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AN ASI / TELESPAZIO COMPANY

The COSMO-SkyMed Satellite Constellation for Earth Observation and applications

JACIE, FairFax, March 2010, 16-18

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- Highligths on COSMO-SkyMed System
- Quality Parameters and Image Quality Control
- Geolocation Accuracy
- Applications with COSMO-SkyMed

Highligths on COSMO-SkyMed System

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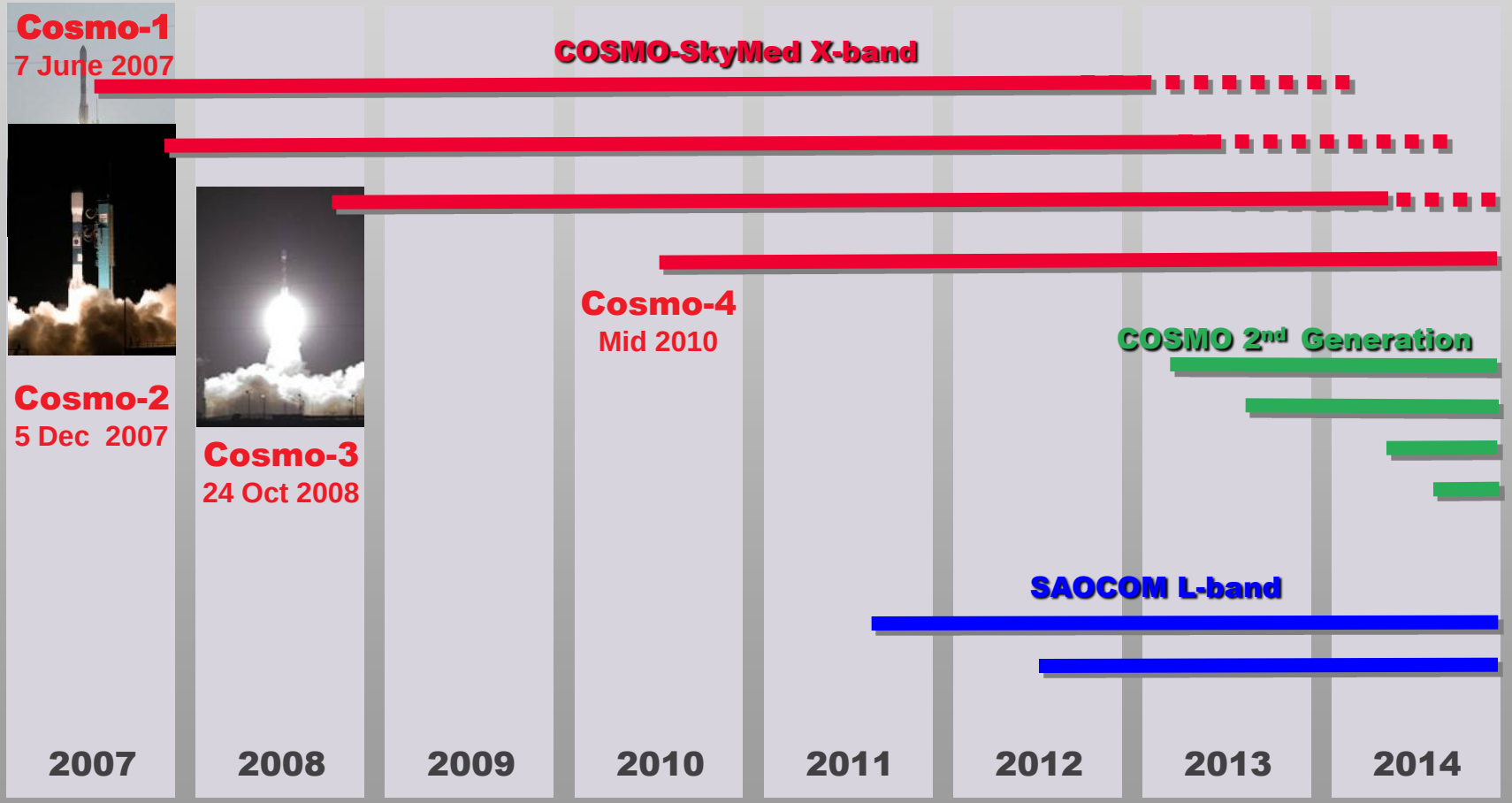
- **4 satellite (now 3 launched, 4th will be launched at within end of 2010)**
- **High orbit altitude (620 Km) – 16 days cycle**
- **Wide incidence angle (20º– 59º)**
- **Right & left looking acquisition**
- **The widest chirp bandwidth (400MHz) – 1 m. resolution even @ 20° incidence angle**

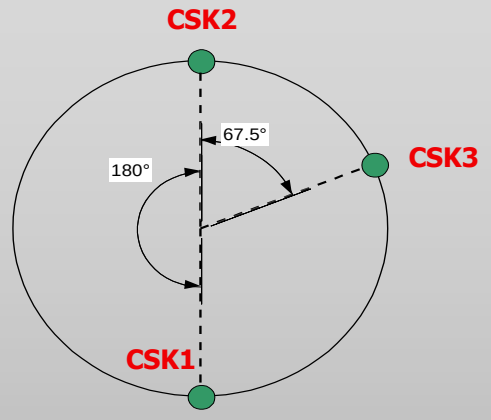
- **Observing modes:**
  - From 100 sqkm 1 meter resolution Spotlight
  - ….to 200 x 200 Km^2 swath in ScanSAR

- **<u>Four identical satellites on the same orbit plane</u> (constellation to be completed by the end of this year)**

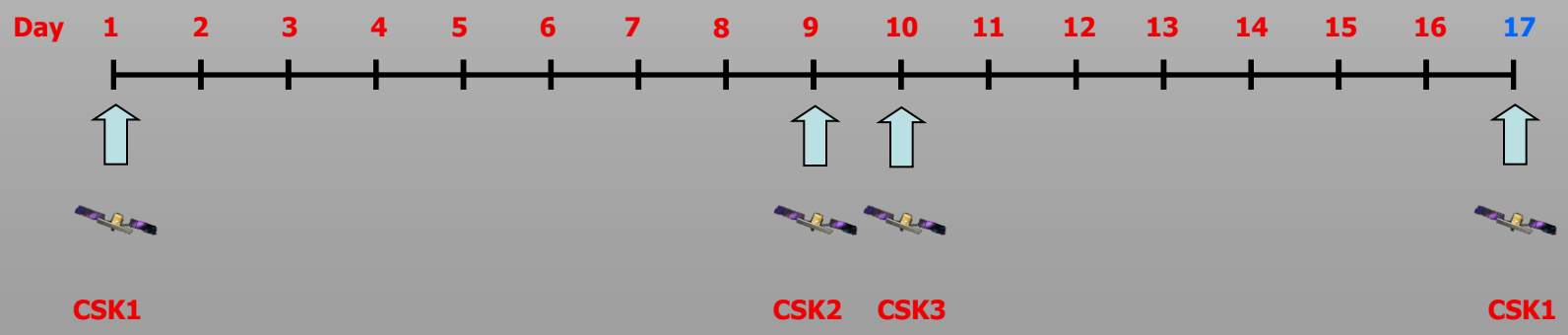
Present & Future Constellation



Current Constellation

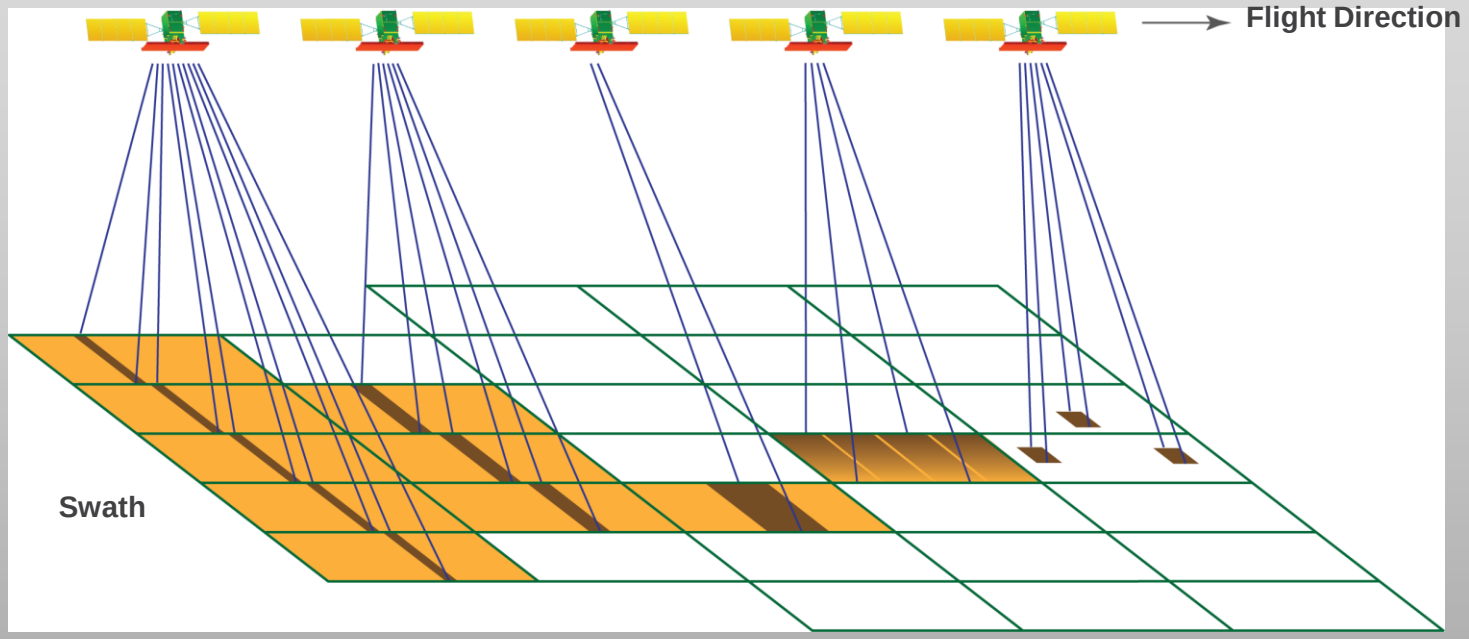


Tandem-like



Interferometric acquisitions (fixed beam, looking direction, pass, observing mode)

Imaging Modes



	HUGEREGION	WIDEREGION	HIMAGE	PINGPONG	MODE-2
Resolution – standard multi-look	100 m	30 m	5 m	15 m	1 m
Swath	200 x 200 km^2	100 x 100 km^2	40 x 40 km^2	30 x 30 km^2	10 x 10 km
	SCANSAR		STRIPMAP		SPOTLIGHT

Products Characteristics

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Mode	Type	Resol. & swath (in ground)
SCANSAR	HUGE	res.: 100 x 100 m^2 sw.: 200 x 200 km^2
	WIDE	res.: 30 x 30 m^2 sw.: 100 x 100 km^2
STRIPMAP	PINGPONG	res.: 20 x 20 m^2 sw.: 30 x 30 km^2
	HIMAGE	res.: 5 x 5 m^2 sw.: 40 x 40 km^2
SPOTLIGHT	SPOTLIGHT	res.: 1 x 1 m^2 sw.: 10 x 10 km^2

Image Levels

- **COSMO images are in 4 main processing levels:**
  - 1A
    - complex images in "slant range"-azimuth projection, practically devoted to interferometry due to the opportunity of phase information
  - 1B
    - detected images "projected" (interpolated) on ground and generally multi-looked in order to have less speckle and square resolution on ground.
    - Multi-look is not applied to SPOTLIGHT images
  - 1C
    - geo-referred images (with vertical side parallel to geographic North-South and horizontal to West-Est directions
  - 1D
    - geo-referred images that are corrected in order to compensate the slant radar vision with the information of the terrain height (on ellipsoid or geoid)

Images Processing Level

Level	Characteristics	Common use
1A	–complex –acq. geometry	–DEM generation –change detection
1B	–detected –ground projected –multi-looked	–change detection –ship detection –Oil Spill detection
1C	–ground projected –georeferenced	–mapping –land use
1D	–ground projected –georeferenced	–high geolocation accuracy mapping –land use

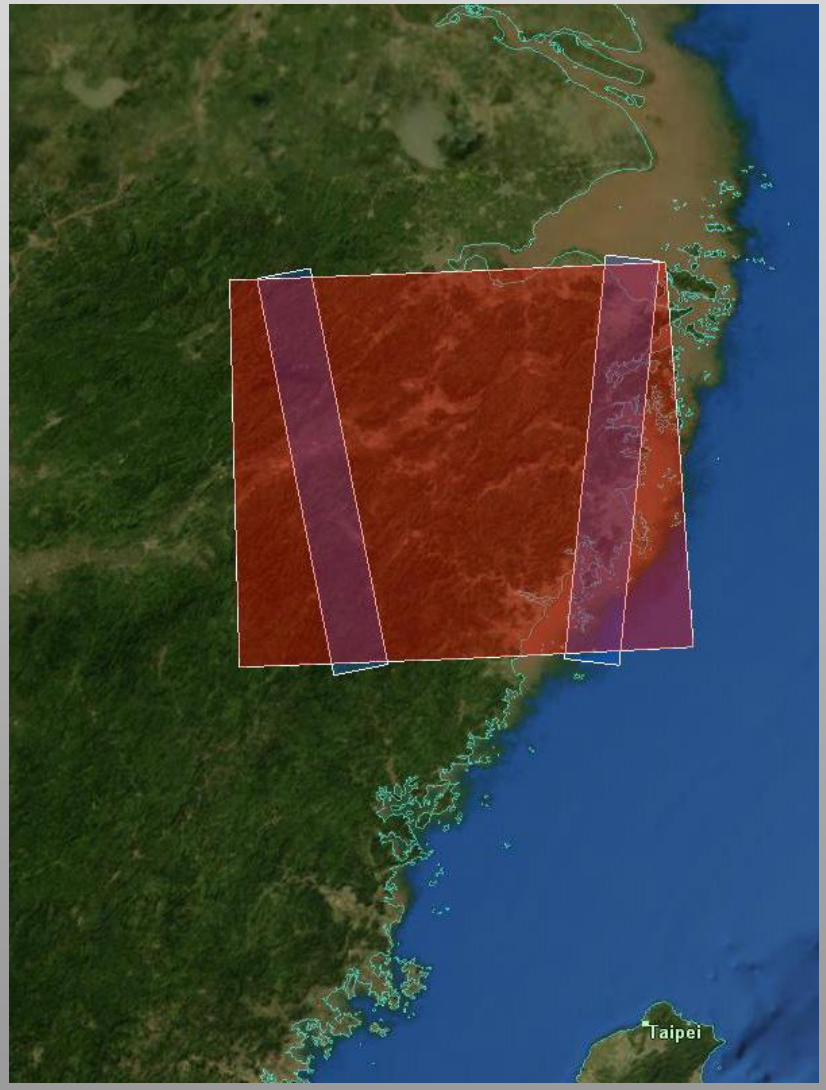
Higher Level Products

- **Standard production of post processing of high level**
- **Products for multi-temporal analysis**
  - Co-registered products
- **Products for interferometry**
  - Phase
  - Coherence
- **DEM**

Area Mapping

- Zhejiang region (China)
- 100,000 km^2
- Only Right looking
- HIMAGE strips @ 3 m

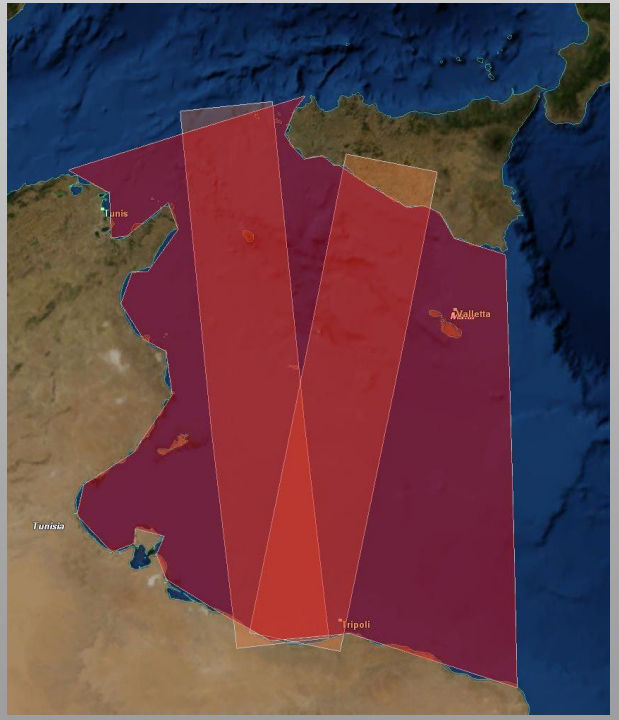
Mission	Approx. time needed for 1 complete coverage
COSMO-SkyMed 1	14 days
COSMO-SkyMed 1+2	8 days
COSMO-SkyMed 1+2+3+4	4 days



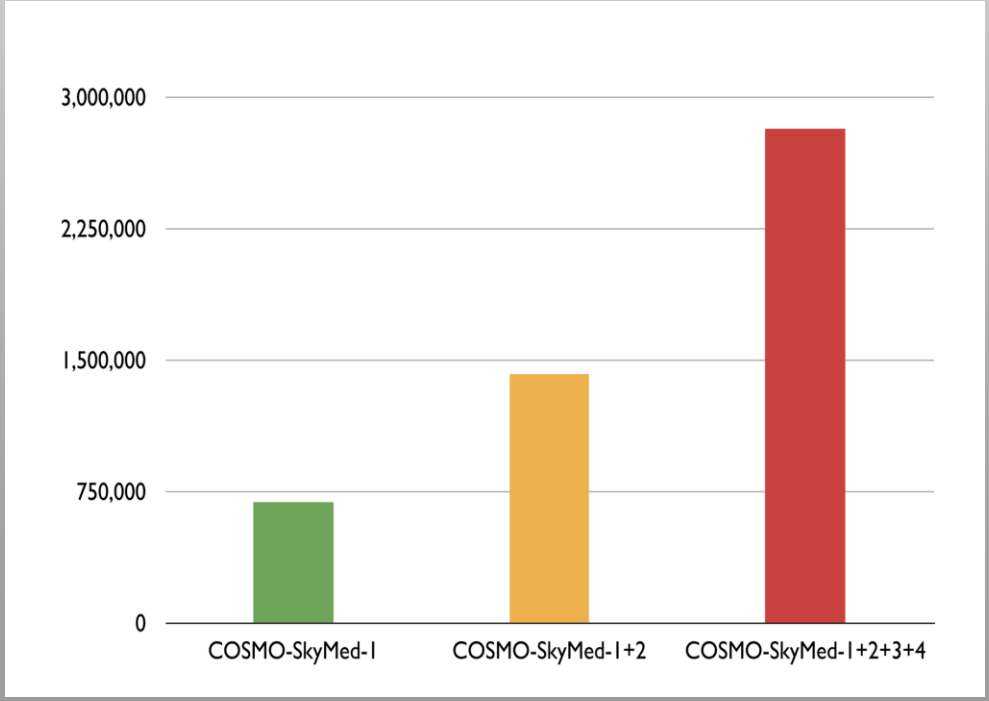
Example of COSMO-SkyMed 1 HIMAGE strips on 4 Dec 2007

Area Monitoring

- **Sicily channel**
- **210,000 km^2 Area of Interest**
- **SCANSAR Wide Region @ 30 m**



Example of COSMO-SkyMed 1 SCANSAR Wide Region strips on 1 Dec 2007



Special Products

- **e-GEOS is working to define products more feasible for applications and commercial use:**
  - SPOTLIGHT images with 7 x 7 km^2 swath
  - Single Look images (SCANSAR at full resolution)
  - Calibrated Images

Commercial User Terminal

- **It is possible to have a system connected with C-UGS that is a replica of the principal system**
- **It could:**
  - Order data in tasking mode or from catalogue
  - Acquire the data with an X-Band antenna
  - Process and archive the data in own Station (a copy of RAW data will be sent to C-UGS)
- **This is important to make NRT application and to provide data where you are**
- **The CUT has its own catalogue and archive**

The MAPS

- **MAPS (Mobile Acquisition and Processing Station) is a deployment of the COSMO SkyMed Ground Segment to which it is connected through the UGS.**
- **MAPS offers a specific functionality, namely that of being able to be relocated and made operational almost anywhere in the world.**
- **MAPS is constituted by a Transportable Antenna, a Mobile Operational Shelter, housing the processors systems and optionally a Service Shelter with the power supply**

- **With MAPS you can:**
  - to acquire images were you need services and reduce on-board data latency (particular for NRT)
  - to do this also for "relative" short time

C-MAPS

- Currently the C-MAPS is in the USA (hosted by Lockheed Martin)
- There will be a demonstration of the C-MAPS in Gaitherburg at the half of April

Quality Parameters and Image Quality Control

Radiometric Quality Parameters

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- **Radiometric Parameters are the same for each image acquisition mode:**

PSLR:	**≤ -22 dB**
ISLR:	**≤ -12 dB**
SSLR	**≤ -22 dB**
IRF shape -6 dB / -3 dB	**≤ 1.39**
IRF shape -10 dB/ -3 dB	**≤ 1.75**
Azimuth Point Target Ambiguity:	**≤ -40 dB**
Radiometric Accuracy:	**≤ -1 dB (at single look)**
Radiometric Linearity:	**≤ -1.5 dB**
Radiometric Stability:	**≤ -1 dB**
Total NE σ^0:	**≤ -19 dB m^2 / m^2**

Geolocation Accuracy

- Nominal accuracy is 25 m for 1C images and 15 m for 1D (GTC)
- These numbers are very high wrt the true numbers
- e-GEOS started a measurement campaign to establish the true geolocation accuracy and to characterize the system measuring the true bias

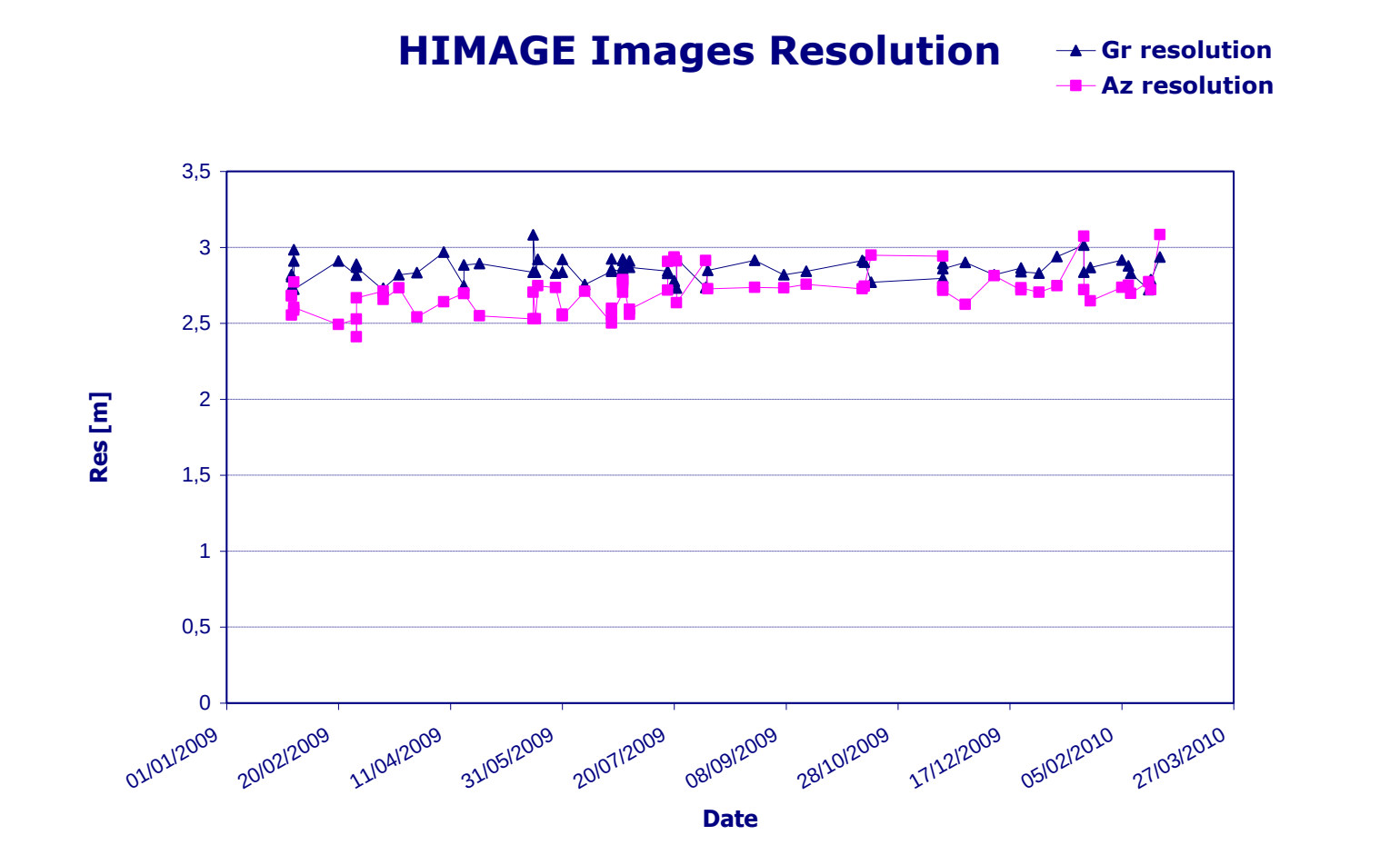
Systematic Quality Control

- **Quality Parameters are measured periodically**
  - Every day measures / monthly measure for each parameter
- **Radiometric and geometric parameters measures are combined given Key Performances Indicators (KPI) that are reported to ASI (system owner)**

PRODUCT PARAMETERS	***QUALITY PARAMETERS***
Swath width	PSLR
Pixel spacing	SSLR
Line spacing	ISLR
Off-nadir angle	Azimuth P. T. Ambig.
Incidence angle	IRF Shape: -6dB/-3dB
GEOMETRIC ACCURACY	Radiom accuracy
Ground range resolution	Radiom. linearity
Azimuth resolution	Radiom. stability
Geolocation ±s accuracy	Local Radiom. Stab.
Geometric conformity	

Quality Measures

- **KPI are all OK currently**
  - An example of last Year values (range and azimuth resolution for Stripmap images)



Quality Parameters

- **Other radiometric parameters**

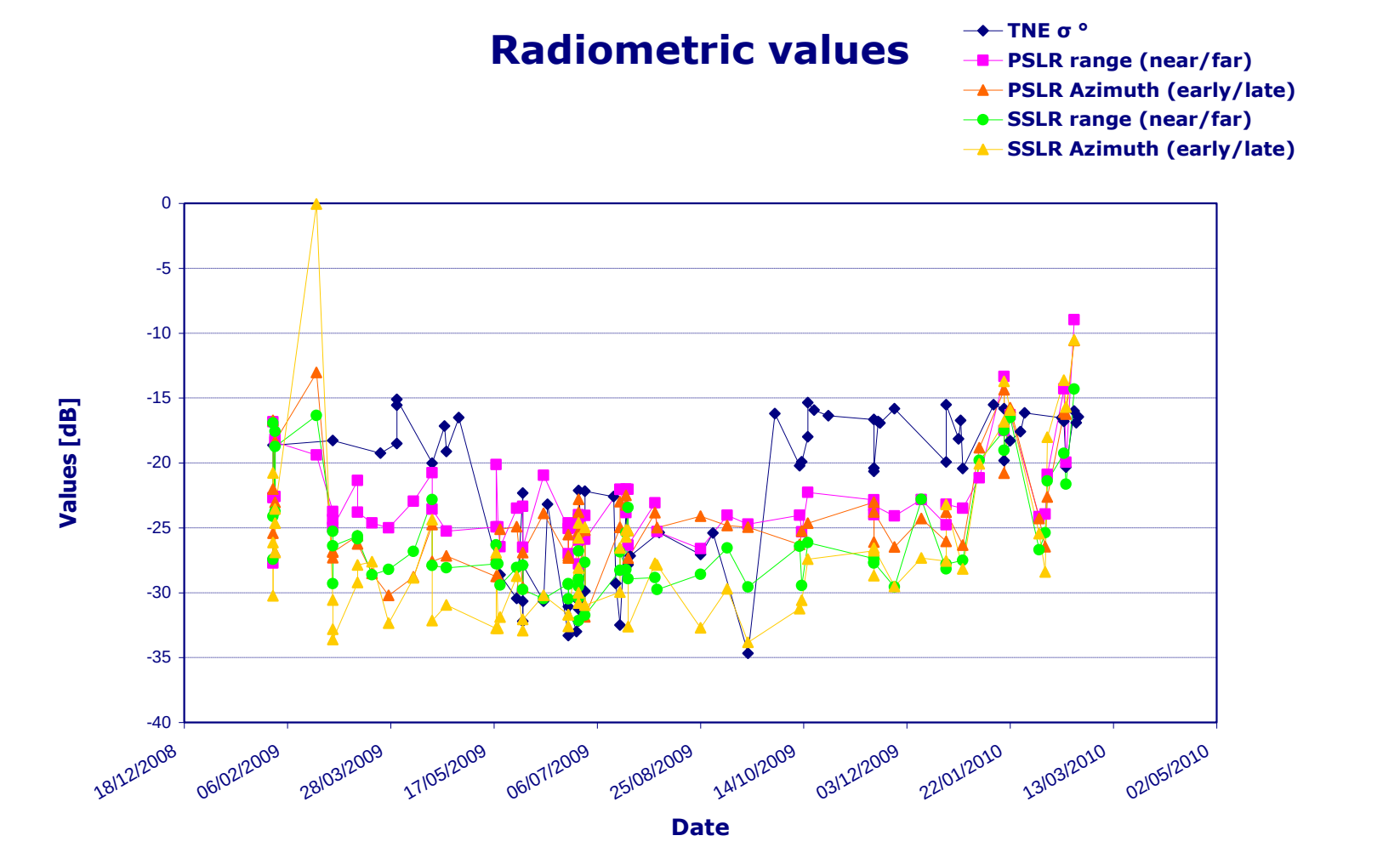
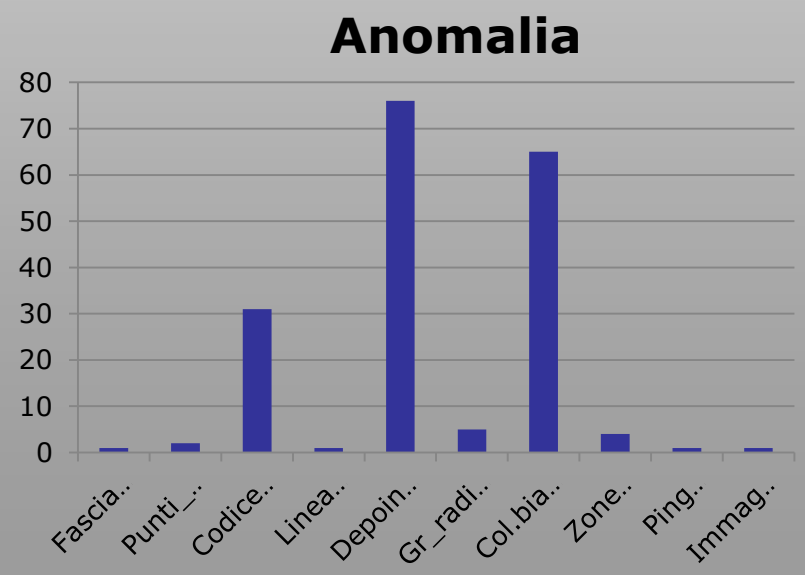


Image Quality Group

- e-GEOS started (almost 1 year ago) a work of off-line images quality analysis of all commercial orders to catch the anomalies (also anomalies that doesn't represent system bugs)
- It has been constructed a database of anomalies
- For each anomaly it's studied if it is due to a system bug, or if not, if there is some action to mitigate it
- There is an internal Point of Contact that manage each signal of anomalies of the images

Anomalies database in January



Geolocation Accuracy

Purpose of the Analysis

- **The Geolocation Accuracy defined as system requirement is not acceptable for applications**

- **e-GEOS (also after the work of NGIA, made by Paul Bresnahan on the measure of the geometric accuracy of COSMO images) has started a work of accurate measure and calibration of the system from the geolocation point of view**

Preliminary Assumptions

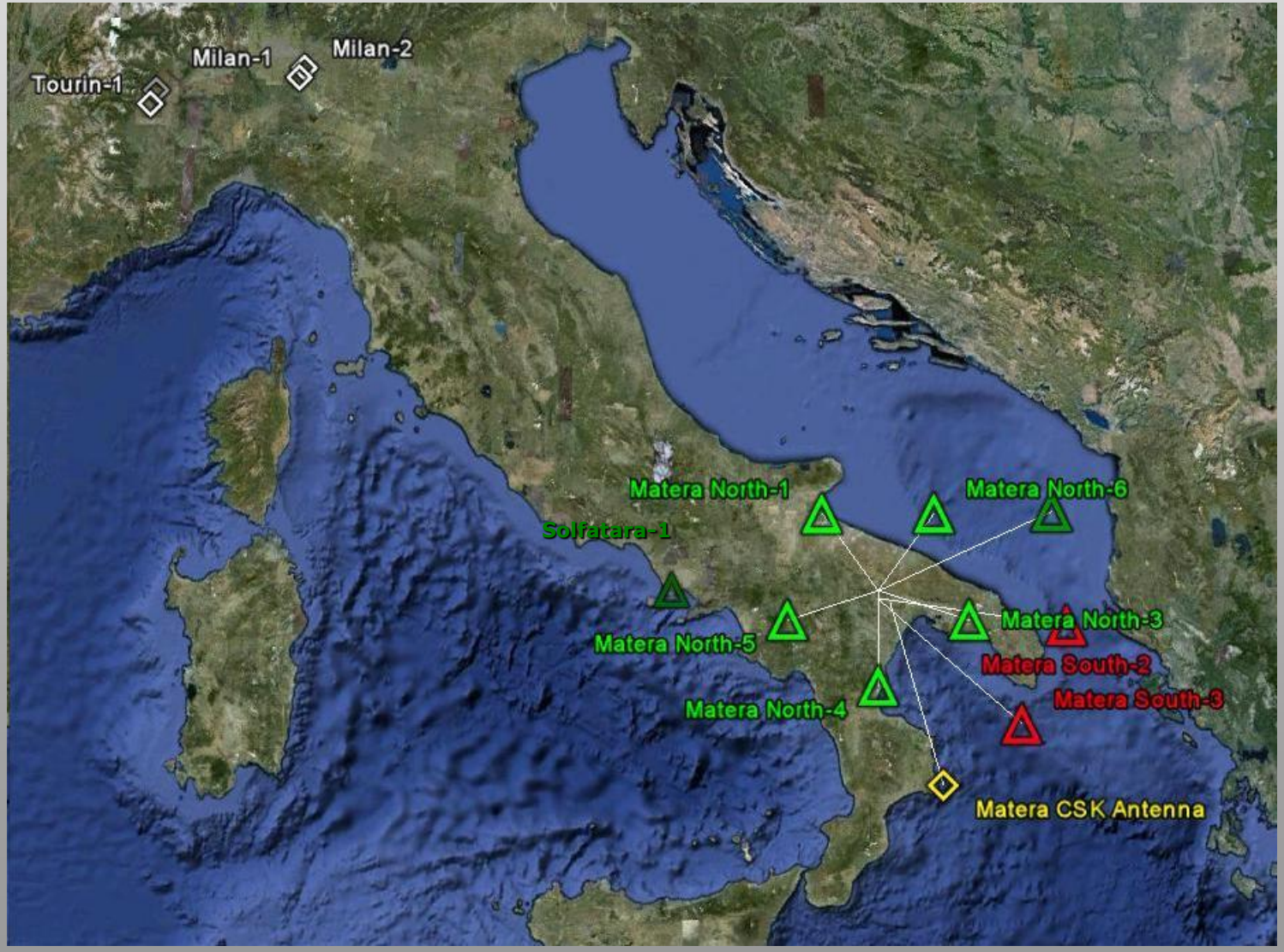
- **Images characterization means to know different parameters for each satellite, mode, side looking, polarization, and so on.**

