Effective methods for detecting interesting patterns in hyperspectral data

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RS&IP Group: main projects

PROJECT	DESCRIPTION	Funded by/users-customers	PRIME
HIGHSENSE	2013-2015 – Very high spatial and spectral resolution remote sensing: a novel integrated data analysis system	Italian Ministry of University and Research - MIUR	University of Genoa
SAP4PRISMA	2010-2014 – Development of algorithms and products for applications in agriculture and land monitoring to support the PRISMA mission	Italian Space Agency - ASI	CNR IMAA
DUCAS	2009 – 2013 – Detection in Urban scenario using Combined Airborne imaging Sensors	European Defence Agency - EDA	FOI
SULA	2010-2012 – Advanced Sensor for Underwater Laser 3D Analysis and Detection	Italian Ministry of Defence	DII
COSMOSkyMed	2010-2012 – Development and validation of multitemporal image analysis methodologies for multirisk monitoring of critical structures and infrastructures	Italian Space Agency - ASI	University of Genoa
ECOMOS	2014- The European Computer Model For Optronic System Performance Prediction (ECOMOS)"	European Defence Agency - EDA	DLR
HIPOD	2006 - Hyperspectral Imaging Program fOr Defense	European Defence Agency - EDA	FOI

Projects funded by or in cooperation with:

- Italian Space Agency (ASI)
- Ministry of Defence
- EDA (ONERA, TNO, RMA, FFI, FGAN etc.)
- MIUR
- Tuscany Region
- National Industry SELEX-ES
- Local companies (IDS, FlyBy, etc.)

- Permanent staff
  - Prof. Marco Diani (Italian Naval Academy)
  - Prof. Giovanni Corsini (University of Pisa)
  - Dr. Nicola Acito (Italian Naval Academy)
  - Dr. Stefania Matteoli (CNR-IEIIT)
- PhD students
  - Matteo Moscadelli
  - Dr. Zingoni Andrea

Outline

- **Object/material detection in HSI**
- **Object/material detection taxonomy**
  - **Single image analysis**
    - Anomaly detection
    - Spectral matching
  - **Multitemporal image analysis**
    - Change detection
    - Object relocation
- **The “Viareggio 2013” trial**
- **Conclusions**

The detection problem

- **Objective:** generate a gray scale image (black/white after thresholding) where intensity measures the degree of interest of the pixels (black=uninteresting/background, white=object/material of interest).
- **Hypothesis:** Object pixels cover a small fraction of the image.
- **Detection approach:**

