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Sensitivity Analysis of Threshold of Overlapping Pixels to the Pixel-Object Fusion Change Detection for Countering Nuclear Proliferation

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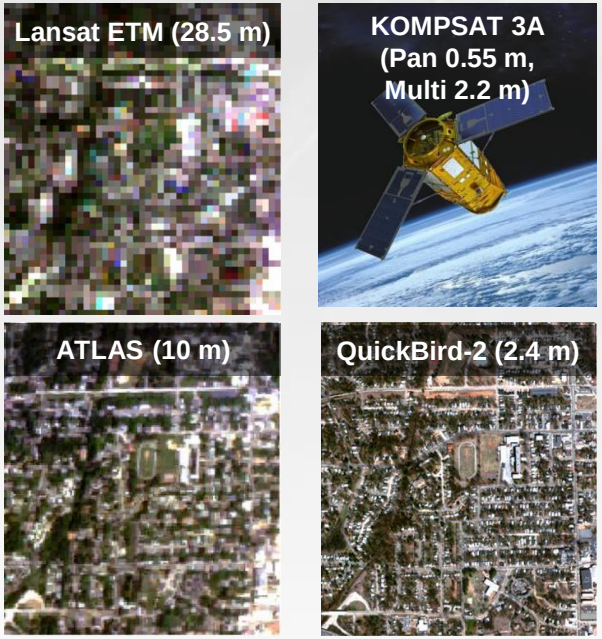
1. Introduction

1.1. Backgrounds

- With the enhancement of **the spatial resolution of satellite imagery (< 1 m),**
  → Satellite image analysis has been utilized as **an indispensable technology** to support remote sensing for nuclear nonproliferation especially **in the restricted access areas.**

Spatial resolution of satellite sensors



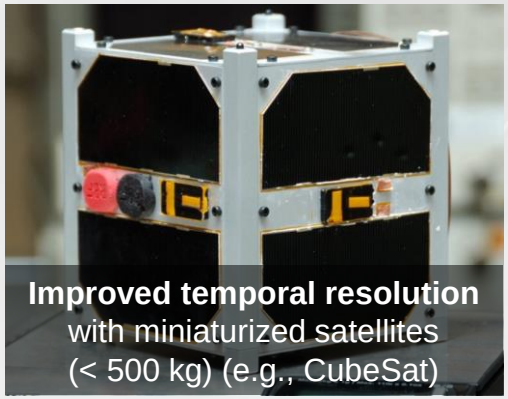
Satellite imagery analysis published in ***38 North***

- For example, **NGOs such as *38 North* and *CSIS***(*Center for Strategic and International Studies)* have **observed and analyzed the major (even minor) changes to imply suspicious nuclear activities in North Korea.**

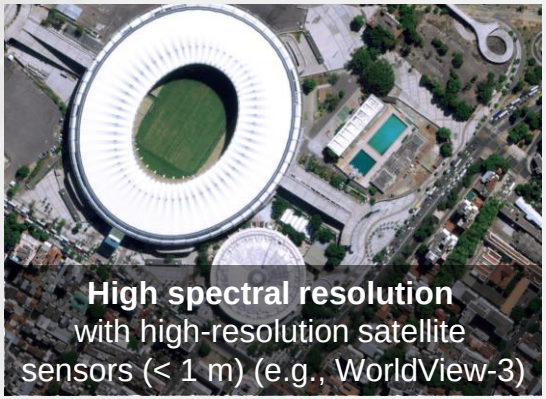
1. Introduction

1.2. Why do we need a computer-based image analysis?

- To efficiently utilize **the rapid increasing number of satellite information (including the number of satellites and the improved spatial and temporal resolution)**



Improved temporal resolution with miniaturized satellites (< 500 kg) (e.g., CubeSat)



High spectral resolution with high-resolution satellite sensors (< 1 m) (e.g., WorldView-3)

Massive amounts of satellite information for interpretation

→ It is necessary to adopt **the computer-based image analysis** for supporting **the human interpretation.**

→ ∴ Since 2019, ***KINAC*** has developed **Pixel-object fusion change detection algorithm**

