Coherence - Change Detection Matrix For Change Analysis From Repeat-Pass SAR images: A Case Study For Volcanic Eruption Monitoring

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Challenge 4: Risques naturels catastrophiques et vulnérabilité socio-économique

Overview

- Introduction
- Methodology
- Experimental results
- Conclusions and perspectives

Introduction

The Earth's surface is affected by different natural and environmental disasters

Volcanic eruptions and Earthquakes

Landslides

Glacier displacements

Floods and flash floods

Deforestation

Mining

Introduction

OBJECTIVE:

- Characterization of environmental changes (progressive, abrupt, periodic, etc.) affecting the Earth surface from temporal evolution of its radar backscattering properties and production of relevant information in terms of:

    1) land use/ land cover mapping ,

    2) vulnerability to natural hazards,

    3) damage assessment after natural disasters (volcanoes or orthers),

    4) resilience dynamics.

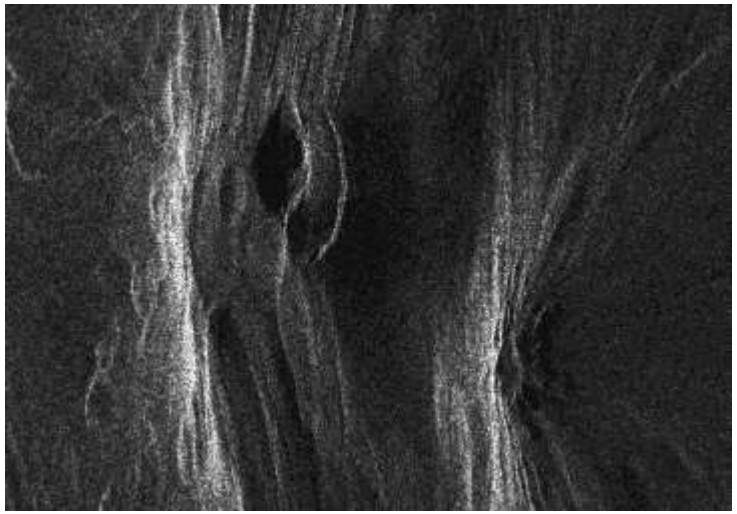
- Exploitation of Copernicus data time series for new natural hazard mitigation strategies.

Introduction

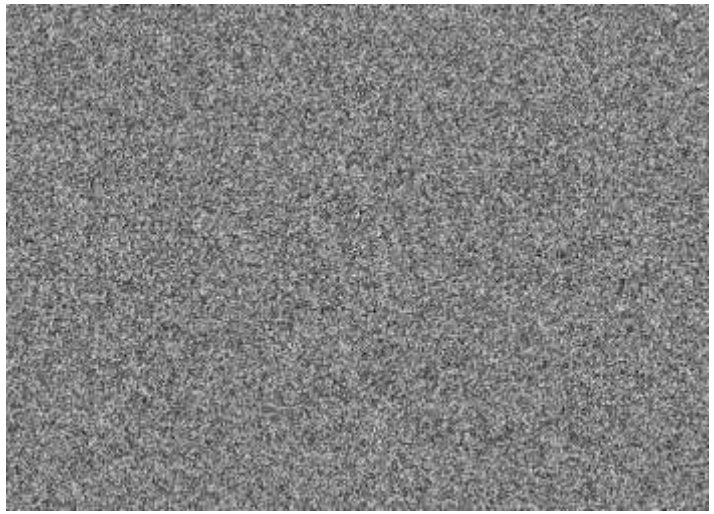
SAR data

Complex images (z = a + ib)

Each pixel: defined by amplitude and phase



Amplitude



Phase

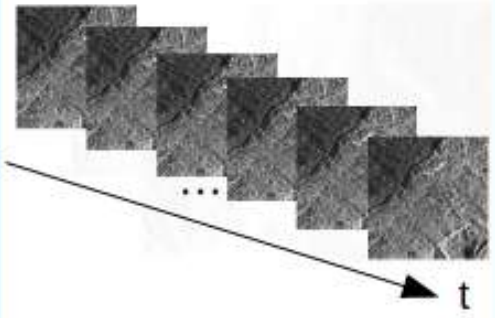
➔ Fully exploit both amplitude and phase information from SAR image time series

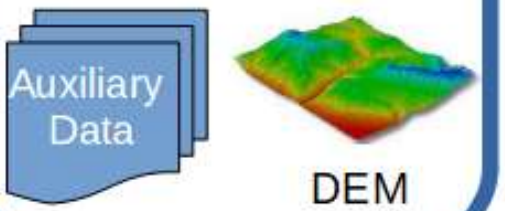
Exemple of a radar image : Lascar, 17 July 2004, ASAR ASC S2 T361 F6705

Methodology / General Strategy

DATA COLLECTION

Repeat – pass SAR images





PRE-PROCESSING

Calibration, Coregistration, Filtering;

Covariance / Coherency Matrix Estimation;

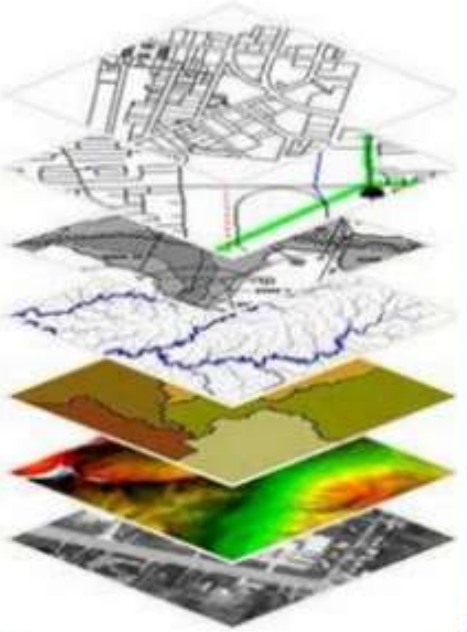
Orbit correction, Topographic Phase Compensation, Phase calibration.

PROCESSING

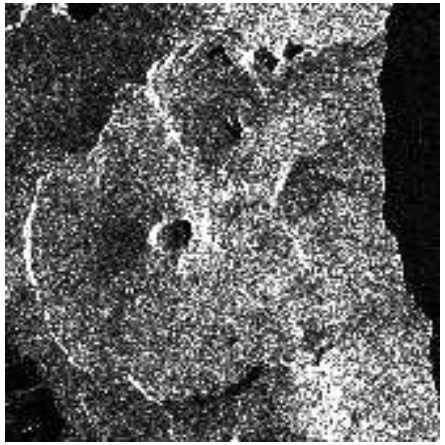
CCDM for Change/Deformation Information Extraction

POST-PROCESSING

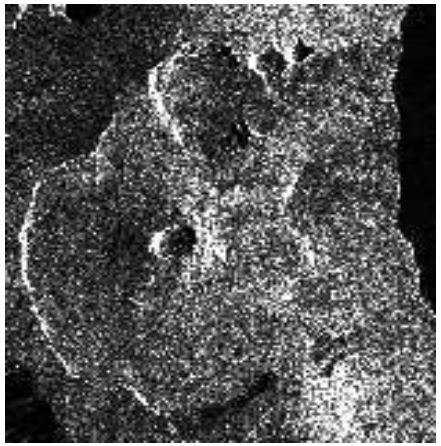
GIS



Interferometric Phase



SAR image S_1

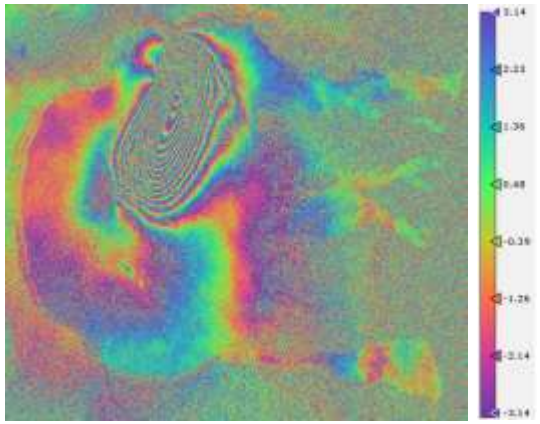


SAR image S_2

Piton de la Fournaise Volcano

$$I = S_1 \cdot S_2^*$$

$$\varphi_{int} = \phi_2 - \phi_1$$



Interferometric Phase

Quality of the interferometric phase: Coherence

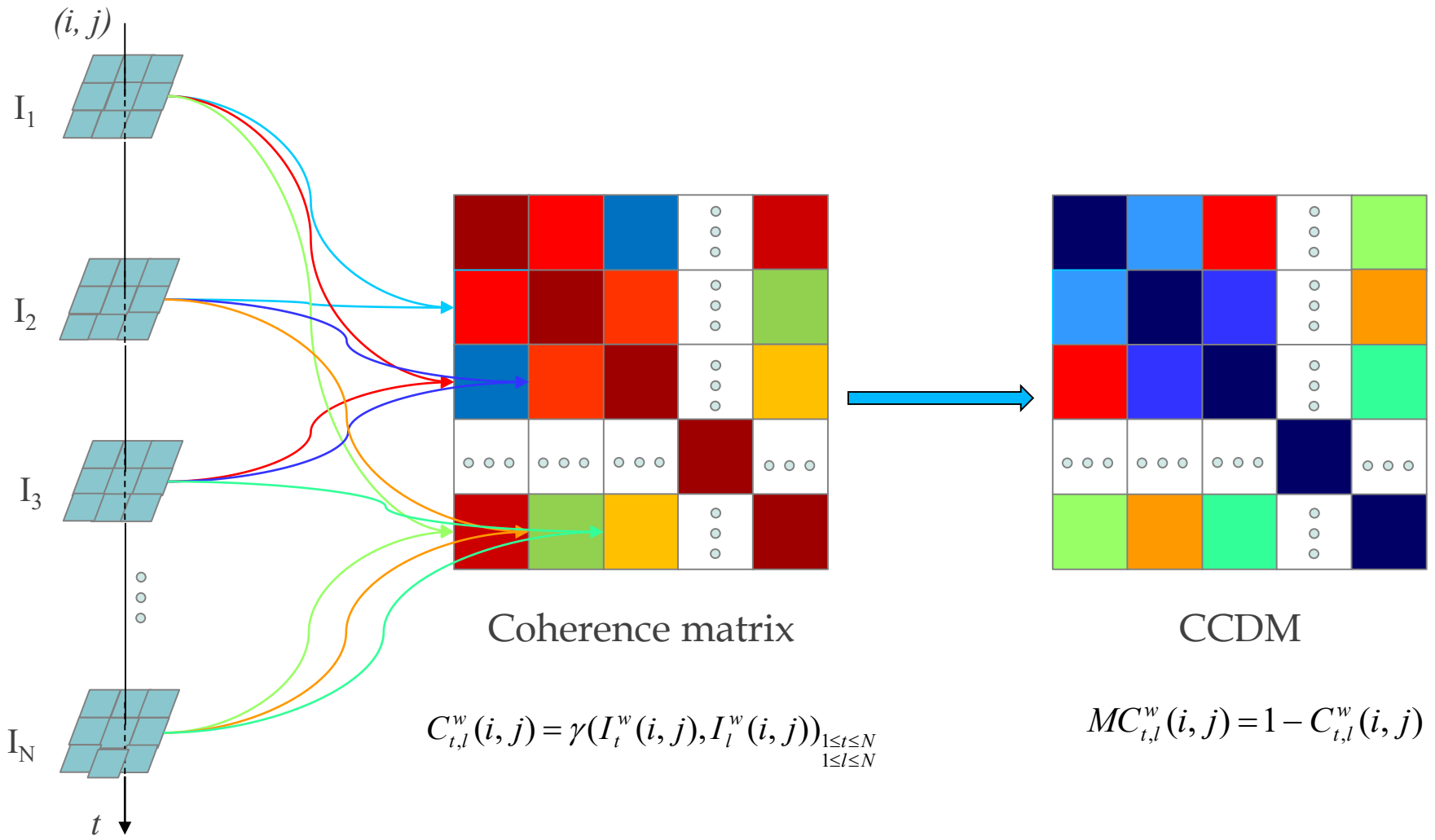
$$\gamma = \frac{E\{S_1 S_2^*\}}{\sqrt{E\{|S_1|^2\} E\{|S_2|^2\}}}$$

$$\hat{\gamma} = \frac{\sum_{i=1}^{L} S_1(i) \cdot S_2(i)^*}{\sqrt{\sum_{i=1}^{L} |S_1(i)|^2 \cdot \sum_{i=1}^{L} |S_2(i)|^2}}$$

