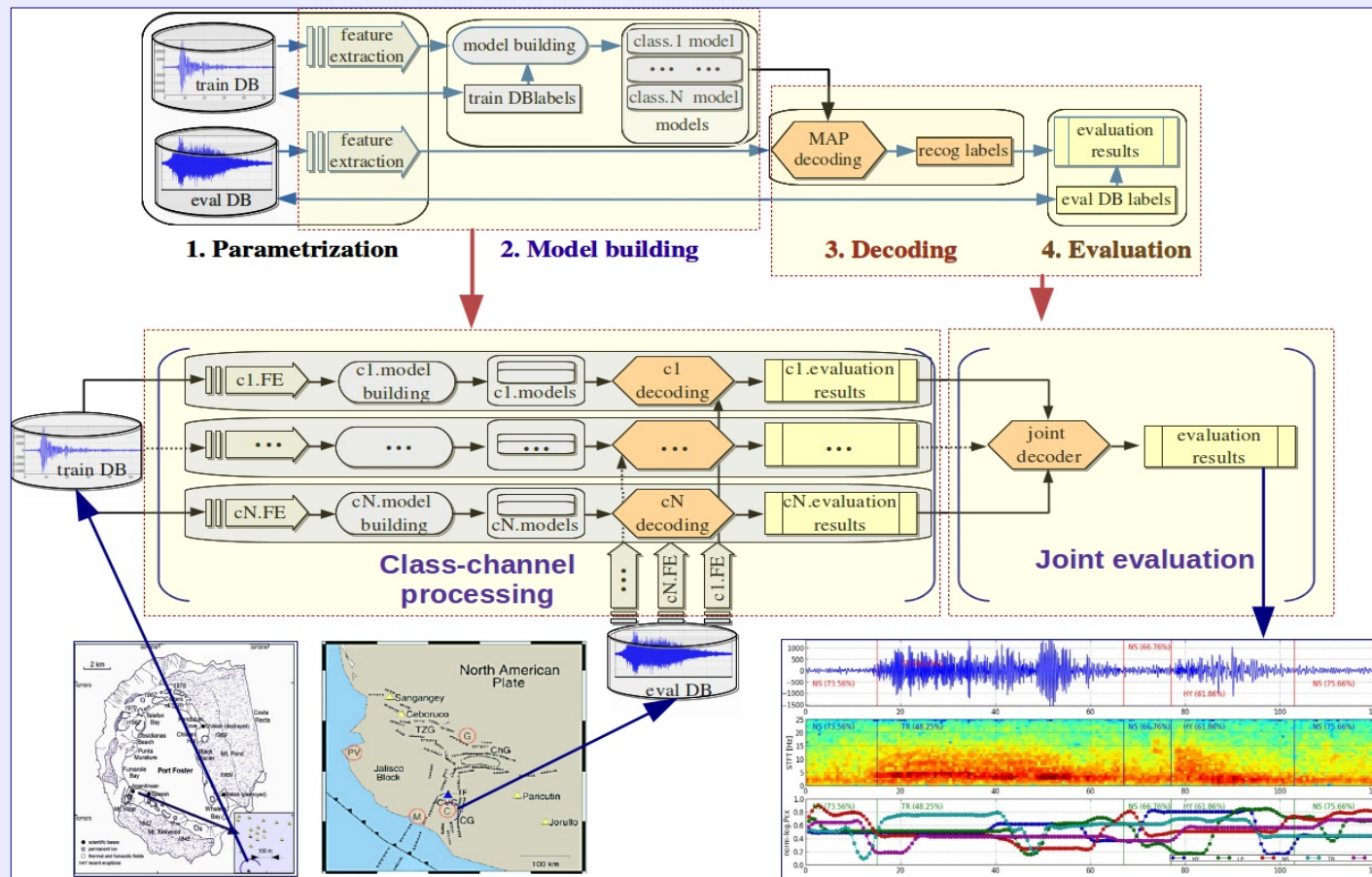


VULCAN.ears project: an Esperanto for the Volcano-Seismic event Recognition as a portable tool for real-time monitoring and eruption forecasting



G. Cortés⁽¹⁾, P. Lesage⁽⁴⁾, R. Carniel⁽¹⁾, J. Ibáñez^(2,5), J. Almendros^(2,5), C. Benítez^(2,3), R. Arámbula⁽⁶⁾, M. A. Mendoza⁽²⁾ & many others!



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(6) Centro Univ de Estudios
e Investigaciones en
Vulcanología @UNAM

I. Intro: Aims & Proposals

II. Volcano-Seismic Recognition (*VSR*)

III. *VULCAN.ears* project

IV. Conclusions and Remarks

I. Intro: Aims & Proposals

- I.1. Actual demands of Volcano Observatories (*VOs*)
- I.2. Unsupervised Volcano-Seismic Recognition (*U.VSR*)
- I.3. *VULCAN.ears* project

II. VSR basics

III. *VULCAN.ears* project

IV. Conclusions and Remarks

Actual (VSR) demands of VOs

- Do Volcano Observatories (VOs) *really* need Volcano-Seismic Recognition (VSR)?

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 - ✓ Need to *detect* (segment) + *classify* (assign them to their physical type or class)
 - ✓ *VSR allows to count* the events of *each class* ↔ *to track the seismic evolution*

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 - ✓ *VSR allows to count* the events of *each class* ↔ *to track the seismic evolution*
 - ii. **VSR must be done in nearly *real-time* to use the *seismicity* as a *risk measure***
 - ✓ Some of these *classes* act as *eruption precursors*:
 - Long Period events (LPs)
 - Volcano tremors (TREs)
 - Volcano-Tectonic earthquakes (VTs)
 - ✓ Some of these *classes* involve *population risk*:
 - Pyroclastic density currents (PYRs)
 - Lahars (LAHs) & Collapses (COLs)
 - Explosions (EXPs)
 - Ash fall (ASHs)

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 - × **Lack of classification reliability:** *Subjectivity* of human operators → *non unified criteria* with less than 80% of agreement among experts

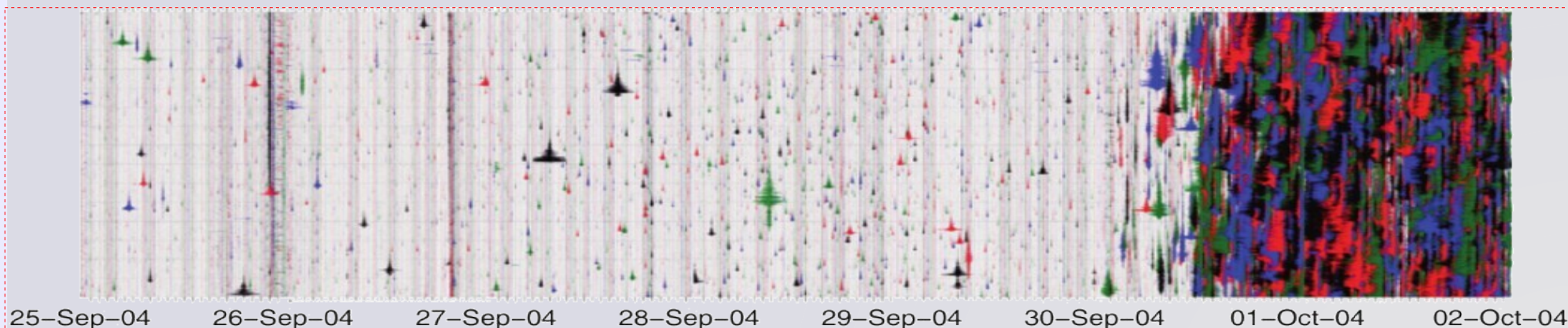
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Unsupervised Volcano-Seismic Recognition (U.VSR)

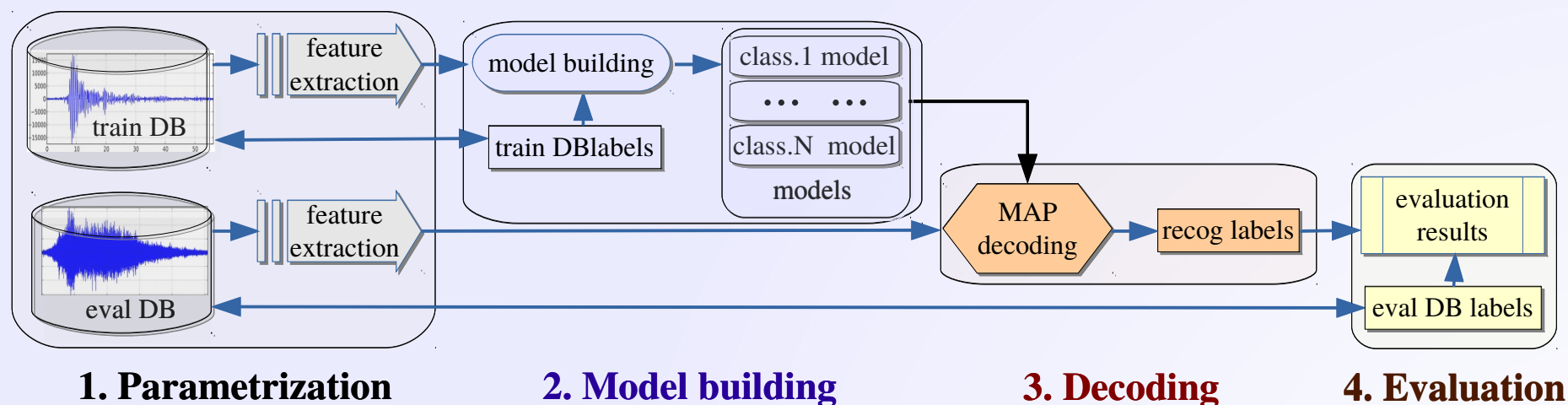
➤ **Aims: *Automatic & Unsupervised & Real-time* Volcano-Seismic Recognition (VSR)**

Unsupervised Volcano-Seismic Recognition (U.VSR)

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- (2) *model evaluation*: by a manually labeled *eval.DB*, using the recognition class-averaged accuracy (%cAcc) or precision (%cPrec) rates

