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A comprehensive observational database of deformation at global volcanoes for machine learning applications

Lin Shen, Andrew Hooper, Milan Lazecký, Matthew Gaddes, Camila Novoa Lizama,
Susanna Ebmeier, Scott Watson, Yasser Maghsoudi, Richard Rigby

COMET, School of Earth and Environment, University of Leeds

L.Shen@leeds.ac.uk



COMET

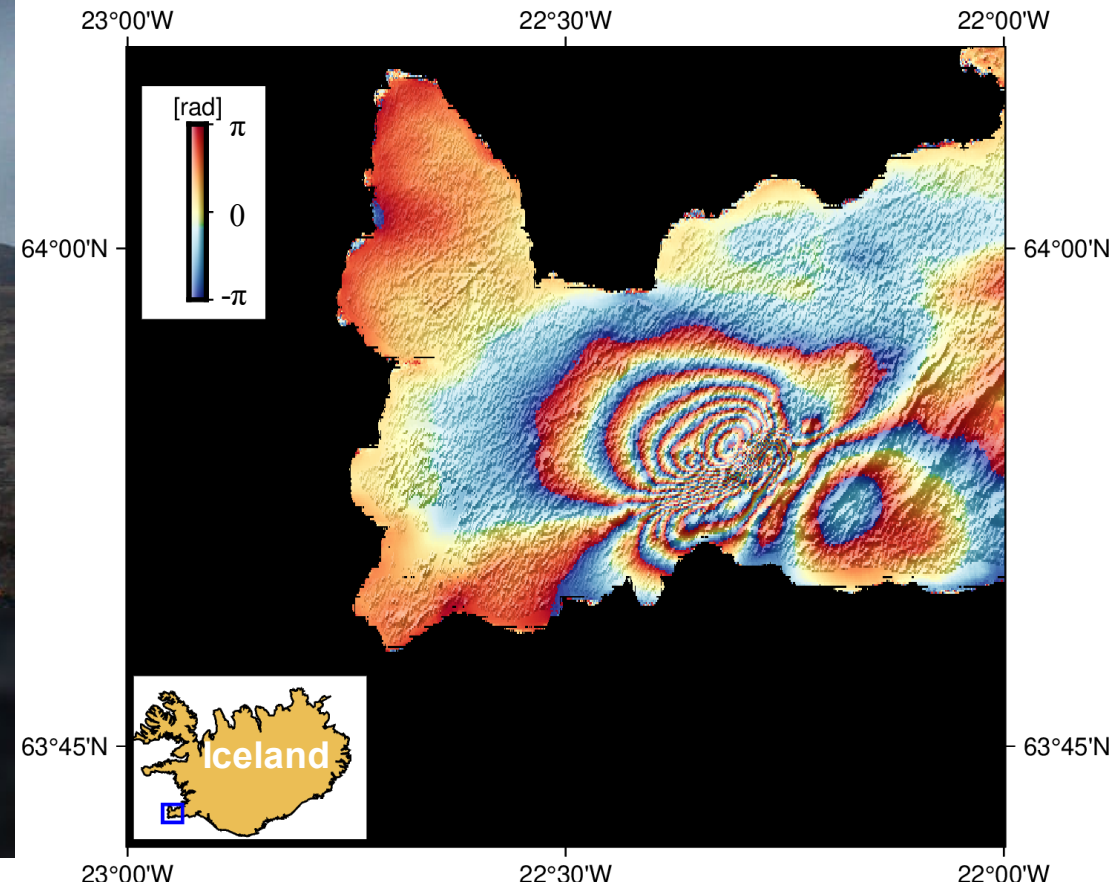
CENTRE FOR OBSERVATION & MODELLING