Decorrelation sources:

Miscoregistration;
Temporal decorrelation;
Geometric decorrelation;
Volume decorrelation;
Thermal decorrelation;
Other terms of decorrelation…

Methodology / Coherence change detection matrix (CCDM)



$$C_{t,l}^{w}(i,j) = \gamma(I_t^{w}(i,j), I_l^{w}(i,j))_{\substack{1\le t\le N \\ 1\le l\le N}}$$

$$MC_{t,l}^{w}(i,j) = 1 - C_{t,l}^{w}(i,j)$$

Methodology / Similarity measures

- Homogeneity Test: Variation Coefficient Test (CV)

Purely homogeneous regions of an L-look amplitude image s I : $\sigma_s = \frac{0.5227}{\sqrt{L}}$

Variation Coefficient: $CV = \frac{\sigma_{\mathcal{I}}}{\mu_{\mathcal{I}}}$

Homogeneity test: $CV(i,j) \leq \sigma_s + \delta(i,j)$

- Kullback-Leibler Distance (KLD) :

$$d_{KL}(X,Y) = \frac{1}{2}\int (f_X - f_Y) log\left(\frac{f_X}{f_Y}\right)$$

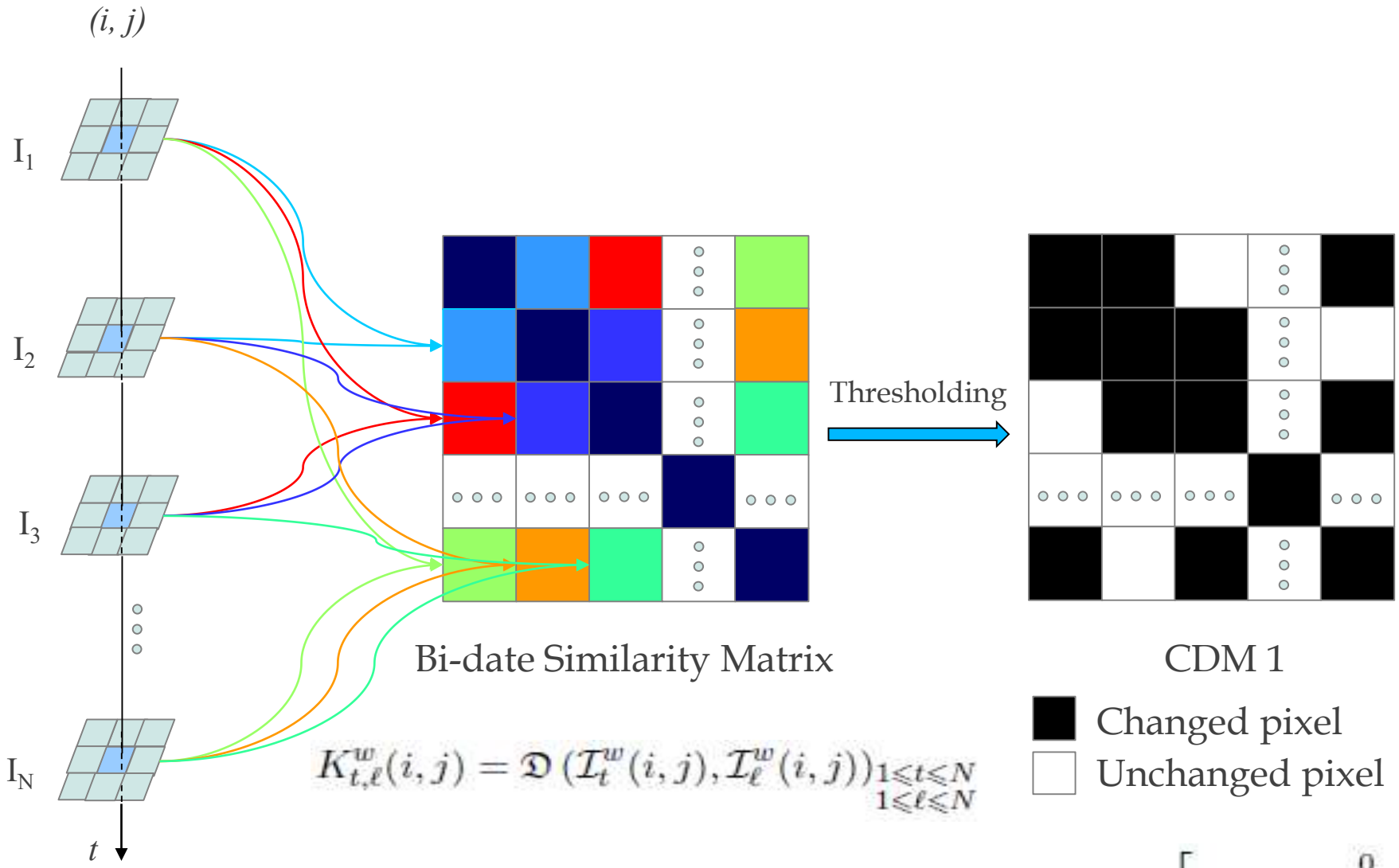
$$KLD_{\text{Log-normal}}(X,Y) = \frac{1}{2}(\mu_X - \mu_Y)^2\left(\frac{1}{\sigma_X^2} + \frac{1}{\sigma_Y^2}\right) + \frac{1}{2}\left(\frac{\sigma_Y^2}{\sigma_X^2} + \frac{\sigma_X^2}{\sigma_Y^2}\right) - 1$$ [Atto *et al*. 2013]

- Wishart Distance (WD) :

$$d_{wishart}\left([T]_1, [T]_2\right) = \ln\frac{\det\{[T]_2\}}{\det\{[T]_1\}} + \text{Tr}\left\{[T]_2^{-1}[T]_1\right\} \;;\; \text{with} \;\; [T] = \frac{1}{L}\sum_{i=1}^{L} k_i k_i^{*T}$$ [Lee *et al*. 1994]

Methodology / Change Detection Matrix (CDM)

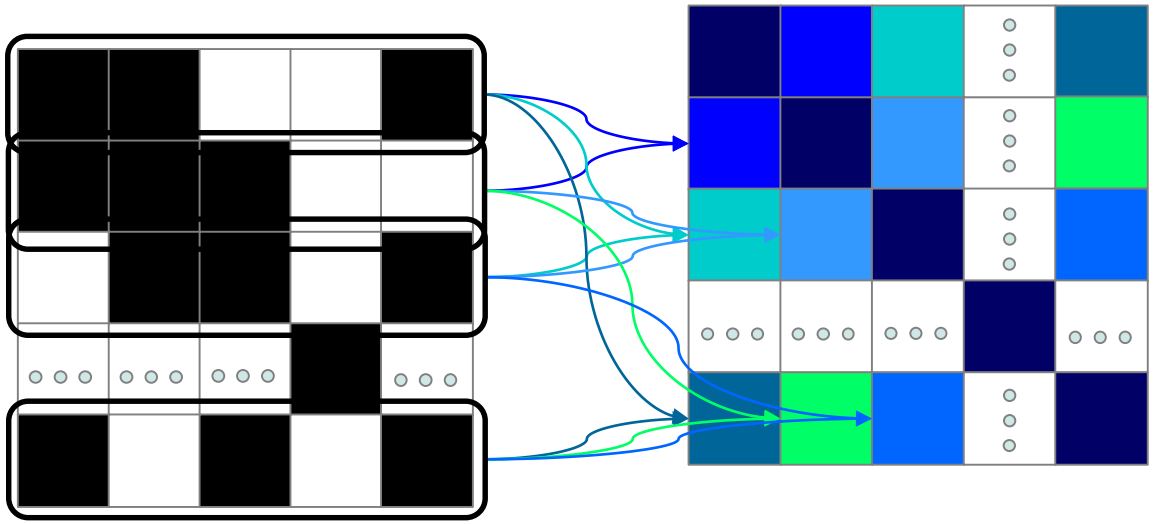
❖ **Bi-date analysis**



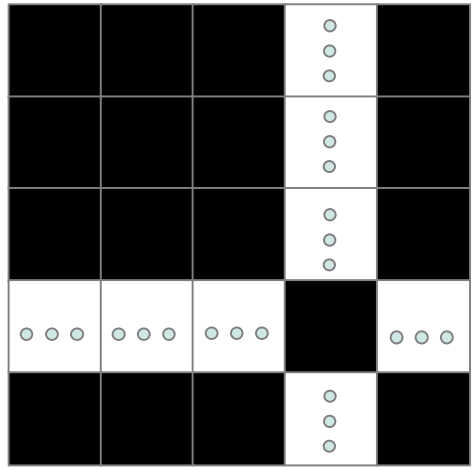
$$K^{w}_{t,\ell}(i,j) = \mathfrak{D}\left(\mathcal{I}^{w}_{t}(i,j), \mathcal{I}^{w}_{\ell}(i,j)\right)_{\substack{1\leqslant t\leqslant N \\ 1\leqslant \ell\leqslant N}}$$

$$M^{w}_{t,\ell}(i,j) = \left[K^{w}_{t,\ell}(i,j) \underset{1}{\overset{0}{\lessgtr}} \lambda\right]$$

❖ Multidate analysis



Thresholding



CDM 1 | Multidate similarity matrix | CDM 2

Unchanged pixel

Changed pixel

$$\hat{K}^{w}_{t,\ell}(i,j) = \mathfrak{D}\left(\Psi\left(\mathcal{I}^{w}_{t}(i,j)\right), \Psi\left(\mathcal{I}^{w}_{\ell}(i,j)\right)\right)_{\substack{1\leqslant t\leqslant N \\ 1\leqslant \ell\leqslant N}}$$

Changed pixel

Unchanged pixel

Temporal neighborhood composed of unchanged pixels

$$\hat{M}^{w}_{t,\ell}(i,j) = \left[\hat{K}^{w}_{t,\ell}(i,j) \underset{1}{\overset{0}{\lessgtr}} \lambda\right]$$

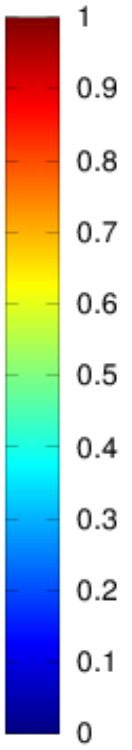
$$\Psi(\mathcal{I}^{w}_{t}(i,j)) = \{\mathcal{I}_{k}(i,j) \mid M^{w}_{t,k}(i,j) = 0; k = 1 \cdots N\}$$