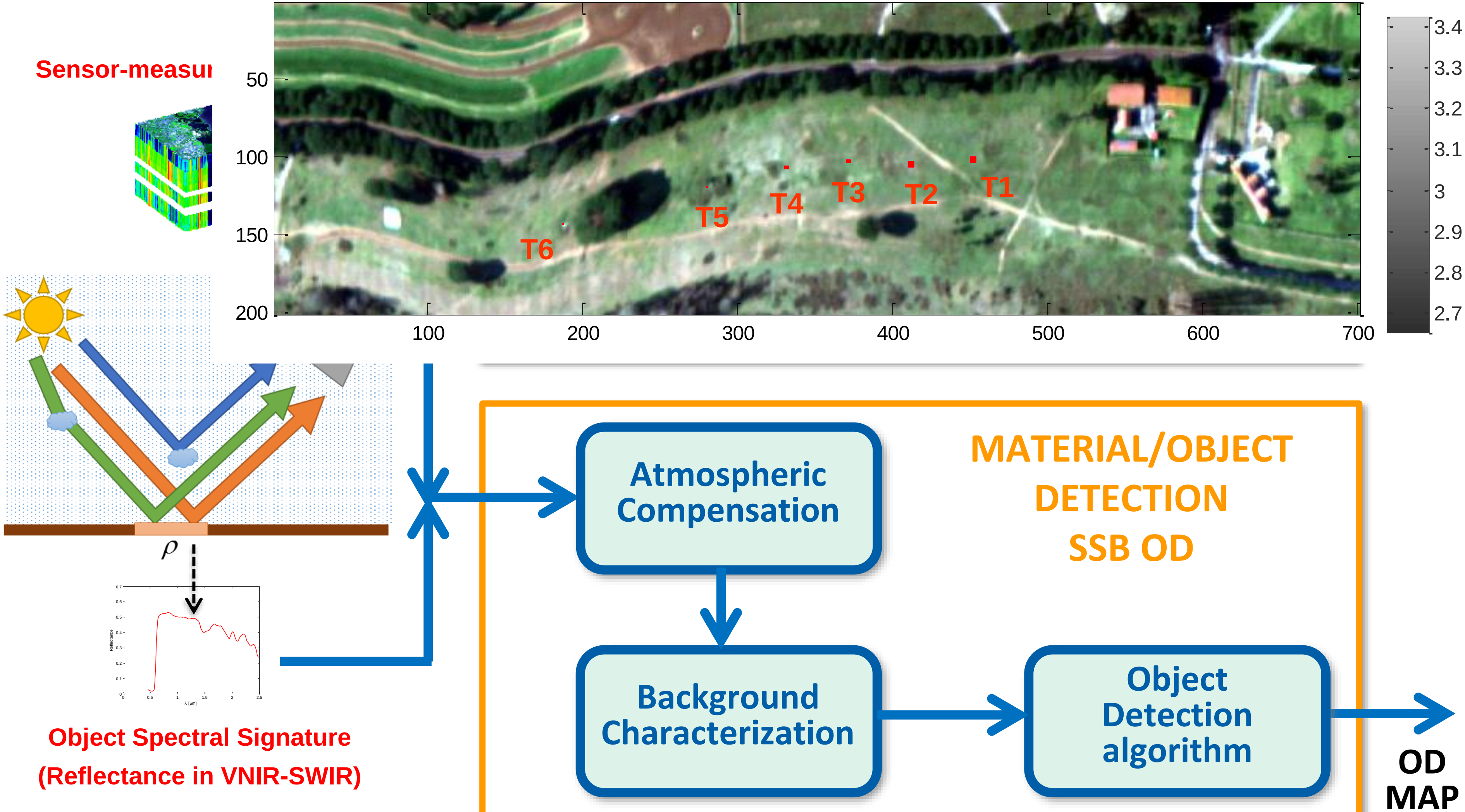
$$\mathbf{X} = \mathbf{S}\mathbf{a}_t + \mathbf{B}\mathbf{a}_b + \mathbf{w} = \underbrace{\sum_{k=1}^{n_T} a_{t_k}\mathbf{s}_k}_{\text{Target materials signatures}} + \underbrace{\sum_{n=1}^{n_B} a_{b_n}\mathbf{b}_n}_{\text{Background signatures}} + \underset{\text{Noise and lack of fit}}{\mathbf{w}}$$

Structured background model (*subpixel*)