1) Pixel-based change detection (MAD)
2) Object-based segmentation
3) Extraction of the change objects

- Although **the algorithm can save time and cost for image interpretation**, the change detection results can include **uncertainties related to governing variables defined by human interpretation expertise, e.g., *threshold of overlapping pixels (TOP)*.**

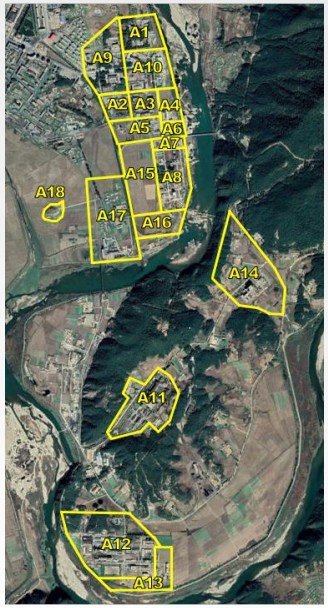
1. Introduction

1.3. Objectives

➢ **To evaluate the sensitivities (uncertainties) of *TOP*** postulated in the pixel-object fusion change detection **by comparing the traditional accuracy assessment indices, i.e., *precision* and *recall*, within various *TOP* values.**

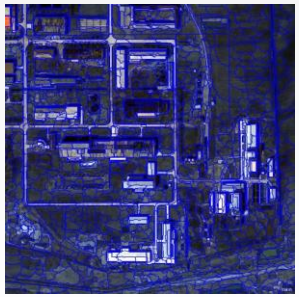
※ Prior to that, **the area of interest (AOI)** and **the process and result of the pixel-object fusion change detection** were also explained in detail.

0) AOI: Yongbyon nuclear complex

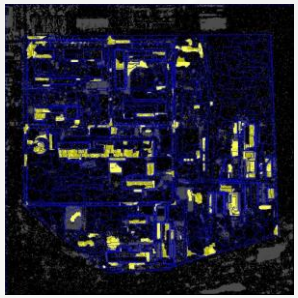


1) Pixel-based change detection

2) Segmentation

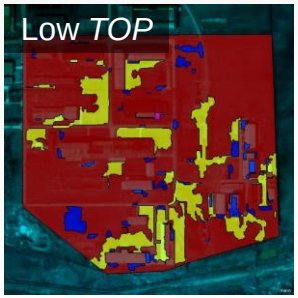


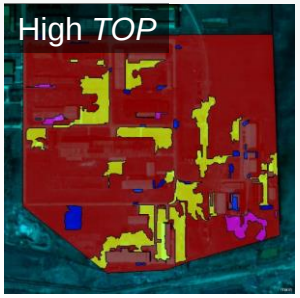
3) Extraction of change objects



Pixel-object fusion change detection algorithm

4) Sensitivity assessment (*precision* & *recall*)





