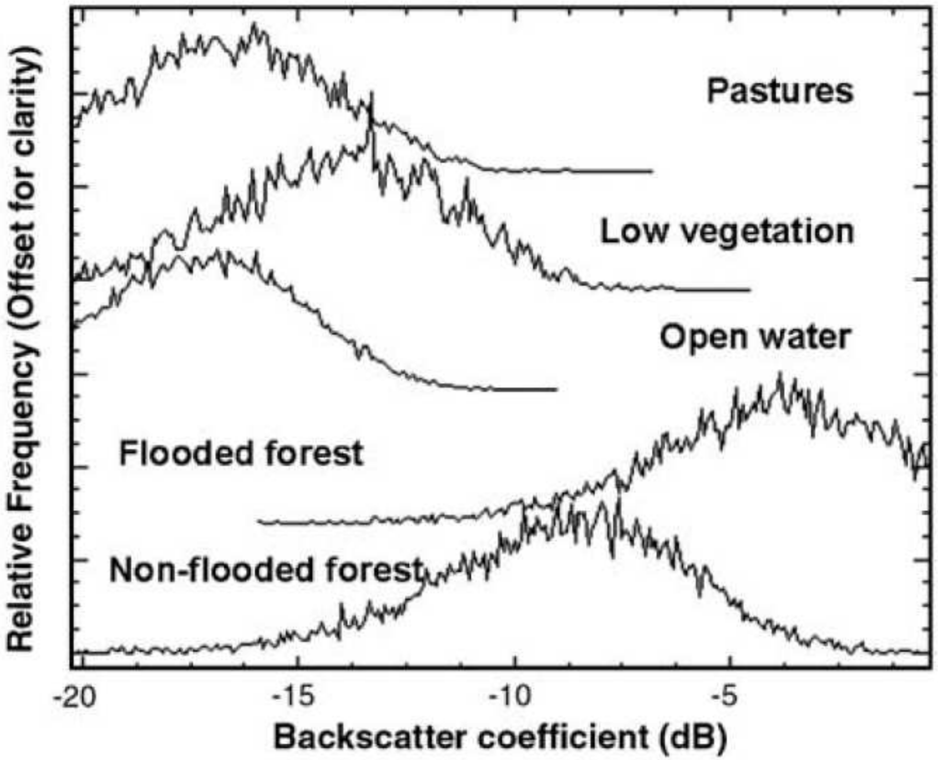
Coherence image of SAR images

Segmentation result from the coherence image

Segmentation result from the average of coherence image

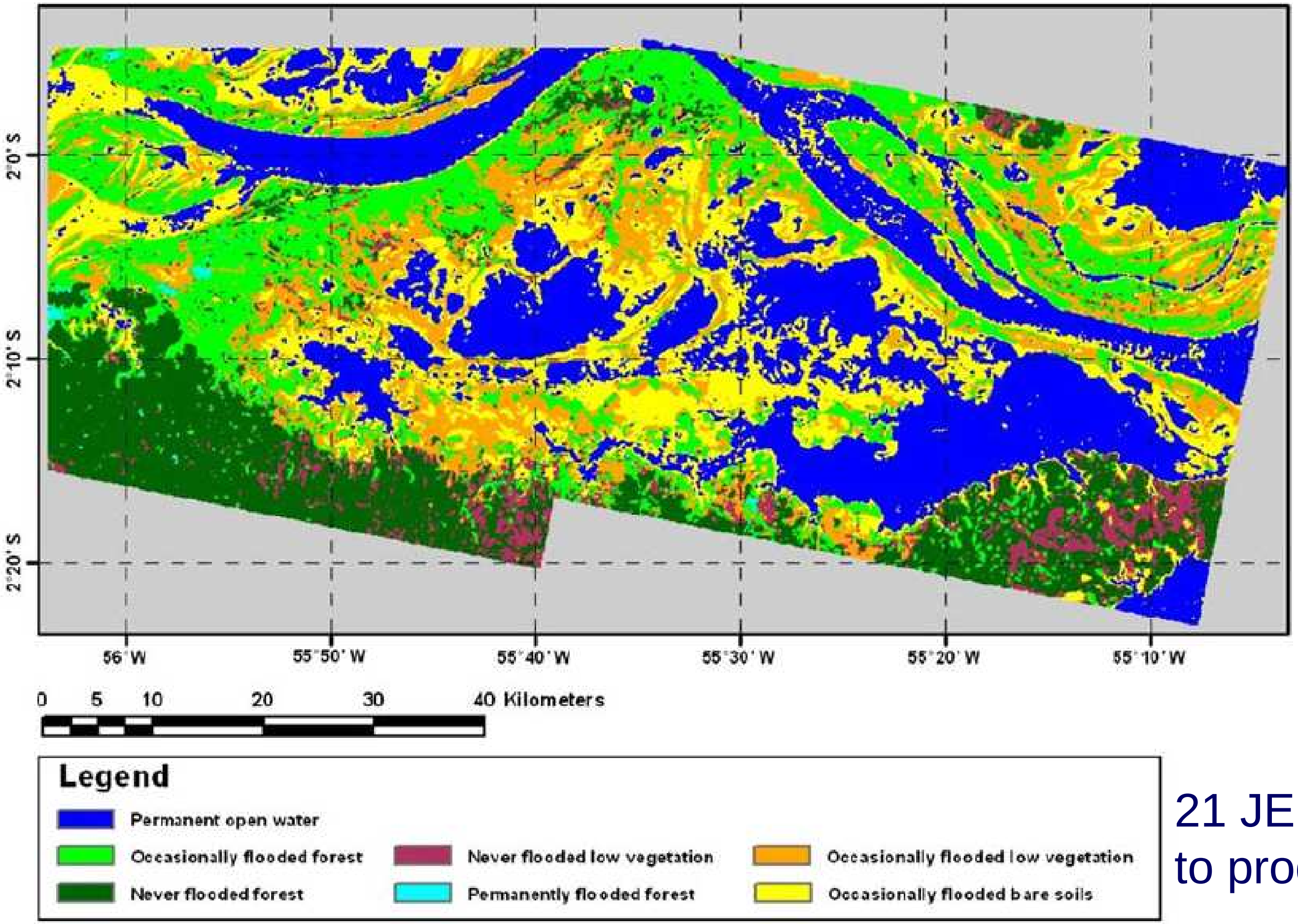
Existing Approaches (cont.)

- **Time-series analysis** [Martinez and Le Toan 2007]
  - use time series of 21 SAR images from L-band PALSAR instrument onboard JERS-1 satellite
  - accuracy depends on number of images: 8 images is required to achieve classification rate of 90%



Existing Approaches (cont.)

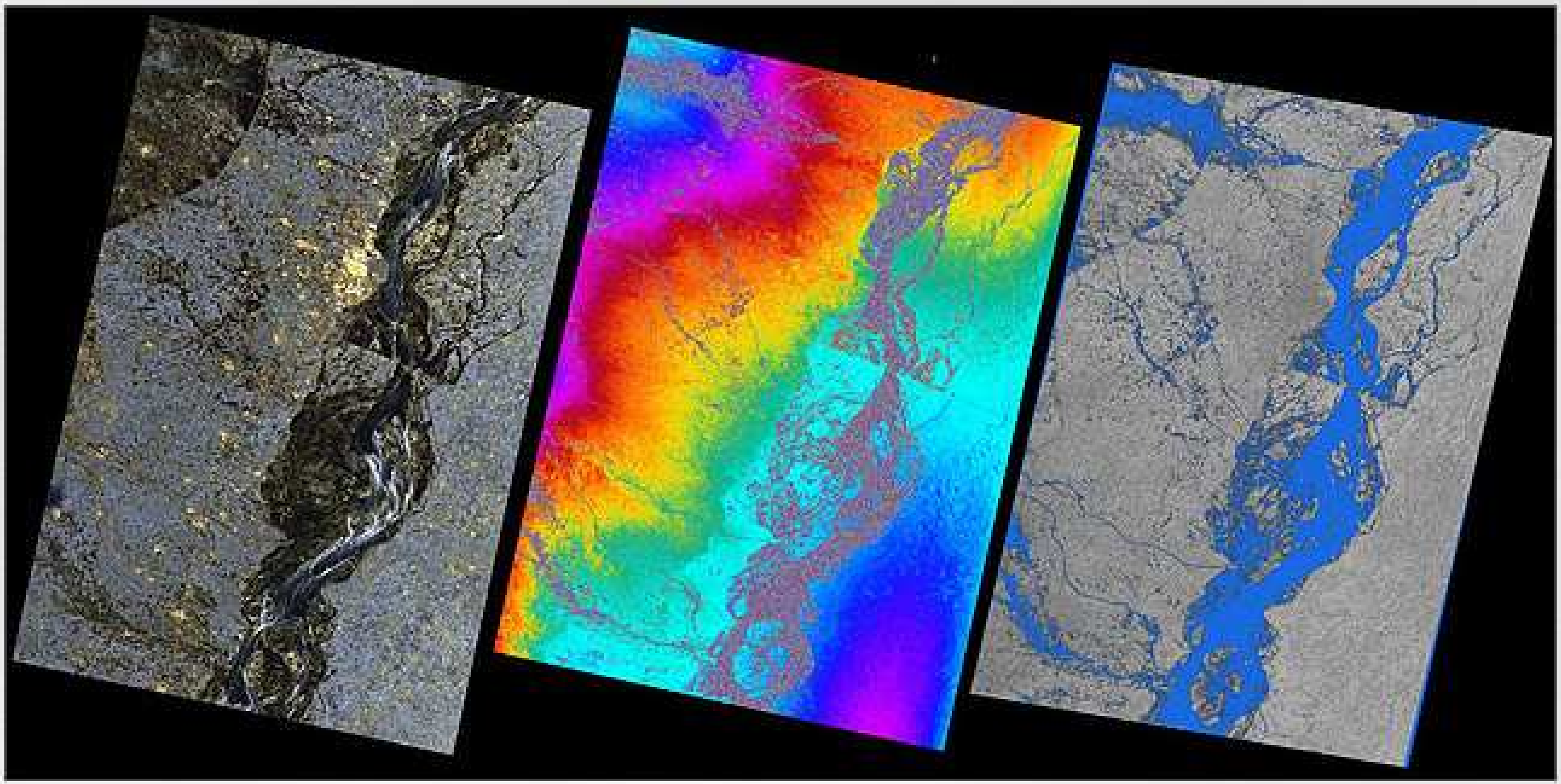
- **Time-series analysis** [Martinez and Le Toan 2007]



21 JERS scenes were used to produce this map

Existing Approaches (cont.)

- **InSAR approach to measure coherence/incoherence**

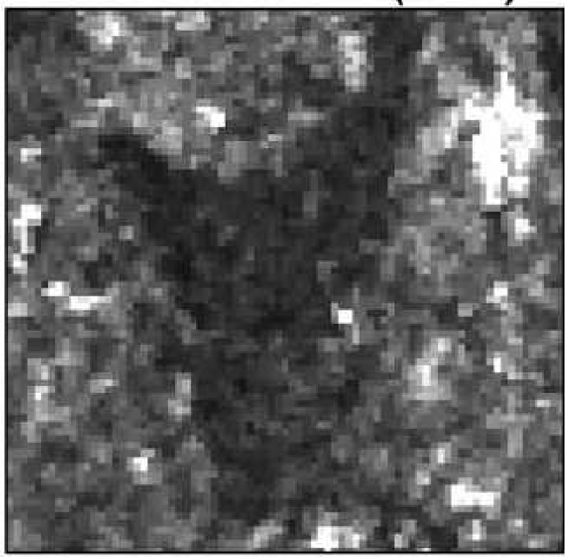


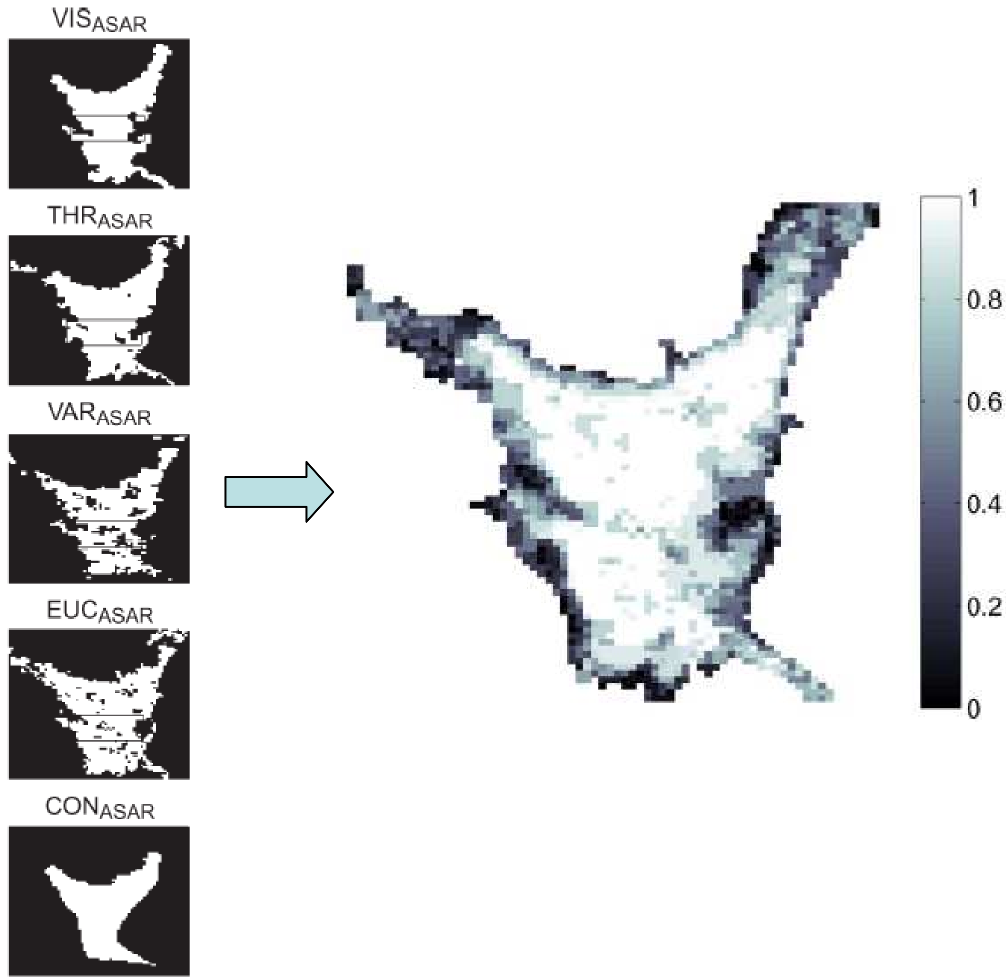
Left: image brightness data. Centre: interferometric phase. Right: incoherent areas marked in blue. Credit: DLR.

Existing Approaches (cont.)

- **Ensemble approach**
  [Schumann et al. 2009]
  - To integrate flood maps produced by different algorithms
  - Still lacks mathematical foundation

ENVISAT-ASAR (75 m)





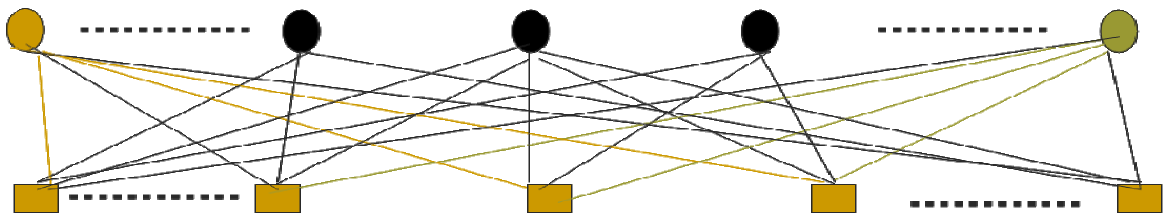
Flood Mapping with Advanced Techniques – A Neural Network Approach

Neural network approach

- Intelligent approach to image segmentation using neural networks – self-organizing Kohonen maps
- Adaptive weights adjustment during training
- Spatial properties between pixels using moving window
- No need to reduce noise (speckle)

Self-Organizing Maps (SOM)