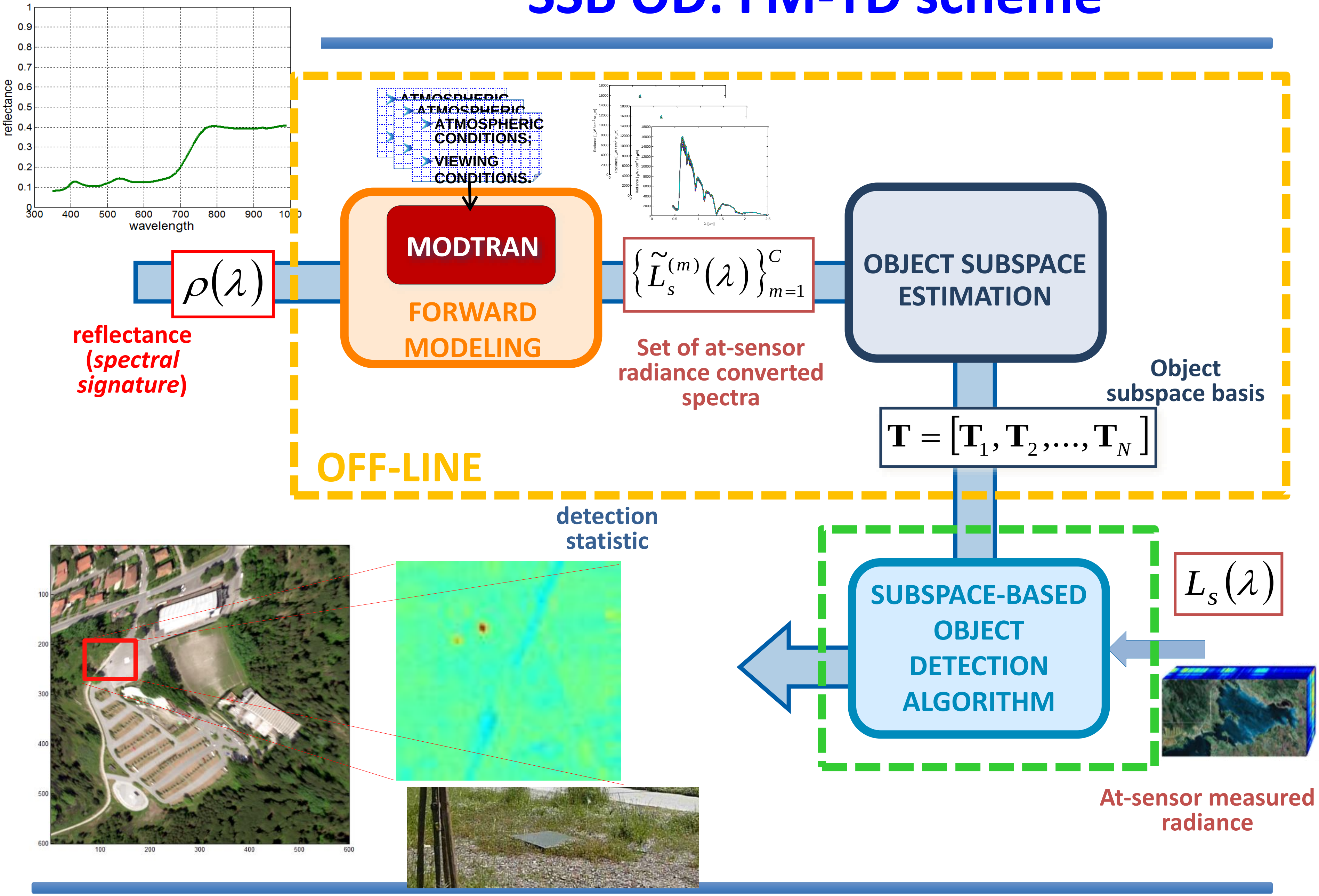
$$\text{On the basis of } \mathbf{X} \text{ decide: } \begin{cases} H_0: \text{ target material not present} \\ H_1: \text{ target material present} \end{cases}$$

- **Detection vs classification:**
  - ✓ **Training:** in general, only one object reference spectrum is available. Background class must be learned from the data themselves. Background includes most of the image pixels and is made up of different classes.
  - ✓ **Decision strategy**: Bayesian approach based on minimization of the average error probability does not fit. Neyman-Pearson criterion is invoked. CFAR property is desired.
  - ✓ **Dimensionality reduction**: methods must preserve rare objects (PCA cannot be used).
  - ✓ **Real-time** or near real-time is often required.
- **Detection vs unmixing**
  - ✓ $\mathbf{b}_n, n = 1, 2, \ldots, n_B$ not estimated as physical endmembers with corresponding abundances.