- **We started with:**
  - CSKS1 (first satellite)
  - Right side looking (both Ascending and Descending)
  - HIMAGE and SPOTLIGHT image modes

- **The tropospheric delay imply to use images at various look angles**

Test Cases

- **They have been used the Corner Reflectors (CR) of the COSMO CalVal**



Dataset

- **In this analysis have been considered only images from the first COSMO vehicle (CSKS1)**
  - They are all Right looking
    - 43 HIMAGE images with incidence angle from ~ 26.5° to ~ 58.5°
    - 13 SPOTLIGTH images distributed with incidence angle from ~ 27° to ~ 50.5°

Definition of Statistics

- **The Geolocation Accuracies is defined for COSMO-SkyMed Mission as the absolute value of the averaged Absolute Location Error (ALE) of the measures plus 3 times the standard deviation**
- **With the following definitions:**
  - $<ALE_{gr}>$ = average of the ground range displacements between expected and effective CCs positions on ground
  - $<ALE_{az}>$ is the same in azimuth direction,
  - G_{gr} is the geolocation accuracy in ground
  - G_{az} is the geolocation accuracy in azimuth
  - σ_{gr} is the standard deviation of the ground range ALE measures
  - σ_{az} is the standard deviation of the ground range ALE measures
- **the Geolocation Accuracies definitions are the following:**

$$G_{gr} = \left| \left\langle ALE_{gr} \right\rangle \right| + 3\sigma_{ALE_{gr}}$$

$$G_{az} = \left| \left\langle ALE_{az} \right\rangle \right| + 3\sigma_{ALE_{az}}$$

Definition of Statistic

- **Circular Error 90% (CE90)**
  - In horizontal plane
  - Radial error distance centered at zero within which 90% of the data points fall

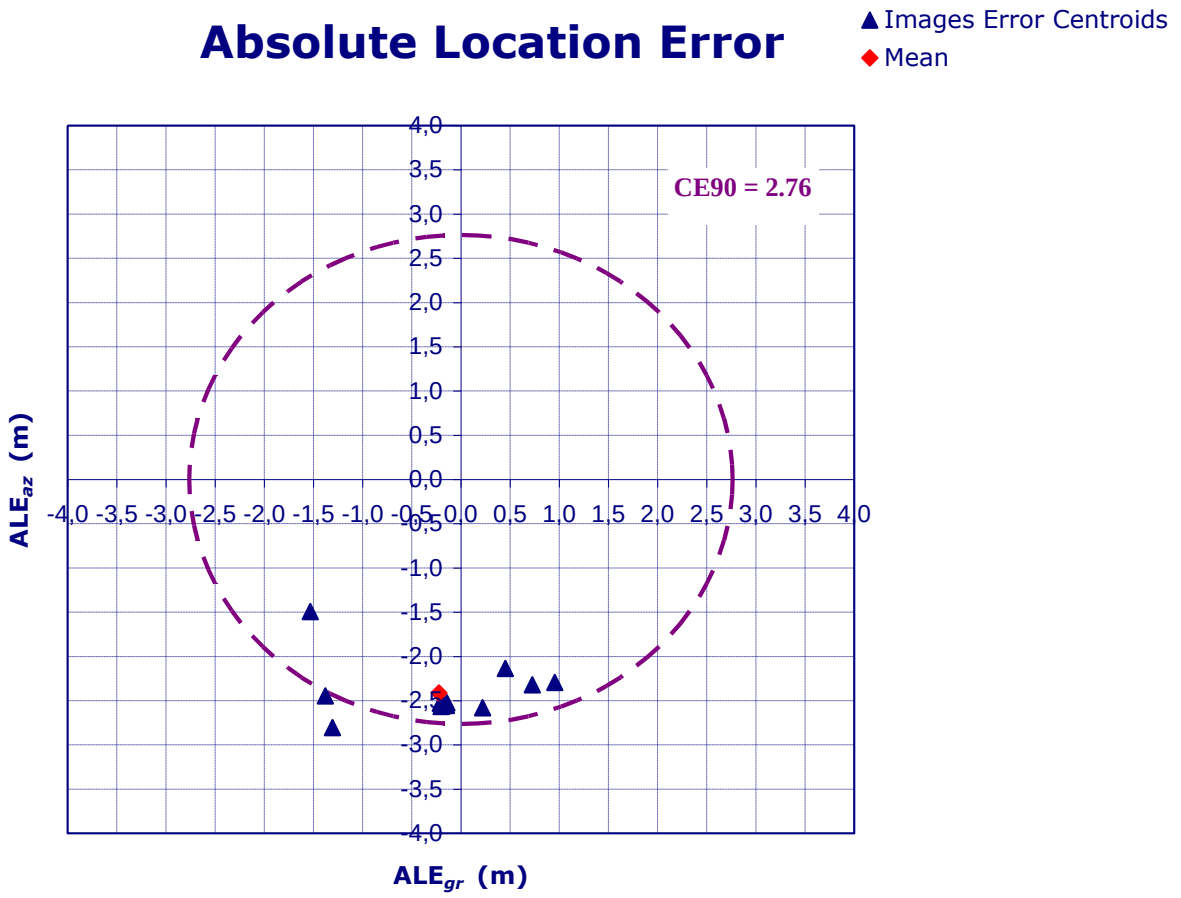
HIMAGE Geolocation Accuracy

- **The dataset is constituted by 43 HIMAGE images covering the sites**

	CR	GCPs	ALE_{gr} (m)	ALE_{az} (m)	r (m)
MIL-1	Milan 1	14	0,7	-2,3	2,4
MIL-2	Milan 2	13	1,0	-2,3	2,5
TOR-1	Tourin 1	14	-1,3	-2,8	3,1
TOR-2	Tourin 2	9	-1,4	-2,4	2,8
MAT-2	Matera 1	11	0,5	-2,1	2,2
MAT-3	Matera 2	11	0,2	-2,6	2,6
MTR-1	Matera 3	11	-0,2	-2,5	2,5
MTR-2	Matera 4	11	-0,2	-2,6	2,6
MTR-3	Matera 5	11	-0,2	-2,6	2,6
MTR-4	Matera 6	11	-0,1	-2,5	2,5
MTR-5	Matera 7	11	-0,1	-2,6	2,6
MTR-6	Matera 8	11	-0,2	-2,6	2,6
SLF-1	Solfatara 1	2	-1,5	-1,5	2,1
CSK-M	Matera ant	11	4,7	-2,0	5,1
Average			-0,2	-2,4	2,5
Standard deviation			0,8	0,3	0,2
Min			-1,5	-2,8	2,1
Max			1,0	-1,5	3,1
Geolocation accuracy ±3σ			2,5	3,4	4,2
CE90					2,76

HIMAGE Horizontal Geolocation Accuracy

- **There is a clear systematic in azimuth**
  - $<ALE_{az}> = -2.5 \quad 0.6$



SPOTLIGTH Geolocation Accuracy

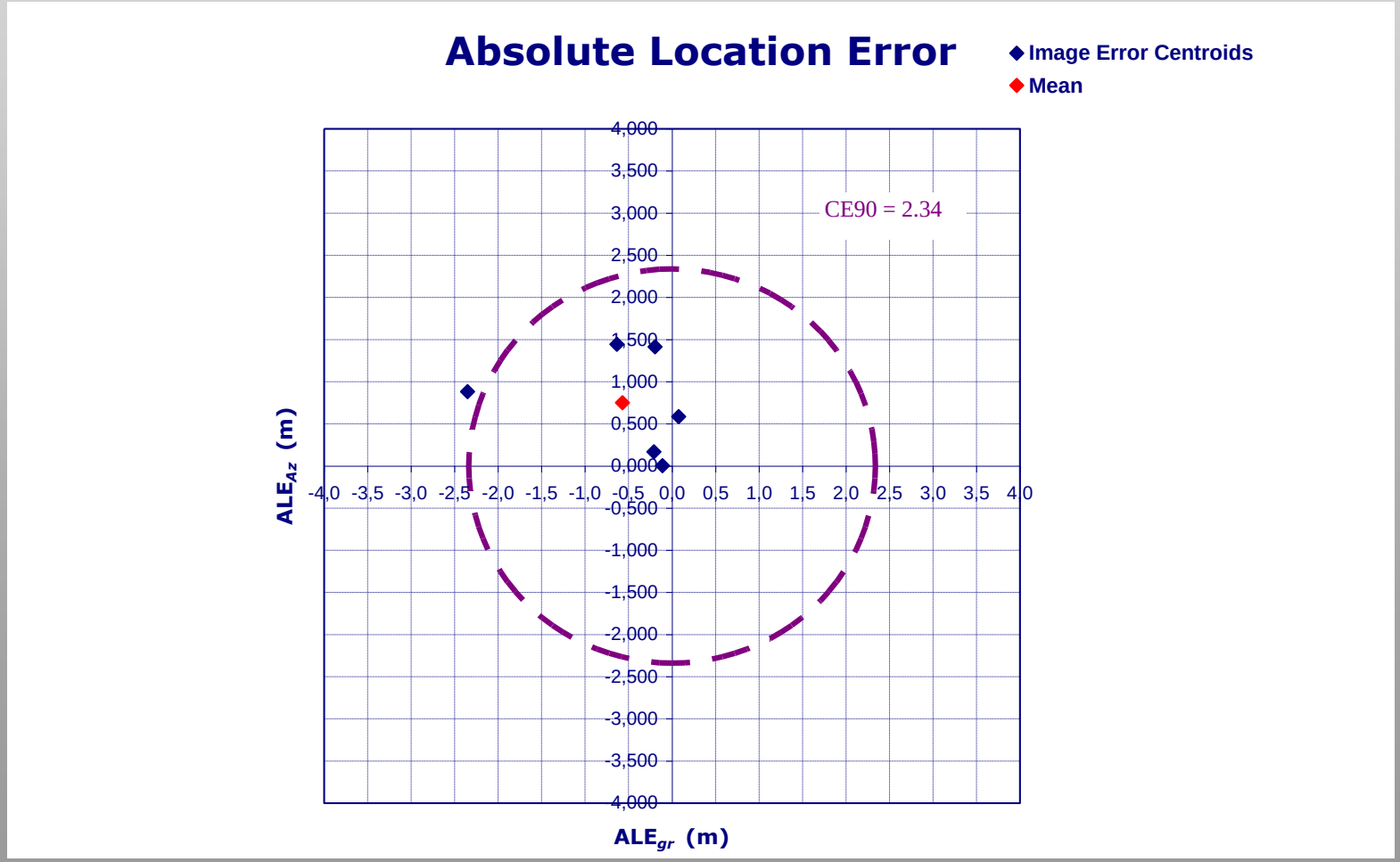
- **The dataset is constituted by 13 SPOTLIGHT images covering the sites**

	CCs	GCPs	ALE_{gr} (m)	ALE_{az} (m)	r (m)
MIL-1	Milan 1	2	-0,1	0,004	0,7
TOR-1	Tourin 1	3	-2,4	0,9	2,5
MAT-2	Matera 2	4	0,1	0,6	1,0
MAT-3	Matera 3	5	-0,2	0,2	0,8
MET-1	Metapontum 1	3	-0,2	1,4	2,0
MET-3	Metapontum 3	3	-0,6	1,4	2,2

Average	-0,6	0,7	1,5
Standard Deviation	0,9	0,6	0,8
Min	-2,4	0,004	0,7
Max	0,1	1,4	2,5
Geolocation accuracy ± 3s	3,3	2,6	4,2
CE90			2,34

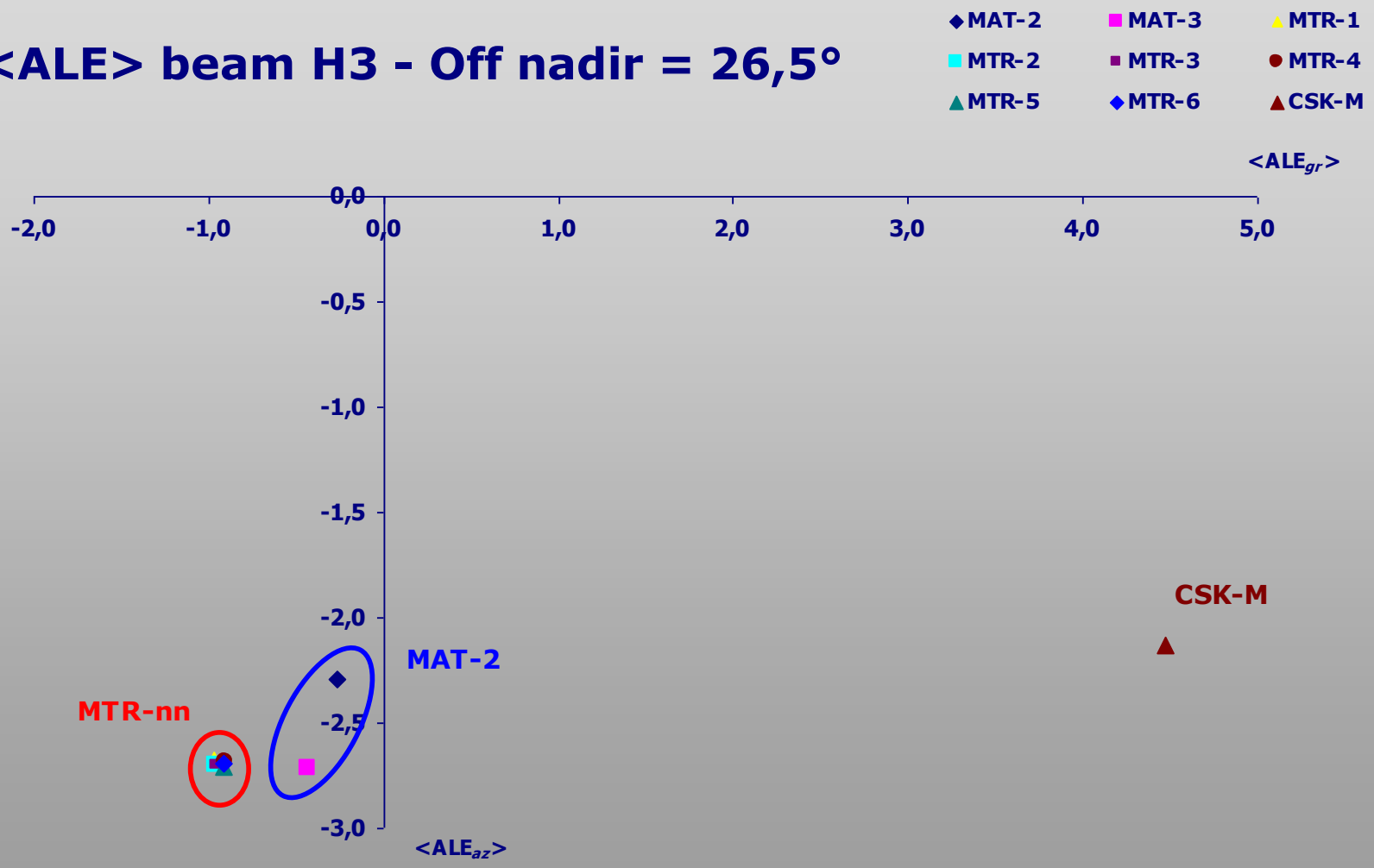
SPOTLIGHT Horizontal Geolocation Accuracy

- **There is a systematic in azimuth (smaller than the HI one):**
  - $<ALE_{az}> = 0.7 \quad 0.6$ m



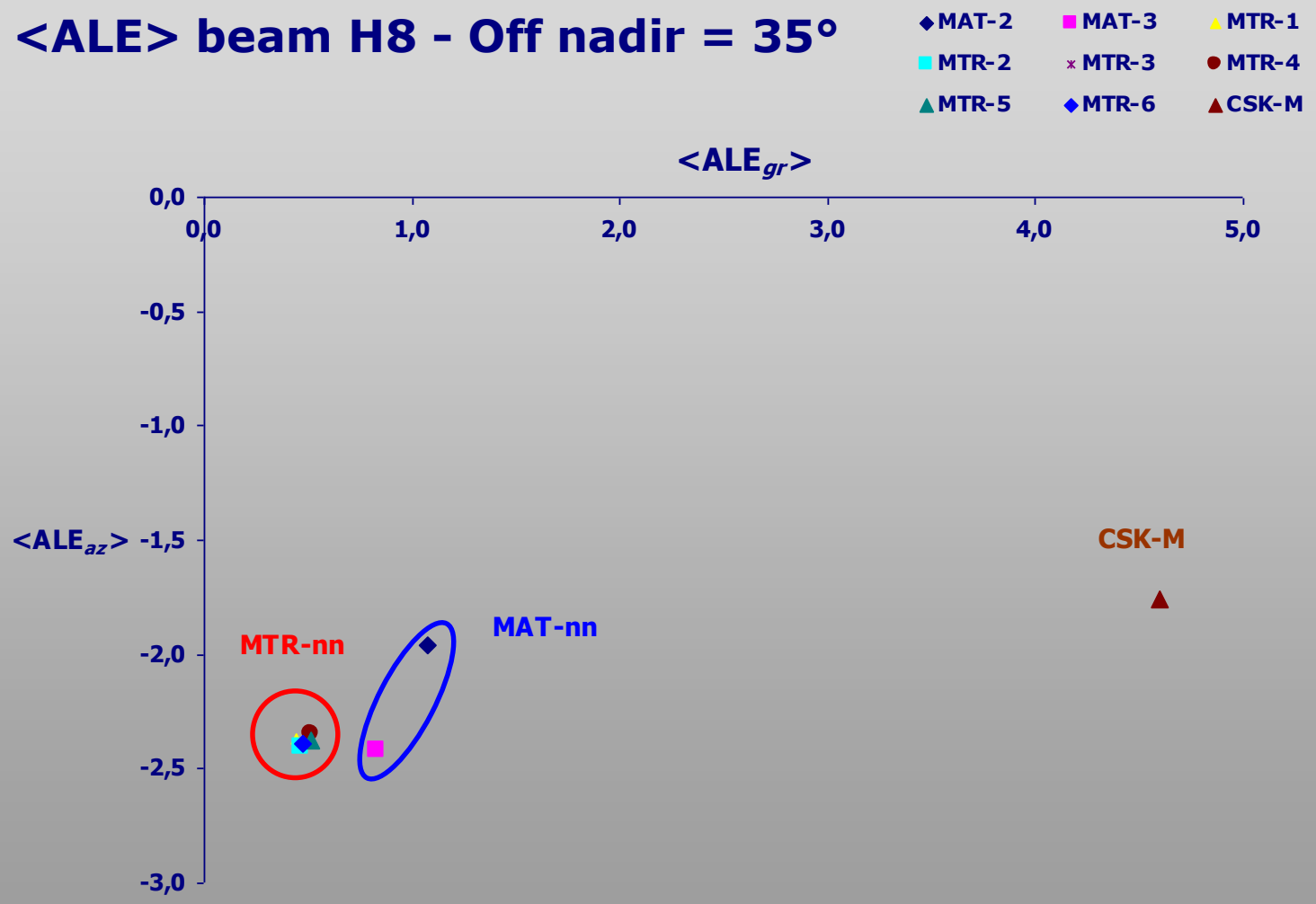
Analysis of the Sites

<ALE> beam H3 - Off nadir = 26,5°



Analysis of the Sites

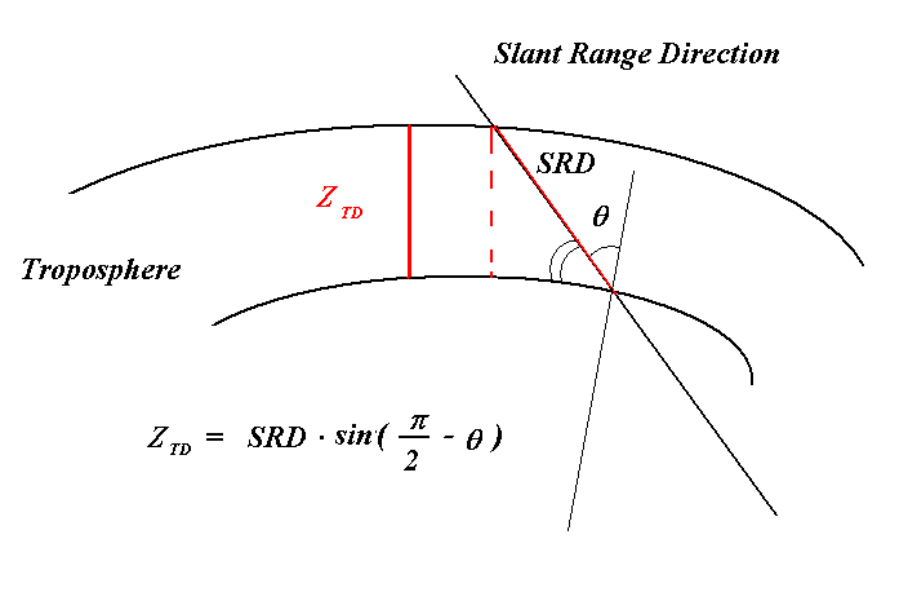
<ALE> beam H8 - Off nadir = 35°



Range Delay Trend Analysis

- **Range delays are projected with the Incidence Angle**

- **The terms that enter in the delay are a constant one and a variable one due main to troposphere**



- **So the ALE in ground:**

$$ALE_{gr} = \left(SWST + \frac{Z_{TD}}{\cos(\theta)} \right) \cdot \frac{c}{2\sin(\theta)}$$

Range Delay Trend Analysis

- The delay due to troposphere has a less variable part that is due to the dry part and a more variable that is the wet.
- The main contribution is given by the dry part, that varies from position and seasons. In principle, we could write:

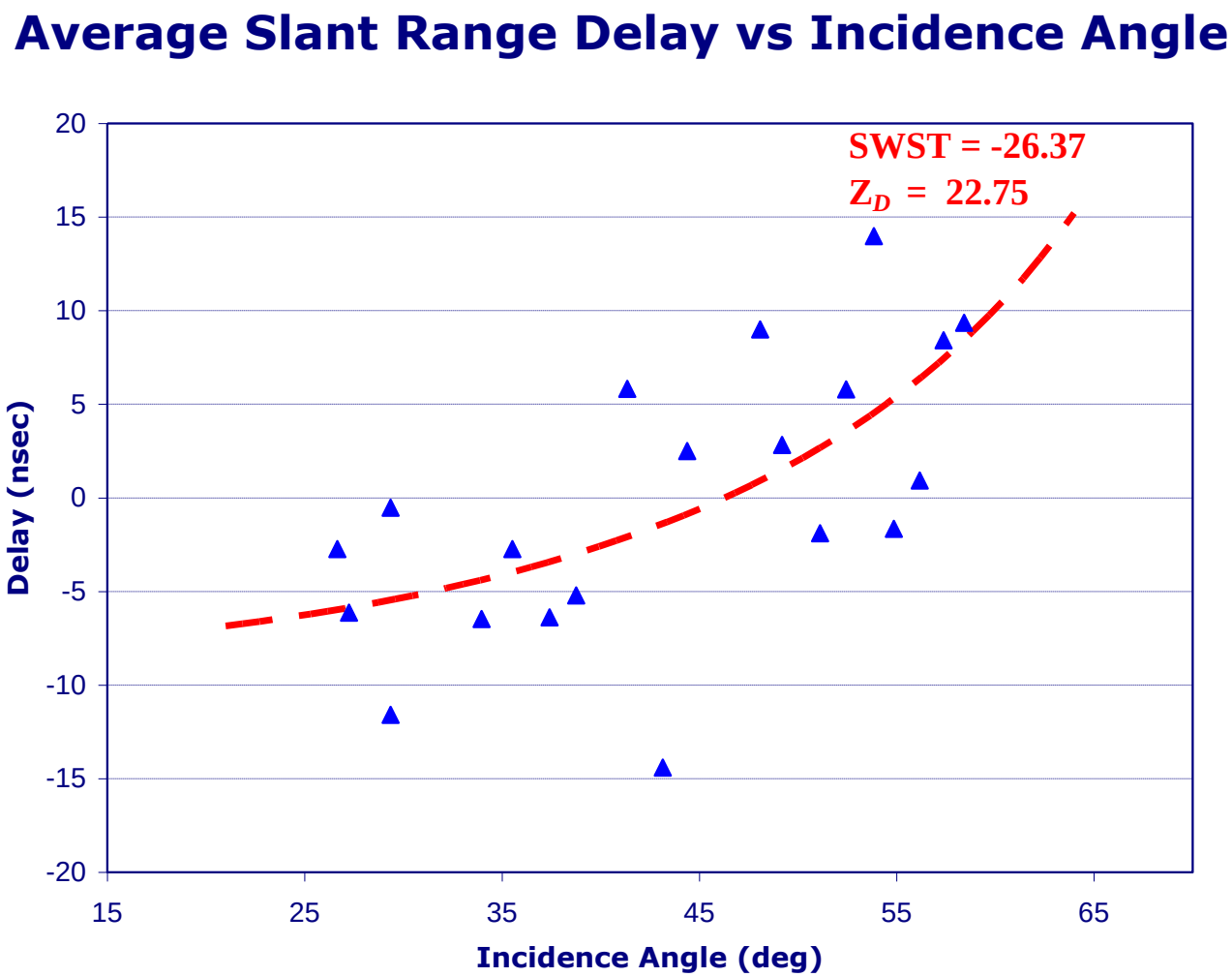
$$Z_{TD} = Z_{TD}^{d}(Lat, Lon, h, doy) + Z_{TD}^{w}(Lat, Lon, h, doy)$$

- From data we could extract an averaged value for the dry part. This means to average all contribution from seasons and weather variations and position (LAt, Lon, h)

- … It's better to use a model

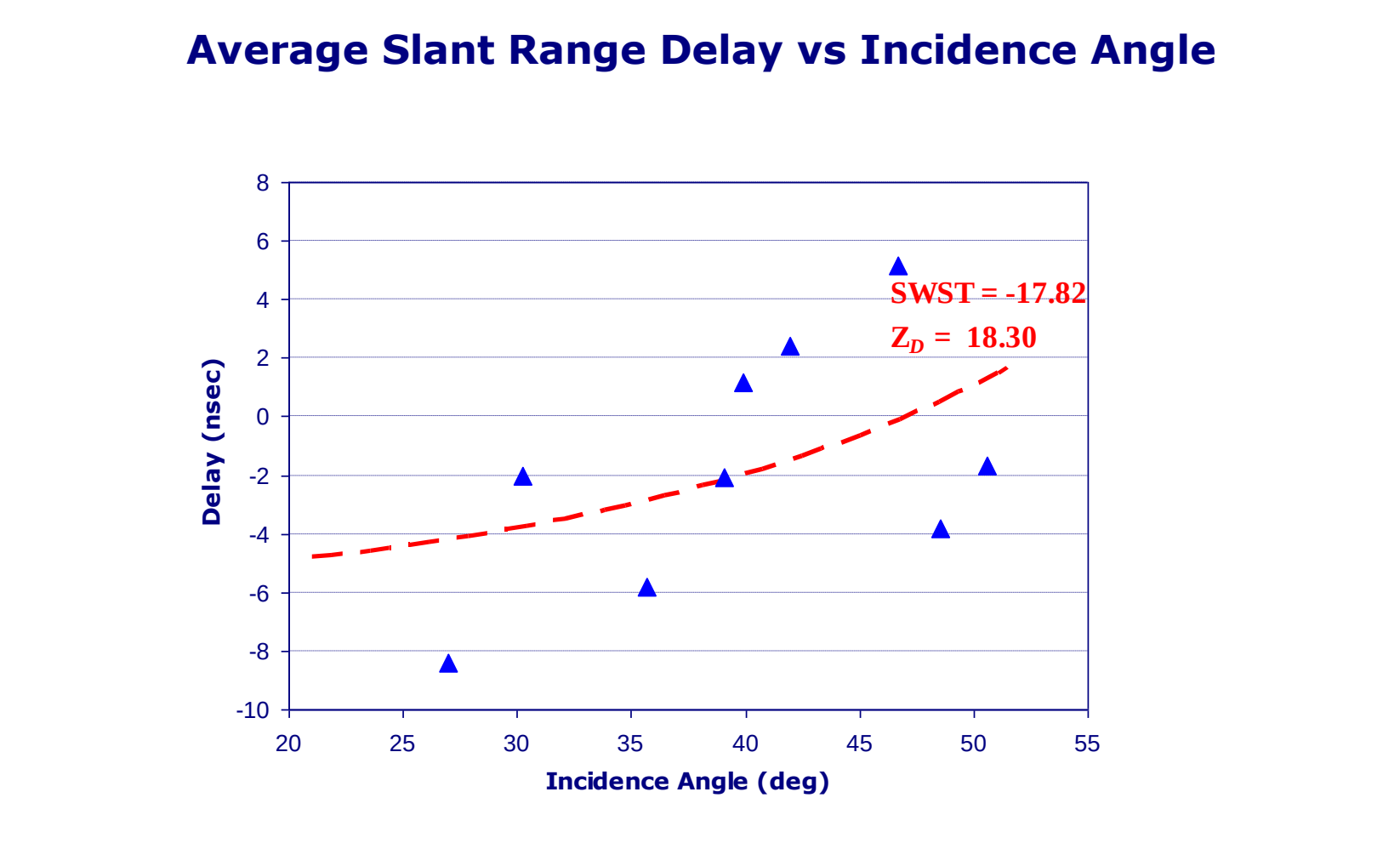
HIMAGE Horizontal Geolocation Accuracy

- **Trend from data gives this:**



SPOTLIGHT Slant Range Delay

- **Range is projected with the Incidence Angle**

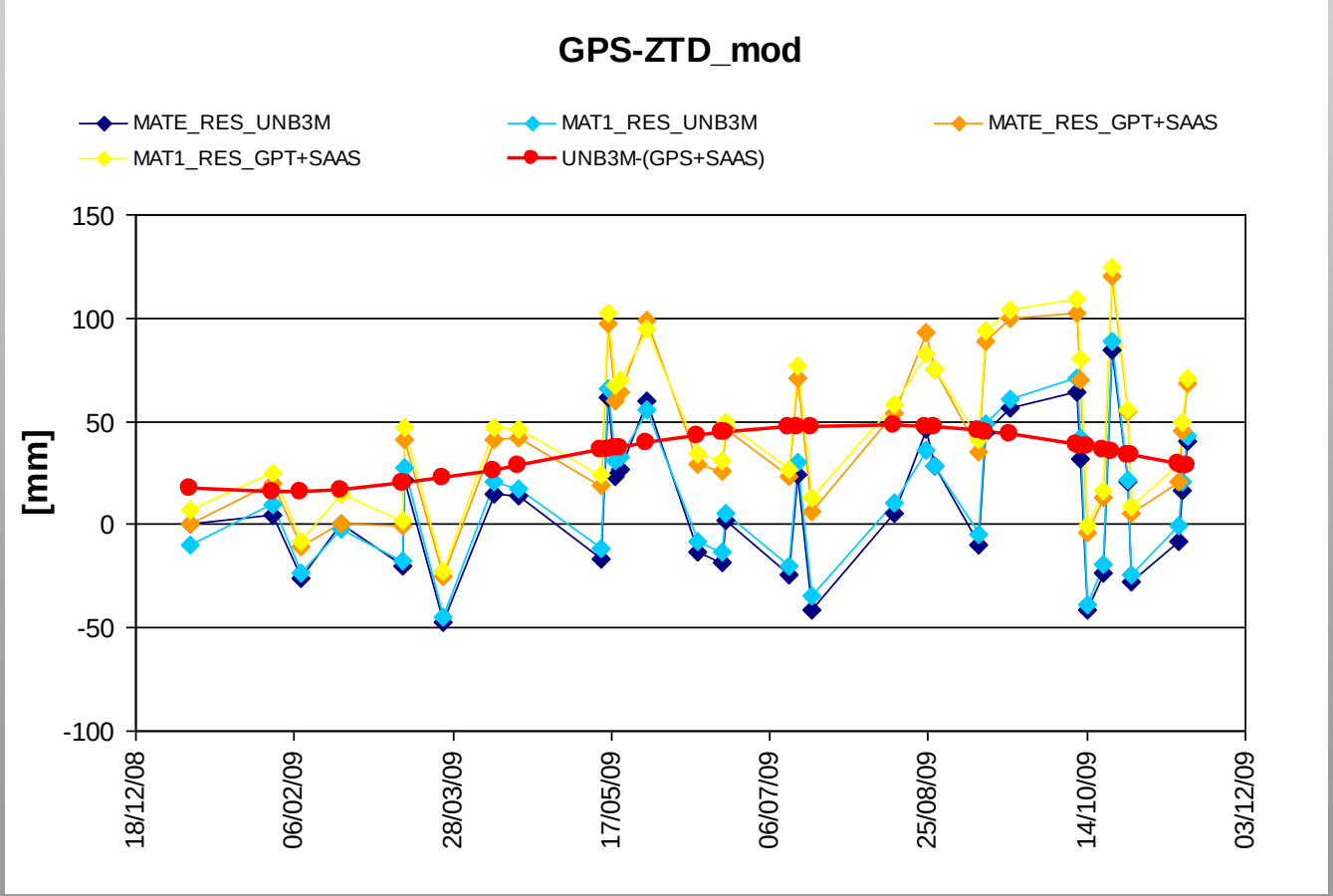


The Models for Troposphere

- For the site were we have fundamental GPS stations (MATE and MAT1 of the IGS) we have a precise 15' Zenith Topospheric Delay estimates
- Data of Z_{TD} from MAT1 have been evaluated at the date of the images
- they have been projected in the slant range direction and compared with the numbers obtained in the images
- Results of the analysis of correlation between the two set of data are shown in the graphic

