Mesure de la Déformation par Imagerie Spatiale,
Besse en Chandesse, France
Wednesday 18th October 2017, 14h10

Applications of blind source separation for analysing volcanic deformation in satellite radar

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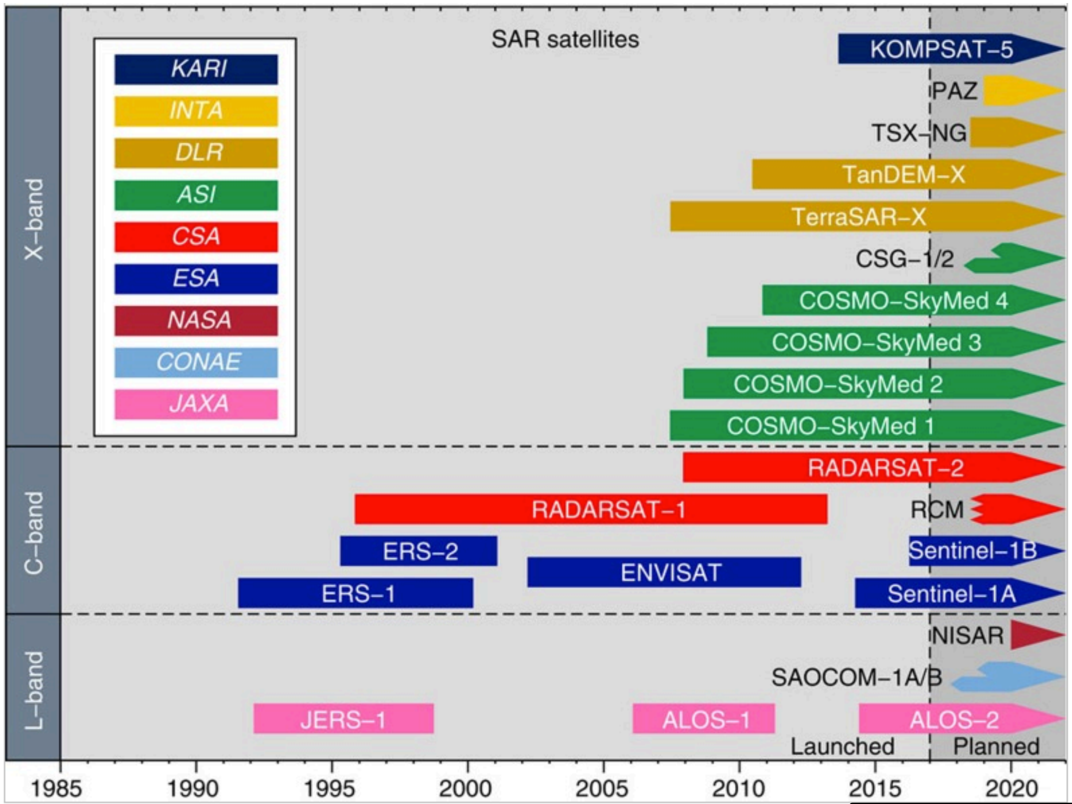
UNIVERSITY OF LEEDS

COMET

University of BRISTOL



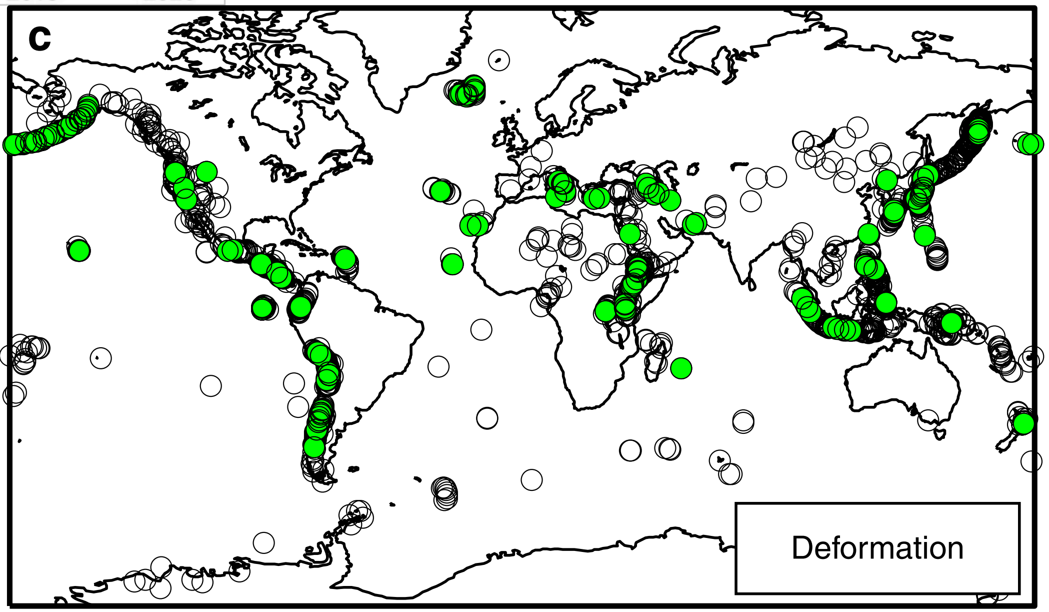
Elliott, Walters & Wright, 2016

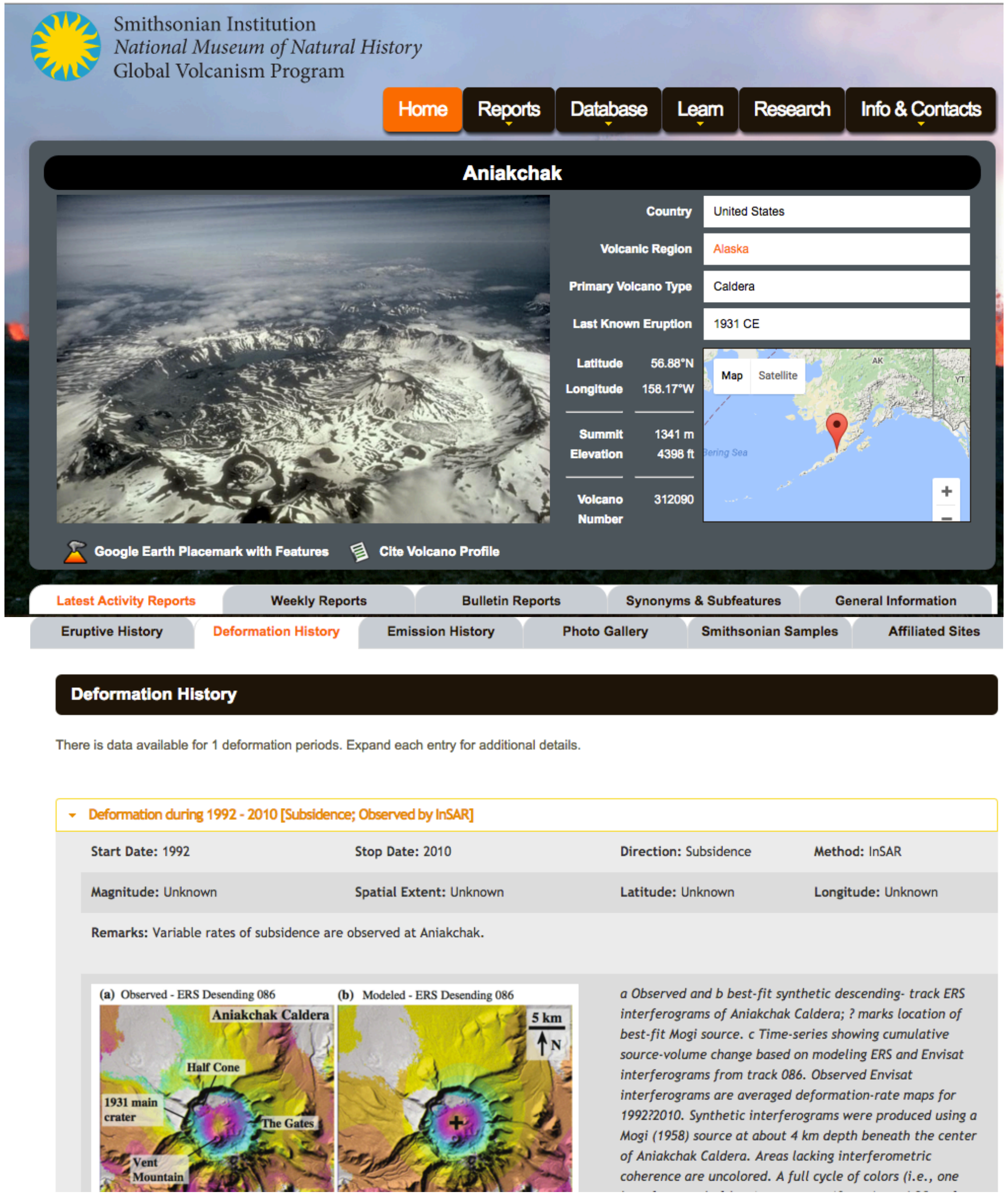
- Order of magnitude increase in availability and quality of SAR imagery

- Improved acquisition strategies and shorter repeat times

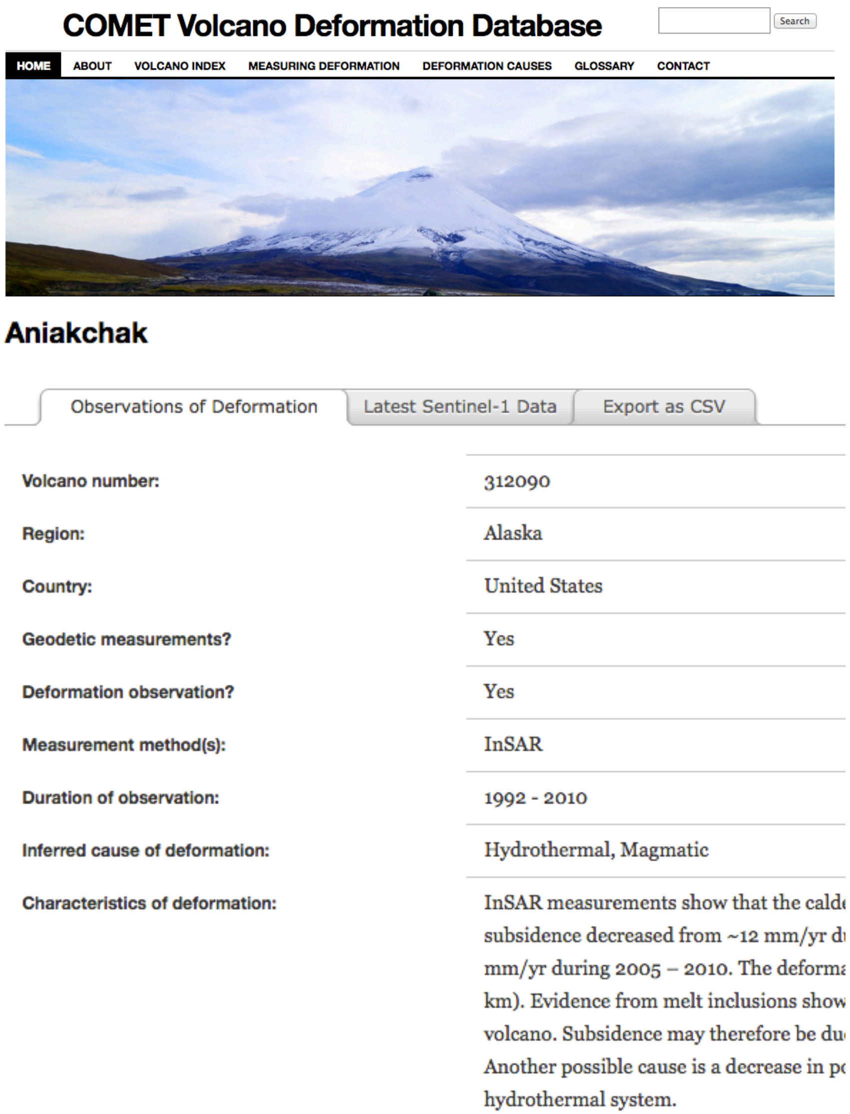
- ~ 340 measurements of magmatic and volcanic deformation