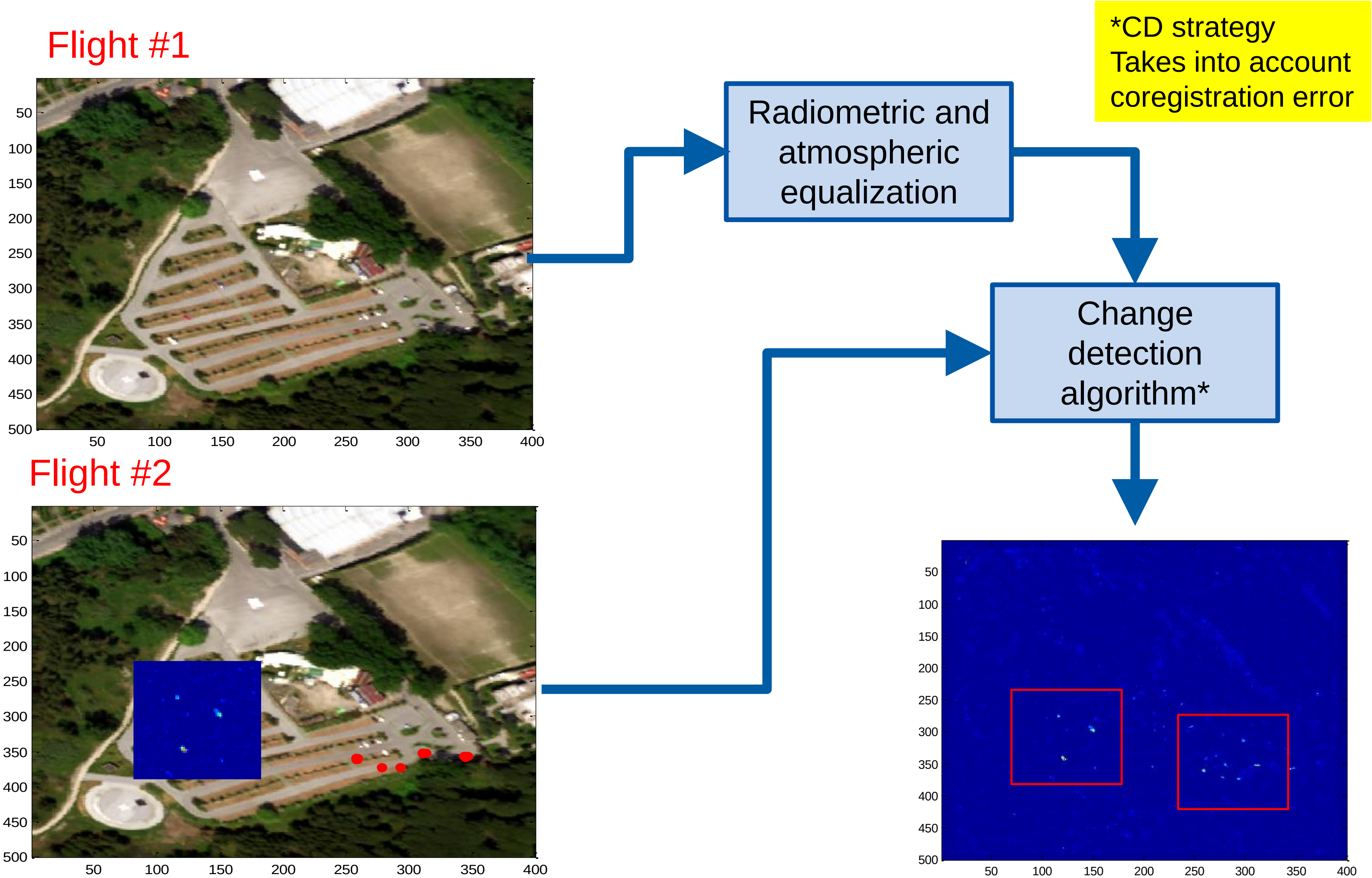
HSI processing for object detection



SSB OD: FM-TD scheme



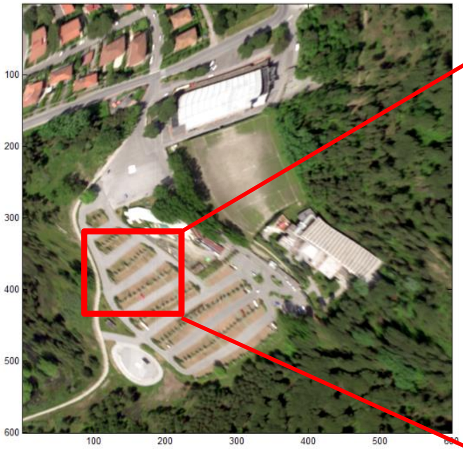
Unsupervised multitemporal analysis: anomalous change detection



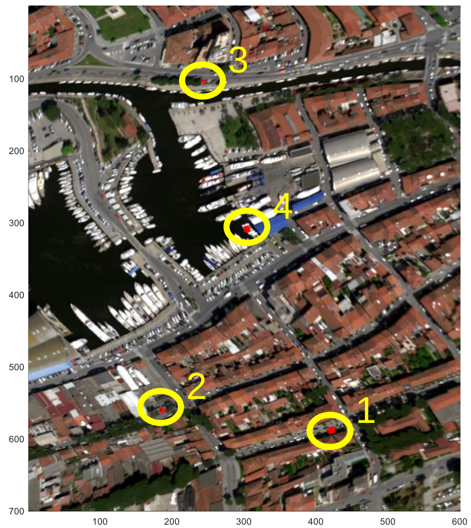
Red spots are changes documented in the ground truth