Theoretic Models

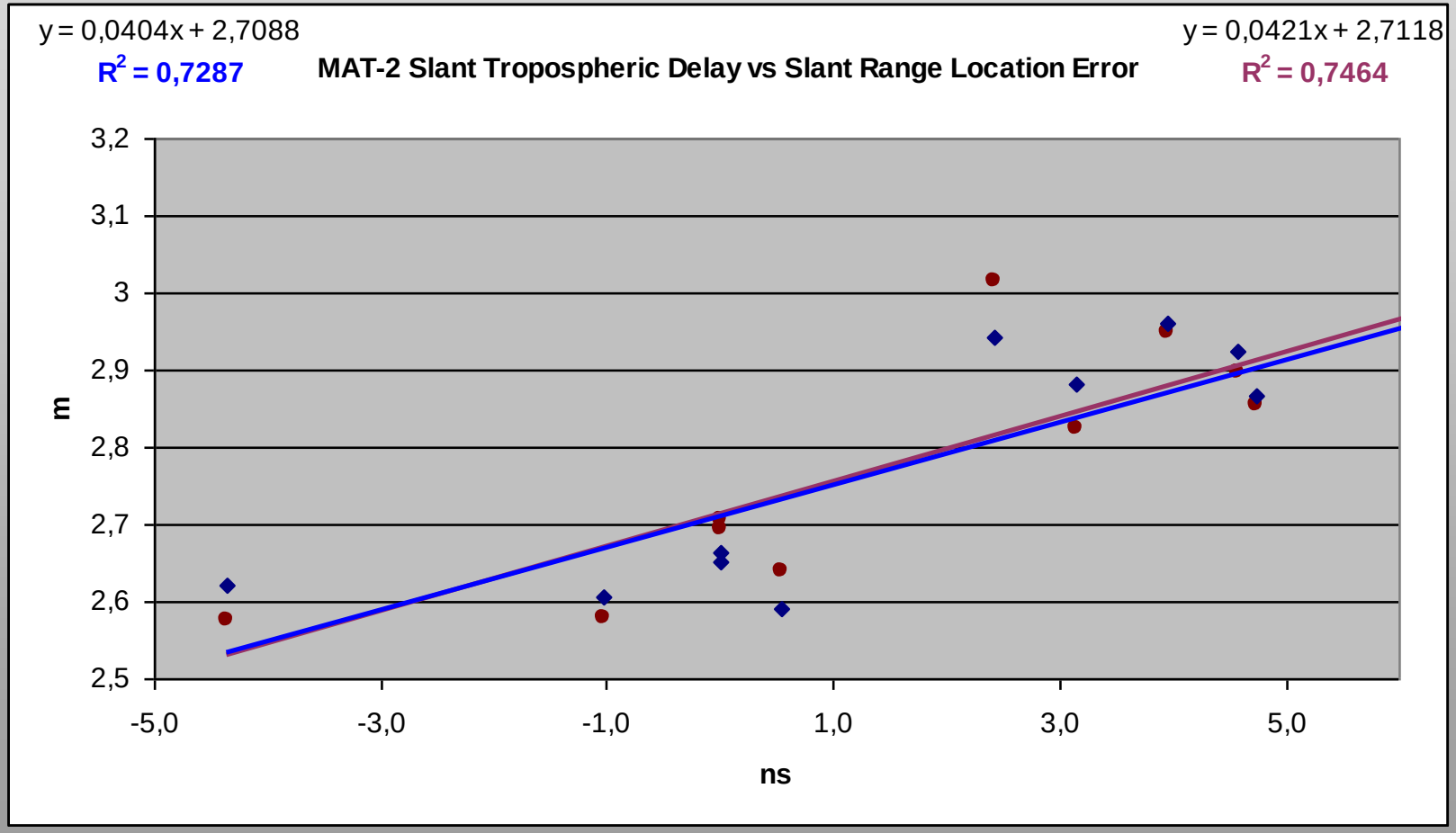
- The data have of ZTD from GPS have been compared with two models: GPT (Global Pressure Temperature) + Saastamoinen and the UNB3M Model
- The results are shown in the graphic:



Models for Troposphere

MOD UNB3M

MAT1
GPS estimates

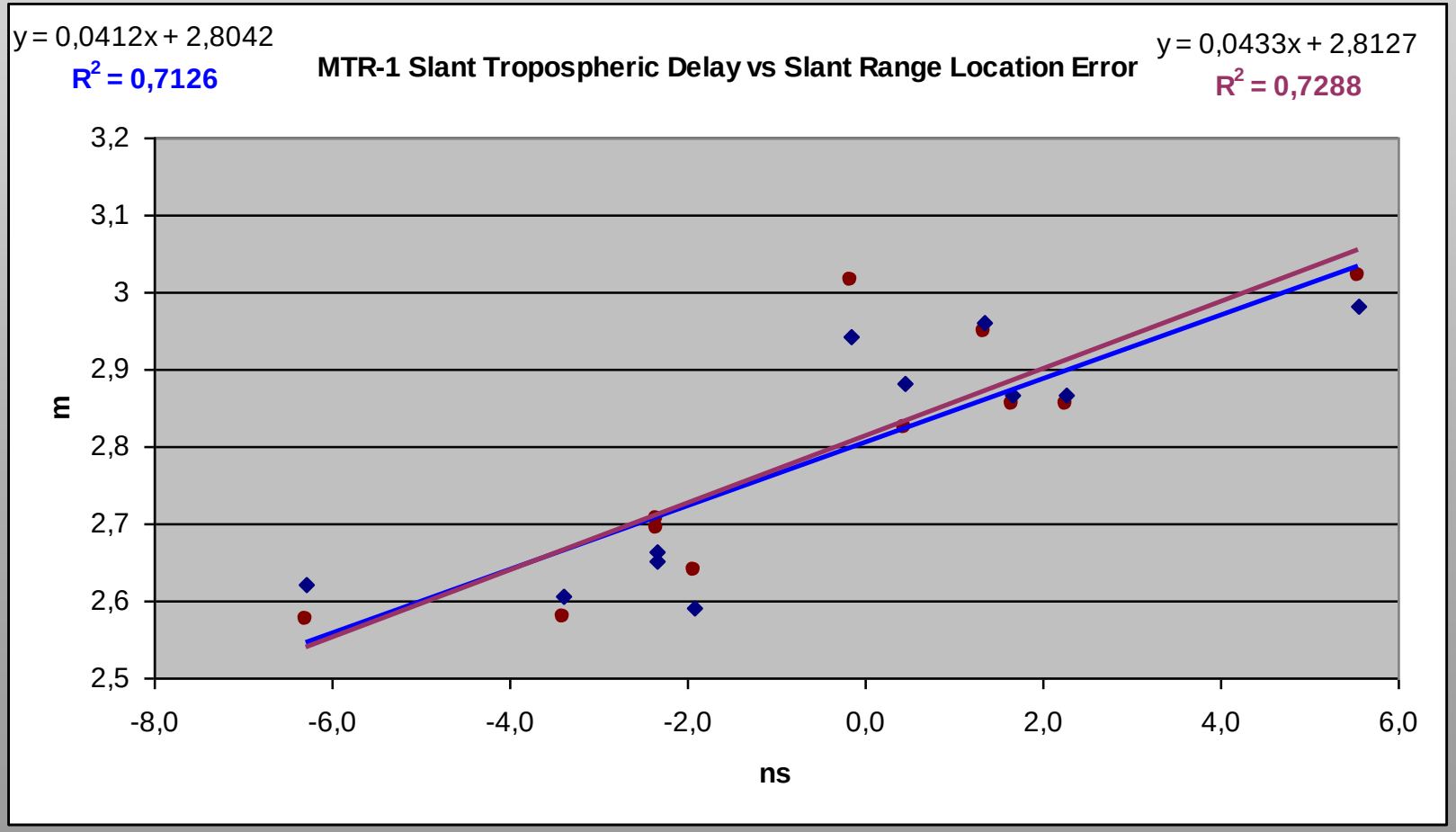


R^2 Azimuth Error/ZTD < 0,03

Models for Troposphere

MOD UNB3M

MAT1
GPS estimates



Future Work

- We demonstrate that also longer arcs of the filtered images used know for standard products, would not improve the geolocation Accuracy of images

- We are working to produce the POD and to use them for standard products

- A troposphere model would be tested and inserted into the system and so the three satellite with all the acquisition modes will be characterised through dedicated campaign to evaluate residual parameters

- It would be better to have numbers also from other sites better distributed also out of Italy

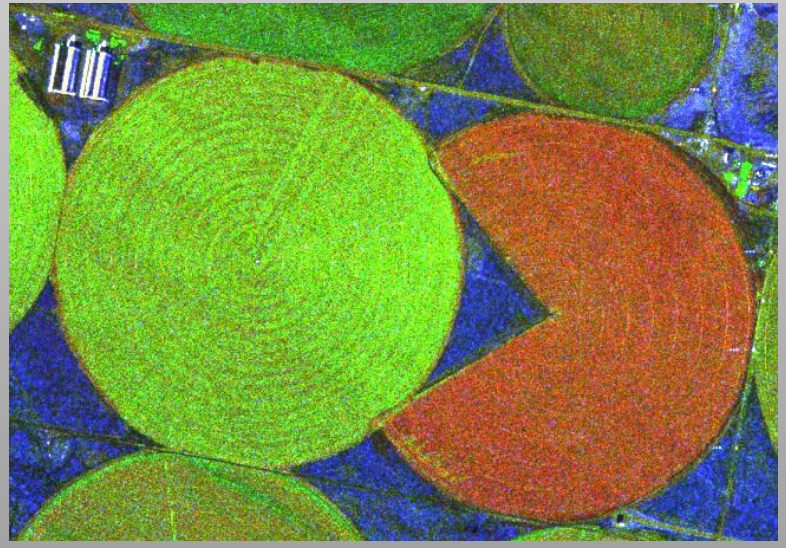
Applications with COSMO-SkyMed

courtesy of Luca Pietranera, e-GEOS

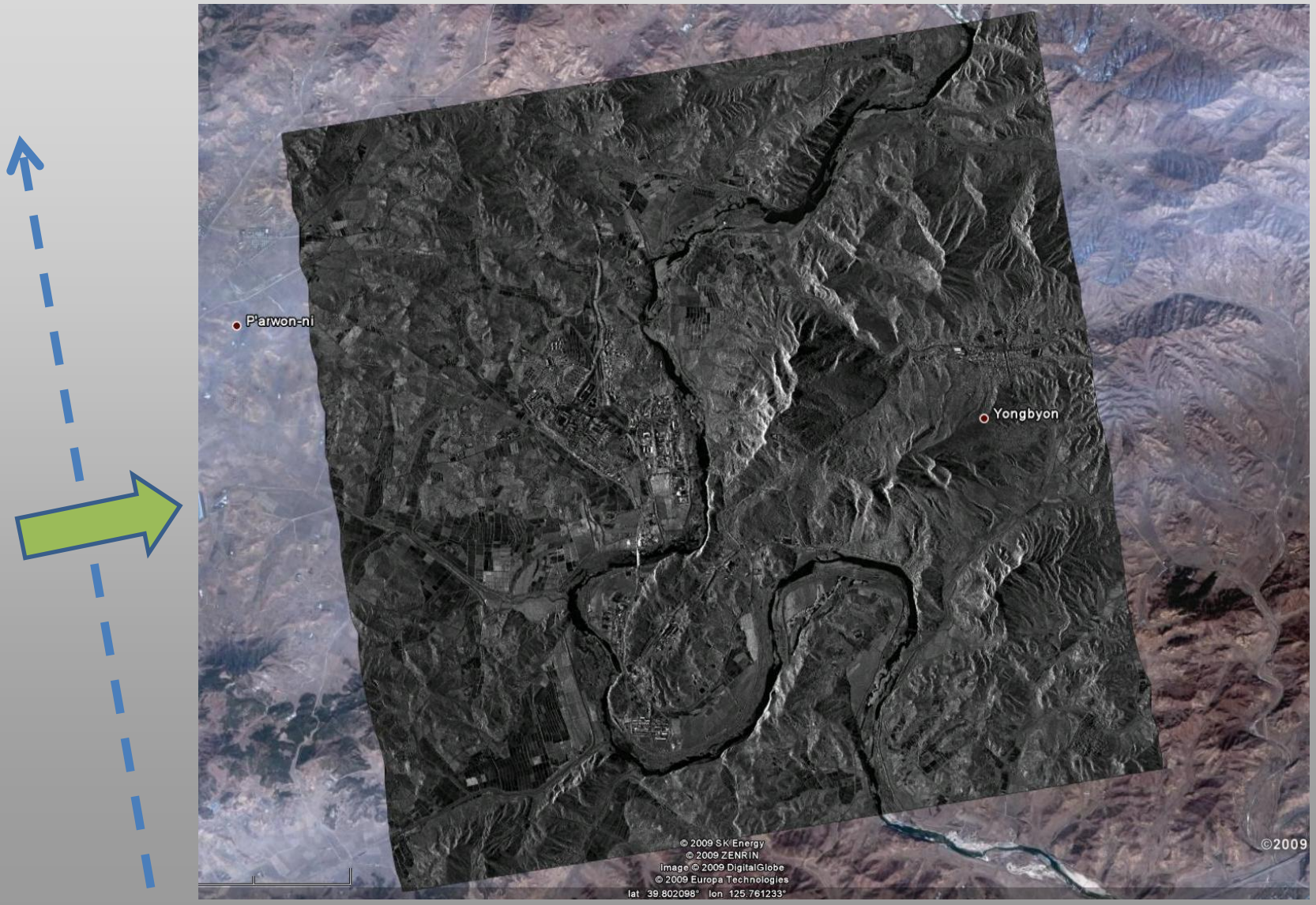
Summary

- **Multitemporal monitoring**
- **Coherence**
- **About streets, roads, tracks**
- **Interferometry**

Multitemporal monitoring



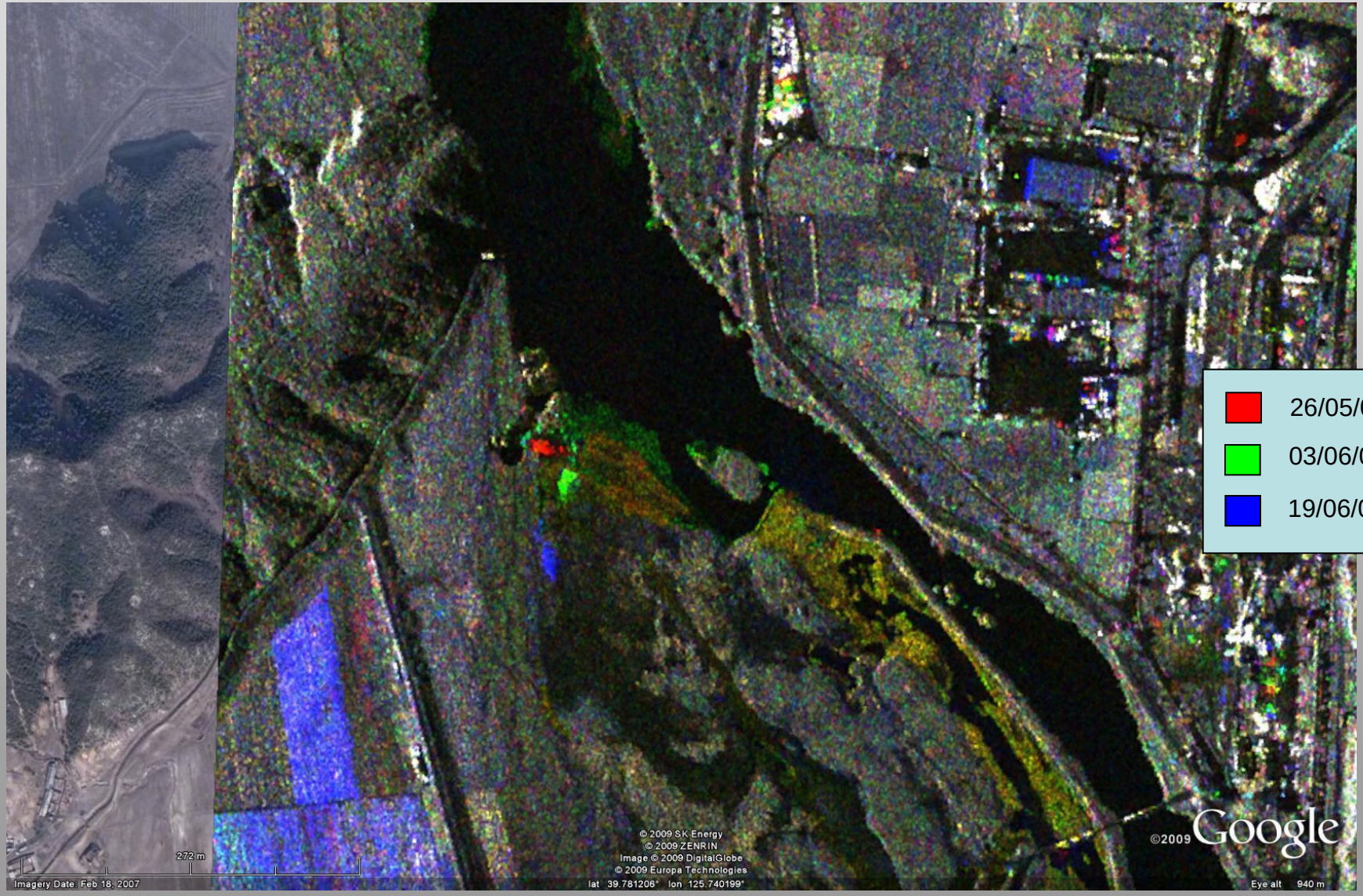
North Korean site monitoring



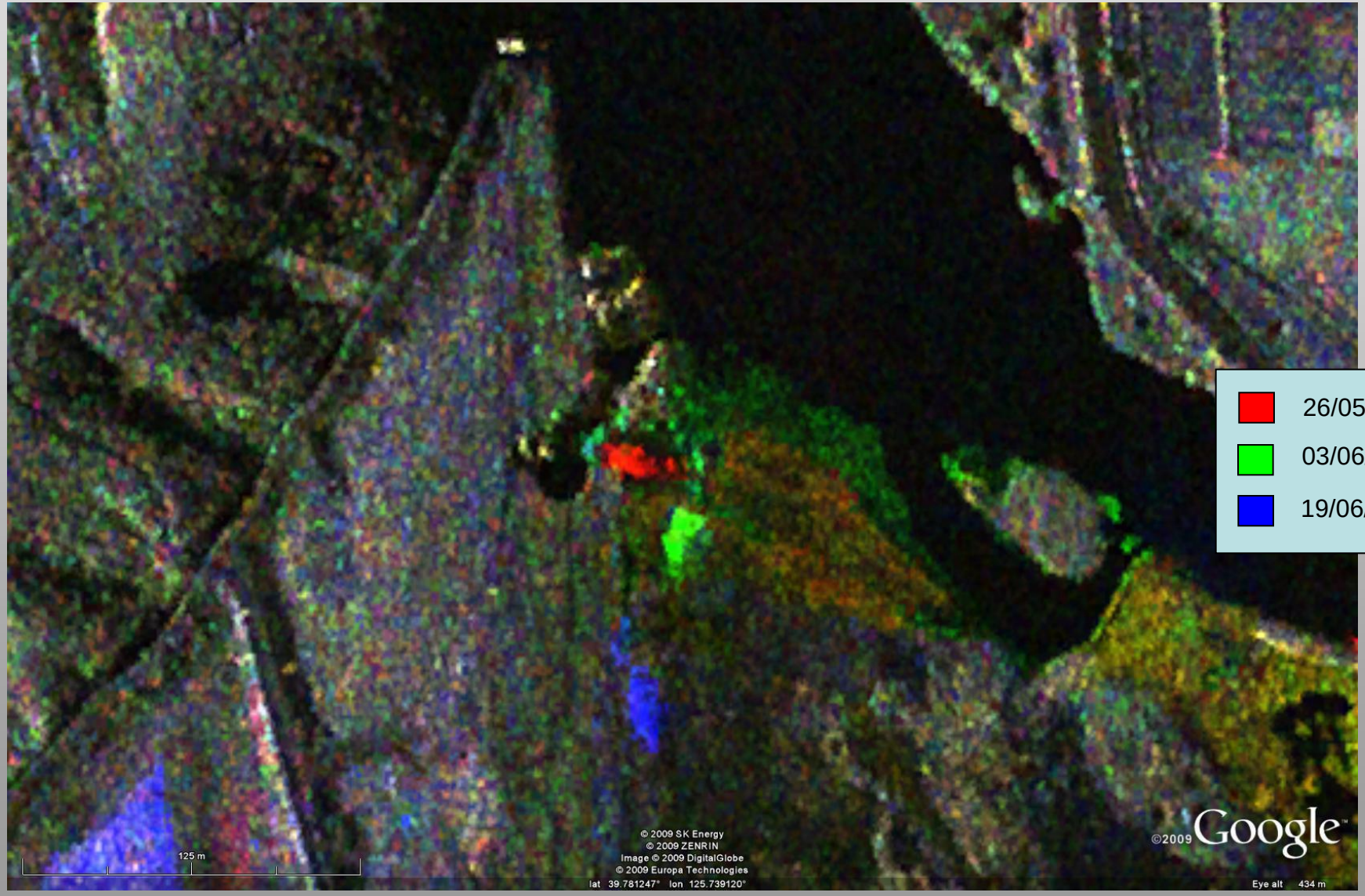
Digging machine in the river
WorldView optical image

SAR multitemporal shows ongoing activity

SAR multitemporal shows ongoing activity: detail



SAR multitemporal shows ongoing activity: detail



Flat area near the power plant

Spotlight SAR single image

Multitemporal SAR monitoring

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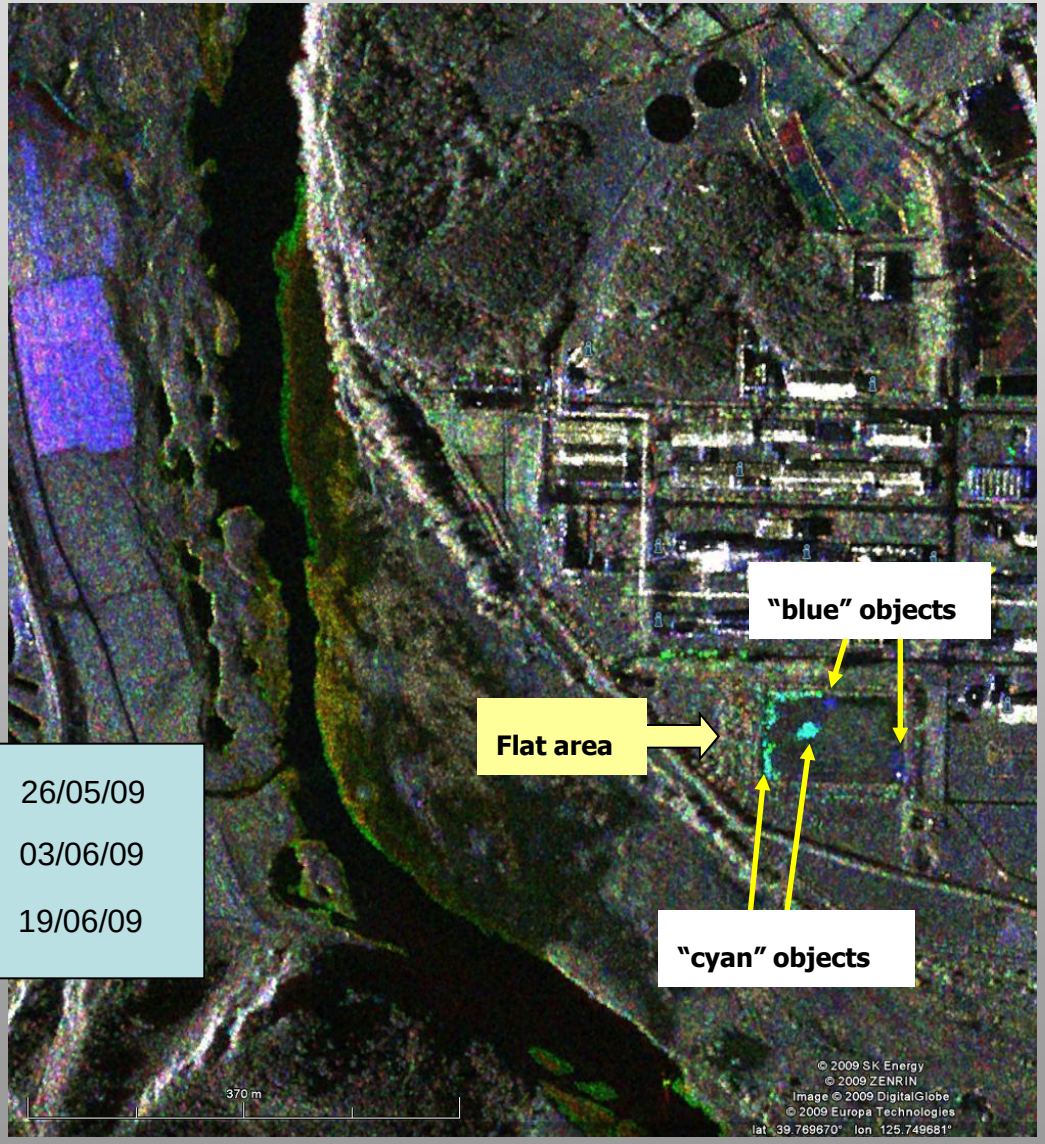