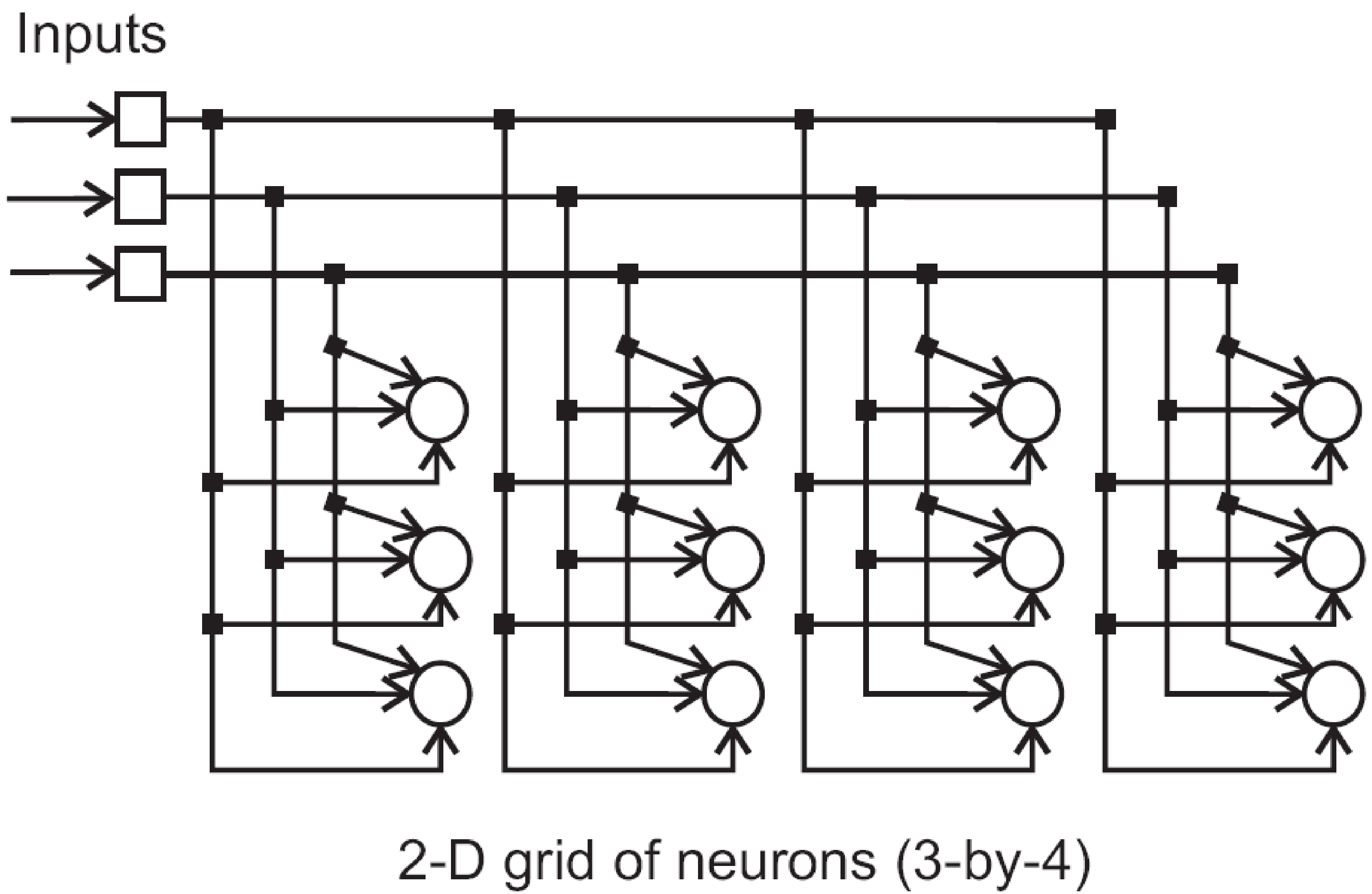
- Effective software tool for the visualization of high-dimensional data
- Feature detectors: automatically discover statistically salient features of pattern vectors in training data set
- Can find clusters in training data pattern space which can be used to classify new patterns



inputs

[Sources: S.Haykin, "Neural Networks: A Comprehensive Foundation" & http://www.cis.hut.fi]

Self-Organizing Maps (SOM)



Self-Organizing Maps (SOM)

- Input layer fully connected to output layer
- Input to output layer connection feedforward
- Output layer compares activation's of units following presentation of pattern vector x via (sometimes virtual) inhibitory lateral connections
- Winner selected based on largest activation
  - **winner- takes-all (WTA)**
- Linear or binary activation functions of output units

Sources: S.Haykin, “Neural Networks: A Comprehensive Foundation” & http://www.cis.hut.fi

SOM training

Loop until stopping criteria satisfied

- Choose pattern vector $\underline{x}$ from training set
- Compute distance between pattern and weight vectors for each output unit

$$|| \underline{x} - \underline{W}i(t) ||$$

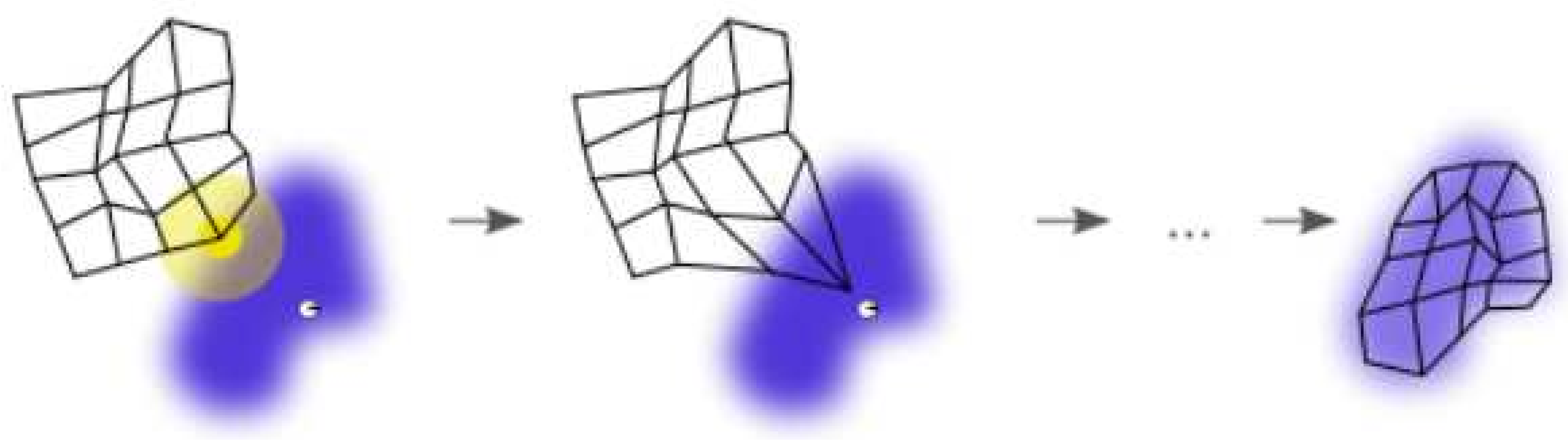
- Find winning unit from minimum distance

$$i^*: \quad || \underline{x} - \underline{W}i^*(t) || = min || \underline{x} - \underline{W}i(t) ||$$

- Update weights of winning ***and*** neighbouring units using neighbourhood functions

$$wij(t+1)=wij(t)+ n(t)\, h(i,i^*,t)\, [xj- wij(t)]$$

SOM training



An illustration of the training of a self-organizing map. The blue blob is the distribution of the training data, and the small white disc is the current training sample drawn from that distribution. At first (left) the SOM nodes are arbitrarily positioned in the data space. The node nearest to the training node (highlighted in yellow) is selected, and is moved towards the training datum, as (to a lesser extent) are its neighbours on the grid. After many iterations the grid tends to approximate the data distribution (right).

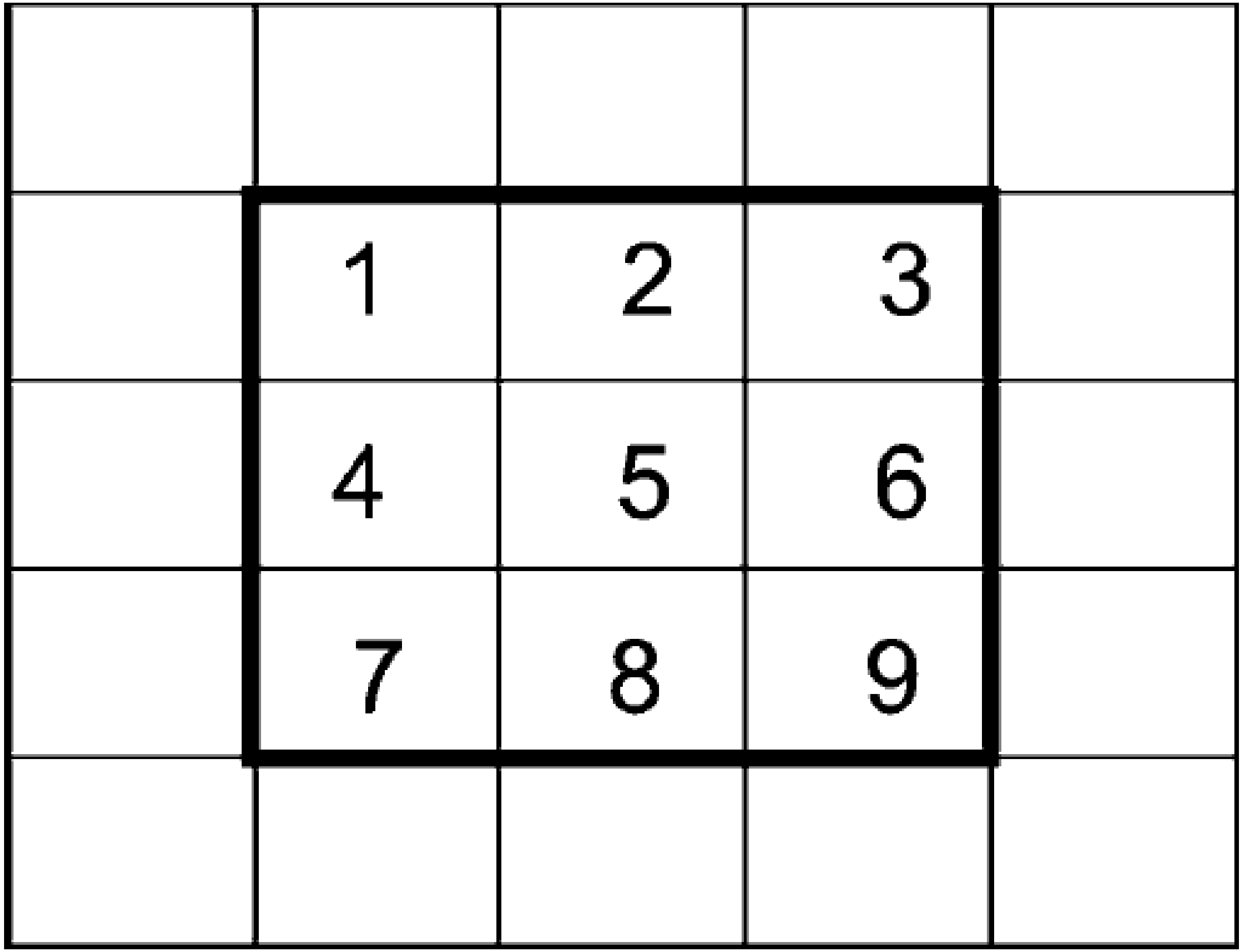
Neighbourhood function

- Relates degree of weight update to distance from winning unit, i* to other units in lattice.
- Gaussian function

$$h(\underline{i}, \underline{i}^*, t) = \exp\left(- \frac{\| \underline{i} - \underline{i}^* \|^2}{2\sigma(t)^2} \right)$$

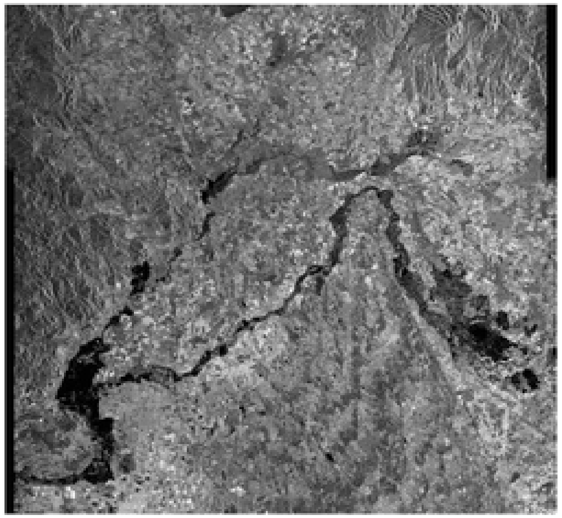
- Stepwise function
- When *i=i** , distance is zero so h=1

Input to neural network

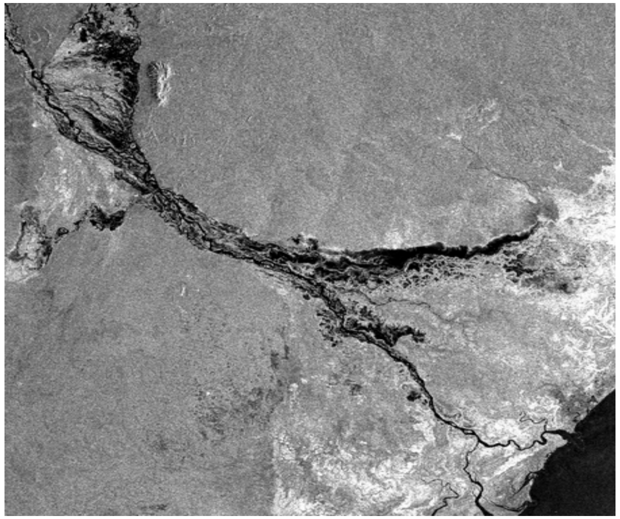


Data sets

- Training & testing sets
  - ERS-2/SAR
    - flood on Tisza river (Ukraine), 2001
  - ENVISAT/ASAR WSM
    - river Huaihe, China, 2007
  - Radarsat-1
    - river Huaihe, China, 2007
- Independent sets
  - ENVISAT/ASAR WSM
    - river Zambezi, Mozambique, 2008
    - river Mekong, Thailand and Laos, 2008
    - river Koshi, India and Nepal, 2008
    - Ha Noi City, Vietnam, 2008
    - river Zambezi, Zambia, 2009
    - Namibia, 2009
  - RADARSAT-2
    - river Norman, Queensland, Australia, 2009
    - Liambezi Lake, Namibia, 2009



ERS-2, Ukraine
March, 2001



Envisat/ASAR, Mozambique
February, 2008

Training and testing pixels

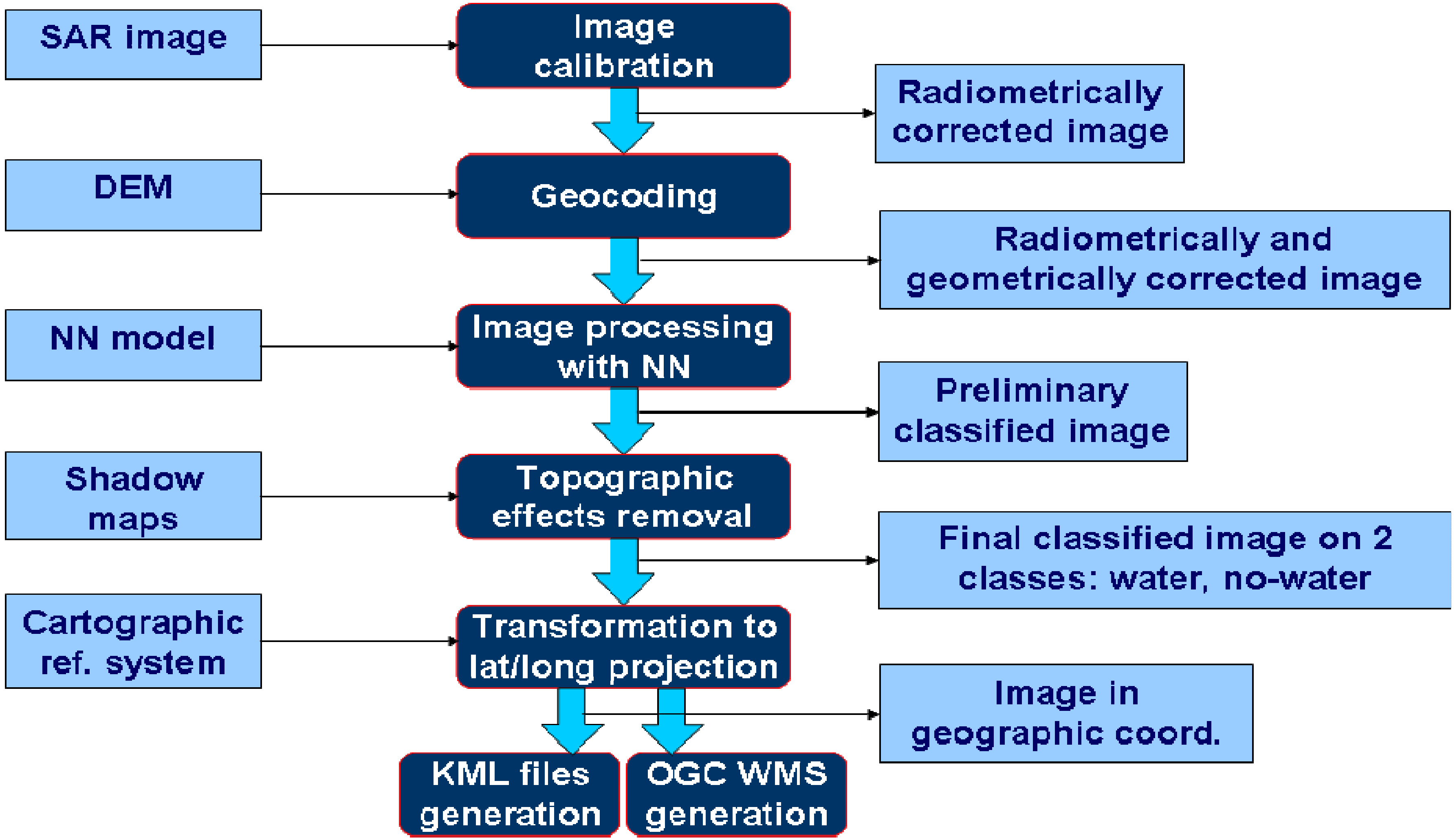
Satellite image/Region	Number of ground-truth pixels for images		
	"No water"	"Water"	Total
ERS-2/Ukraine	148,182	153,096	301,278
ENVISAT/China	60,575	34,493	95,068
RADARSAT-1/China	135,263	130,244	265,507

- For each image, these data were randomly divided into
  - the **training** set (75% of total amount) - were used to train the neural networks
  - the **testing** set (25%) - verify the generalization ability of the neural networks

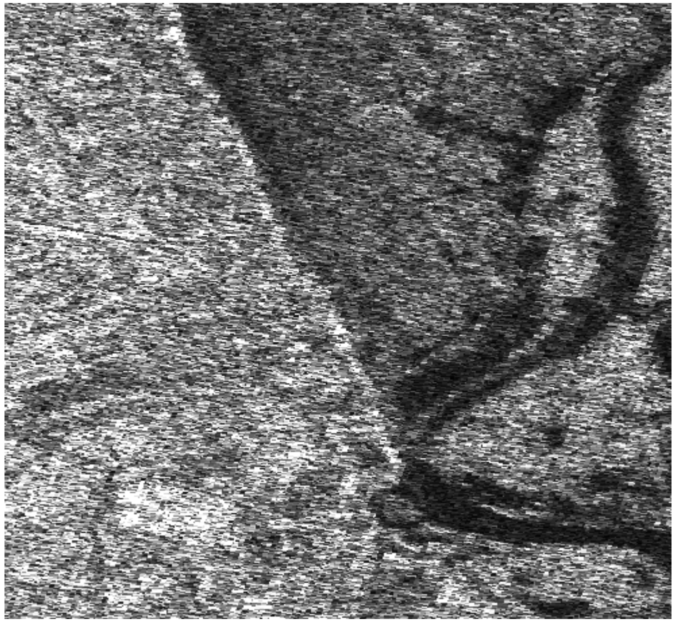
Results of SAR images classification using SOMs