❖ **Measure of change dynamics**

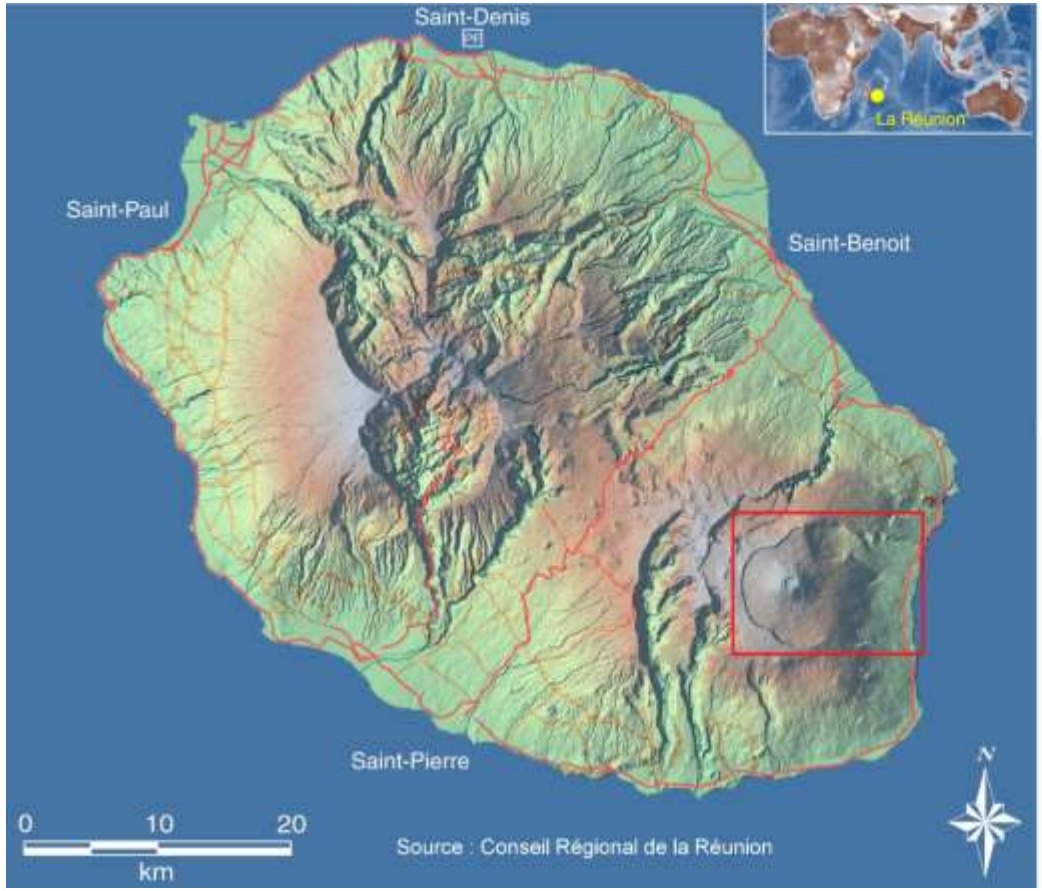
CDM

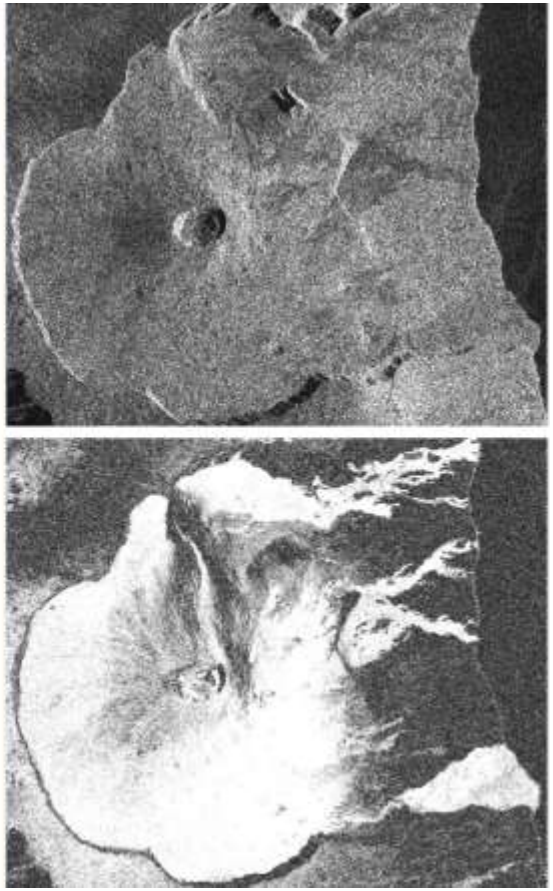
CCDM

$$\delta(i,j) = \frac{2}{N(N-1)} \sum_{t=1}^{N} \sum_{k=t+1}^{N} M_{(t,k)}(i,j)$$



Experimental results / Study area and data used

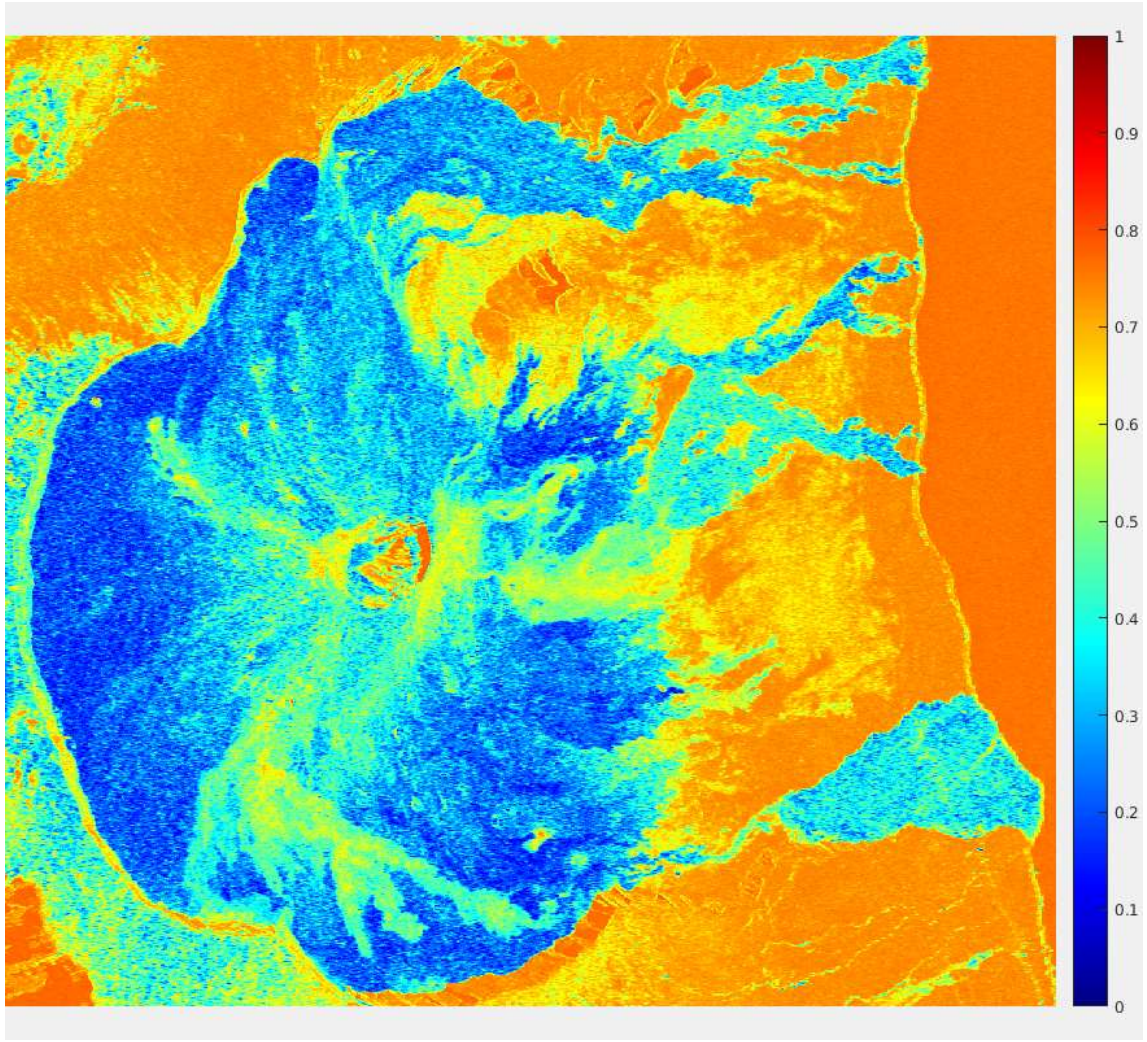




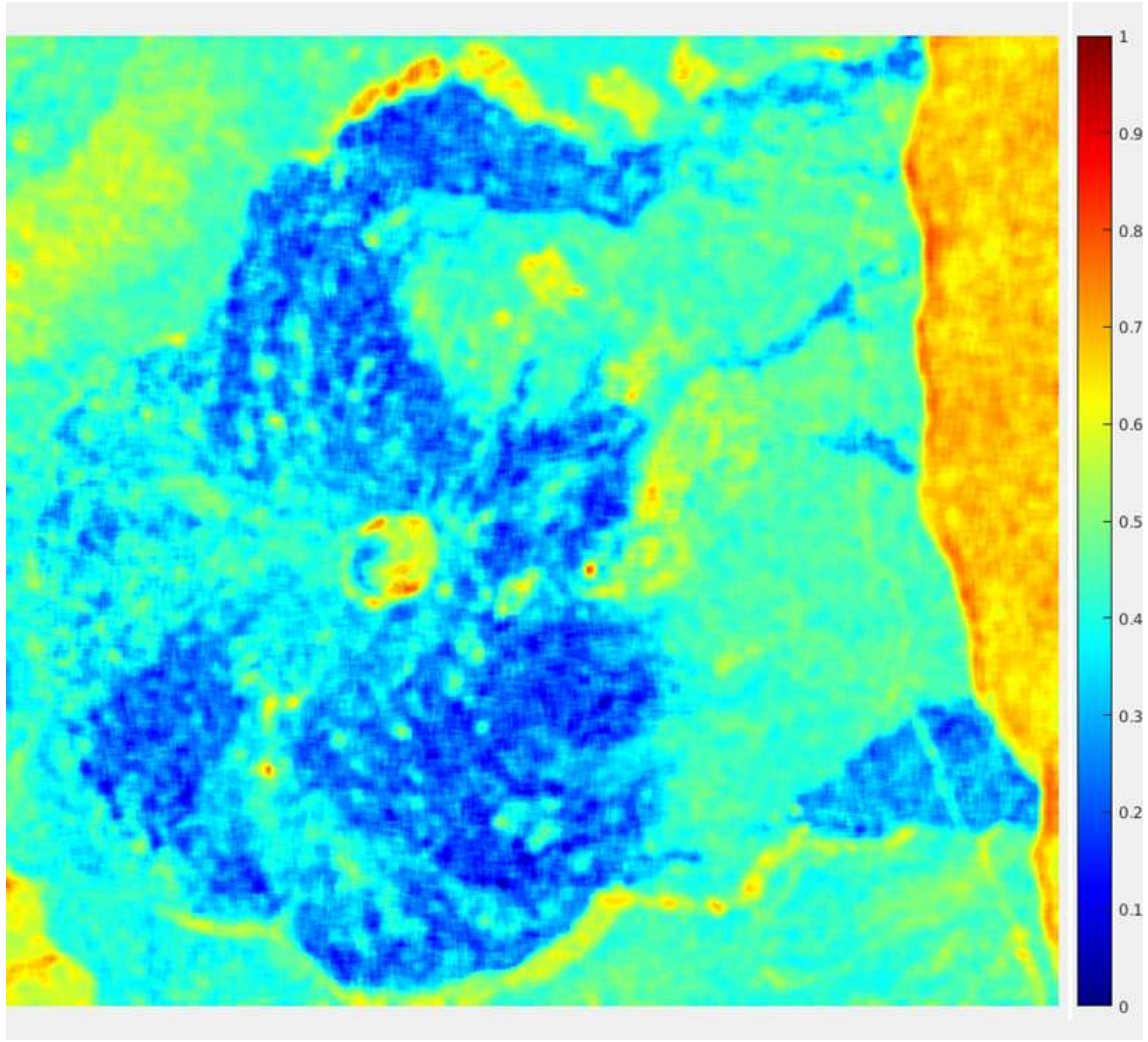
Coherence image after the eruption on Avril 03, 2018 (between two images acquired on March 23 and Avril 04, 2018)

Specifications	Sentinel-1 dataset
Satellite	Sentinel-1A
Launched date	April 03, 2014
Satellite orbit	Descending
Repeat cycle	12 days
Imaging frequency	C-band at 5.4 GHz
Imaging mode	SM
Data product	SM-SLC
Resolution	3.3 m×4.9 m (range×azimuth)
Polarization	VV
Beam	S4
Number of images	49 images
Acquisition dates (YYYY/MM/DD)	20180110; 20180122; 20180203; 20180215; 20180227; 20180311; 20180323; 20180404; 20180416; 20180428; 20180510; 20180522; 20180603; 20180615; 20180627; 20180709; 20180721; 20180802; 20180814; 20180826; 20180907; 20180919; 20181001; 20181013; 20181106; 20181118; 20181130; 20181212; 20181224; 20190105; 20190117; 20190129; 20190210; 20190222; 20190306; 20190318; 20190330; 20190411; 20190423; 20190505; 20190517; 20190529; 20190610; 20190622; 20190704; 20190716; 20190728; 20190809; 20190821.