Biggs, Ebmeier et al., 2014





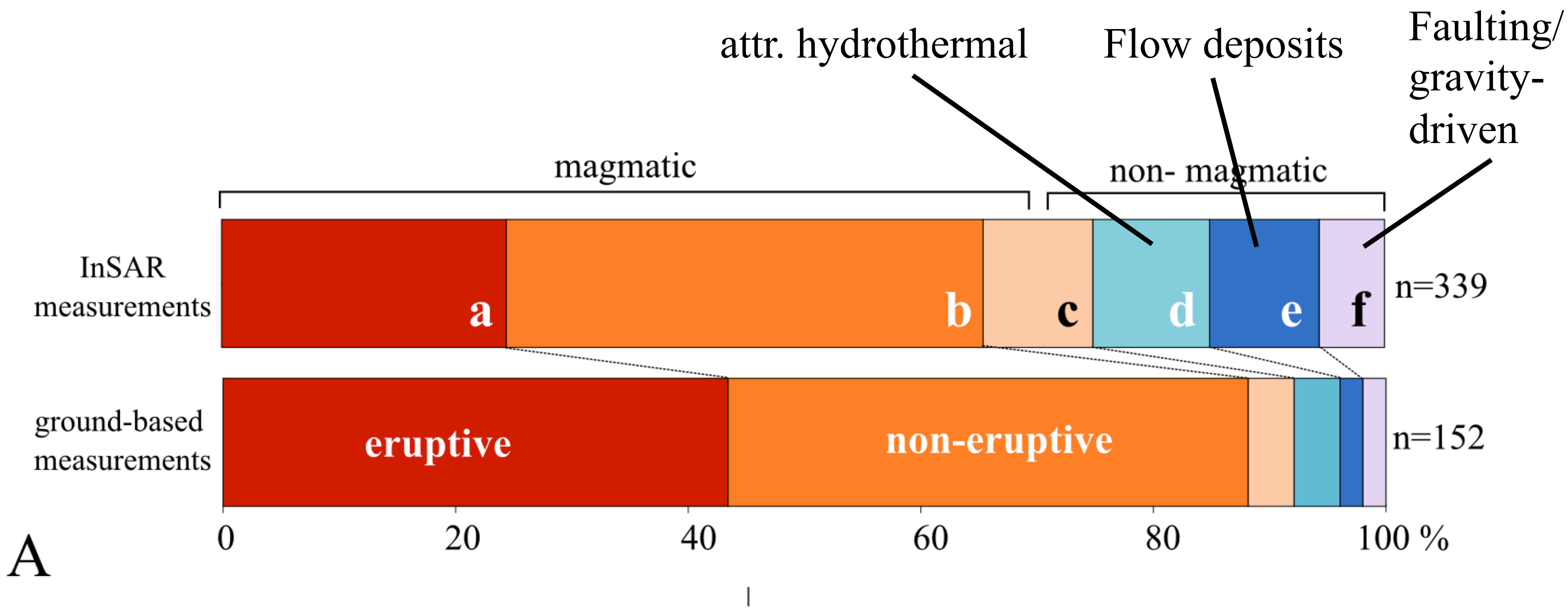
Global Volcano Programme Database, hosted by the Smithsonian Institution. Jennifer Jay, Matt Pritchard, Maria Furtney, Ben Andrews, Ed Venzke

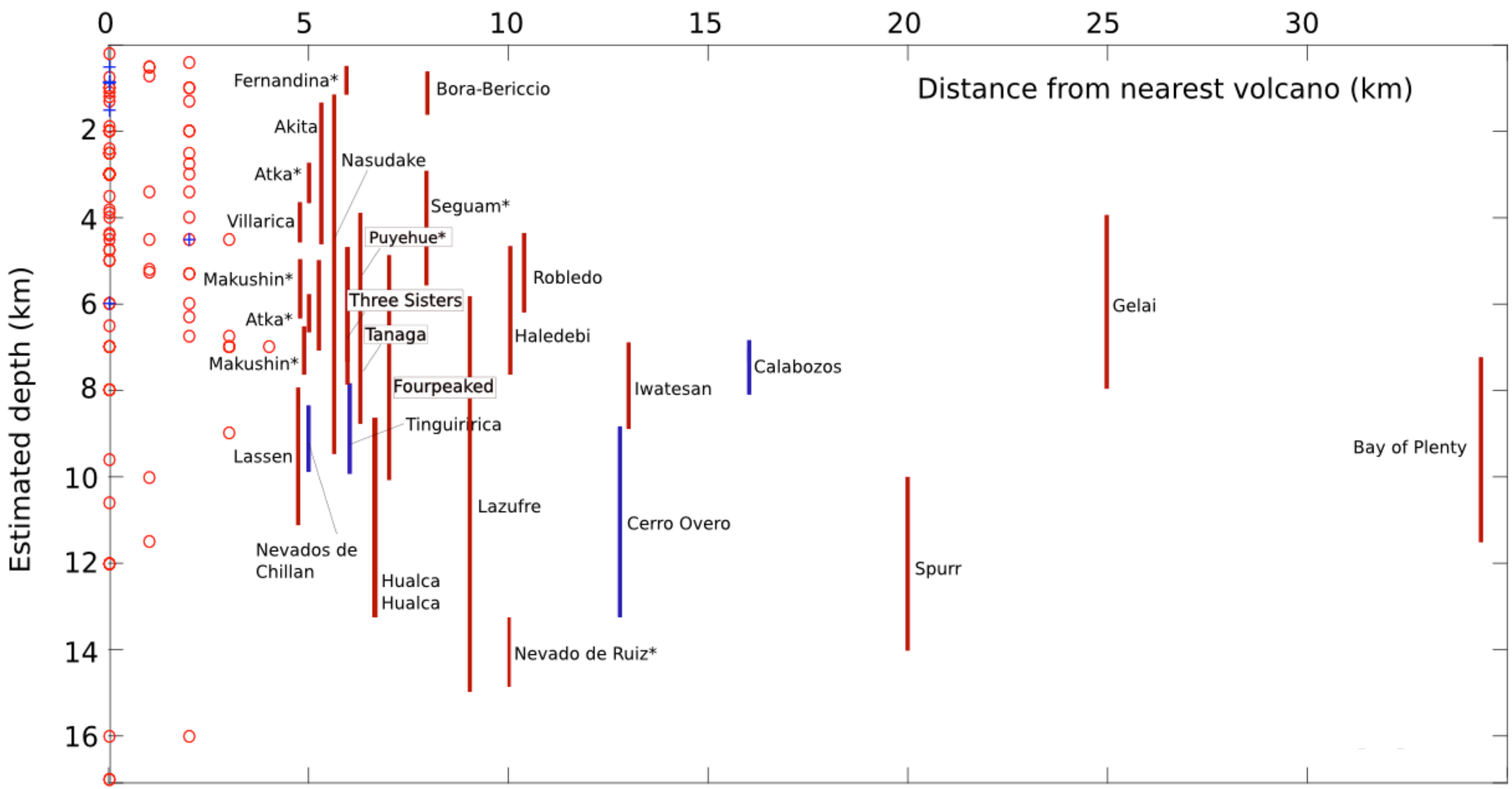


COMET catalogue: Susanna Ebmeier, Juliet Biggs, Amy Parker, James Hickey, David Arnold, Ryan Lloyd & Elspeth Robertson

- **Additions** presented: (1) displacement signal area & rate
  interpreted: (2) depth & distance from volcano

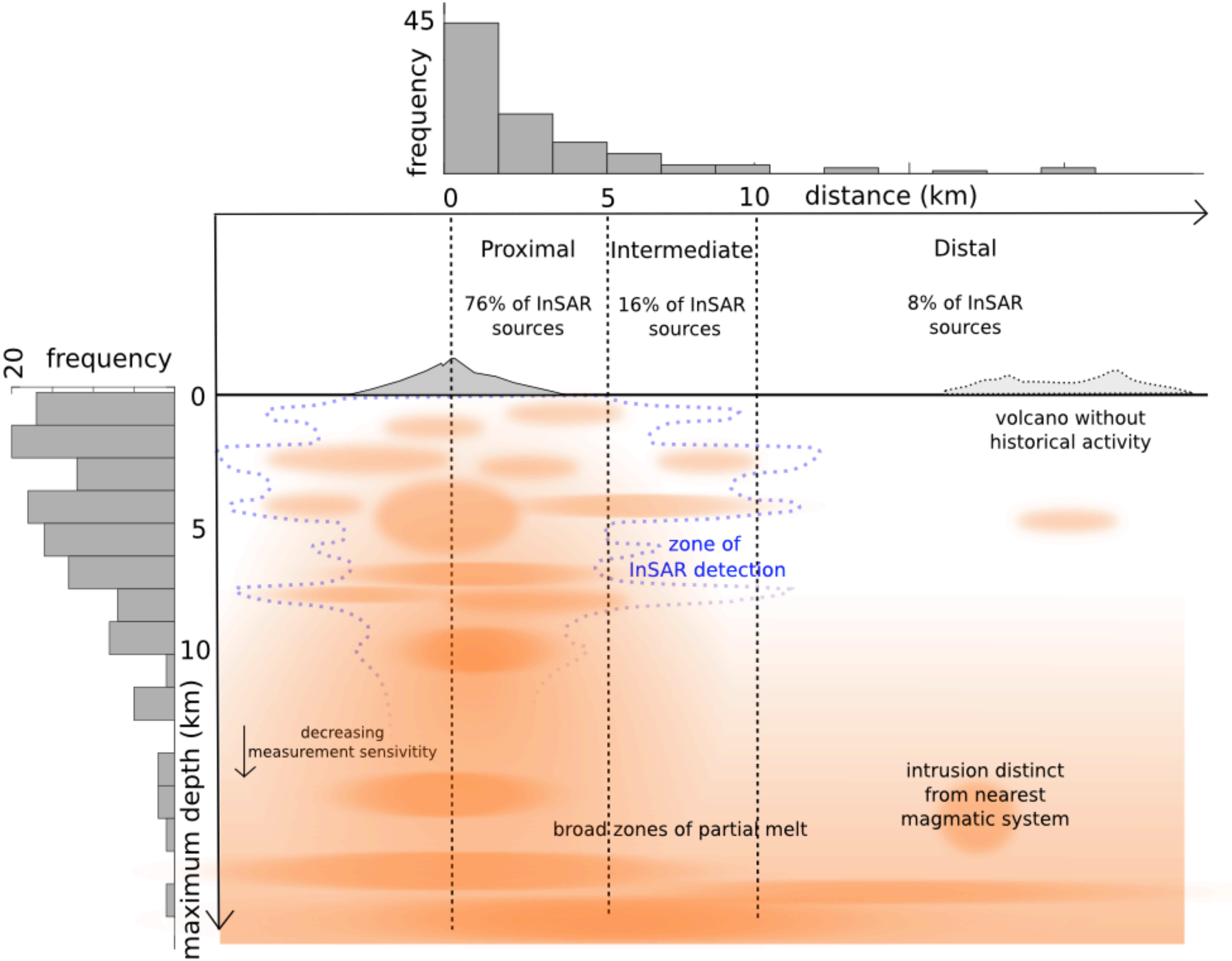
- Higher proportion of InSAR measurements capture non-magmatic and non-eruptive processes than ground based measurements