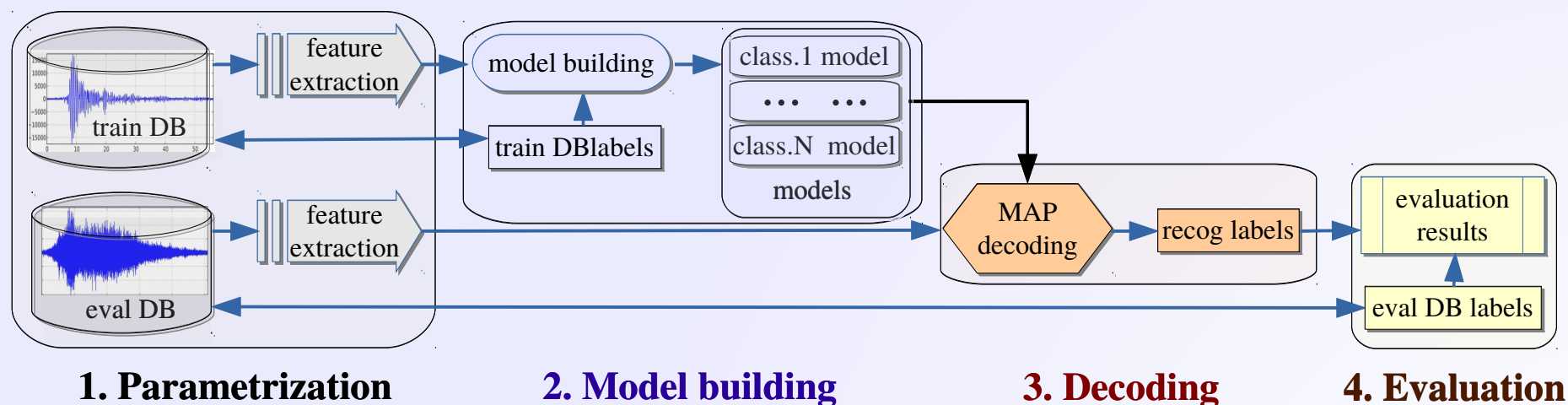


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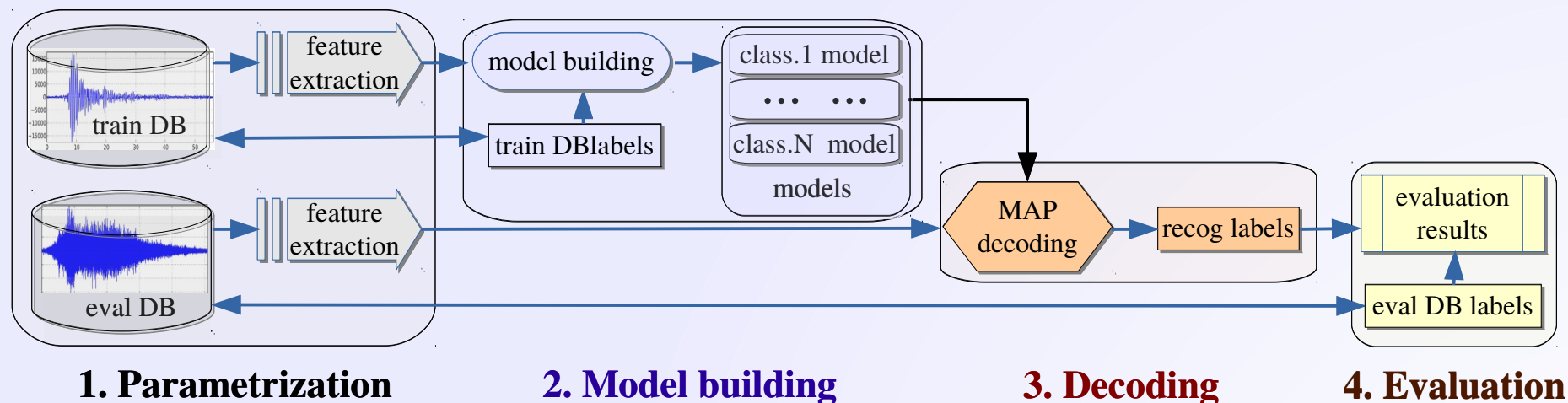
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✓ **Real-time VSR**: *on-demand labelling* on continuous monitoring

VULCAN.ears project

- **Aims: *Automatic & Unsupervised & Real-time* Volcano-Seismic Recognition (VSR)**

VULCAN.ears project

➤ **Aims: *Automatic & Unsupervised & Real-time* Volcano-Seismic Recognition (VSR)**

➤ **Proposal: *VULCAN.ears* project:**

Volcano-seismic Unsupervised Labelling and Classification Embedded in A Real-time Scenario

i. Real-time VSR and *portable* solution, relying on:

- ✓ **Integration** into most VO acquisition frameworks (Earthworm & WebObs^(Maggi et al., 2017)) by an easy-to-use GUI designed in a Python-based environment
- ✓ **A *universal* solution:** with built-in, general, recognition models able to recognize events from most volcanoes in unsupervised scenarios

ii. EC-funded (*excellent science*) MSCA-IF-H2020 fellowship: 2 years scheduled project, *collaborative-nature, open-source & open access*, focused on knowledge sharing

I. Intro: Aims & Proposals

II. VSR basics

II.1. Event description

II.2. Class modelling

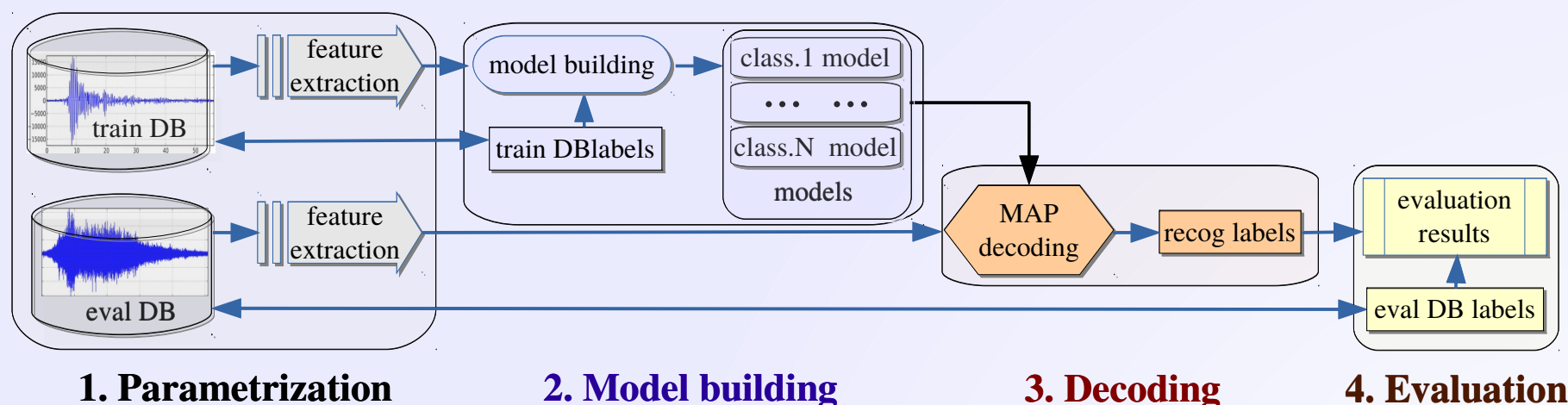
II.3. VSR system evaluation

III. *VULCAN.ears project*

IV. Conclusions and Remarks

VSR system

'Classic' Serial System Architecture (SSA) VSR



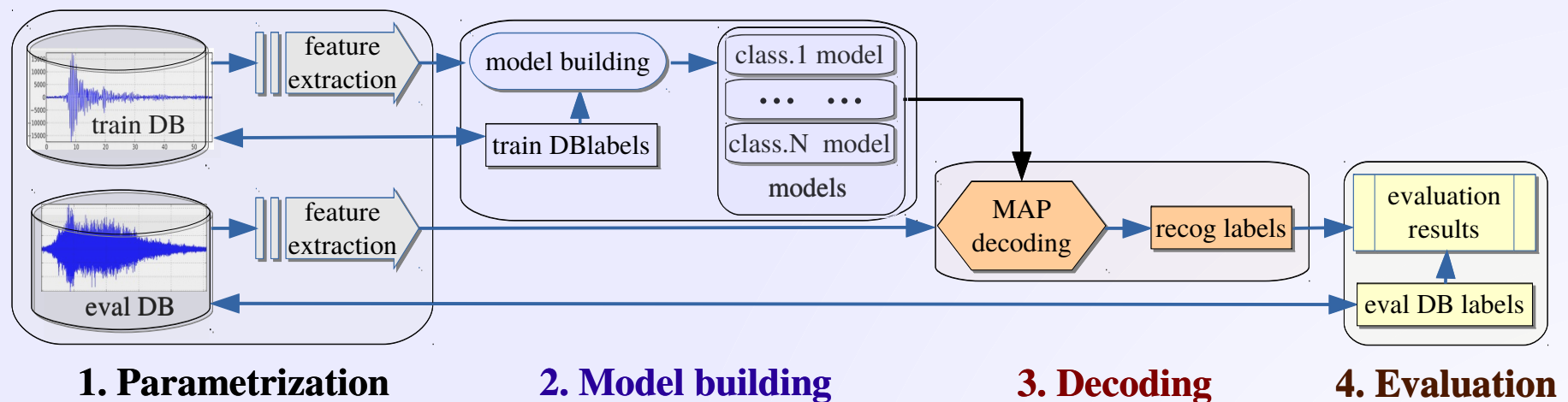
(Benítez et al., 2007)

(Ibañez et al., 2009)

VSR system

'Classic' Serial System Architecture (SSA) VSR

... Attend this talk!: "Methods of automatic recognition of seismo-volcanic events: State-of-the-art and perspectives" @ Sicilia[14:45] - S01.04!