Experimental results / Analysis of change dynamics



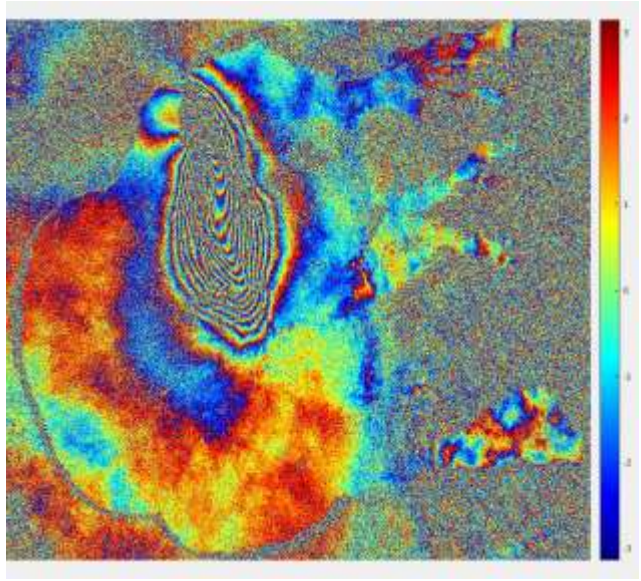
Map of change dynamics derived from CCDM



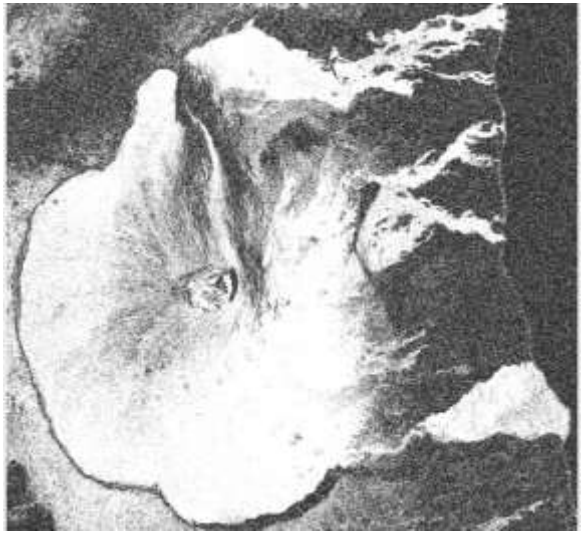
Map of change dynamics derived from KLD - CDM

Experimental results / Volcanic eruption monitoring

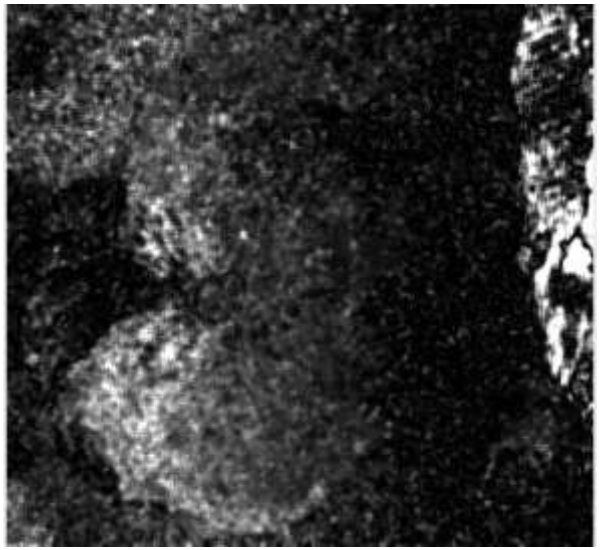
Eruption on 2018/04/03



Interferogram (2018/03/23 – 2018/04/04)

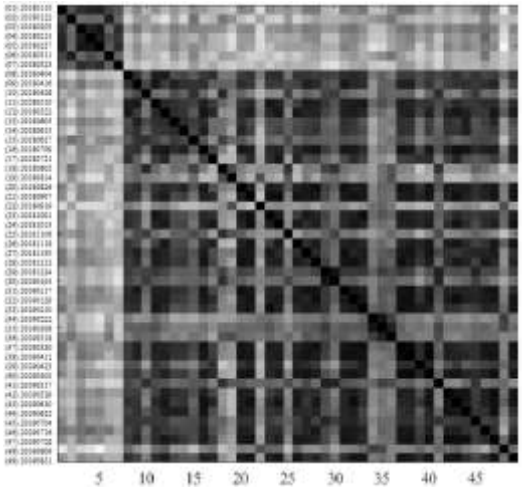


Coherence (2018/03/23 – 2018/04/04)

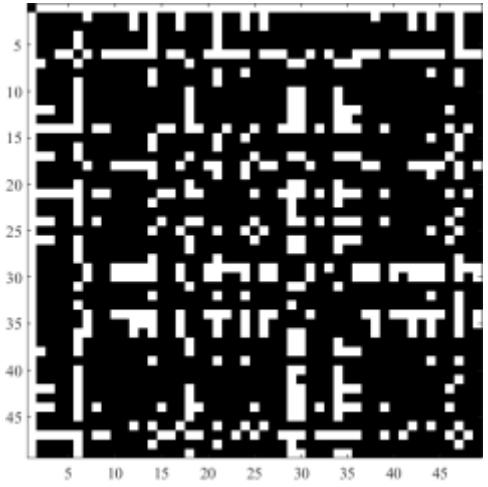


KLD (2018/03/23 – 2018/04/04)

CCDM

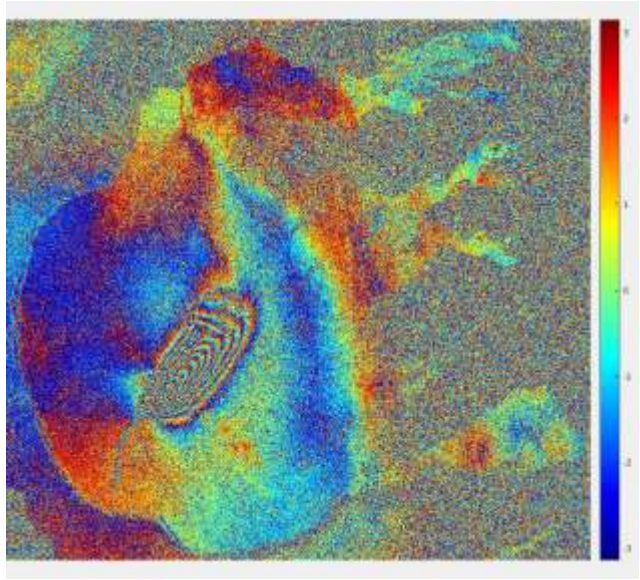


CDM

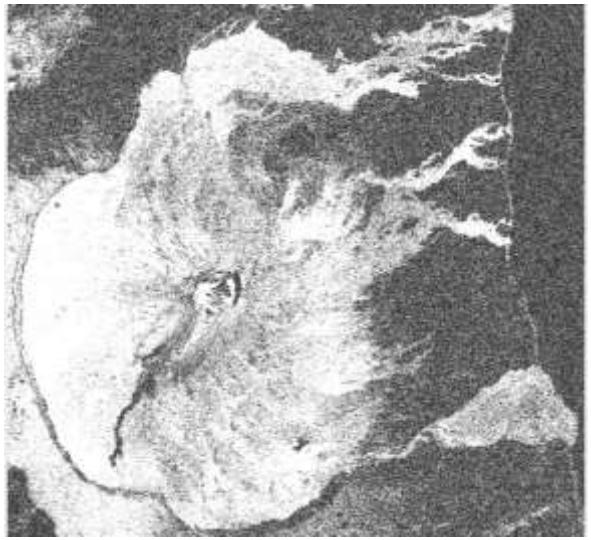


Experimental results / Volcanic eruption monitoring

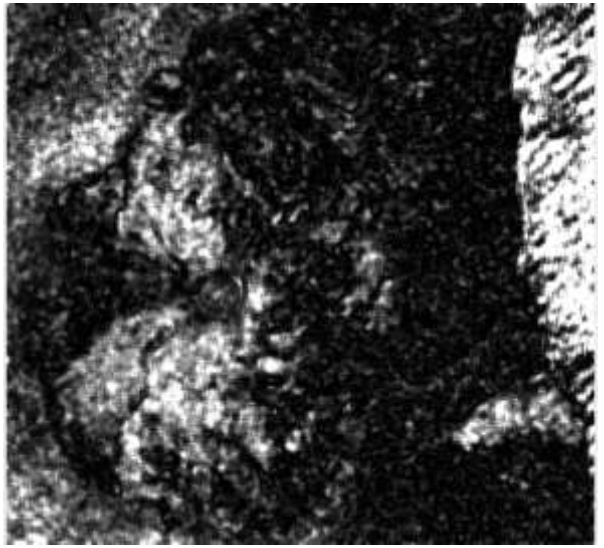
Eruption on 2018/04/27



Interferogram (2018/04/16 – 2018/04/28)

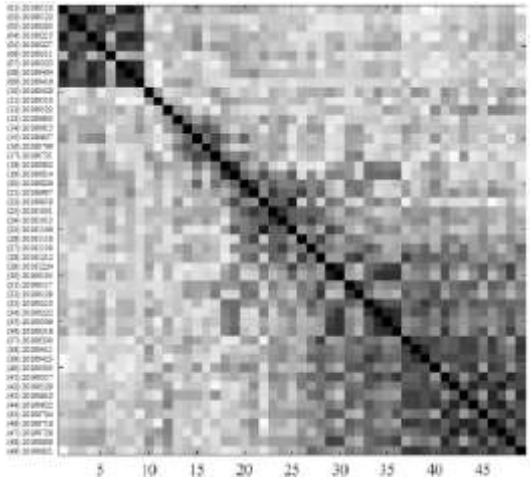


Coherence (2018/04/16 – 2018/04/28)



KLD (2018/04/16 – 2018/04/28)

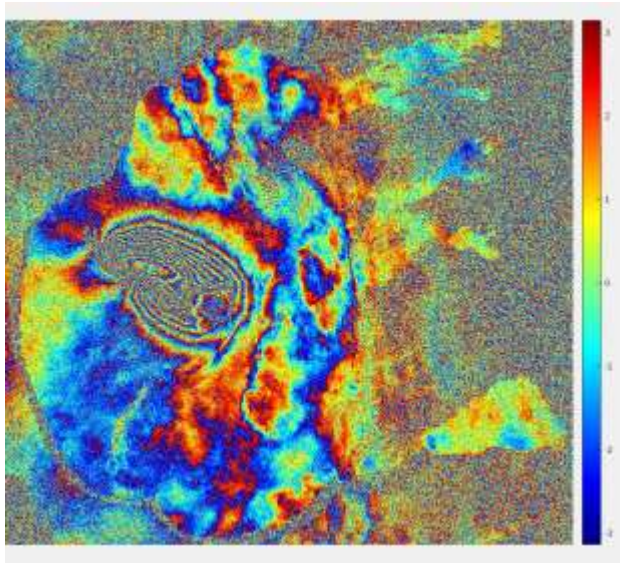
CCDM



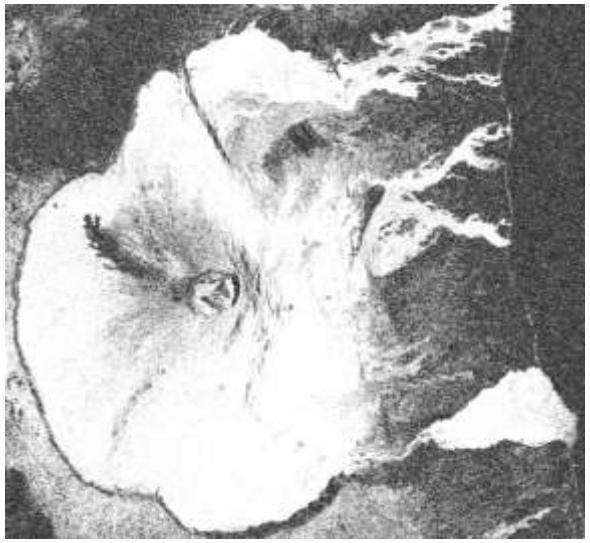
CDM

Experimental results / Volcanic eruption monitoring

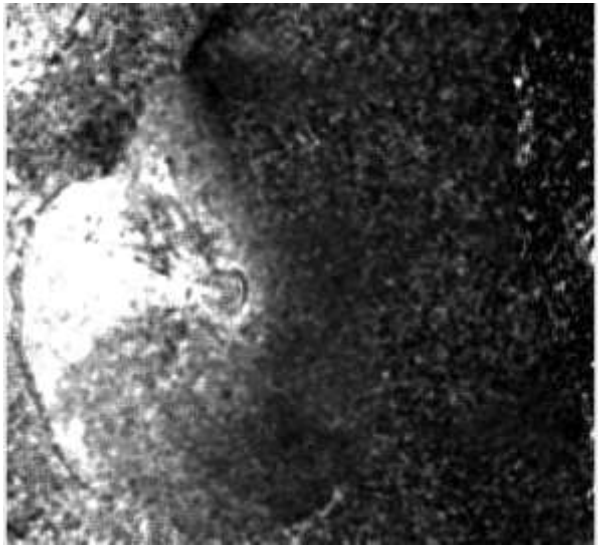
Eruption on 2018/07/13



Interferogram (2018/07/09 – 2018/07/21)