Ebmeier et al., under review

STREVA COMET University of BRISTOL UNIVERSITY OF LEEDS Smithsonian CORNELL UNIVERSITY FOUNDED A.D. 1865



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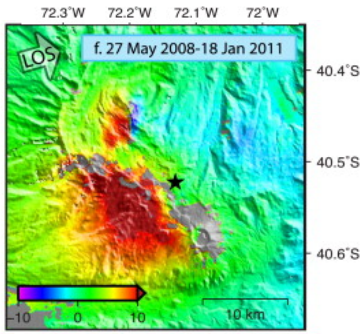
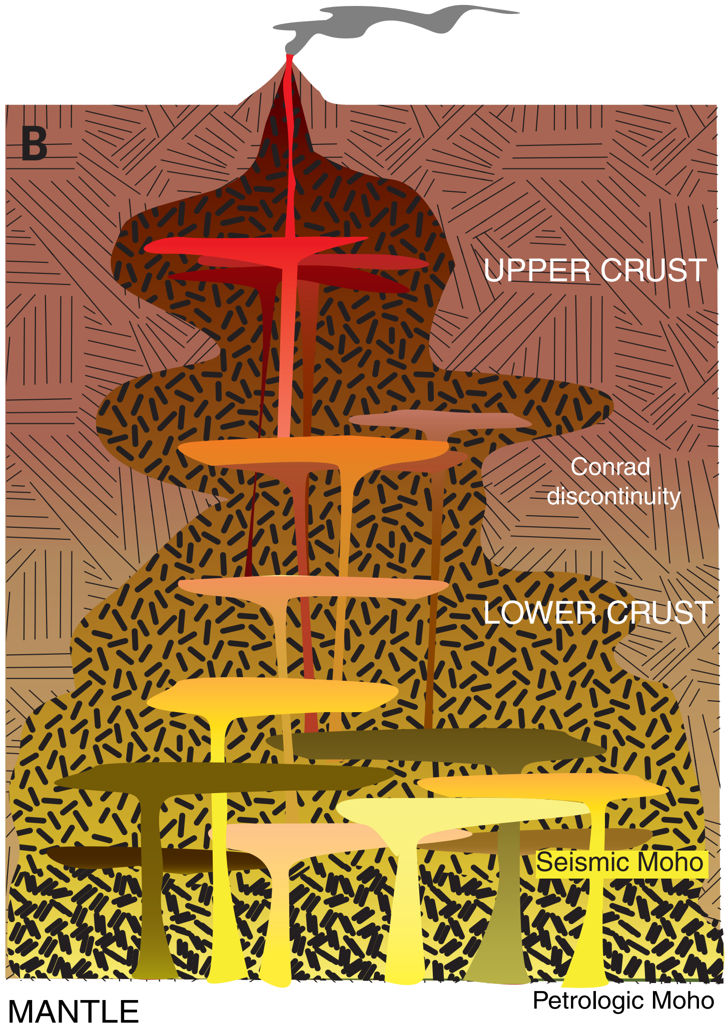


Jay et al., 2015



Cashman et al., 2017

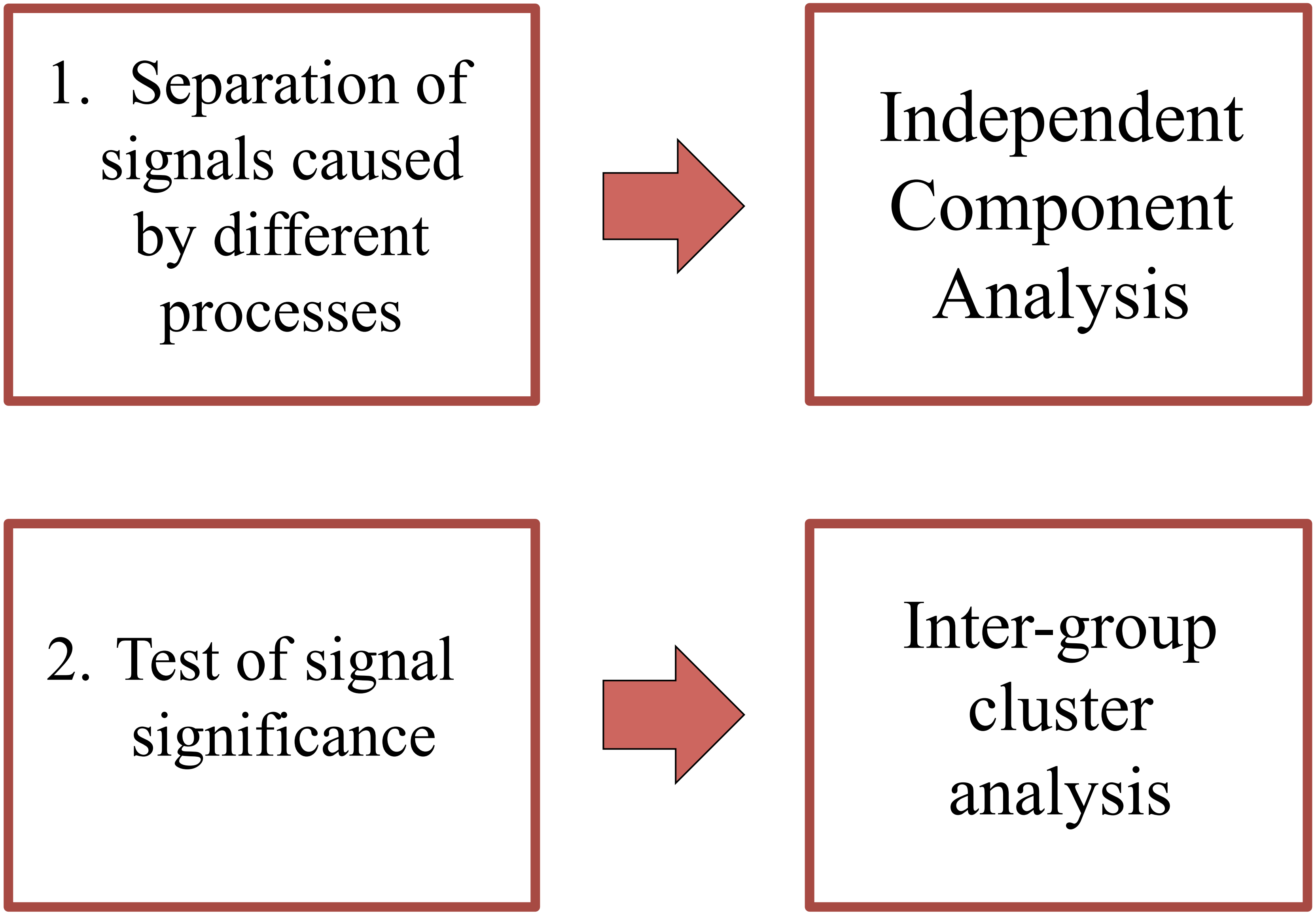
- Multiple deformation sources at the same volcano & multiple cycles of deformation

- Source location ≠ reservoir location: elastic deformation can be caused by volume changes in different parts of a reservoir

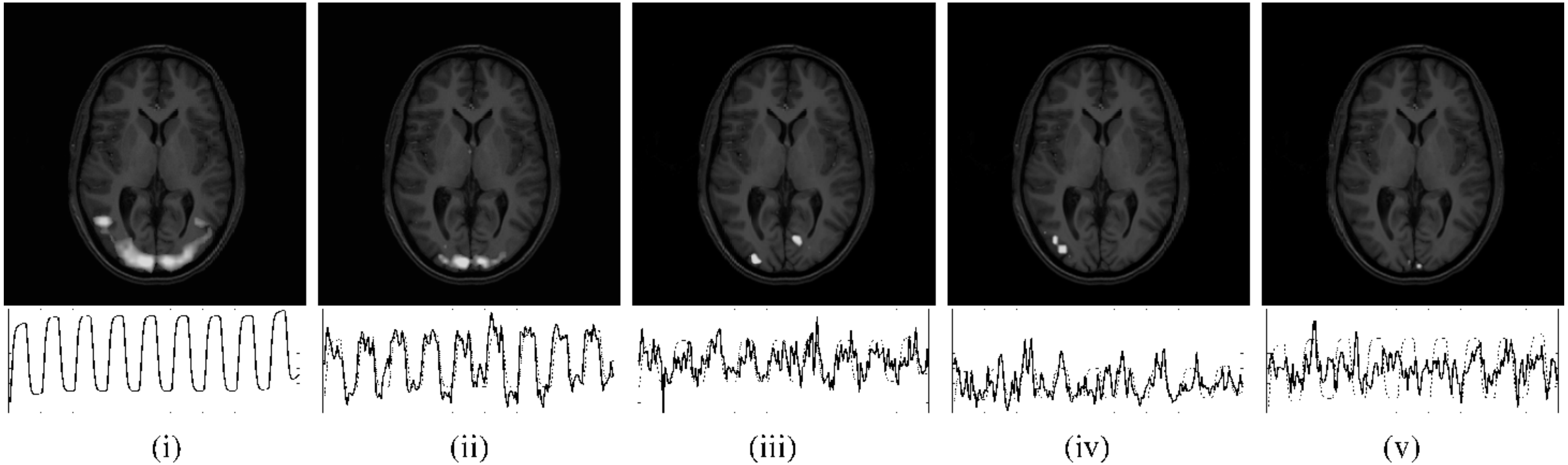
- The relationship between distinct deformation sources provides information about processes within a magmatic zone
    - mechanisms for melt or volatile movement
    - local response to stress changes

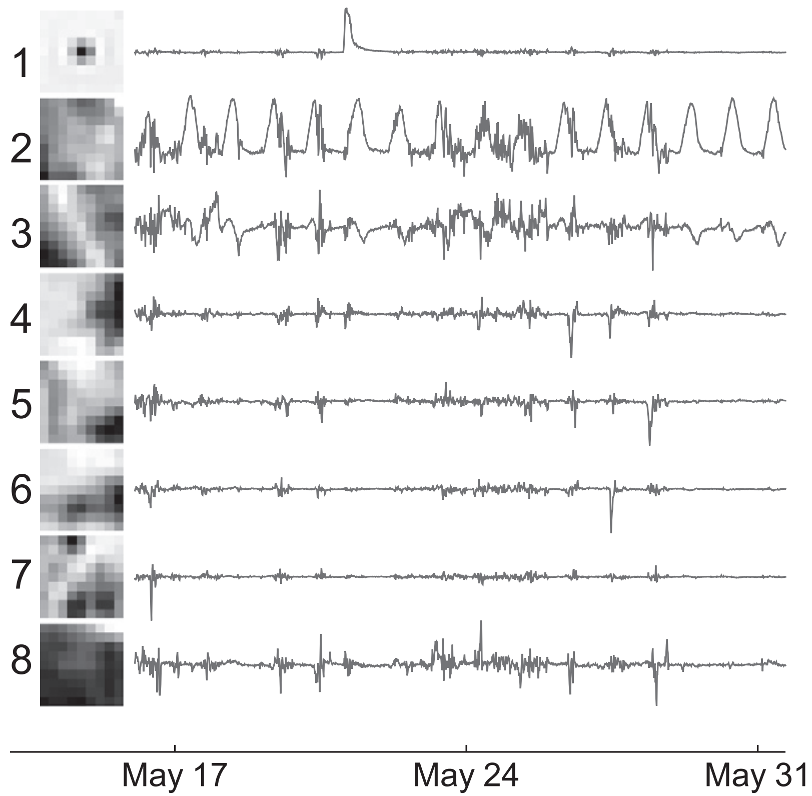
Methods for separating volcanic signals from each other and from noise

	Assumptions
1. A priori knowledge of signal	that signal has been observed before
2. Increasing signal to noise ratio	displacement has constant rate
3. Filtering (spatial or temporal)	signal and noise have different magnitudes
4. Blind source separation	signal characteristics only