OF EARTHQUAKES, VOLCANOES & TECTONICS



Fringe 2023, 11-15 September

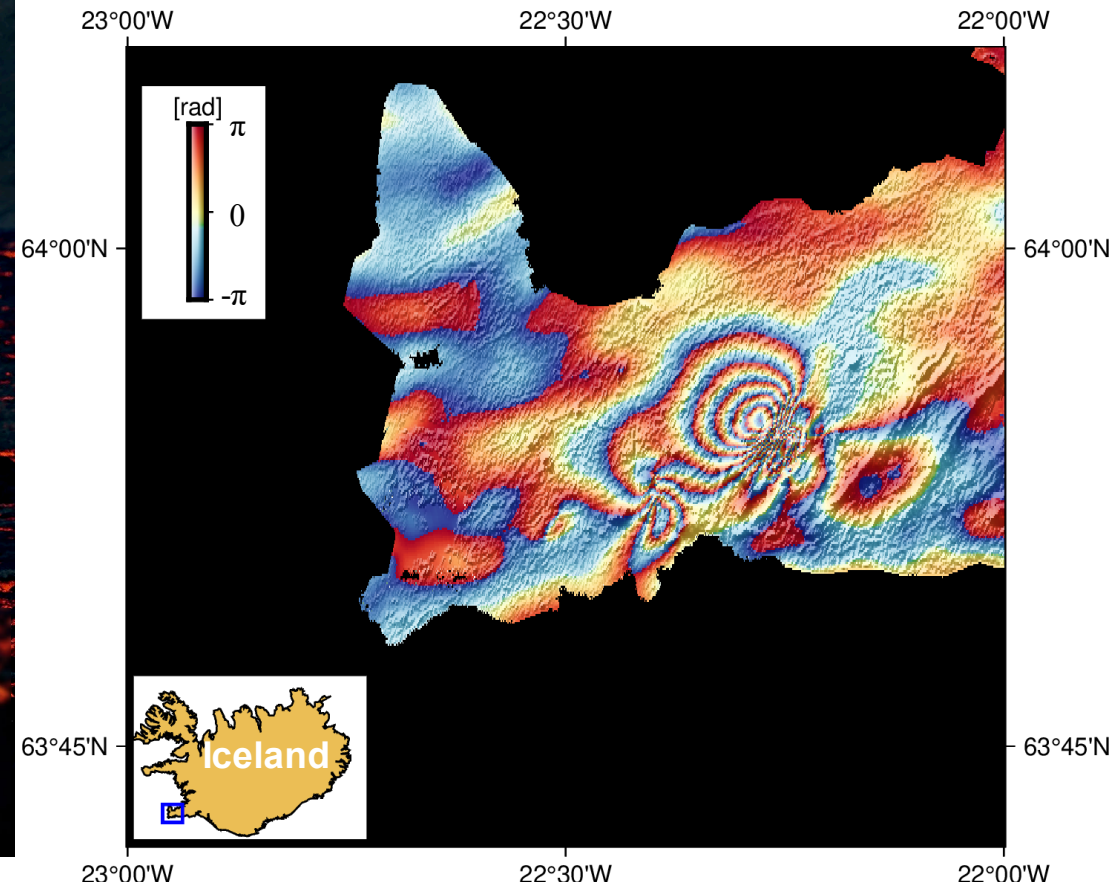
Satellite measurements of deformation using InSAR include a high proportion of inter- and pre-eruptive signals

Sentinel-1 interferogram, Reykjanes 03 Mar 2021 to 15 Mar 2021



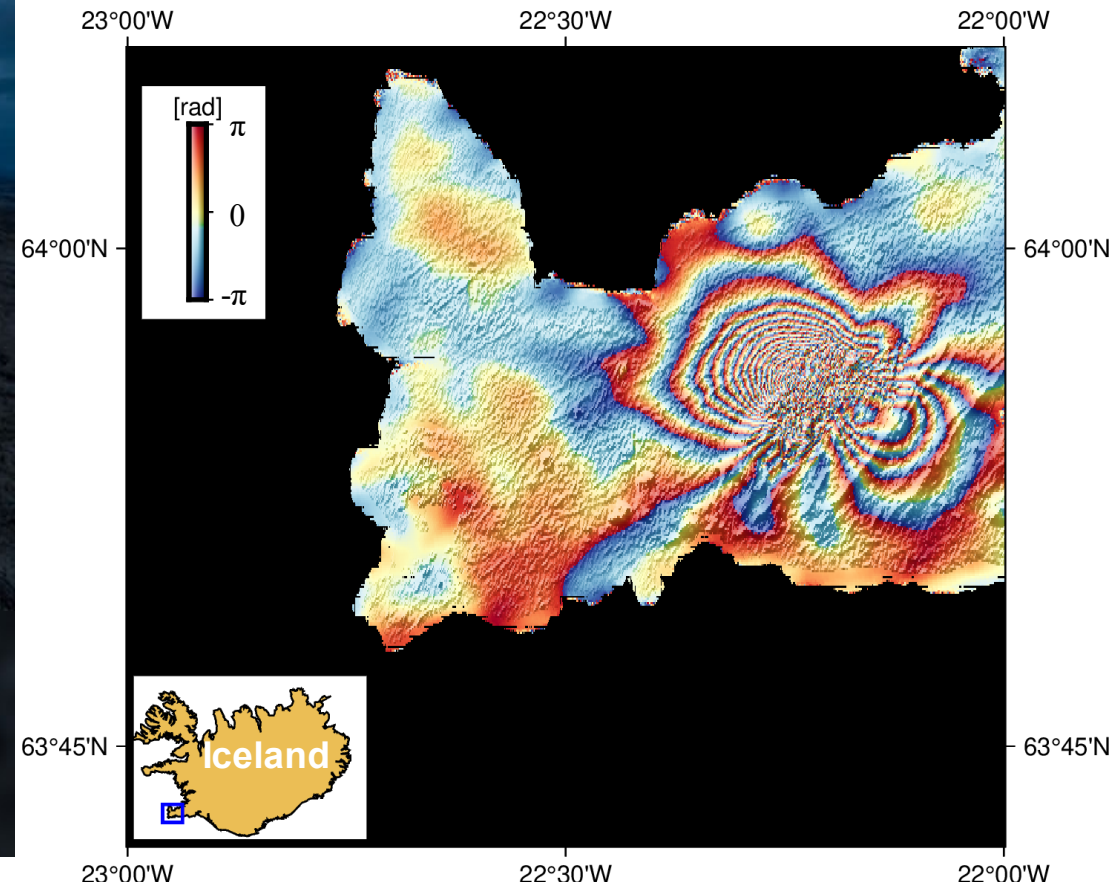
Satellite measurements of deformation using InSAR include a high proportion of inter- and pre-eruptive signals

