A swap randomization approach for mining motion field time series over the Argentière glacier

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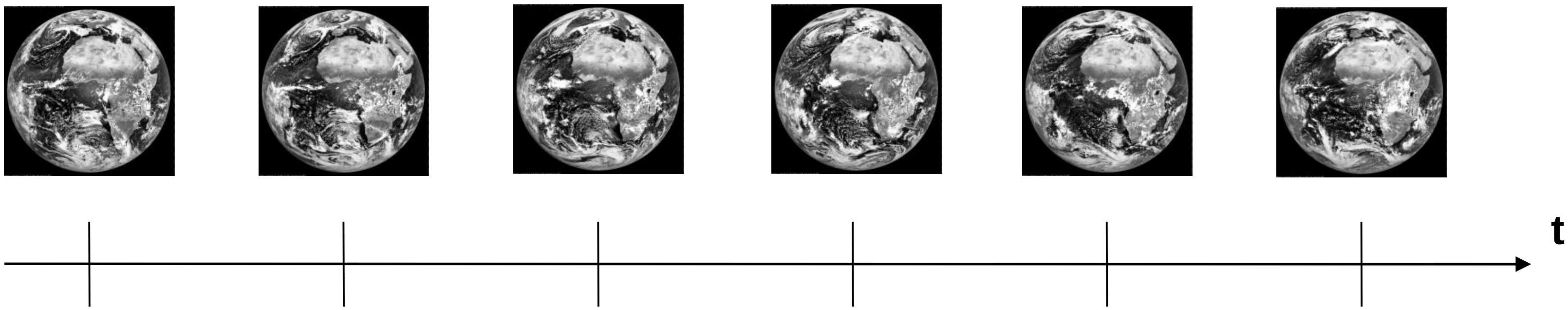
MultiTemp 2015, Annecy.

Previous work

- Satellite Image Time Series (SITS) can be mined using Grouped Frequent Sequential patterns (GFS-patterns) [Julea11].
  - Unsupervised techniques implemented at the pixel level
  - GFS-patterns can be numerous
- End users can be guided towards the most promising GFS-patterns thanks to a swap randomization ranking method [Méger12].
  - The stability of the ranking method w.r.t the number of swaps has been evidenced for a single randomization seed.
  - The focus was on patterns with occurrences strongly affected by a randomization of the SITS.



Proposal

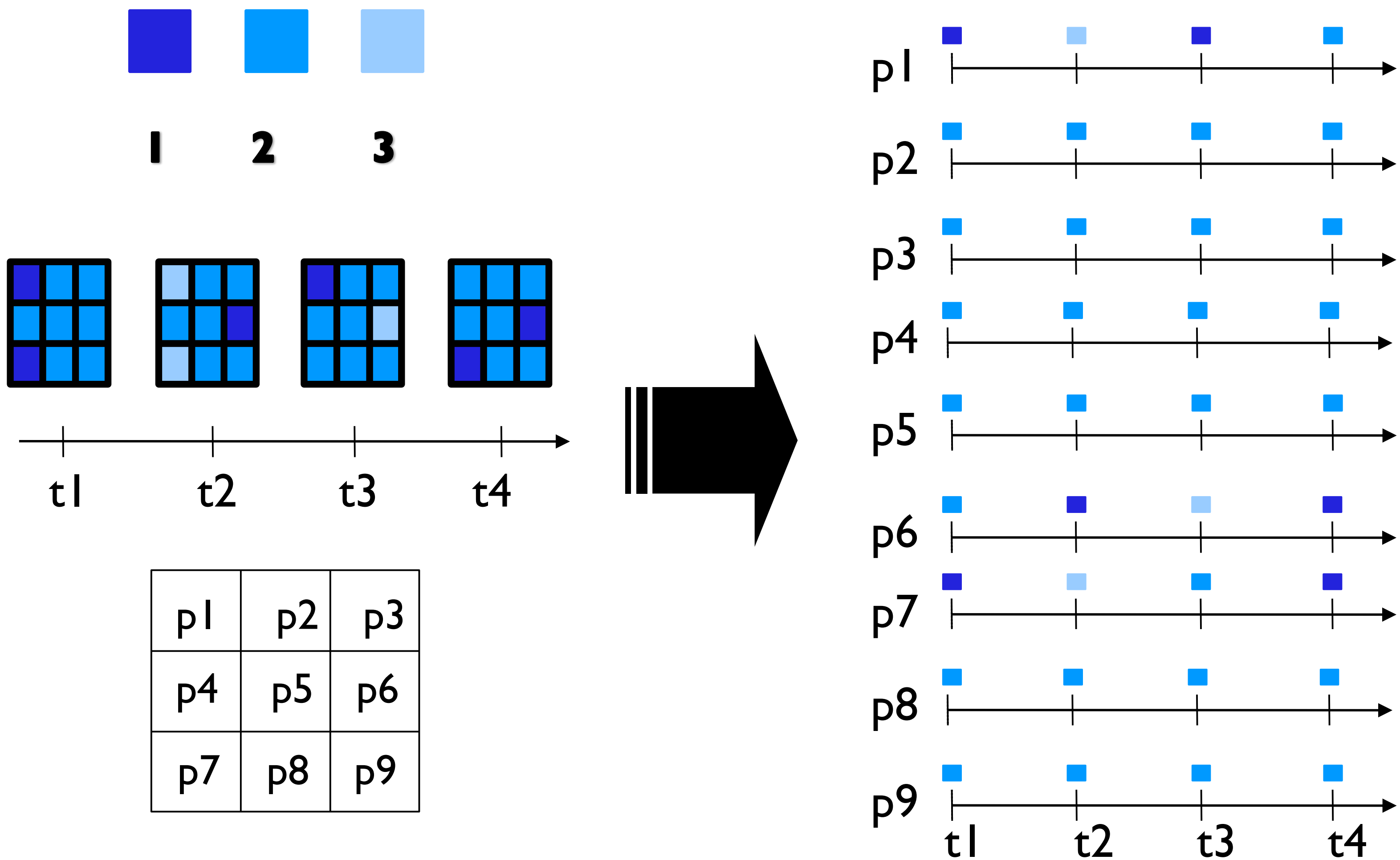
- Investigating the extraction and ranking of GFS-patterns on a Displacement Field Time Series (DFTS) obtained by terrestrial photogrammetry.

- Assessing the stability of the swap randomization ranking method for multiple randomizations of the DFTS.

- Extending the focus on GFS-patterns with occurrences destroyed OR maintained by randomization.

SITS and base of sequences

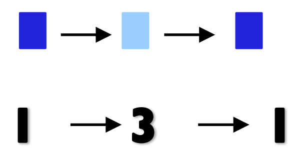
Pixel values are described using symbols (e.g., quantization, clustering).



Base of sequences [Agrawal95]

Frequent sequential patterns

- Model: sequential patterns

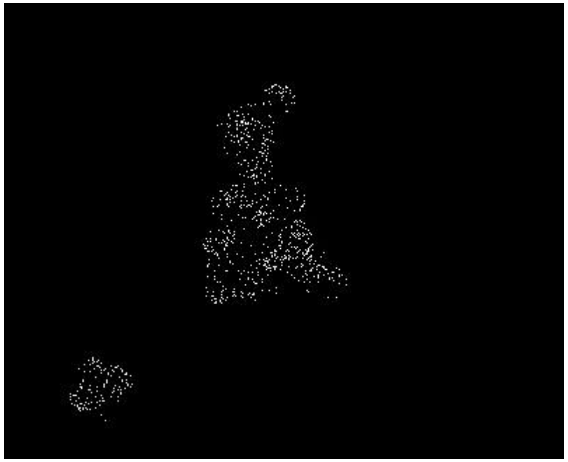


- Measure: support, i.e., the number of pixels affected by a sub-evolution.
- Sequential patterns covering at least σ pixels are frequent sequential patterns.
- σ, the minimum support, is used to prune the search space.

[Agrawal95]

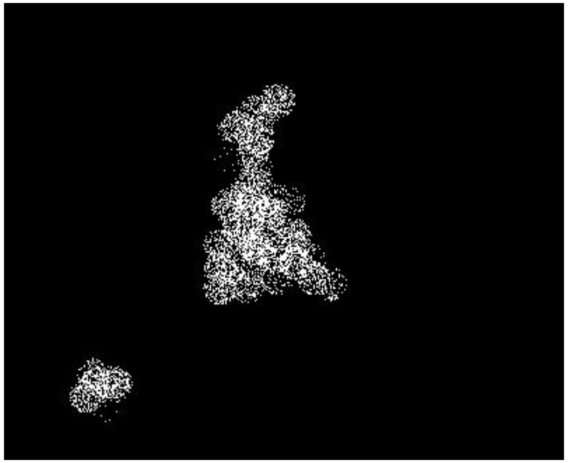
Towards spatiality

σ is a minimum surface



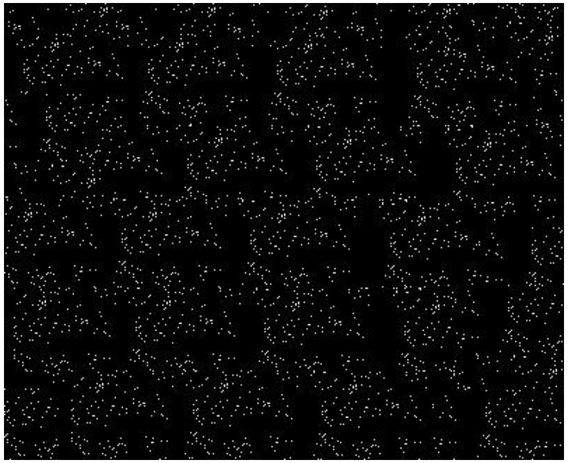
1 → 2 → 2 → 1

support < σ



1 → 3 → 1

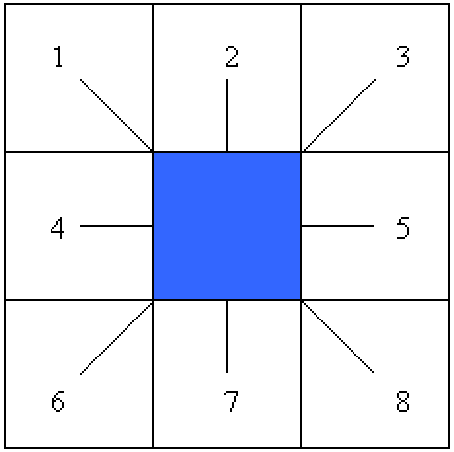
support ≥ σ



3 → 3 → 1

support ≥ σ

Incorporating spatiality: the GFS-patterns



- Measure: the average connectivity (AC) of evolution α, i.e. the average number of pixels covered by α in the 8-neighborhood

- Frequent sequential patterns covering pixels that are sufficiently connected (AC(α) ≥ κ) are Grouped Frequent Sequential patterns (GFS-patterns).