26/05/09

03/06/09

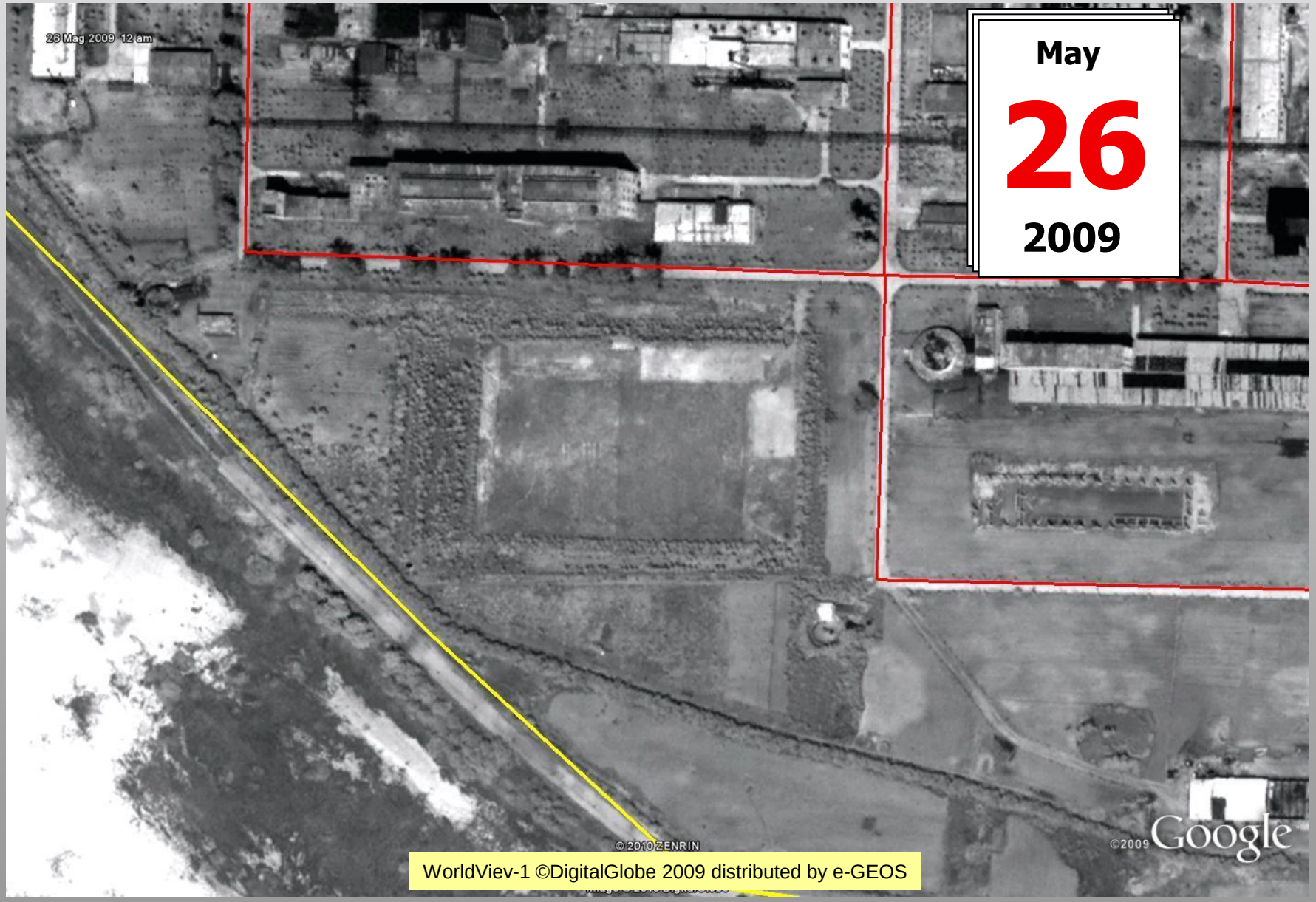
19/06/09

= +

Objects added between 26/05 and18/06

Objects added between 3-18/06/09

CD based on optical image

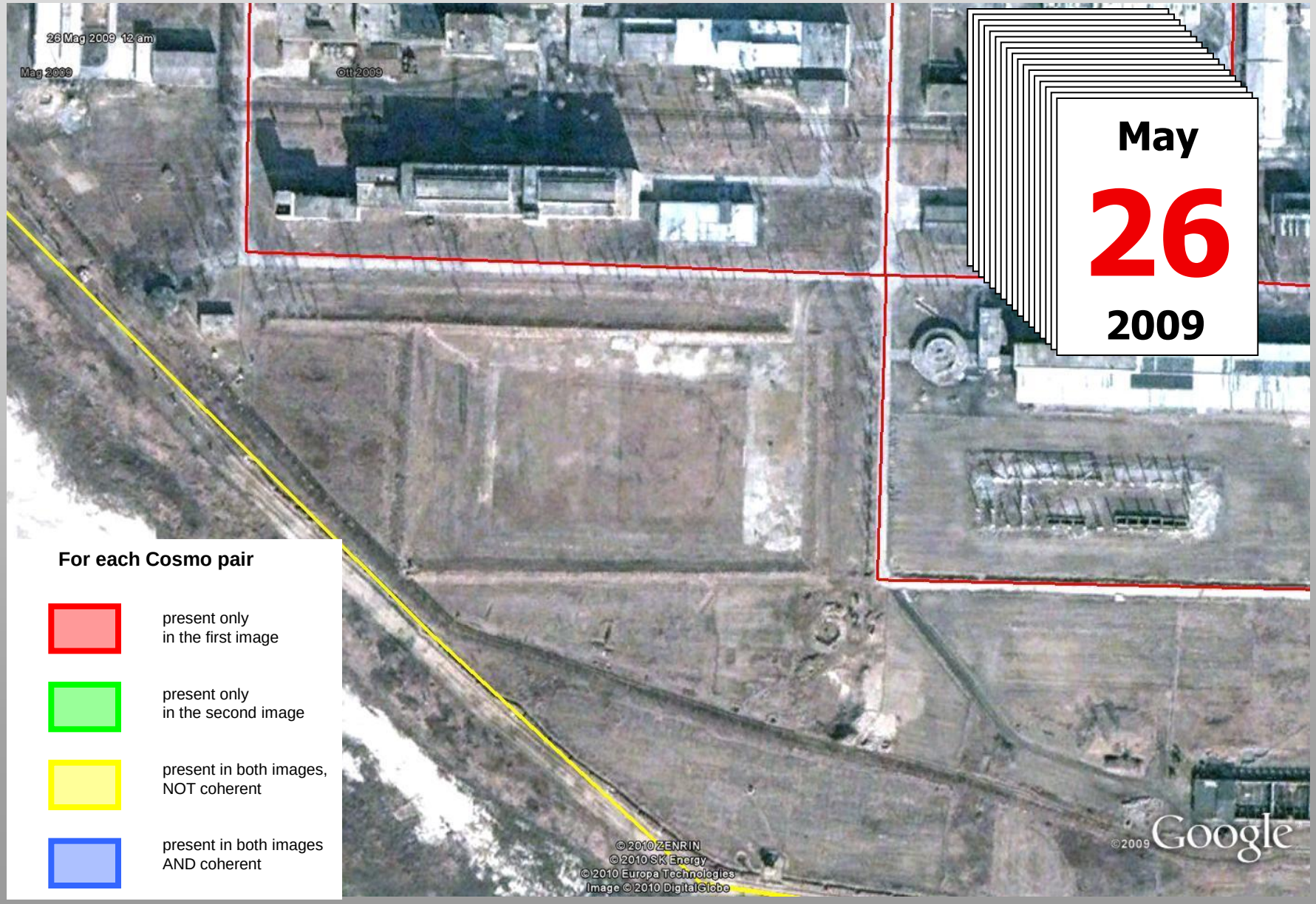


WorldViev-1 ©DigitalGlobe 2009 distributed by e-GEOS

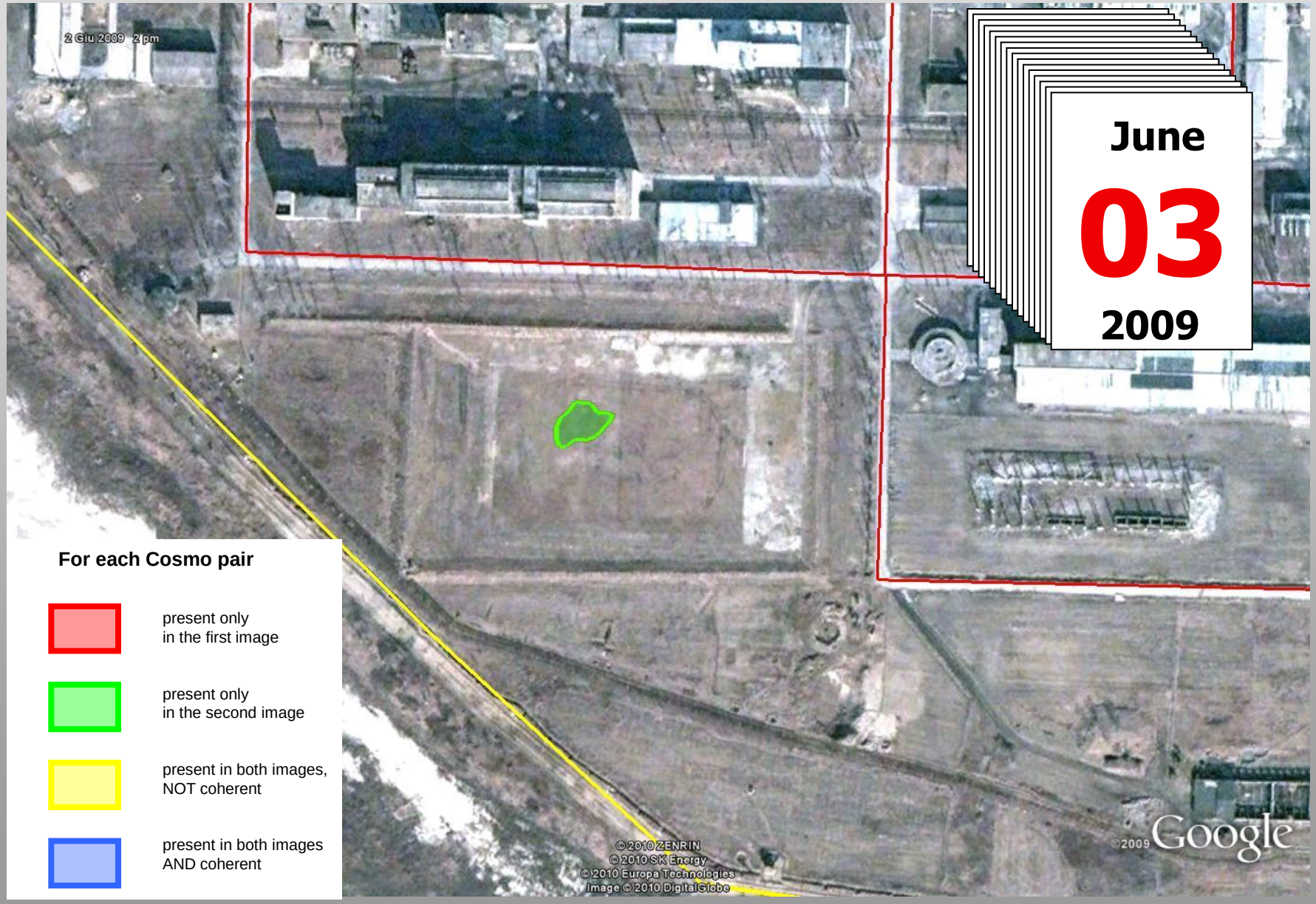
CD based on optical image

WorldViev-1 ©DigitalGlobe 2009 distributed by e-GEOS

Area evolution based on Cosmo

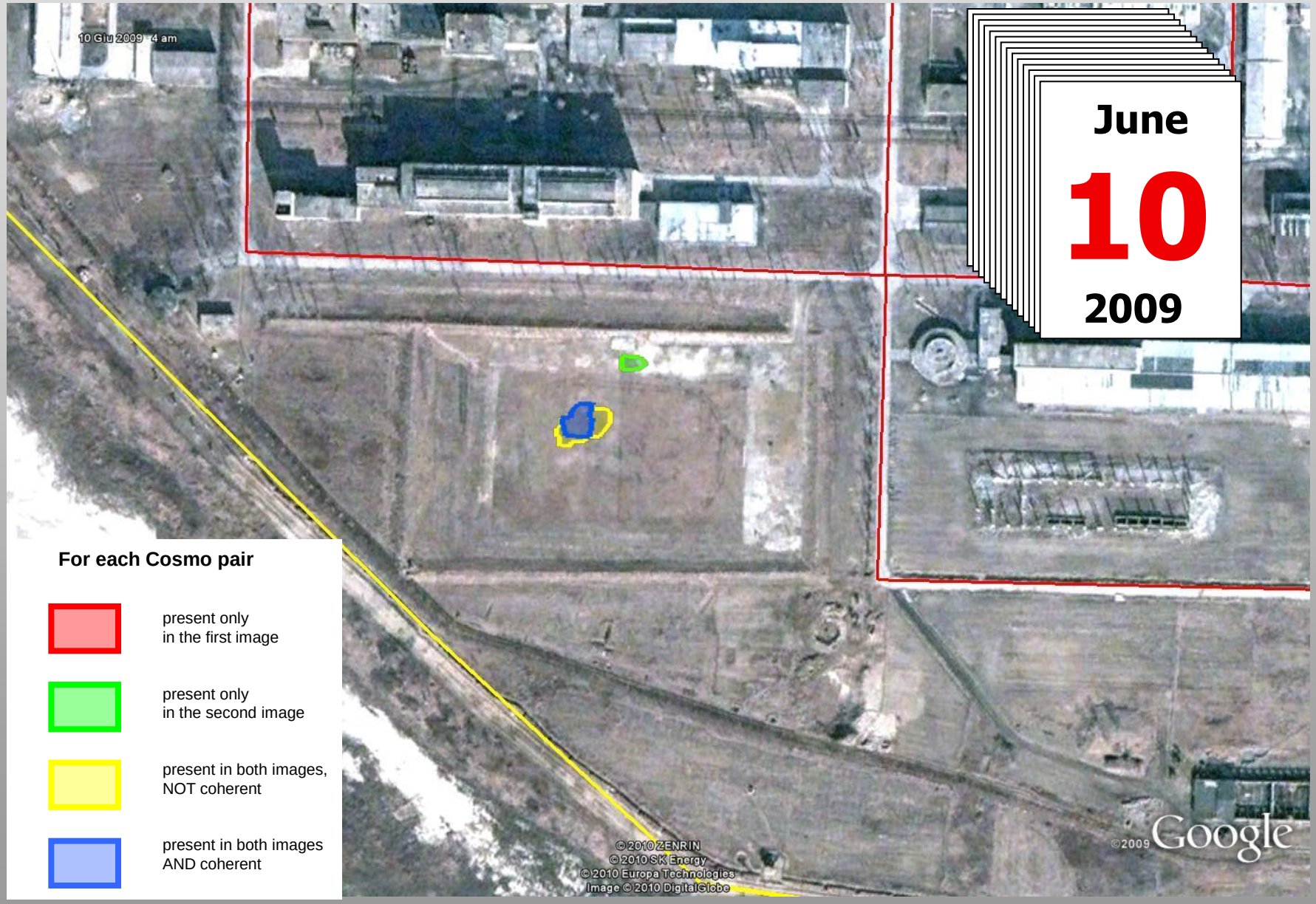


Area evolution based on Cosmo

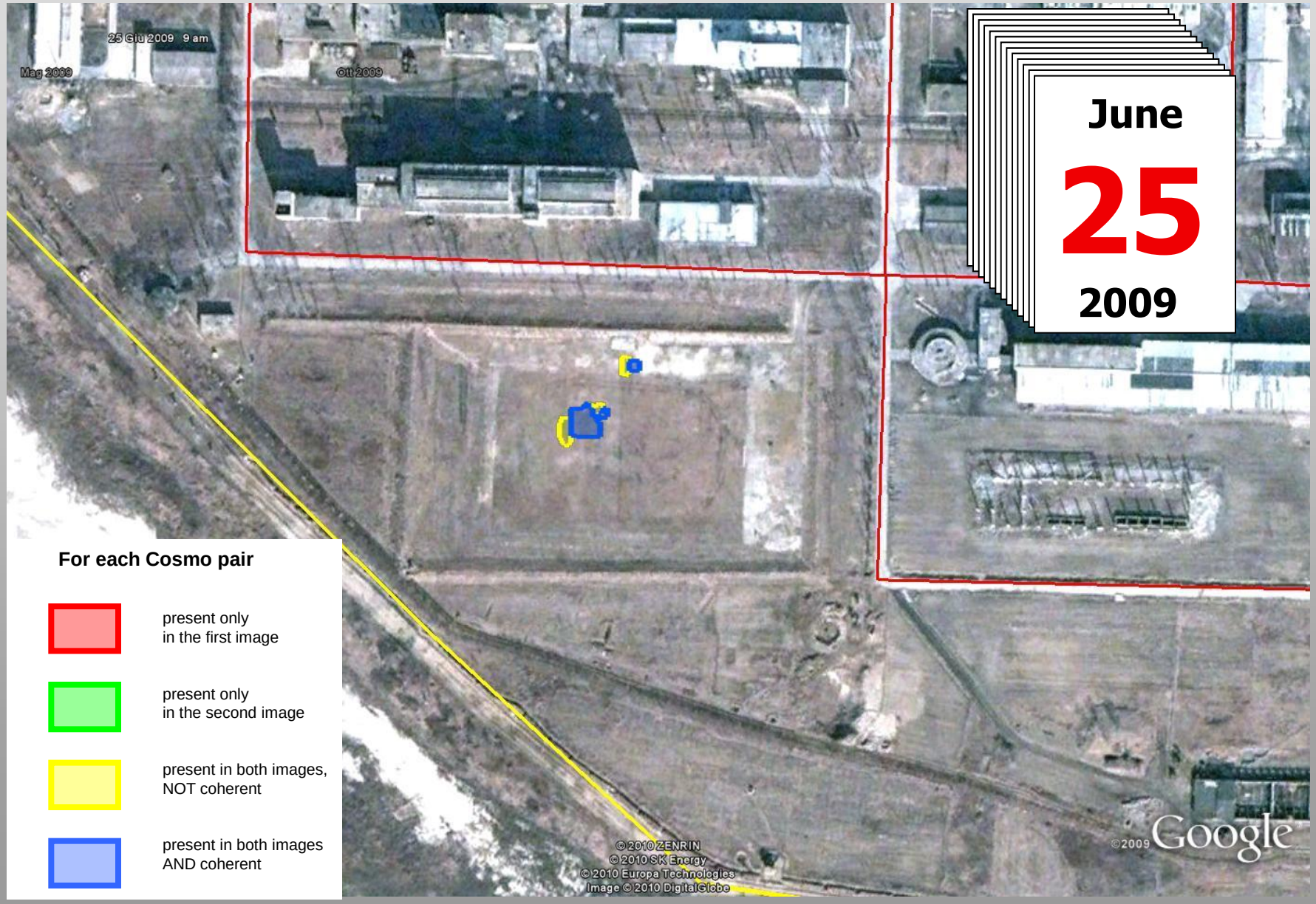


Area evolution based on Cosmo

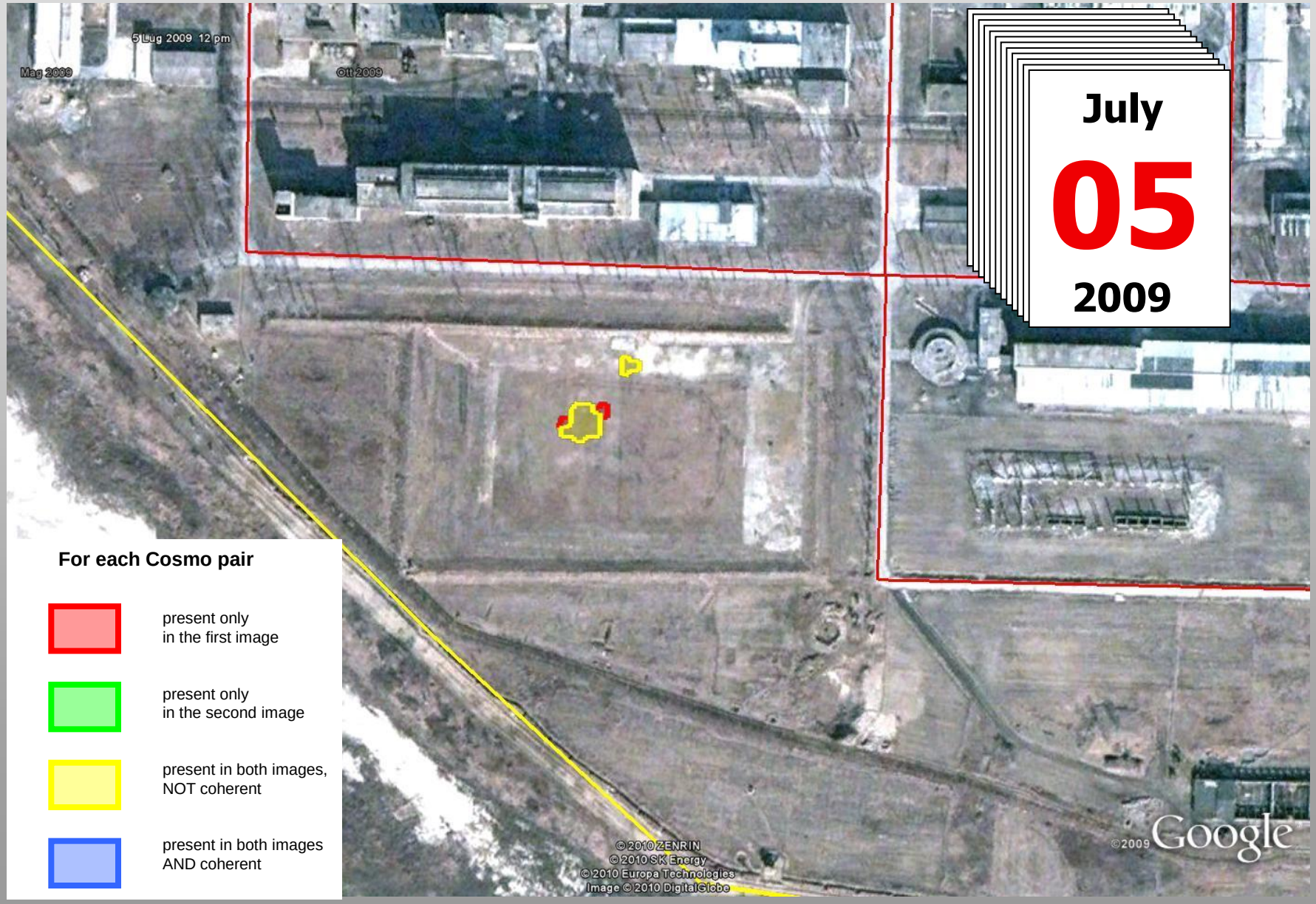
Area evolution based on Cosmo



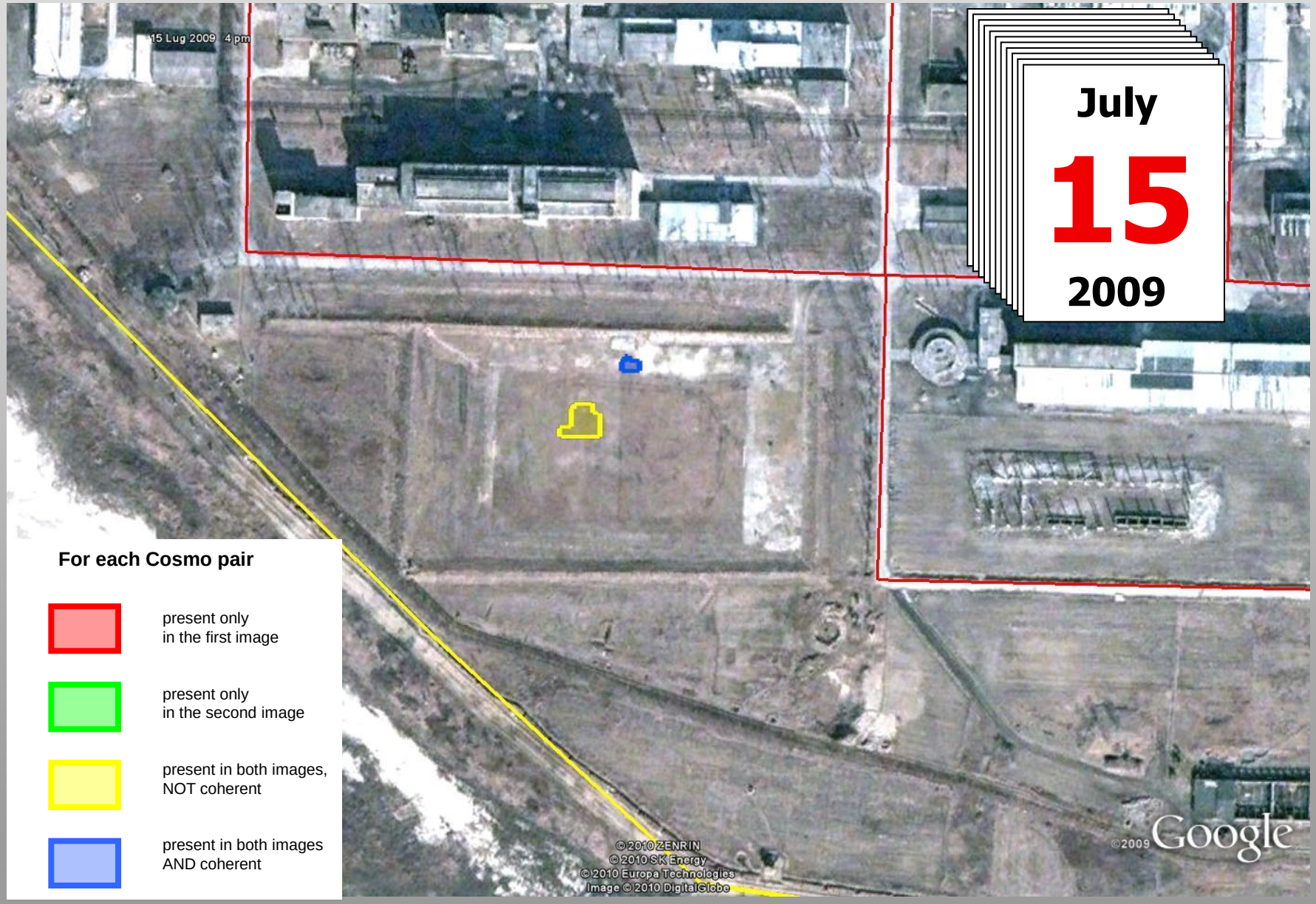
Area evolution based on Cosmo



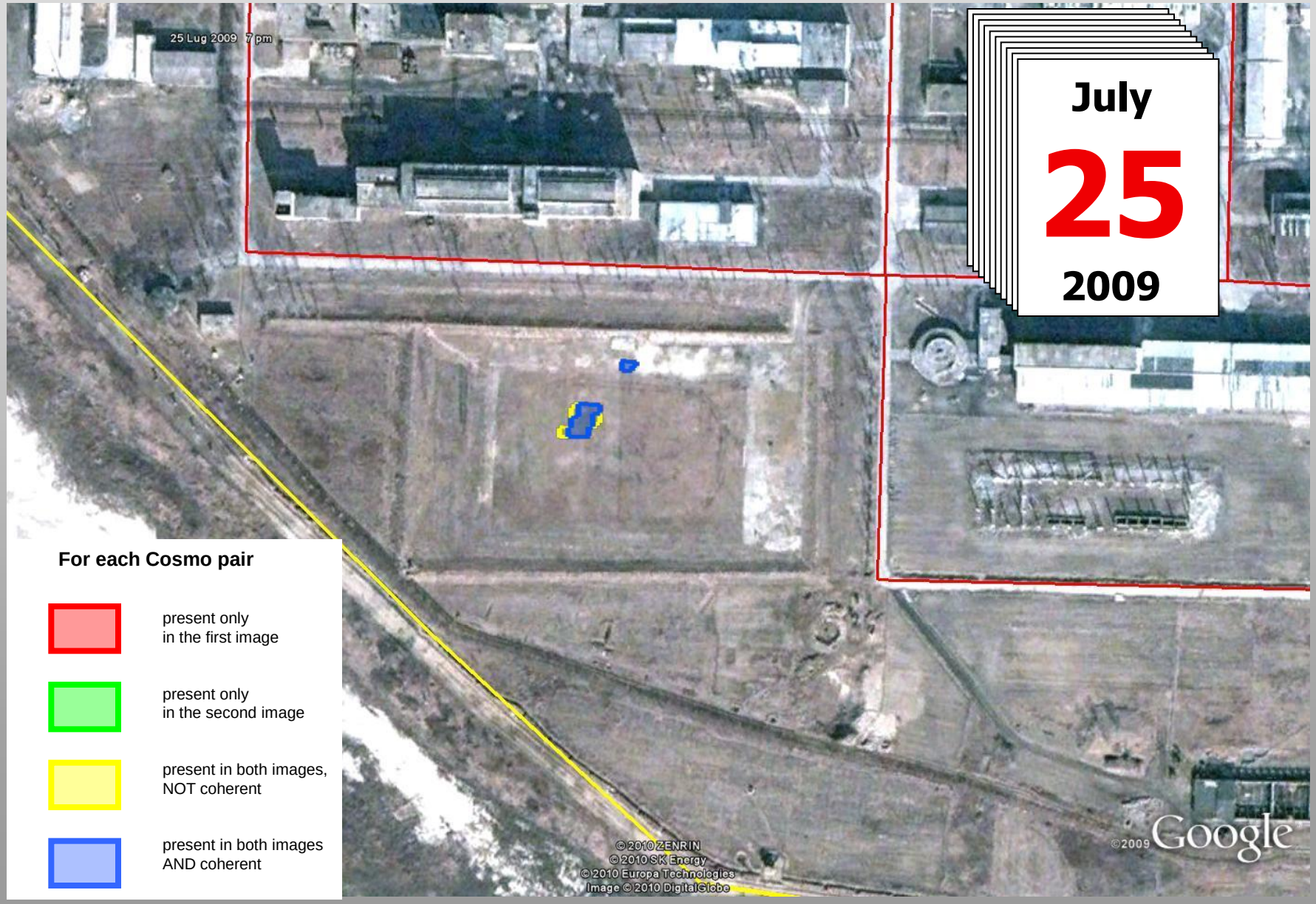
Area evolution based on Cosmo



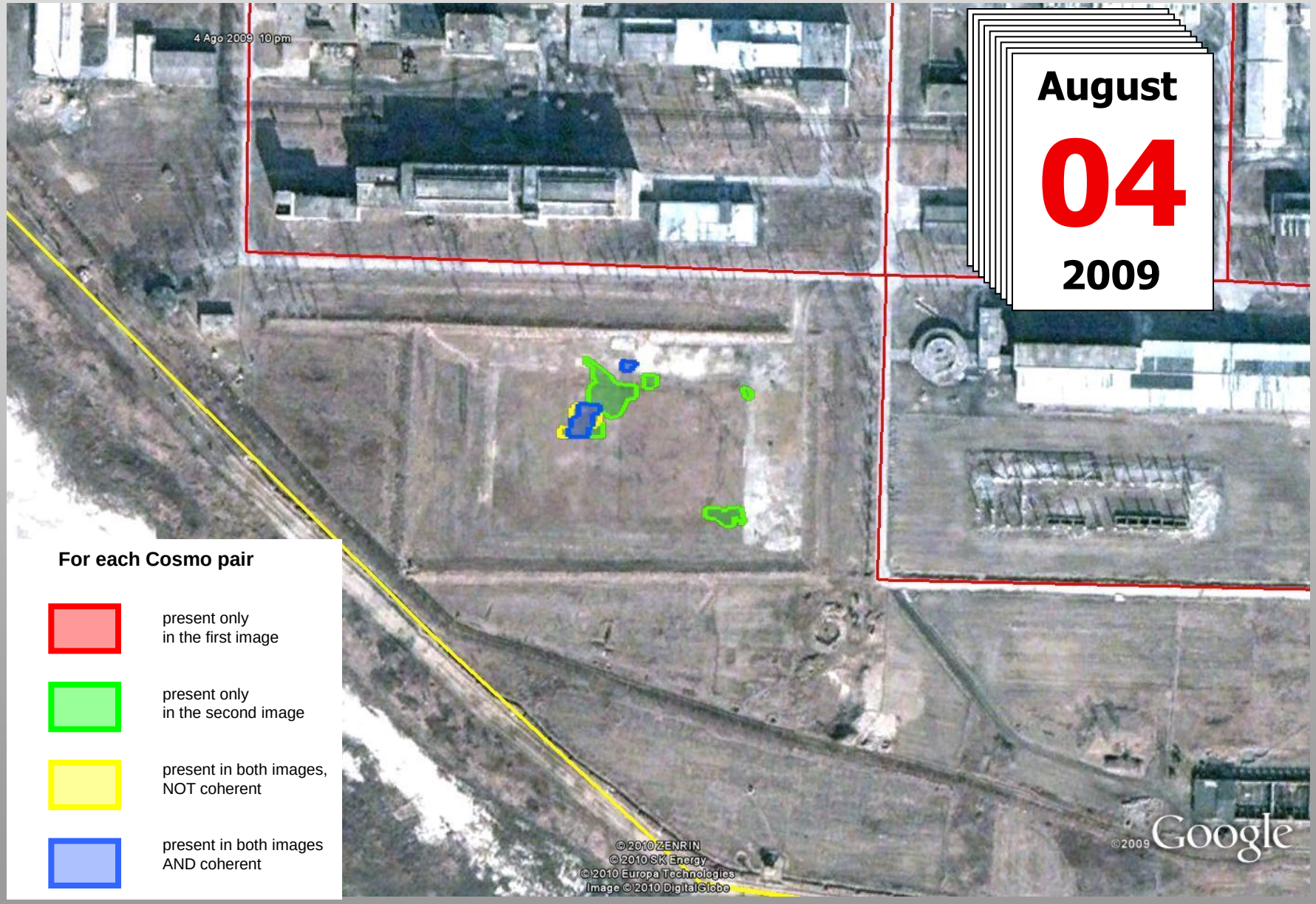
Area evolution based on Cosmo



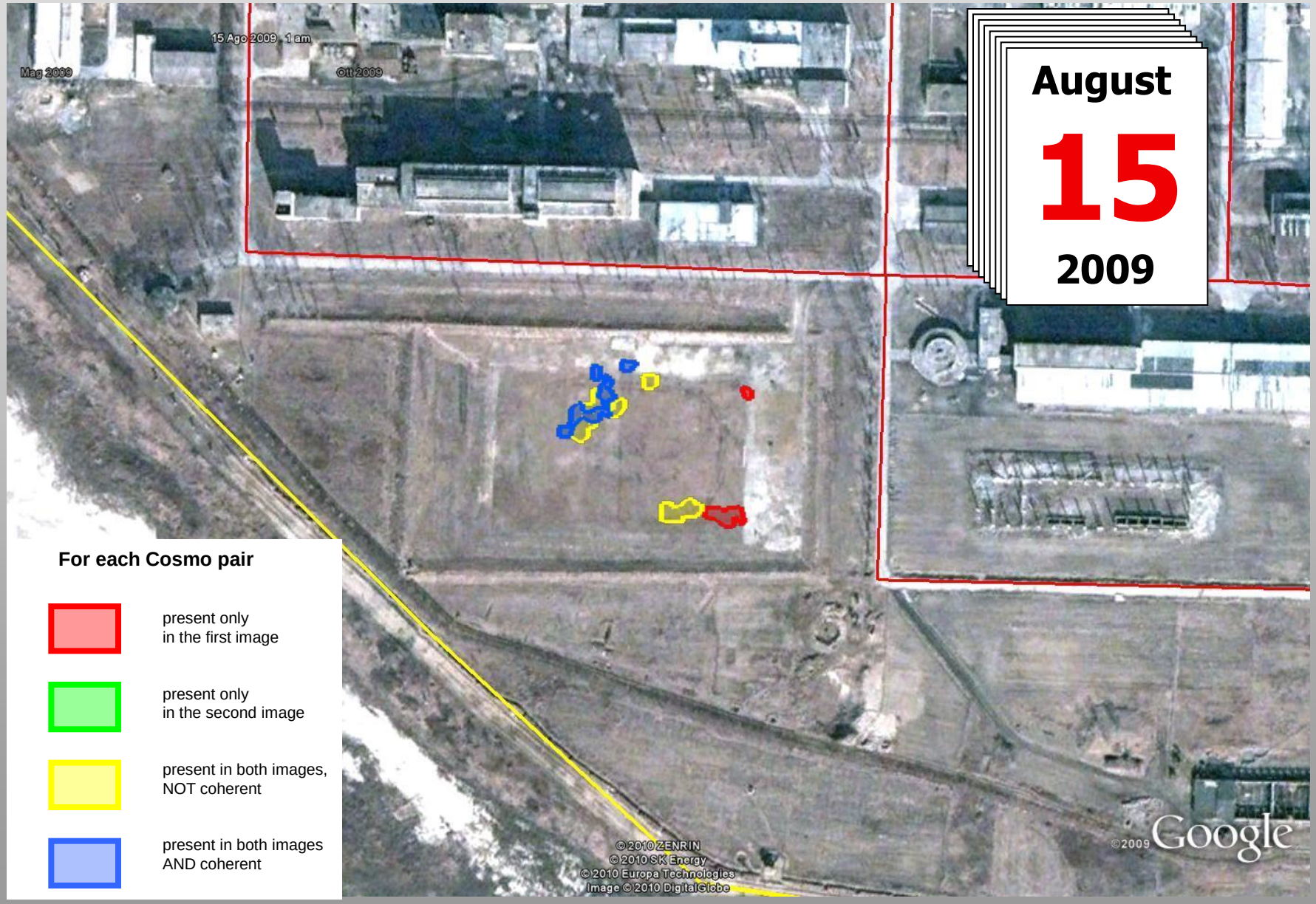