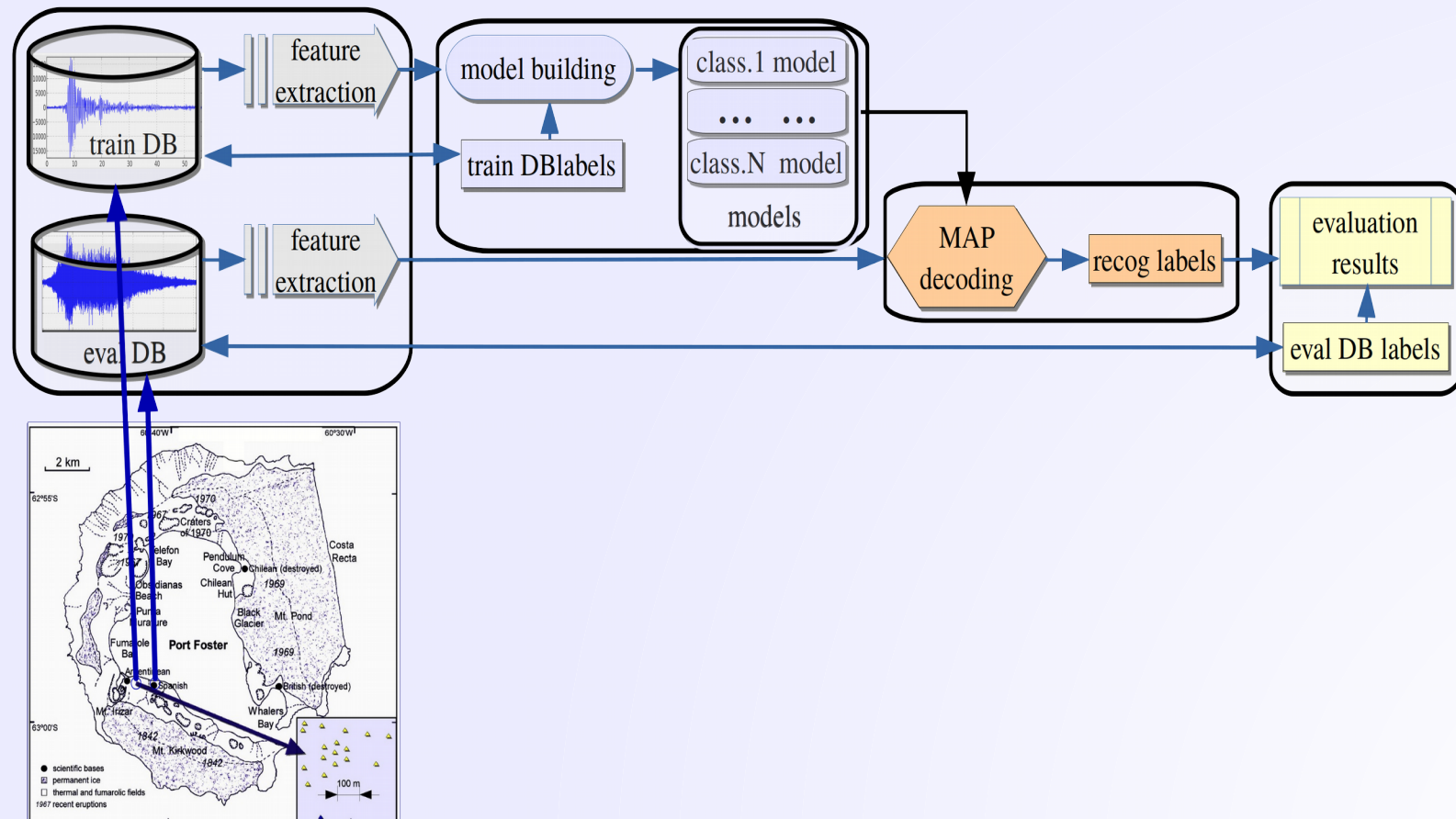


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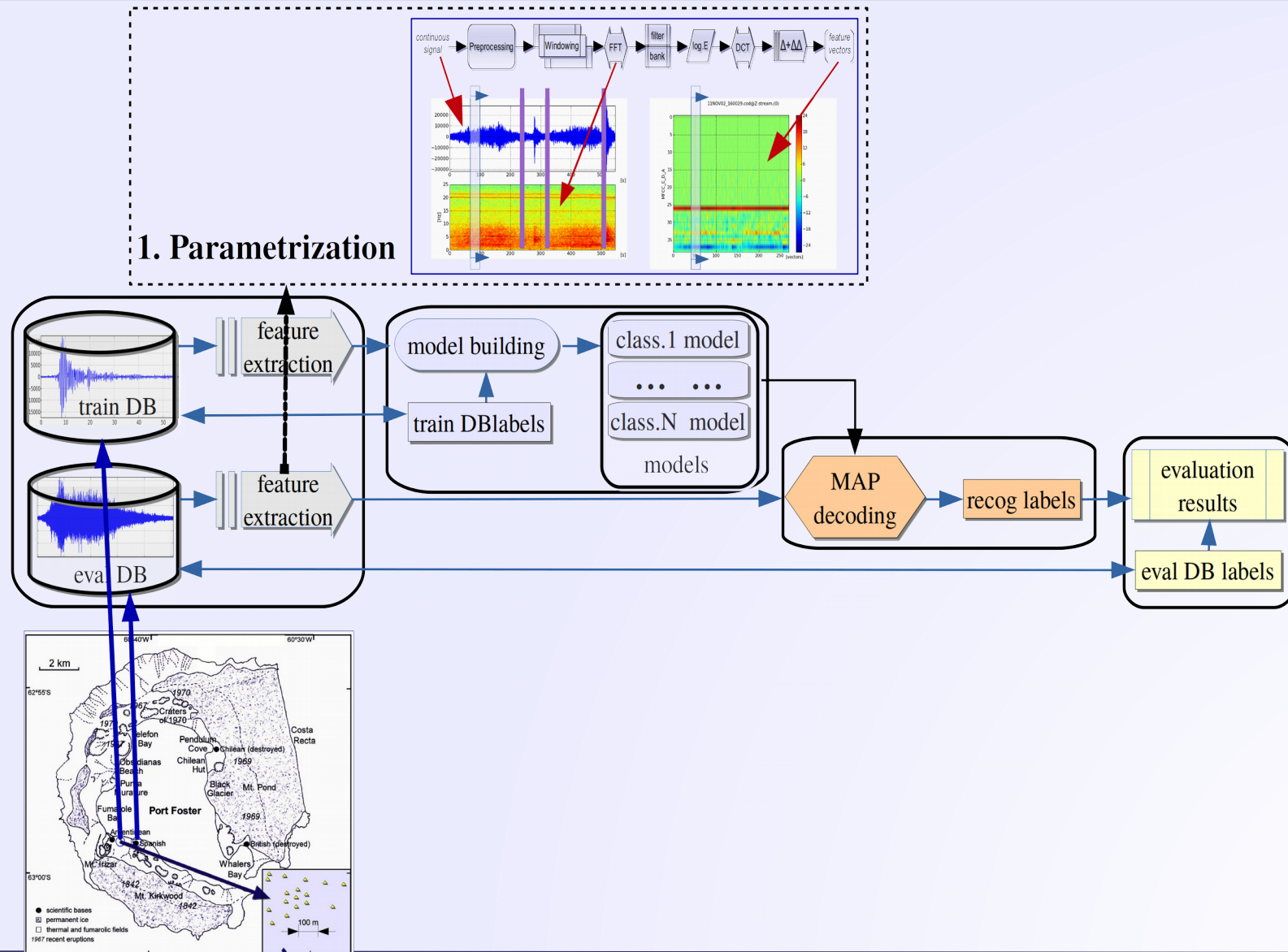
VSR system > DB building

- ✓ Need *labeled* DBs to build statistical models
- ✓ The *VSR system reliability* largely depends on the *quality* of the data & labels @ *train.DB*



1. Parameterization > feature vector sequence

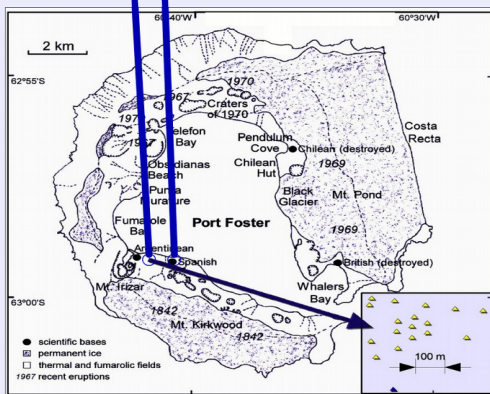
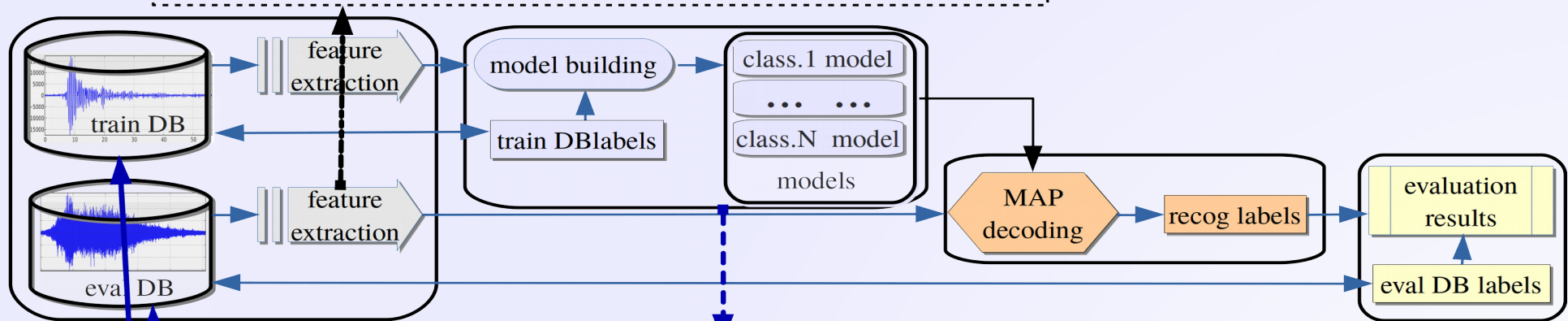
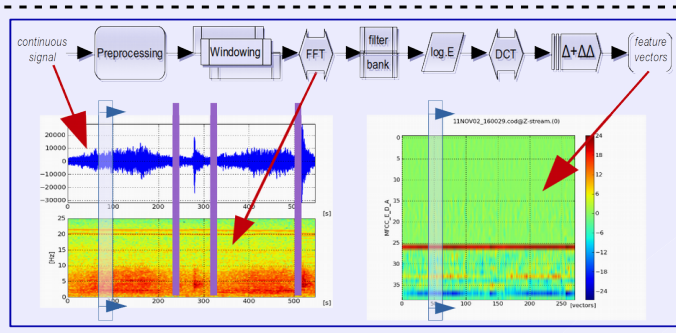
- ✓ **Dimensionality Reduction:** continuous *waveform* \rightarrow *sequence of feature vectors*
- ✓ **Type of features:** geophysical, statistical, spectral-based, transforms,... & hybrid!