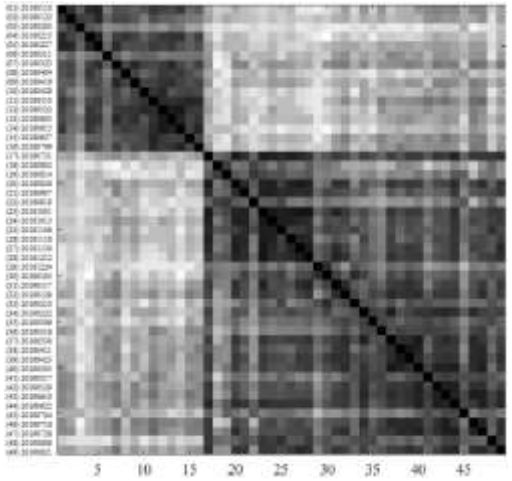


Coherence (2018/07/09 – 2018/07/21)



KLD (2018/07/09 – 2018/07/21)

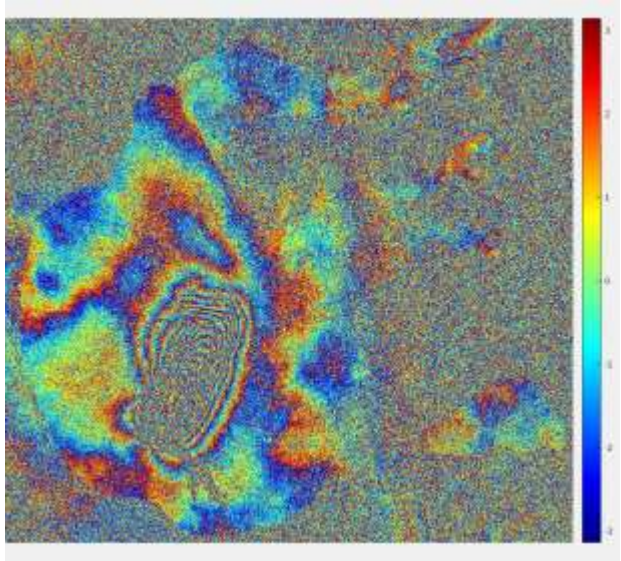
CCDM



CDM

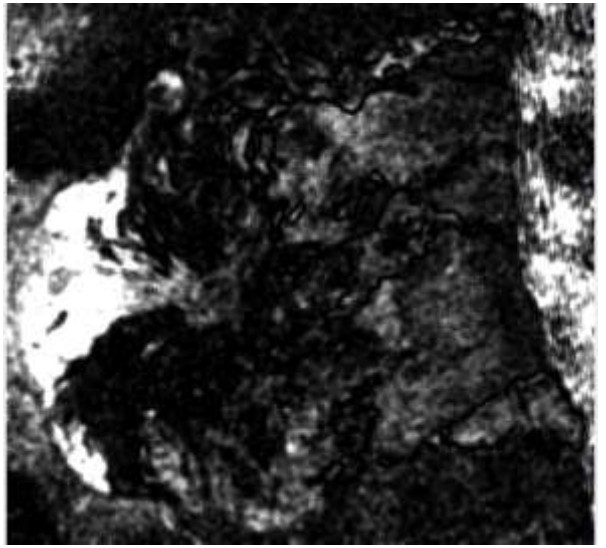
Experimental results / Volcanic eruption monitoring

Eruption on 2018/09/15



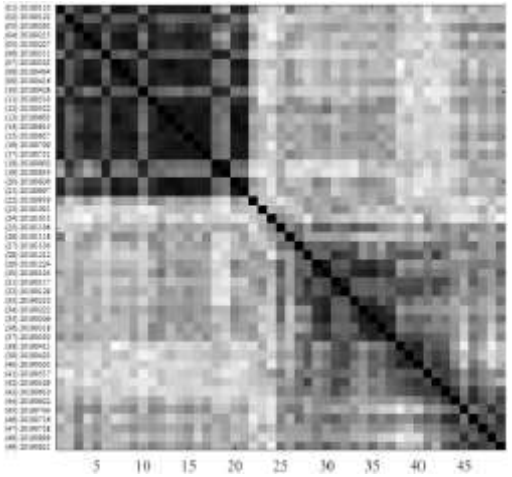
Interferogram (2018/09/07 – 2018/09/19)

Coherence (2018/09/07 – 2018/09/19)

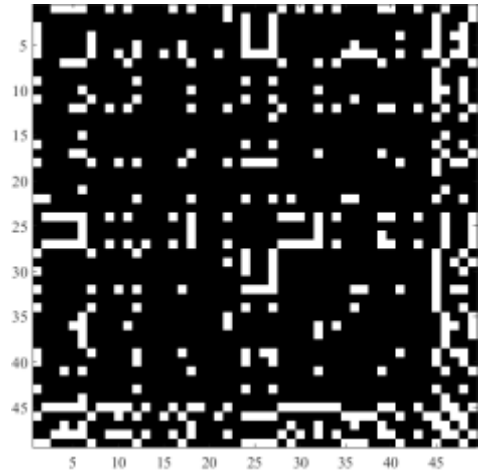


KLD (2018/09/07 – 2018/09/19)

CCDM

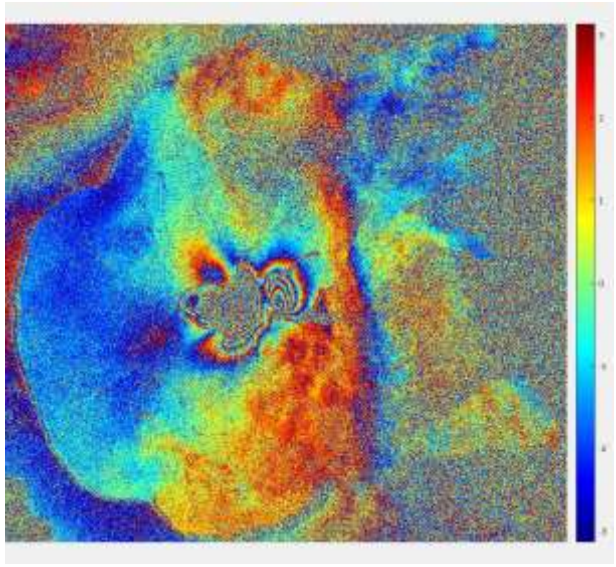


CDM

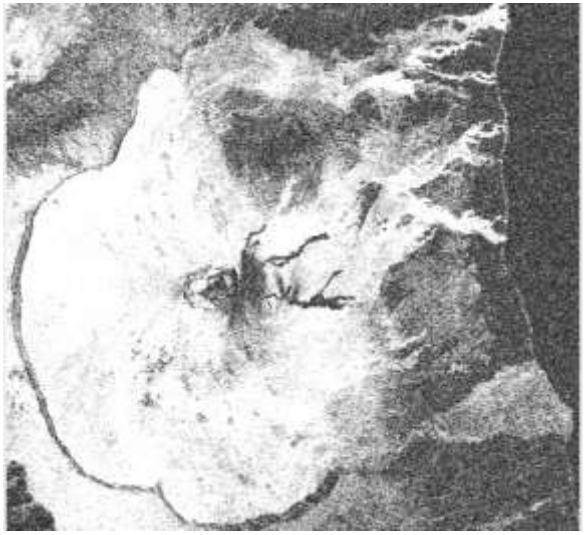


Experimental results / Volcanic eruption monitoring

Eruption on 2019/02/18



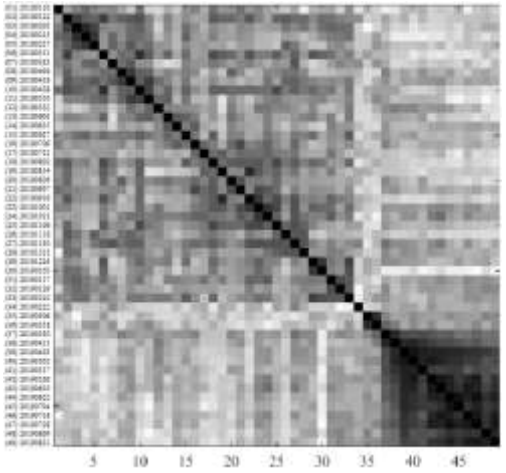
Interferogram (2019/02/10 – 2019/02/22)



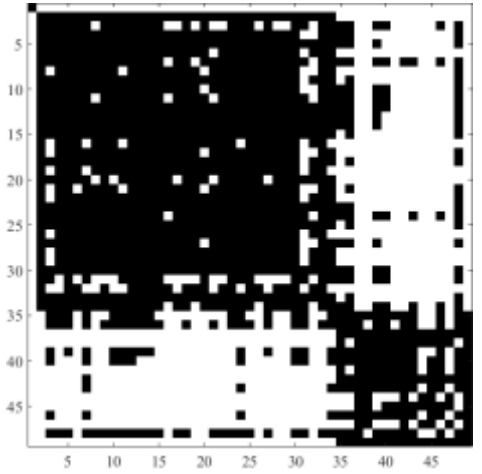
Coherence (2019/02/10 – 2019/02/22)

KLD (2019/02/10 – 2019/02/22)