Sentinel-1 interferogram, Reykjanes 20 Jul 2022 to 1 Aug 2022



Satellite measurements of deformation using InSAR include a high proportion of inter- and pre-eruptive signals

Sentinel-1 interferogram, Reykjanes 03 Jul 2023 to 15 Jul 2023



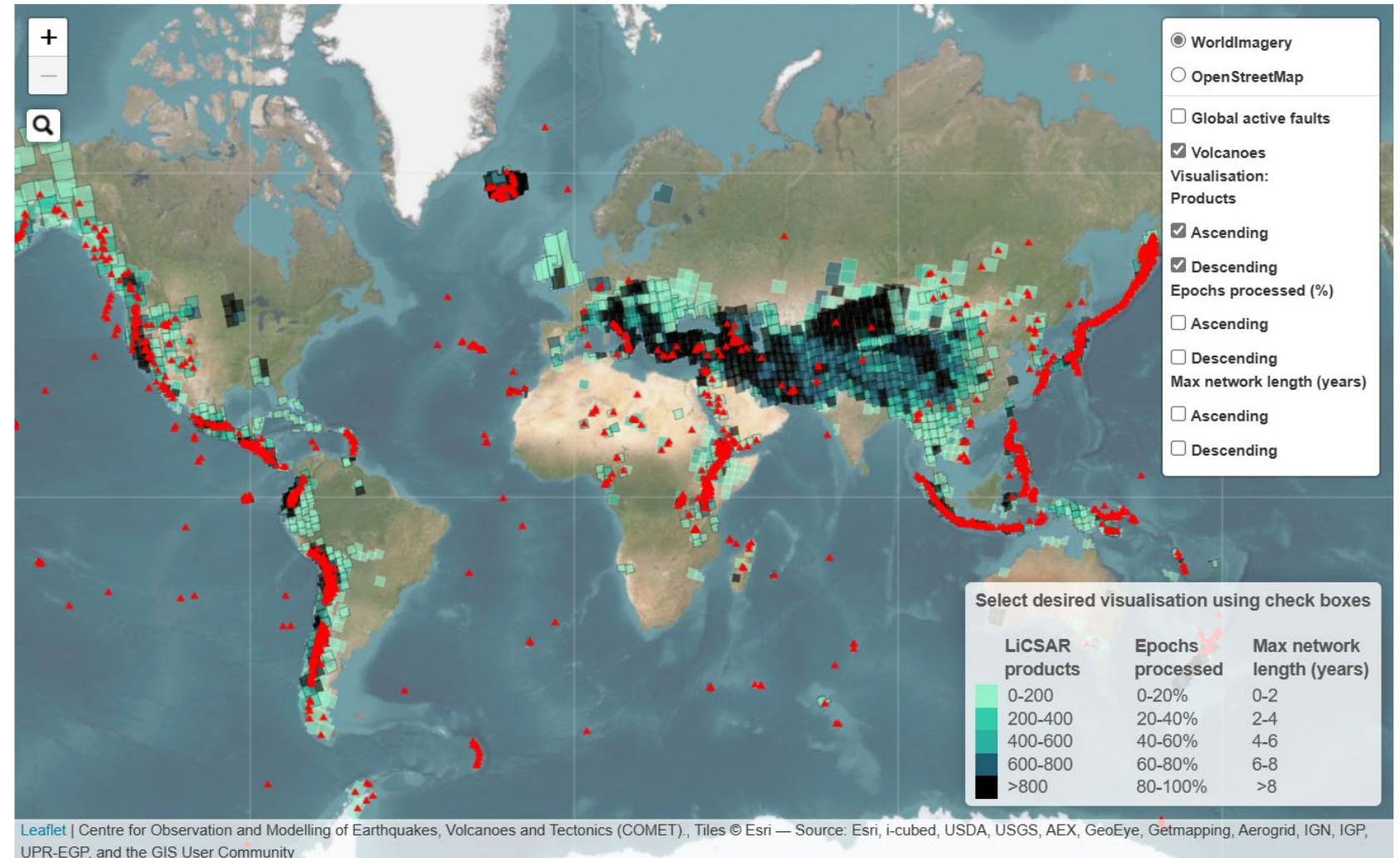
Towards volcano deformation monitoring using InSAR