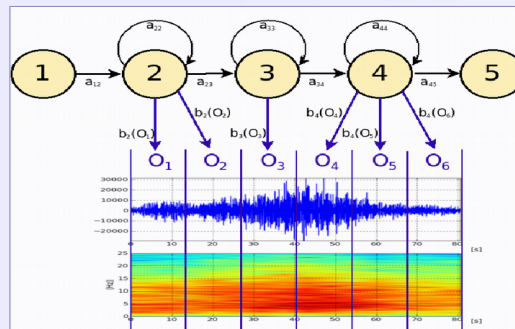
2. model building: by Hidden Markov Models (HMMs)

HMM_i: double [feature vector + time] spaces stochastic modelling of the class_i events

1. Parametrization

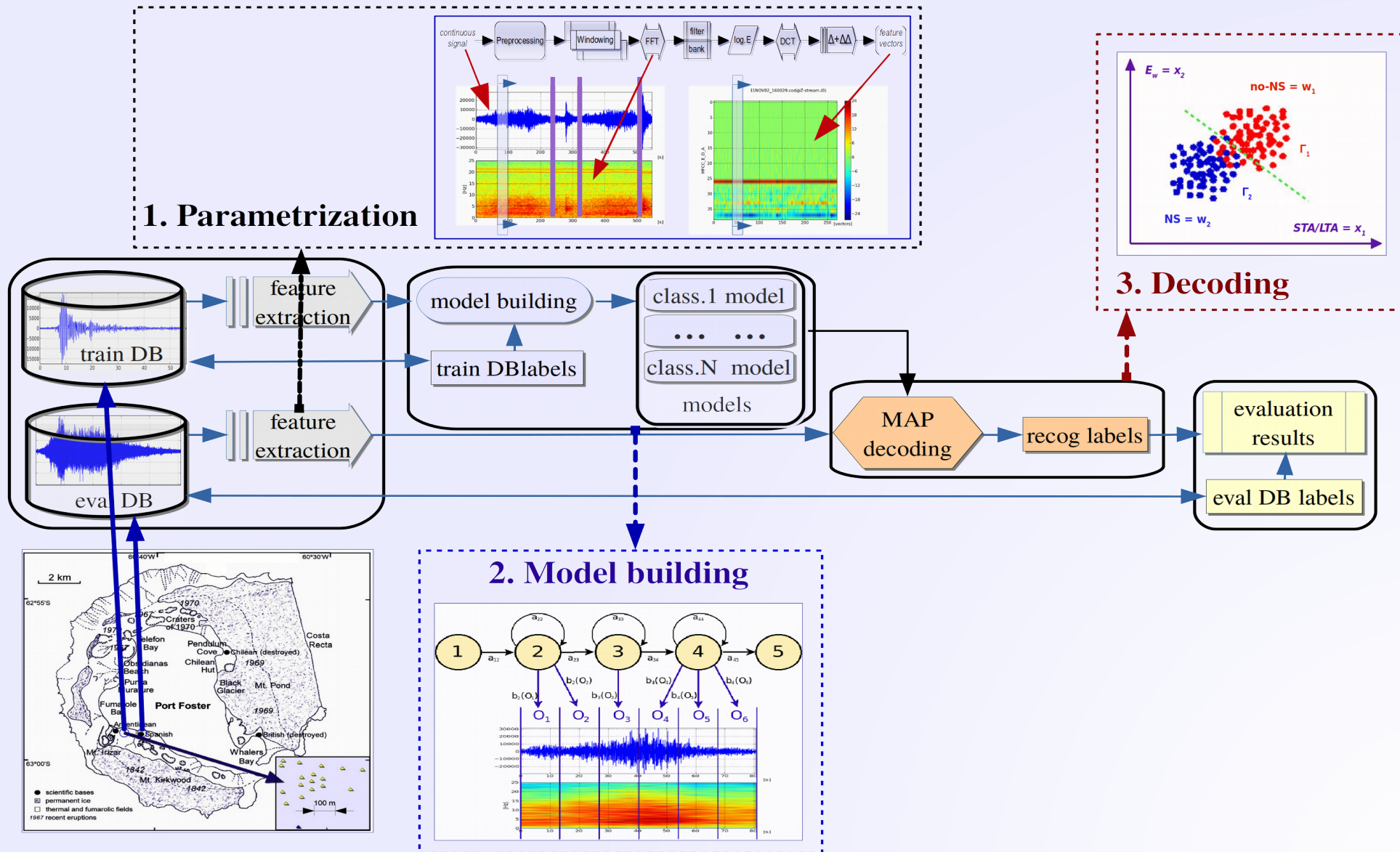


2. Model building



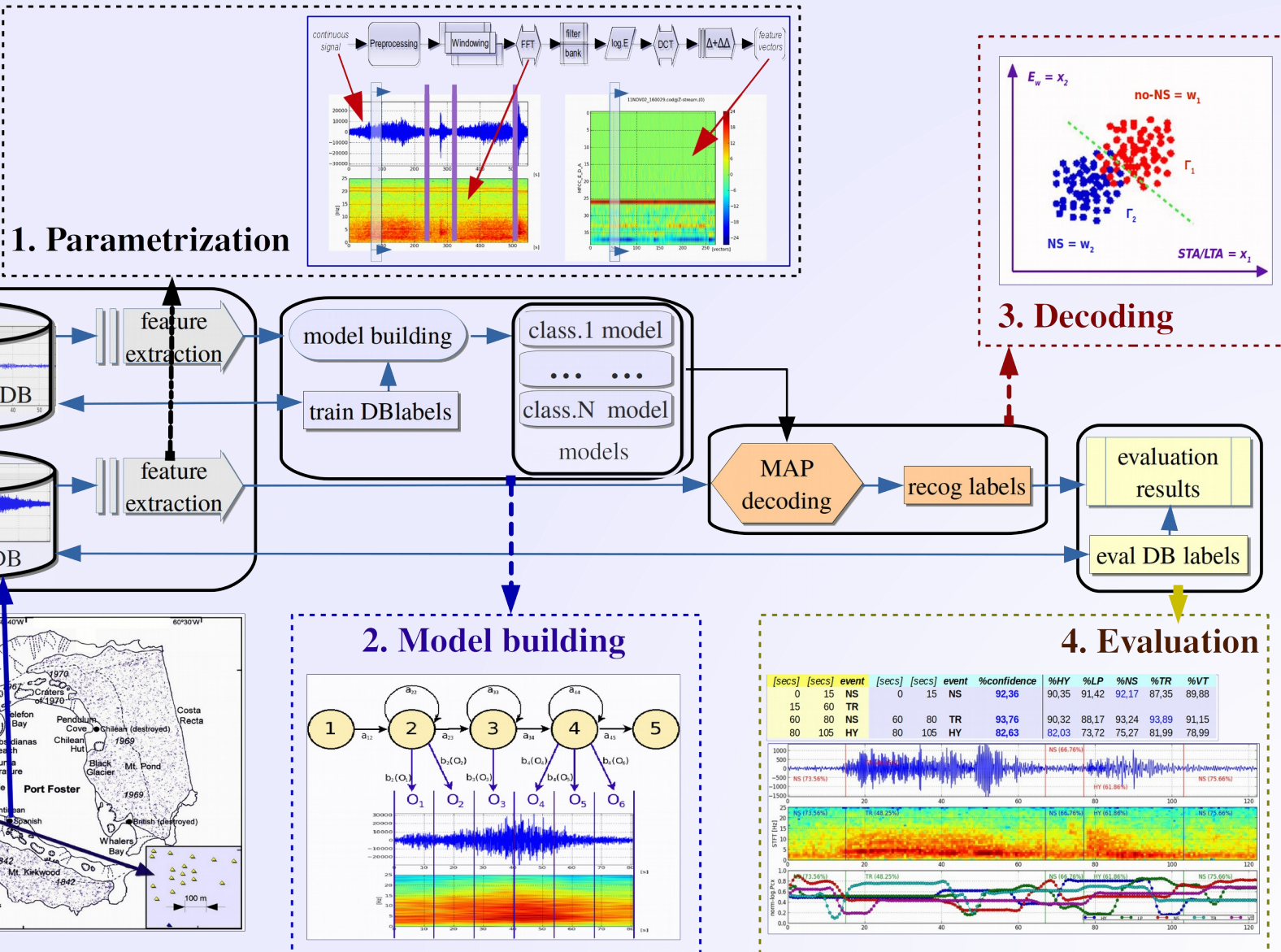
3. Decoding: event detection & classification

recognition: the events in *eval.DB* are detected and classified → *recog labels*



4. Evaluation: VSR (recog) labels vs. eval DB labels

evaluation: *recog labels* are compared against *eval.DB labels* (if available...)
→ recognition scores are computed (%cAcc, %cPrec)



I. Intro: Aims & Proposals

II. VSR basics

III. VULCAN.ears project

III.1. Universalization of the VSR system

III.2. VULCAN.ears apps & impact

III.3. Early results

IV. Conclusions and Remarks

VULCAN.ears project

- ***Aims: Automatic & Unsupervised & Real-time*** Volcano-Seismic Recognition (VSR)

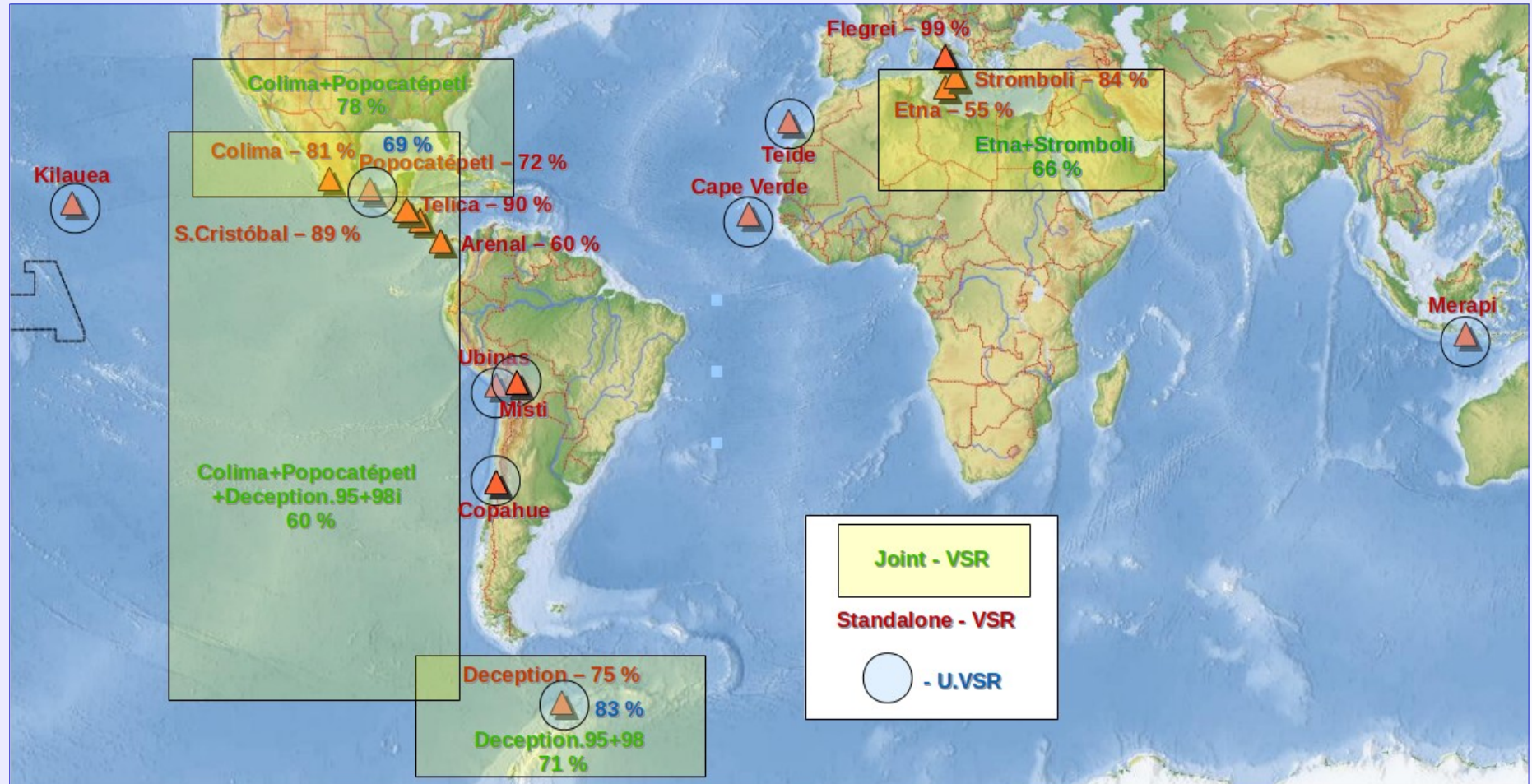
VULCAN.ears: VSR universalization > How?