CCDM

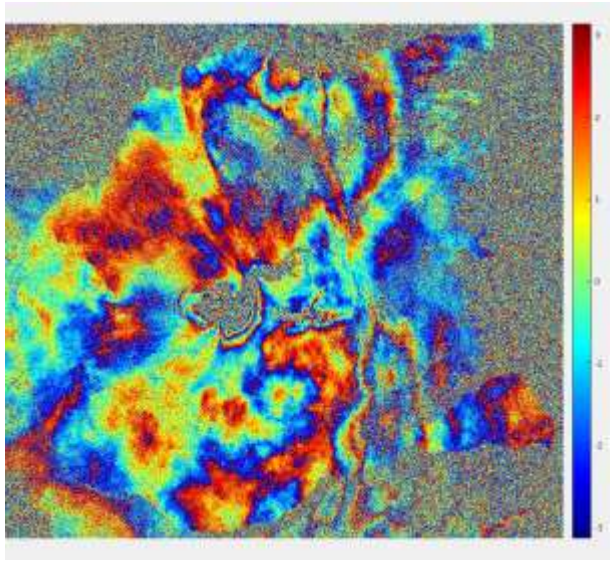


CDM

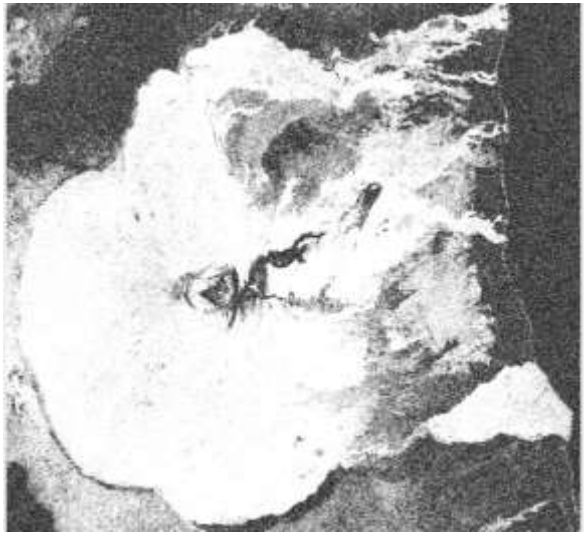


Experimental results / Volcanic eruption monitoring

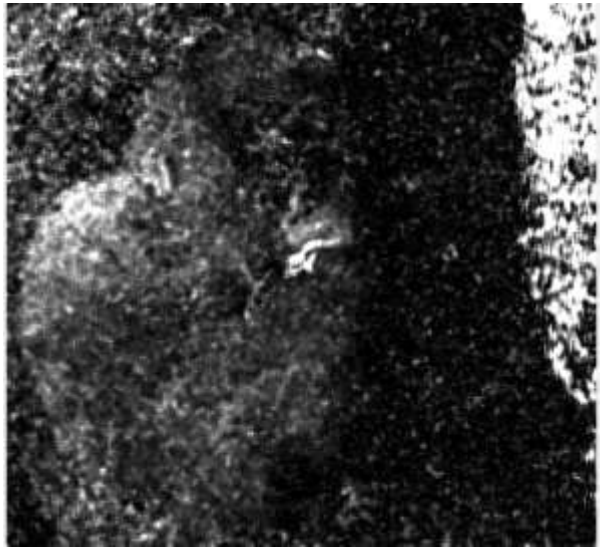
Eruption on 2019/06/16



Interferogram (2019/06/10 – 2019/06/22)

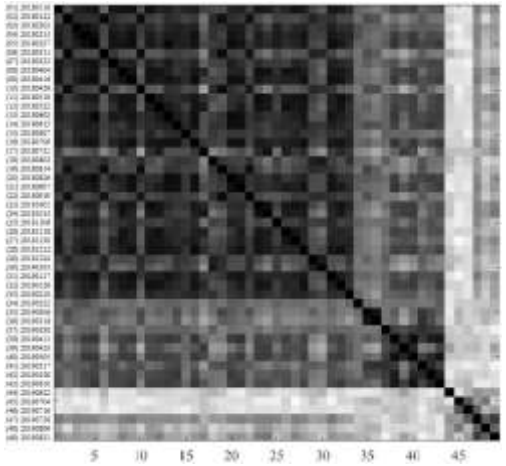


Coherence (2019/06/10 – 2019/06/22)

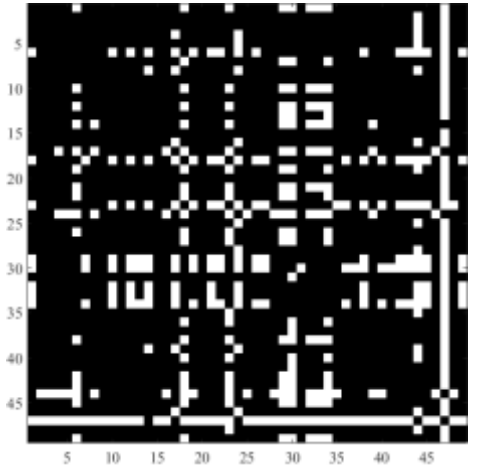


KLD (2019/06/10 – 2019/0/22)

CCDM

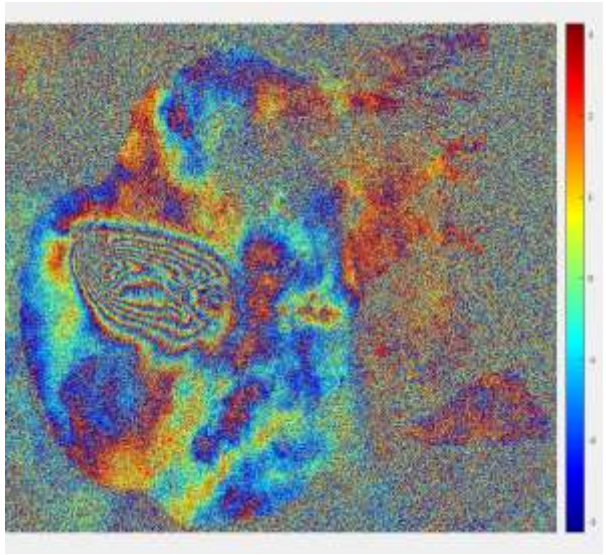


CDM

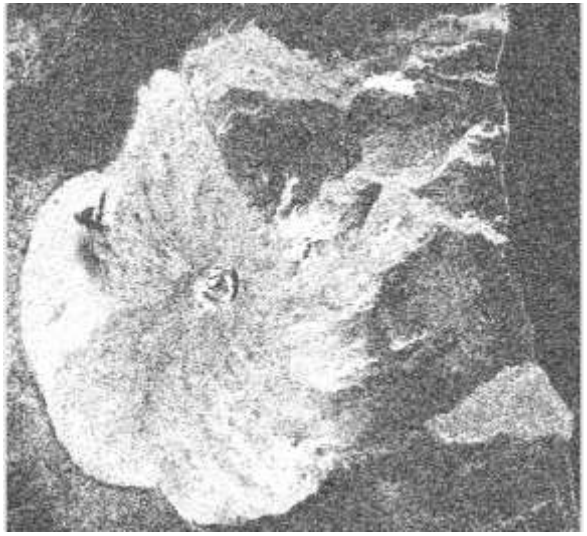


Experimental results / Volcanic eruption monitoring

Eruption on 2019/07/29



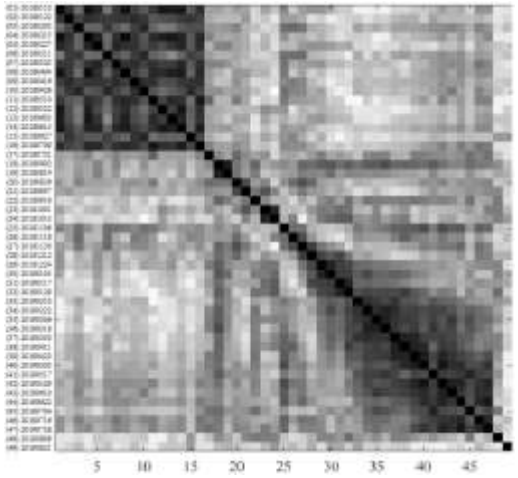
Interferogram (2019/07/29 – 2019/08/09)



Coherence (2019/07/29 – 2019/08/09)

KLD (2019/07/29 – 2019/08/09)

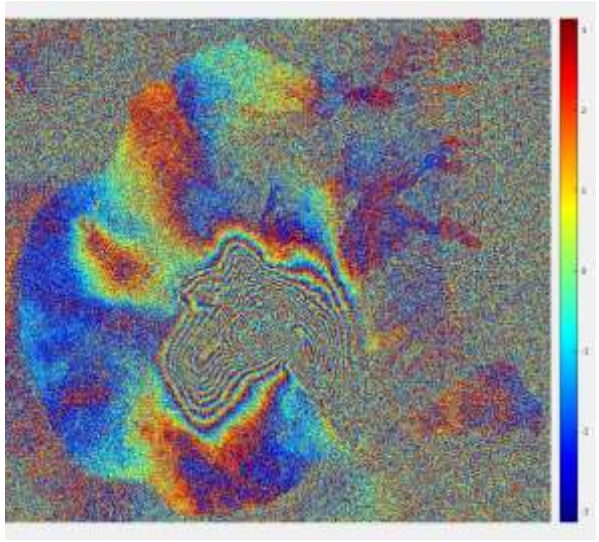
CCDM



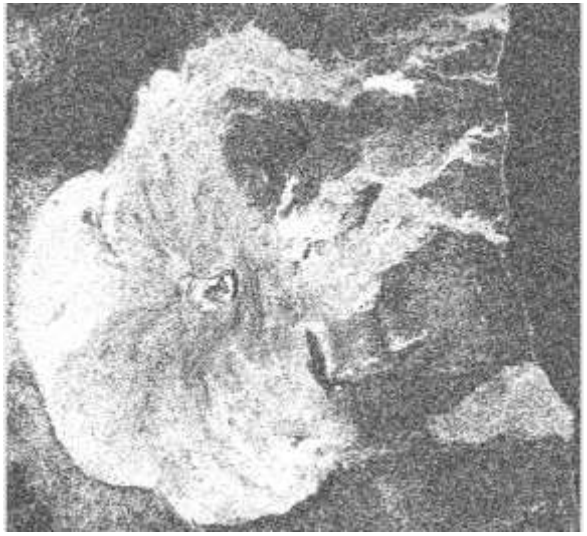
CDM

Experimental results / Volcanic eruption monitoring

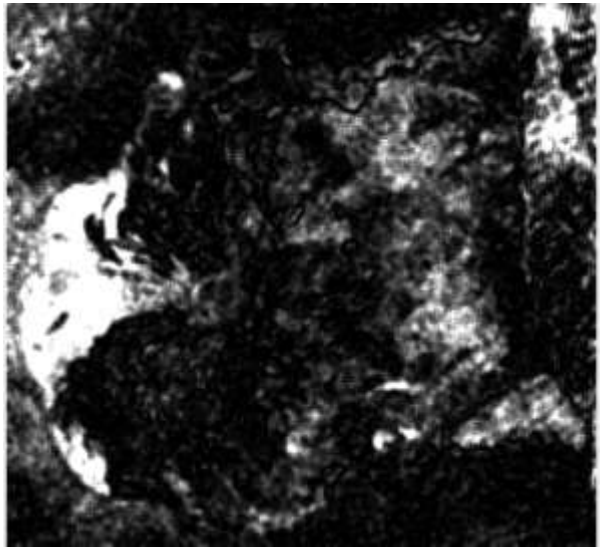
Eruption on 2019/08/13



Interferogram (2019/08/09 – 2019/08/21)

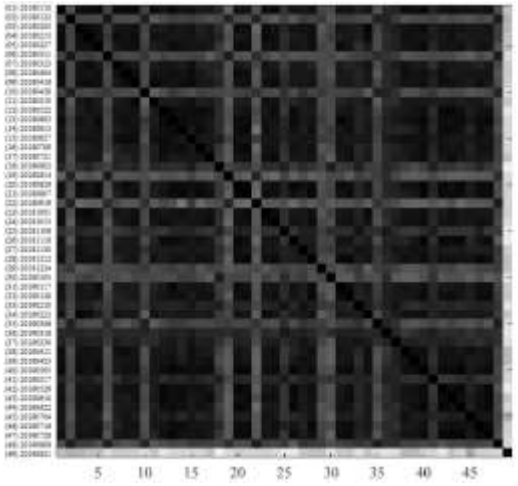


Coherence (2019/08/09 – 2019/08/21)