Area evolution based on Cosmo



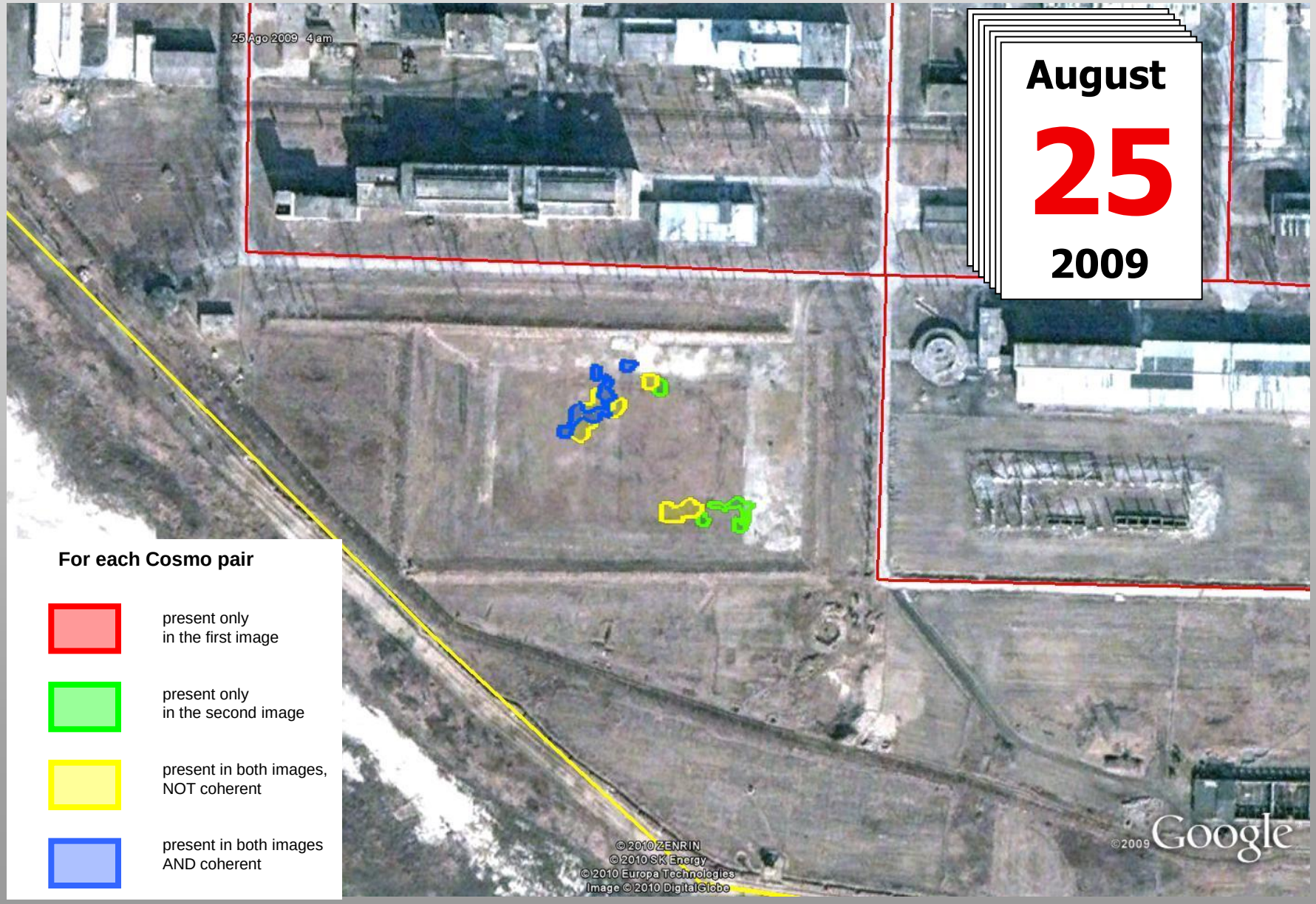
Area evolution based on Cosmo



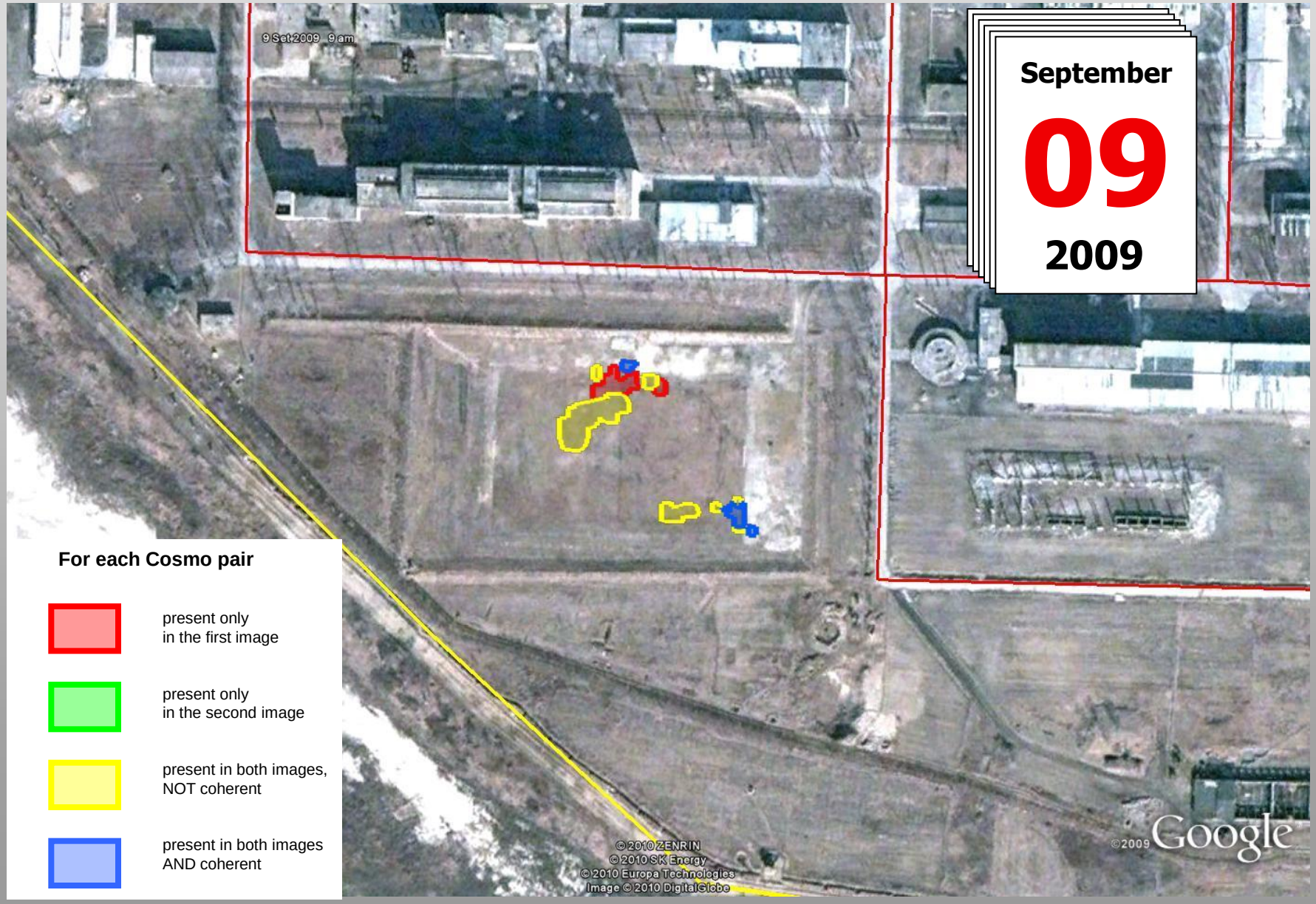
Area evolution based on Cosmo



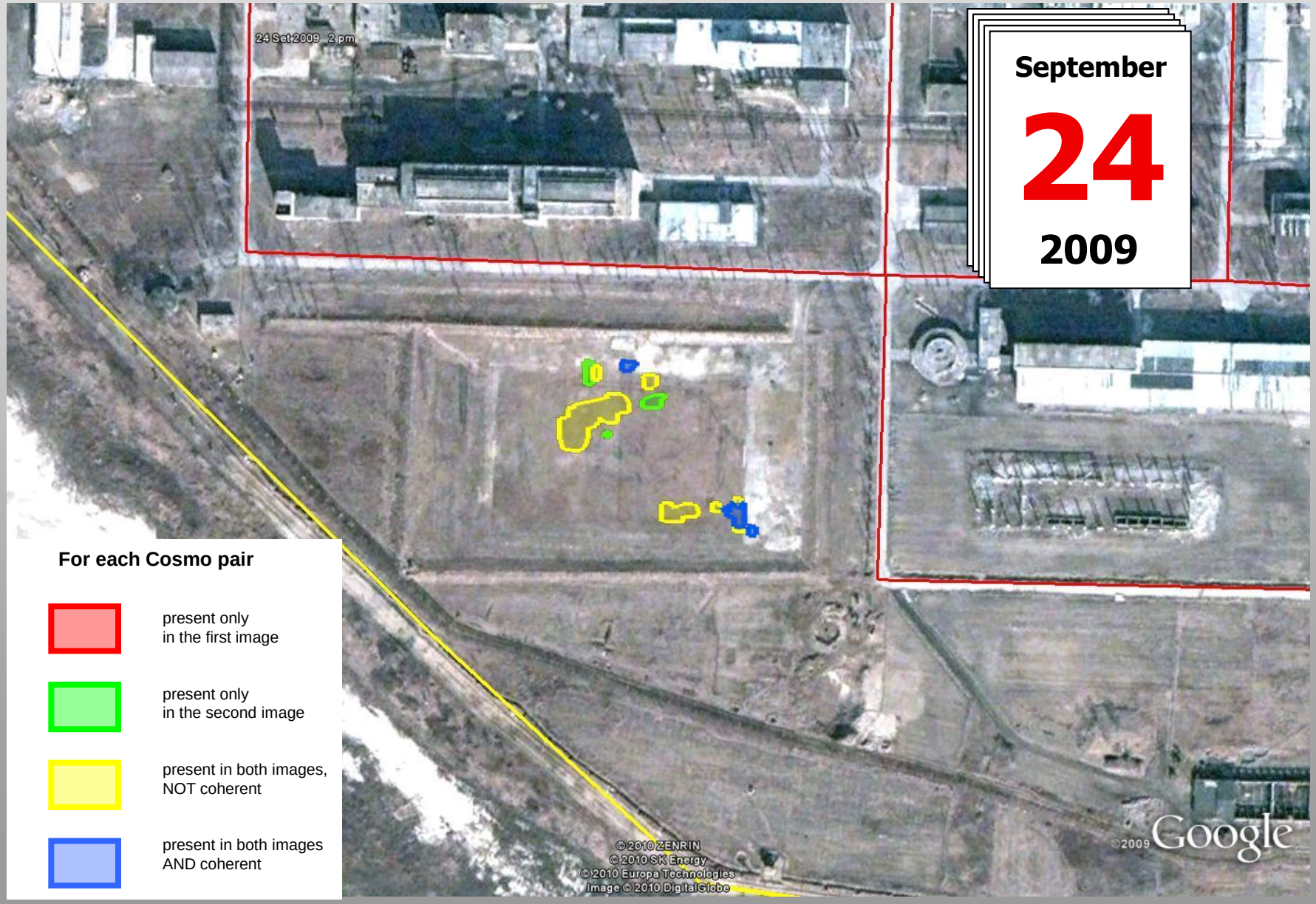
Area evolution based on Cosmo



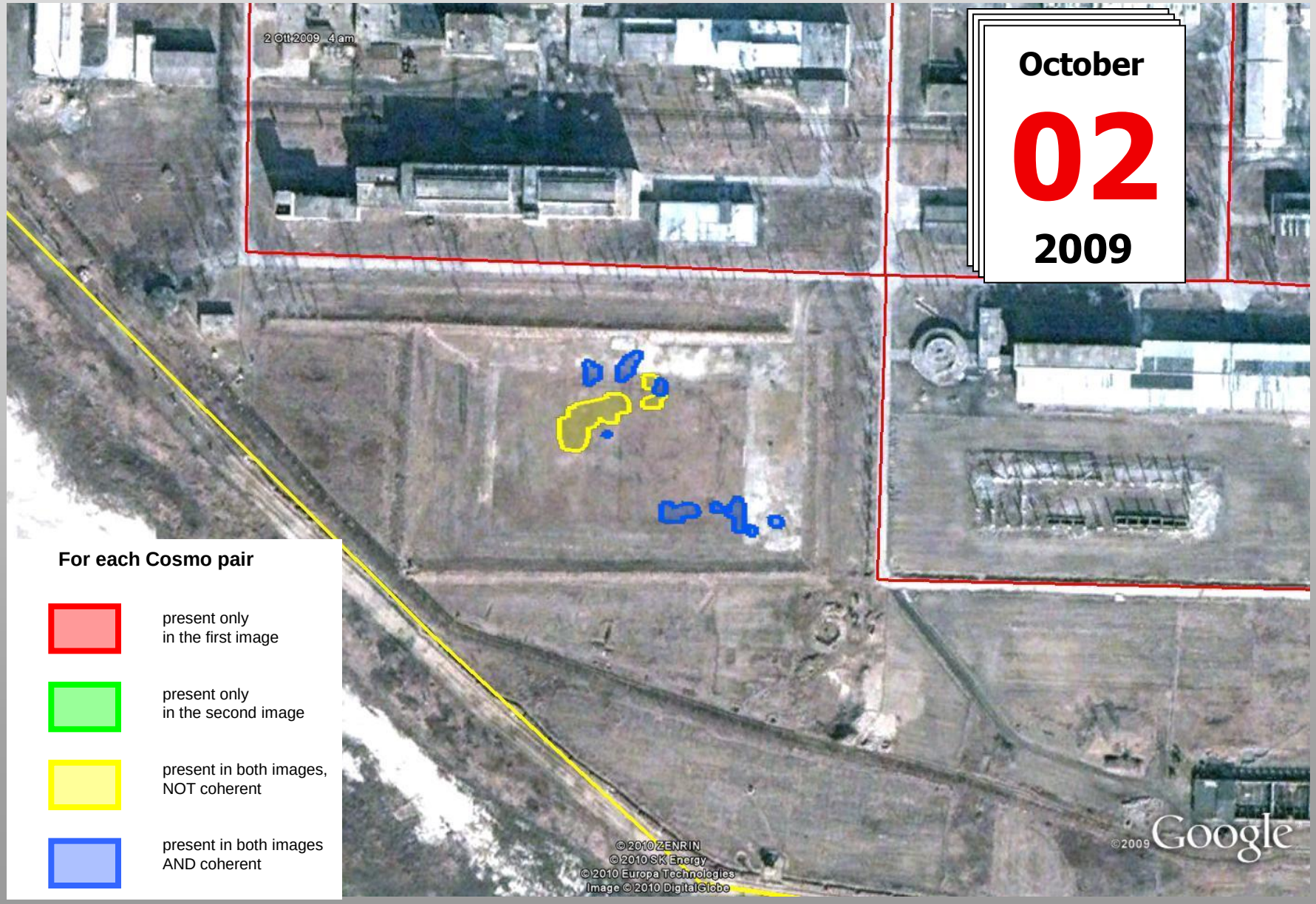
Area evolution based on Cosmo



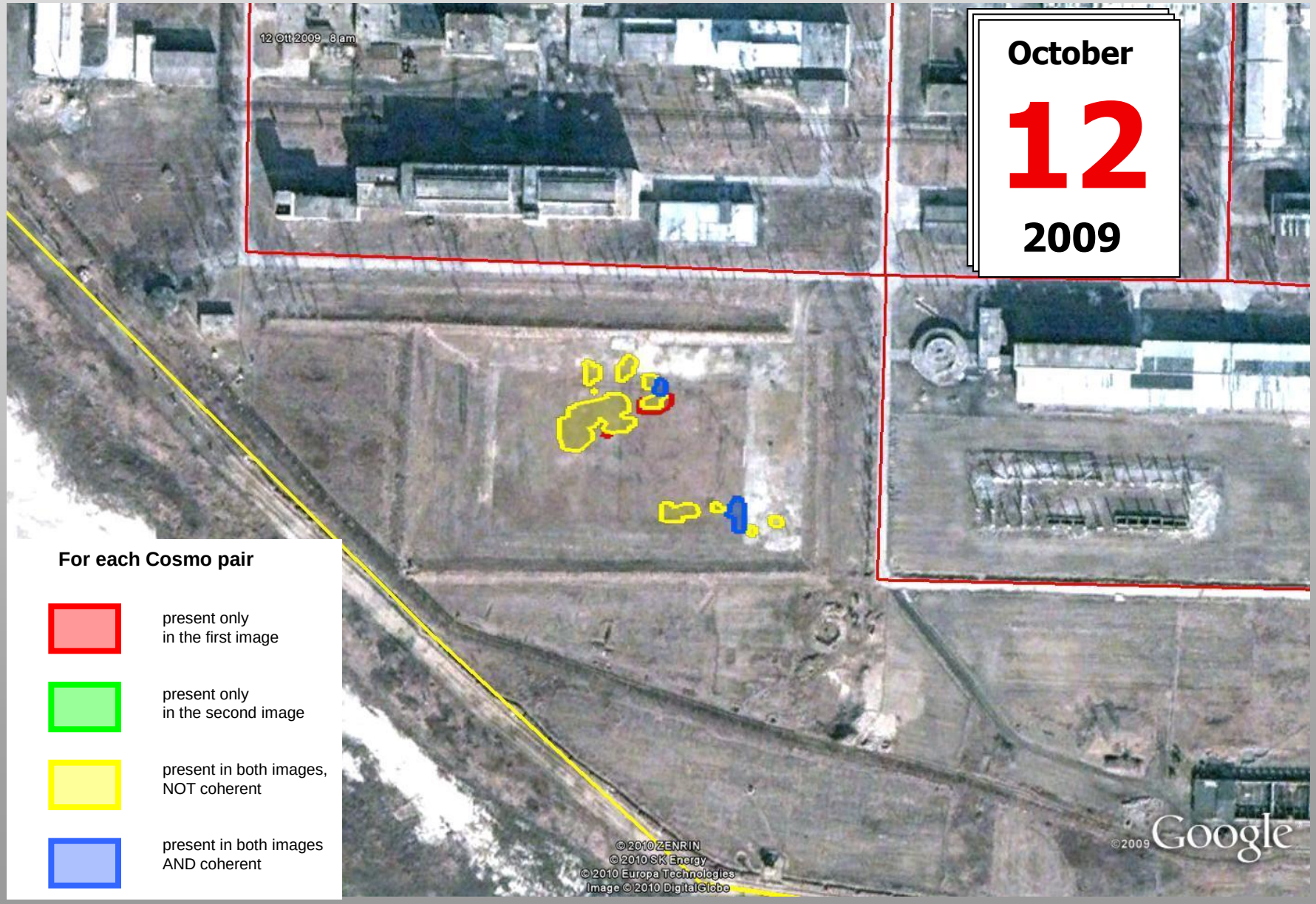
Area evolution based on Cosmo



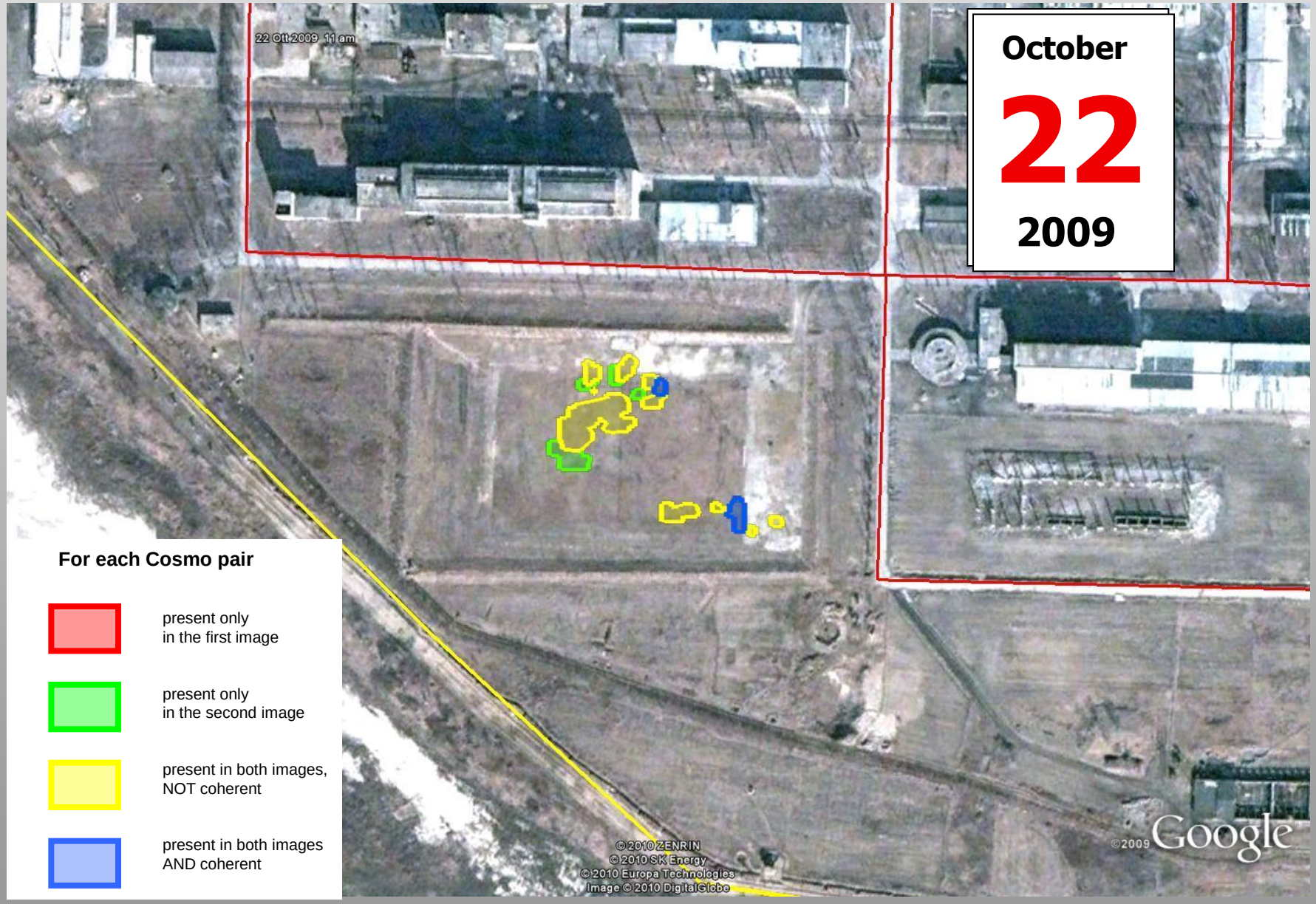
Area evolution based on Cosmo



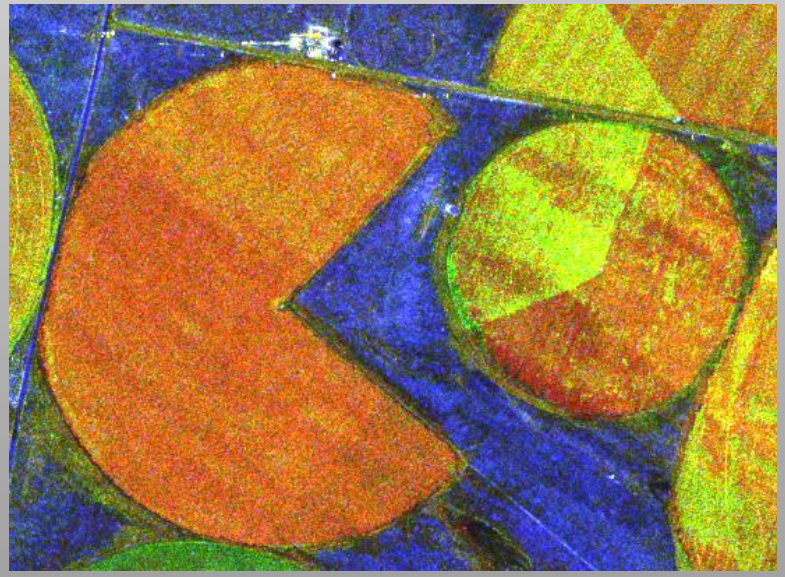
Area evolution based on Cosmo



Area evolution based on Cosmo



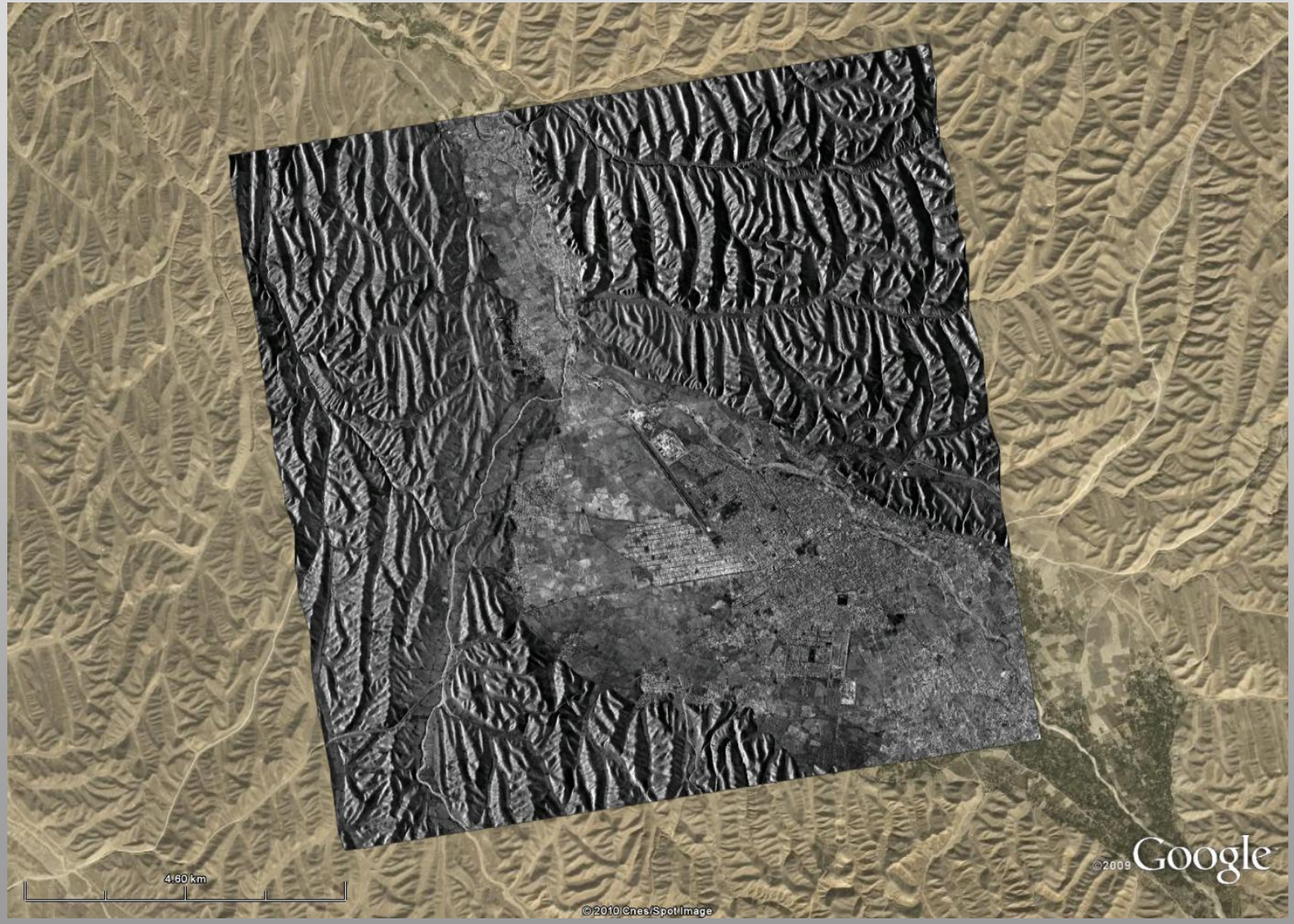
Coherence



Northern Afghanistan area

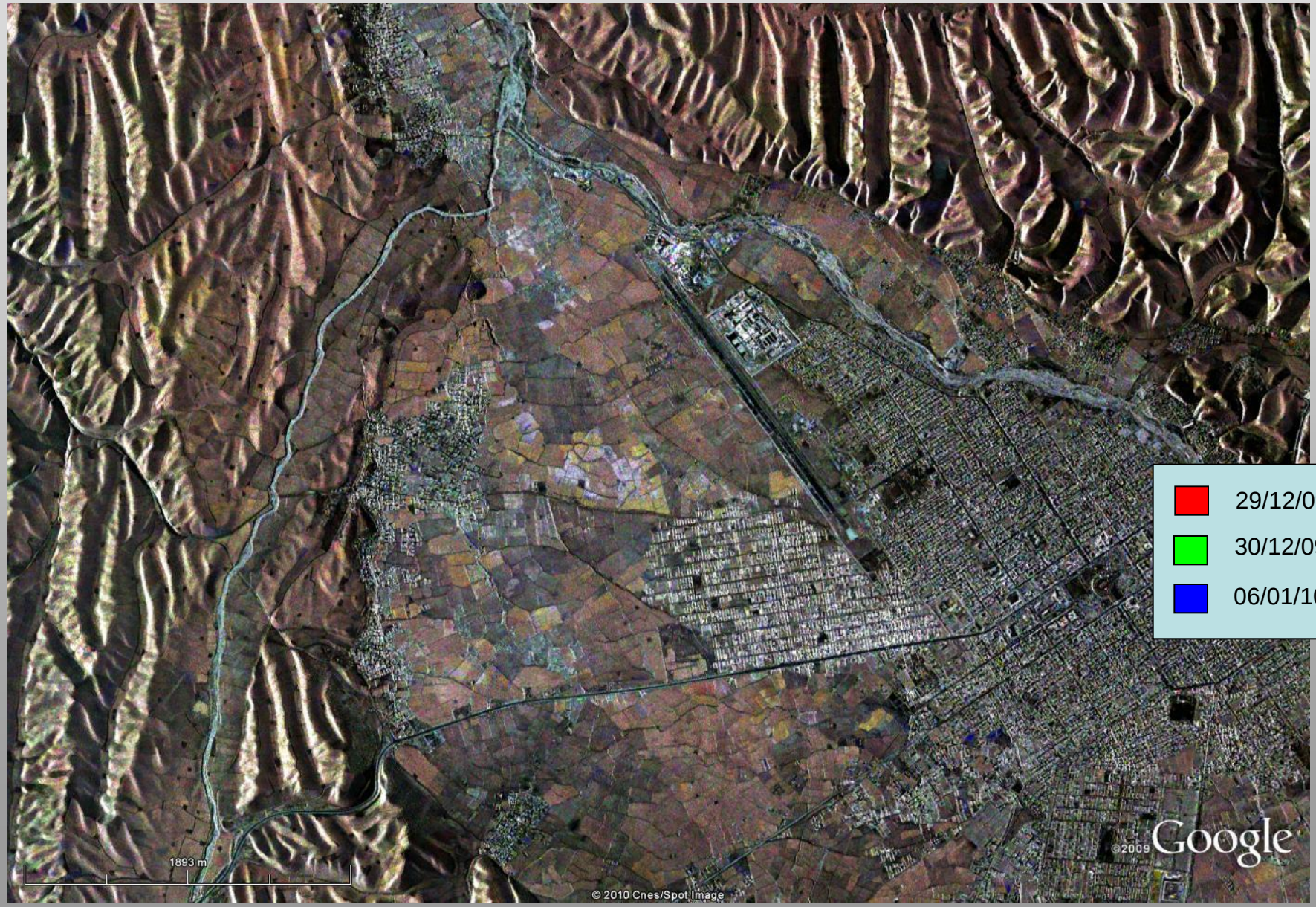
- **Pilot project in cooperation with Norwegian Defence**
- **Three 1,8,9 (CSK1, CSK2 & CSK3) SAR interferometric triplet (two ascending, one descending)**
- **First six images collected between December 29, 2009 and January 10, 2010**