- ***Aims: Automatic & Unsupervised & Real-time*** Volcano-Seismic Recognition (VSR)
- ***Proposal: VULCAN.ears*** project:
Volcano-seismic Unsupervised Labelling and Classification Embedded in A Real-time Scenario
- ✓ ***A universal solution ↔ volcano independent:*** with built-in, general, recognition models able to recognize events from most volcanoes in unsupervised scenarios

... but HOW??

VSR universalization > DB joining

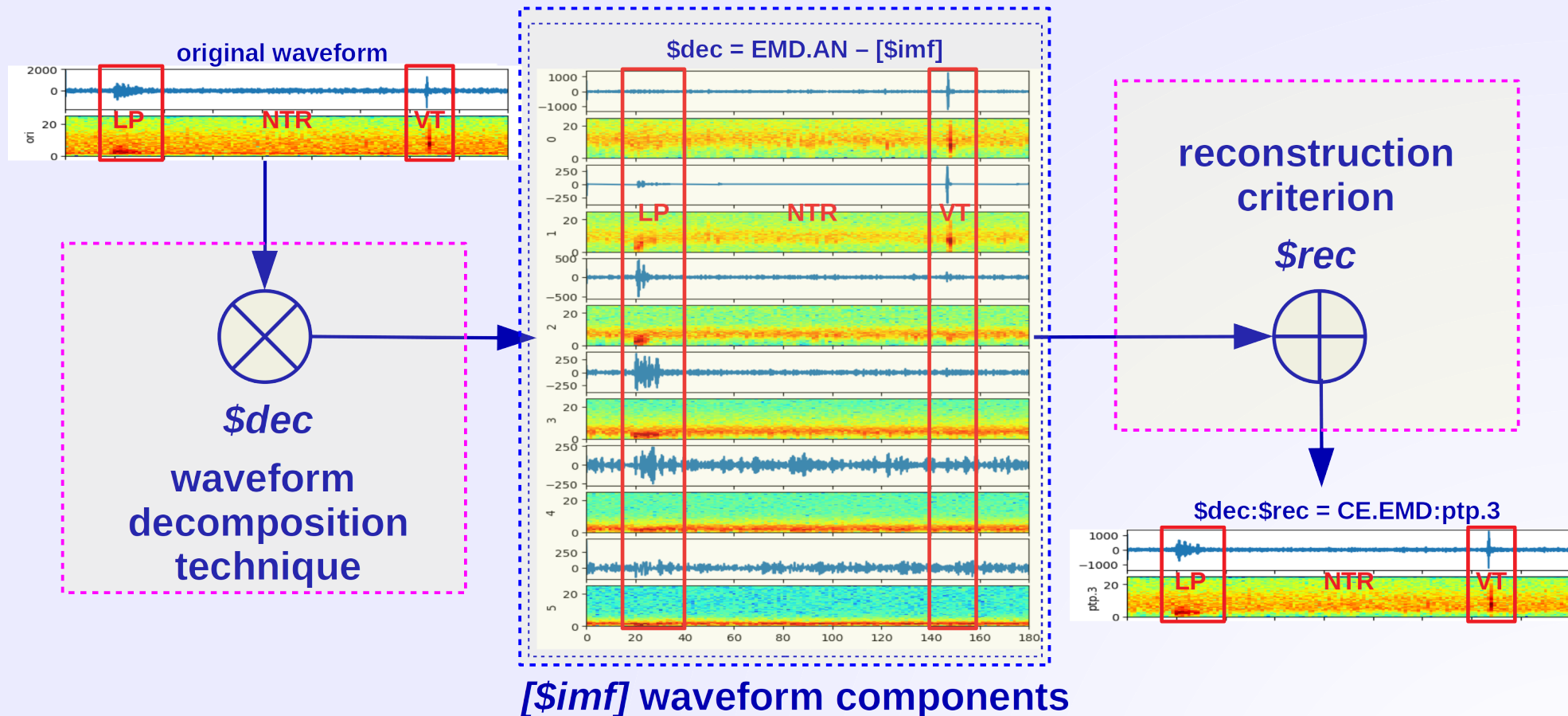
- ✓ **Data gathering:** a *Joint DBs* can be built merging *standalone DBs*
- ✓ *Joint DBs mixing* → A *Universal DB* → *universal models* → **Unsupervised VSR ?!**



- ✓ **Current VULCAN.ears partner DBs & installed VSR systems** (Recognition accuracy cAcc% is shown if is available): (**Standalone-VSR**): Standalone SSA-VSR recognisers. (**Joint-VSR**): SSA-VSR systems using joint DBs. (**U.VSR**): other available DBs to apply the unsupervised VSR.

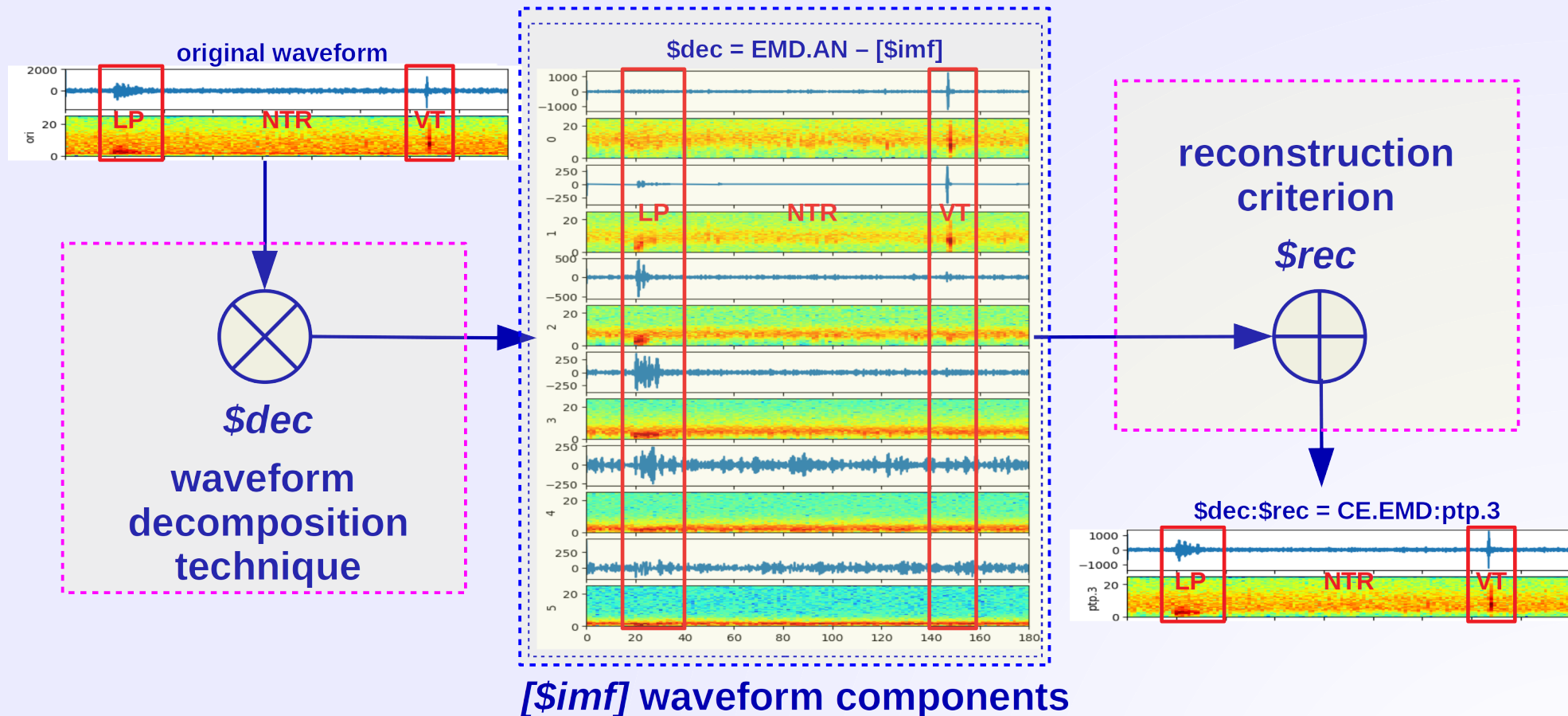
VSR universalization > Waveform standardisation

- ✓ **Standardisation approach** = $\$EMD.decomposition:\$reconstruction$, mixing $\$r-IMF$ compos
 → +16% @ VSR accuracy using $train.DB = dec.95$ and $eval.DB = dec.09$ in SSA-VSR