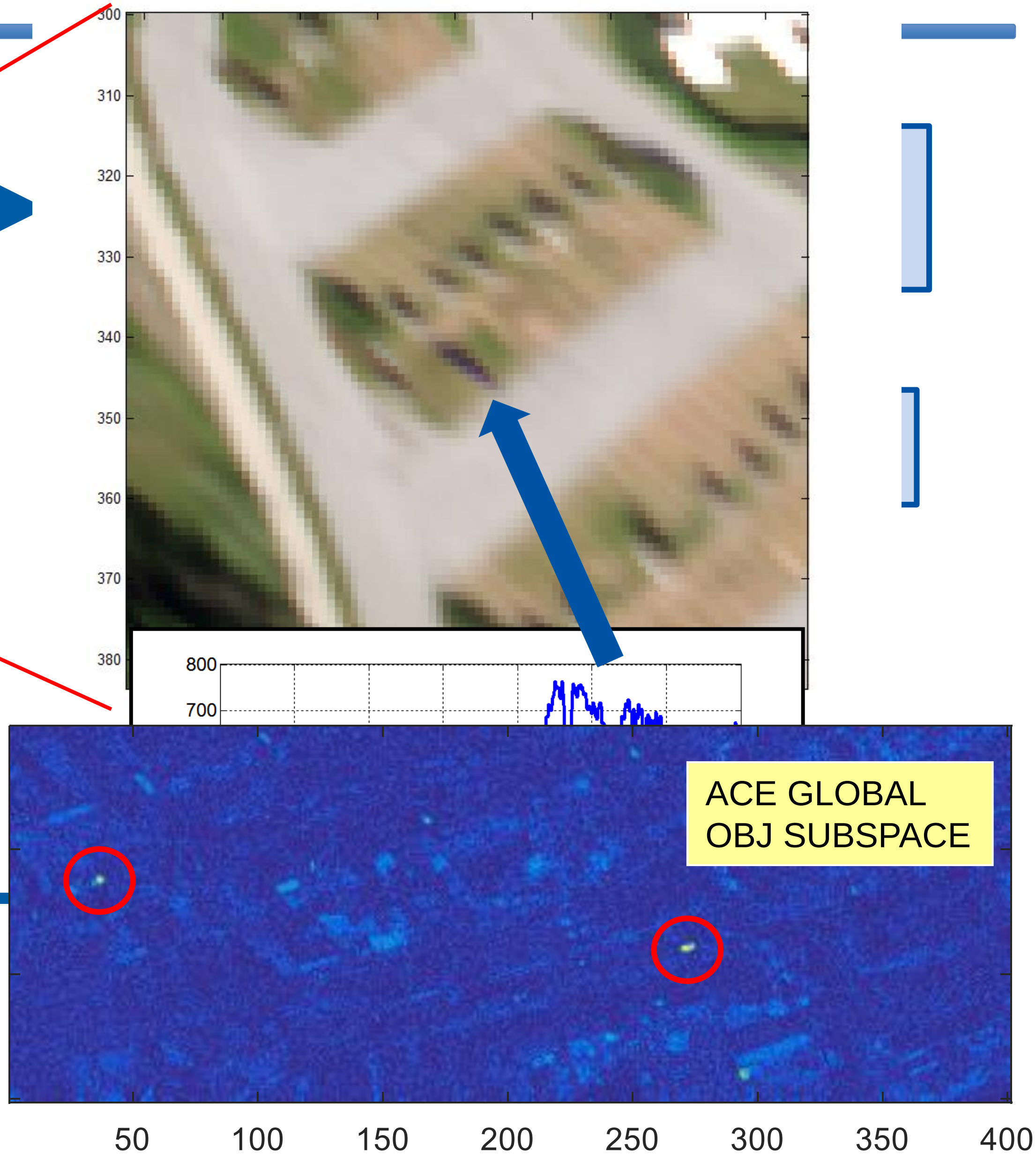
Supervised multitemporal analysis: object rediscovery

Flight #1



Flight #2 (wider area)