- κ is the minimum average connectivity and is also used to prune the search space.

[Julea11]

Maximal GFS-Patterns

- Definition : A maximal GFS pattern has the property of not being a sub-pattern of any other of the extracted GFS patterns.

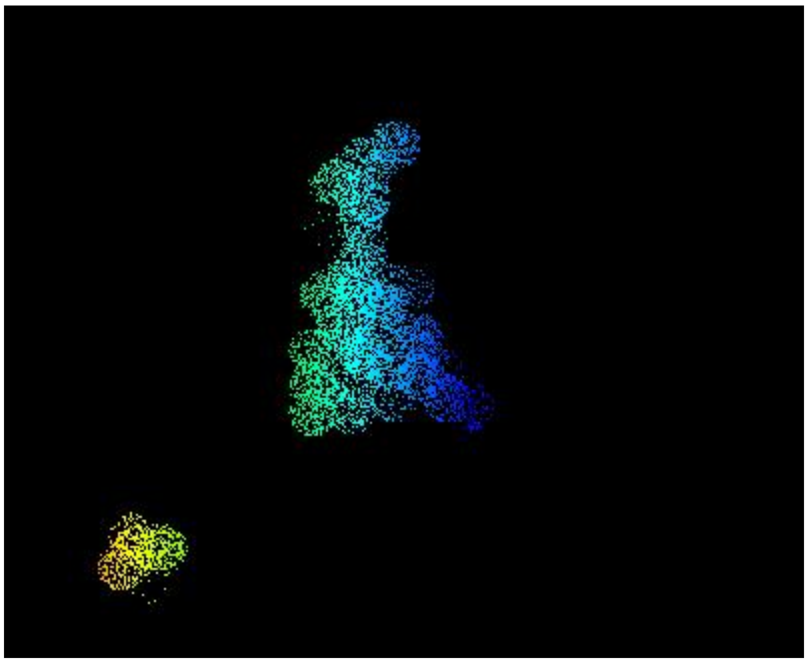
- (2,1) and (2,2) are sub-patterns of (2,1,2) therefore (2,1,2) is the only maximal GFS pattern of the set {(2,1),(2,2) ,(2,1,2)}.

- Selecting maximal patterns enables to focus on the most specific evolutions.

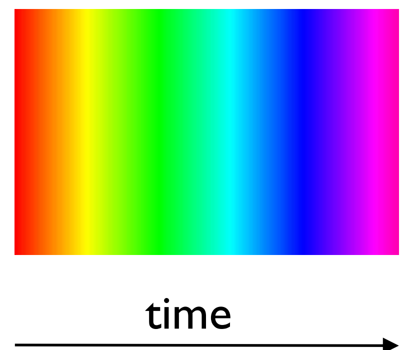
- Experiments on an optical Landsat SITS over New Caledonia : 15620 GFS-Patterns ; 295 maximal GFS-Patterns.

[Julea12]

SpatioTemporal Localization maps (STL-maps)

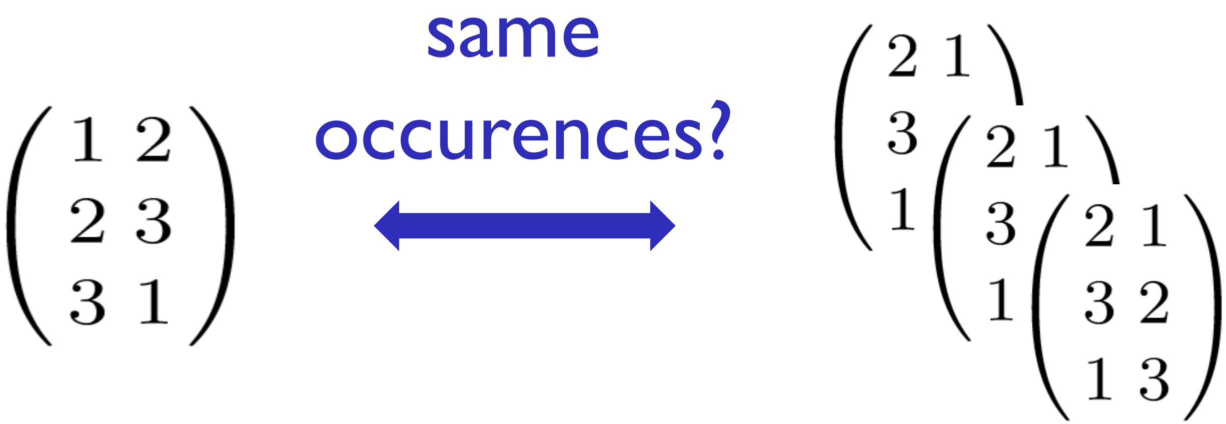


1 → 2 → 2



[Méger11]

Swap randomization for symbolic matrices



- A base of sequences expressing SITS can be expressed as a symbolic matrix: row ⇔pixel, column ⇔date

- To assess GFS-patterns obtained from symbolic matrices representing a SITS.

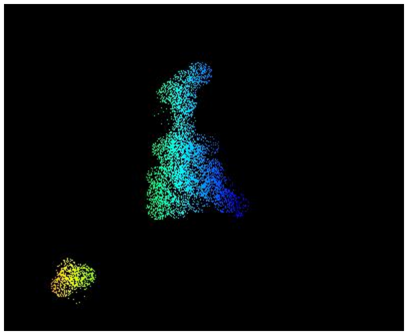
- The spatiotemporal nature of the observed phenomena must be preserved.

Swap randomization for symbolic matrices

$$C = \begin{pmatrix} \underline{3} & \underline{2} \\ 1 & 1 \\ \underline{2} & \underline{3} \end{pmatrix}, C' = \begin{pmatrix} \underline{2} & \underline{3} \\ 1 & 1 \\ \underline{3} & \underline{2} \end{pmatrix}$$

- Pairs of elements sharing the same symbol are chosen at random.
- If a pair B(i,j) = B(k,l) = α and if B(k,j) = B(i,l) = β (α ≠ β) then α's and β's are swapped.
- Column and row margins are maintained while GFS-patterns occurrences are affected.
- Failed swap attempts are counted as self-loops to explore equiprobable matrices.

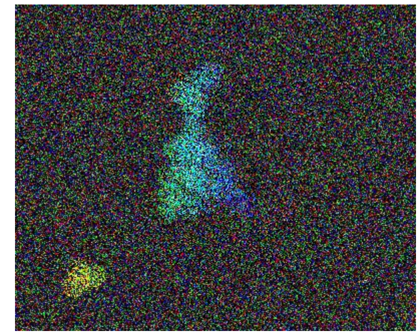
Normalized Mutual Information (NMI)



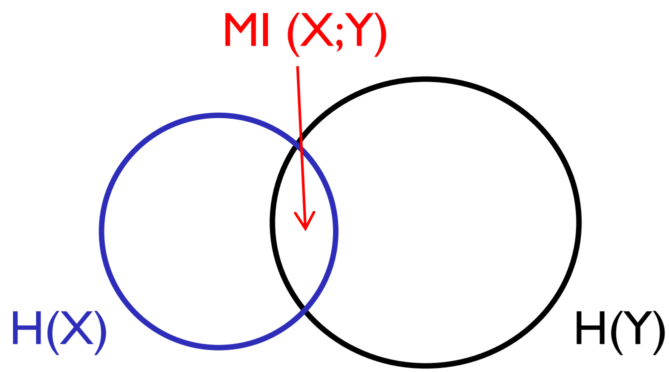
STL-map
original SITS

How similar?

X ⟷ Y



STL-map
swap-randomized SITS

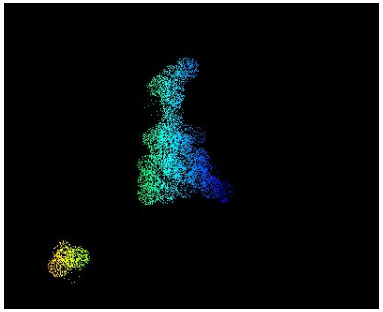


$$NMI(X;Y) = \frac{\sum_{x,y\in\Omega^2} P(x,y)\log\frac{P(x,y)}{P(x)P(y)}}{min(H(X),H(Y))}$$

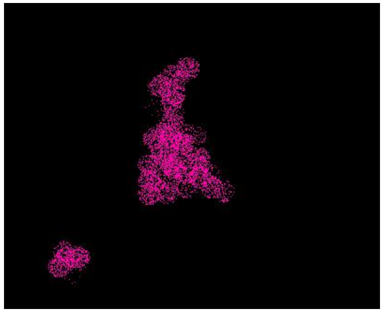
$$H(X) = -\sum_{x\in\Omega} P(x)\log P(x),$$

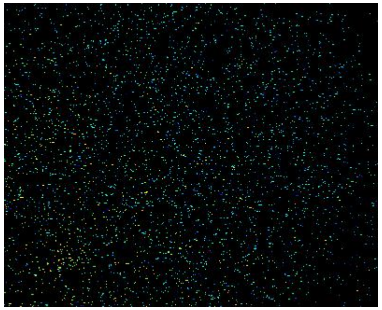
[Méger12]