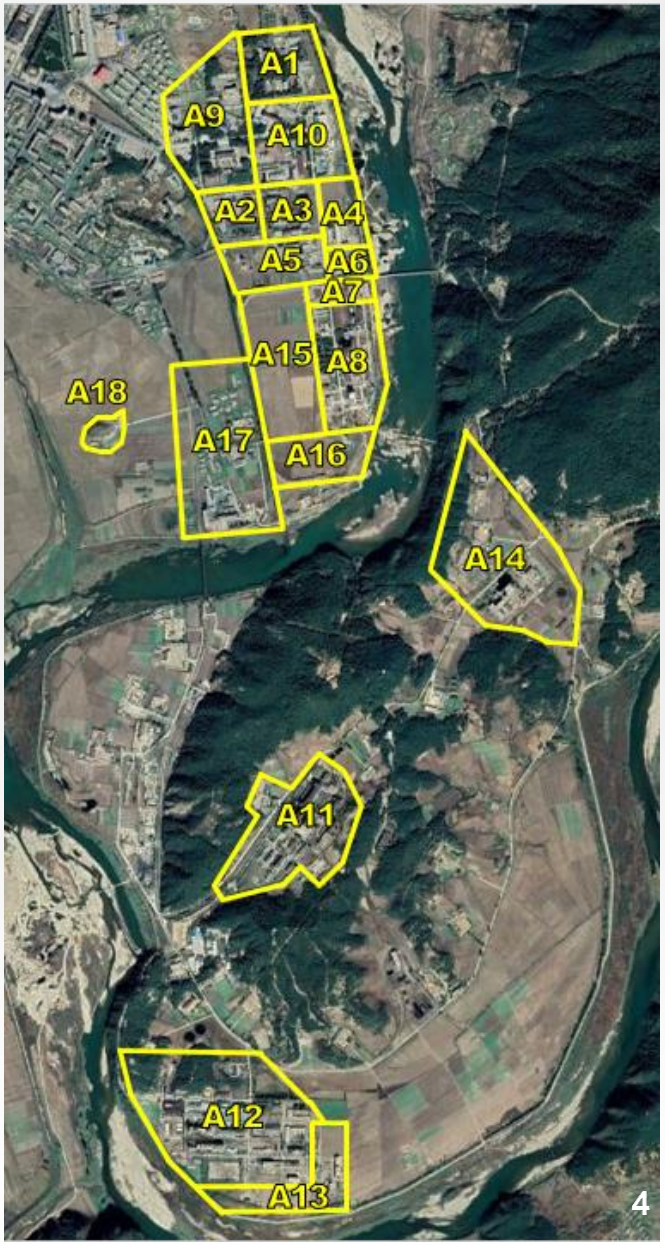
2. Methods and Results (1/8)

2.1. AOI: *The Yongbyon nuclear complex* (1)

- The Yongbyon nuclear complex has played a decisive role for North Korea's nuclear weapon program.
- It consists of **the 5 MW_e reactor (A8), the radiochemical laboratory (RCL) (A11), and the uranium enrichment plant (UEP) (A12 & A13).**

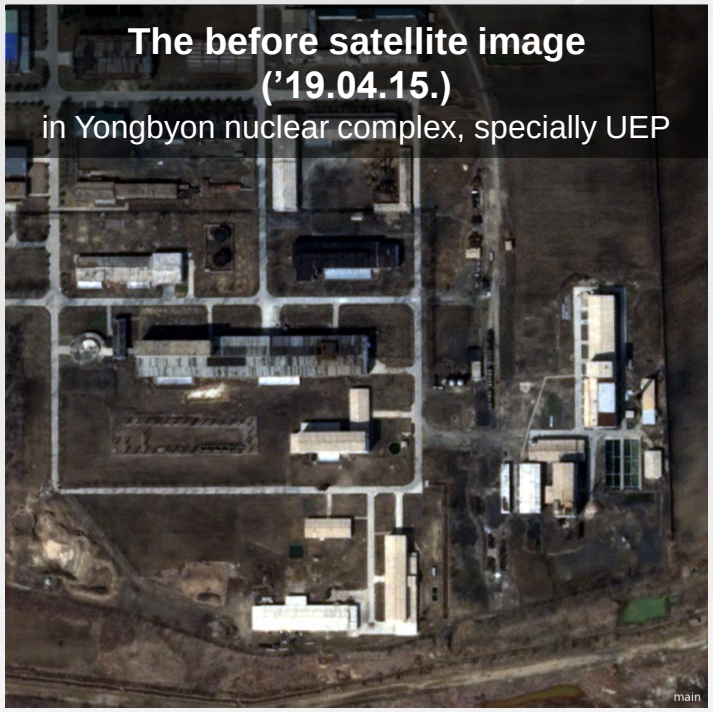
※ The latest article in *38 North* for Yongbyon

→ ∴ **From the perspective on nuclear nonproliferation**, the Yongbyon nuclear complex **(specially UEP) (A13) was selected as the monitored AOI.**



2. Methods and Results (2/8)

2.1. AOI: *The Yongbyon nuclear complex* (2)



※ Characteristics of satellite images	
Satellite sensor	SkySat (Planet Explore)
Sensor bands	Panchromatic, Red, Green, Blue, NIR (Near Infrared)
Spatial resolution	0.50 m
Off-nadir angle	8.5 ° / 0.2 °
Subset image size	890×890