COMET- LiCS Sentinel-1 InSAR Portal

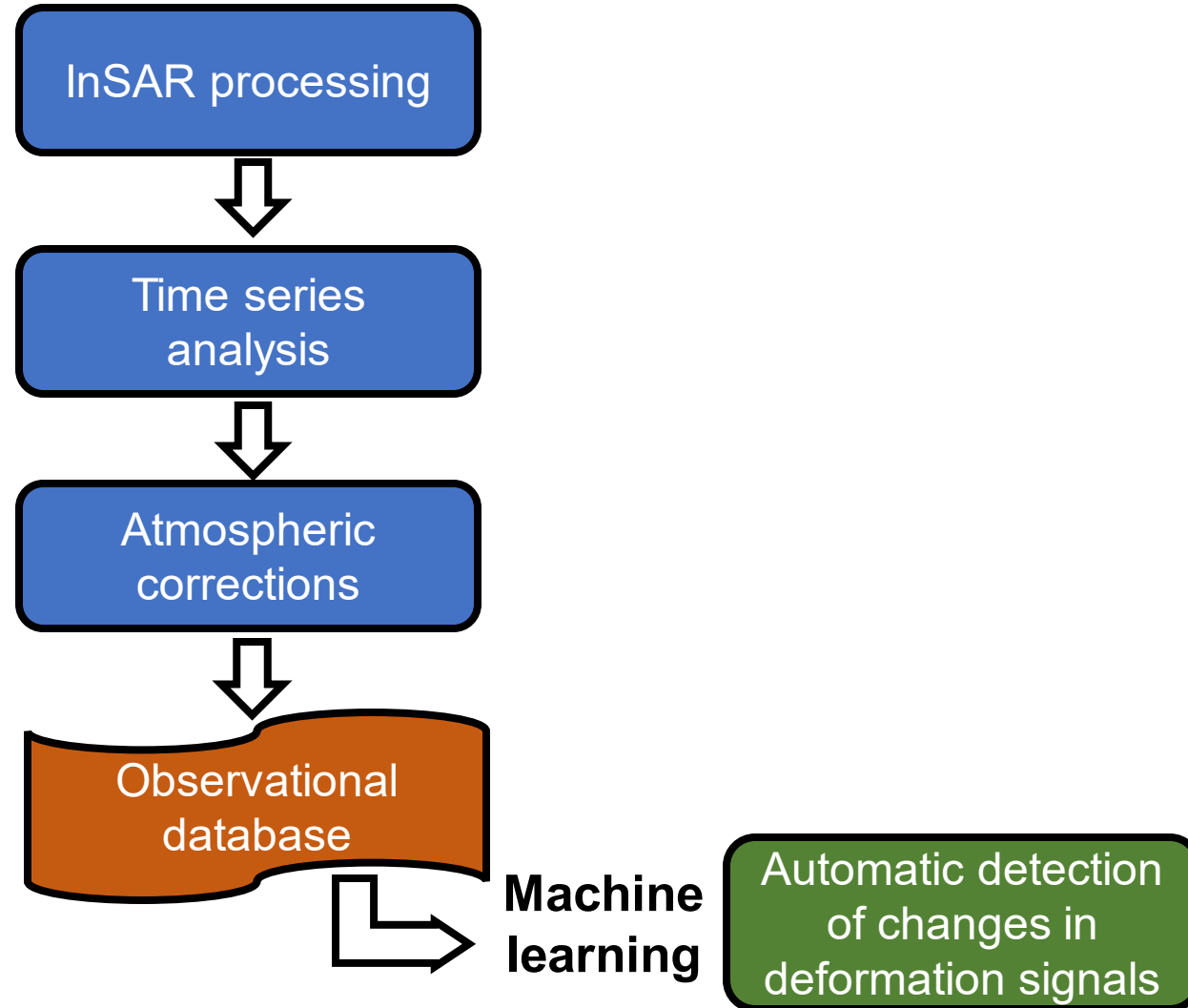
❖ Data collected systematically every 6 or 12 days, and available within hours

❖ Allow the generation of interferograms over all active volcanoes as soon as Sentinel-1 SLC data is delivered from ESA