NMI-based ranking

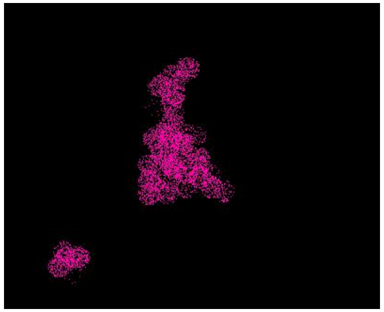


Original SITS





RandomizedSITS



Destroyed by randomization

Hardly altered by randomization

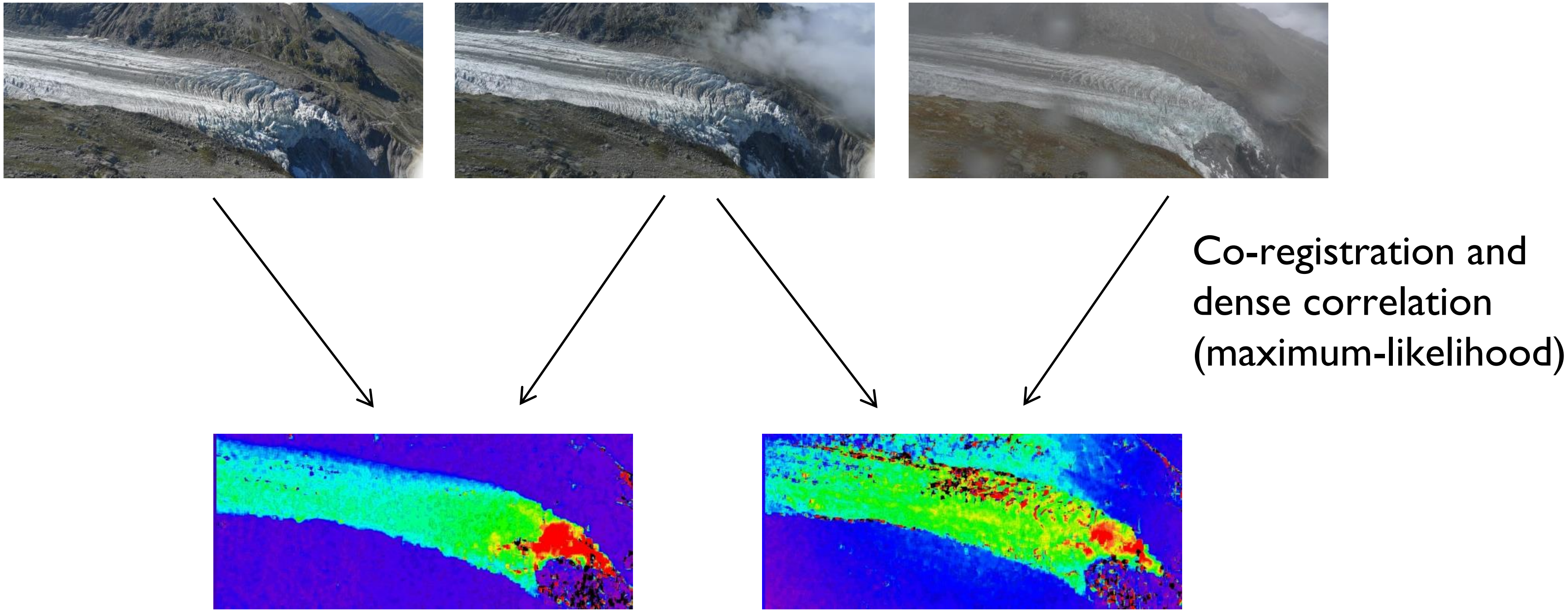
0 ⟵ **NMI** ⟶ 1

2 → 1 → 3

2 → 2 → 2 → 2 → 2 → 2

Monitoring of the Argentière glacier

- 21 images of the glacier automatically acquired every 2 days from September to November 2013.
- Optical camera Leica, DMC-LX, 10 mega-pixels.

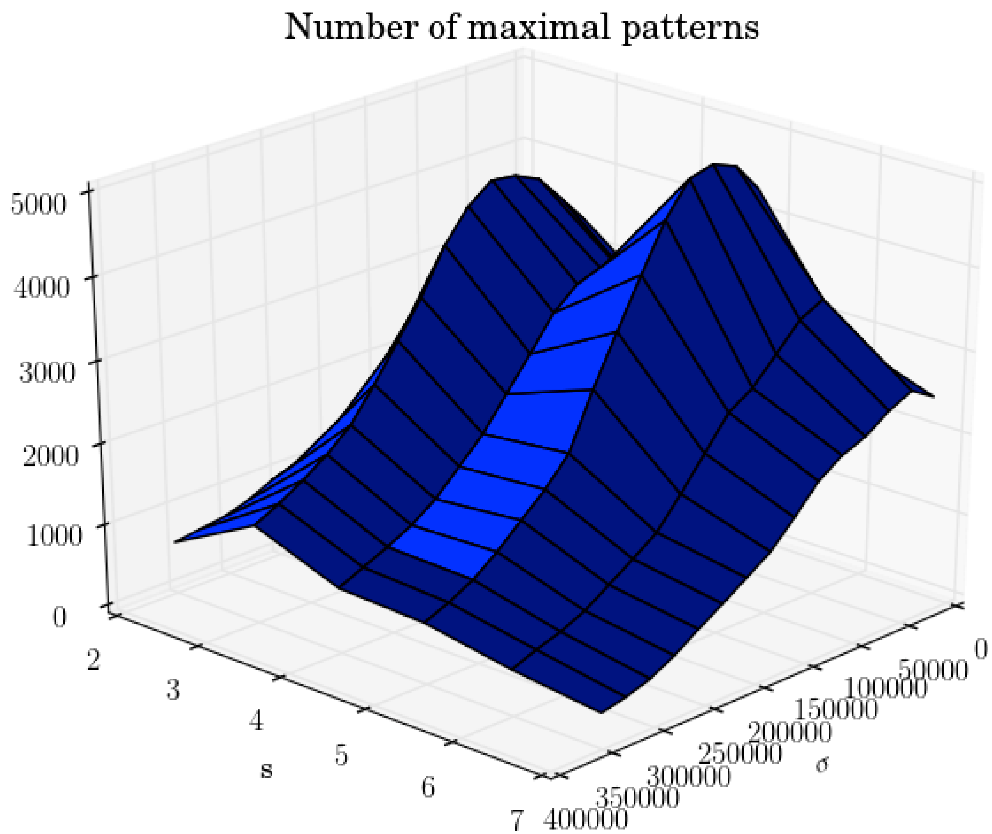


- 20 displacement fields in pixels (horizontal component). Size : 1675*700 pixels.

[Benoit15]

Setting the quantization and extraction parameters

- κ set to 5 (standard setting)
- σ ranging in [2%;20%]
- s ranging in [2;7]
- Multiple quantization and extraction in order to maximize the number of maximal GFS-Patterns.
- Maximum of 4900 maximal GFS-patterns for s=5 and σ=6% (70350 pixels)



GFS-pattern extraction

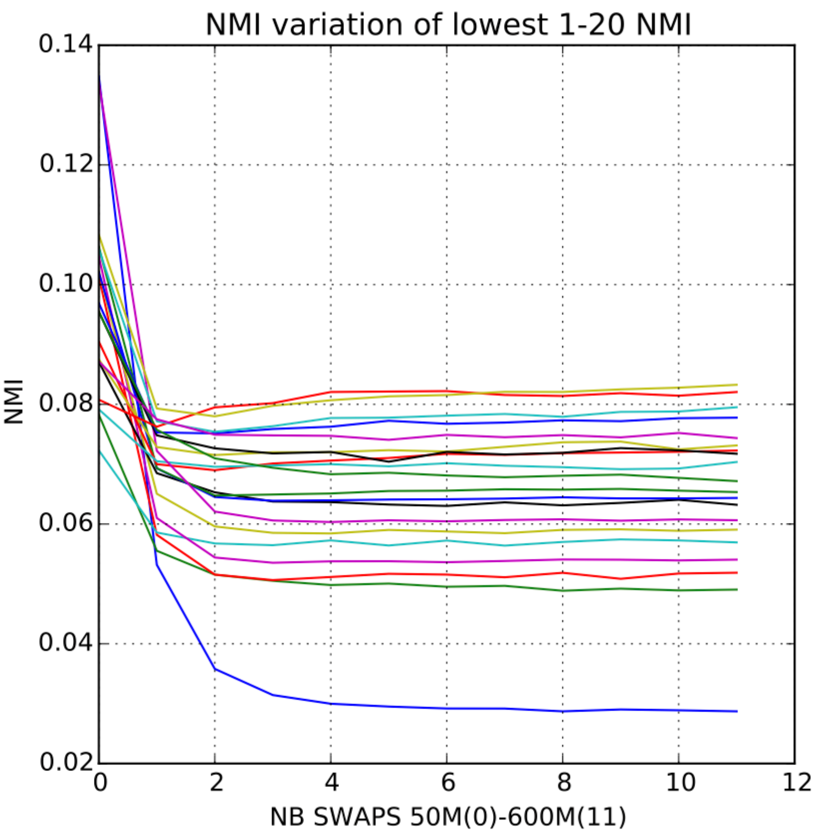
- prototype: C/Python
- platform : a single core on 2.9 GHz Intel Core i7