1. Separation of signals caused by different processes
Independent Component Analysis
2. Test of signal significance
Inter-group cluster analysis

fMRI resting state networks, Beckmann & Smith, 2004

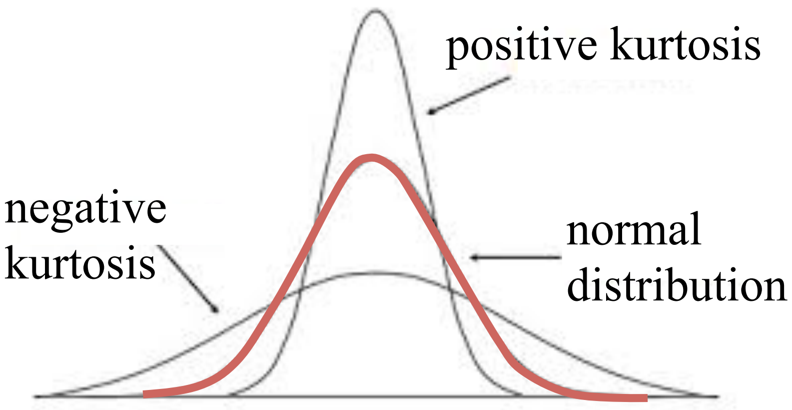


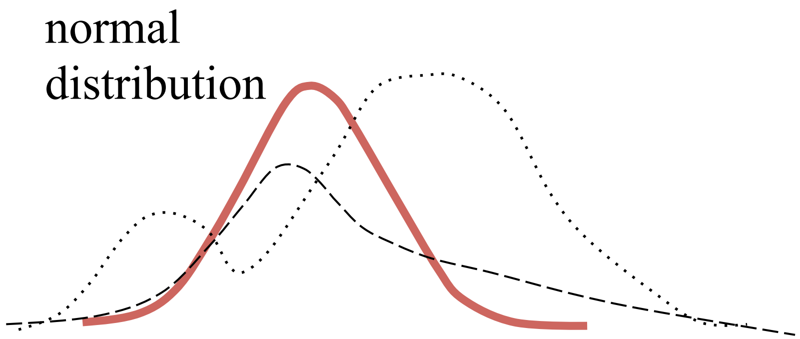


High temperature events from SEVIRI,
Barnie & Oppenheimer, *Remote Sensing*, 2015

Widely applied in medical physics, signal processing and other branches of remote sensing

Independence is assessed using kurtosis or approximation of negentropy





- Decomposition performed with FastICA algorithm

FastICA
Hyvärinen & Oja, 2000

Preparation:
- centring & whitening
- dimension reduction using PCA
- iterative correction of choice of dimensions

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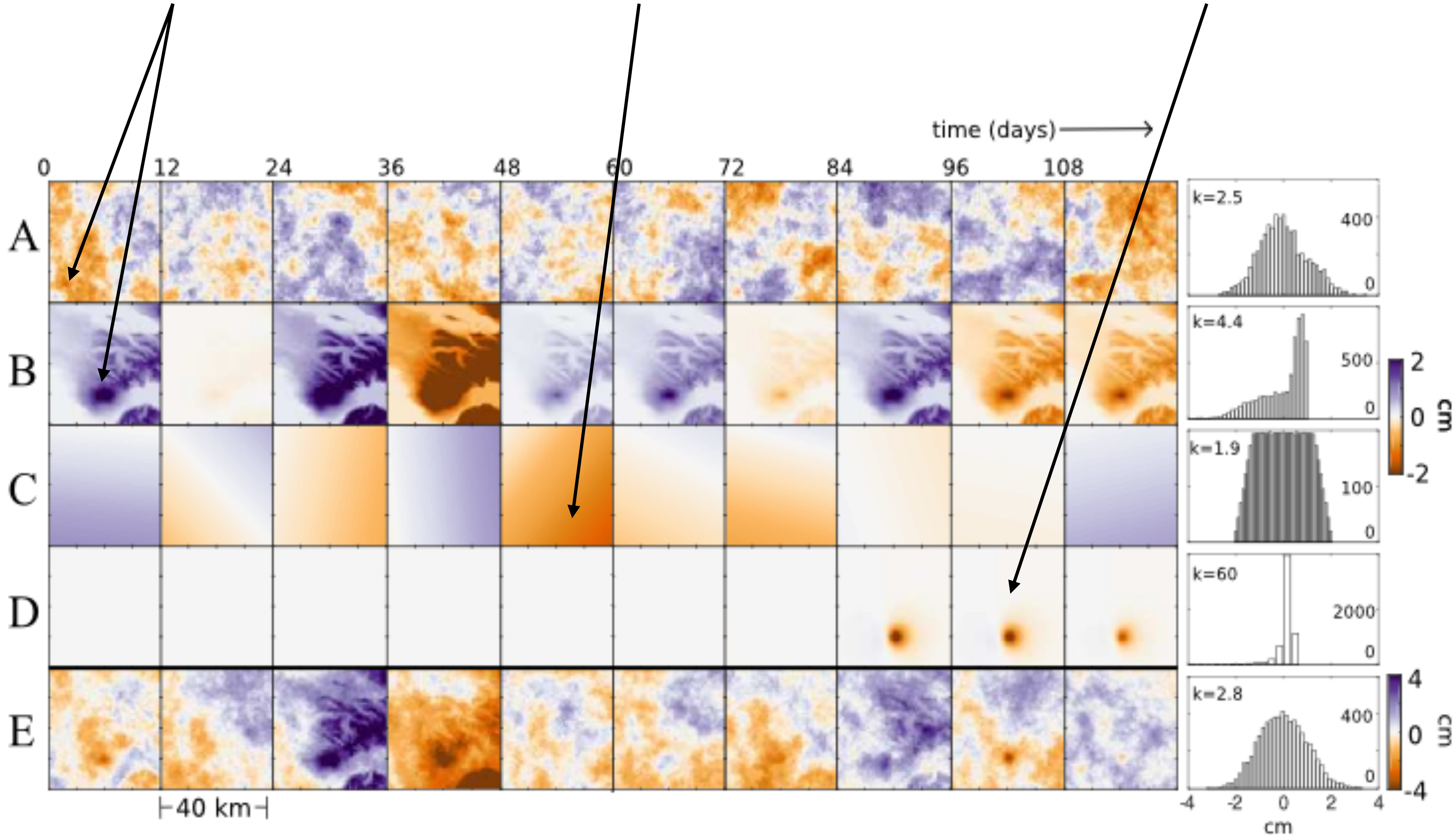
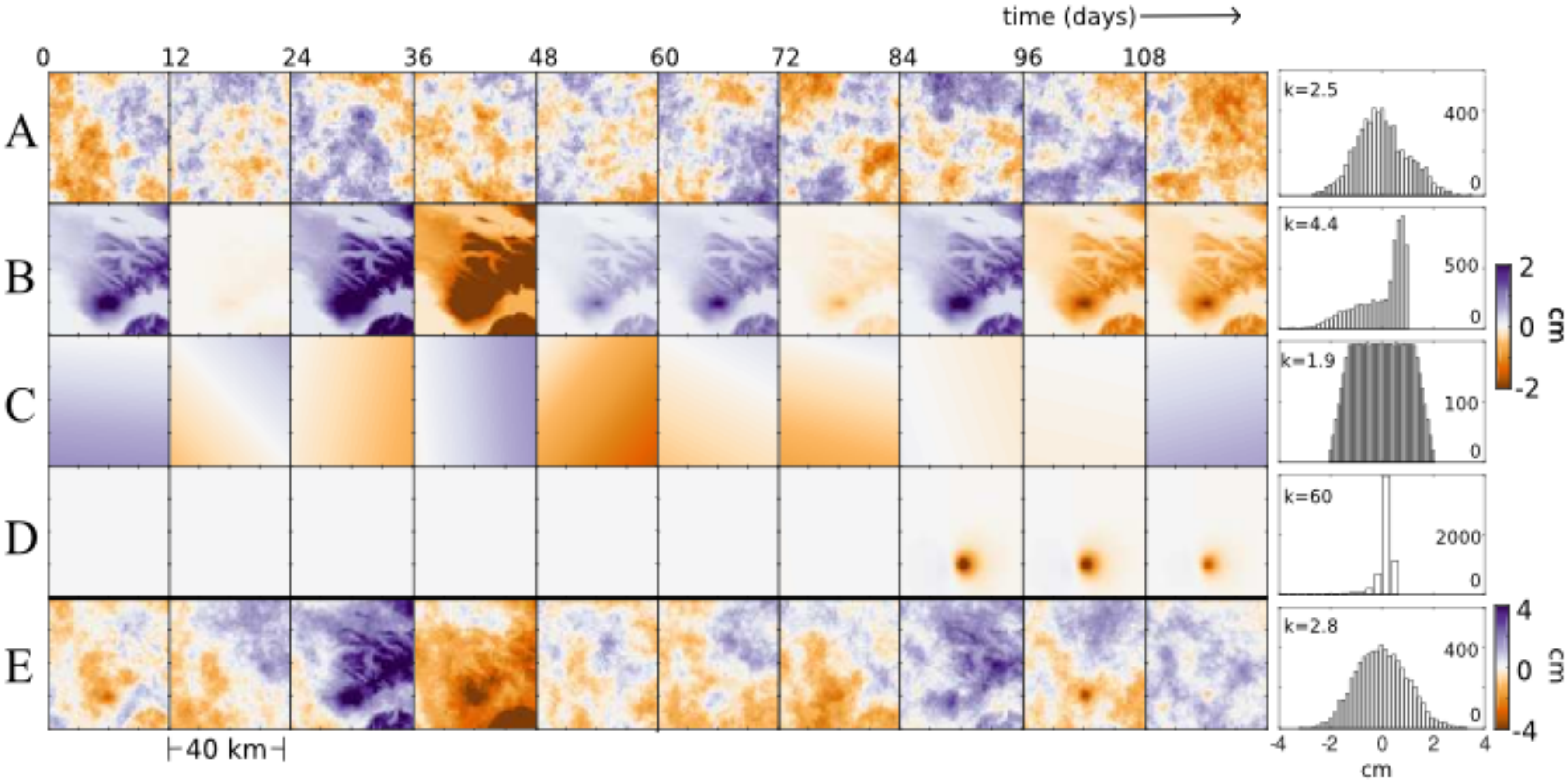
Interferograms are linear combinations of phase changes with different origins