Overview

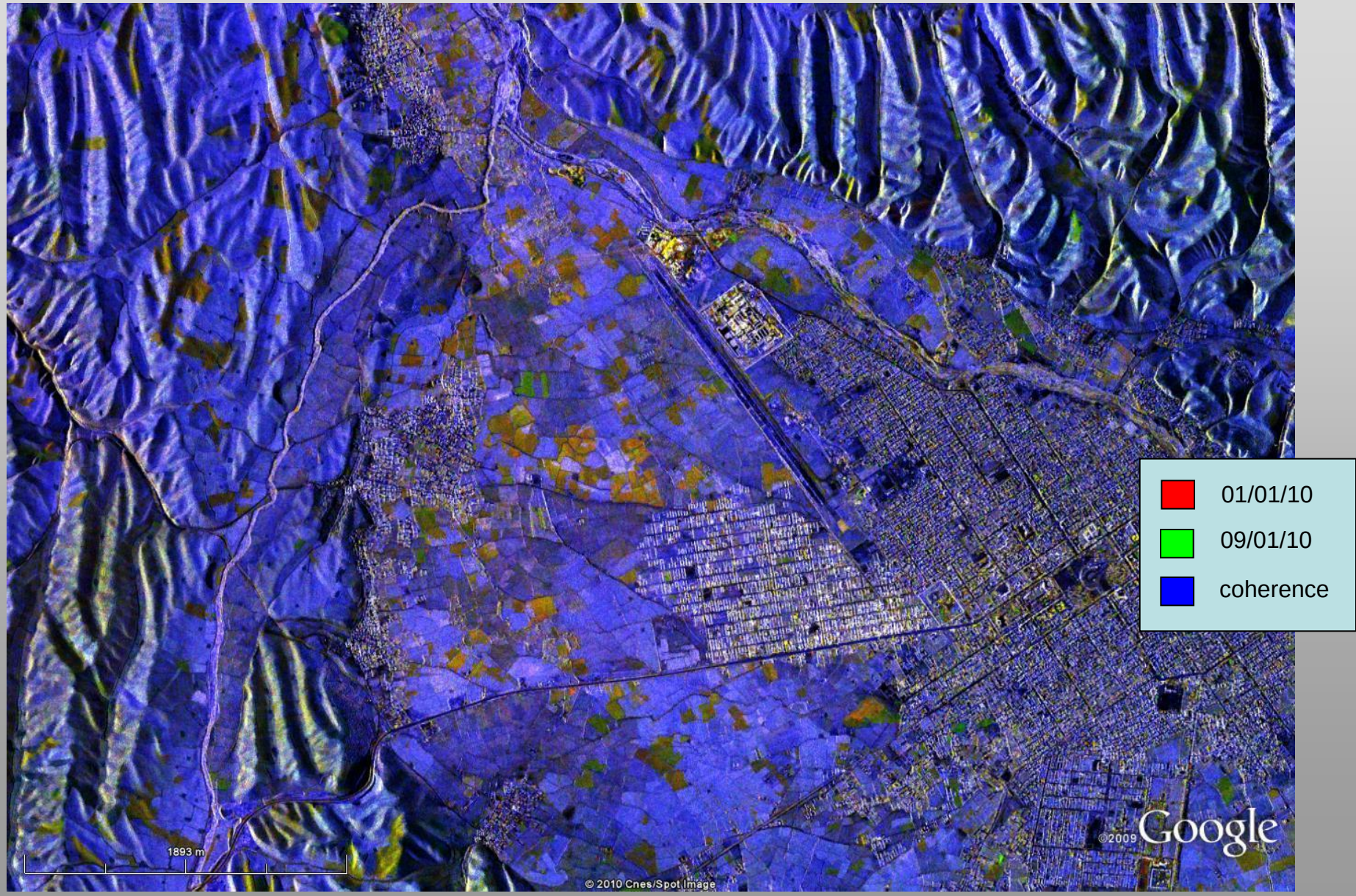


1893 m
© 2010 Cnes/Spot Image
©2009 Google

Multitemporal combination

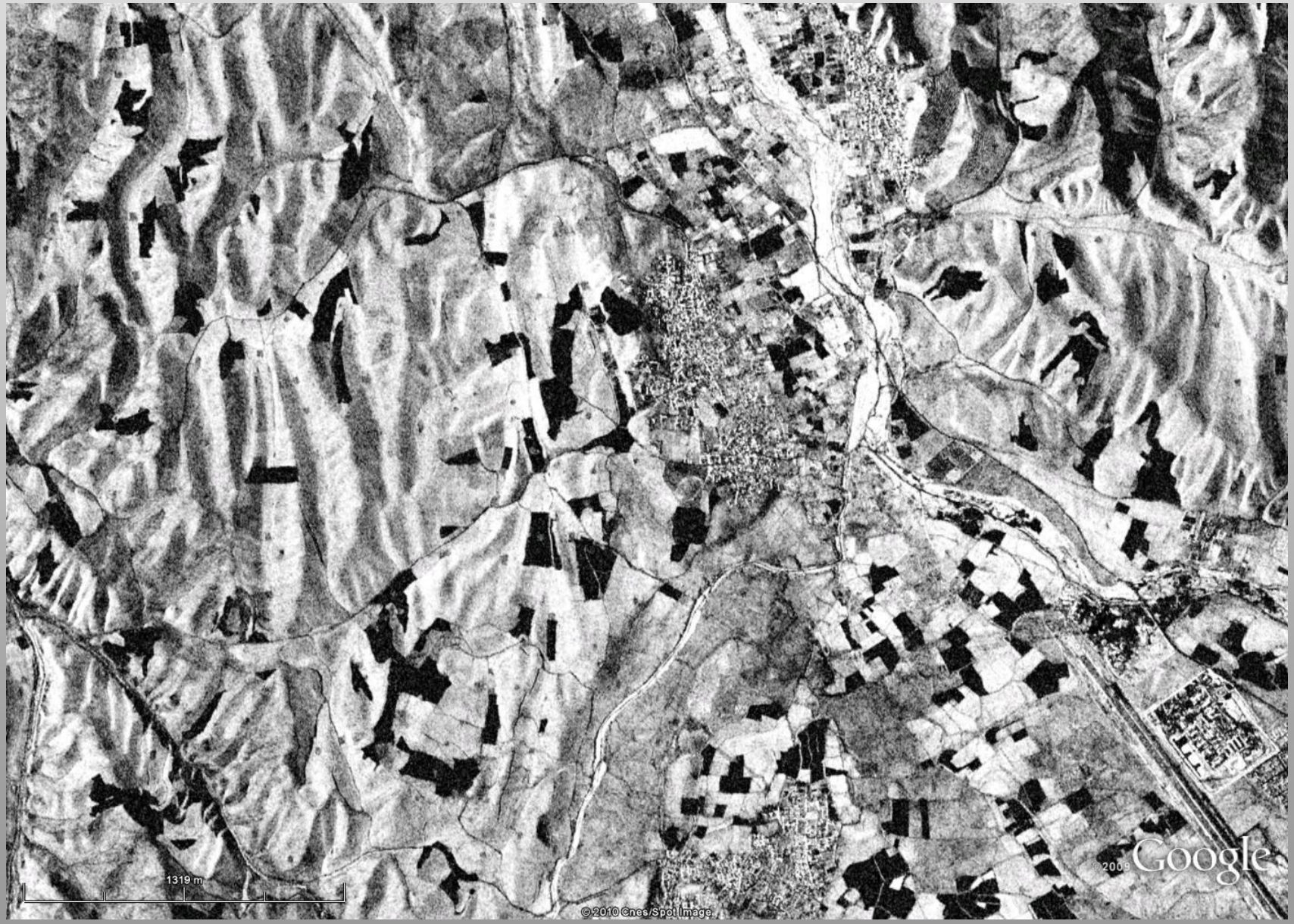


Coherent change detection

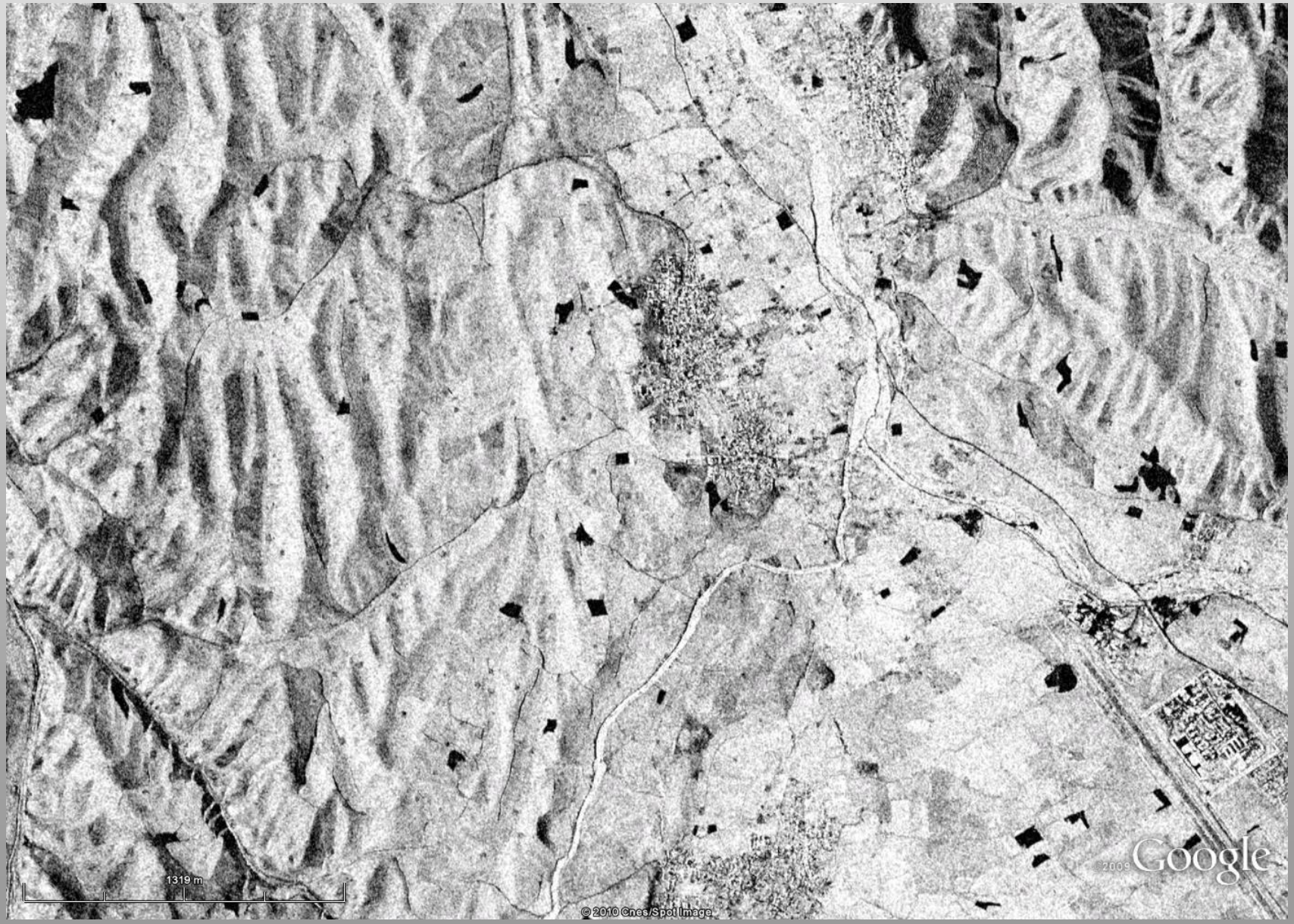


Hilly area

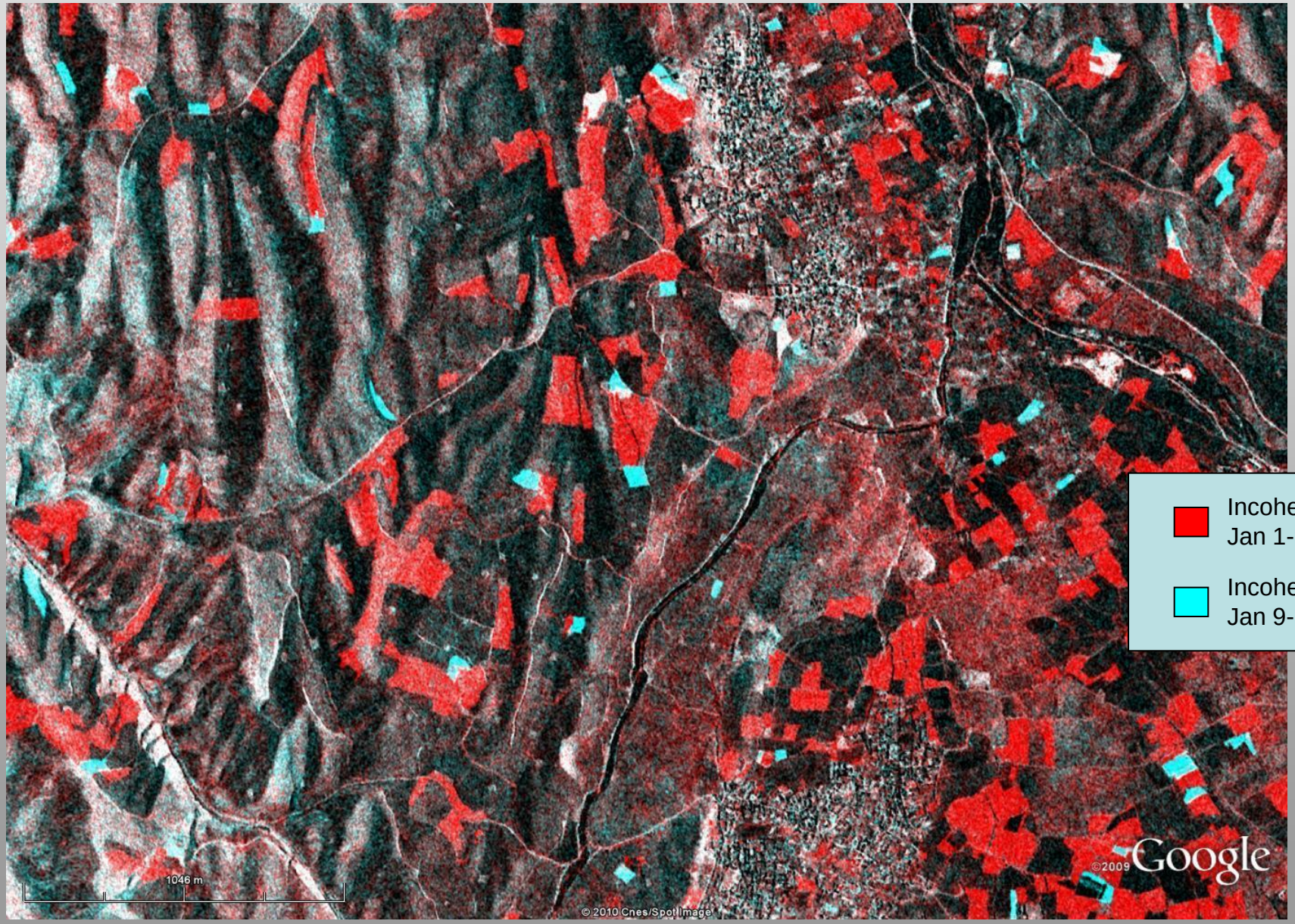
Eight days coherence (1-9 Jan 2010)



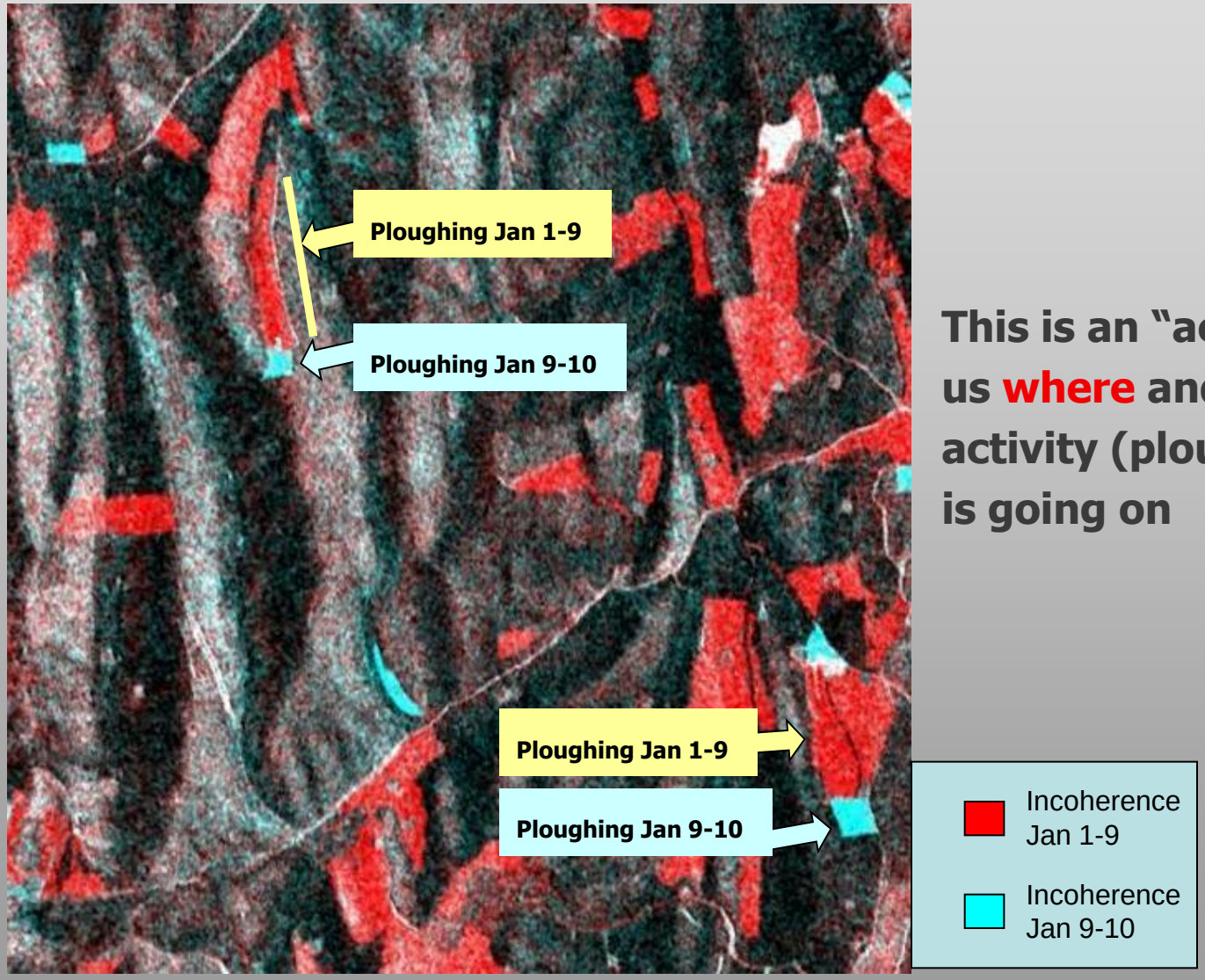
One day coherence (9-10 Jan 2010)



Two color incoherence map



Two color incoherence map



This is an "activity" map: it tells us where and when some activity (ploughing, in this case) is going on

About streets, roads, tracks

“The streets are fields that never die……”

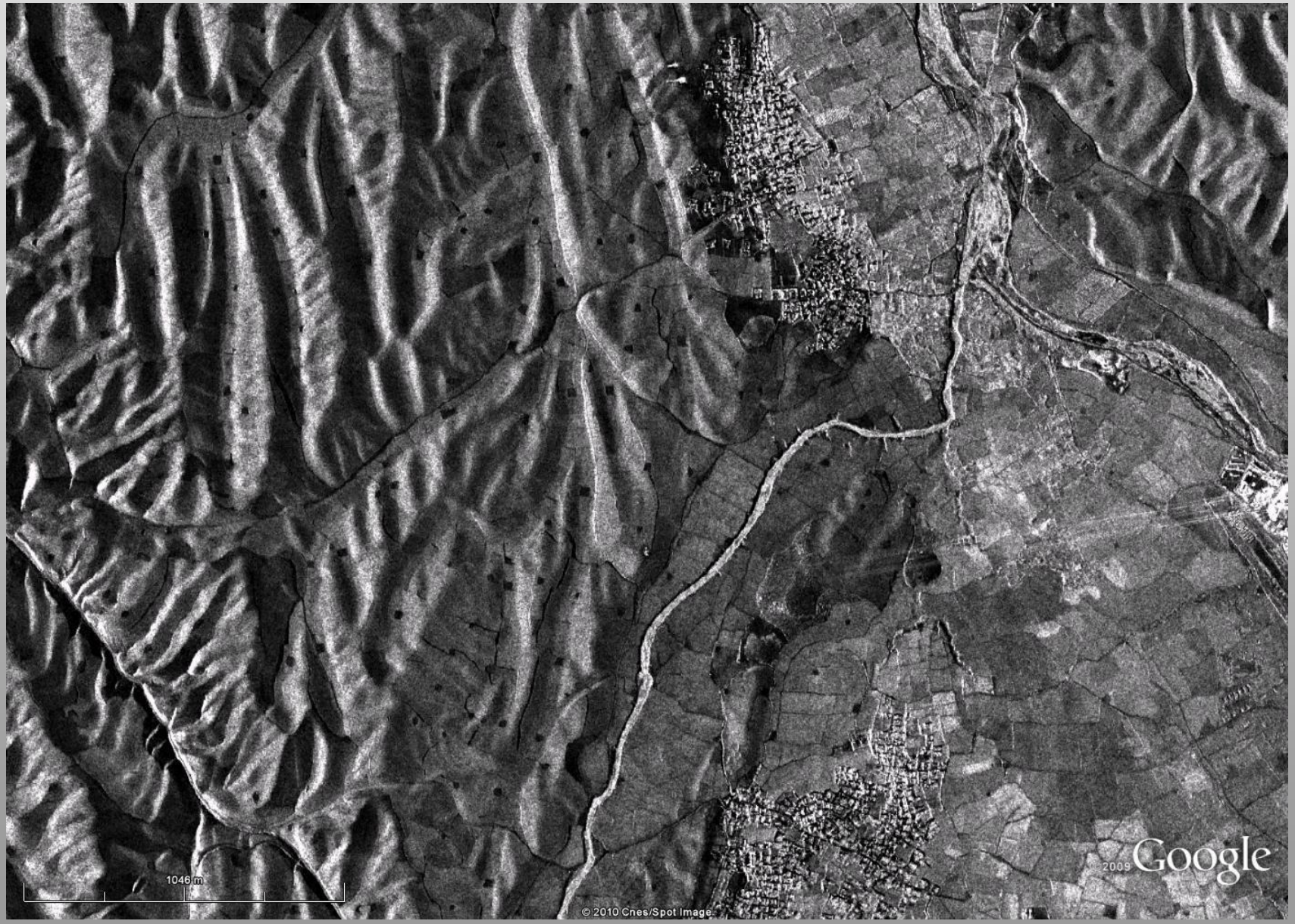
from “The Crystal Ship”, Jim Morrison

Airport area

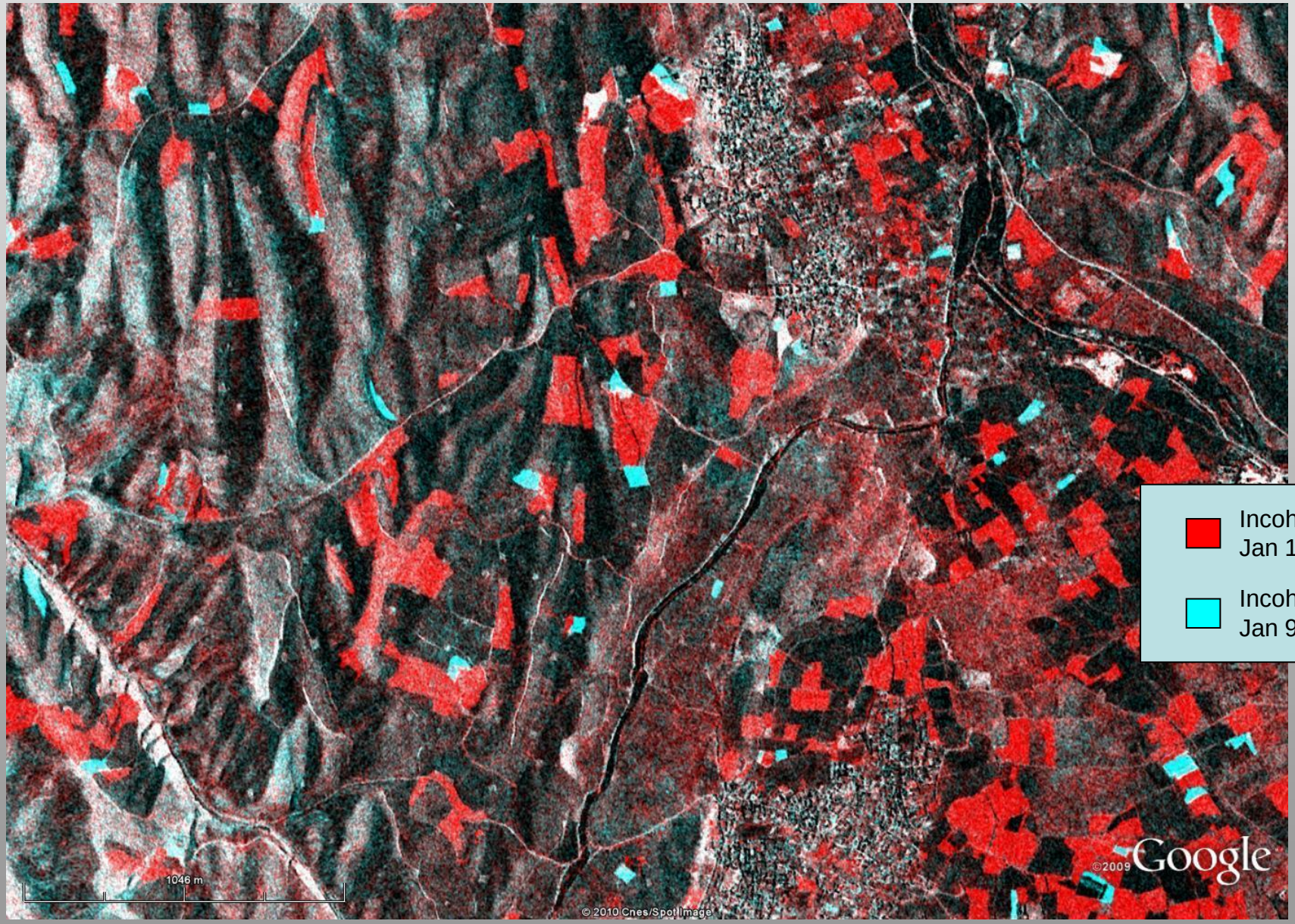
Airport area

White roads

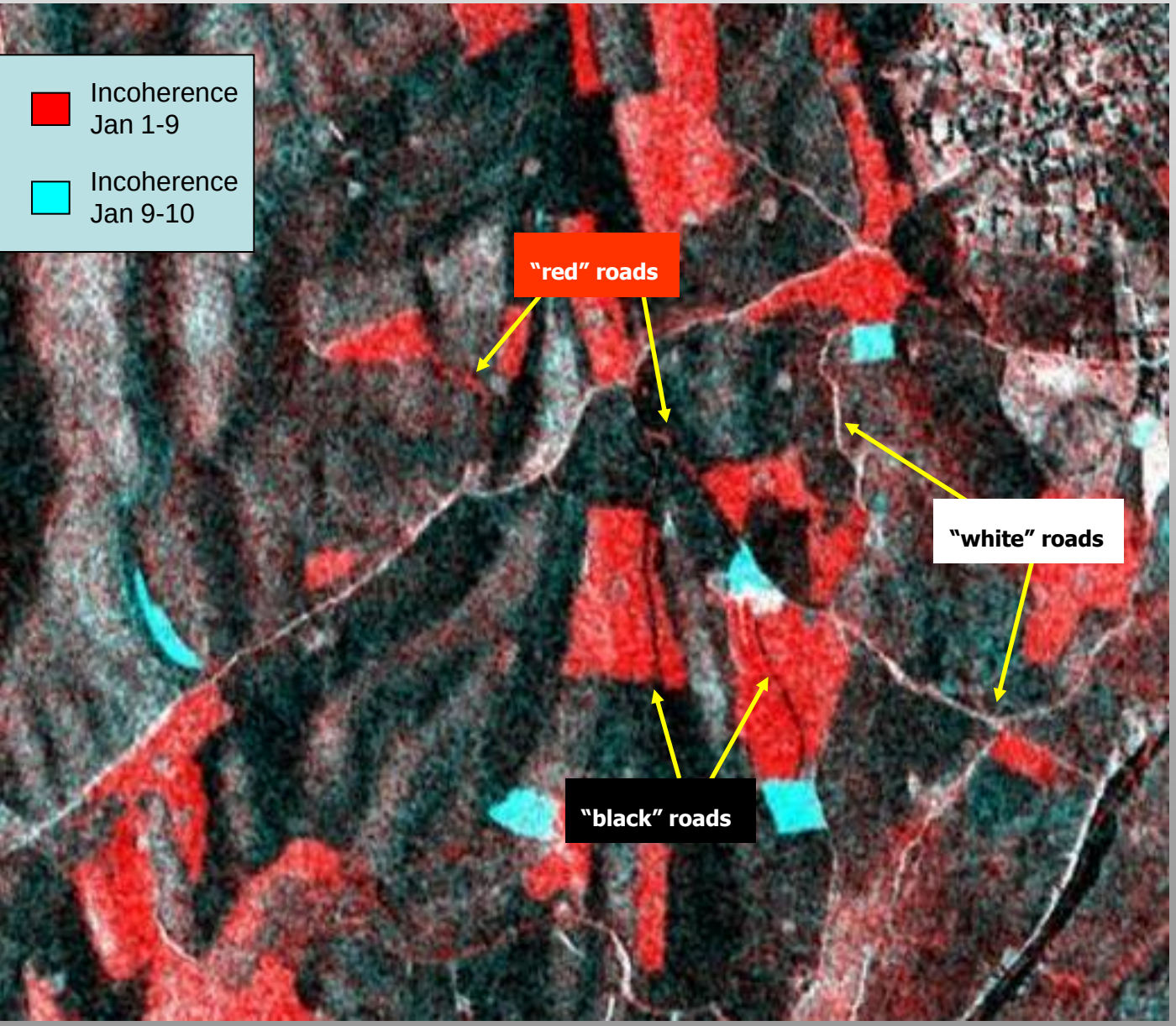
SAR amplitude image



Incoherence map



incoherence map: road colours



White road:

used Jan 1-10

Red road:

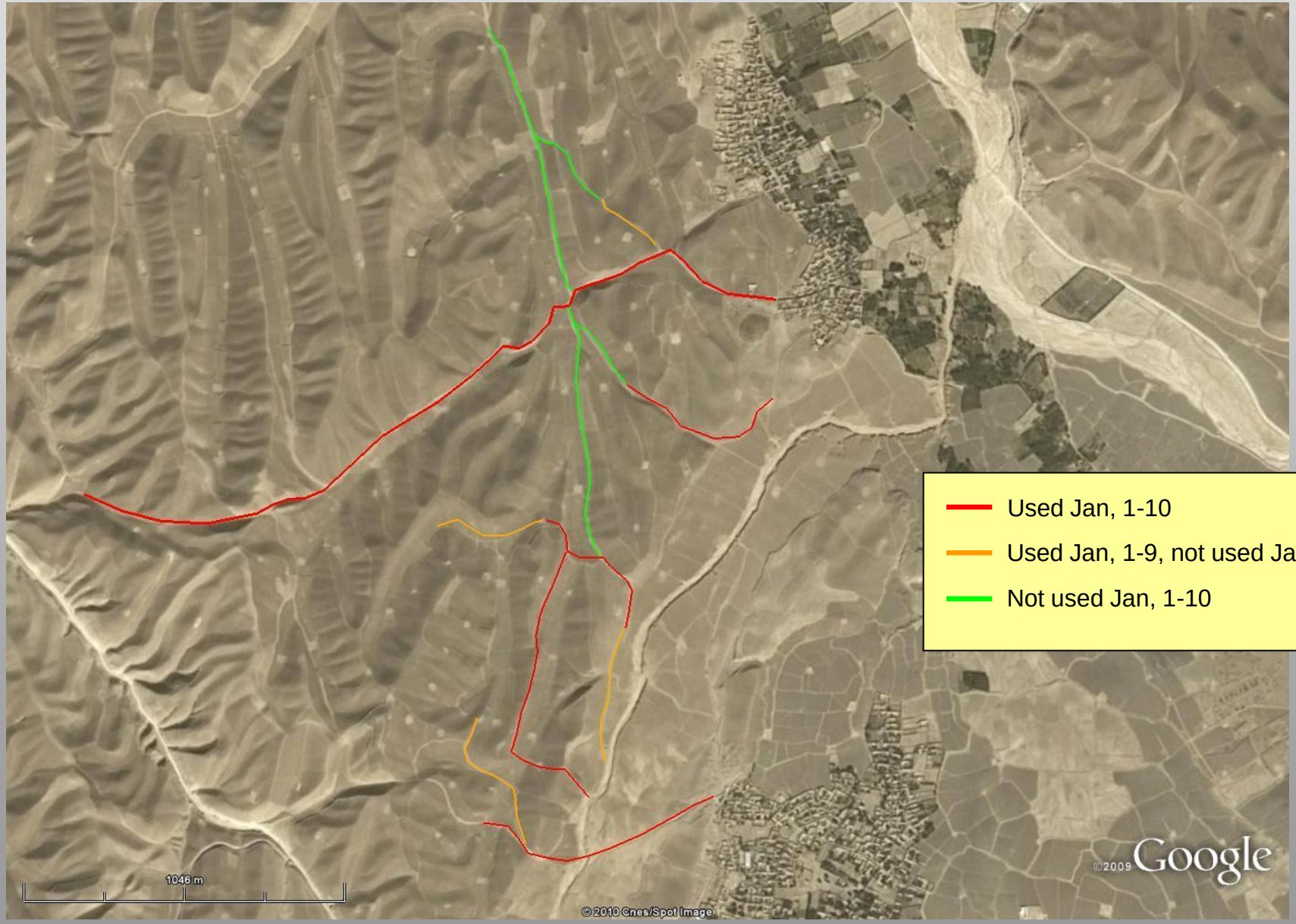
used Jan 1-9

not used Jan 9-10

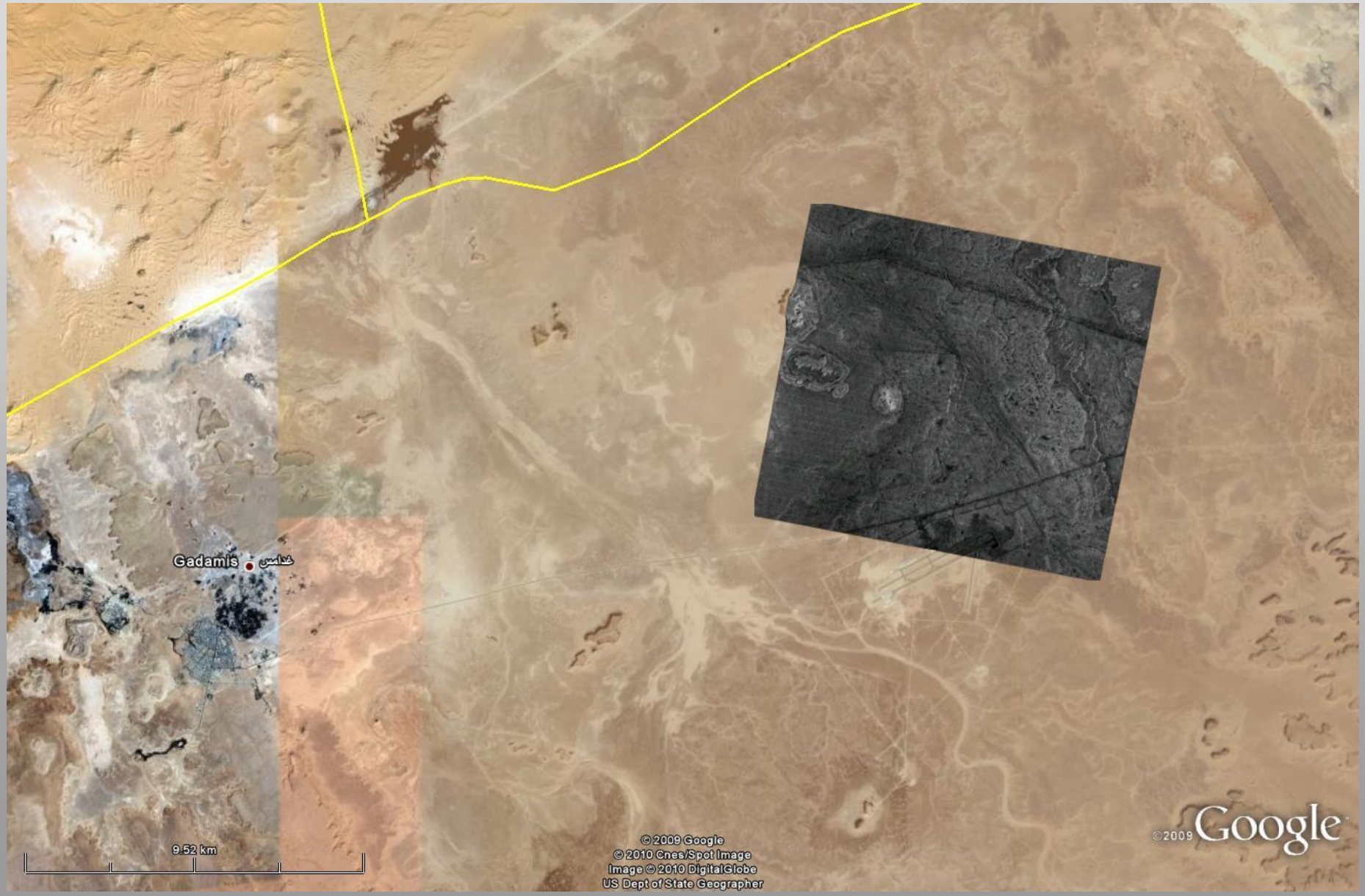
Black road:

not used Jan 1-10

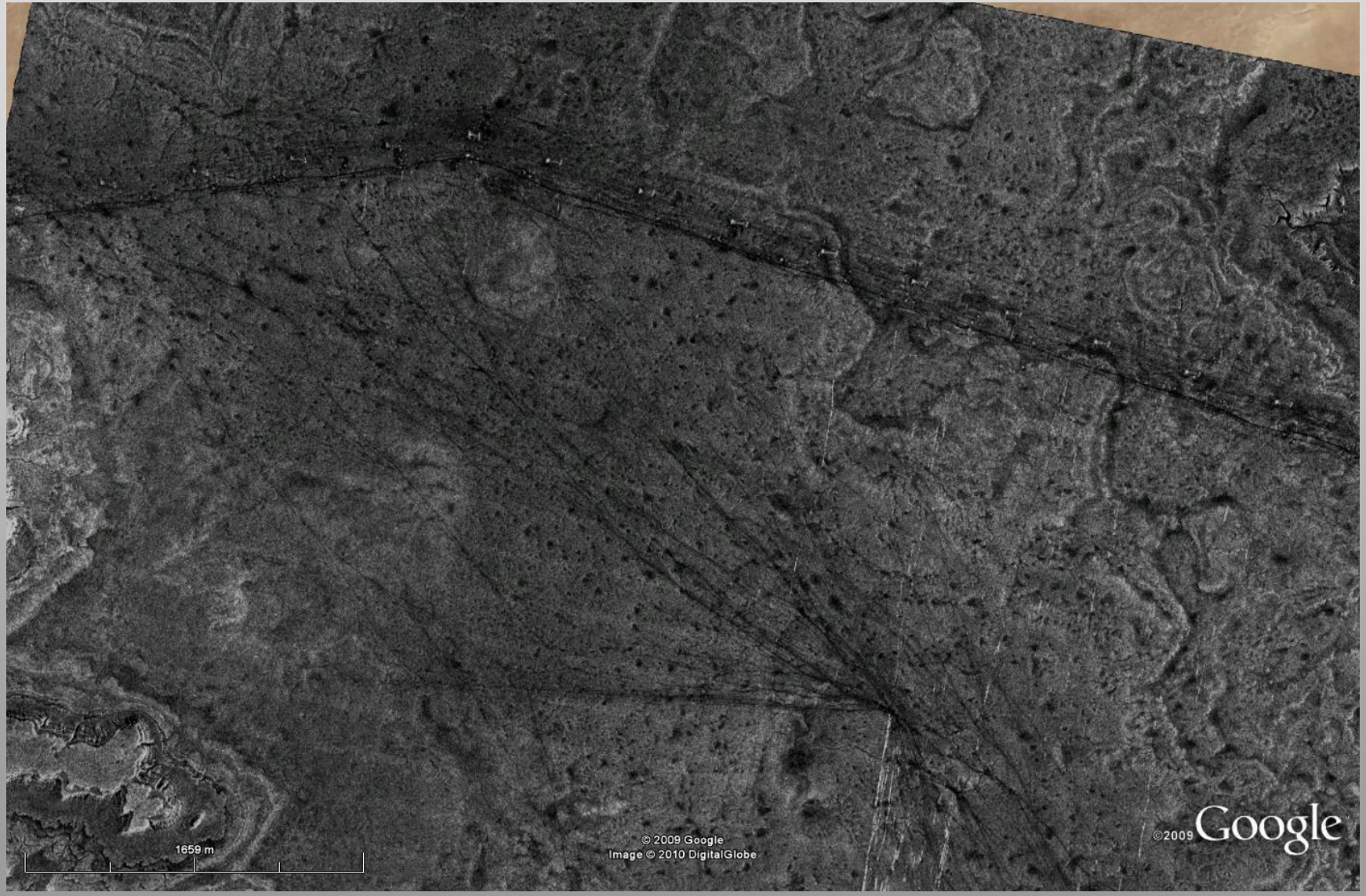
Road use map


Used Jan, 1-10
Used Jan, 1-9, not used Jan 9-10
Not used Jan, 1-10
1046 m
©2009 Google
© 2010 Cnes/Spot Image