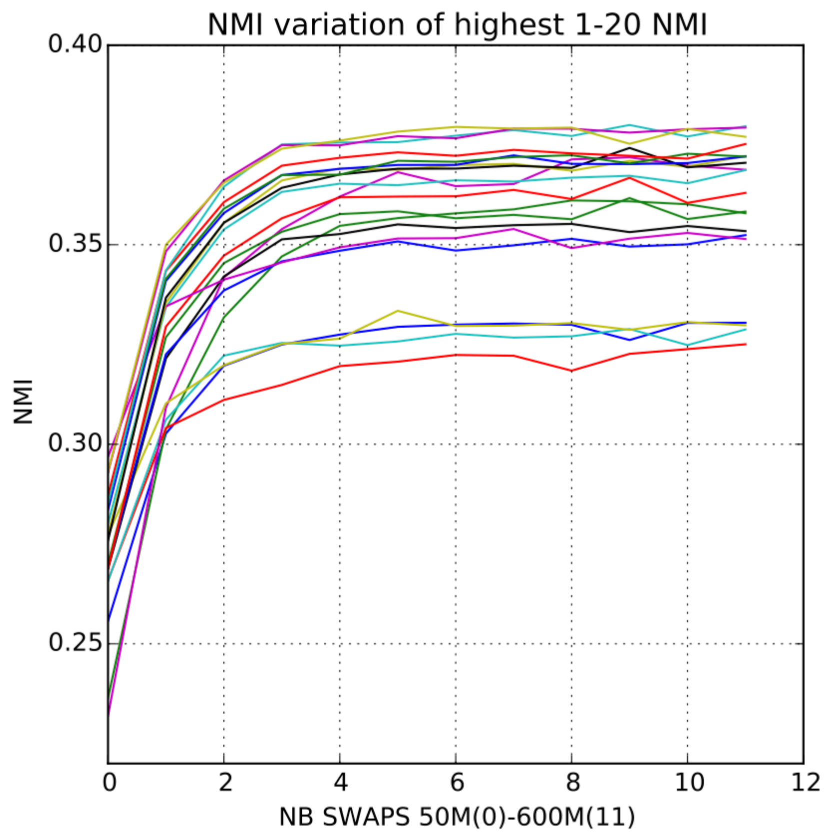
- Quantization with 5 symbols (1,2 : small negative displacements ; 3,4,5 small to large positive displacements)

- σ = 70350 (6%, set w.r.t. the maximum number of maximal patterns)
- k = 5
- Number of GFS-patterns: 19234
- Number of maximal GFS-patterns: 4900

- space/time requirements: 2,93 GB, 84 minutes.

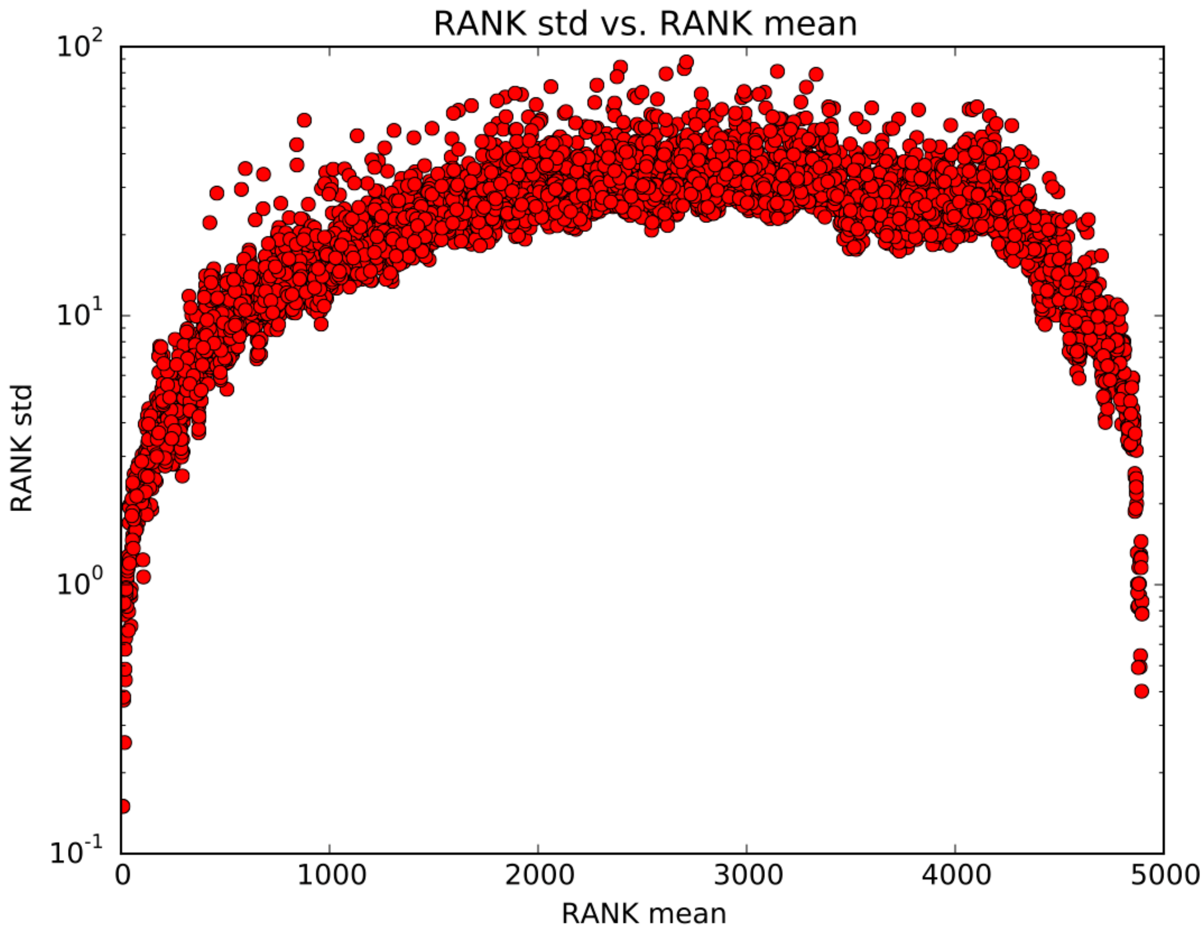
Setting the number of swap attempts





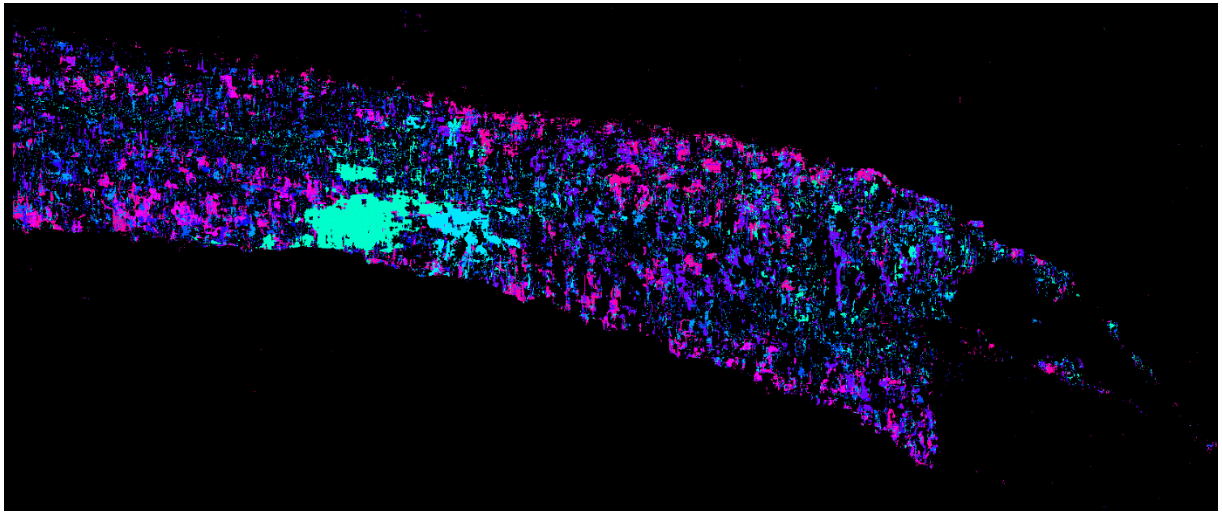
- Reference is 500M of swap attempts

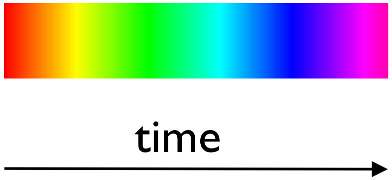
Ranking stability



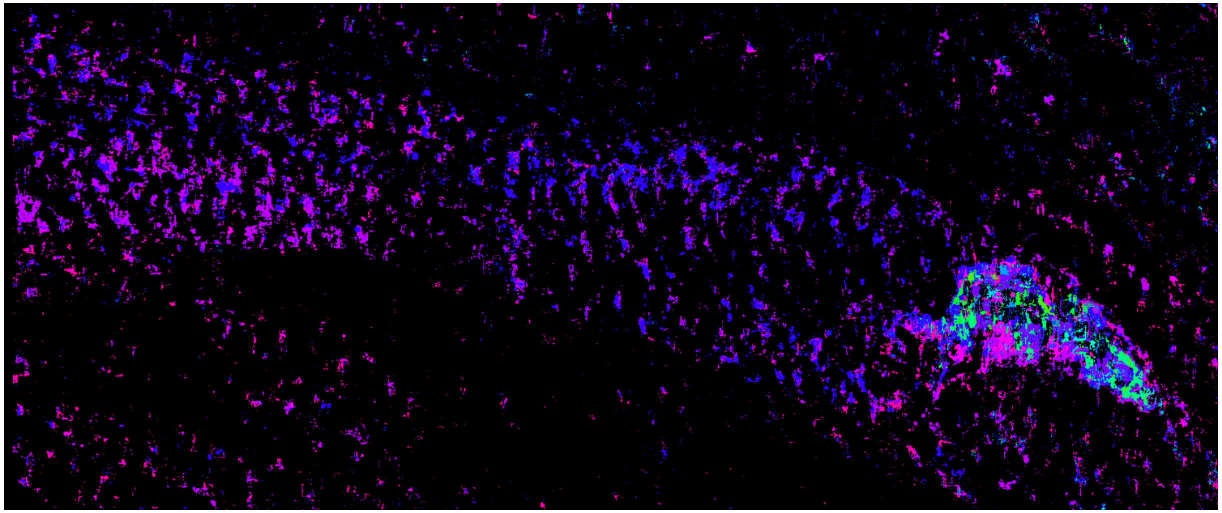
- The ranking experiment has been repeated 1000 times.