atmospheric changes, change in satellite position & Earth surface displacement

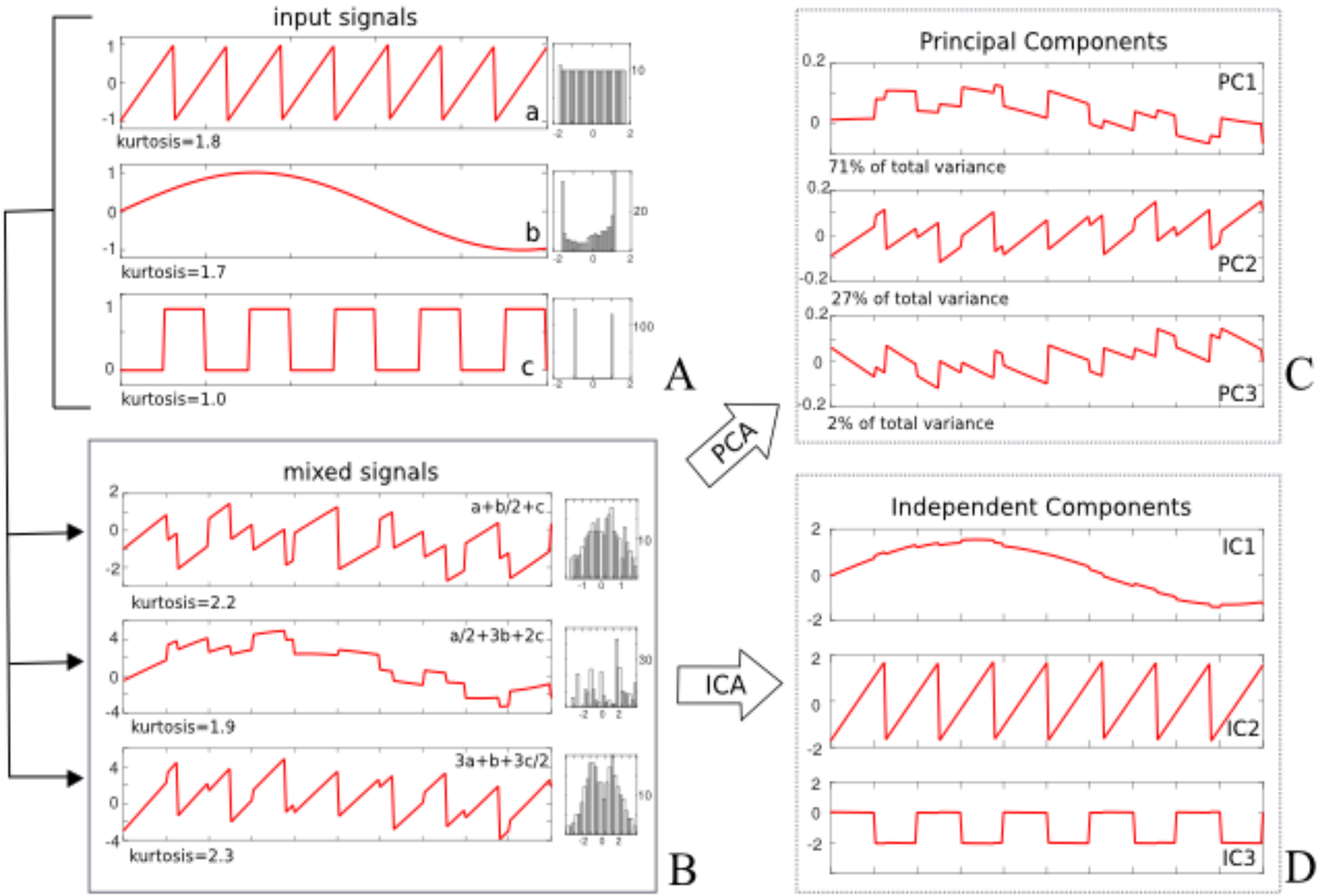


• Each pixel in an interferogram is a linear combination of points from several time series.

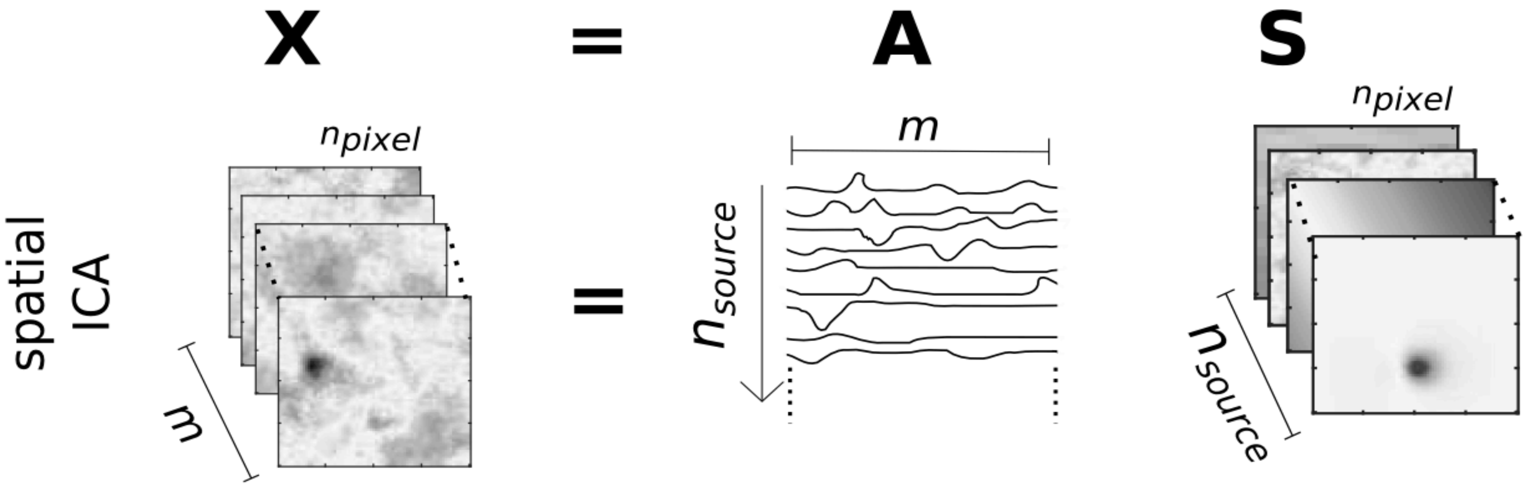
• We assume that an interferogram is closer to a Gaussian distribution than all (most) of the signals that make it up



Independent Component Analysis



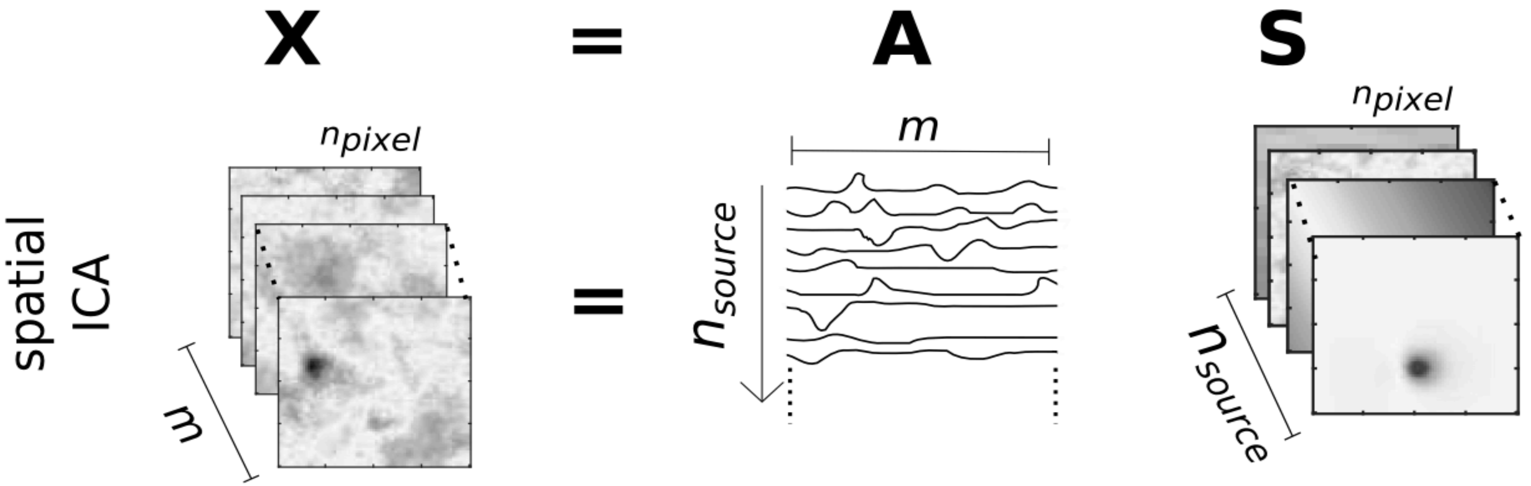
Assume that signals of interest are spatially independent



Rows of mixing matrix record the contribution of a source to each interferogram

Sources maximise the independence of spatial patterns

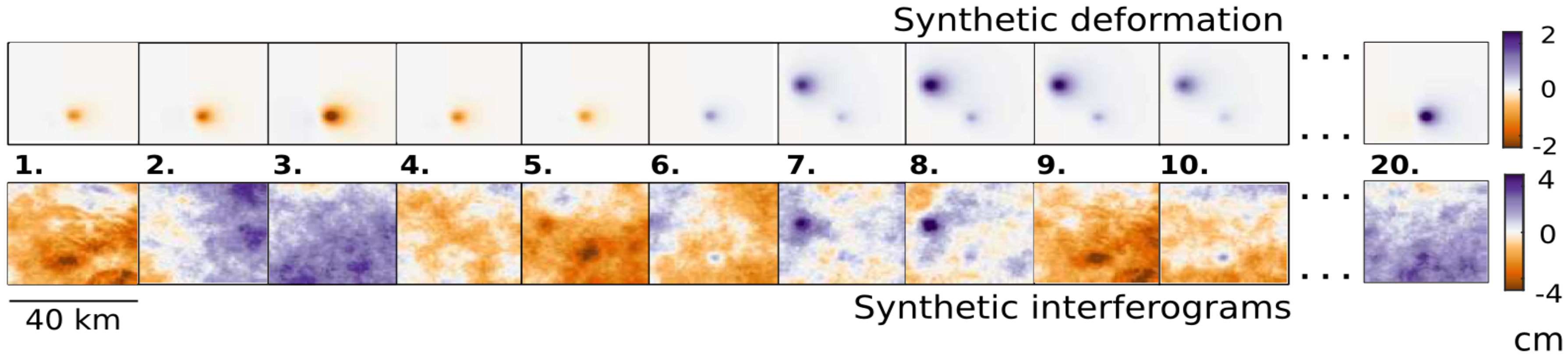
Assume that signals of interest are spatially independent