VSR universalization > Waveform standardisation

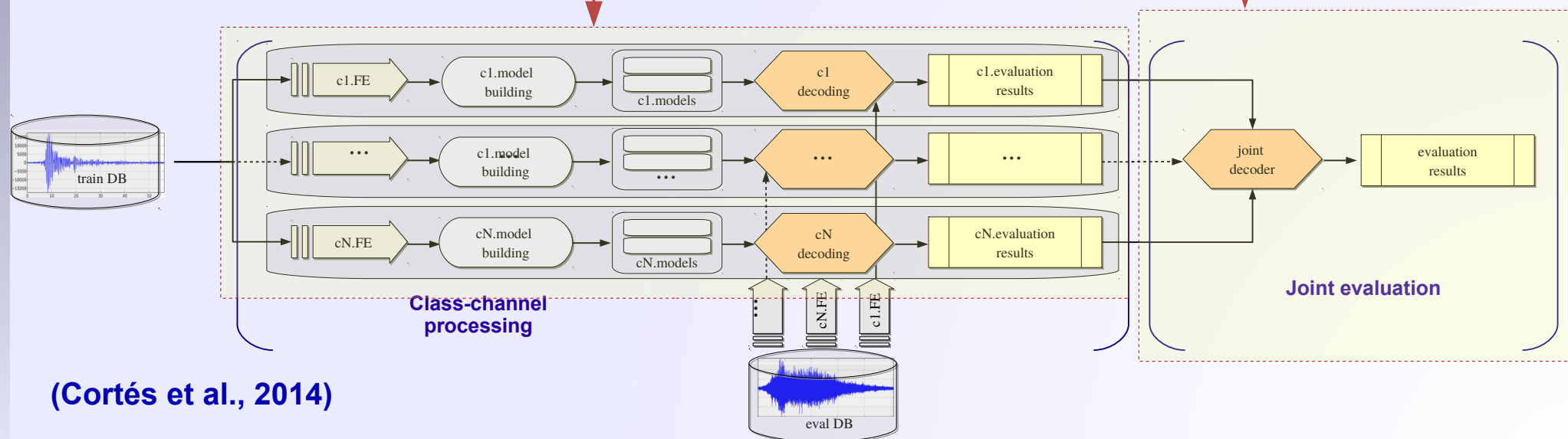
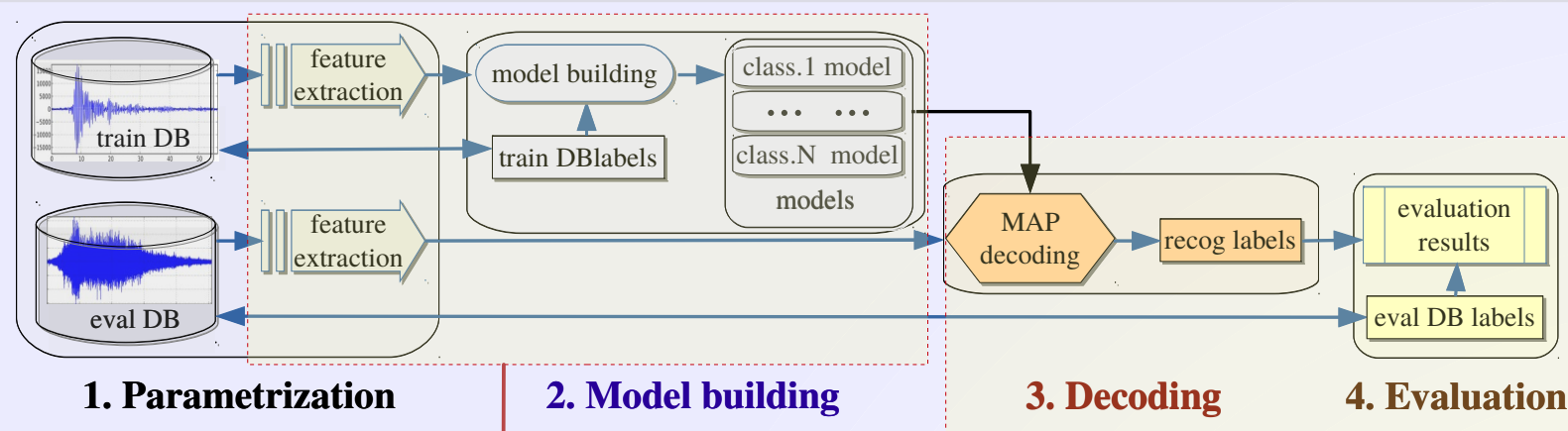
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... Check our poster "VSR under noisy conditions via waveform reconstruction" @ Ischia[12:00] - S01.04!

VSR universalization > Parallel VSR (PSA-VSR)

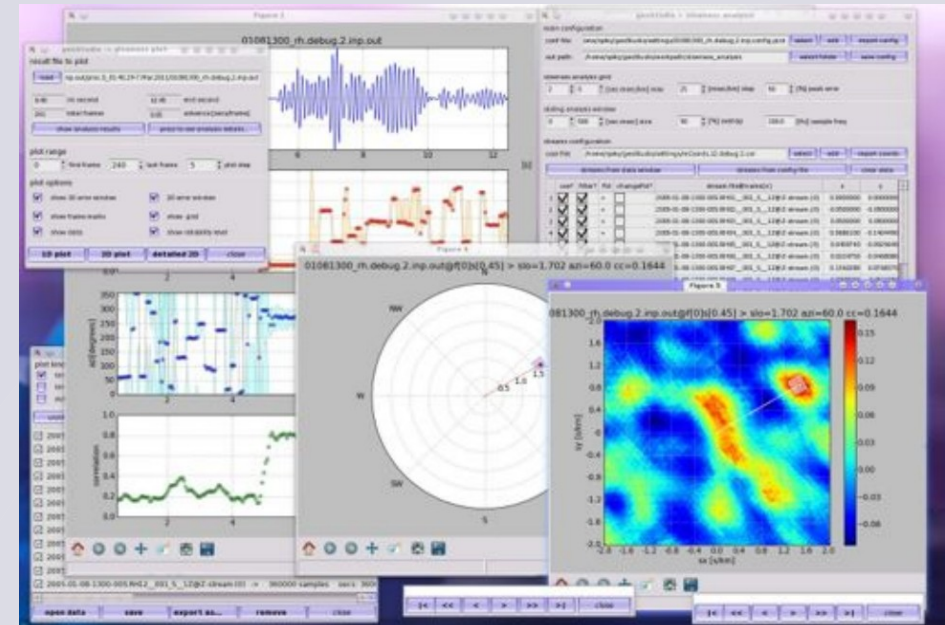
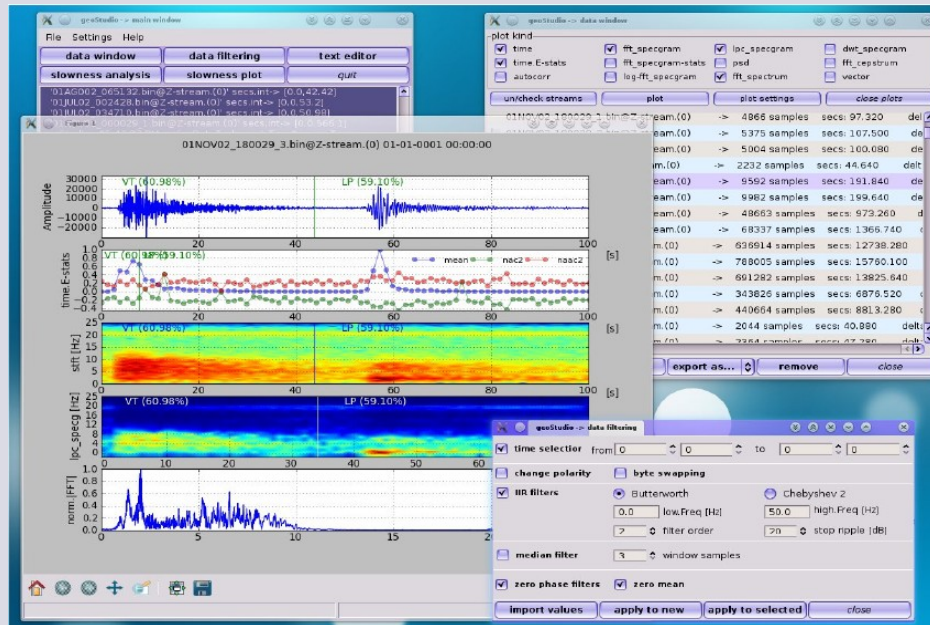
- ✓ **Parallel VSR:** *specialized VSR-channels* to recognise events of just one class (VT, TRE,...)
- ✓ **VSR.channel, setting** \leftrightarrow custom{HMM.topo + \$stand + BPF + param + DFS} for class_i
- ✓ this specialization \rightarrow *increases* the global system *robustness & recognition scores*



(Cortés et al., 2014)

apps & impact > geoStudio

- **Aim:** open-source, multiplatform GUI designed to simplify the use of 2D seismic source location and Volcano-Seismic Recognition (VSR), to be integrated into real-time VO monitoring systems



- **(current) Main features:**

(Carmona et al., 2014)

- Read / write of seismic data supporting several standardised formats
- Data filtering & advanced seismogram visualization (using Python – matplotlib & scipy)
- VSR support as a Hidden Markov Models Toolkit® (HTK) wrapper
- 2D source location by slowness maps (via seismic array Zero-Lag Cross Correlation, ZLCC)
- detailed documentation: [html-API](#), [ChangeLog](#) and [Readme](#) files

apps & impact > geoStudio > VSR-GUI

● VSR (detection and classification *labelling* in the selected streams):

(1) Open the 'data labelling' window

(2) Load files @ 'data window' and (3) select those you want to analyse

(4) (fast) VSR config:

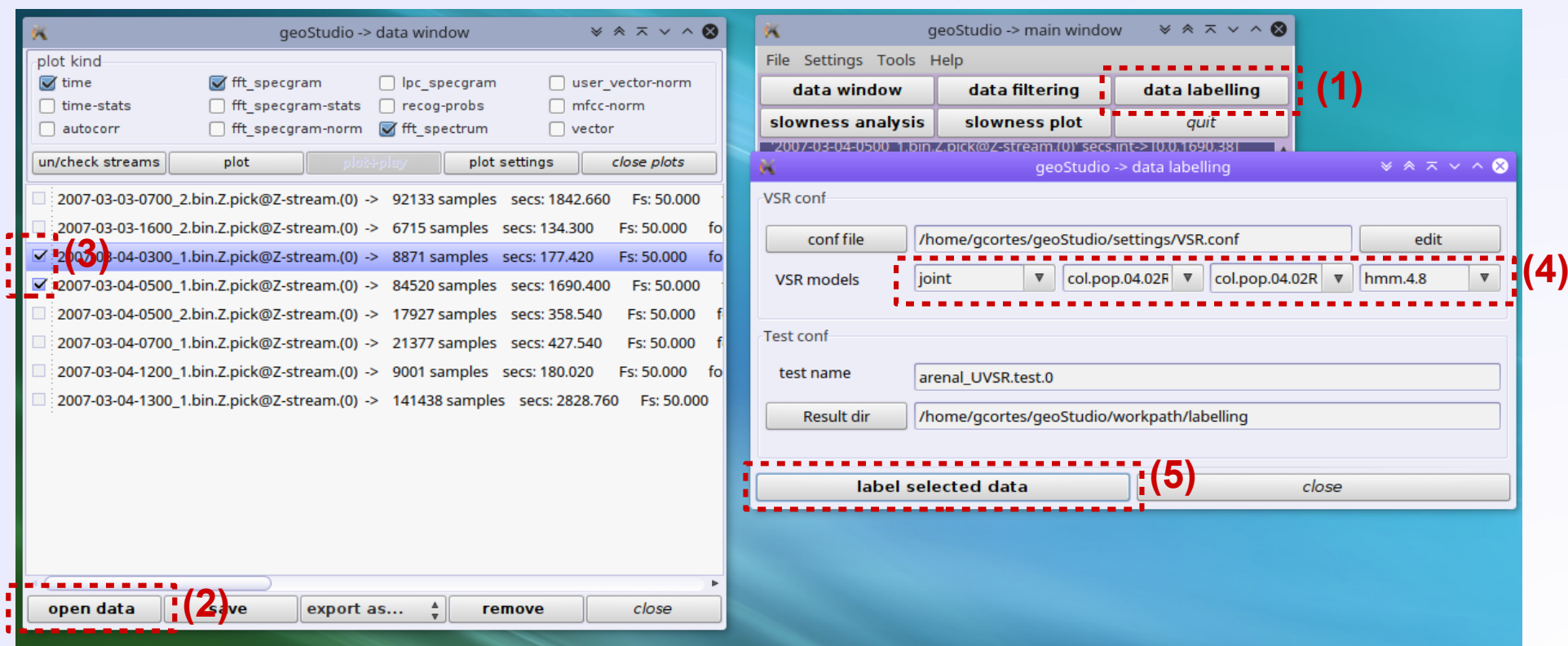
1.<site> origin of the VSR models

2.<DB> used to build the models

3.<DBconf> specific model building configuration

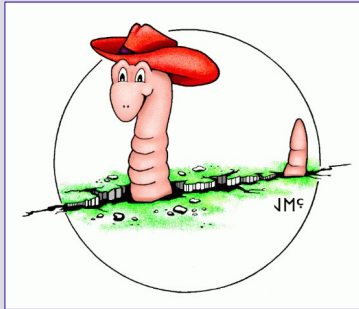
4.complexity of the <models> to be used

(5) **Go!**

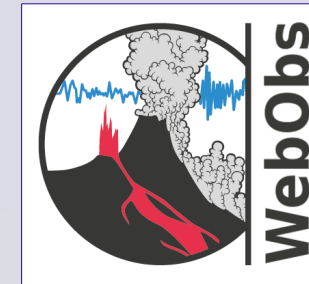


apps & impact > VO integration

- ✓ **VO integration:** the VSR backend will be embedded into popular monitoring systems as:

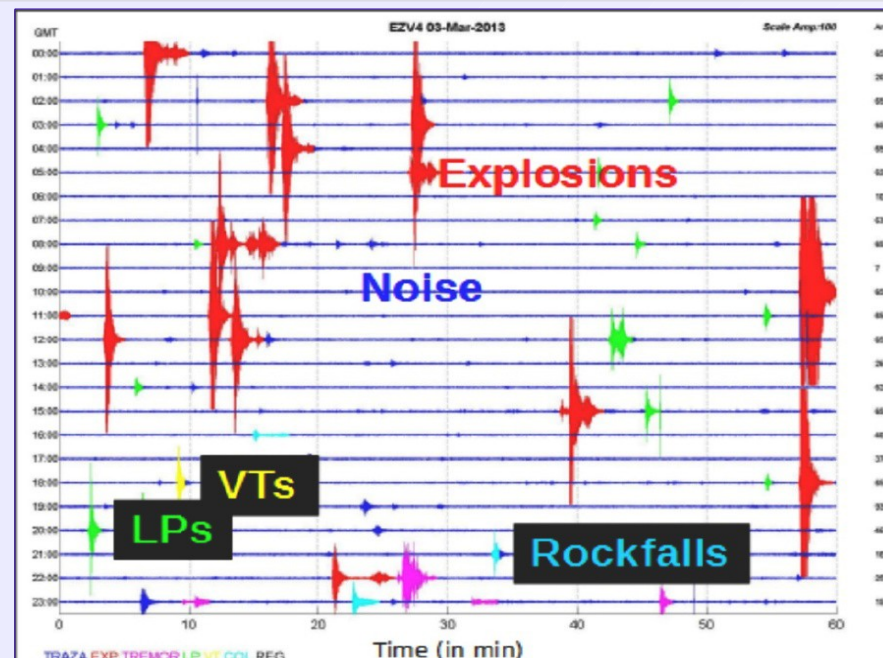


<http://www.earthwormcentral.org/>



<https://github.com/IPGP/webobs>

- ✓ **VSR monitoring @ Colima VO:** SSA-VSR integrated at Volcán de Fuego since 2009!



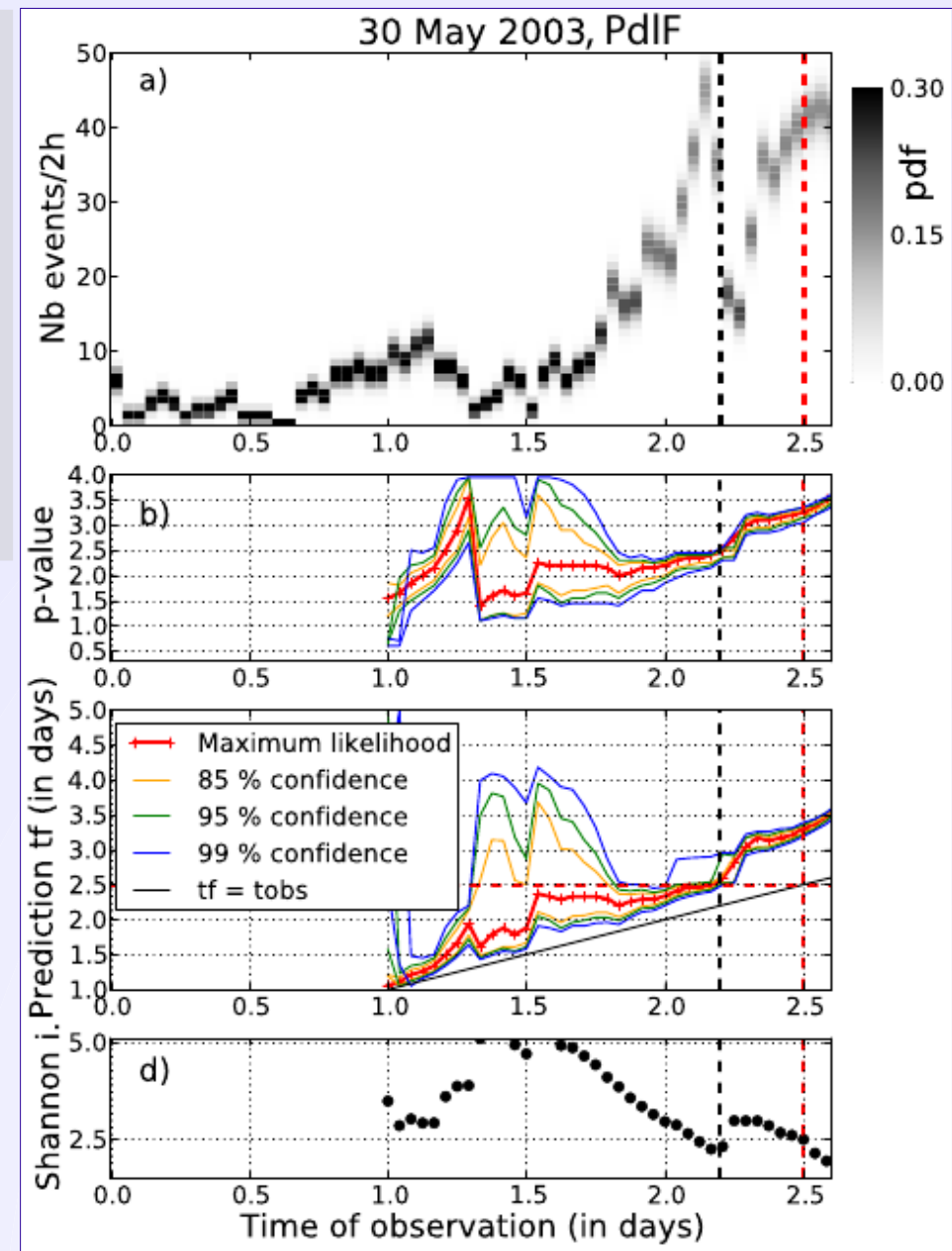
(Cortés et al., 2009)

apps & impact > VSR & Volcano Forecasting

Bayesian Failure Forecasting Method:

- ✓ *VSR* can be used to achieve *real-time (online) volcano forecasting*
- ✓ *83% of forecasting success* when the method criteria are fulfilled.
- ✓ VSR is applied to 23 years of continuous data from 3 volcanoes.

(Boué et al., 2015;2016)



“Early” results > Unsupervised SSA-VSR

- **Unsupervised classification:** the system is robust enough to score good cAcc% even in unsupervised scenarios

system	recog type	train.DB	events / classes	dur[h]	eval.DB	events / classes	dur[h]	cAcc%
SSA-U.VSR	isolated	dec.95s.1	2001 / 3	10	dec.98s.1	1579 / 3	16	64
SSA-U.VSR	isolated	col.04.s3	4682 / 6	195	pop.02s.3	2099 / 6	139	56

- **Joint.DBs recognition by data of 3 volcanoes:** the reliability is shown modeling heterogeneous data from Colima, Popocatépetl and Deception

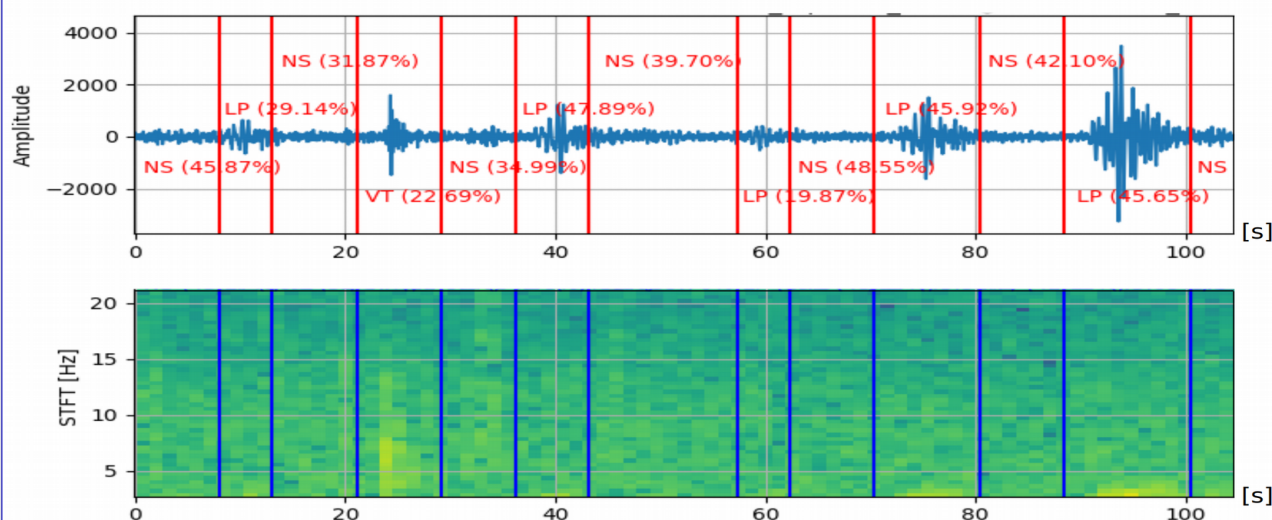
system	recog type	train.DB	events / classes	dur[h]	eval.DB	events / classes	dur[h]	cAcc%
SSA-VSR	continuous	JOINT.1	5154 / 10	173	JOINT.2	5335 / 10	172	65

- **Unsupervised cataloging of large DBs:**

365 days of continuous data were recognized in only 20 hours!