		Satellite image		
		ERS-2	ENVISAT	RADARSAT-1
Input dimension		7×7	3×3	7×7
Output grid of neurons		10×10	7×5	5×5
Classification rate	«No water»	79.40%	100.0%	99.99%
for training set	«Water»	90.99%	95.64%	91.93%
	Total	85.29%	98.41%	96.04%
Classification rate	«No water»	79.57%	100.0%	99.99%
for testing set	«Water»	91.06%	95.90%	91.89%
	Total	85.40%	98.52%	95.99%

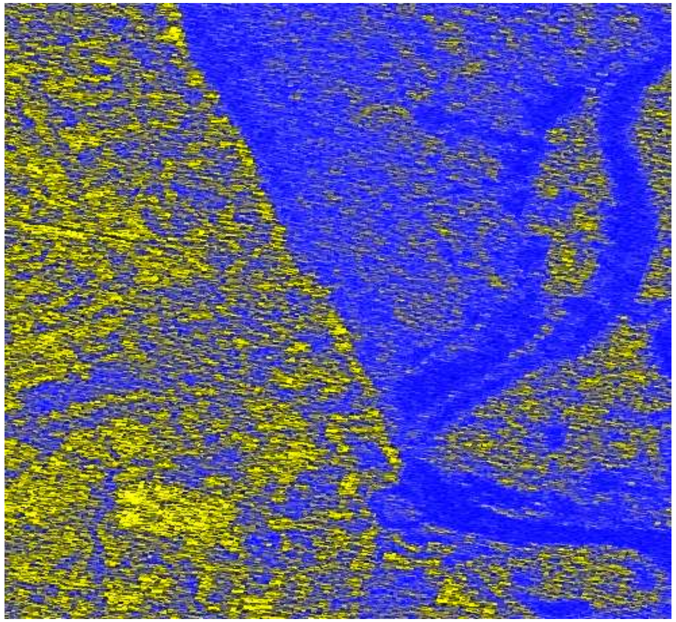
Processing Workflow



Results



Raw ERS-2 image



Flood extent (marked with blue)

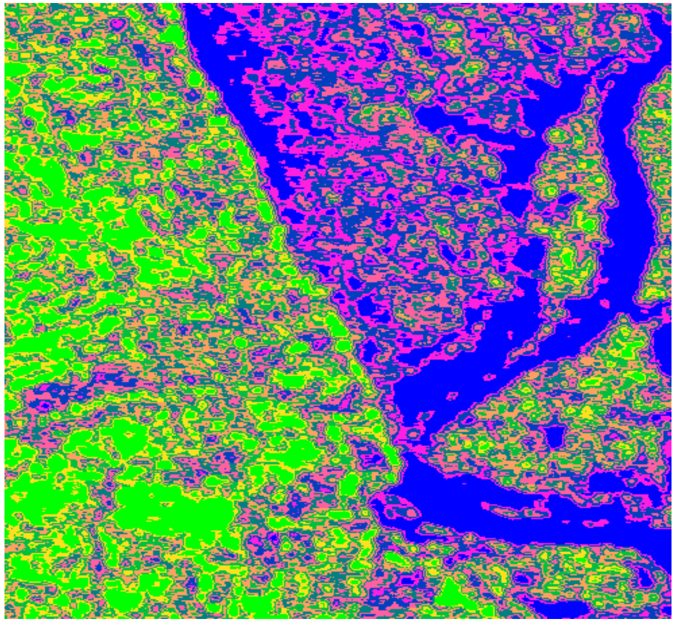
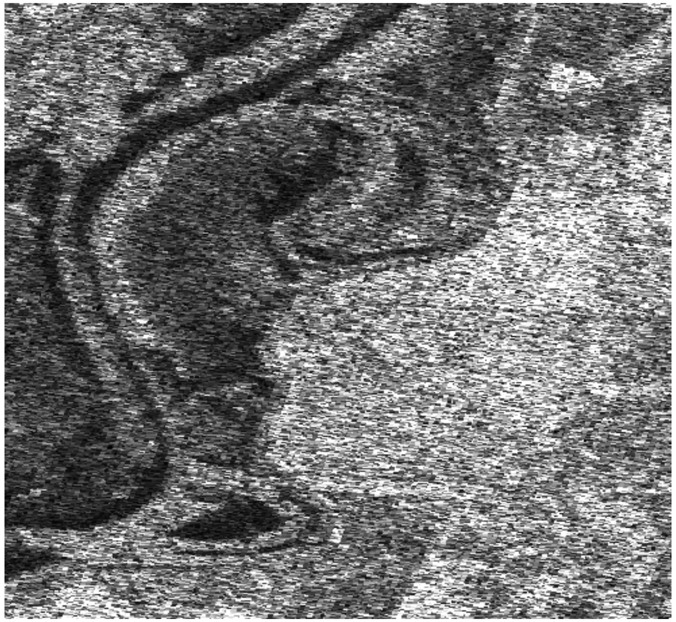


Image segmentation using SOM

Results



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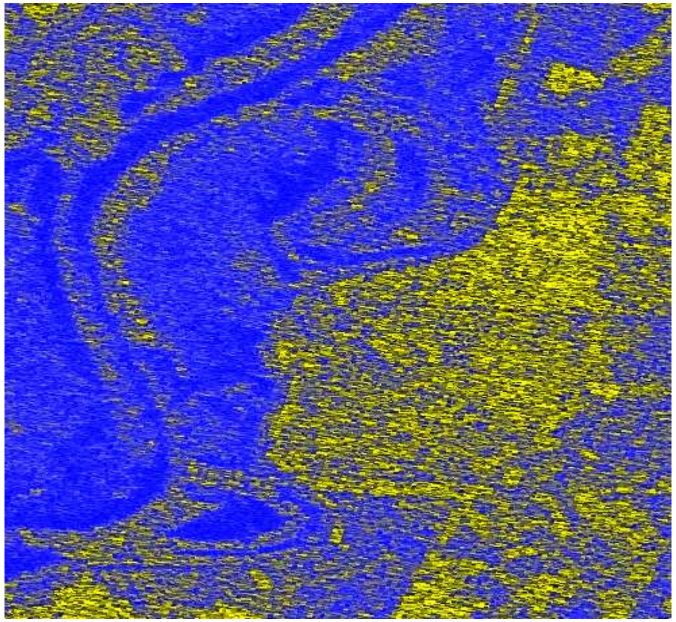

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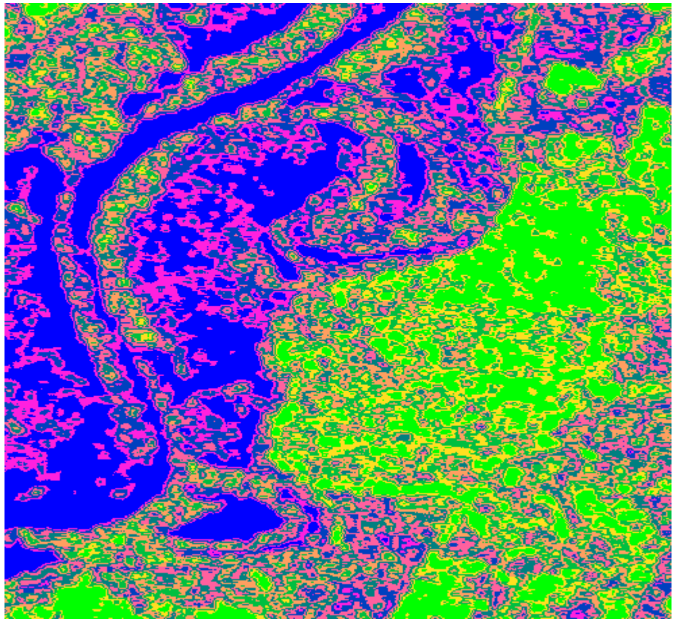
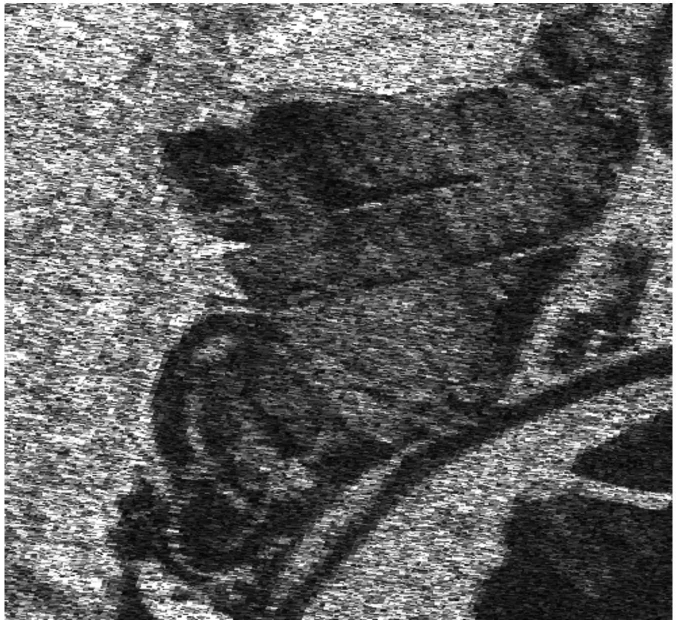
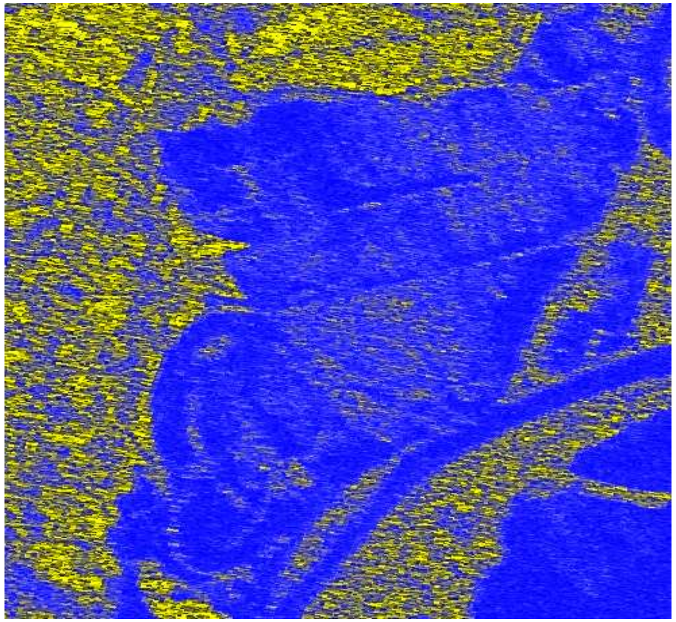


Image segmentation using SOM

Results



Raw ERS-2 image



Flood extent (marked with blue)

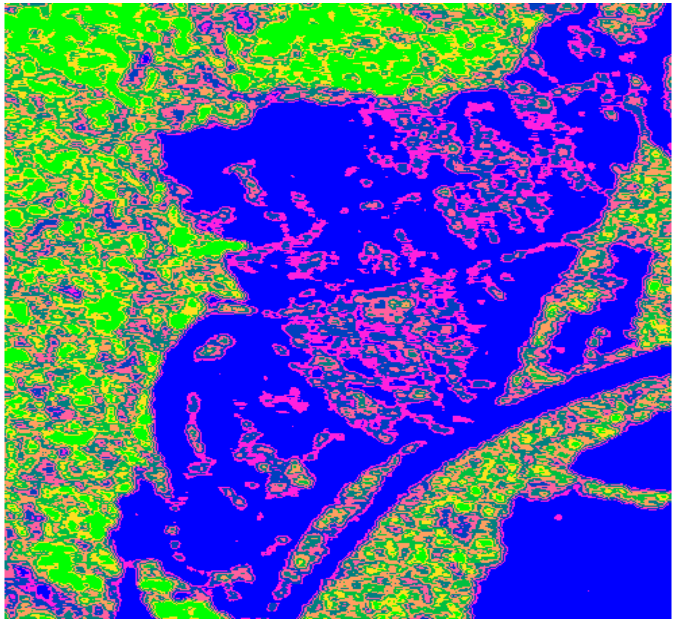
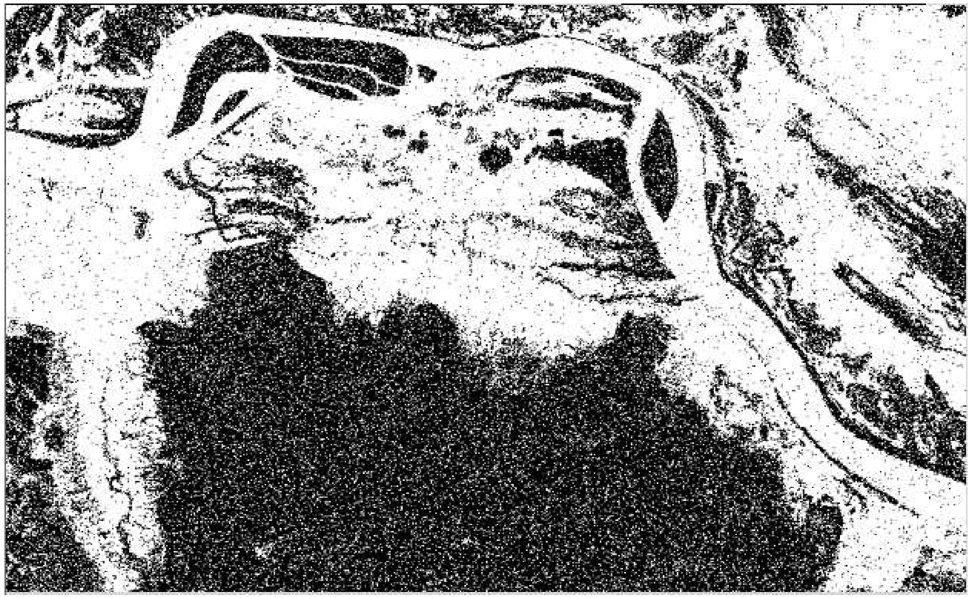


Image segmentation using SOM

Comparison

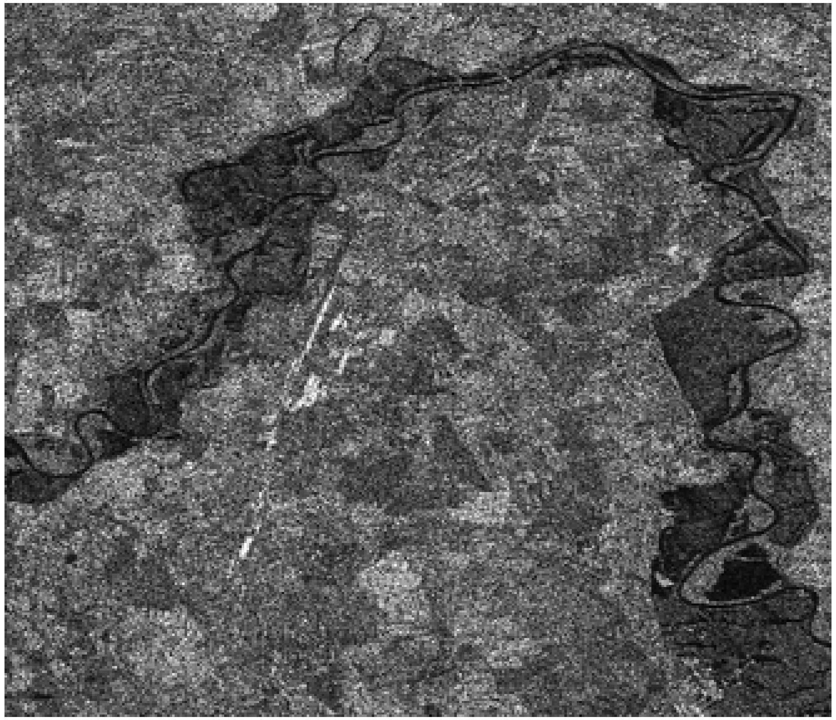
SAR Image (RADARSAT-2 Ultra Fine Mode, 3 m res)