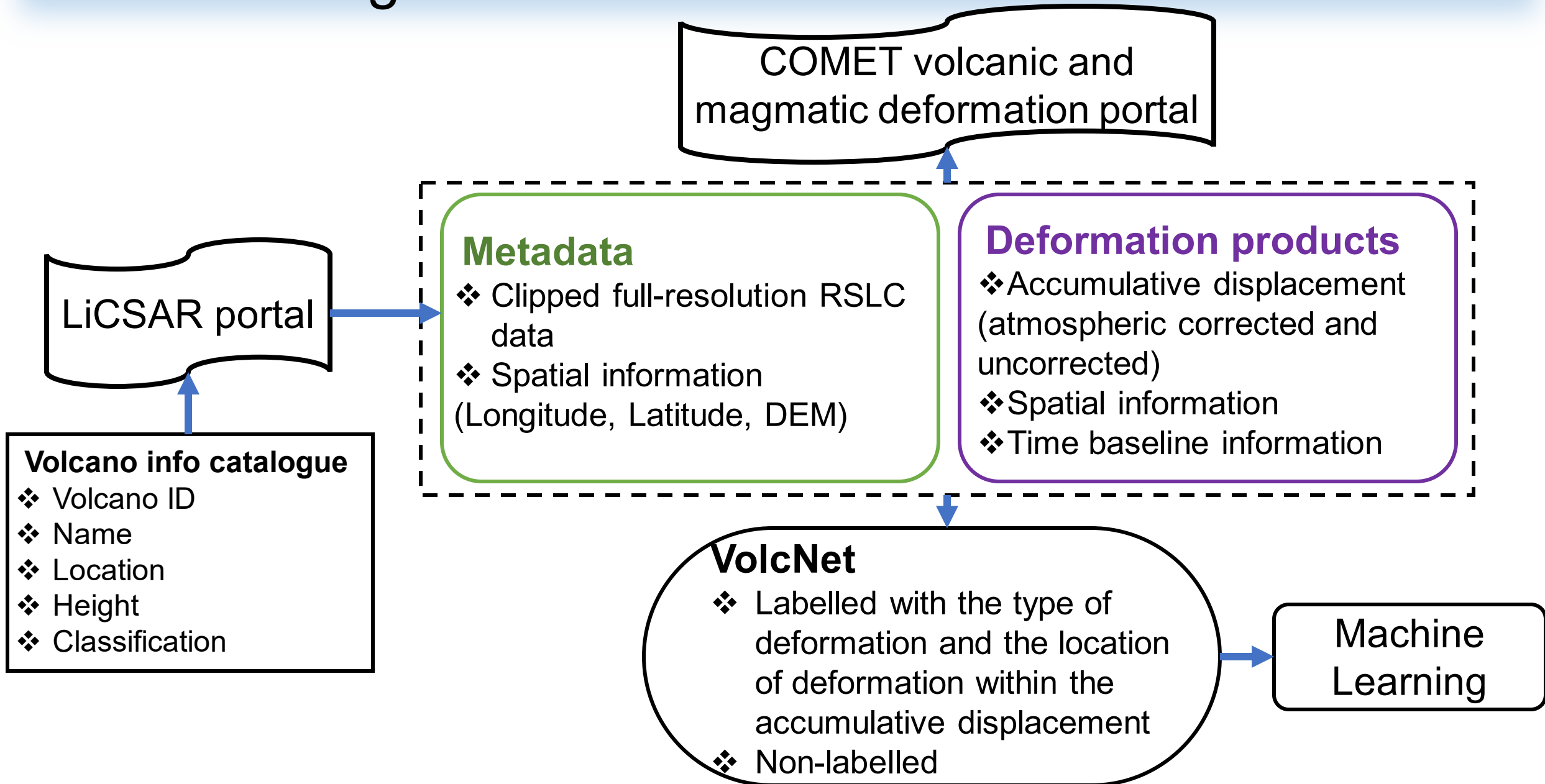


An automatic processor to derive high-resolution displacement time series over global subaerial volcanoes

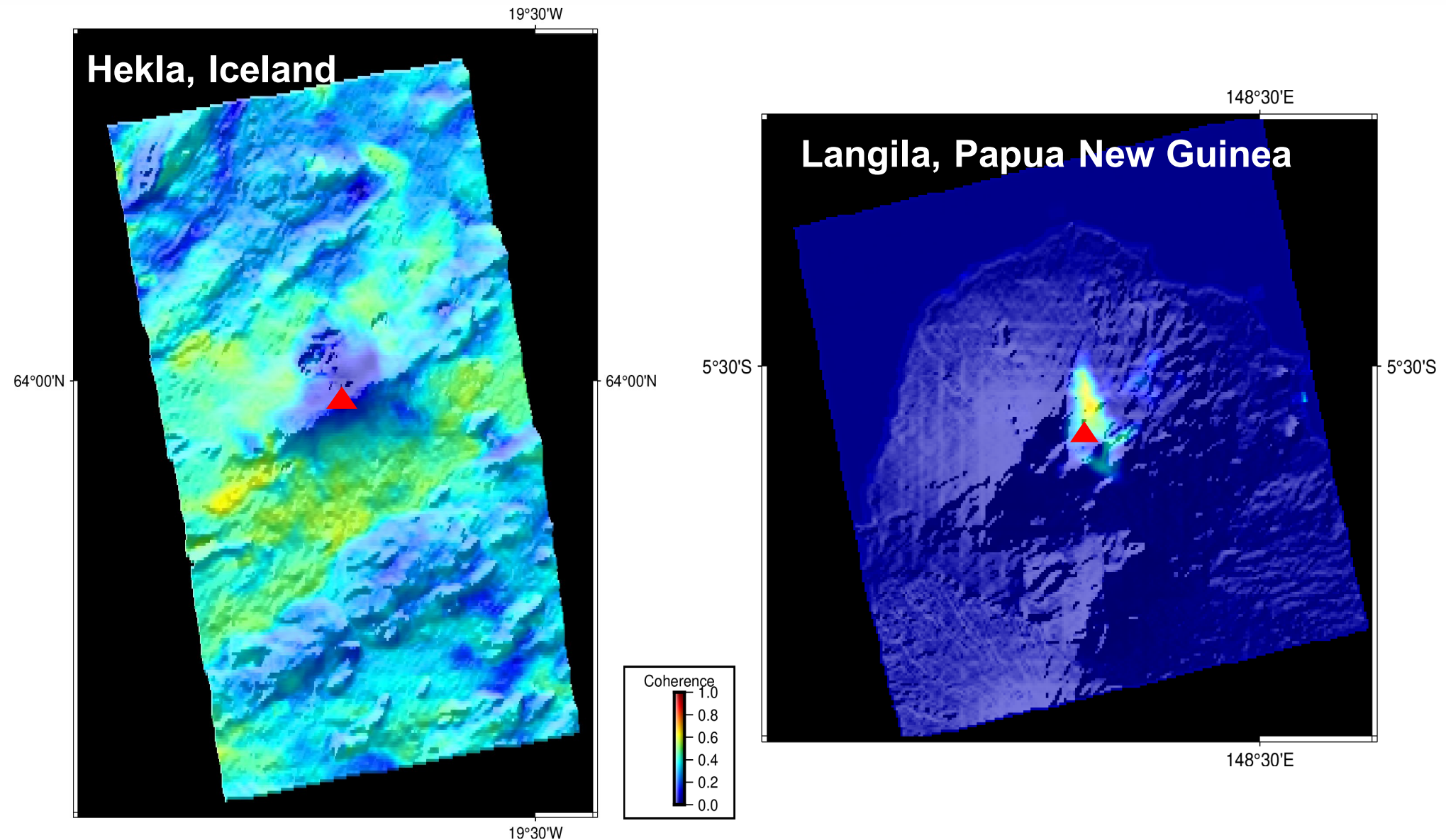
- ❑ Interferograms with inter, co and pre-eruptive signals over all subaerial volcanoes, including some volcanoes have not been systematically analysed at all
- ❑ Improved algorithms to address major limits on the effectiveness of InSAR
- ❑ Displacement time series in high resolution of 30 m
- ❑ A minimum data storage requirements by only cropping the area around each volcano