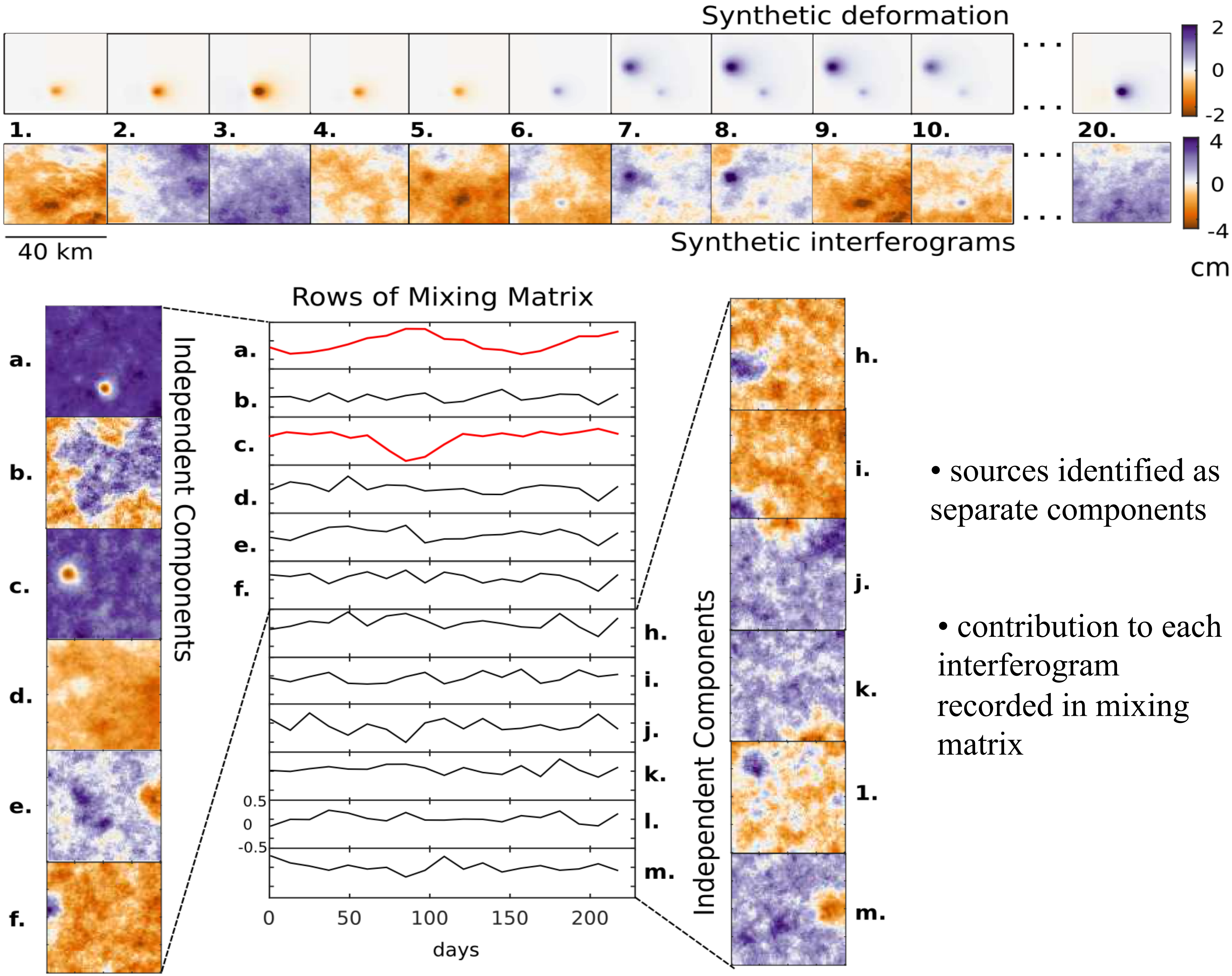


• Independent components and mixing matrix rows are ambiguous

• Order of independents components in Source matrix is not significant

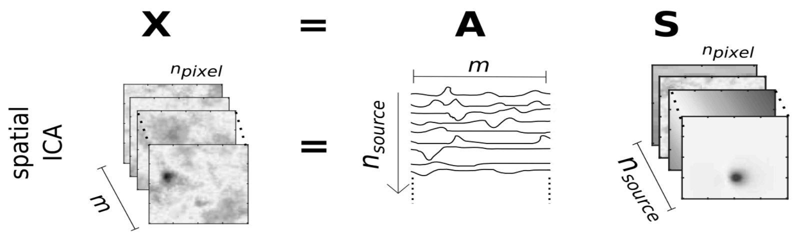
• Spatial of temporal filtering can be applied to interferograms before decomposition


Synthetic deformation
2
0
-2
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
20.
4
0
-4
40 km
Synthetic interferograms
cm

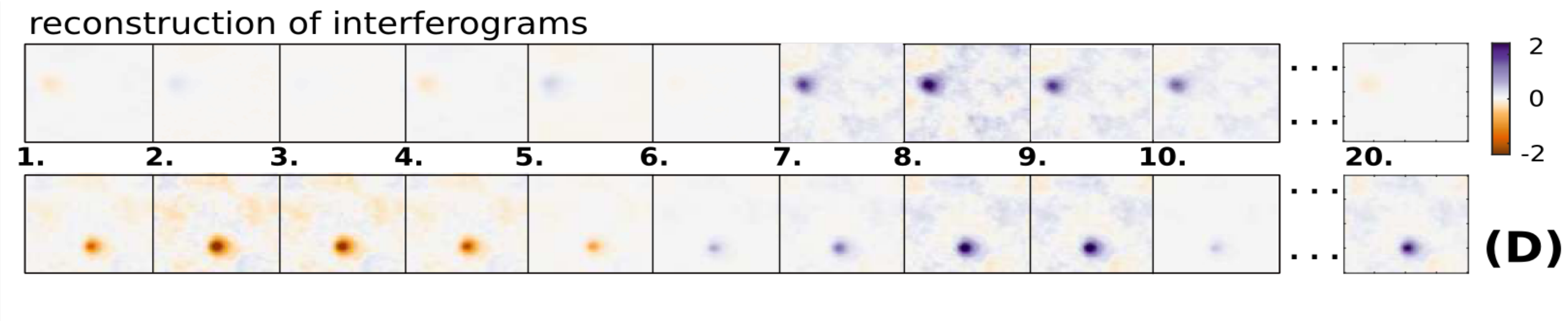


- sources identified as separate components

- contribution to each interferogram recorded in mixing matrix



• signal reconstructed from only components of interest (with some noise)



• independent synthetic deformation sources are separated from each other, and from the atmospheric noise

• for these synthetic data, sources were separated at signal to noise ratio as low as ~0.1

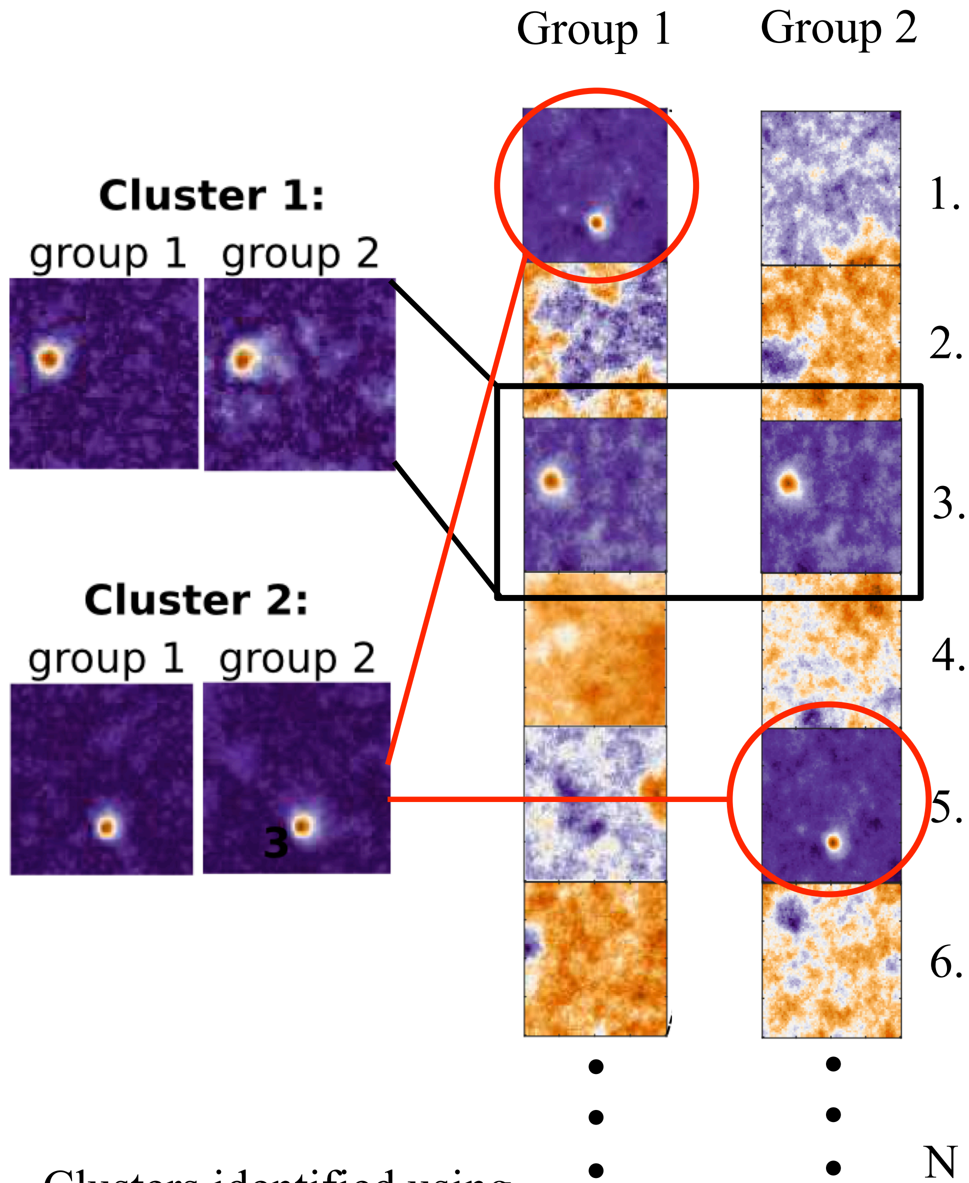
Identifying significant sources

Cluster Analysis performed on two independent groups of data

• spatial patterns that capture a real property of the data appear in both groups and will be assigned to a cluster.

• Groups can be:

1. different time periods
2. the same time periods but independent groups of images



Clusters identified using ISCTEST algorithm
Hyvärinen & Ramkumar, 2013

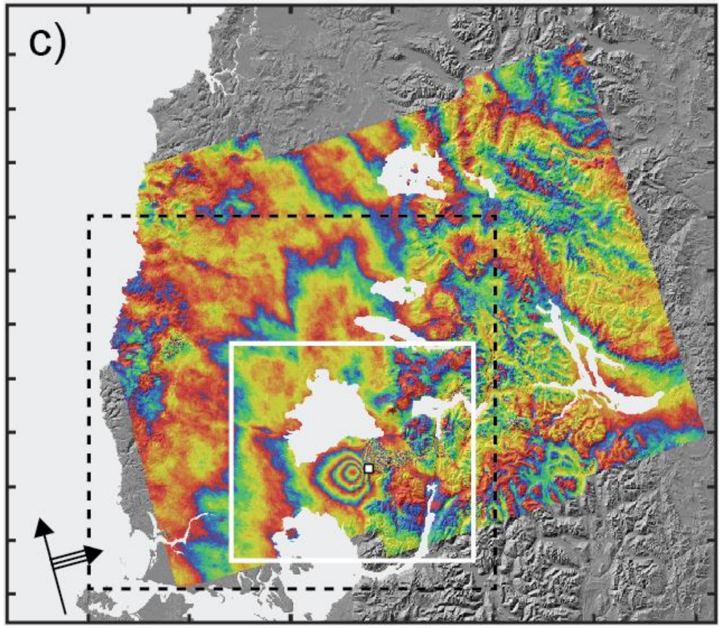
Volcán Calbuco, Chile

- Calbuco erupted on 22 April 2015, 43 years after its last recorded activity

- VEI 4, 17 km a.s.l. plume

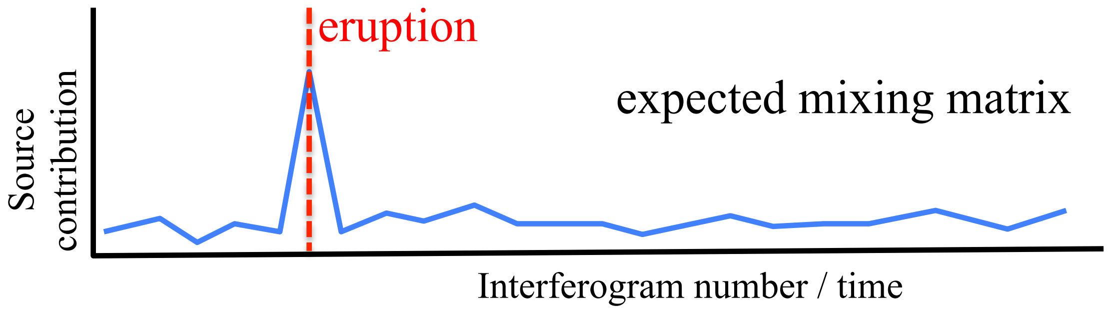
- no pre-eruptive deformation evident in Sentinel-1 interferograms