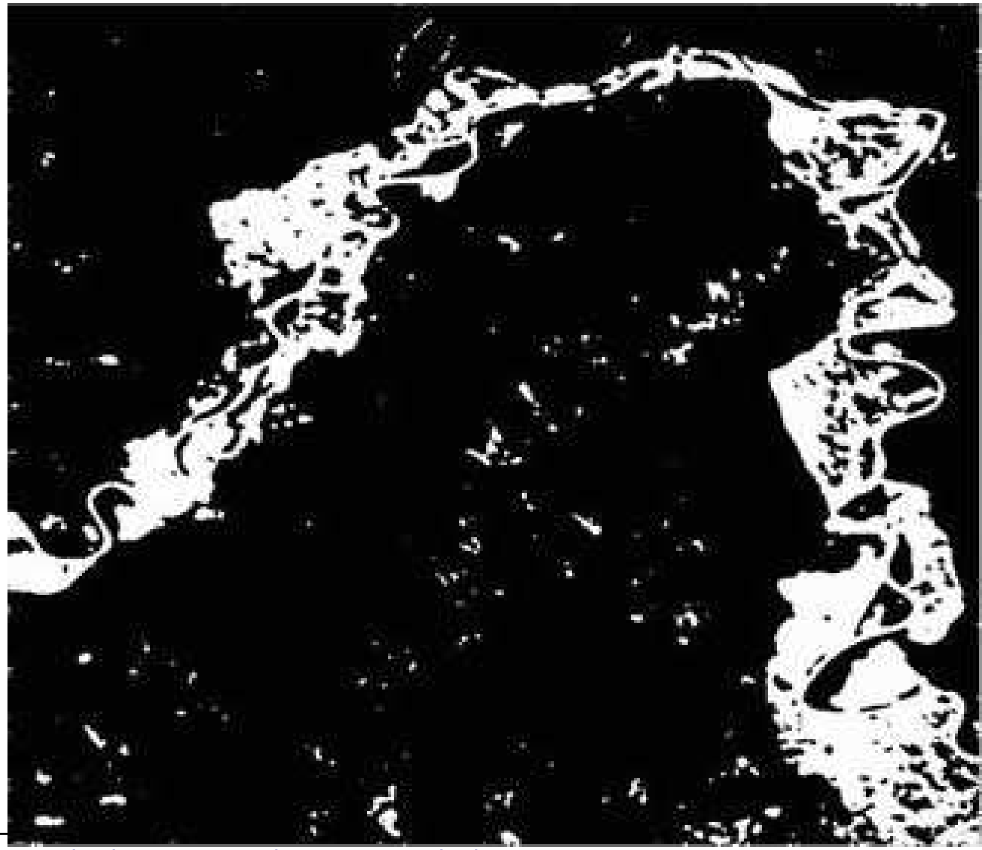
Threshold

Our approach

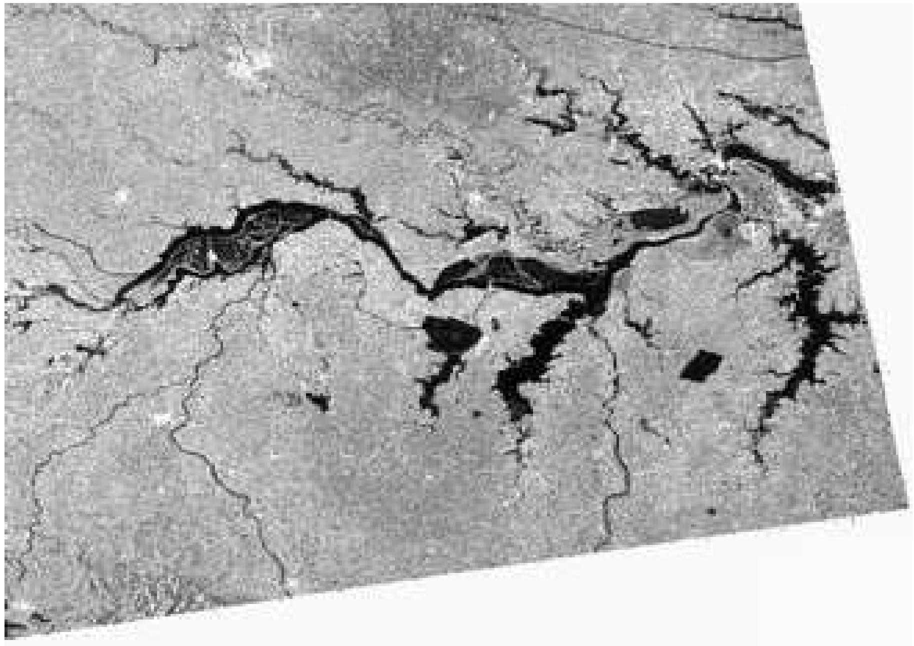
Results of classification



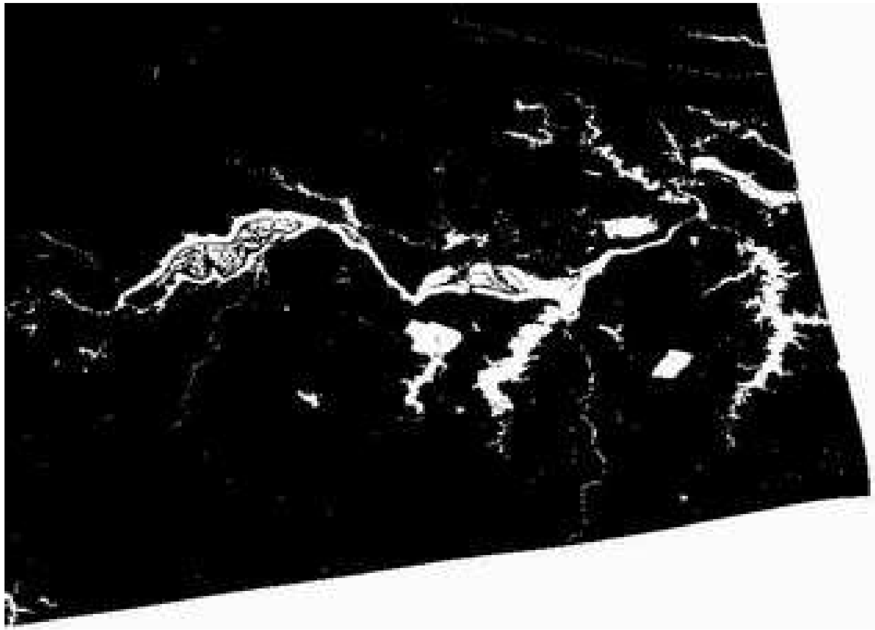
ERS-2/SAR, flood on Tisza river (Ukraine), 2001



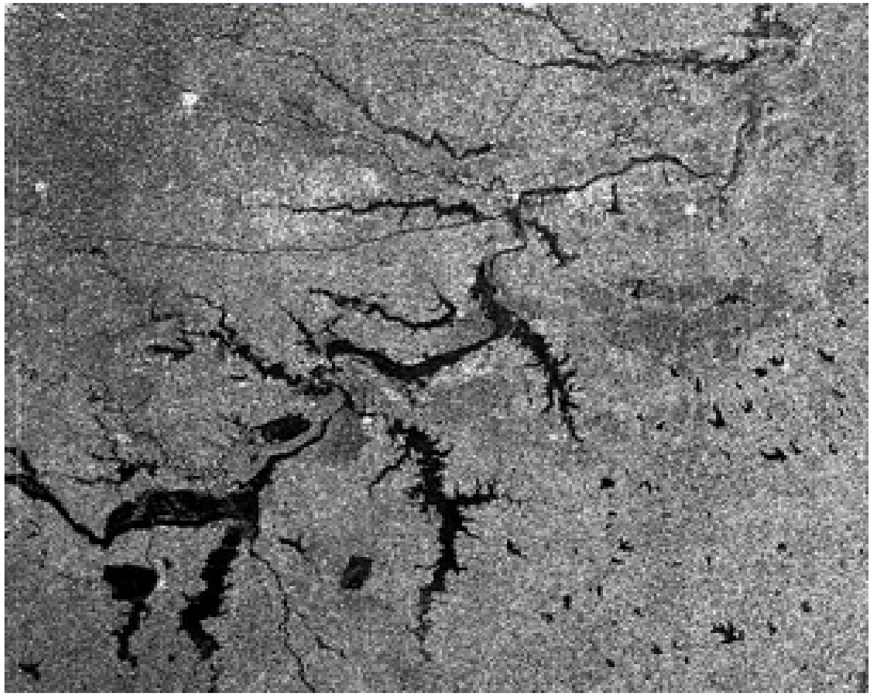
Results of classification (cont.)



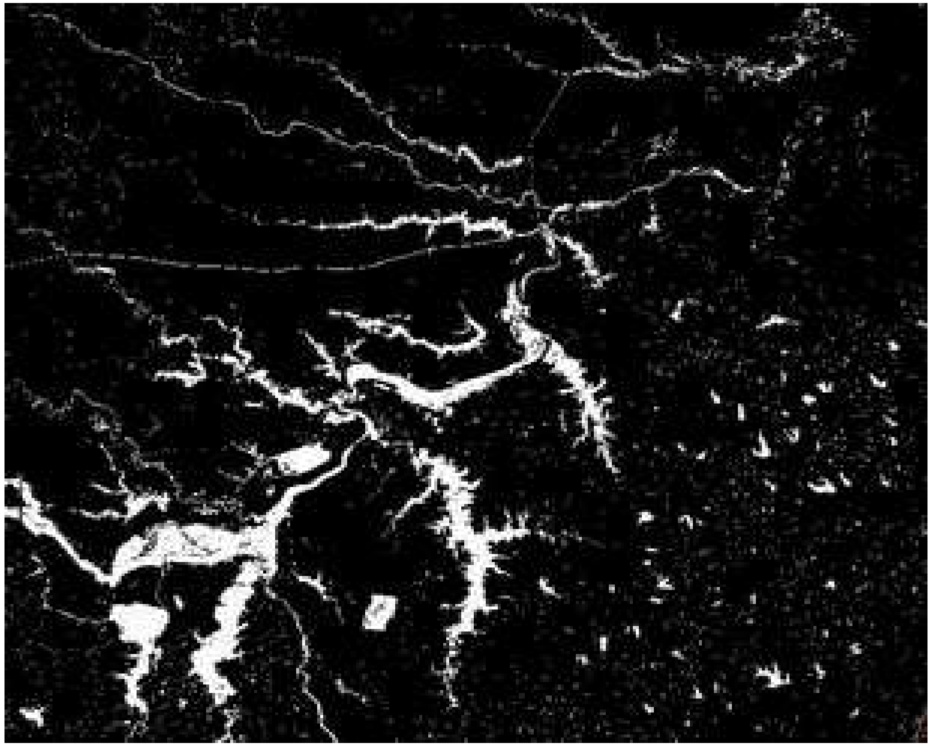
Envisat/ASAR WSM, flood on Huaihe river (China), 2007



Results of classification (cont.)



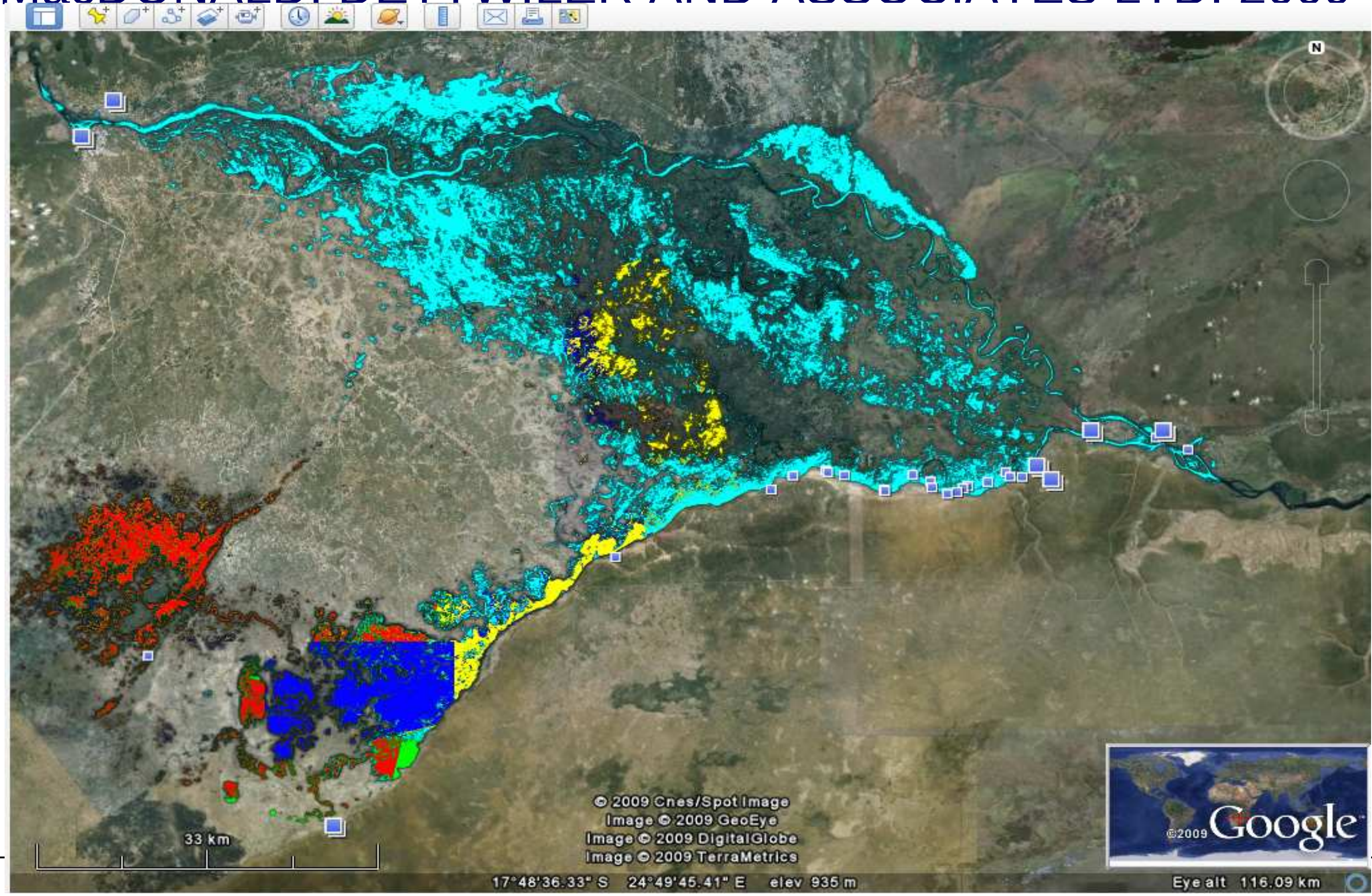
Radarsat-1, flood on Huaihe river (China), 2007



Real-World Examples of Flood Monitoring: Practical Issues

Namibia, 2009

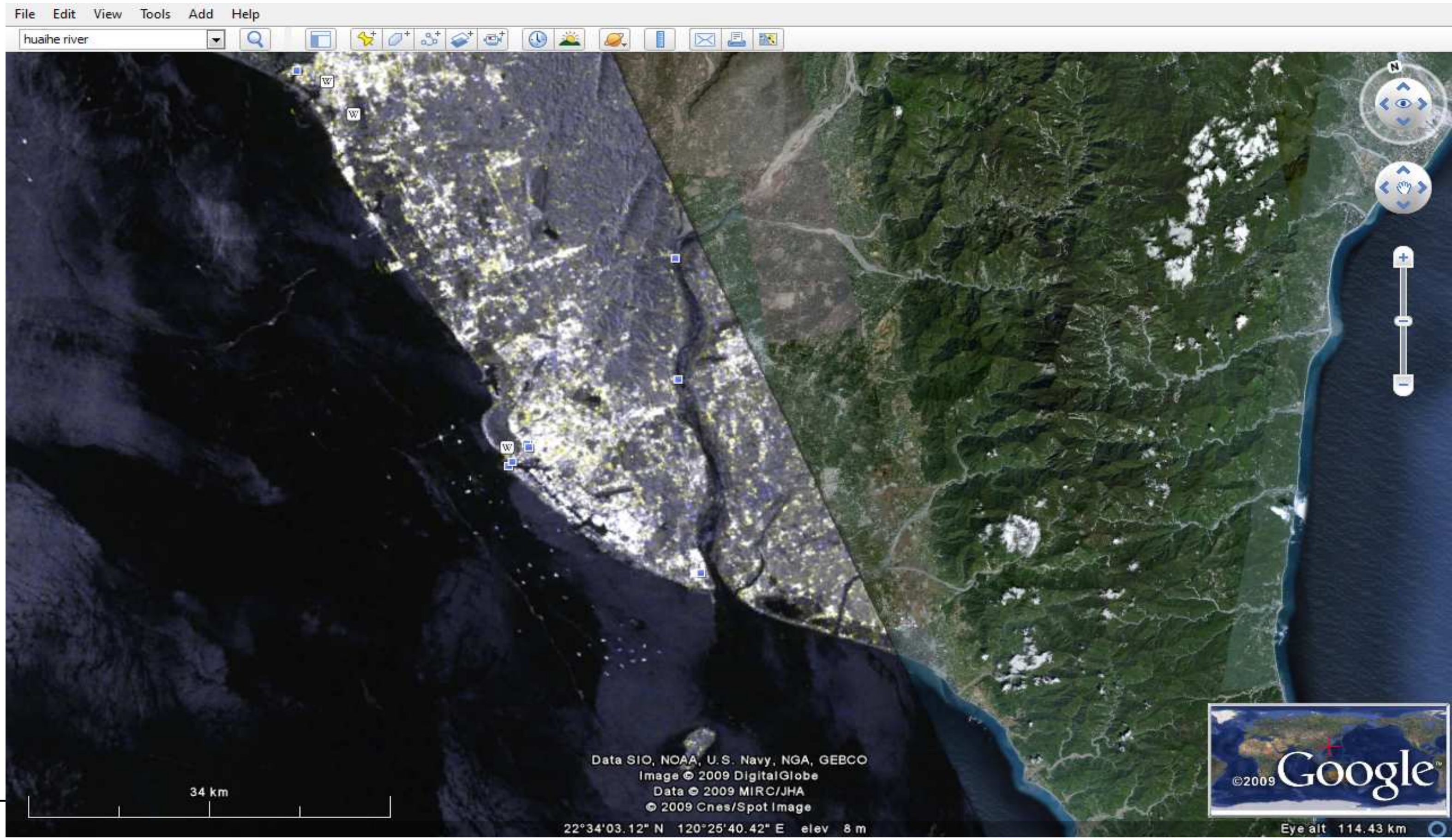
- Data source: 5 RADARSAT-2 images
  © MacDONALD, DETTWILER AND ASSOCIATES LTD. 2009