2. Methods and Results (3/8)

2.2. Pixel-object fusion change detection algorithm

1. Pixel-based change detection
(MAD)

Python

2. Segmentation
considering multi-temporal images

eCognition

3. Extraction of the change objects
by overlaying MAD with the segmentation layer

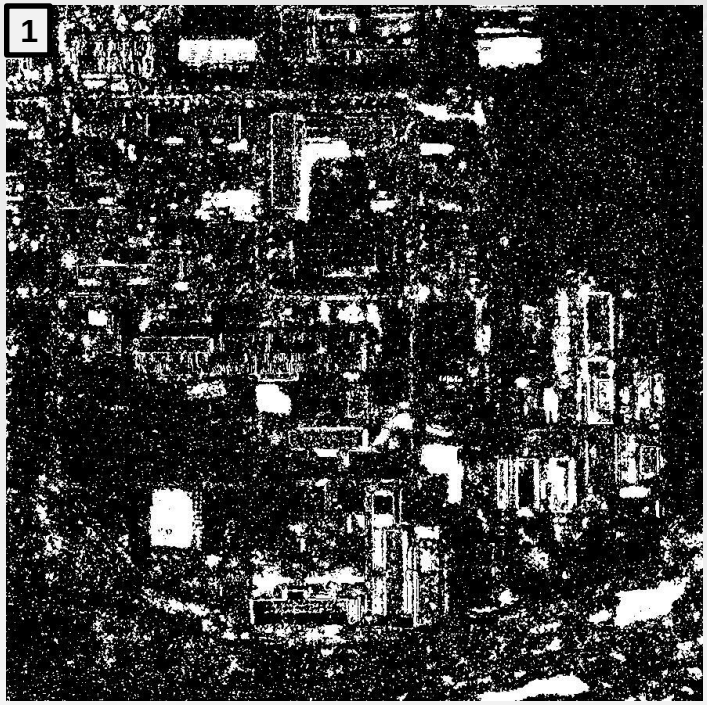
eCognition

※ Pre-processing of SkySat satellite imagery

- To correct the radial and the geometric distortions, pre-processing need to be performed, i.e., the Gram-Schmidt pan-sharpening and the image-to-image registration.
- However, since **Planet Labs provides the high-quality pre-processed SkySat satellite imagery, no additional pre-processing is required in most cases.**

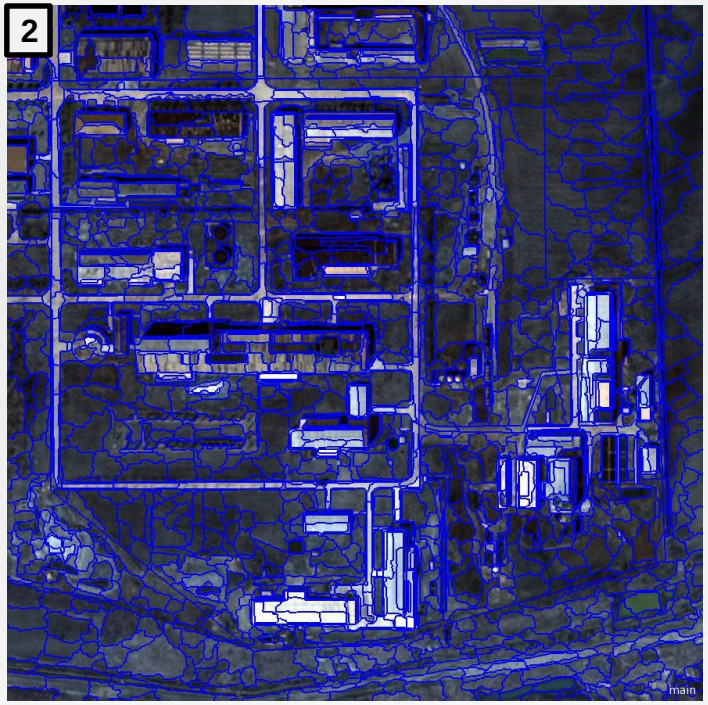
2. Methods and Results (4/8)