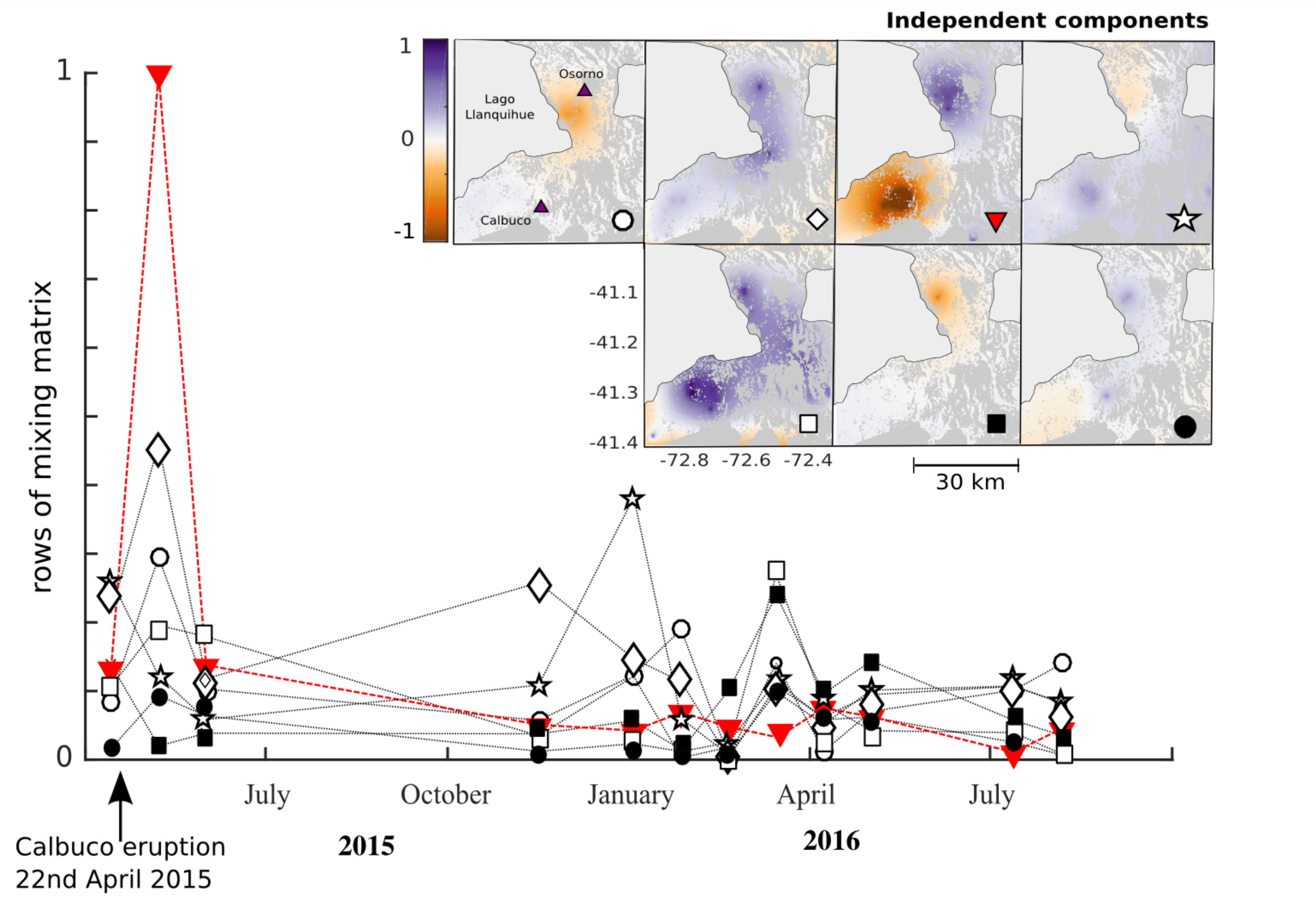
Track 164 Asc. 20150414–20150426



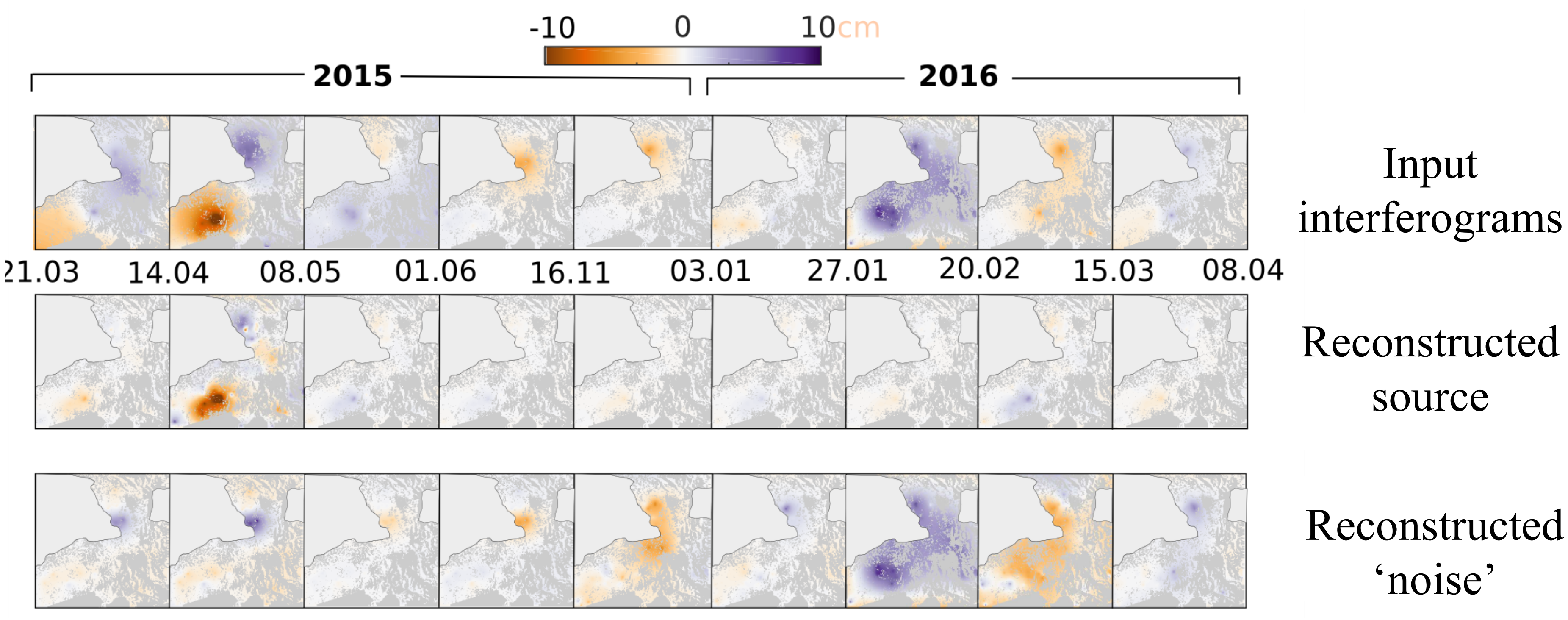
by Marco Bagnardi, from Pyle et al., in prep

- Subsidence captured by three Sentinel-1 tracks, consistent with subsidence during first phase of eruption with a source ~13 km depth



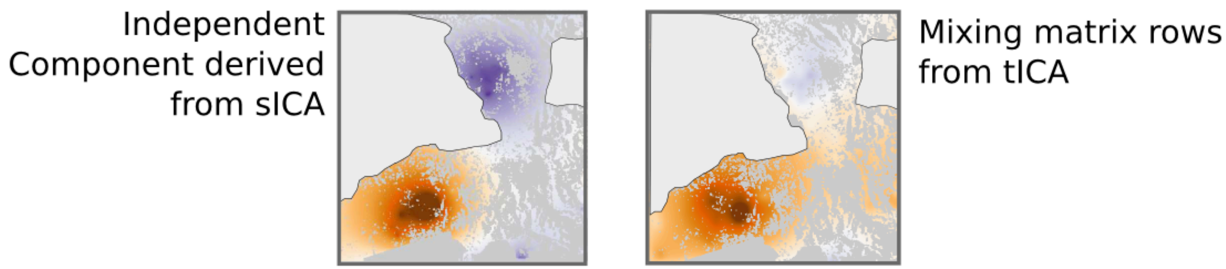


- Component that represents deformation can be identified from mixing matrix, given time of event alone
- End member test -> separation of subsidence and atmospheric features most difficult where deformation appears in > 1 interferogram

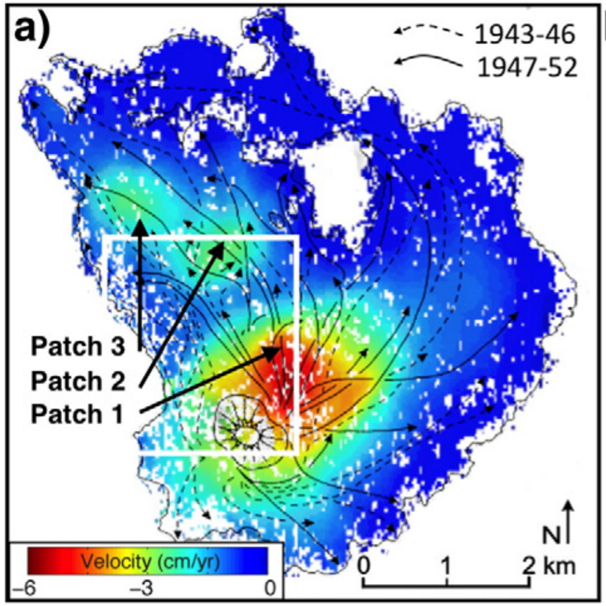


Deformation and atmospheric features are separated without any a priori information

Isolation of deformation from atmospheric signals also successful using the assumption of time independence …. but dimension estimation and computation is much harder