Qualitative results



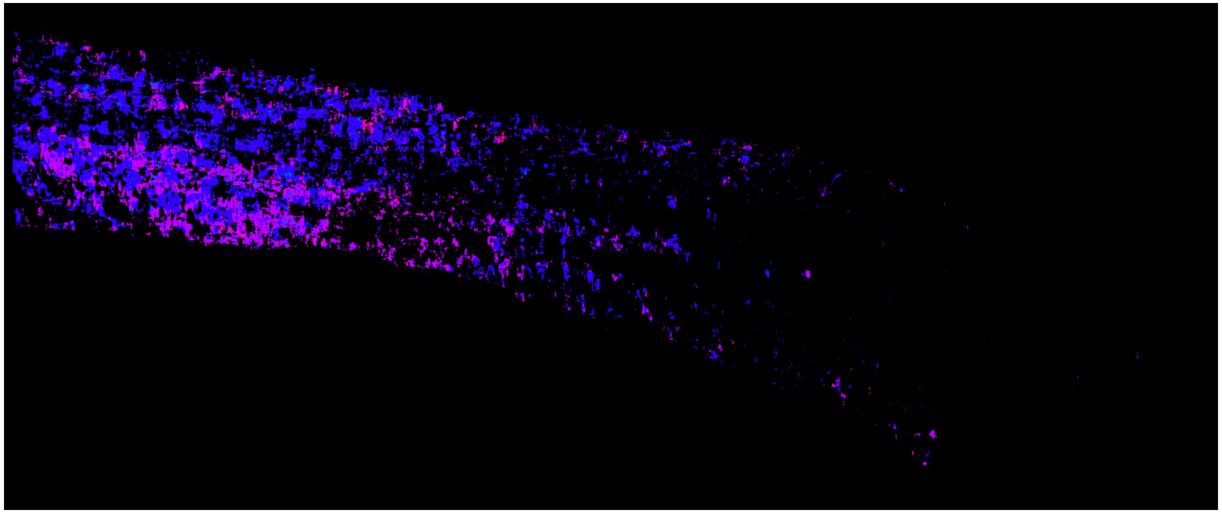


- 14th lowest NMI pattern
  5,4,4,4,4,4,4,2

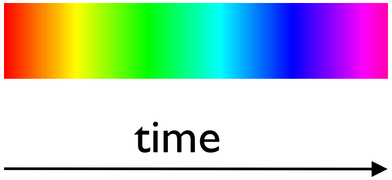


- 15th lowest NMI pattern
  5,5,5,5,5,5,4

Qualitative results



- 12th highest NMI pattern
  4,4,4,4,4,3,4,4,1,5,1,4



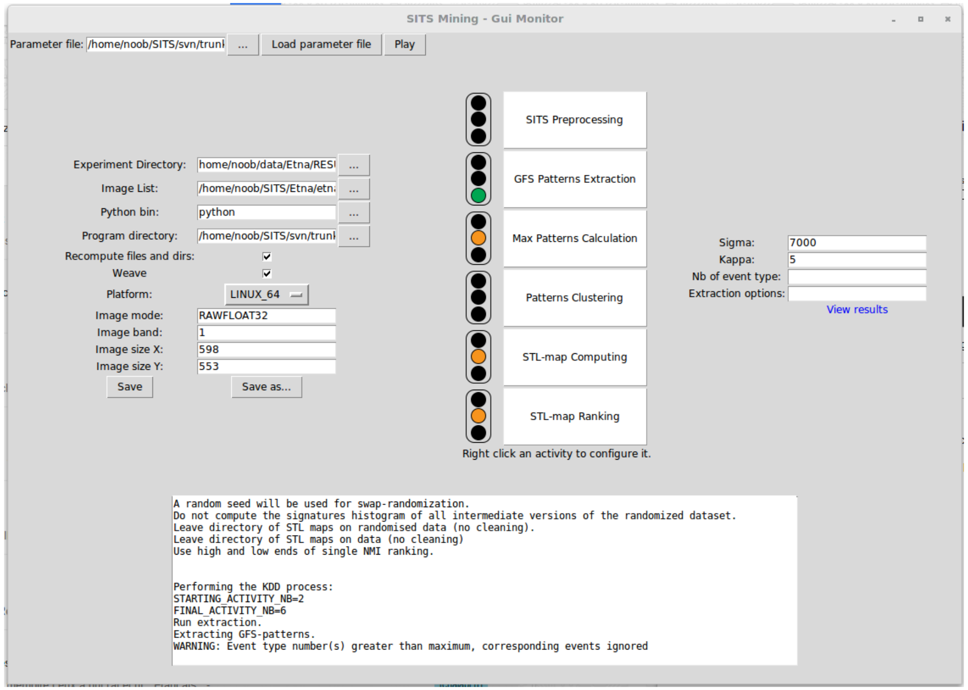
Conclusion & future work directions

- Encouraging qualitative results on a displacement field time series obtained by terrestrial photogrametry.
- Both ends of the NMI ranking can be of interest.
- Stability of both ends of the ranking for multiple randomizations.
- An operating point could be found to maximize the number of maximal GFS-patterns / get the richest description.

- Future work directions : raw optical images / considering the uncertainties during the extraction / longer time series.

SITS Miner

- Quantize SITS
- Extract GFS-patterns
- Select maximal ones
- Cluster patterns
- Compute STL-maps
- Rank STL-maps/patterns



- C/Python 2.7, free, open source, multiplatform (Linux, Mac OS, Windows)

Open source package soon available for download

References

[Agrawal95] Agrawal, R., Srikant, R.: Mining sequential patterns. In: Proceedings of the Eleventh International Conference on Data Engineering, Taipei, Taiwan. pp. 3– 14 (1995)

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[Julea11] Julea A., Méger N., Bolon P., et al. Unsupervised spatiotemporal mining of satellite image time series using grouped frequent sequential patterns. In: IEEE Transactions on Geoscience and Remote Sensing, vol. 49, 4, 2011, pp. 1417–1430.

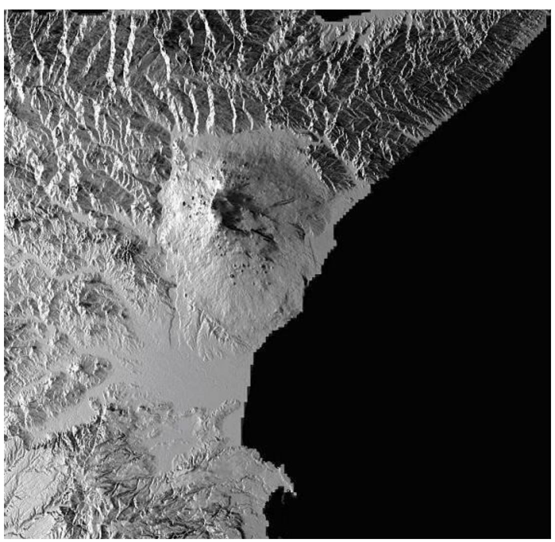
[Julea12] Julea A., Méger N., Rigotti C., et al. Efficient Spatiotemporal Mining of Satellite Image Time Series for Agricultural Monitoring. In: Transactions on Machine Learning and Data Mining, vol. 5, 1, 2012, pp. 23–45.

[Méger11] Méger N., Jolivet R., Lasserre C., et al. Spatio-temporal mining of ENVISAT SAR interferogram time series over the Haiyuan fault in China. In: Proc. of the 6th Int. Workshop on the Analysis of Multitemporal Remote Sensing Images (MULTI-TEMP'2011), July 2011, pp. 137–140.

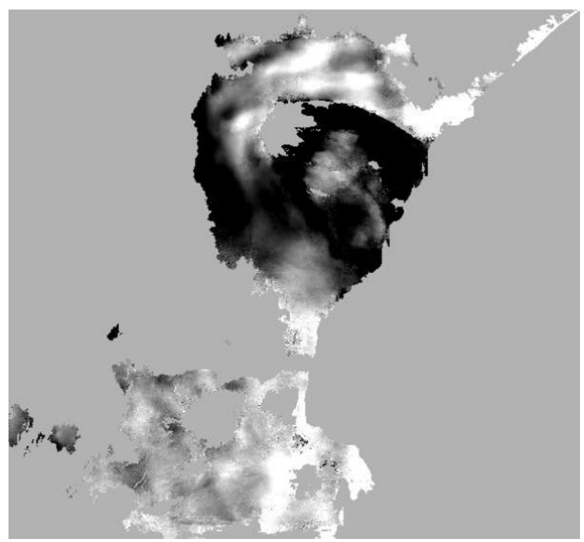
[Méger12] Méger N., Rigotti C., Gueguen L, et al. Normalized Mutual Information-Based Ranking of Spatio-Temporal Localization Maps. In: Proc. of 8th European Spatial Agency (ESA) - EUSC - JRC Conference on Image Information Mining, Oct. 2012, pp. 11–14.

Deformation monitoring of Mount Etna

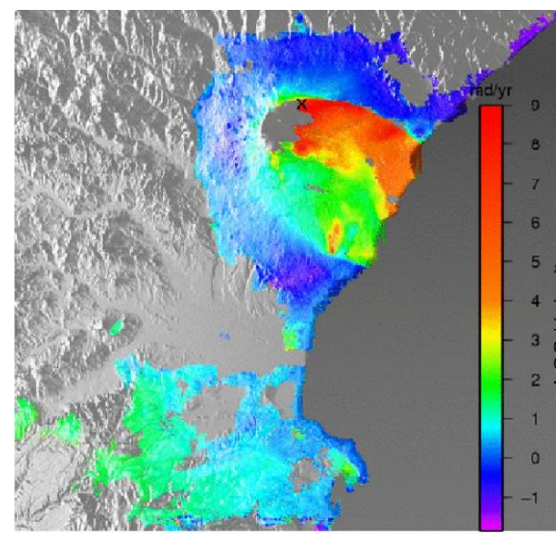
- 16 co-registered total phase delays images (553X598), 2003-2010, SAR geometry, ≈160 m, over the site of the Mount Etna volcano.
- Data produced by M-P. Doin, laboratory ISTerre.
- Phase delays were quantized into 3 levels (33rd et 66th percentiles).