1. Pixel-based change detection (*MAD*)



- Discrimination of **the changed pixels** between images by ***MAD (Multivariate Alteration Detection)*** **with a static reliability of 70 %**
- ***White: the changed pixels***

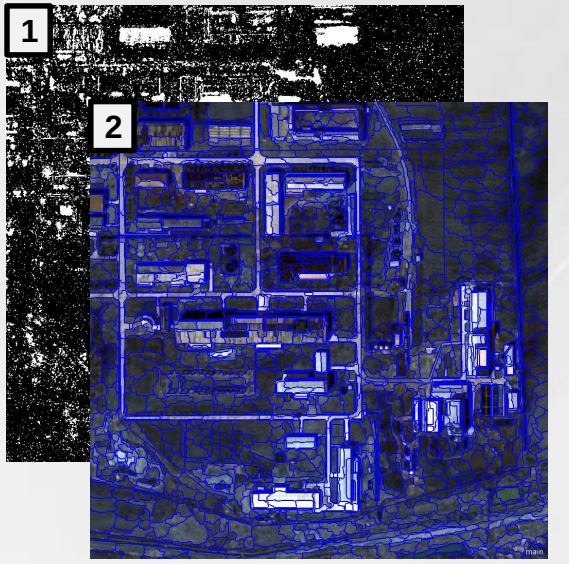
2. Segmentation considering multi-temporal images



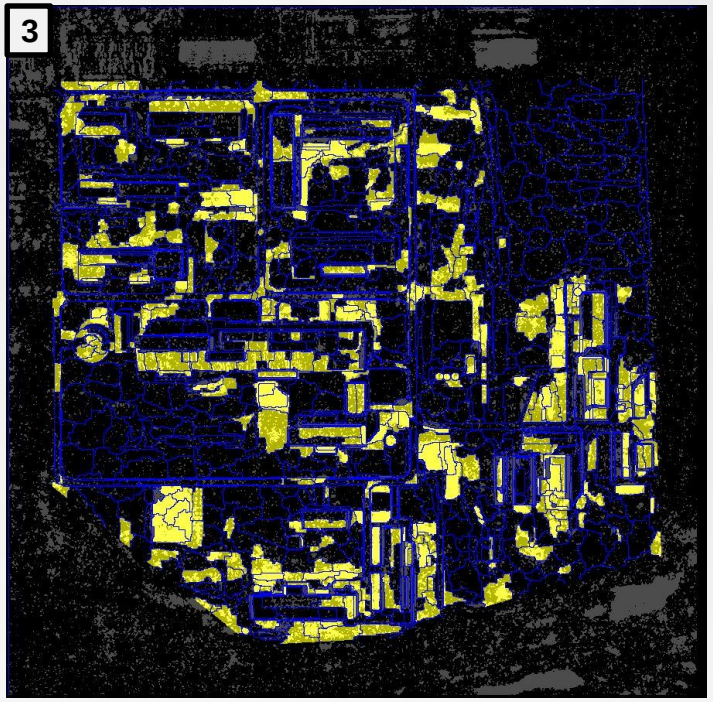
- Segmentation into image objects with **similar spectral homogeneity by considering all layers** (8 bands of both images)
- ***Blue: the boundaries surrounding image objects***

2. Methods and Results (5/8)

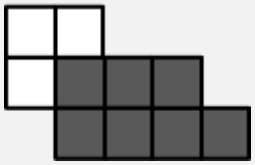
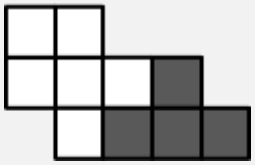
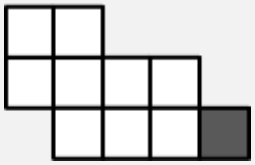
3. Extraction of the change objects by overlaying MAD with the segmentation layer



- Distinguishing the change objects from the no-change objects with ***TOP (Threshold of Overlapping pixels)***
- ***Yellow: the change objects***