Spotlight data collection over a border area in Sahara desert

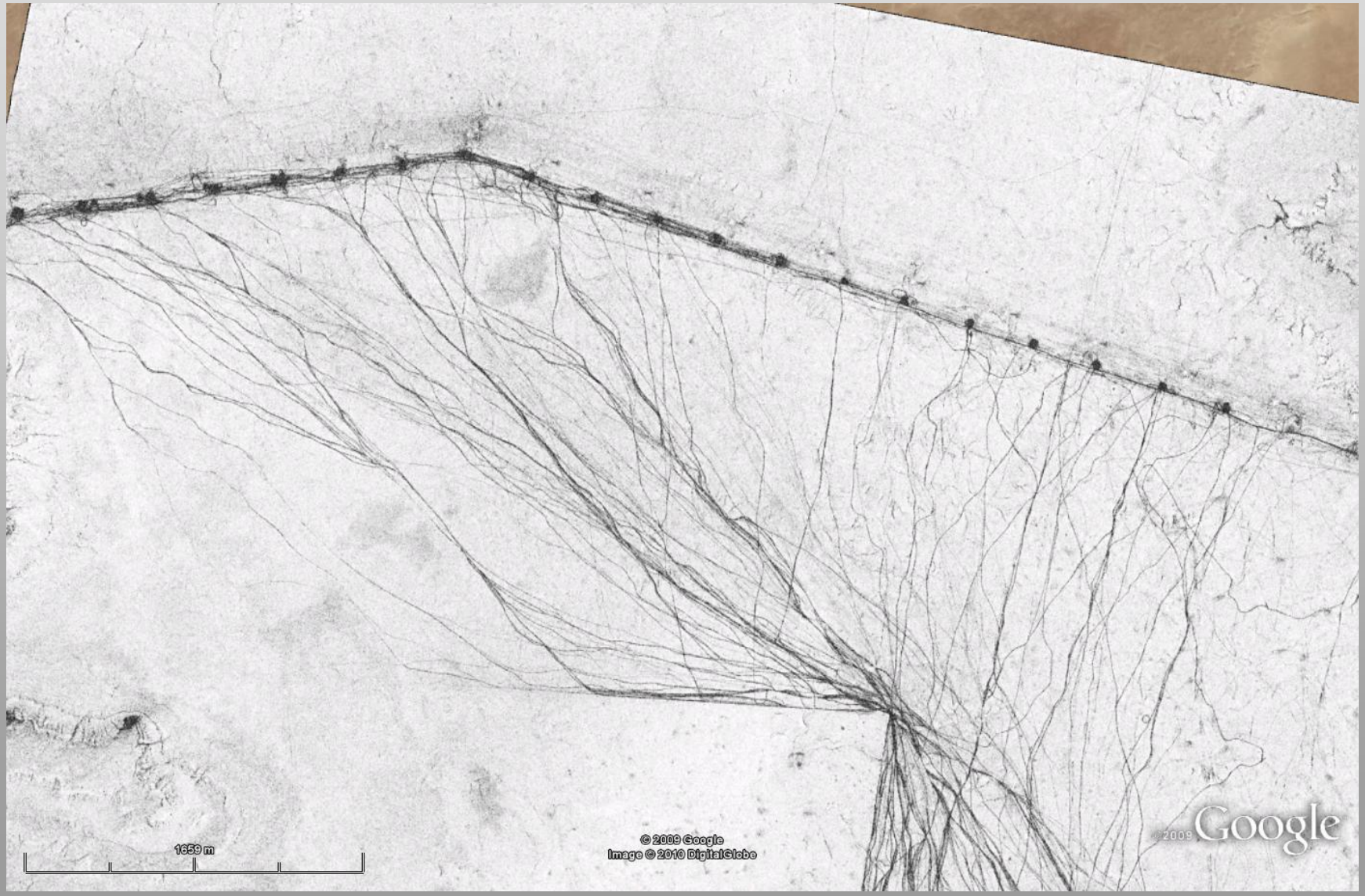


Spotlight COSMO image 27 December, 2009

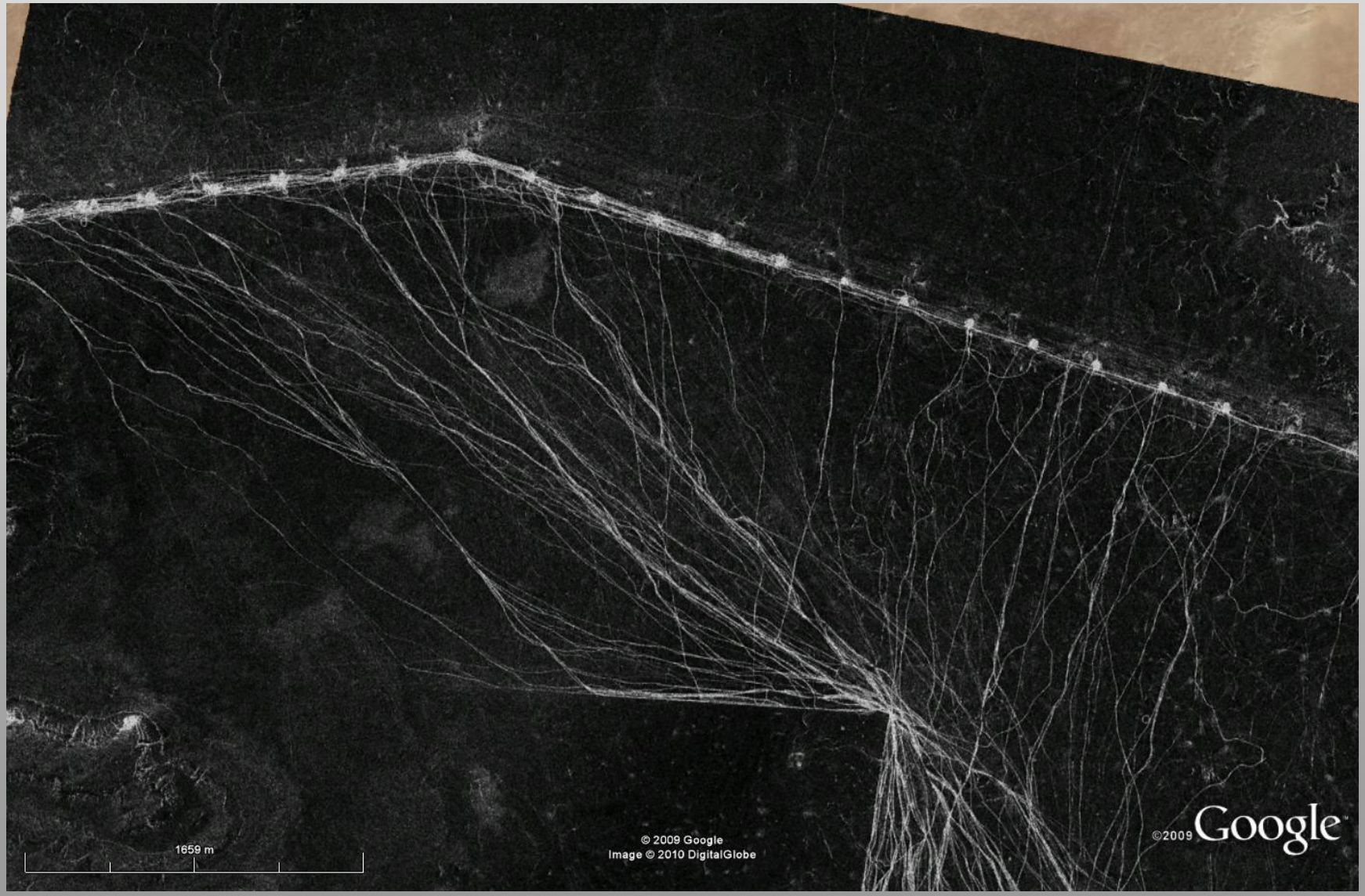


What are we seeing there?