- 25.03.2009
- 20.05.2009
- 22.05.2009
- 29.05.2009
- 30.05.2009

Taiwan, 2009

- Data source: Envisat ASAR APM, med-res
- Date: August, 14, 2009

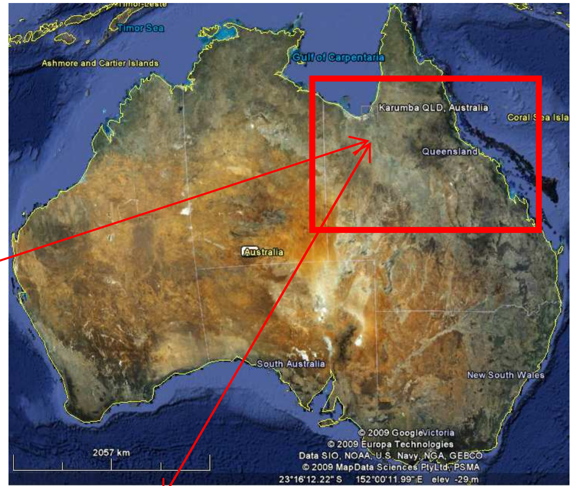


RGB composition

R=HH, G=VV, B=VV

Australia, 2009

- Queensland Area



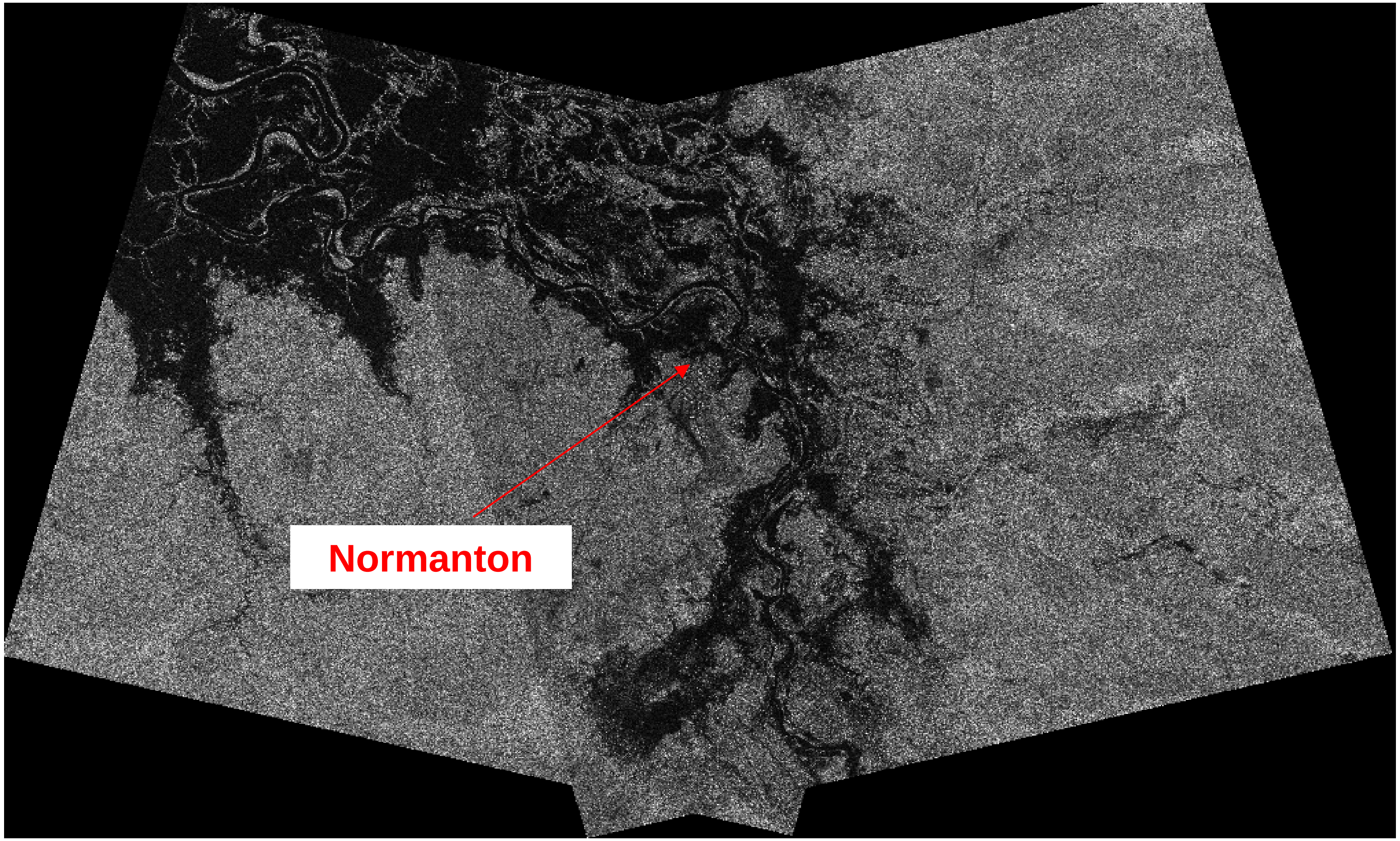
Normanton surrounded by flood waters

The road from Normanton to Karumba cut by floodwaters

[*Photos courtesy:* ABC North West]

RADARSAT-2 Images

Provided by MacDONALD, DETTWILER AND ASSOCIATES LTD (MDA)



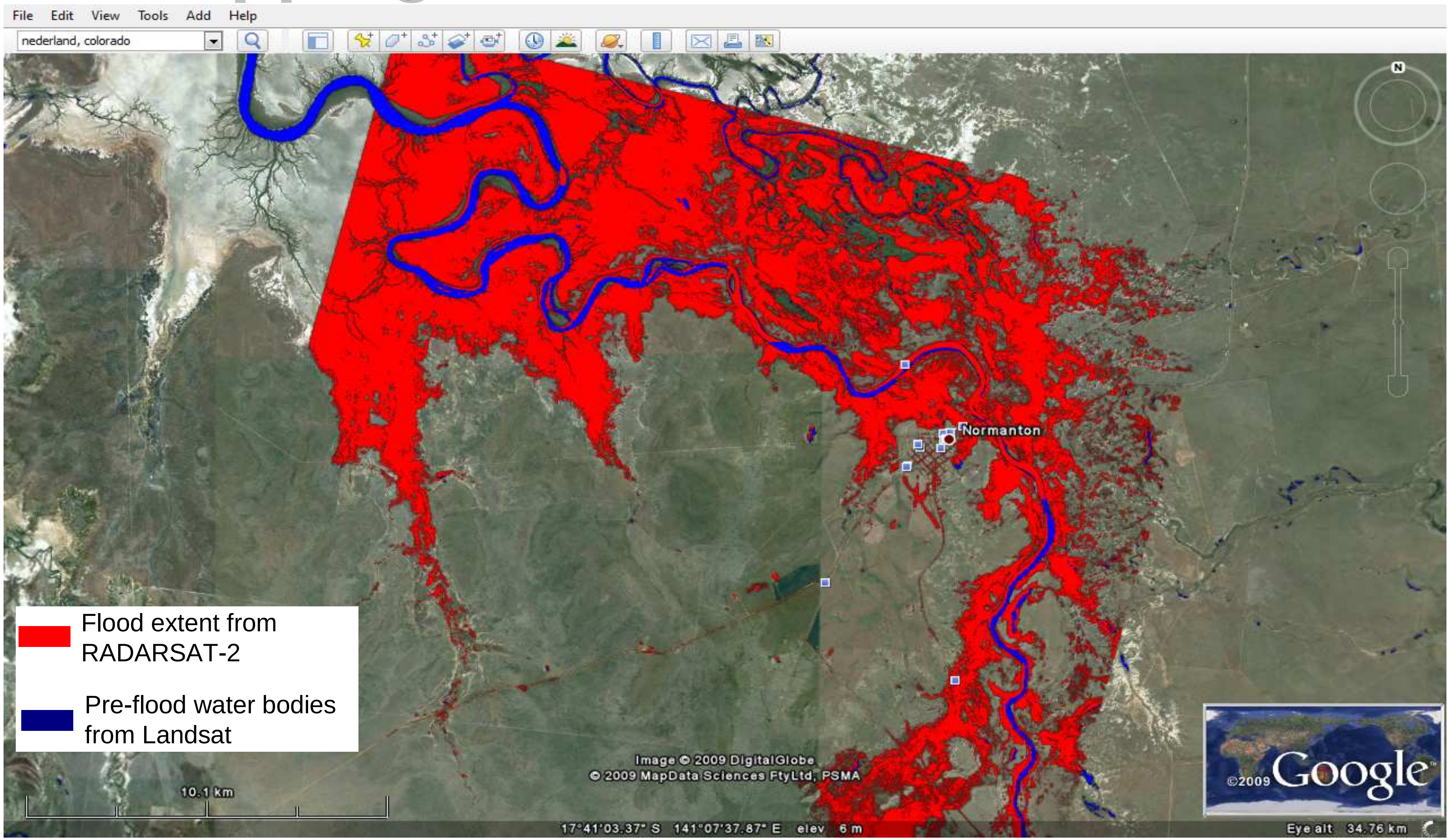
Date of acquisition is February 14, 2009 Date of acquisition is February 17, 2009

RADARSAT-2 Product Details

BEAM MODE	PRODUCT	Pixel Spacing Rng x Az m	Resolution Rng x Az m	Scene Size Rng x Az km x km	Incidence Angle o	No. Looks Rng x Az	Polarizations Options
Ultra-Fine	SLC	1.3 x 2.1	1.6 - 2.4 x 3	20 x 20	30 – 49	1 x 1	Single Pol
	SGX	1 x 1	3.3 – 3.0 x 3				
	SGF	1.56 x 1.56					
	SSG, SPG	1.56 x 1.56					
Multi-Look Fine	SGX	3.13 x 3.13	10.4 - 6.8 x 7.6	50 x 50	30 – 50	2 x 2	HH or VV or HV or VH
	SGF	6.25 x 6.25					
	SSG, SPG	6.25 x 6.25					
Fine	SLC	4.7 x 5.1	5.2 x 7.7	50 x 50	30 – 50	1 x 1	Single Pol
	SGX	3.13 x 3.13	10.4 – 6.8 x 7.7				
	SGF	6.25 x 6.25					
	SSG, SPG	6.25 x 6.25					
Standard	SLC	8 or 11.8 x 5.1	9.0 or 13.5 x 7.7	100 x 100	20 – 49	1 x 1	HH or VV or HV or VH
	SGX	8 x 8	26.8 – 18.0 x 24.7			1 x 4	
	SGF	12.5 x 12.5					- or -
	SSG, SPG	12.5 x 12.5					
Wide	SLC	11.8 x 5.1	13.5 x 7.7	150 x 150	20 – 45	1 x 1	Dual Pol
	SGX	10 x 10	40.0 – 19.2 x 24.7			1 x 4	
	SGF	12.5 x 12.5					(HH + HV) or (VV + VH)
	SSG, SPG	12.5 x 12.5					

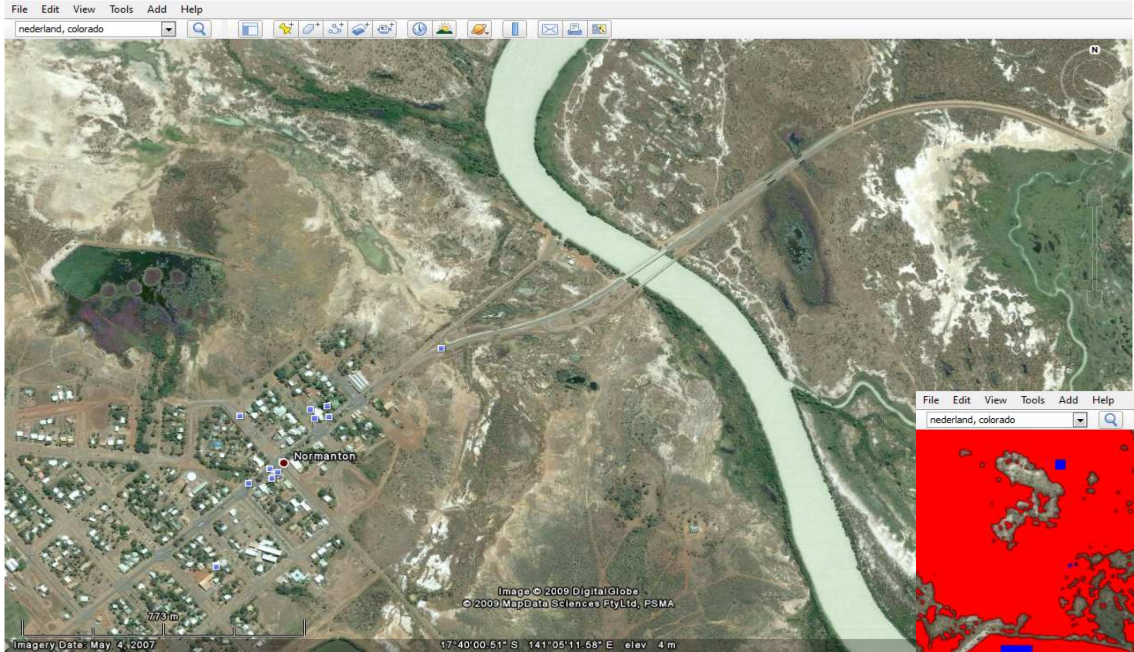
[From http://www.radarsat2.info]