※ Conceptual diagram of *TOP* in a segment

Segment	*a*	*b*	*c*
Ratio of overlapping pixels	0.3	0.6	0.9
Conceptual diagram			

- If ***TOP* is 0.5**, **segment *b* and *c* are the change objects**.
- If ***TOP* is 0.8**, **segment *c* is the change object.**

2. Methods and Results (6/8)

2.3. Sensitivity of *TOP* to the change detection accuracy (1)

※ Traditional change detection accuracy indices: ***Precision*** and ***Recall***

- Requirement for the outstanding change detection algorithm
  → **Minimizing false positives and false negatives**

Confusion matrix (Error matrix)		Actual Class	
		Positive	Negative
Predicted Class	Positive	True Positive ↑	False Positive ↓ **(False Detection)**
	Negative	False Negative ↓ **(Undetected)**	True Negative

Type *II* error

$$Recall \uparrow = \frac{TP \uparrow}{TP \uparrow + FN \downarrow}$$

Type *I* error

$$Precision \uparrow = \frac{TP \uparrow}{TP \uparrow + FP \downarrow}$$

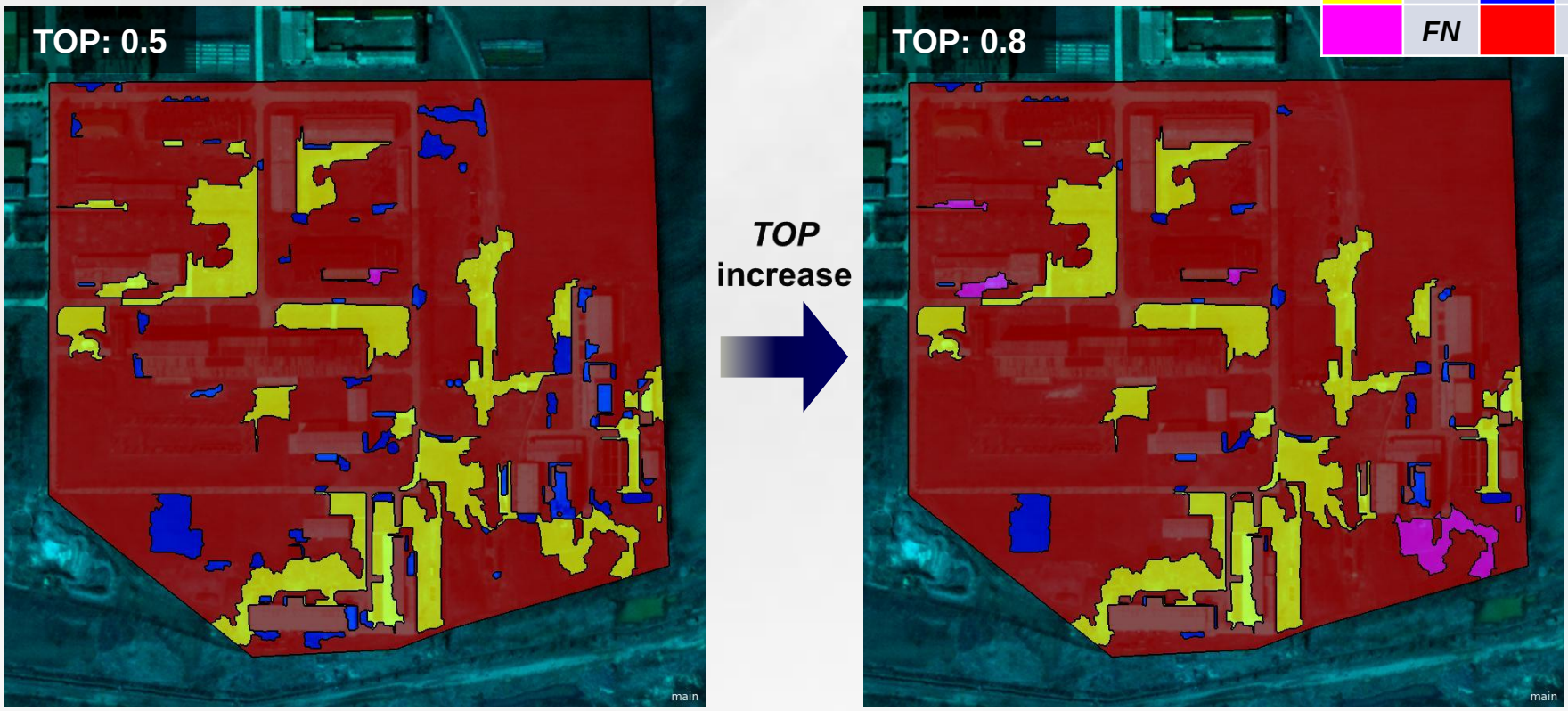
- In this study, to analyze the sensitivity of *TOP*, ***precision*** **and** ***recall*** were **estimated in accordance with various *TOP* values, i.e. 0.1 to 0.8,** where **a step size is 0.1.**