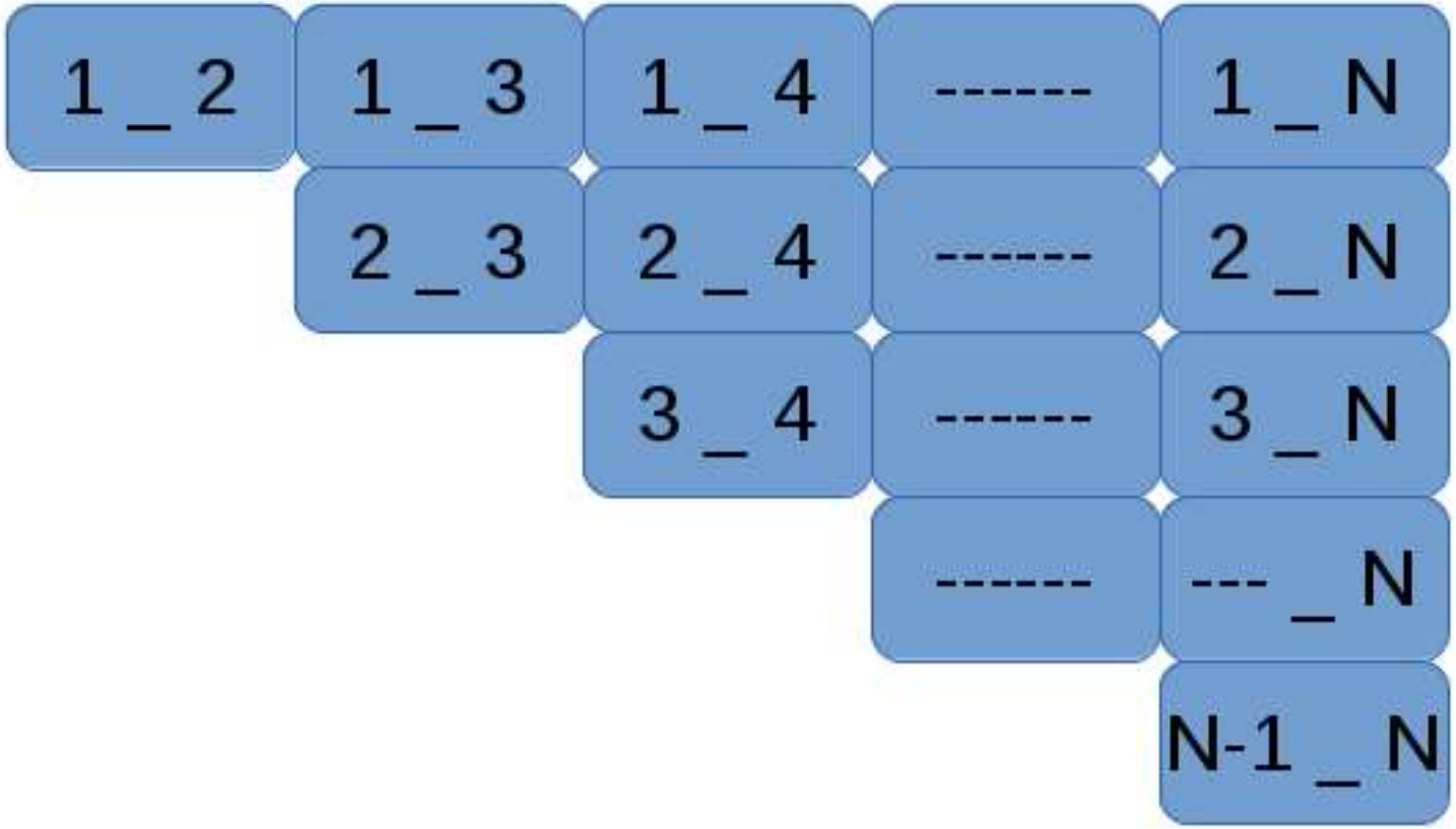
KLD (2019/08/09 – 2019/08/21)

CCDM



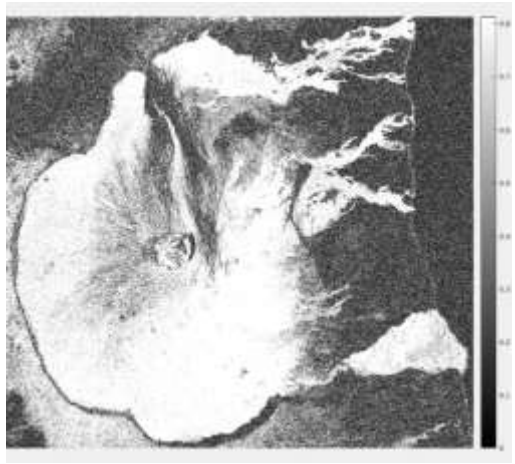
CDM

Multitemporal coherence/change maps

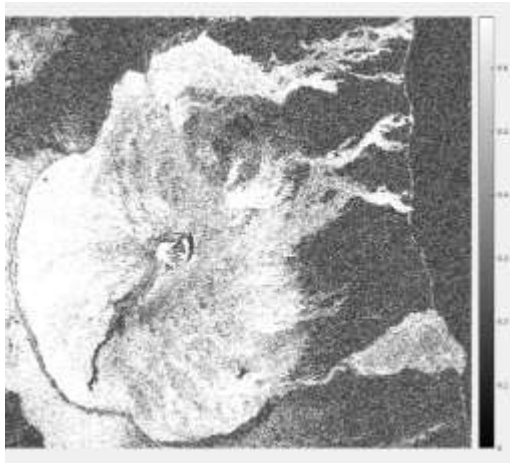


Experimental results / Volcanic eruption monitoring

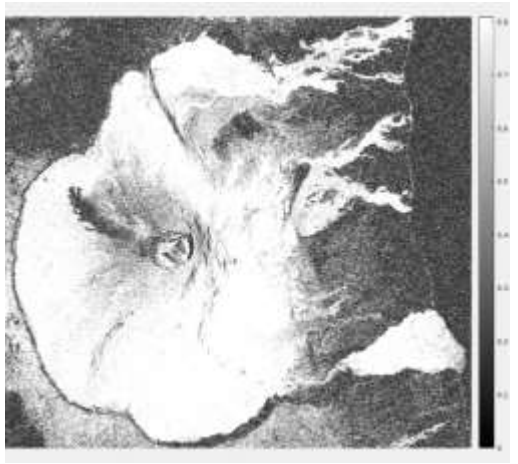
Coherence images between two consecutive acquisitions



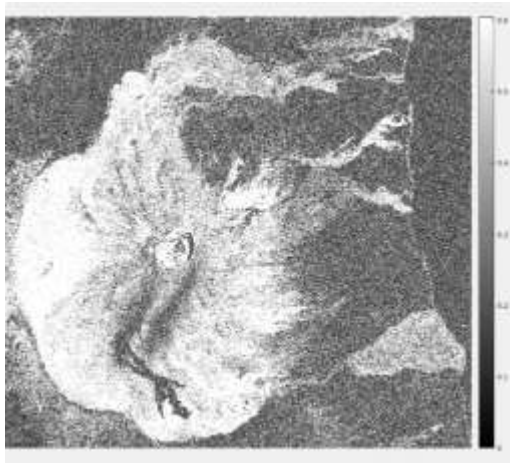
20180323 - 20180404



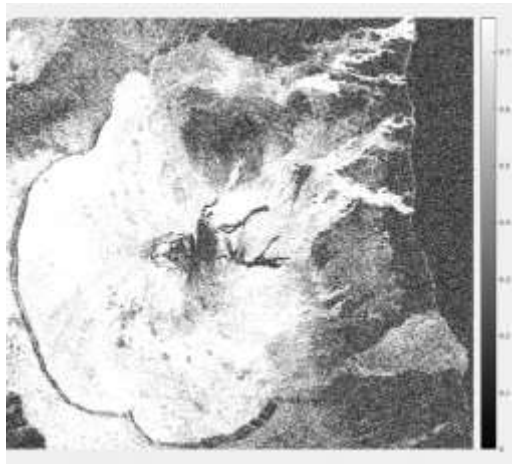
20180416 - 20180428



20180709 - 20180721

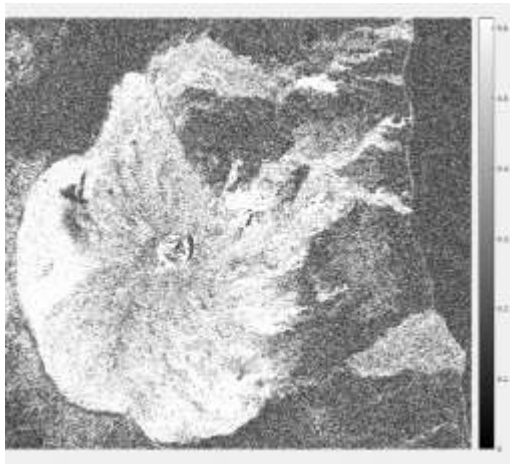


20180907 - 20180919

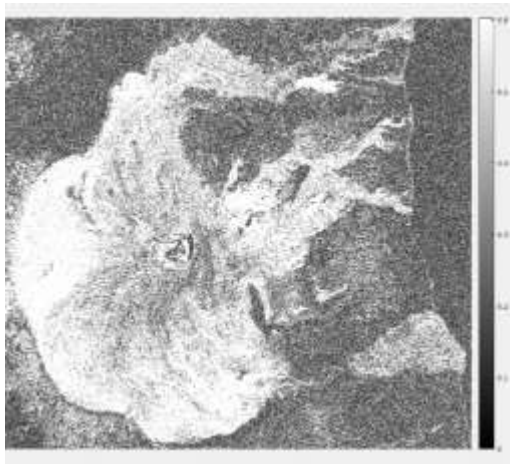


20190210 - 20190222

20190610 - 20190622



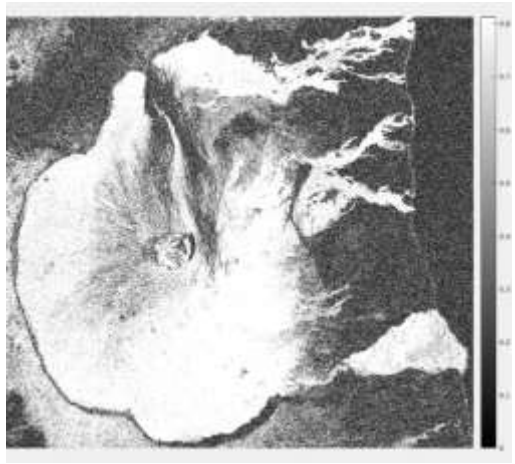
20190728 - 20190809



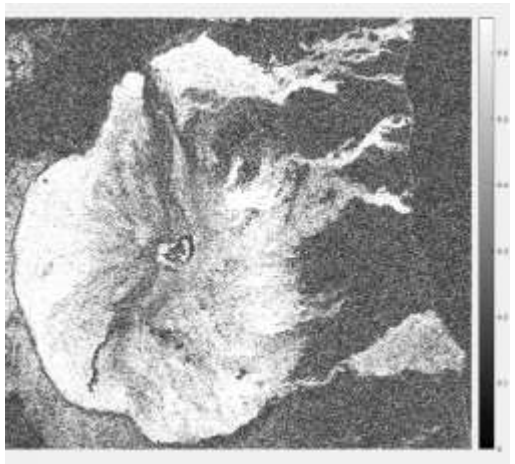
20190809 - 20190821

Experimental results / Volcanic eruption monitoring

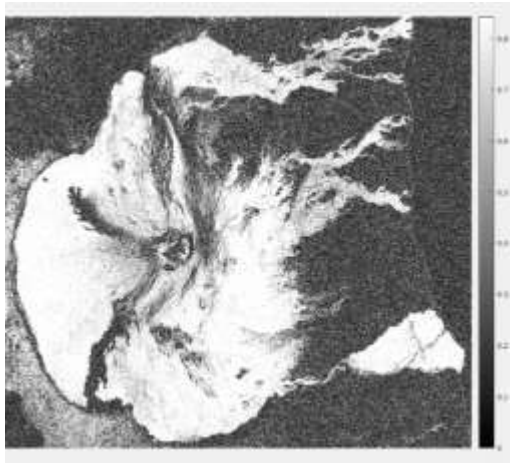
Coherence images between a reference acquisition and the others