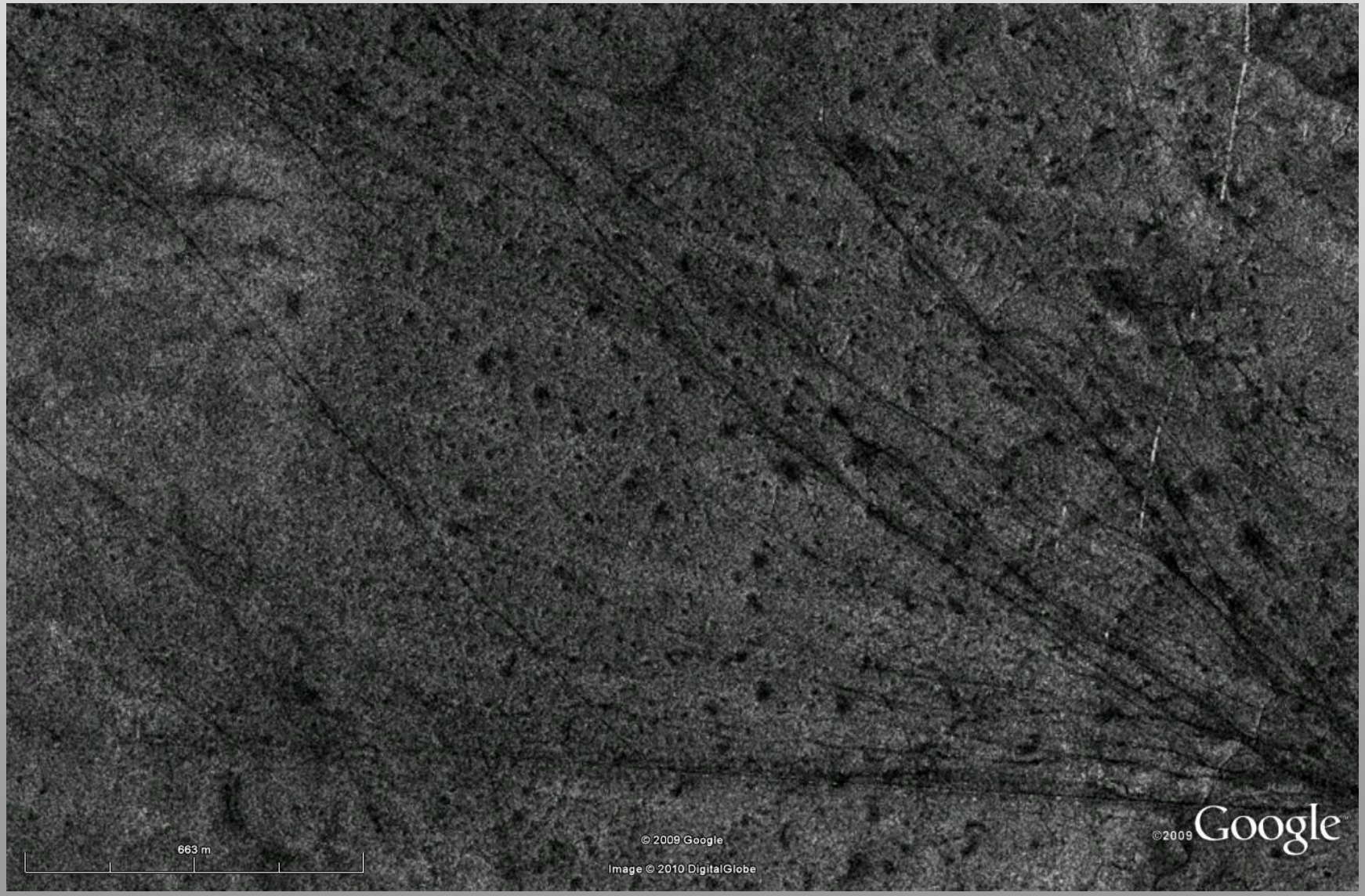
Coherence 18-26 December, 2009



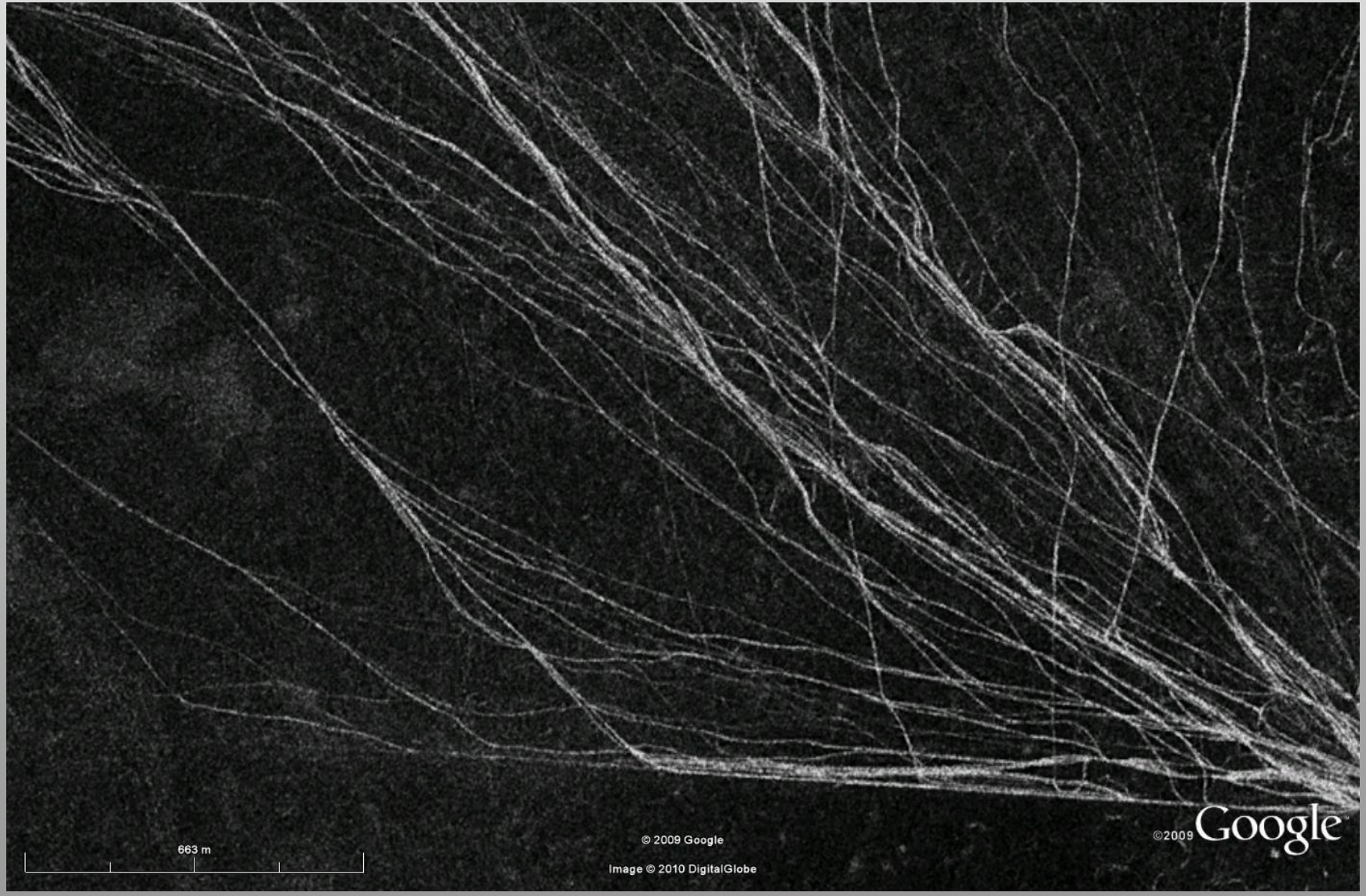
Incoherence 18-26 December, 2009



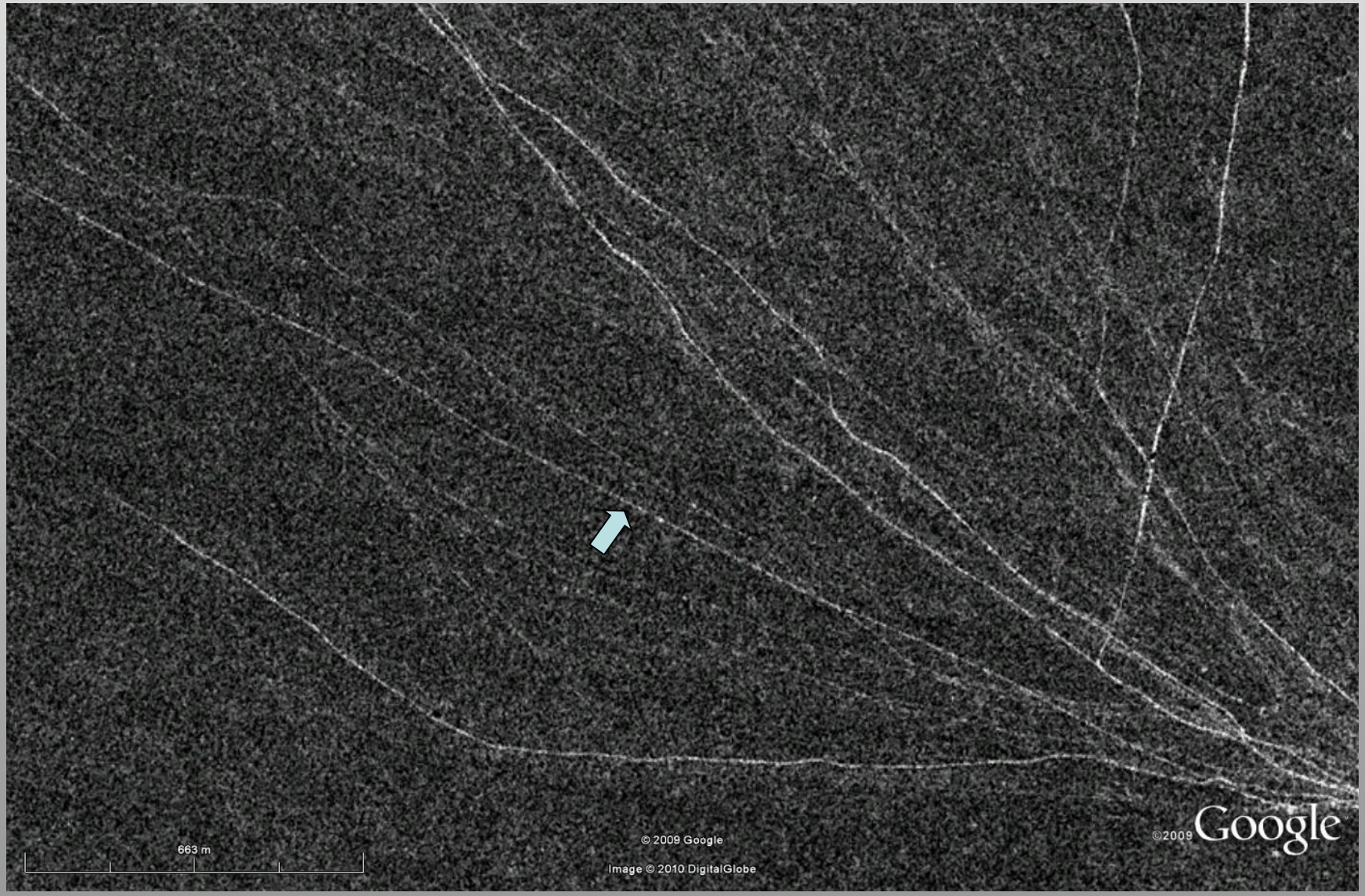
Detail on SAR amplitude



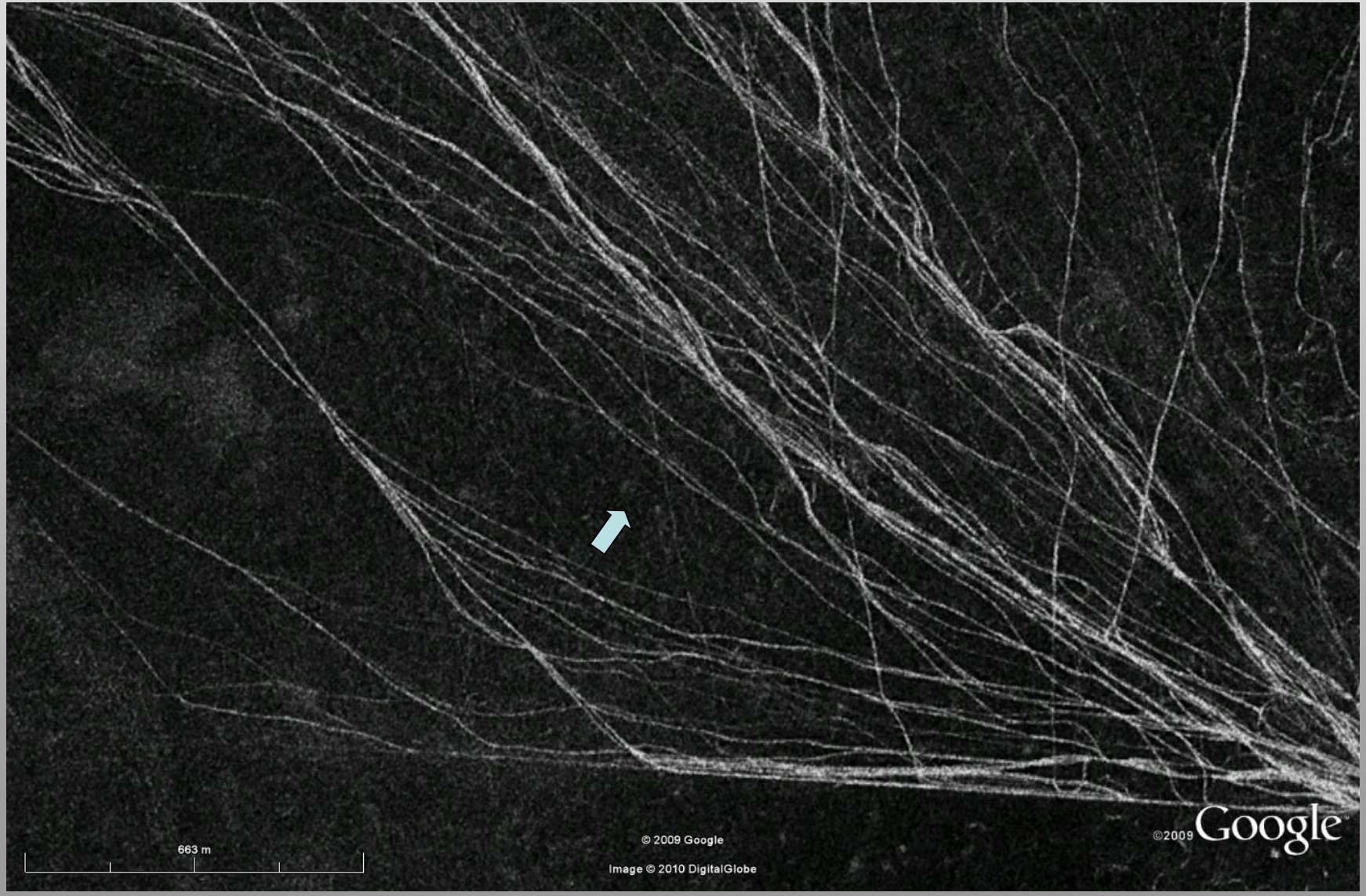
Detail Incoherence 18-26 December



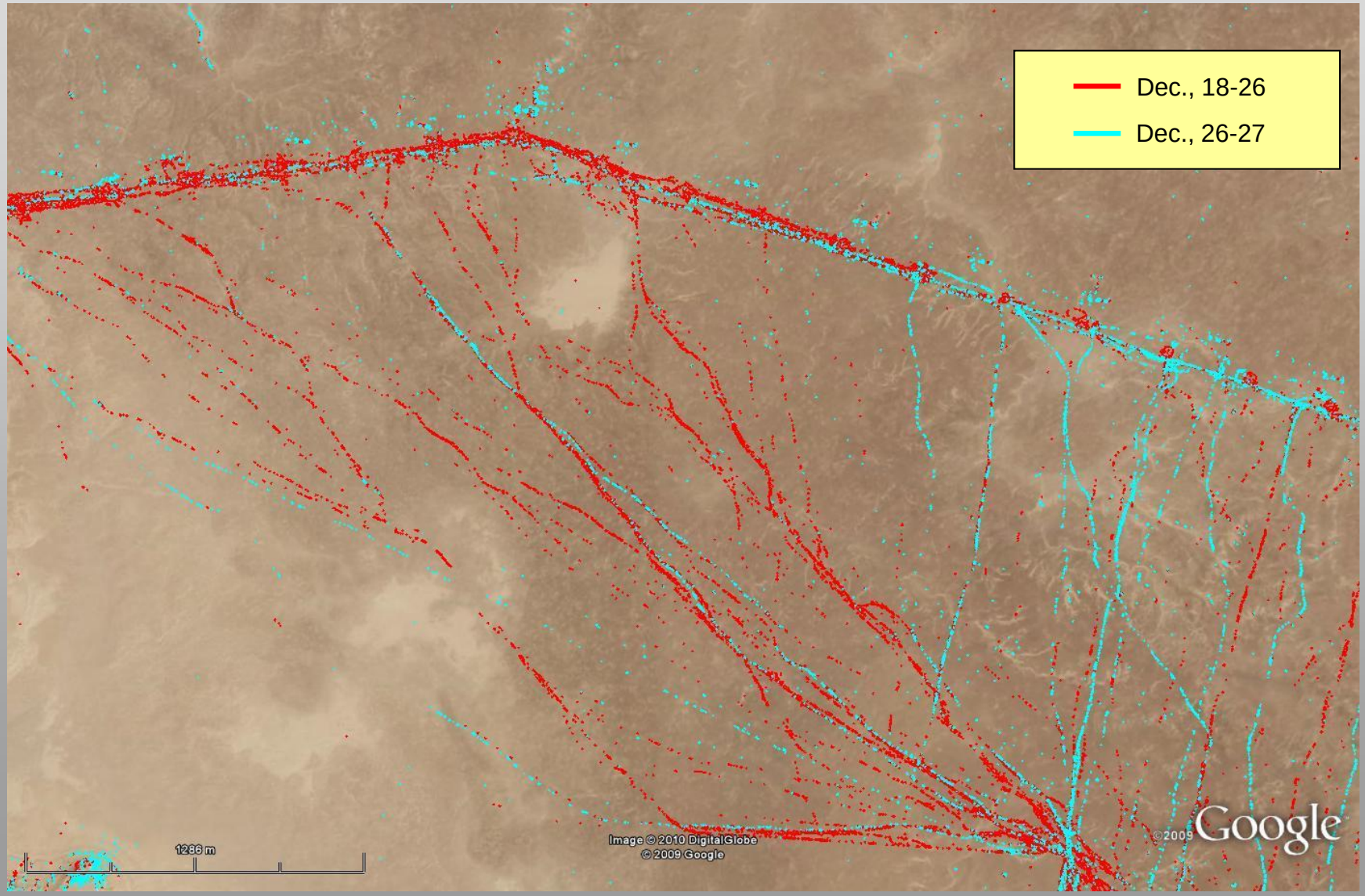
Detail Incoherence 26-27 December



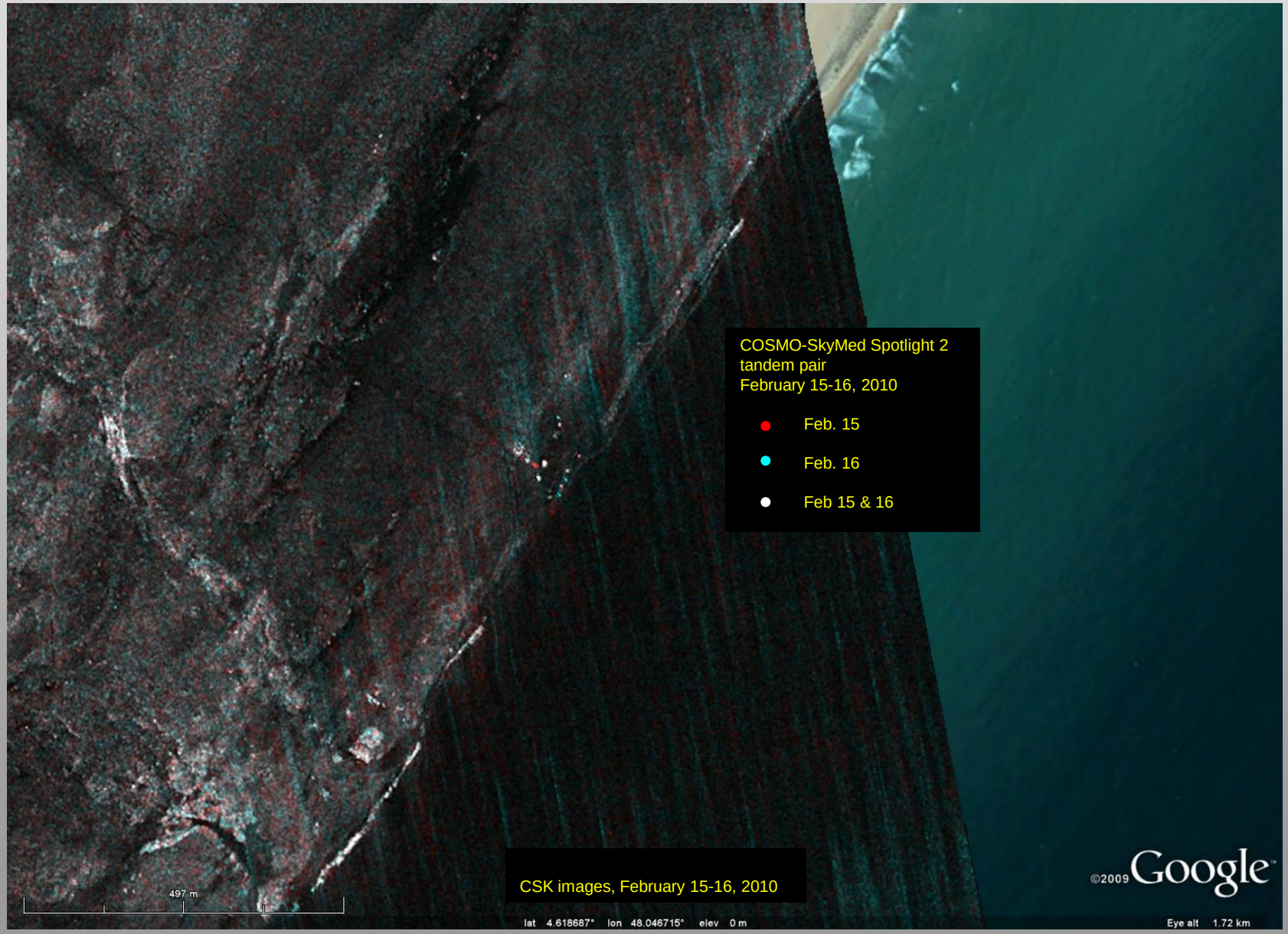
Detail Incoherence 18-26 December



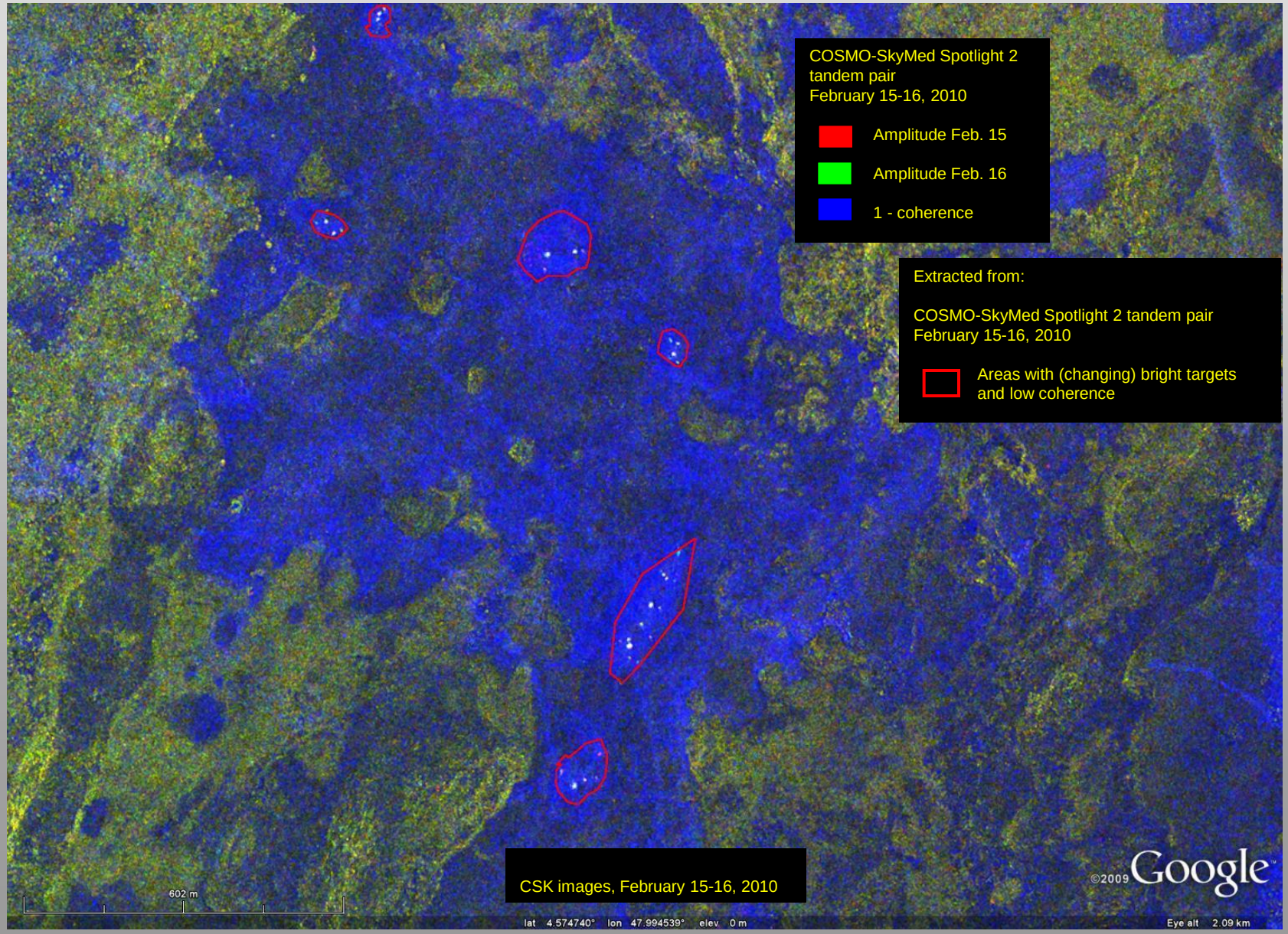
Tracks used during 18-27 December



Bright point target map



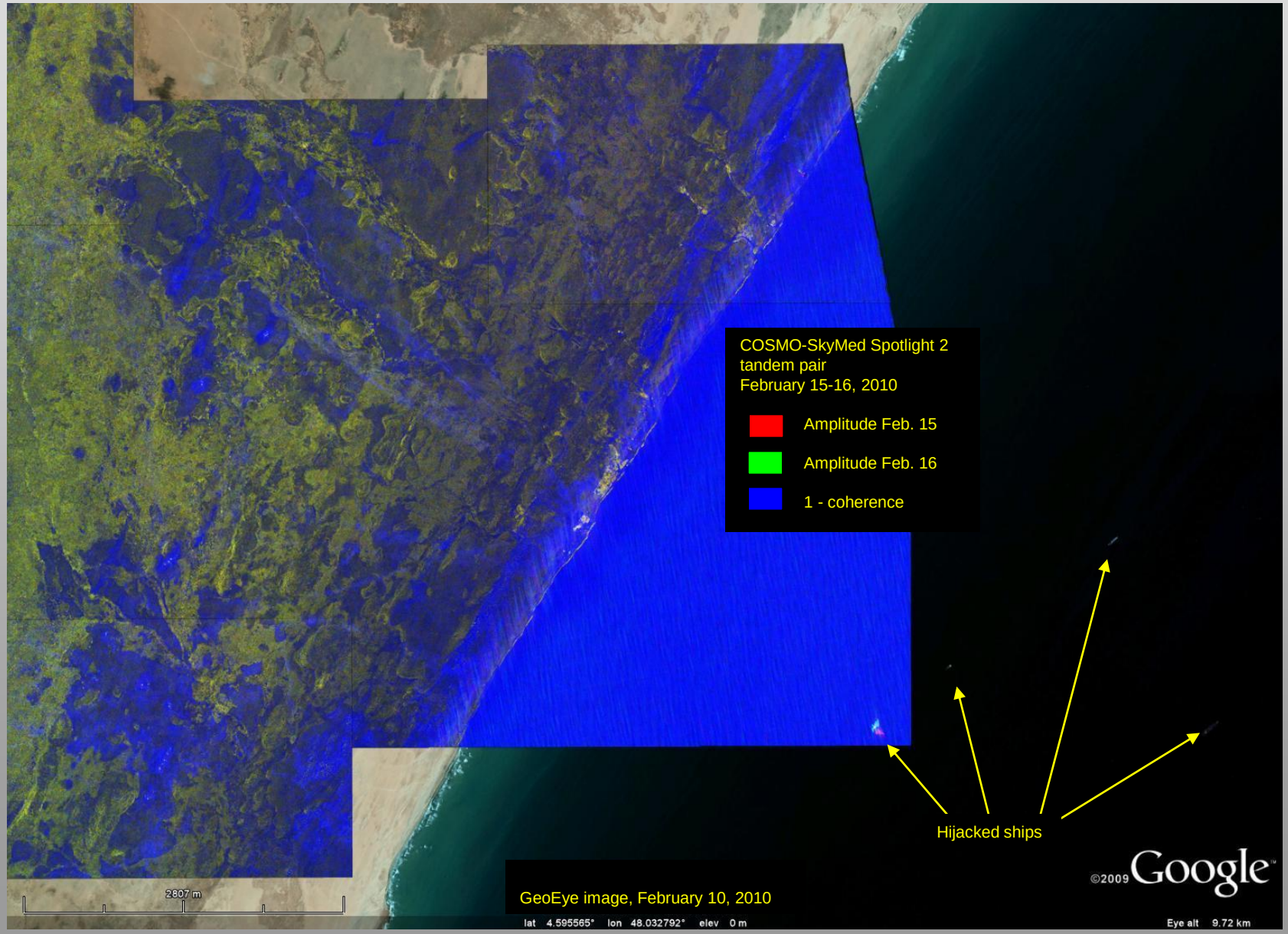
GeoEye detail


COSMO-SkyMed Spotlight 2
tandem pair
February 15-16, 2010
Amplitude Feb. 15
Amplitude Feb. 16
1 - coherence
Extracted from:
COSMO-SkyMed Spotlight 2 tandem pair
February 15-16, 2010
Areas with (changing) bright targets
and low coherence
CSK images, February 15-16, 2010
602 m
©2009 Google
lat 4.574740° lon 47.994539° elev 0 m
Eye alt 2.09 km

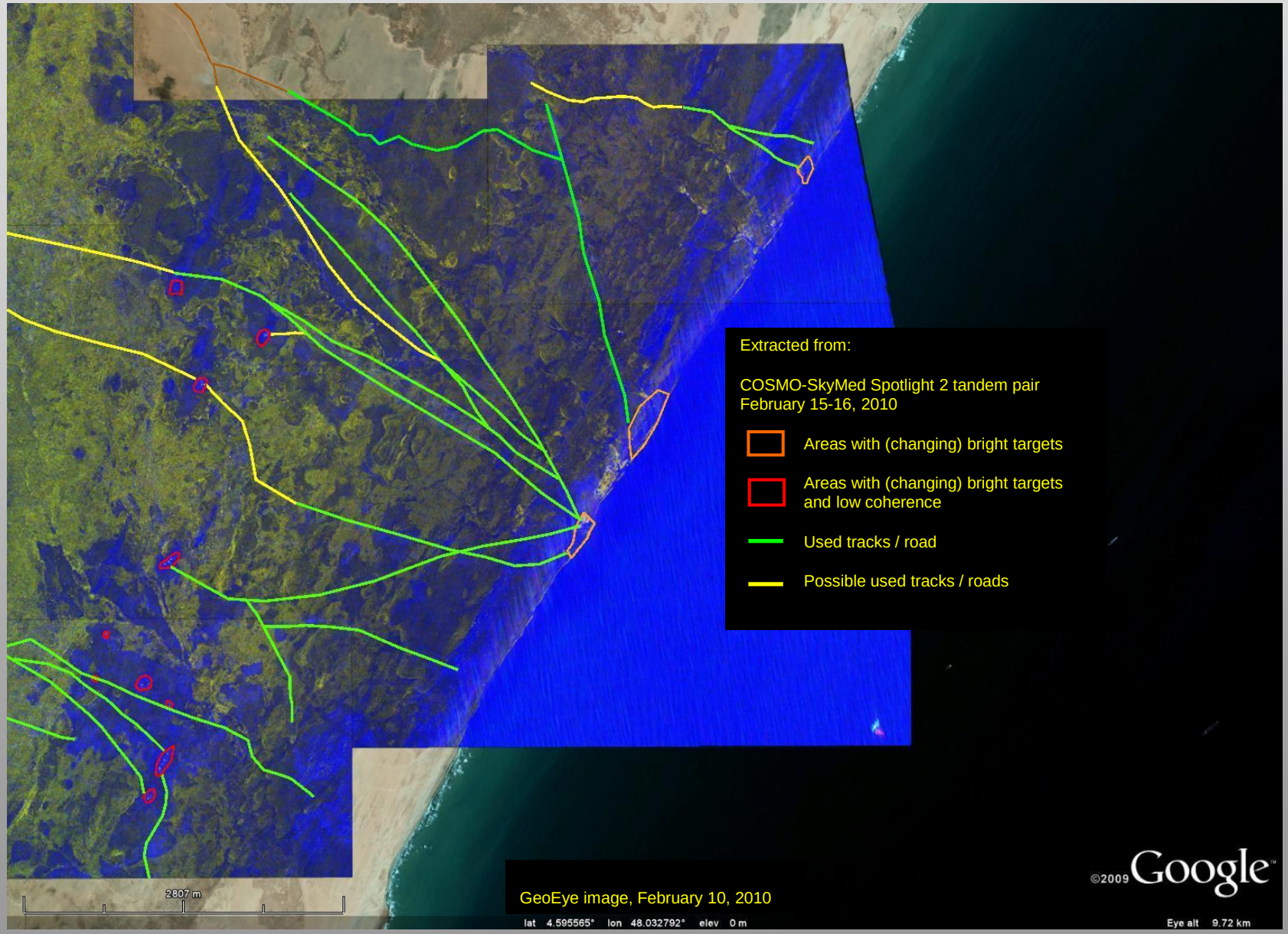
Detail

GeoEye image,February 10, 2010
204 m
©2009 Google
lat 4.571239° lon 47.994289° elev 0 m
Eye alt 707 m

Images

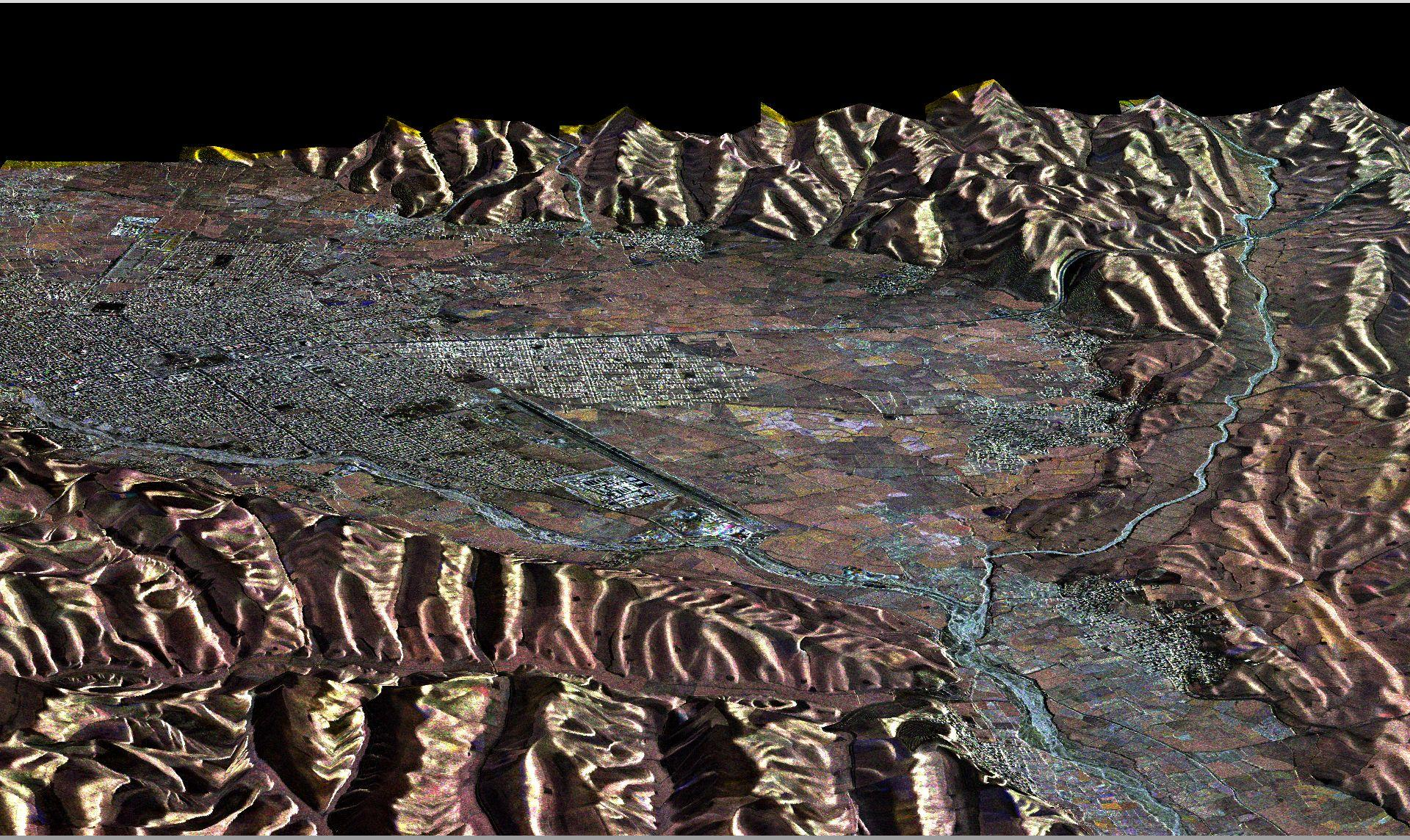

COSMO-SkyMed Spotlight 2
tandem pair
February 15-16, 2010
Amplitude Feb. 15
Amplitude Feb. 16
1 - coherence
Hijacked ships
GeoEye image, February 10, 2010
©2009 Google
2807 m
lat 4.595565° lon 48.032792° elev 0 m
Eye alt 9.72 km

Active areas analysis



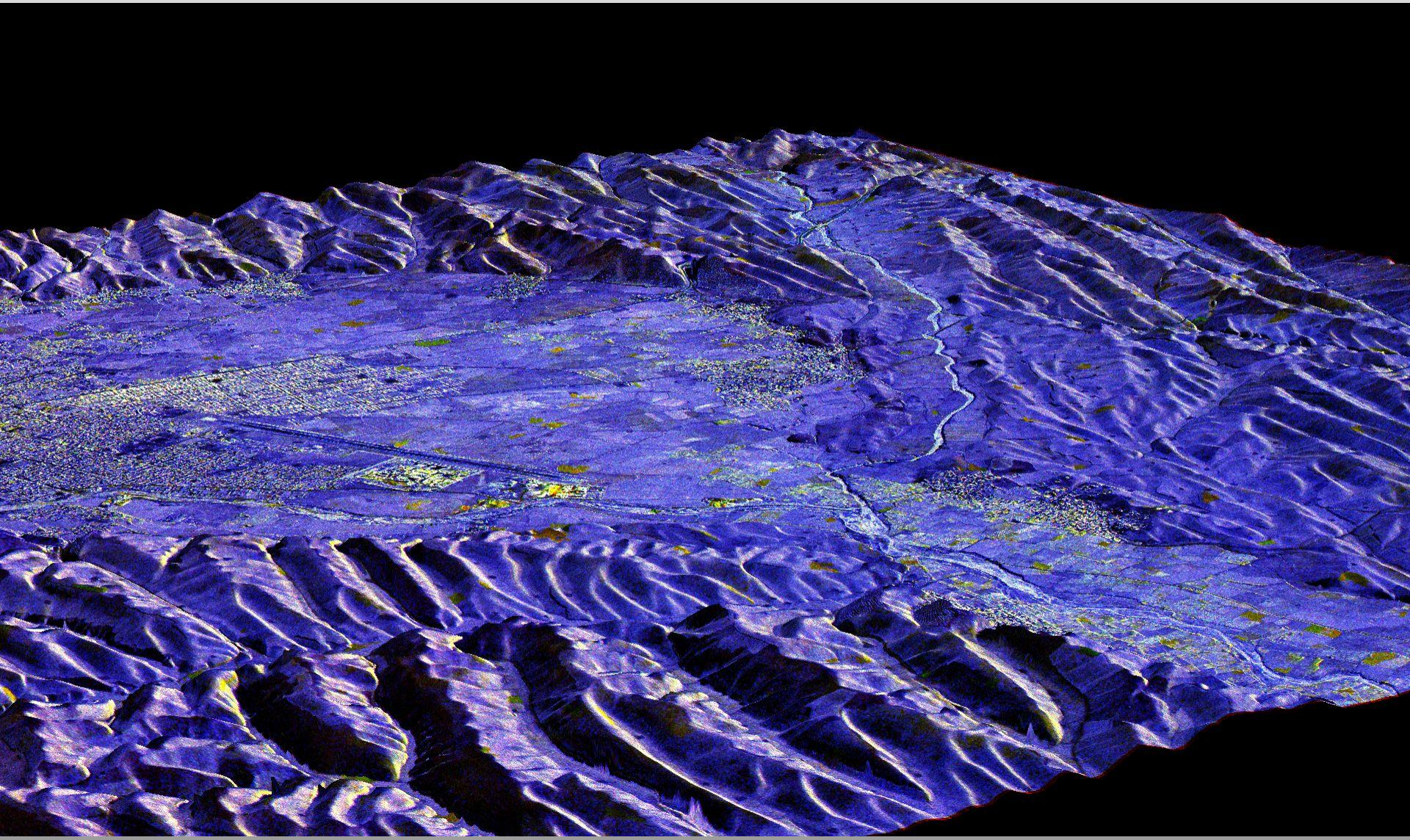
Interferometry

Multitemporal overlayed on CSK DTM



Derived from a tandem interferometric pair; 5 meters posting

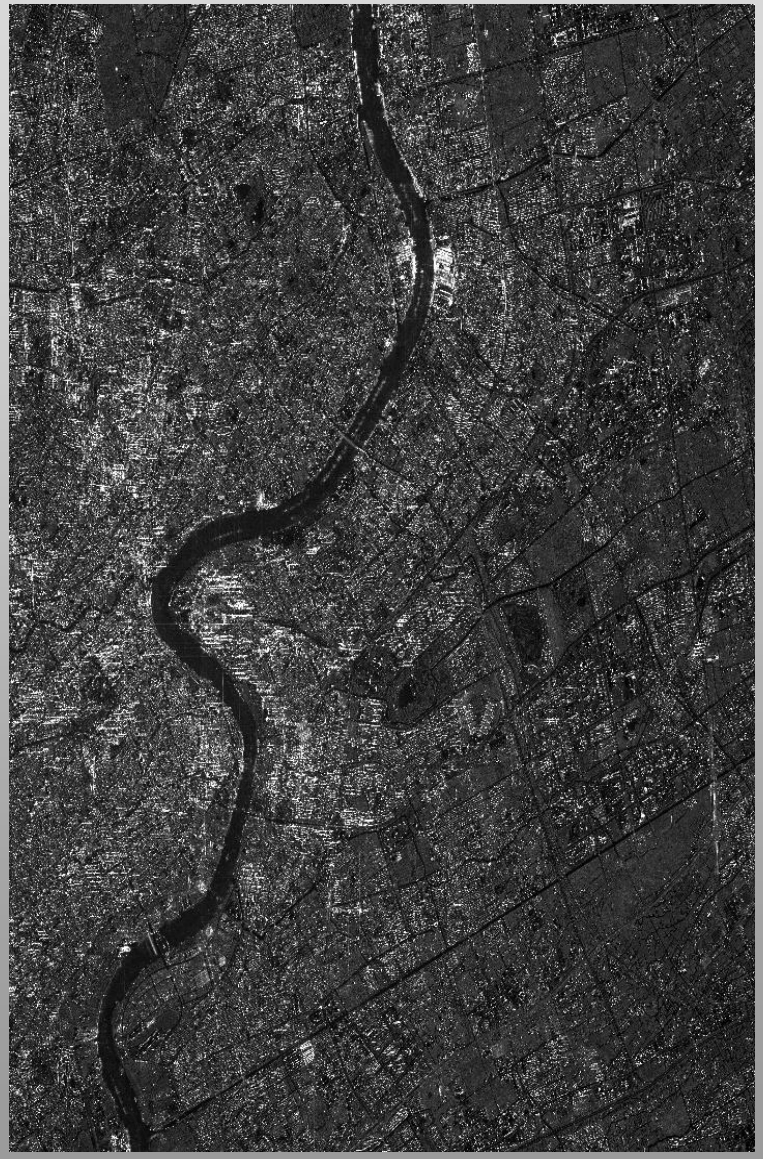
CCD overlayed on CSK DTM



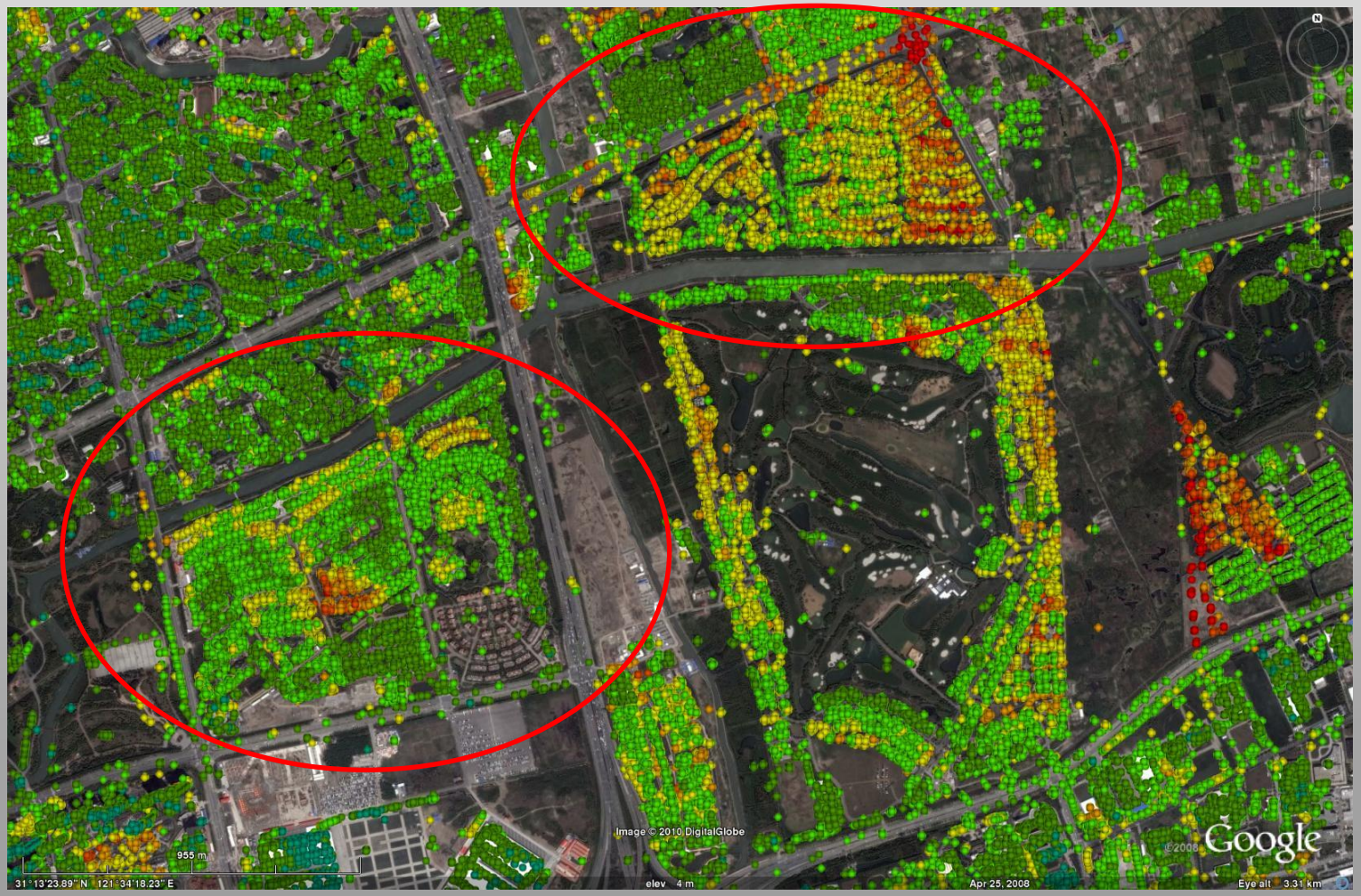
Derived from a tandem interferometric pair; 5 meters posting

Shanghai: COSMO-SkyMed acquisitions used for PSP-IFSAR analysis

- Stripmap H4-0B acquisition mode
- Ground resolution 3 m x 3 m
- Polarization HH
- Incidence angle 23.96°
- Right looking, descending pass
- Analyzed period:
  May. 2008 – Dec. 2009
- Number of acquisitions: 36



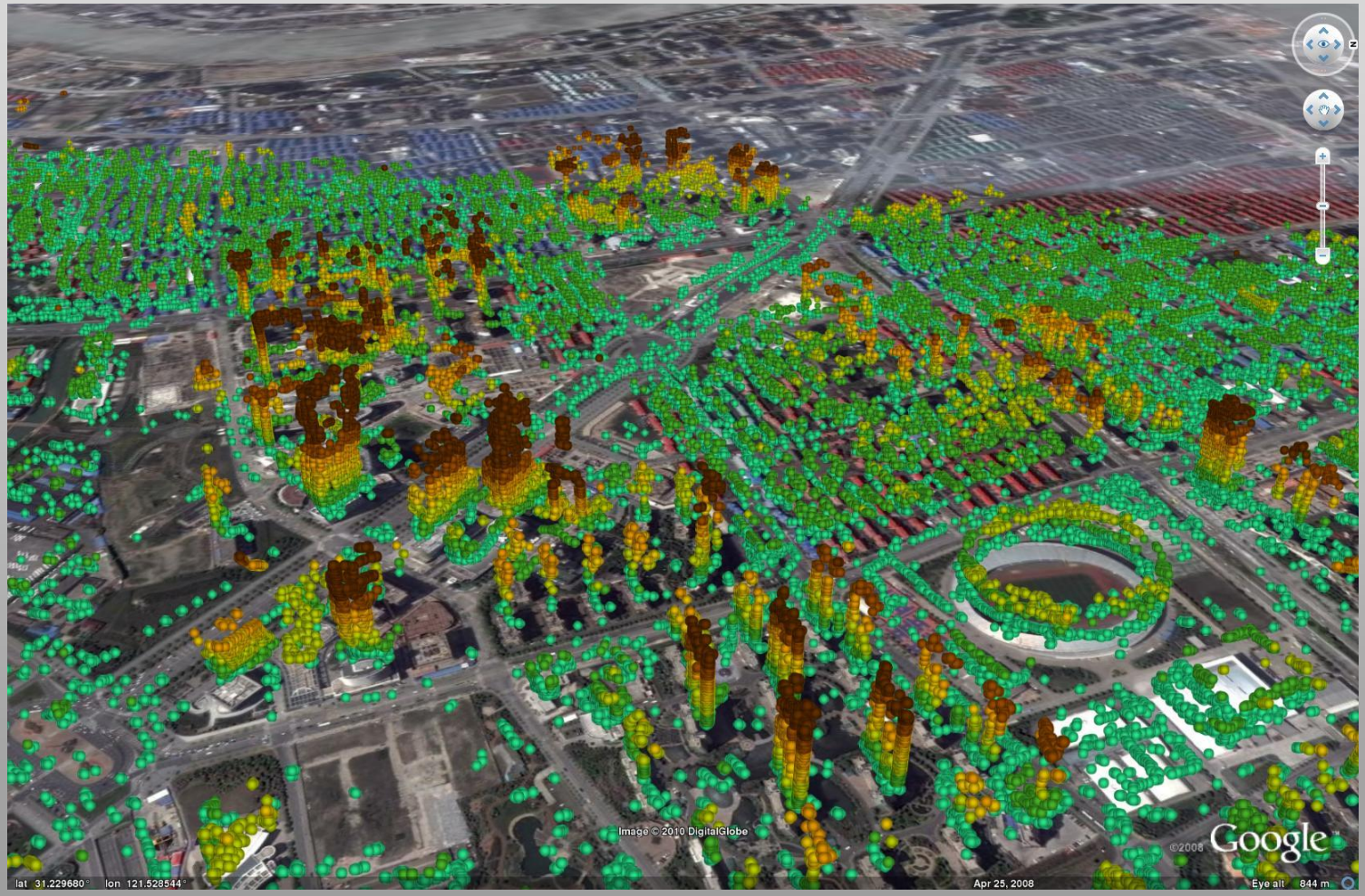
Shanghai: PS mean velocities



Mean velocity (mm/year)

- -100 - -17.5
- -17.5 - -12.5
- -12.5 - -7.5
- -7.5 - -2.5
- -2.5 - 2.5
- 2.5 - 7.5
- 7.5 - 12.5
- 12.5 - 17.5
- 17.5 - 22.5
- 22.5 - 100

Tall buildings: PS heights 3D view



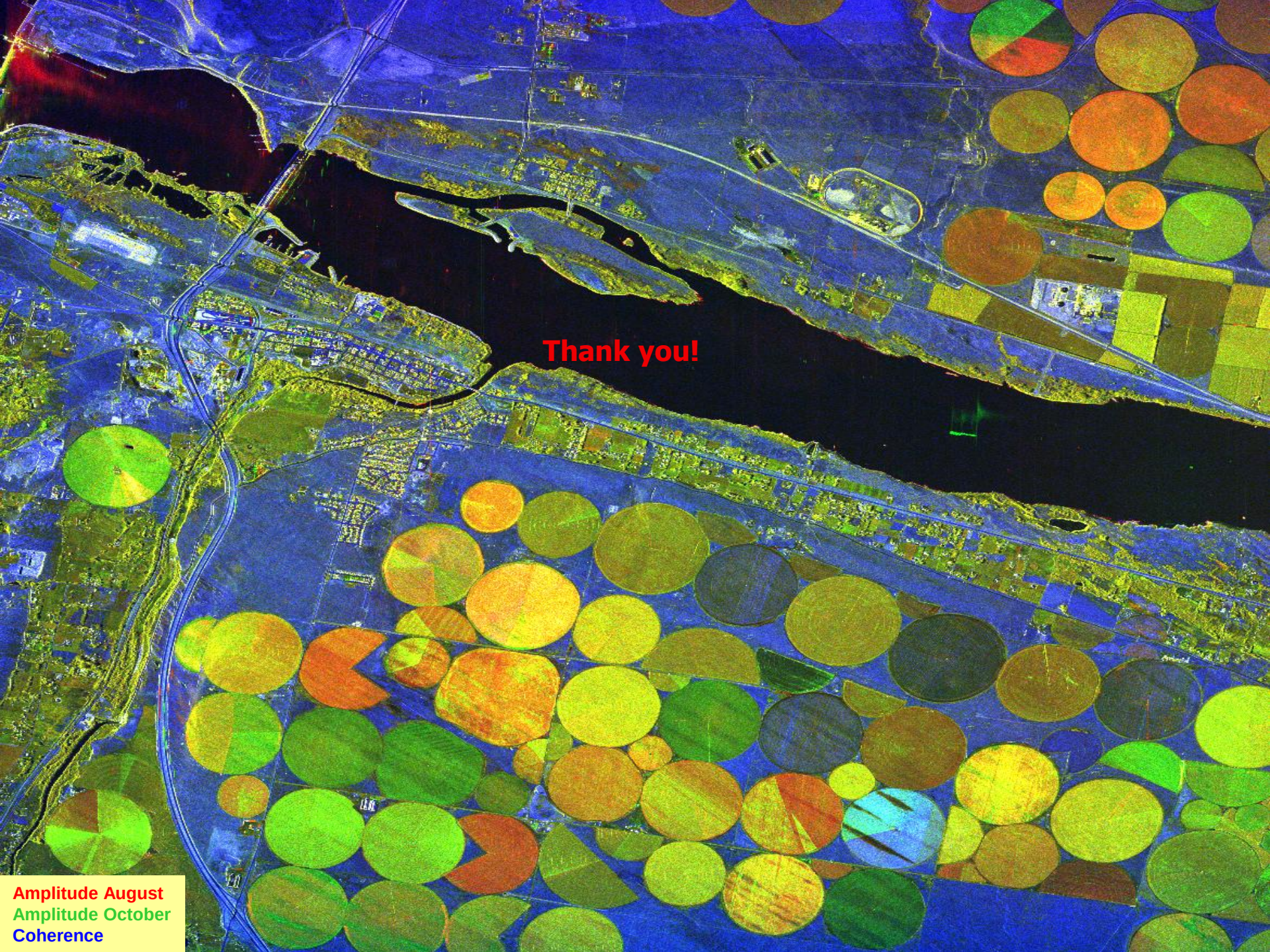
Height (m)

- 0 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80
- > 90

Memo

- **There will be a demonstration of the C-MAPS in Gaitherburg at the half of April**

- **COSMO-Skymed Imagery now available to US Government Users through NGA contract with e-GEOS/Lockheed Martin**
  - Contact: Luciana Di Domenico (Luciana.didomenico@e-geos.it), info (info.cosmo@e-geos.it)


Thank you!
Amplitude August
Amplitude October
Coherence