2. Methods and Results (7/8)

2.3. Sensitivity of *TOP* to the change detection accuracy (2)

※ Legend

	TP		*FP*
	FN		*TN*



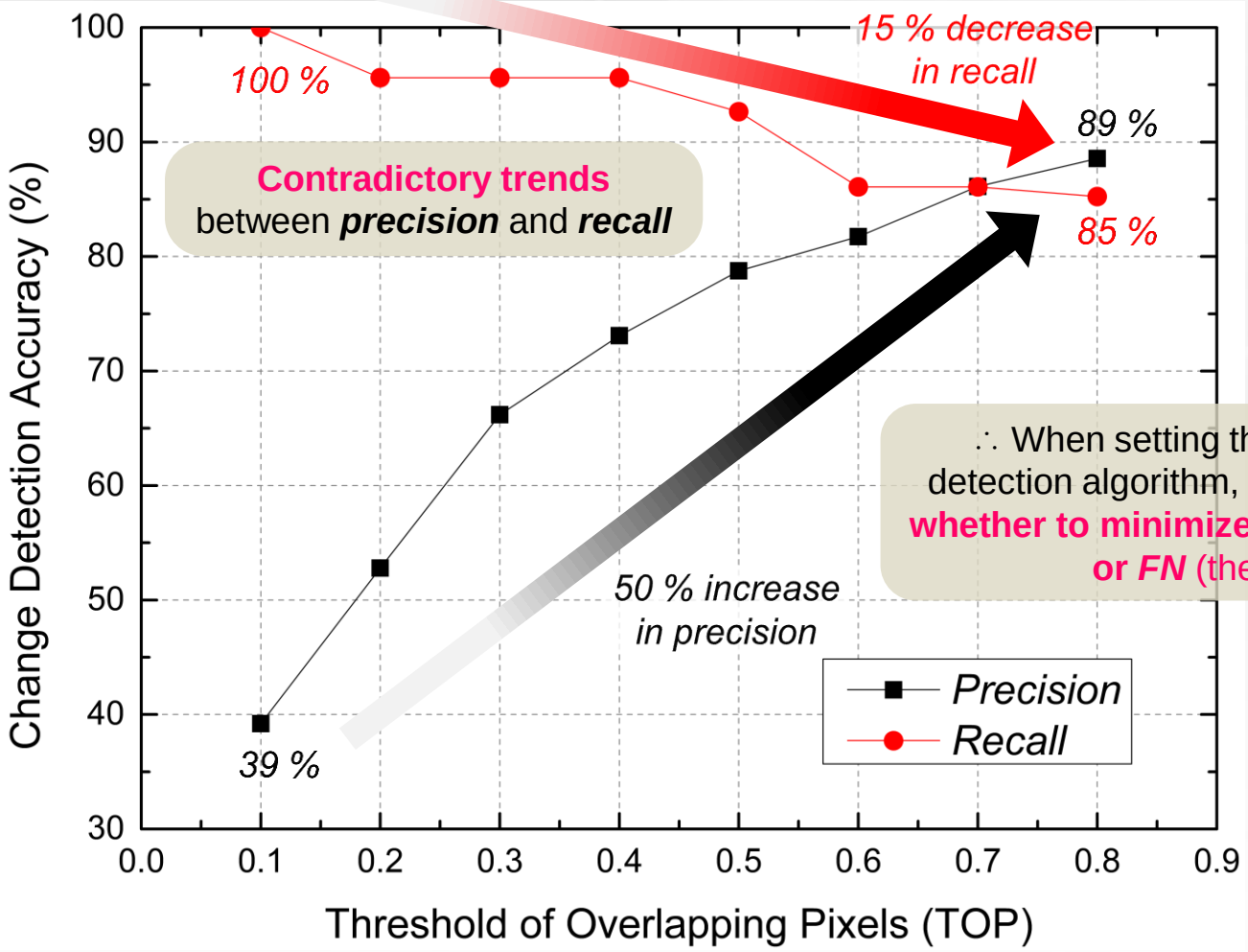
- In both images above, **positives (*TP+FP*)** were **the change objects.**
- In addition, **the lager *TOP*, the less *FP* (↓) and the more *FN* (↑).**