Flood Mapping

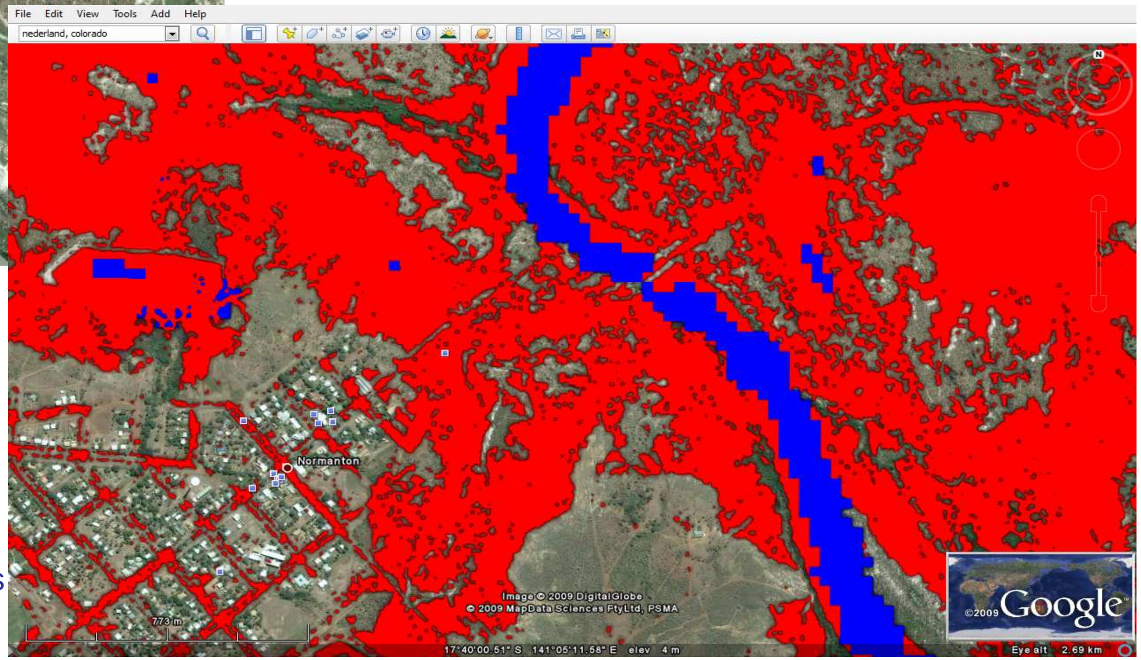


Flood Mapping

Without flood



With flood

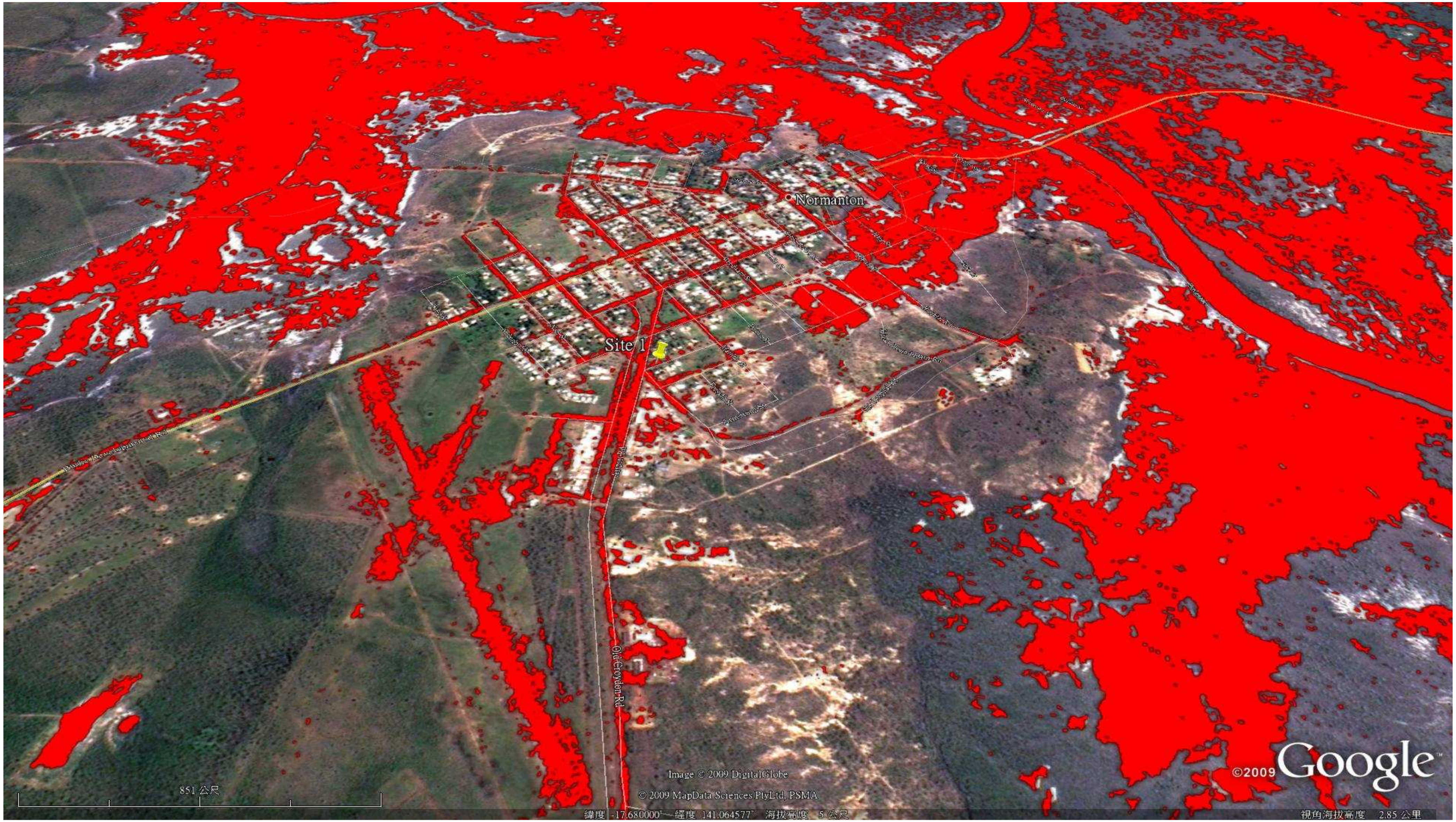


Normanton area, Queensland, Australia

Flood extent from RADARSAT-2

Pre-flood water bodies from Landsat

Radarsat-2 Water regions 14 Feb 2009



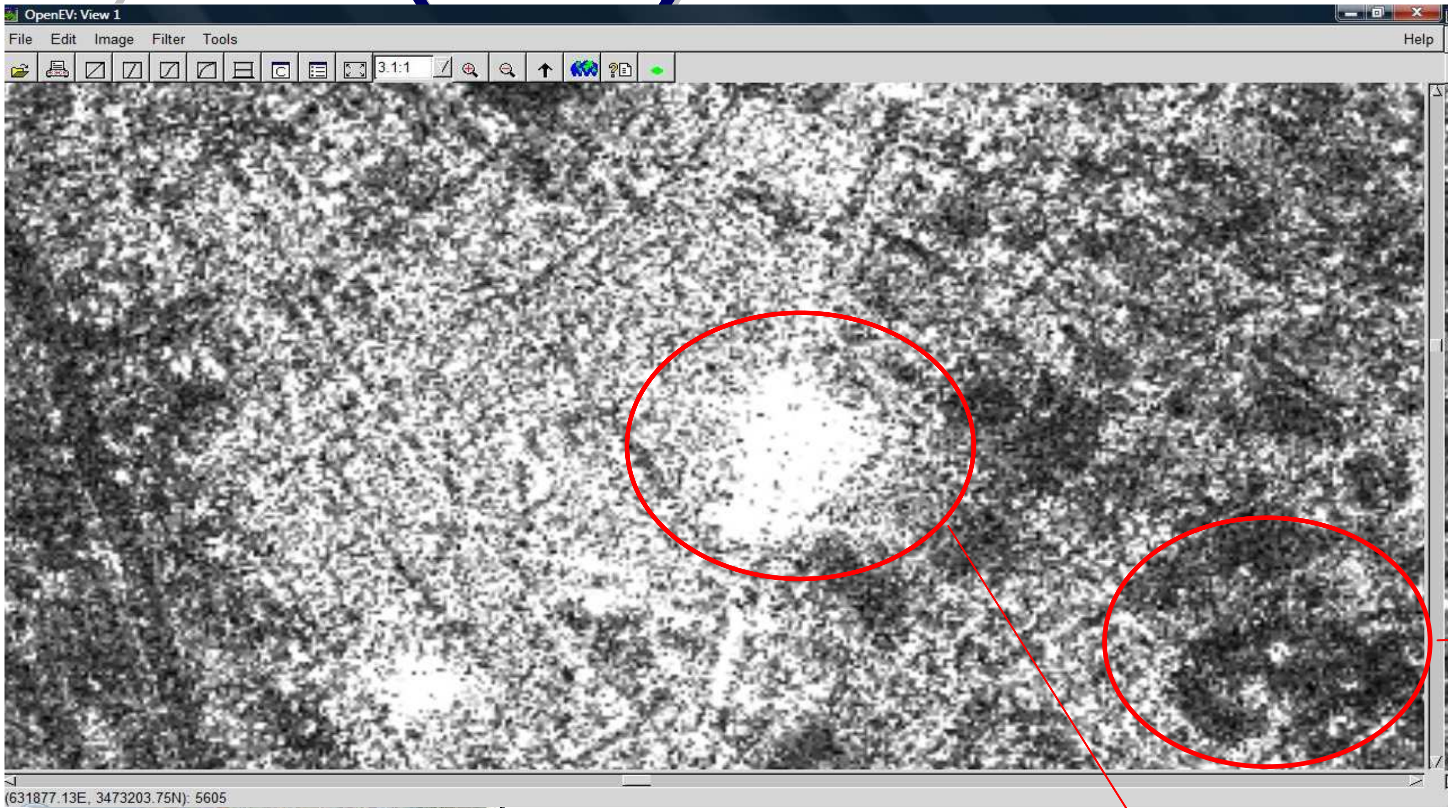
Formosat-2 image 18 Feb 2009

Dr. Cheng-Chien Liu
Department of Earth Sciences
Earth Dynamic System Research Center
Institute of Satellite Informatics and Earth Environment
National Cheng-Kung University

Gaza, 2010

- UNOOSA has activated the International Charter: Space and Major Disasters on 21 January 2010 on behalf of UNOCHA for recent floods in Gaza, which affected 500 people
- Flash flood
  - **occurred on Monday evening (18 Jan 2010)** because "Israel opened one of its dams that were overfilled with heavy rain water“ (http://www.imemc.org)
  - **characteristic time** for flash floods is **hours** (for ordinary floods are days-weeks)
  - flash flood meaning the **water was running very fast** through the region which has **a lot of sands that absorbs water very fast**
- Satellite data
  - ALOS/PALSAR
    - < Pre-disaster data > : November 5, 2008 (2 scenes)
    - < Post-disaster data > : January 22, 2010
  - RADARSAT-1
    - < Pre-disaster data > : December, 12, 2007
  - RADARSAT-1
    - < Post-disaster data > : January 23, 2010

Gaza, 2010 (cont')

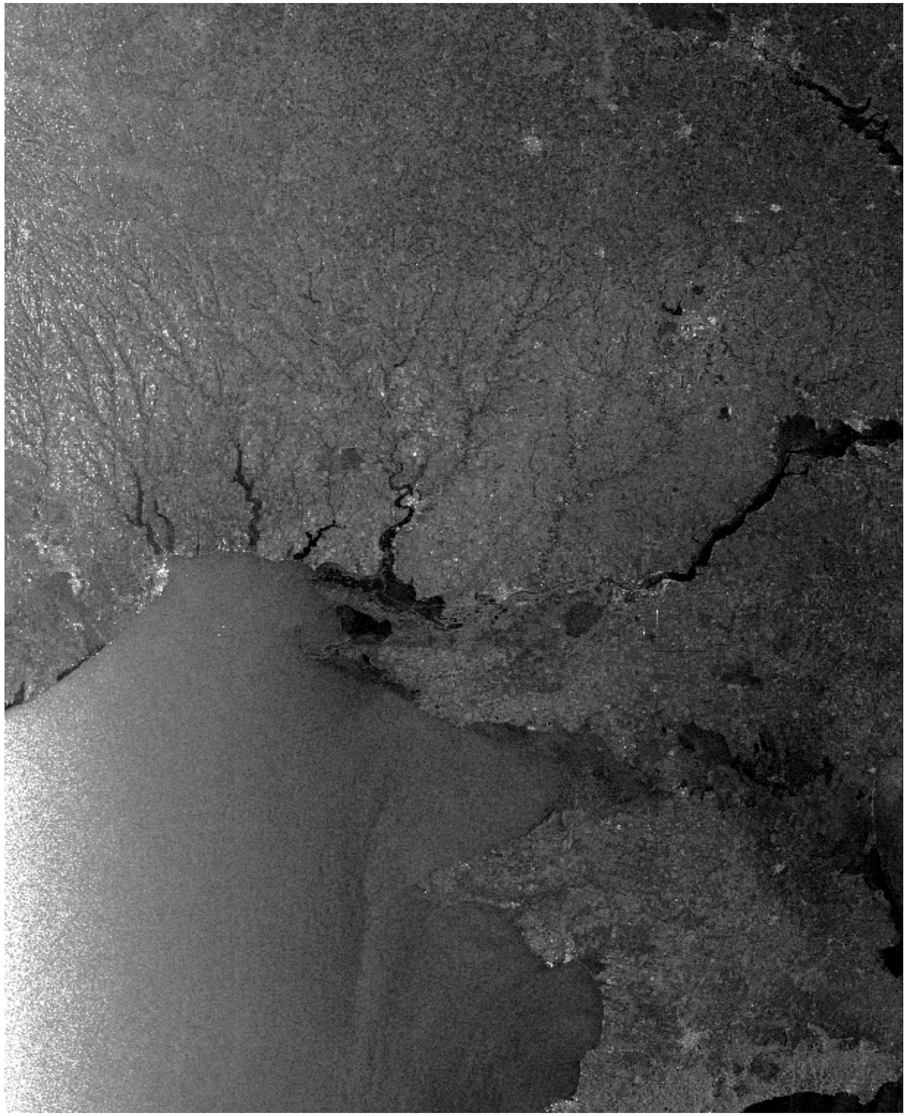


Sand "looks" similar to open water!

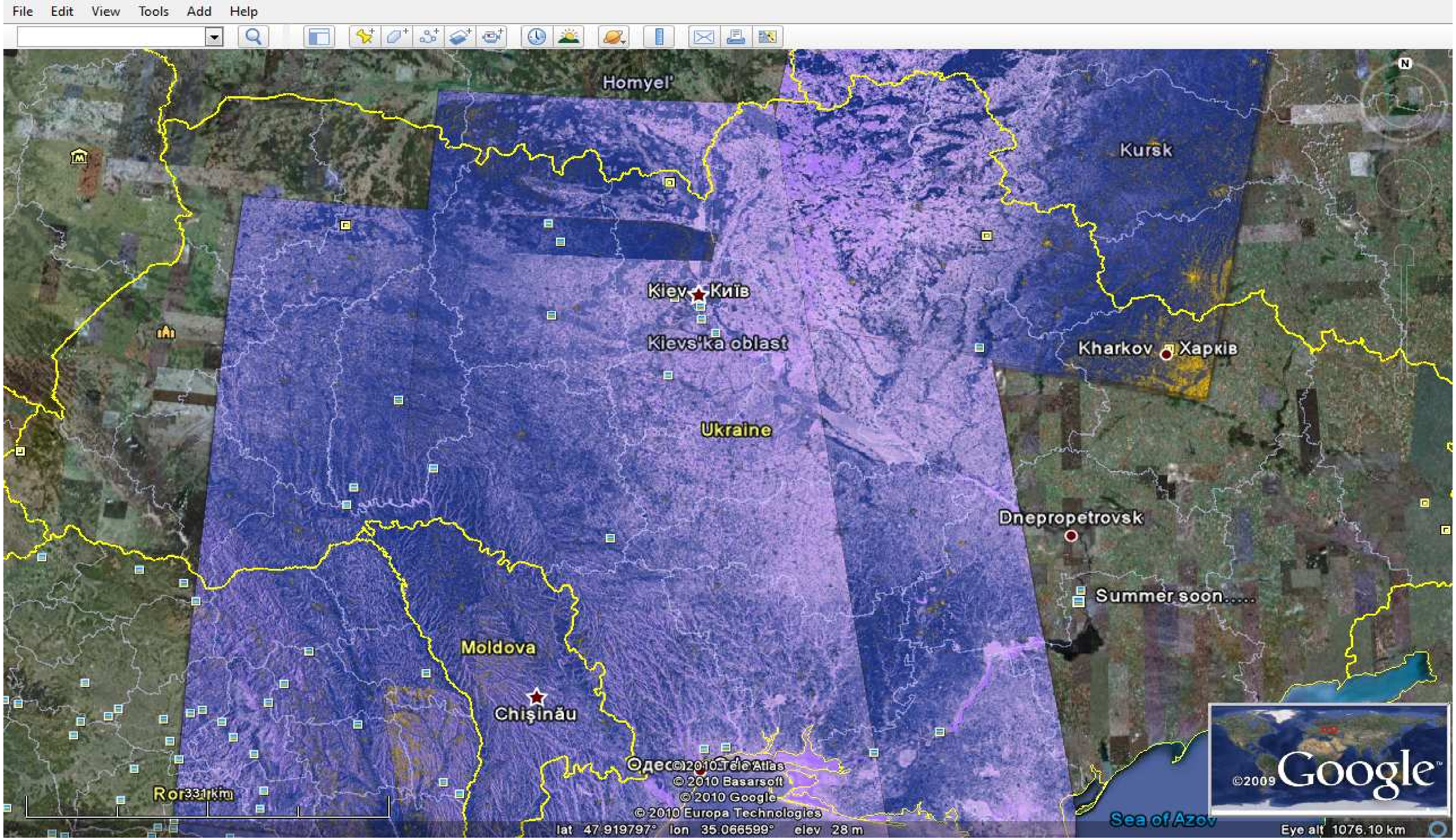
How the city looks in SAR image

Ukraine, 2010

- Flood Risk Assessment on the base of UN-SPIDER RSO
- Envisat/ASAR imagery
  - **>25 images** within **1 January through 16 April 2010**
  - **>50 images** for autumn **2009** (for comparison)
- NASA EO-1/ALI
  - 3 images: 10, 23 March and 13 April 2010

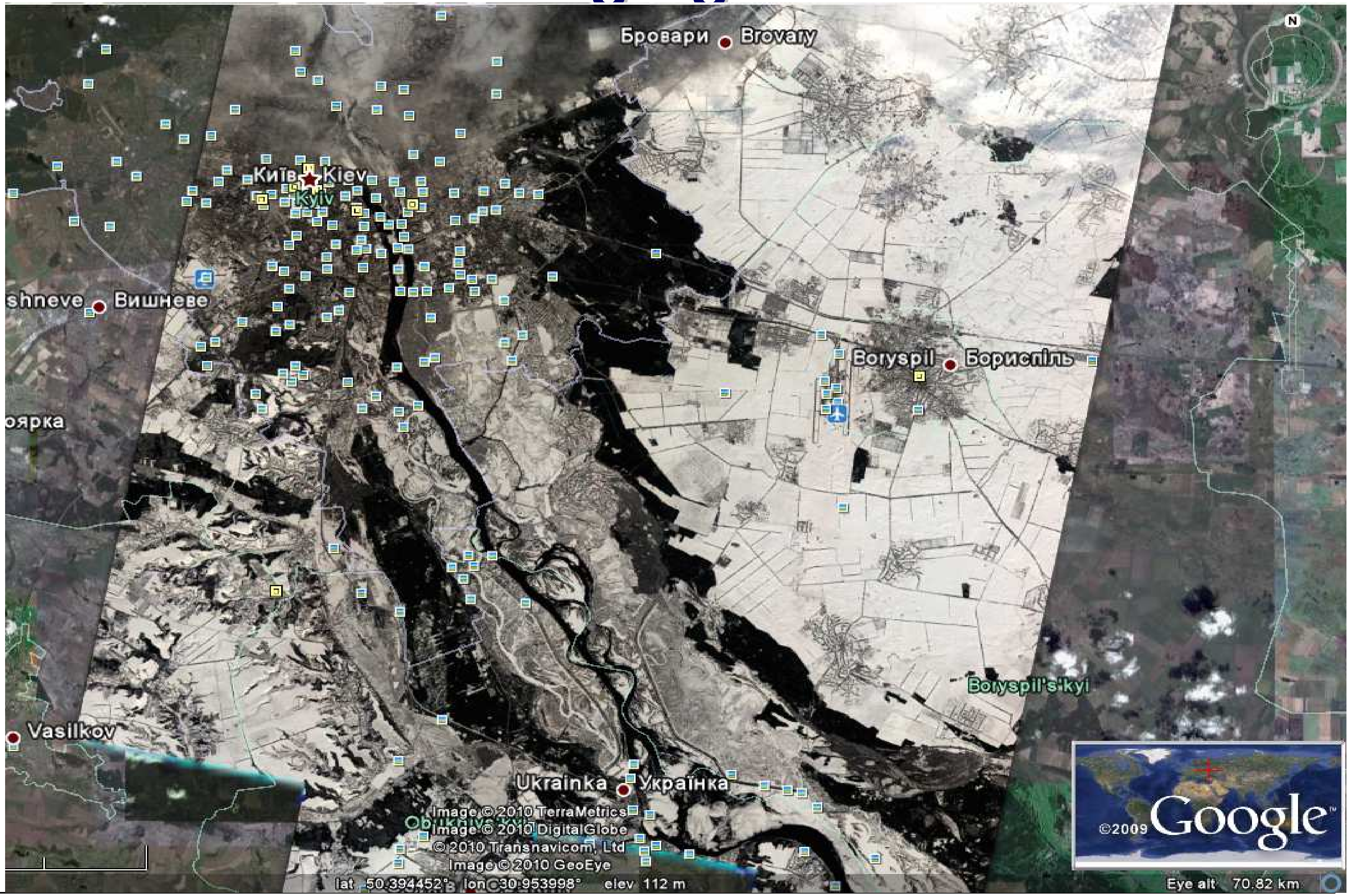


Snow cover from ASAR



EO-1 / Advanced Land Imaging

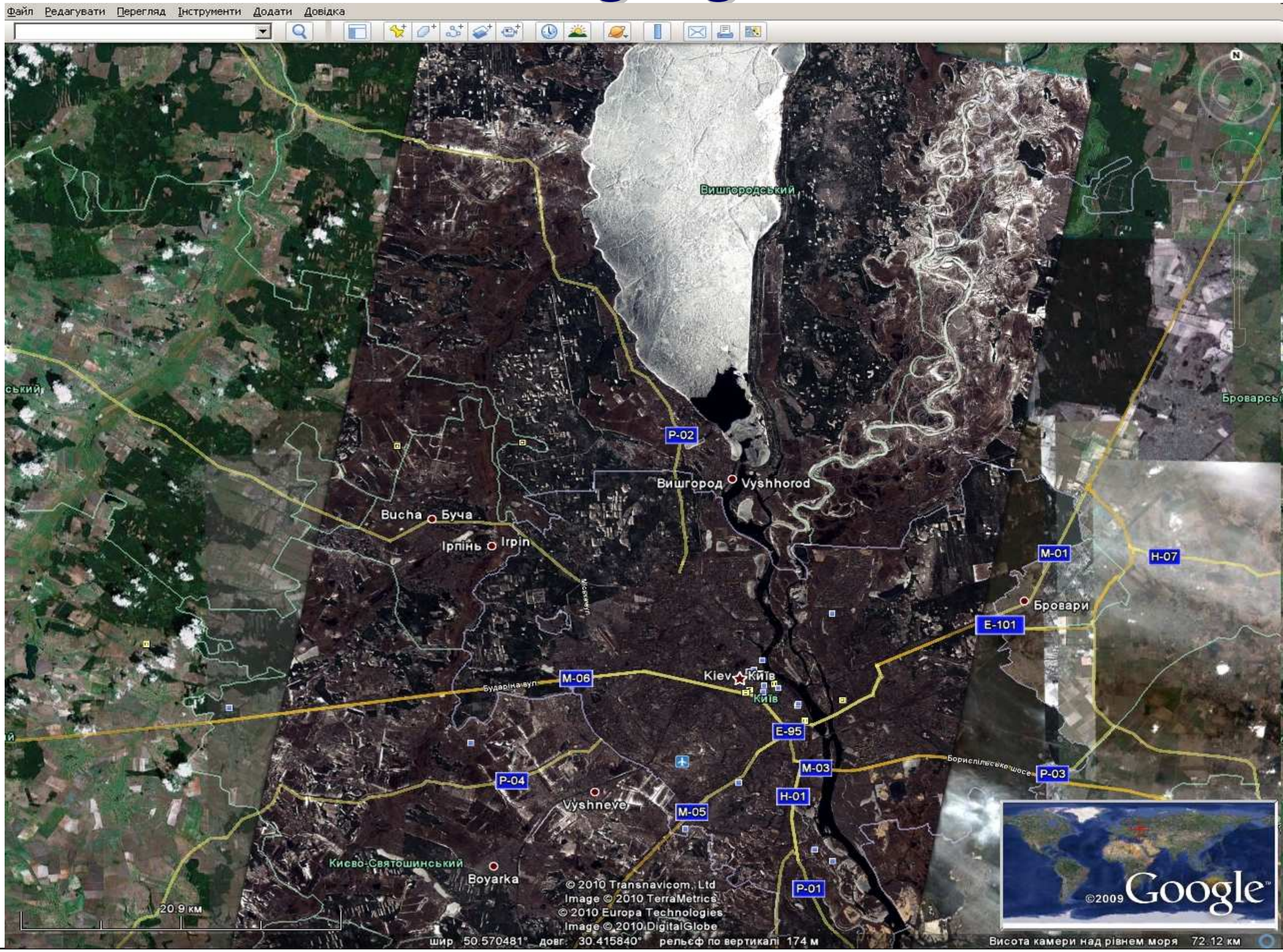
10 March 2010



Data courtesy of the NASA Earth Observing One (EO-1) mission operated by the Goddard Space Flight Cente