@ Deception Island

achieving a x400 factor over the speed required for real-time..



“Early” results > Parallel VSR vs. Serial (classic) VSR

PSA vs. SSA (U.)VSR @ Deception and Colima: the custom modelling and features (in *param_#feats* vectors) used to describe one class in its VSR channel outperforms SSA

PSA vs. SSA in supervised VSR:

system	recog type	train.DB = dec.95.8s.1 events / classes @ duration	eval.DB = dec.95.8s.2 events / classes @ duration	param_#feats	%cAcc
SSA-VSR	isolated	168 / 5 @ 1,3 [h]	160 / 5 @ 1,2 [h]	geoLFCC.D_26	87
PSA-VSR	isolated	168 / 5 @ 1,3 [h]	160 / 5 @ 1,2 [h]	DFS[geoLFCC.D]_15	91
		train.DB = dec.95.5c.1	eval.DB = dec.95.5c.2		
SSA-VSR	continuous	252 / 5 @ 1,4 [h]	122 / 5 @ 0,7 [h]	DFS[geoLFCC.D]_15	64
PSA-VSR	continuous	252 / 5 @ 1,4 [h]	122 / 5 @ 0,7 [h]	DFS[geoLFCC.D]_15	69
		train.DB = col.04.15c.1	eval.DB = col.04.15c.2		
SSA-VSR	continuous	427 / 11 @ 32,3 [h]	242 / 11 @ 17,2 [h]	DFS[geoLFCC.D]_15	55
PSA-VSR	continuous	427 / 11 @ 32,3 [h]	242 / 11 @ 17,2 [h]	DFS[geoLFCC.D]_15	67

PSA vs. SSA in unsupervised VSR:

system	recog type	train.DB = dec.95.8s events / classes @ duration	eval.DB = dec.95.3s events / classes @ duration	param_#feats	%cAcc
SSA-U.VSR	isolated	328 / 5 @ 2,5 [h]	404 / 5 @ 2,5 [h]	geoLFCC.D_26	60
PSA-U.VSR	isolated	328 / 5 @ 2,5 [h]	404 / 5 @ 2,5 [h]	DFS[geoLFCC.D]_15	65
		train.DB = dec.95.10c	eval.DB = dec.98.3c		
SSA-U.VSR	continuous	313 / 4 @ 1,8 [h]	482 / 4 @ 4,2 [h]	DFS[geoLFCC.D]_15	6
PSA-U.VSR	continuous	313 / 4 @ 1,8 [h]	482 / 4 @ 4,2 [h]	DFS[geoLFCC.D]_15	50

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IV. Conclusions and Remarks

Conclusions & remarks

- Volcano observatories demand automatic & real-time VSR tools
- Automatic VSR is becoming operational for monitoring systems.
- DB+soft sharing & scientific collaboration is *mandatory* to advance!
 - ✓ *everyone is welcome to joint our “train DB → geoStudio” treat*
- Unsupervised (*volcano independent*) VSR is closer than appears thanks to deployment of new technologies as:
 - ✓ *Joint DBs & waveform standardization → universal models*
 - ✓ *Parallel-VSR → class-custom VSR channels*
- VULCAN.ears project will be able to supply *free & portable & robust U.VSR solutions*

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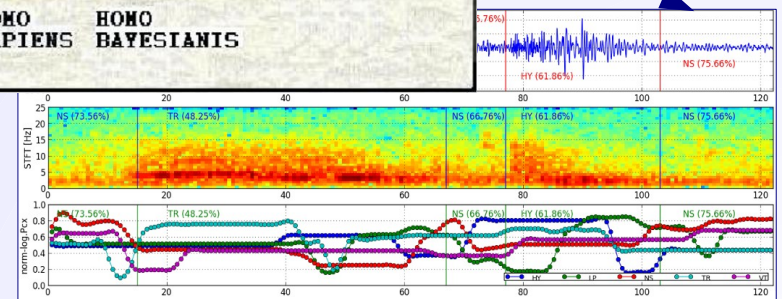
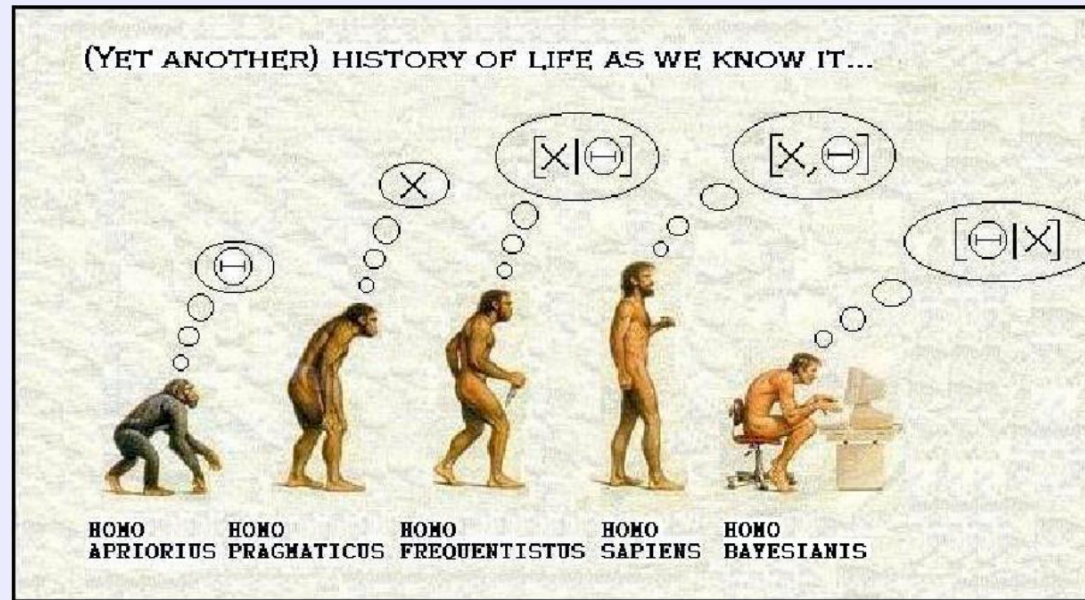
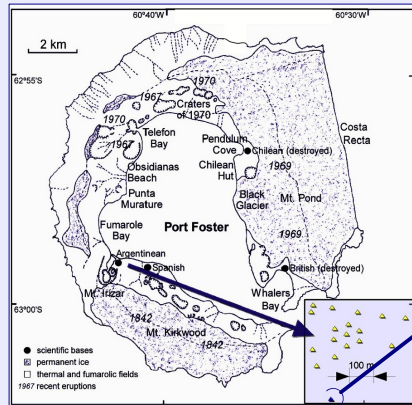
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... *Thank you for your time !*



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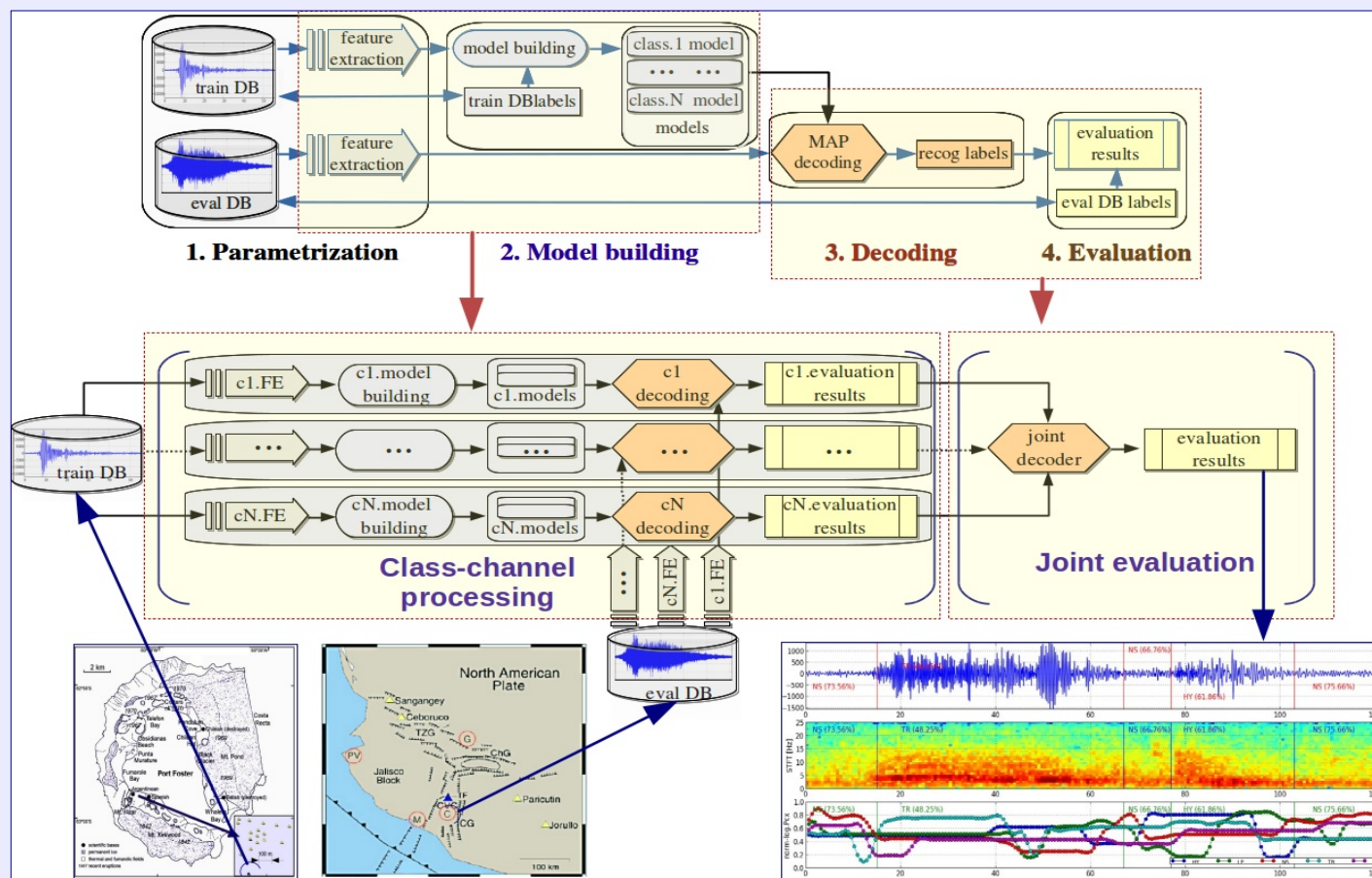
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