DEM of the Mount Etna area



Phases delays 2003/01/22



Average velocity in rad/yr [Doin11]
2π = 2.8 cm

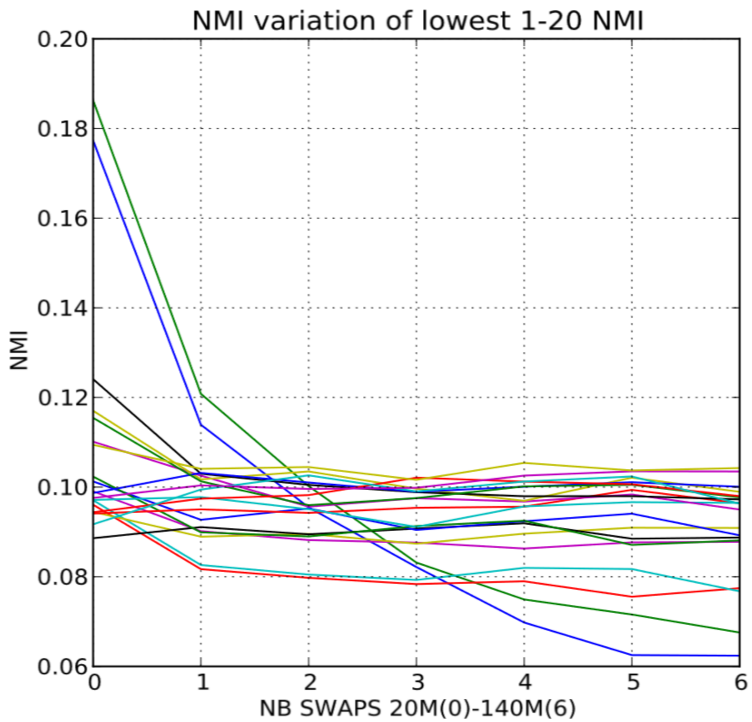
GFS-pattern extraction and ranking

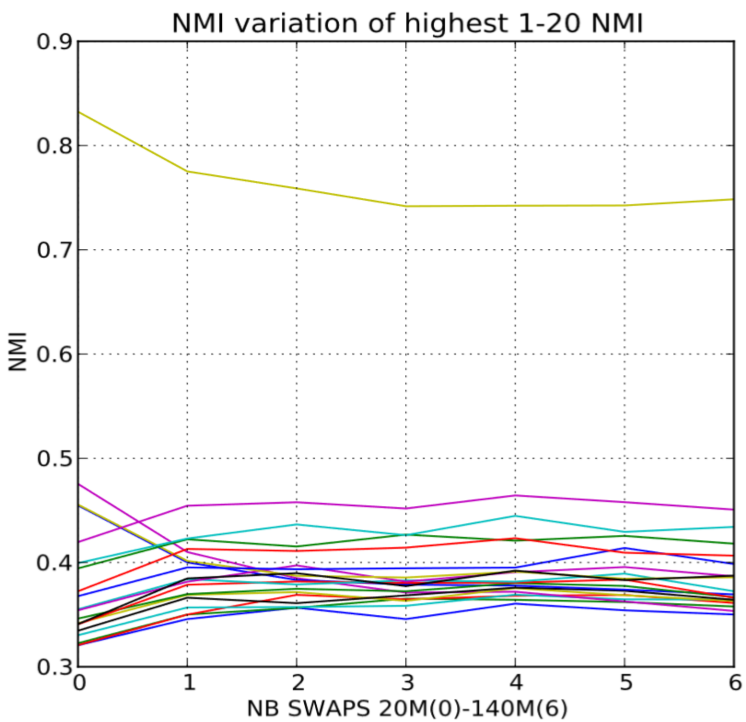
- prototype: C/Python
- platform : a single core on 2.7 GHz Intel Core i7

- σ = 7000 (2.1%, set w.r.t. the maximum number of maximal patterns)
- k = 5
- Number of GFS-patterns: 2658
- Number of maximal GFS-patterns: 508
- #swaps: 100M

- space/time requirements: 1.66 GB, 700 s.

#swaps: 100 M


NMI variation of lowest 1-20 NMI
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
NMI
0
1
2
3
4
5
6
NB SWAPS 20M(0)-140M(6)


NMI variation of highest 1-20 NMI
0.9
0.8
0.7
0.6
0.5
0.4
0.3
NMI
0
1
2
3
4
5
6
NB SWAPS 20M(0)-140M(6)

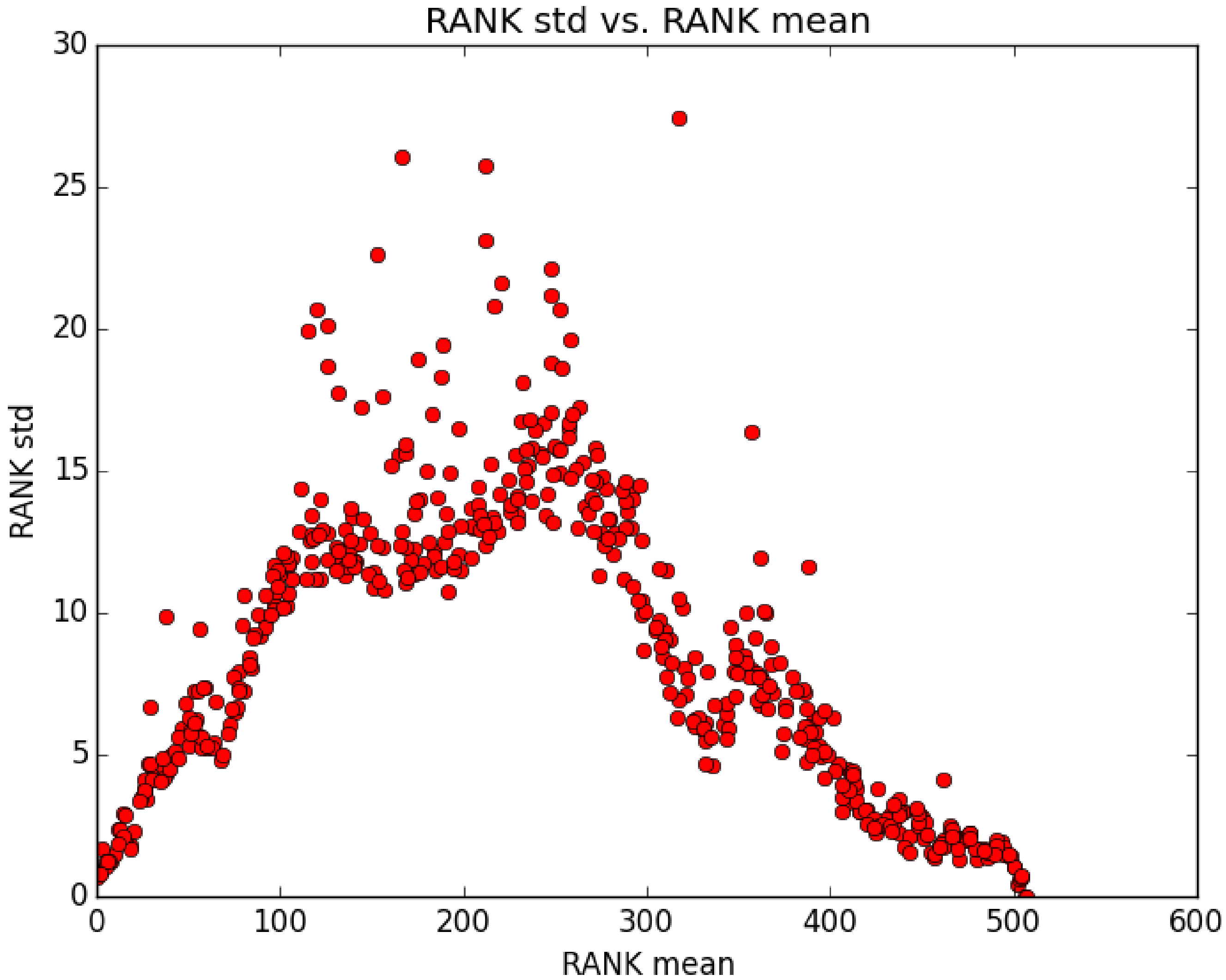
Randomization procedure behavior

73,9% of the dataset can not be swapped

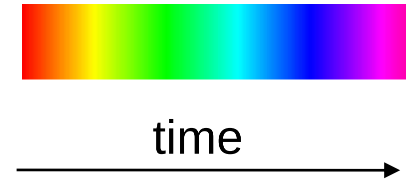
- 1000 swap randomizations
- Average swapped events rate: 6,5% (standard deviation ≈ 0, stable)

- 1 swap randomization
  - 1,070,219 matrices are explored.
  - All matrices are reached only once (except one, 8 times)

Ranking stability (over 1000 matrices)