EO-1 / Advanced Land Imaging

23 March 2010



Data courtesy of the NASA Earth Observing One (EO-1) mission operated by the Goddard Space Flight Cente

EO-1 / Advanced Land Imaging

13 April 2010

Data courtesy of the NASA Earth Observing One (EO-1) mission operated by the Goddard Space Flight Cente

EO-1 / Advanced Land Imaging - Timeline

Notification on EO-1 tasking through SPS	Image taken	Image available @ ftp	Pan-sharpened image available as KML on Web
Mon Apr 12, 2010 @10:33 PM	Tue Apr 13, 2010 @11:33 AM	Tue Apr 13, 2010 @04:30 PM	Tue Apr 13, 2010 @11:30 PM

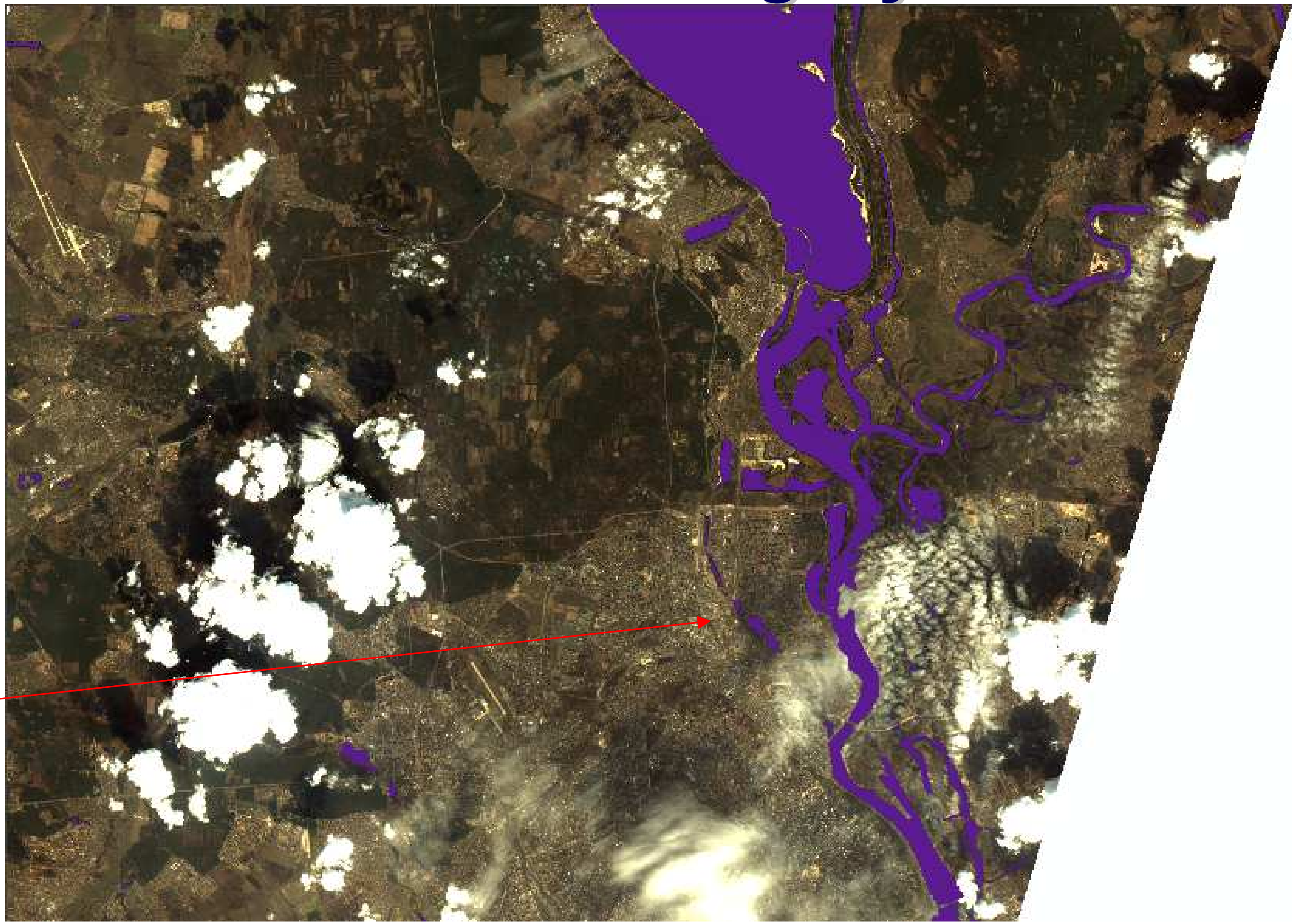
~ 12 hours

All time local Ukrainian

Flood extent from EO-1 imagery

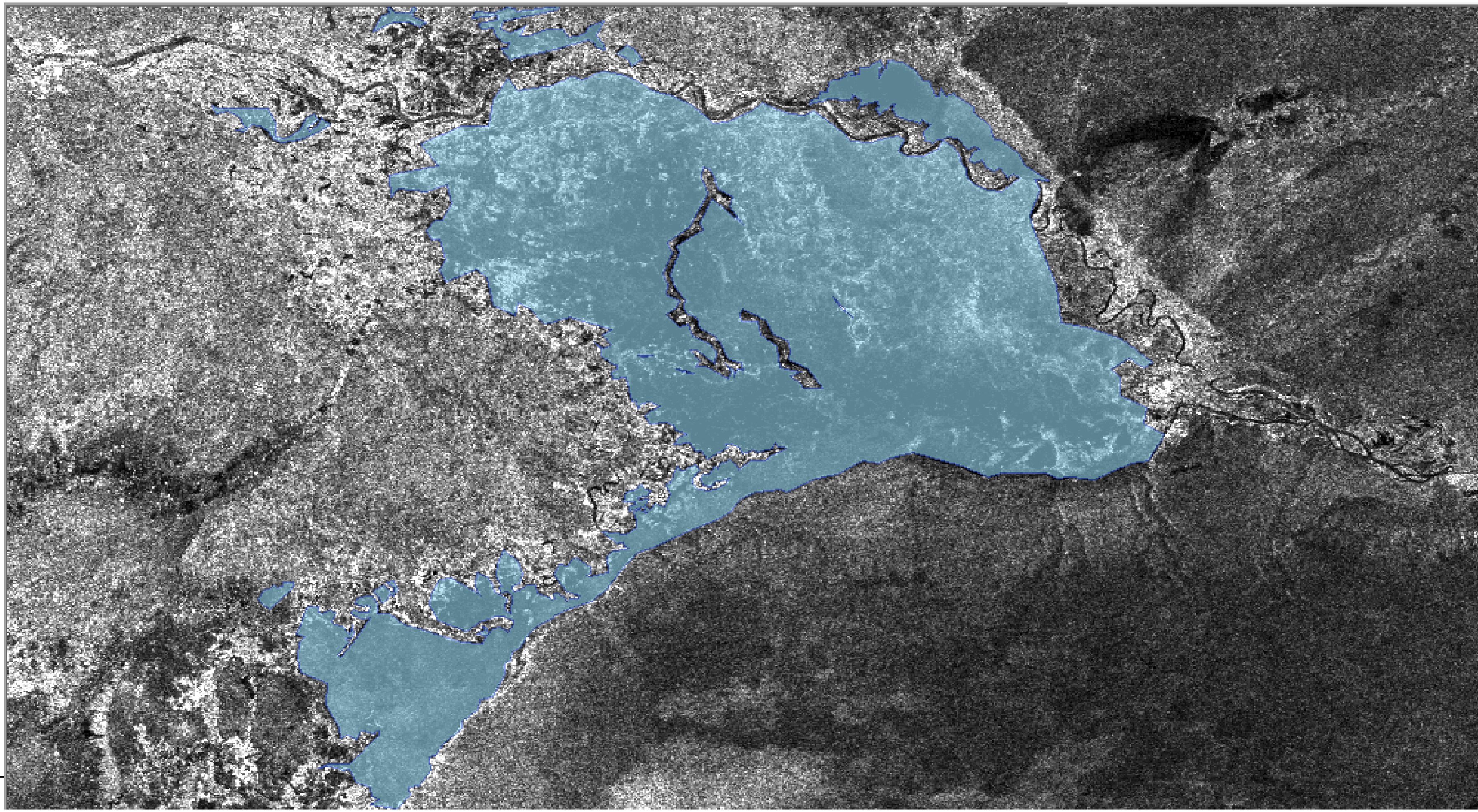
13 April 2010

Kyiv city,
Ukraine



Namibia, 2010

- Envisat/ASAR WSM, 30 May 2010



Integration and analysis of ground and satellite data

- Location: Namibia
- Ground data
  - 25-27 January 2010
  - UN Technical Advisory Meeting in Namibia
  - Collected with GPS and camera using

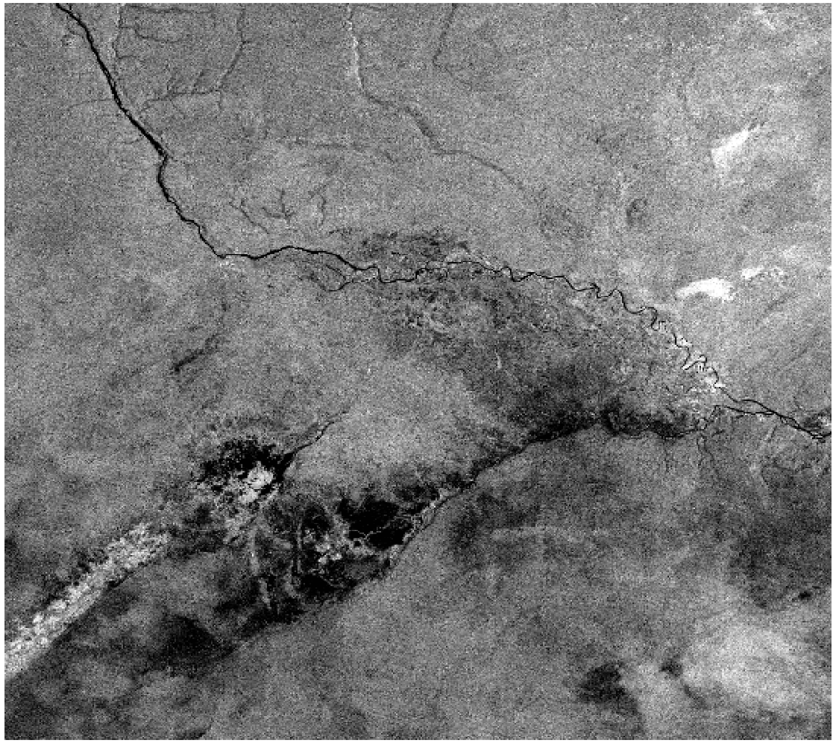
Car

Boat

Air

Integration and analysis of ground and satellite data (cont')

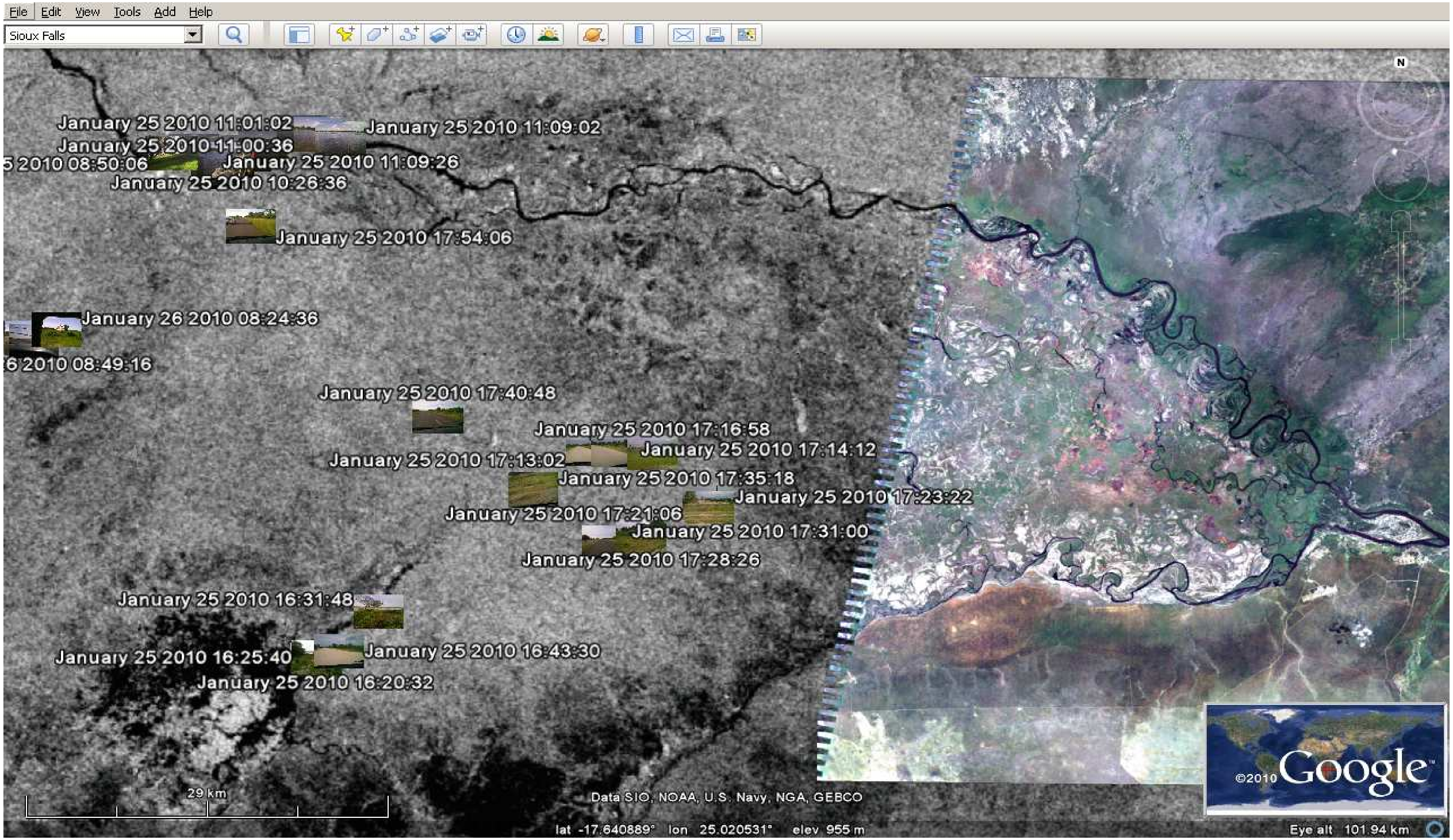
- Satellite data
  - Envisat/ASAR, 30 January 2010
  - Landsat-5/TM, 26 January 2010