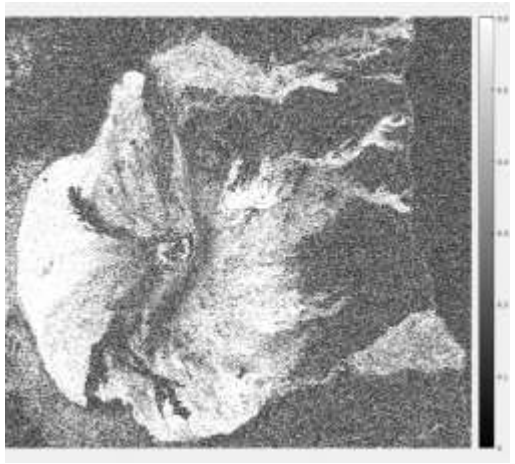
20180323 - 20180404



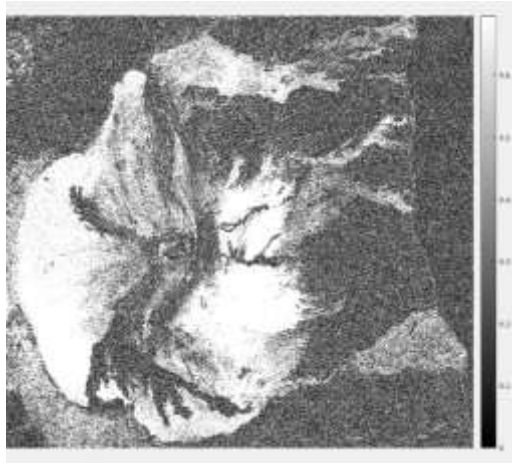
20180110 - 20180428



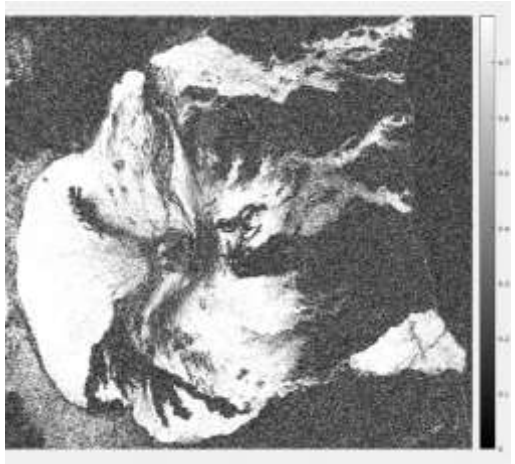
20180110 - 20180721



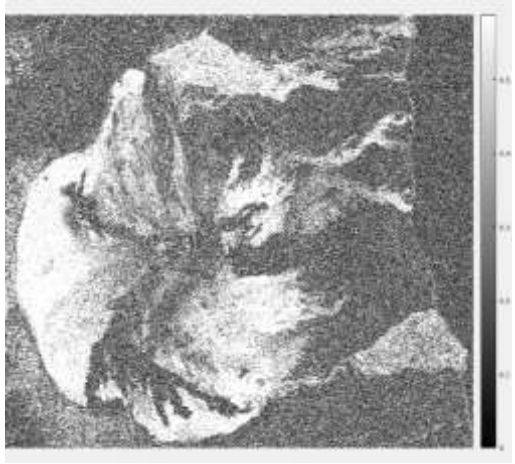
20180110 - 20180919



20180110 - 20190222



20180110 - 20190622

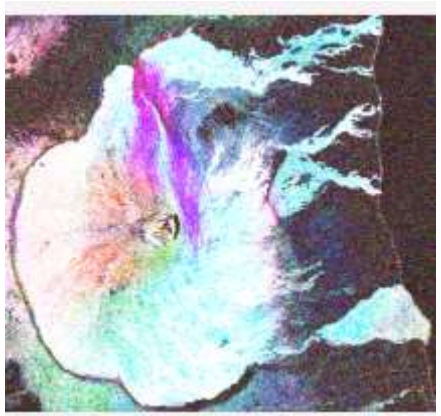


20180110 - 20190809

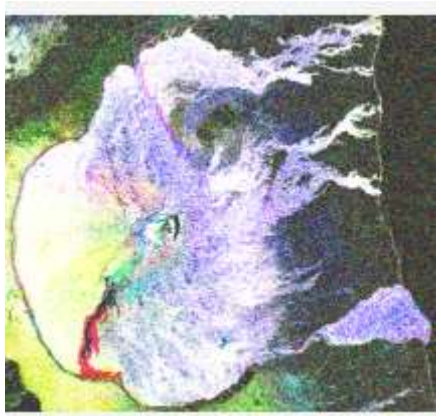
20180110 - 20190821

Experimental results / Volcanic eruption monitoring

Lava flow extent: Color composition images



R: 2018/03/11 - 2018/03/23;
G: 2018/03/23 - 2018/04/04;
B: 2018/04/04 - 2018/04/16



R: 2018/04/16 - 2018/04/28;
G: 2018/04/28 - 2018/05/10;
B: 2018/05/10 – 201//05/22

R: 2018/07/09 - 2018/07/21;
G: 2018/07/21 - 2018/08/02;
B: 2018/08/02 - 2018/08/14

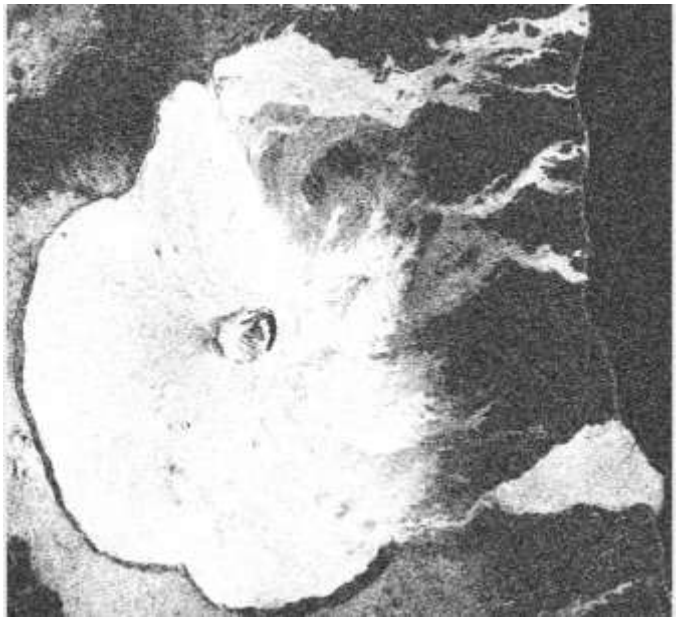
R: 2018/09/07 - 2018/09/19;
G: 2018/09/19 - 2018/10/01;
B: 2018/10/01 - 2018/10/13

R: 2019/02/10 - 2019/02/22;
G: 2019/02/22 - 2019/03/06;
B: 2019/03/06 - 2019/03/18

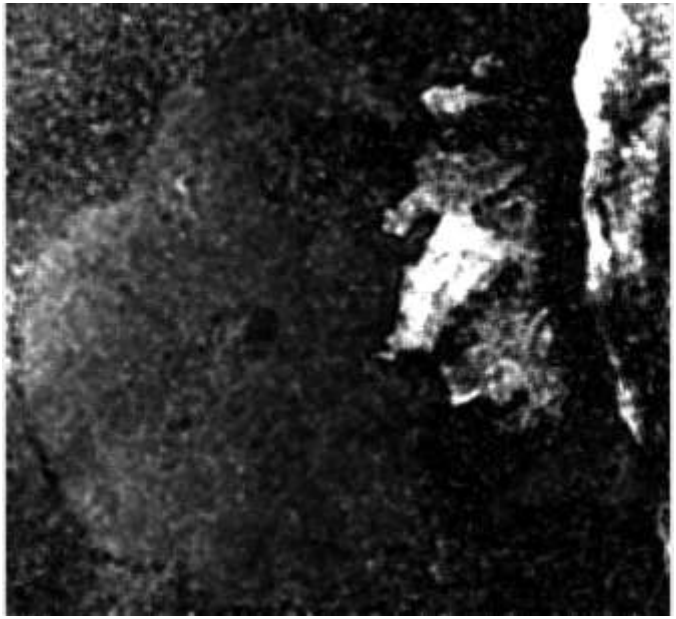
R: 2019/06/10 - 2019/06/22;
G: 2019/06/22 - 2019/07/04;
B: 2019/07/04 - 2019/07/16

R: 2019/07/16 - 2019/07/28;
G: 2019/07/28 - 2019/08/09;
B: 2019/08/09 - 2019/08/21

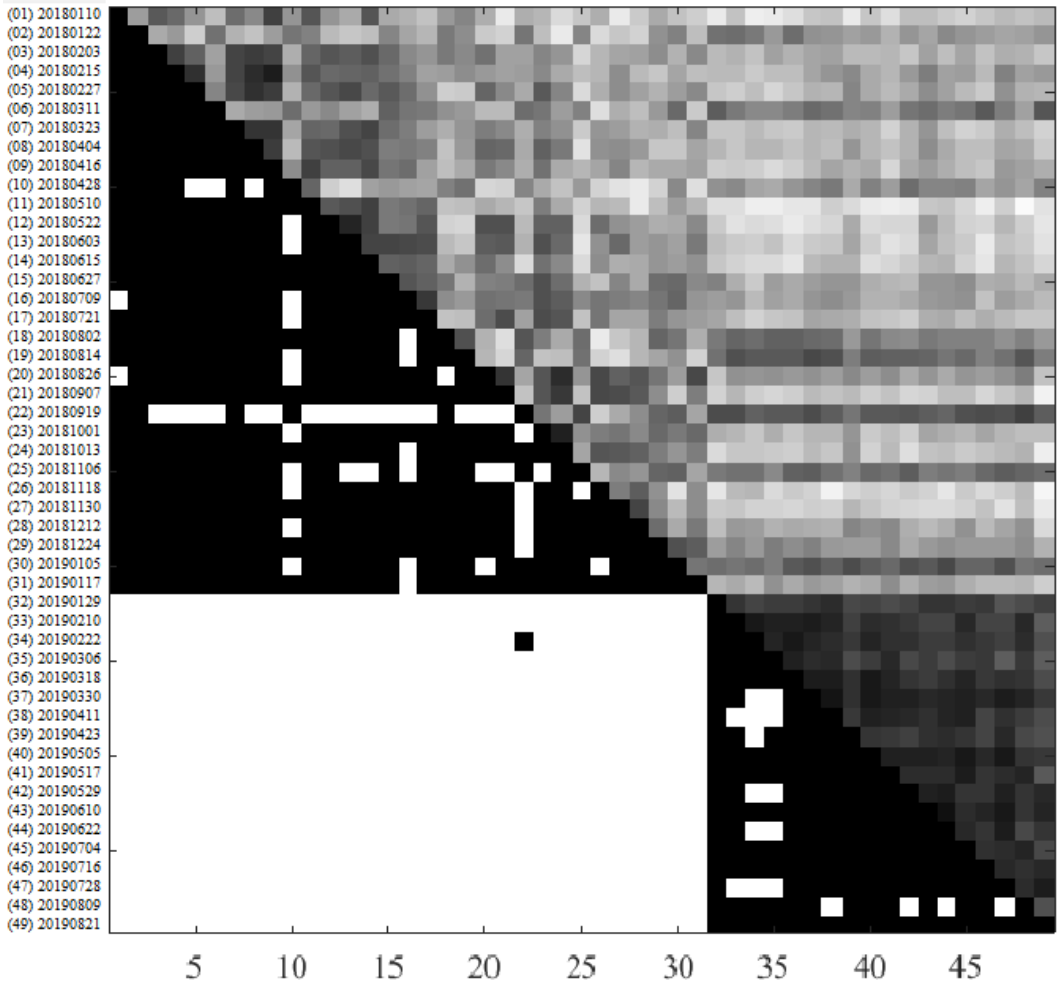
Experimental results / Detection of change due to forest fire



Coherence (2018/09/07 – 2018/09/19)



KLD (2018/09/07 – 2018/09/19)



Mixed CCDM

Conclusions and perspectives

- ✓ Extend CDM approach with interferometric coherence, similarity measure of phase signals.
- ✓ Mixed CDM allows a better understanding of change behavior of different objects on the ground
- ✓ Change information from mixed CDM used alongside GIS ➔ reduce uncertainty and serve in producing thematic maps

- ➢ Spatial prediction of hazards and vulnerability assessment;
- ➢ LULC classification from temporal coherence images.

Thank you for your attention!