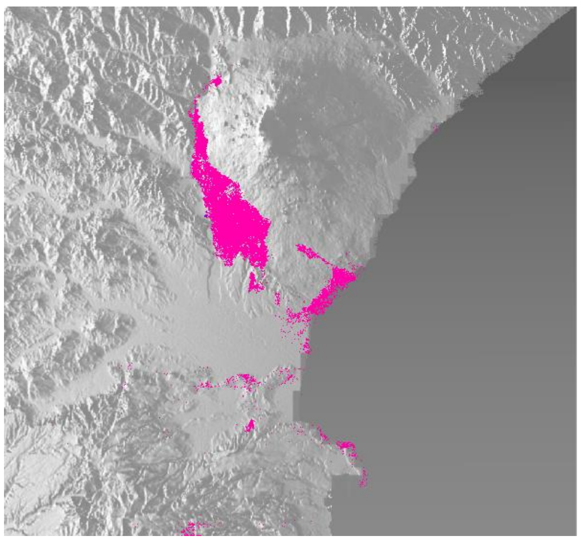


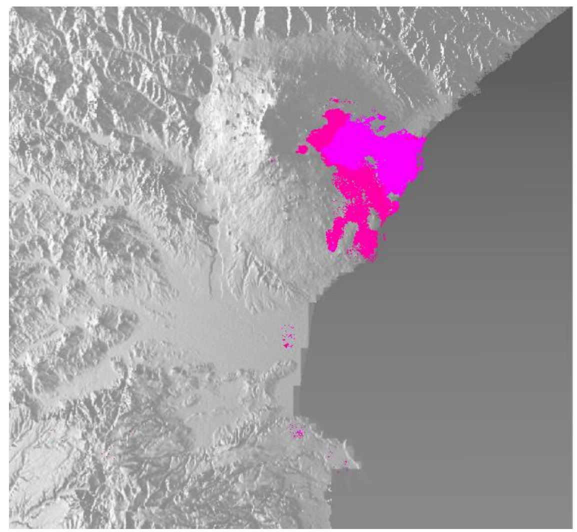
Qualitative results

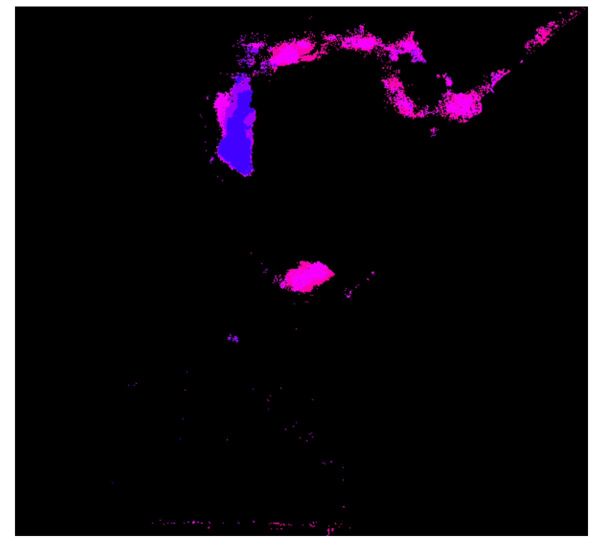


1→1 → 2 → 1 → 1 → 1 → 1 → 3

1 → 1 → 1 → 1 → 1 → 1 → 1 → 1 → 1 → 1 → 1 → 1 → 1







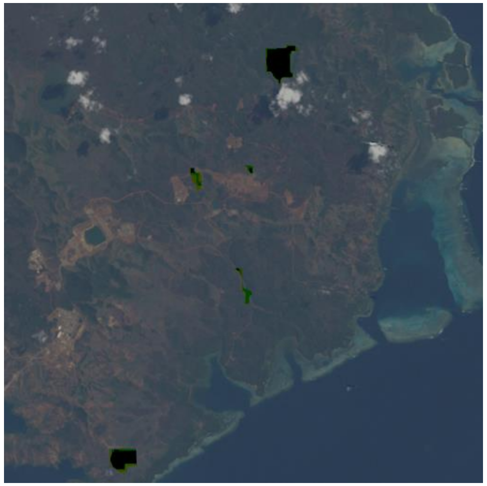
1 → 2 → 3 → 3 → 3 → 3 → 3 → 3 → 3 → 3 → 3 → 3 → 3 → 3 → 3

Noisy/cloudy optical data can also be analysed

Monitoring the Yaté area

- 16 co-registered Landsat 7 images (513X513), 2000-2011, 30 m, over New Caledonia (Yaté rural district, nickel open cast mining activities, scrub fires, erosion, landsildes, UNESCO protected coral reefs and lagoons).
- Bands: blue (450-520nm), green (520-600nm), red (630-690nm), near infra-red (750-900nm).
- Synthetic band NDVI and ground truth provided by Bluecham SAS. NDVI values were quanitized into 3 levels (33rd et 66th percentiles).

Clouds ...

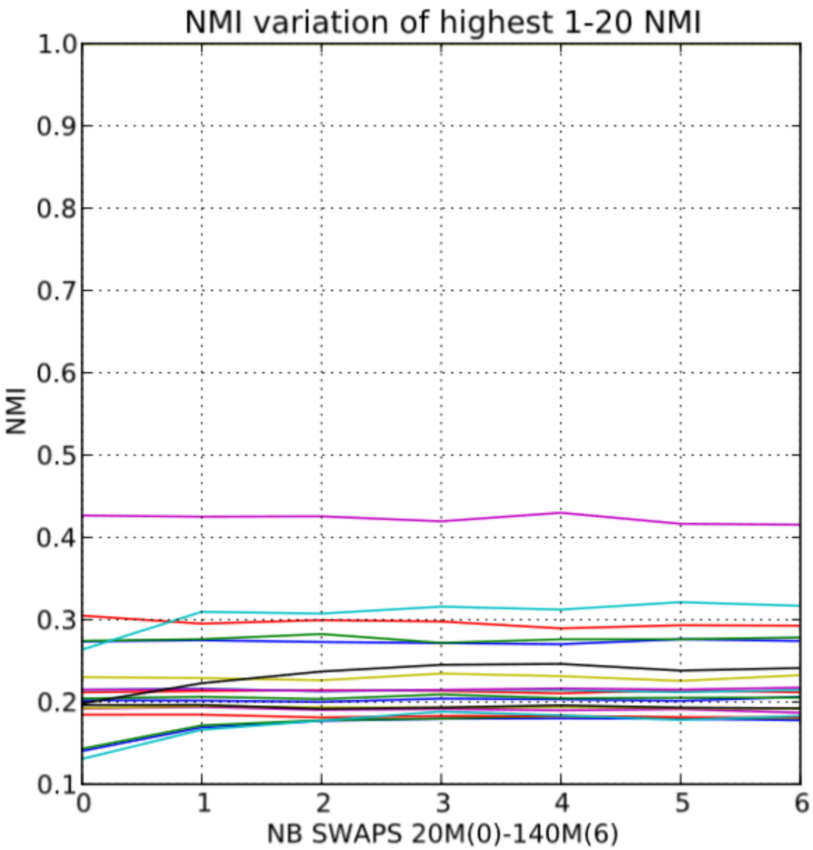


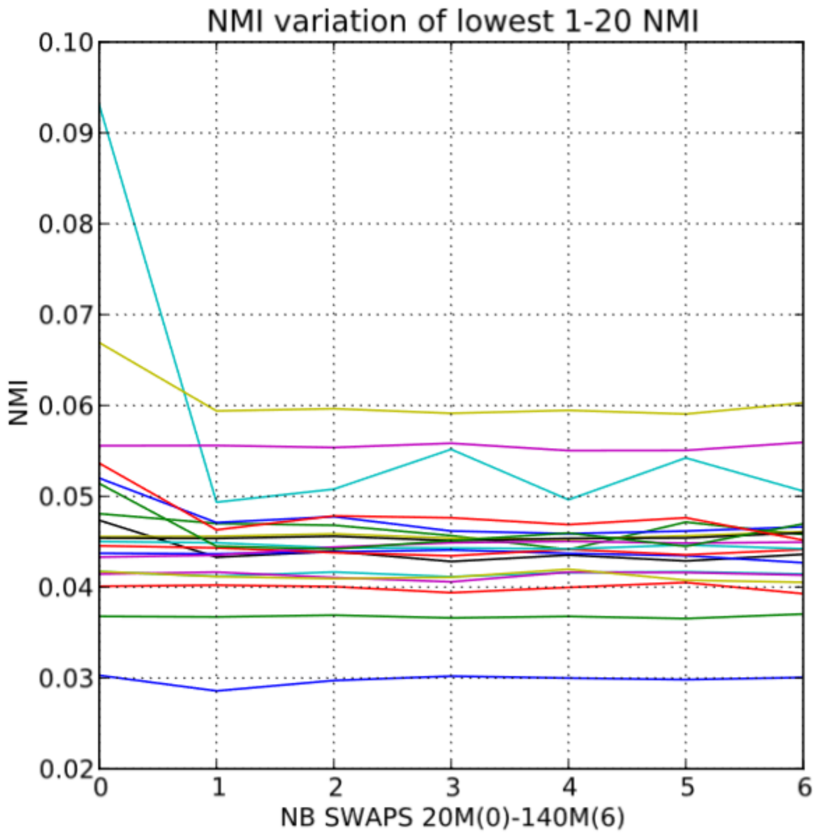
… artefacts

GFS-pattern extraction and ranking

- σ = 7000 (2.6%, set w.r.t. the maximum number of maximal patterns)
- k = 5
- Number of GFS-patterns: 15620
- Number of maximal GFS-patterns: 295
- NMI rankings at 100M swaps

#swaps: 100 M


NMI variation of highest 1-20 NMI
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
NMI
0
1
2
3
4
5
6
NB SWAPS 20M(0)-140M(6)


NMI variation of lowest 1-20 NMI
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
NMI
0
1
2
3
4
5
6
NB SWAPS 20M(0)-140M(6)