GoogleEarth



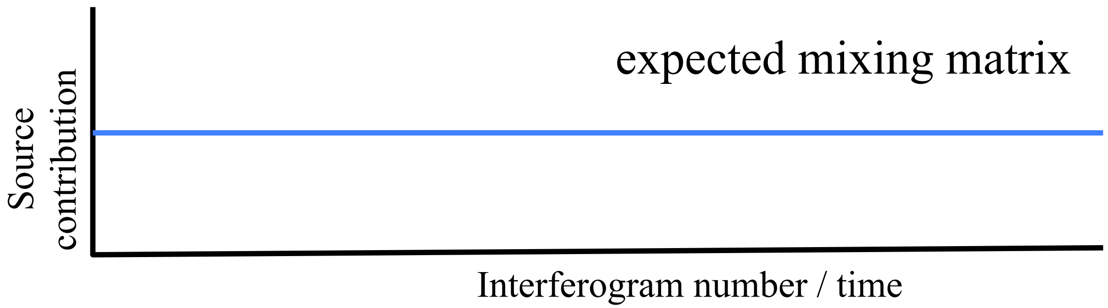
Chaussard, 2016

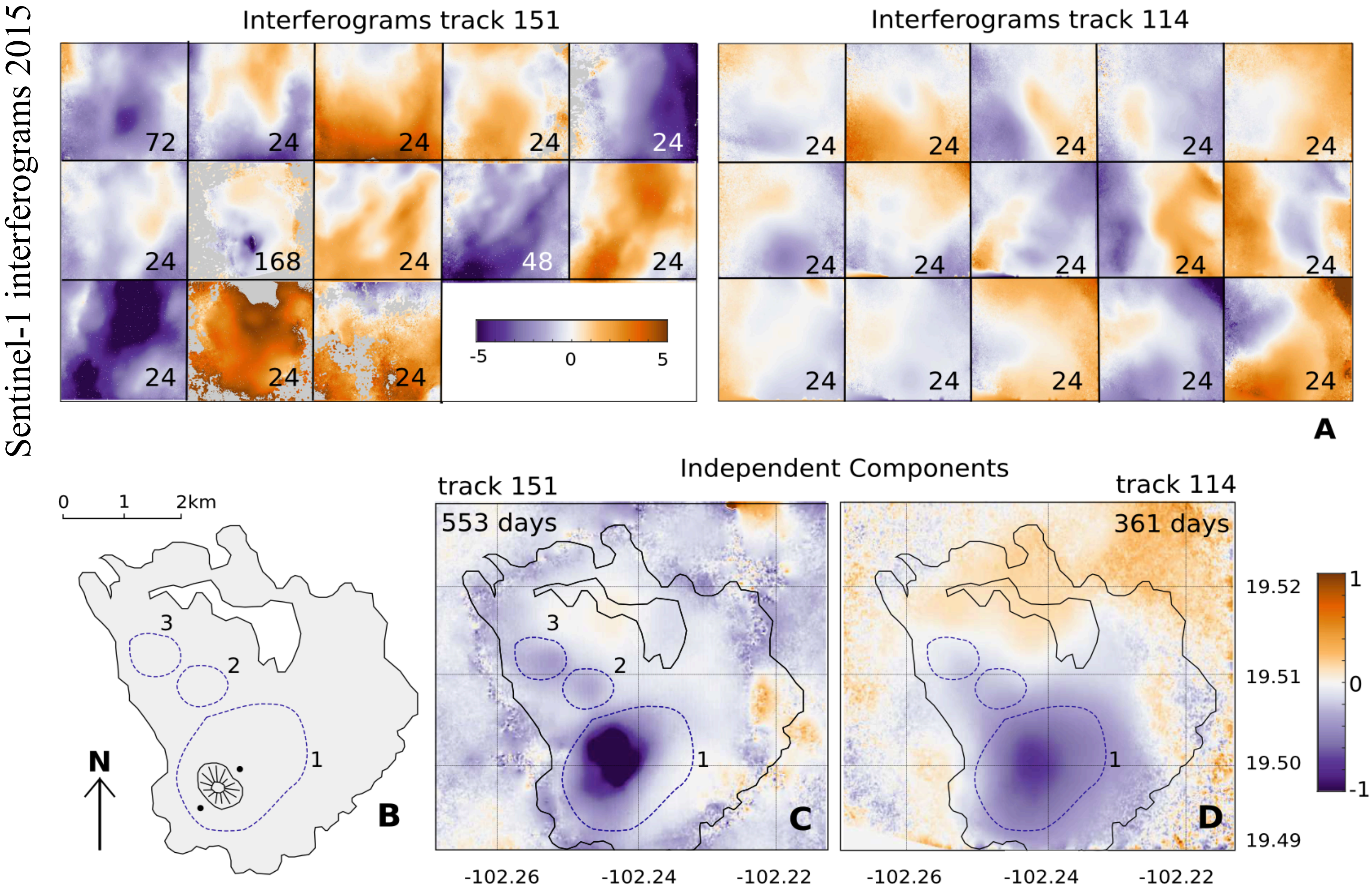
Parícutin lava fields

• Monogenetic eruption in 1943-1952 -> cinder cone and lava fields 100s of metres thick

• Lava subsidence well constrained by InSAR studies: *Fournier et al., 2010; Chaussard, 2016*

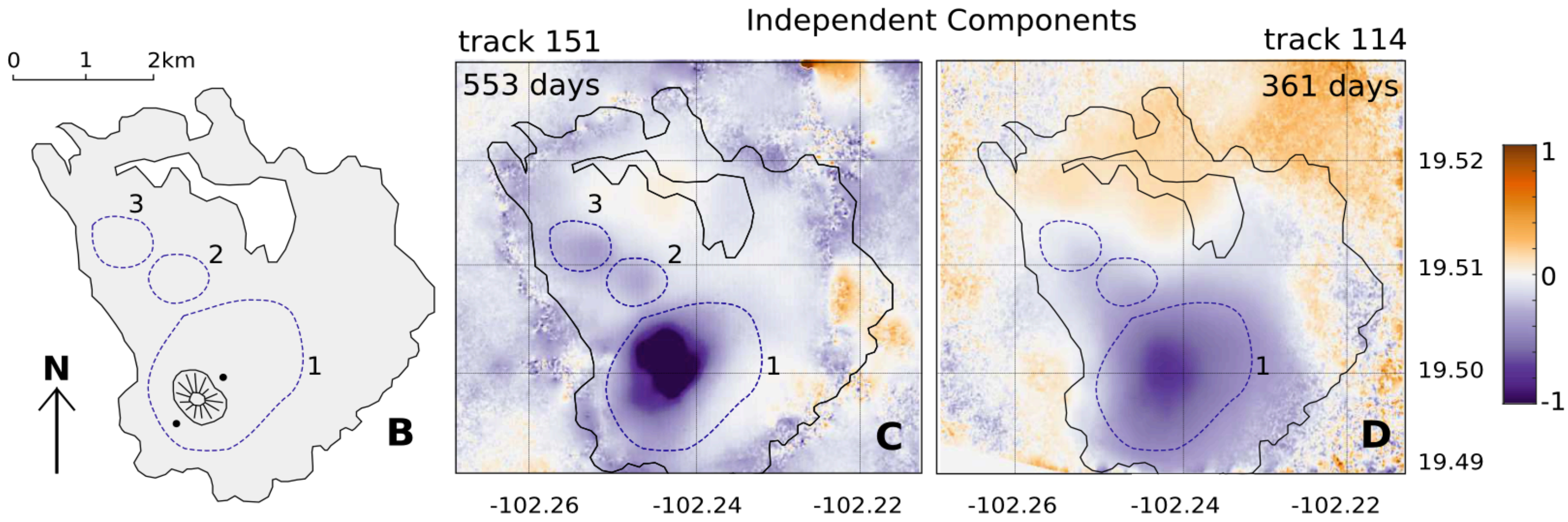
• Expectation: three patches of subsidence retrieved in the same component




Sentinel-1 interferograms 2015
Interferograms track 151
Interferograms track 114
72
24
168
48
-5
0
5
A
Independent Components
track 151
track 114
553 days
361 days
0
1
2km
N
1
2
3
B
C
D
19.52
19.51
19.50
19.49
-102.26
-102.24
-102.22
1
0
-1

- Three patches of deformation extracted in one spatial component
    - > implies that source is the same

- Subsidence rates with error of previous ALOS measurements: 5.3 +/- 0.5 cm/yr , compared to 5.5 cm/yr 2007-10



Considerations for testing the independence of volcanic deformation signals:

1. Components/mixing matrices retrieved from spatial and temporal ICA can be compared to test their significance
   -
2. Amendments can be made to decomposition procedure to test for correlated signals that are temporally offset from each other
   -
3. How should we interpret evidence of spatial/temporal correlation ?
   -

Considerations for identifying deformation and for automation

1. How are ‘relevant’ signals identified?
    - *a priori* information about signal shape or duration
    - matching ICs to past deformation (machine learning?)
2. What resolution to apply analysis?
    - Need to know past spatial and temporal scales
    - Nested approach, with higher resolution over active volcanoes
3. Regional or local application?
    - Implications for Gaussianity of some components
    - Size of co-variance matrix
    - Statistical independence depends on spatial scale

Further details of method and tests with synthetic data:

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Solid Earth

RESEARCH ARTICLE

10.1002/2016JB013765

Key Points:

- Independent component analysis is appropriate for exploratory analysis of InSAR data
- Deformation can be identified automatically by cluster analysis of independent components
- Application of ICA demonstrated on Sentinel-1A imagery using contrasting volcanic examples

Application of independent component analysis to multitemporal InSAR data with volcanic case studies

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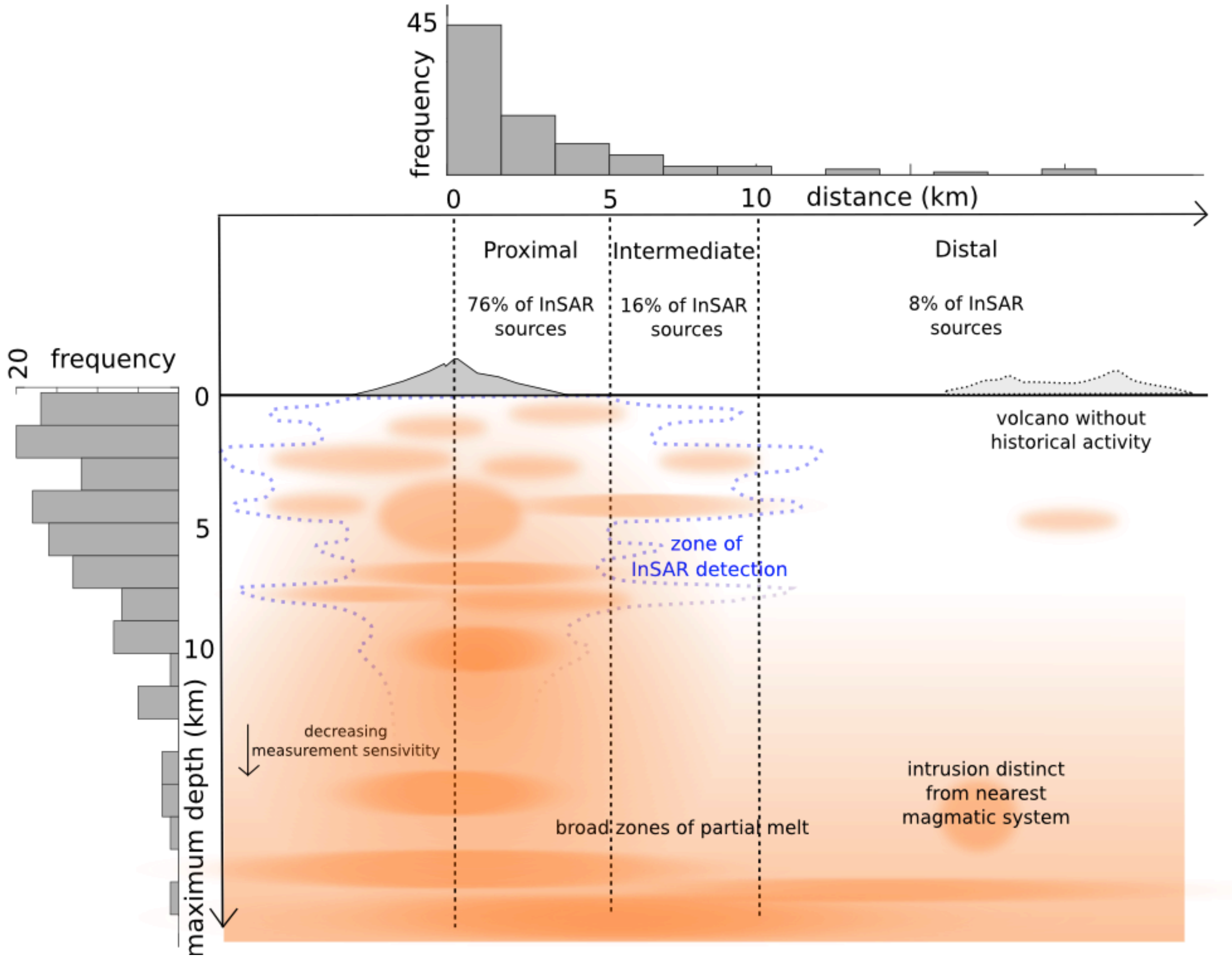
[1]School of Earth and Environment, University of Leeds, Leeds, UK

Abstract A challenge in the analysis of multitemporal interferometric synthetic aperture radar (InSAR) data is distinguishing and separating volcanic, tectonic, and anthropogenic displacements from each other and from atmospheric or orbital noise. Independent component analysis (ICA) is a method for decomposing a



45
frequency
0
5
10
distance (km)
Proximal
Intermediate
Distal
76% of InSAR sources
16% of InSAR sources
8% of InSAR sources
20
frequency
0
5
10
maximum depth (km)
volcano without historical activity
zone of InSAR detection
decreasing measurement sensivitity
intrusion distinct from nearest magmatic system
broad zones of partial melt