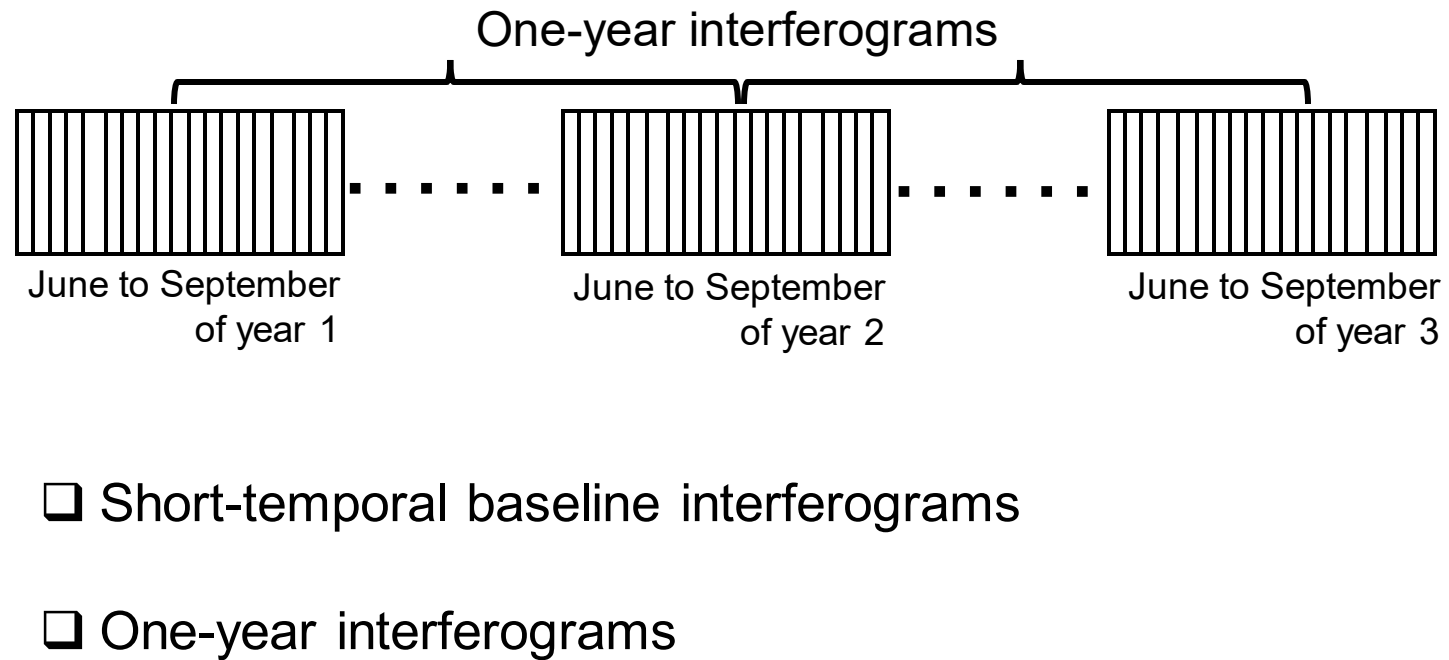
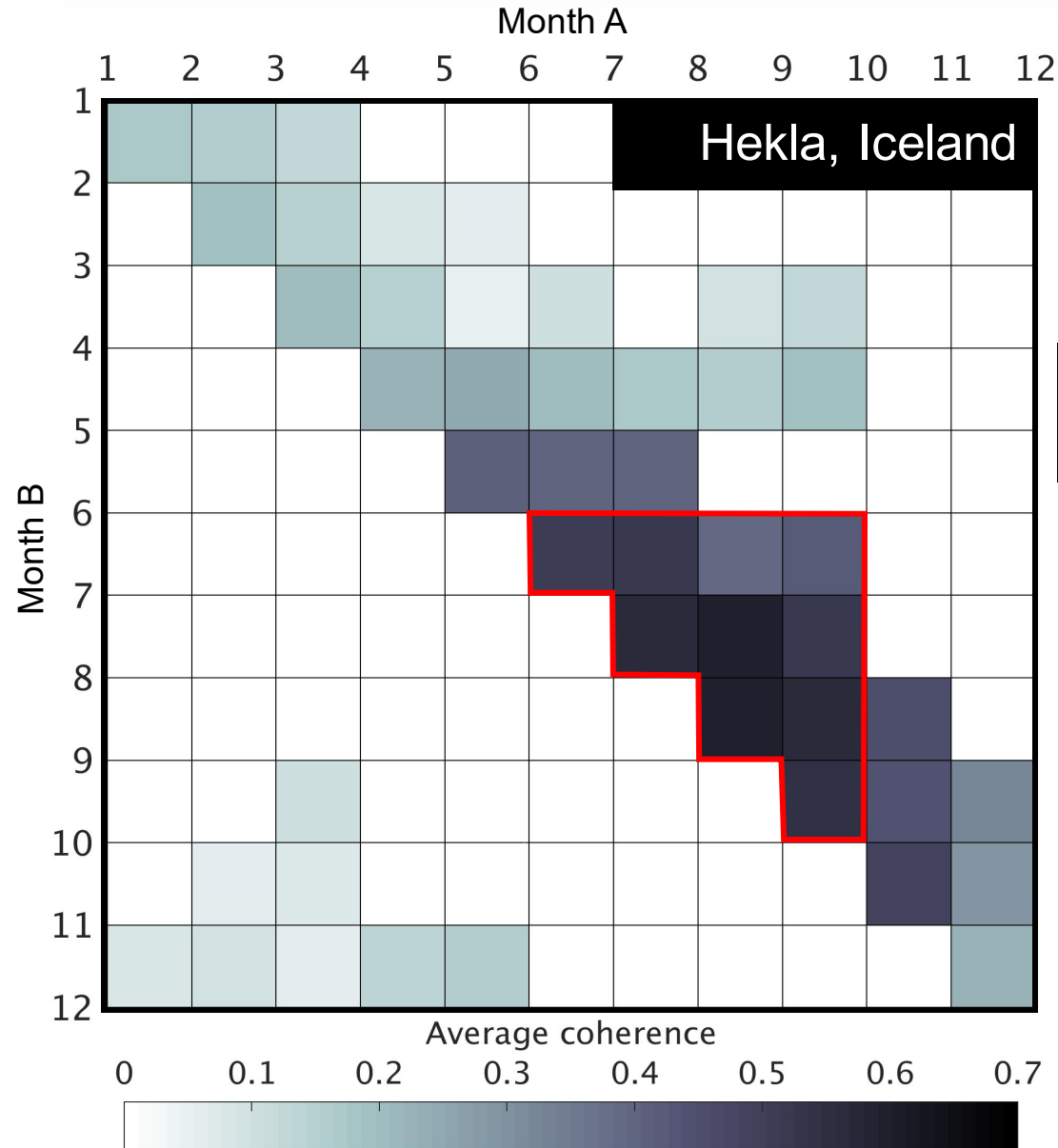
Database design