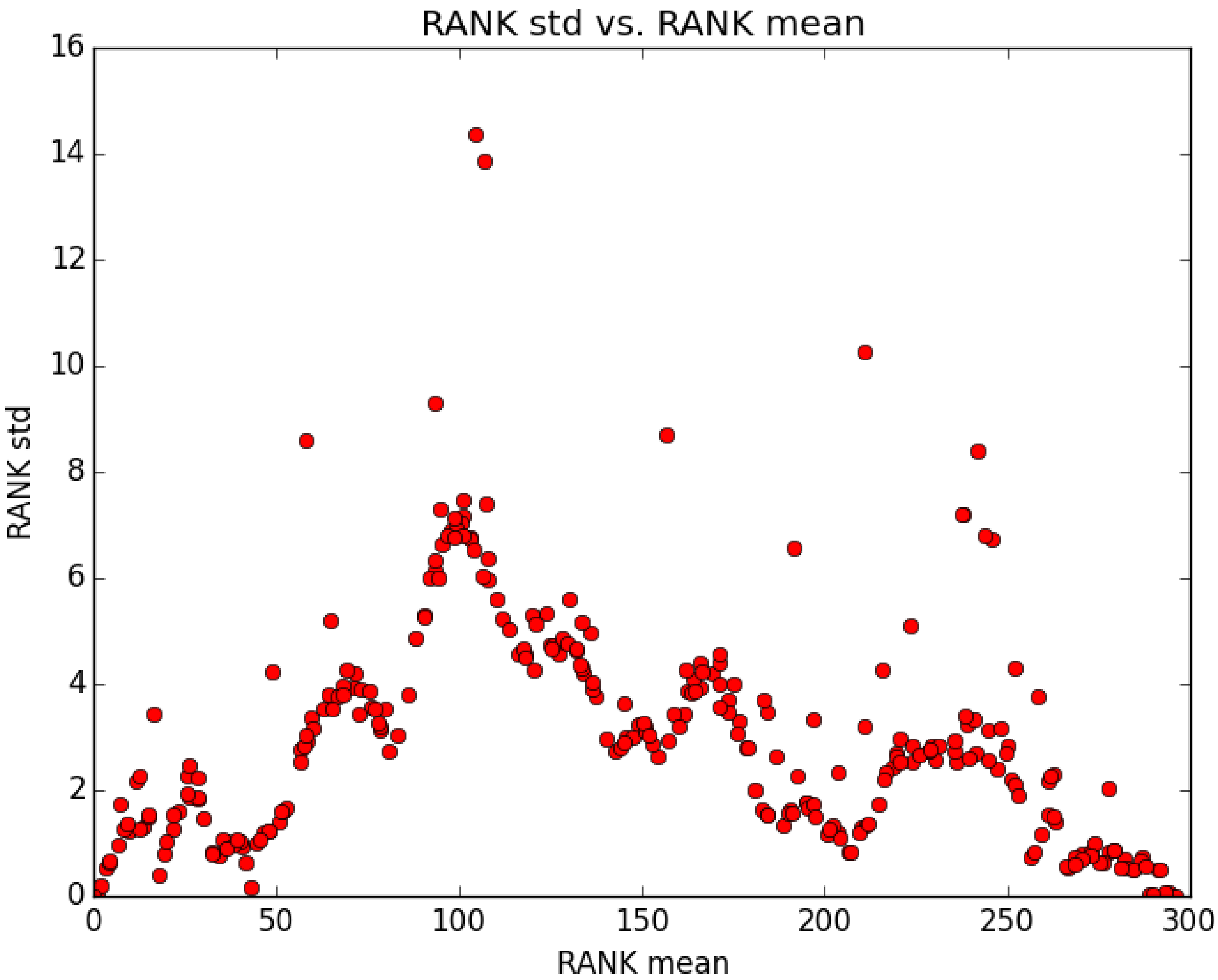
Randomization procedure behavior

16,2% of the dataset can not be swapped

- 1000 swap randomizations
- Average swapped events rate: 32,9% (standard deviation ≈ 0, stable)

- 1 swap randomization
  - 8,911,591 matrices are explored.
  - All matrices are reached only once (except one, 4189 times and another one, 44 times)

Ranking stability (over 1000 matrices)



Yaté qualitative results

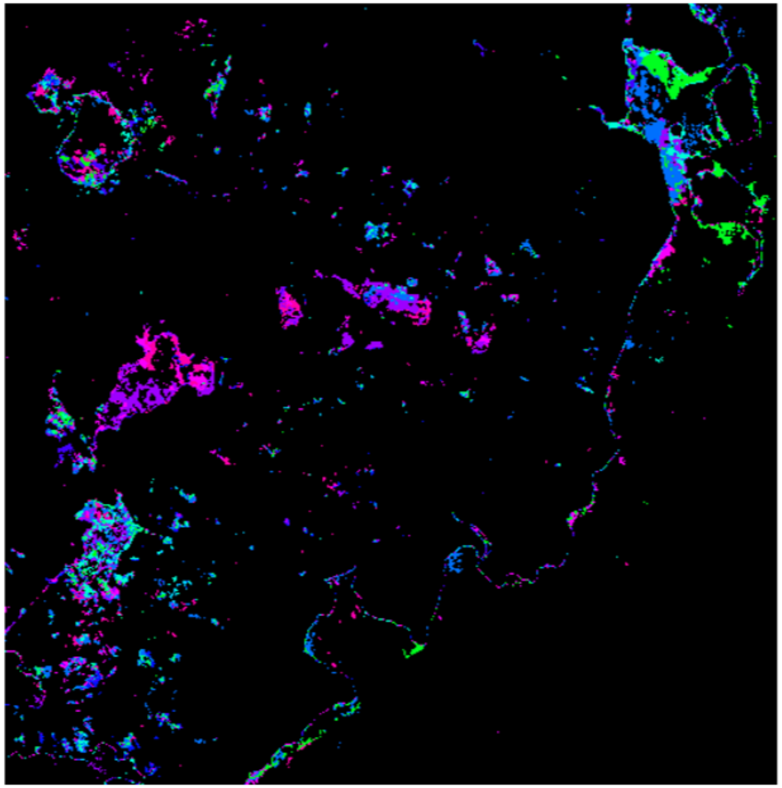


Fig. 13. STL-map: 6^{th} lowest NMI pattern $\langle 2,2,1,1,1,2 \rangle$, NC.

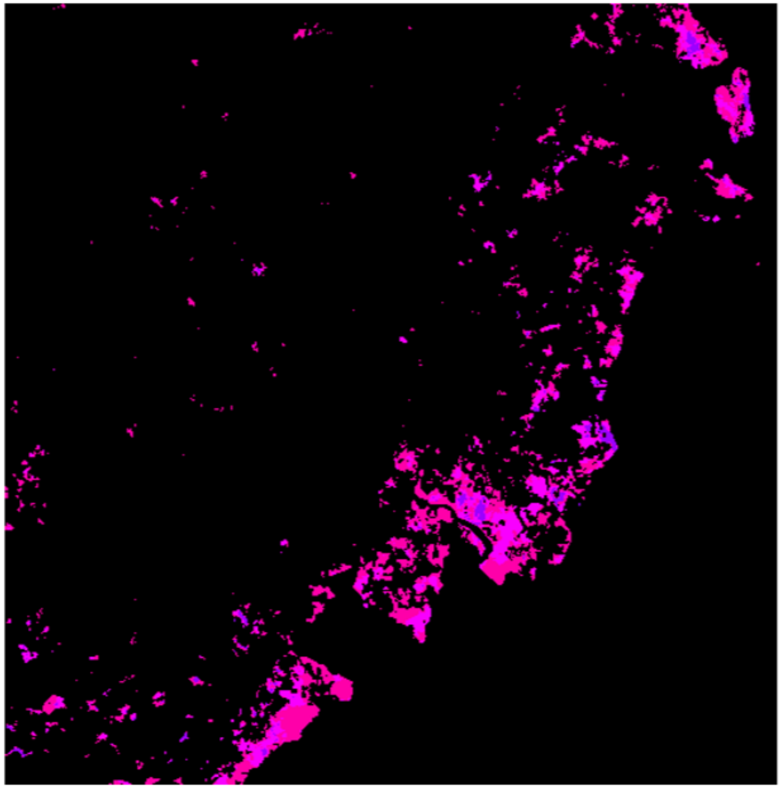
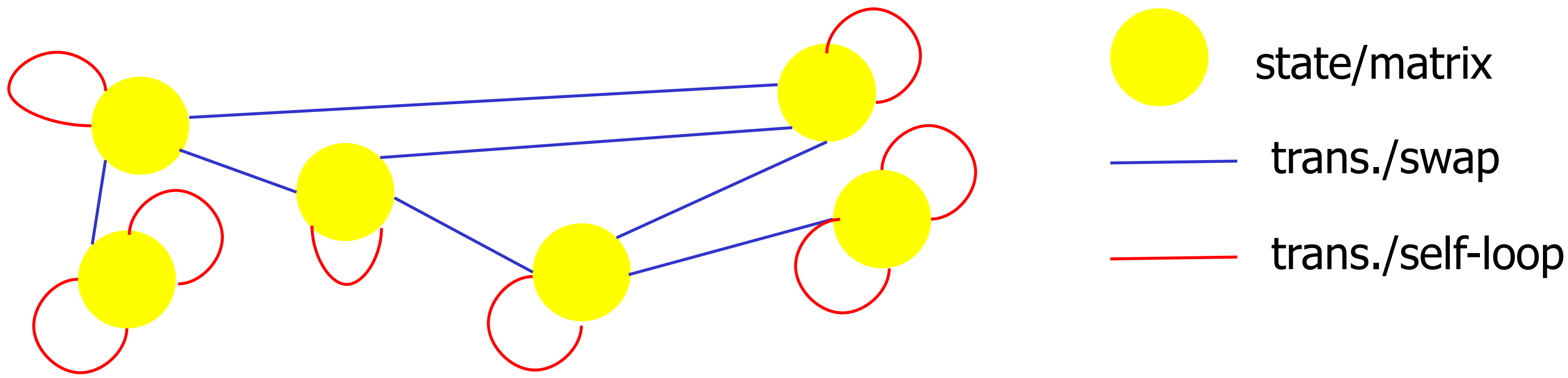


Fig. 14. STL-map: 2^{nd} highest NMI pattern $\langle 3,3,3,3,3,3,3,3,3,3,3,3,3,3 \rangle$, NC.

Equiprobable matrices and self-loops



- All matrices having the same structure are equiprobable if failed swap attempts are counted as self-loops.

  [Gionis07]

- A swap attempt = a step in Markov chain M(S,T)
  S – set of states/matrices, T – set of transitions/swap attempts

- Each state degree = P = |T|

- All states have the same degrees ➔ uniform distribution

Why maintaining column and row margins?

Maintaining margins ≈ preserving histograms

Colum margins: within a single image, the nature of the observed scene must not be modified.

Glaciers and forests should not be transformed into bare soils.

Row margins: the nature of a pixel evolution should be preserved.

Variations between snow and rocks should not be transformed into permanent vegetation.