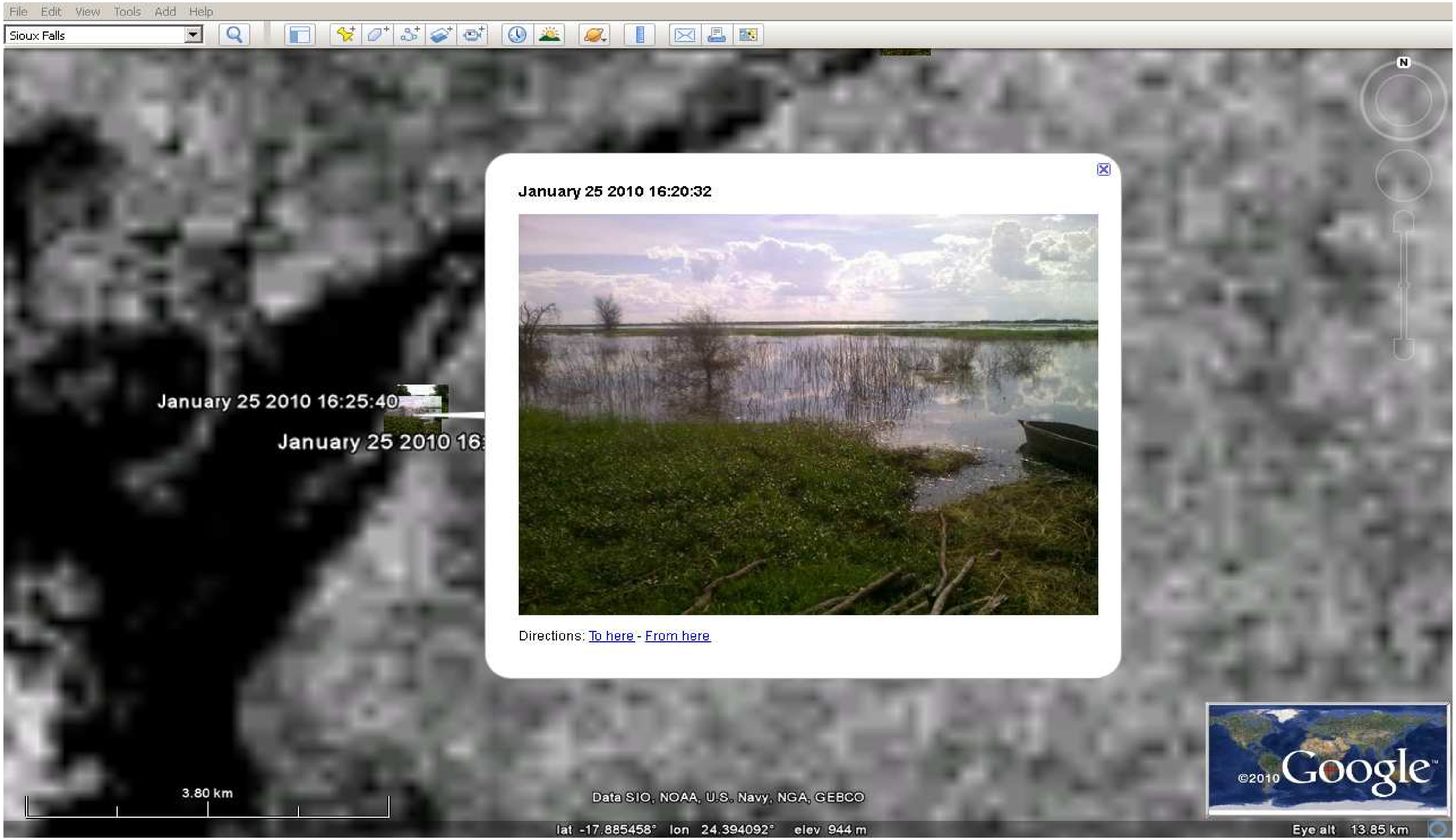
Envisat/ASAR

Landsat-5/TM

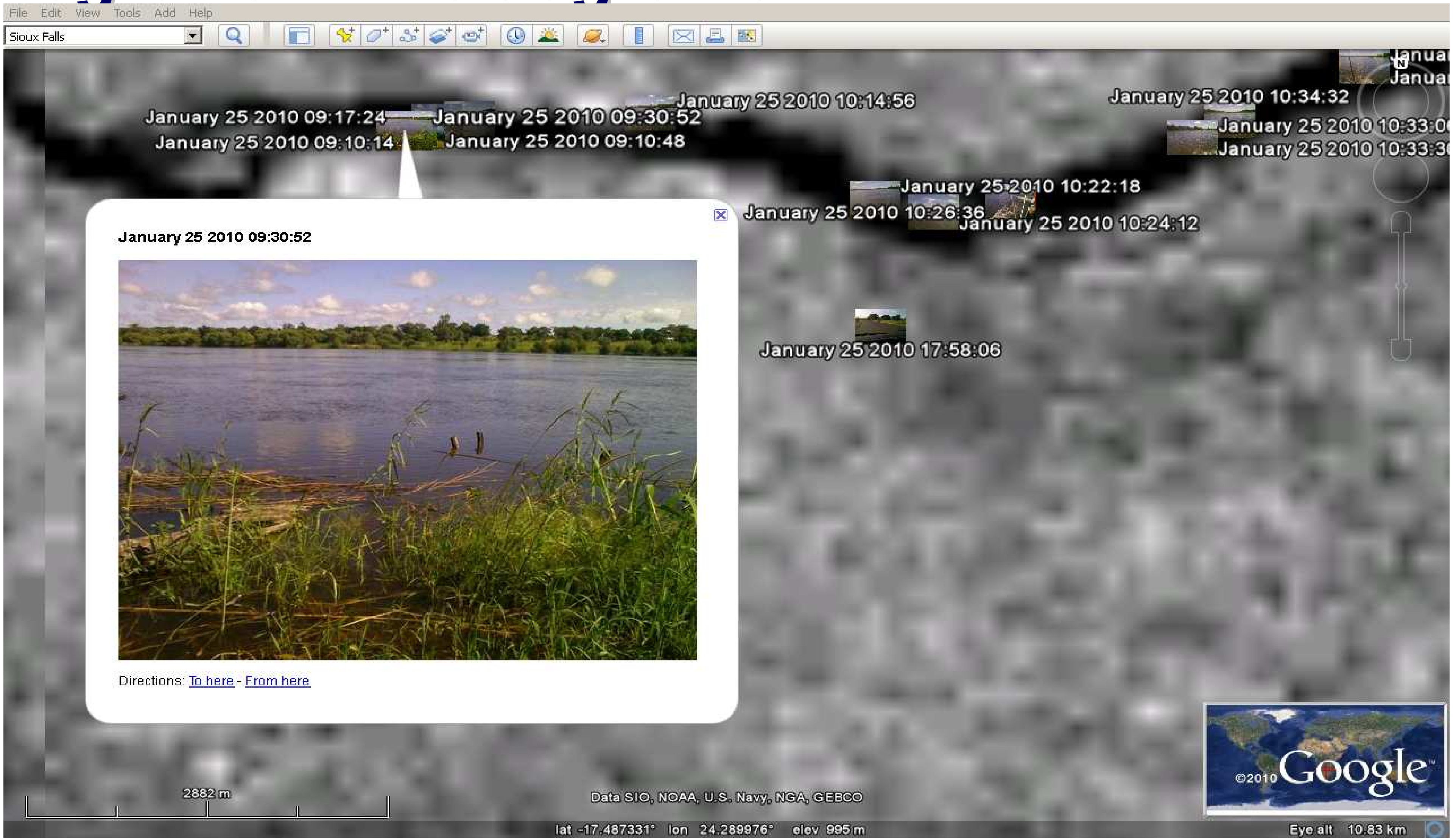
Integration in Google Earth



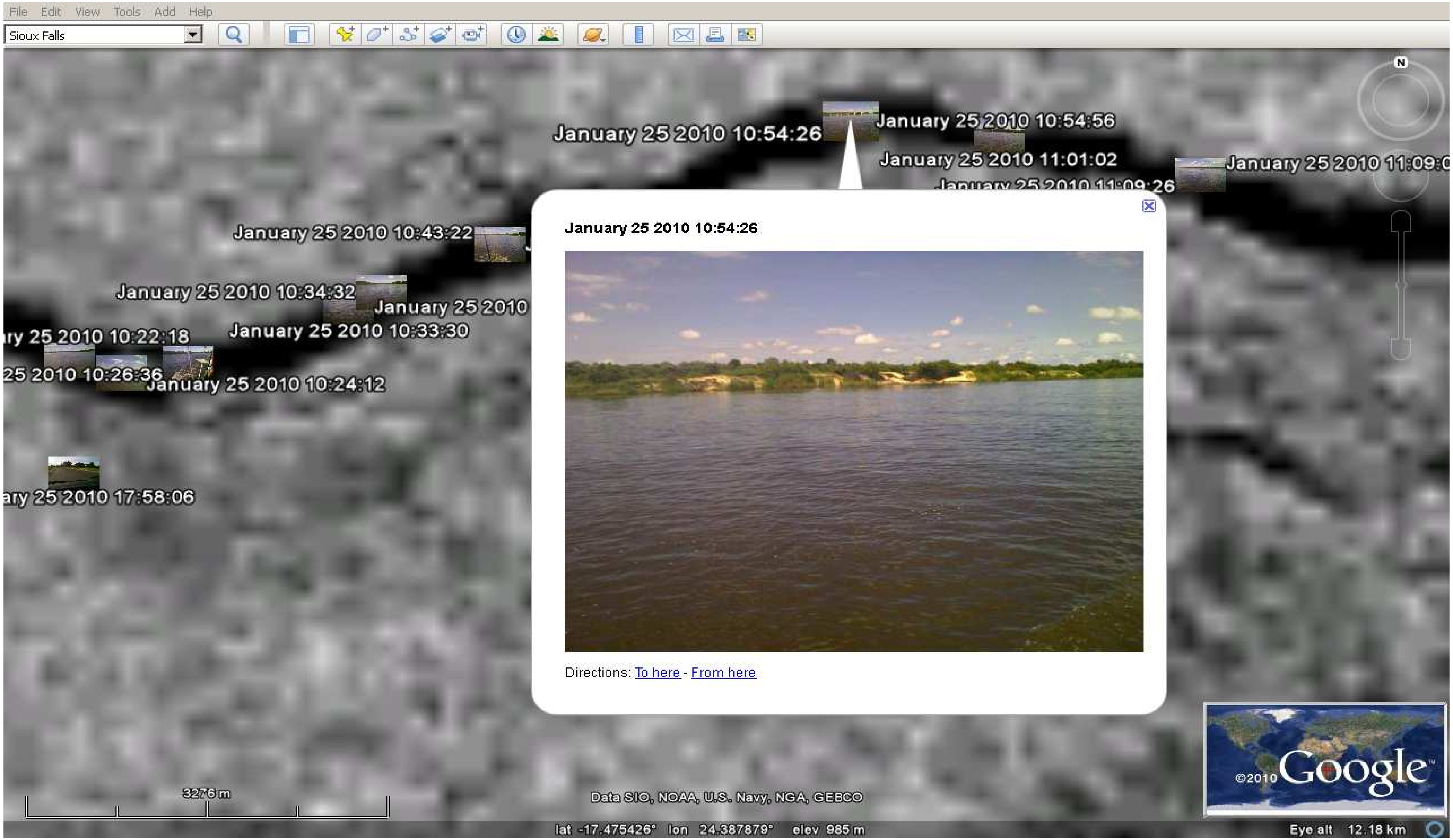
Integration in Google Earth



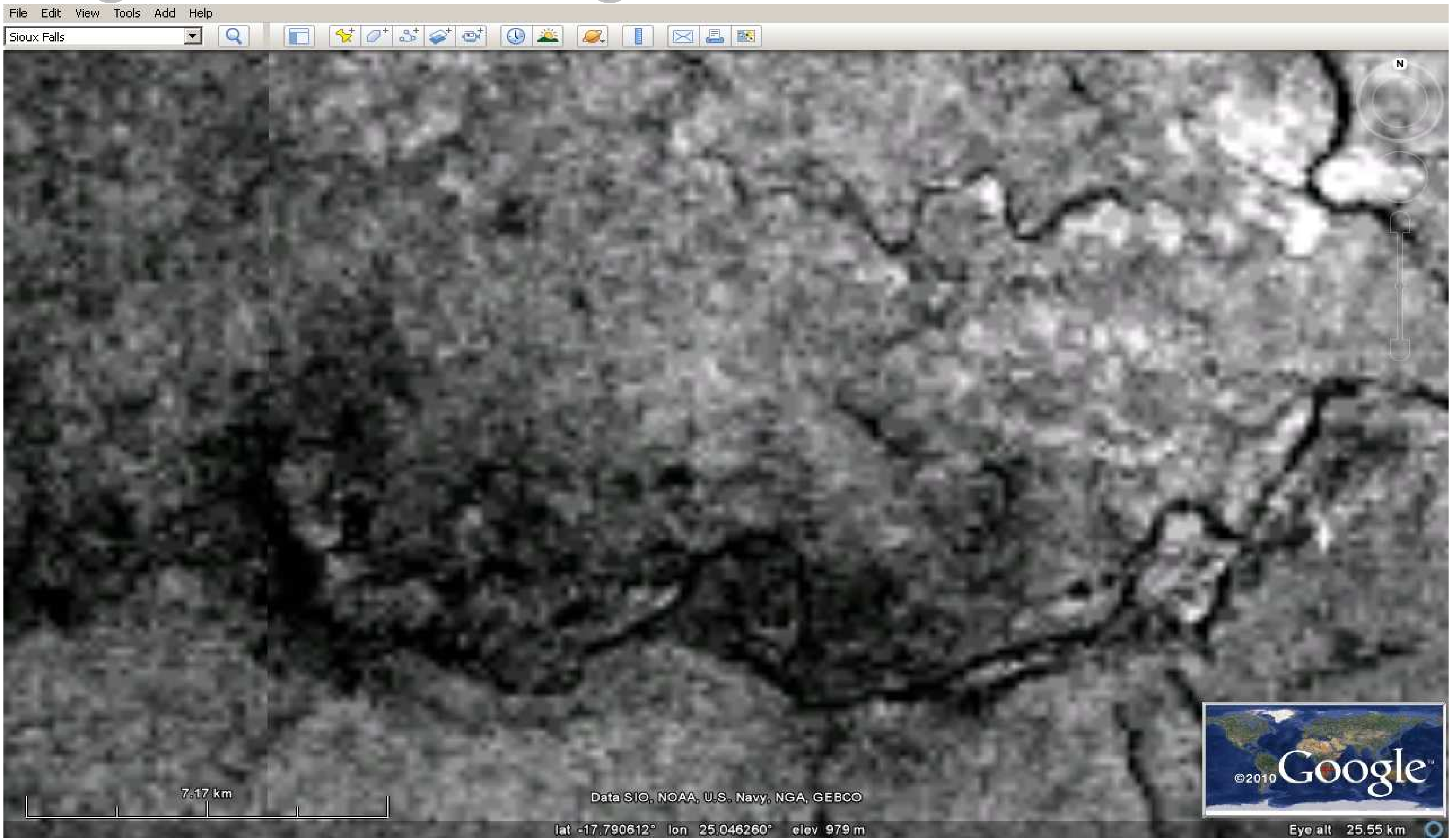
Integration in Google Earth



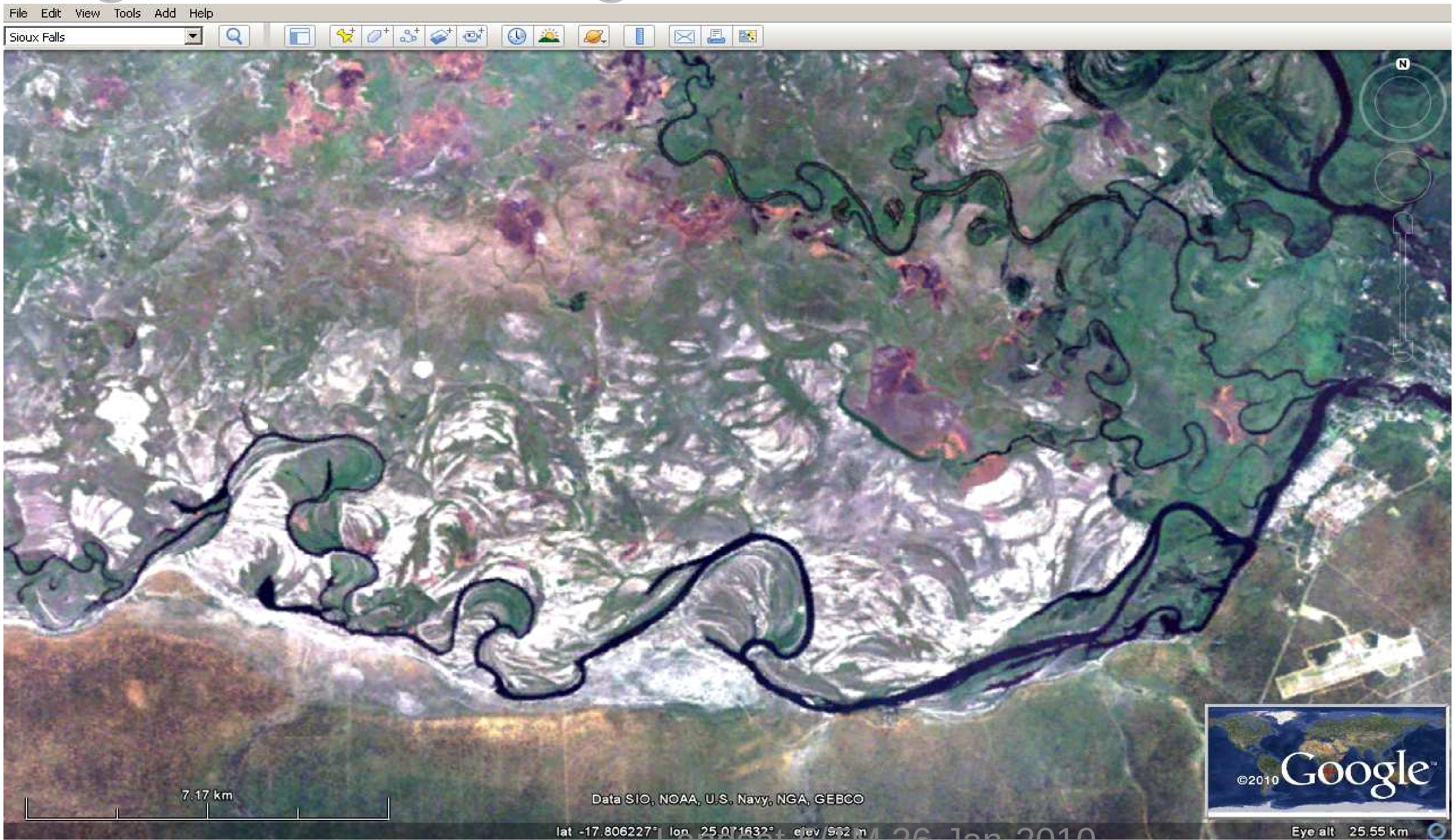
Integration in Google Earth



Integration in Google Earth



Integration in Google Earth



Landsat-5/TM 26-Jan-2010

Thank you and questions…