※ TP, FP, FN, and TN were determined **with the user-defined *ROI (Regions of Interest)* for the actual change objects.**

2. Methods and Results (8/8)

2.3. Sensitivity of *TOP* to the change detection accuracy (3)

Sensitivities of *TOP* to *precision* and *recall* in the change detection results



∴ When setting the goal of the change detection algorithm, it is necessary to decide **whether to minimize *FP*** (the false detections) **or *FN*** (the undetected).

3. Conclusions and Future work

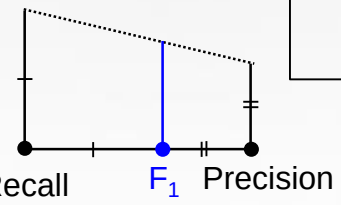
1) ***Precision*** **(FP, the false detections) and** ***recall*** **(FN, the undetected) were estimated as contradictory with increasing** ***TOP*****.**
→ ∴ It is necessary **to decide whether to minimize FP or FN for supporting remote sensing for nuclear nonproliferation.**

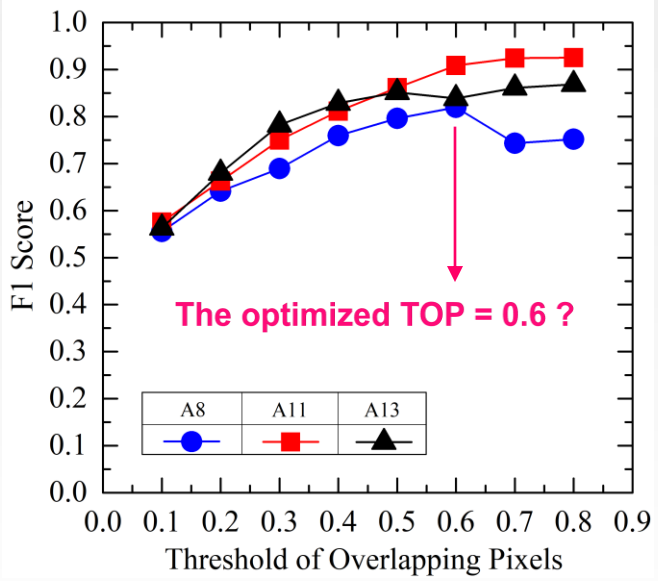
2) Sensitivities of *TOP* to the change detection accuracy was investigated as **50 % increase and 15 % decrease in** ***precision*** **and** ***recall*** **with the** ***TOP*** **variation from 0.1 to 0.8.**

Future work: Optimizing *TOP*

- *TOP* in the pixel-object fusion change detection need to be optimized **by minimizing both FP and FN reasonably.**
- For example, **the F_1 score, which is the harmonic mean of precision and recall, can be applied and analyzed to the optimization work.**

$$\therefore F_1 \uparrow = \frac{2}{\frac{1}{Precision \uparrow} + \frac{1}{Recall \uparrow}}$$





Thank You!

Q&A