Combining search criteria reduces # of detections

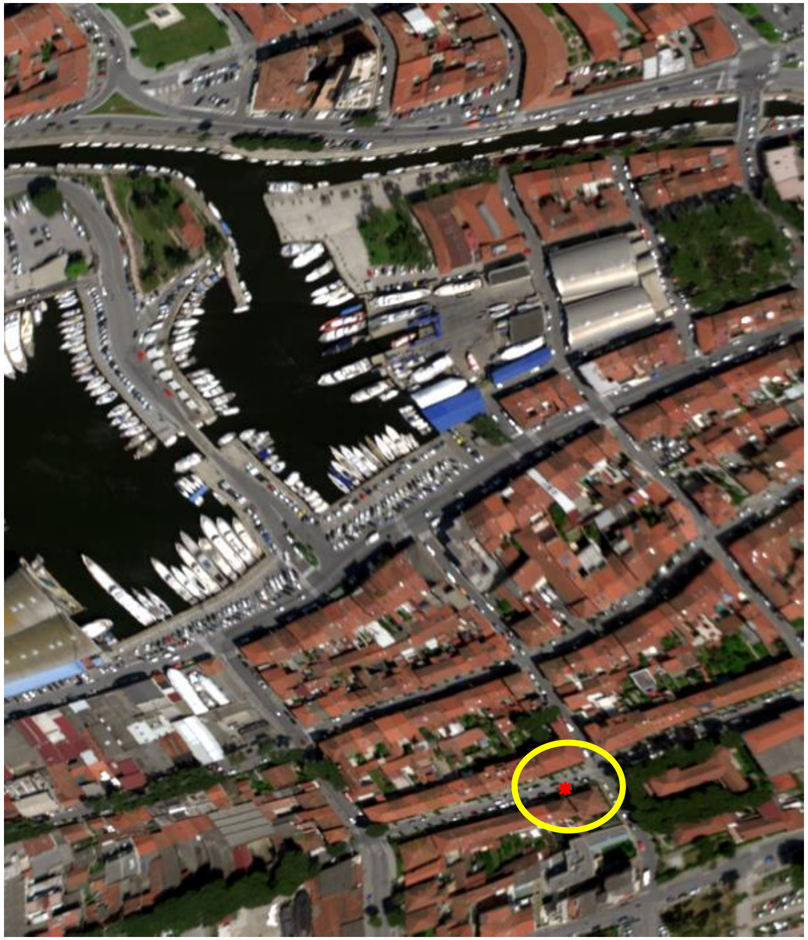
SSB Object detection

Map of pixels whose spectrum resembles the reference one

ACD map

Map of pixels where an object has entered the scene

Combining search criteria reduces # of detections



Pixels whose spectrum resembles the reference one

.AND.

Pixels where an object has entered the scene

«Viareggio 2013» trial

Campagna di misura condotta da
CISAM – Pisa
Leonardo (Finmeccanica)
Università di Pisa

Free data and ground truth available online at **http://rsipg.dii.unipi.it/**

N. Acito, S. Matteoli, A. Rossi, M. Diani, G. Corsini, *Hyperspectral Airborne «Viareggio 2013 Trial» Data Collection for Detection Algorithm Assessment*, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, Vol. 9, Issue: 6, June 2016.

Conclusion

- Object/material detection is a method for the automatic analysis of hyperspectral images which is of potential interest in different applications (detection and tracking of pollutants, detection of areas of vegetation stress, geology, wide area surveillance, search and rescue - SAR) and for different final users (civil protection, coast guard, agencies for defense and security, etc.).
- Object detection aim to drive the operator's attention to few ROIs that deserve further analysis. This reduces the time required to explore wide areas searching for specific objects and materials.
- Hyperspectral sensors complement the information carried by other instruments (broadband imagery, SAR, etc.) and improve the capability of detecting objects/materials in a monitored area using the information carried by the spectrum of the radiance emitted/reflected from an object.
- Custom advanced multidimensional signal processing is needed to detect small dim objects.
- Research is still ongoing on many aspects of the HSI detection problem.
  - Detectability in a subpixel framework.
  - Technological and processing aspects related to the exploitation of such spectral regions as SWIR, MWIR, LWIR. This is especially true for MWIR and LWIR regions that are necessary to guarantee day/night operability.
  - Benefits from big data analysis?