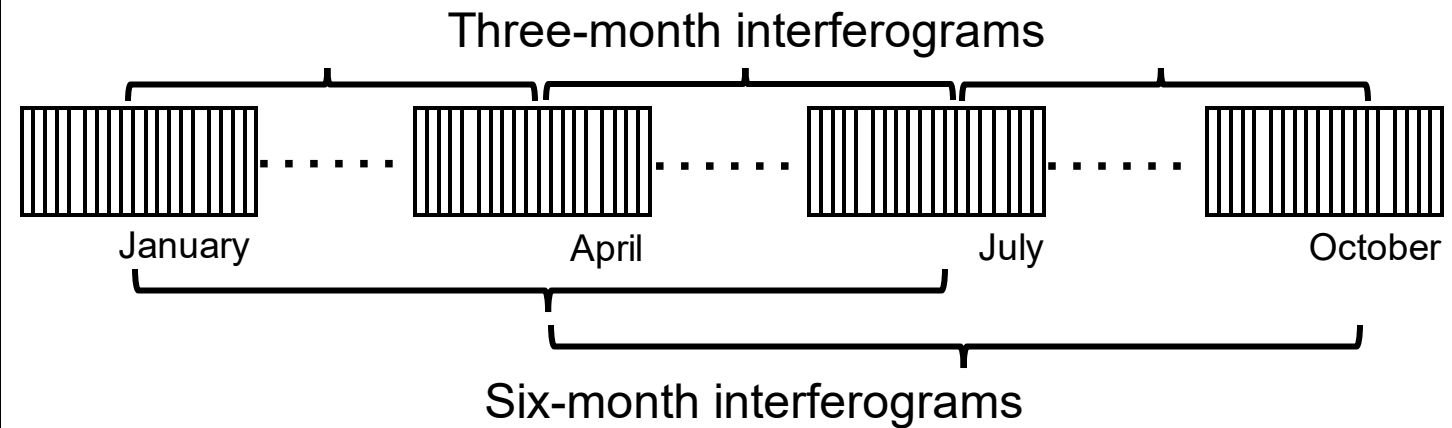
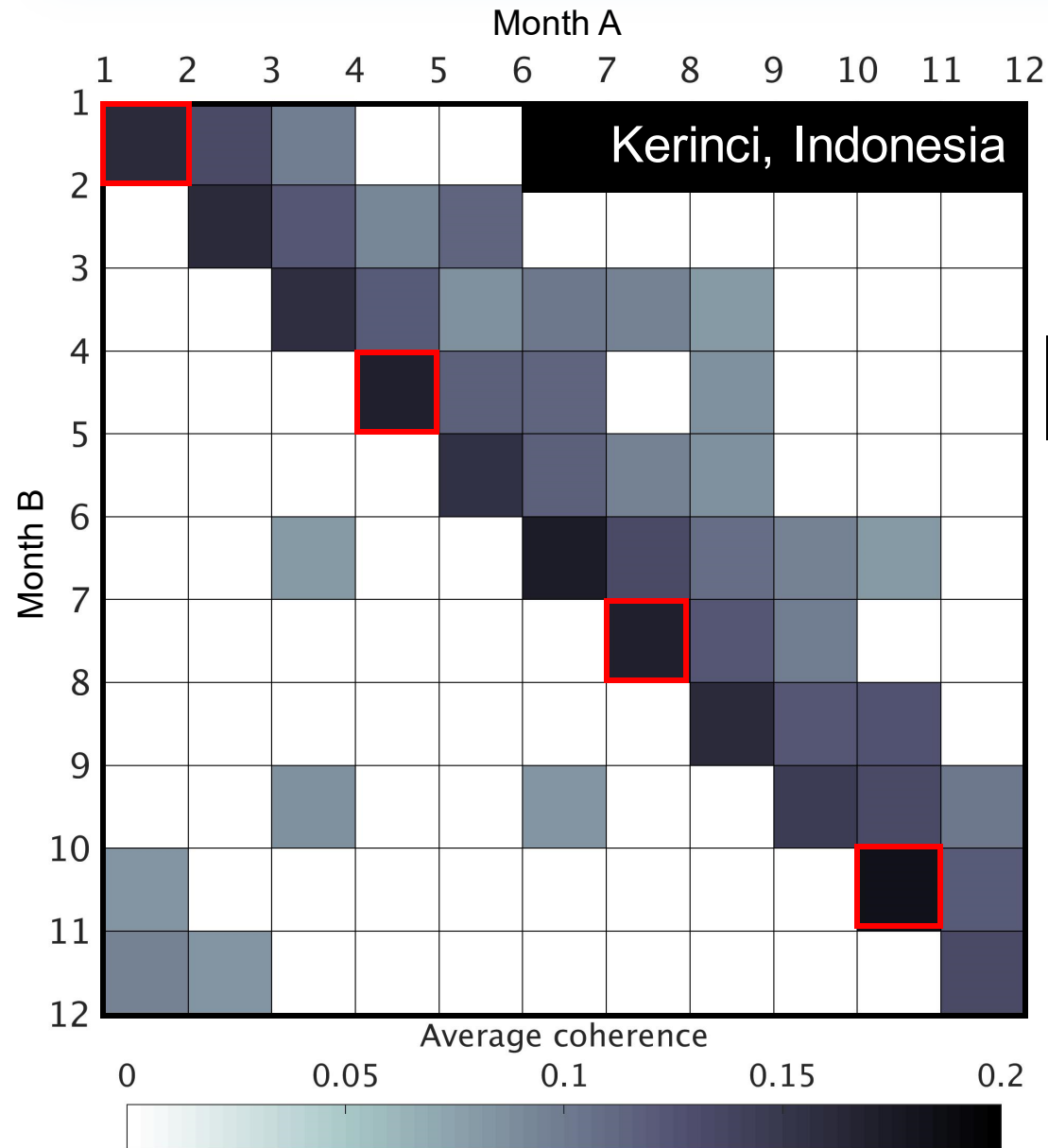
Decorrelated signals in areas of glacial coverage, winter snow and heavy vegetation



A coherence analysis for building highly redundant small baseline network of interferograms



A coherence analysis for building highly redundant small baseline network of interferograms

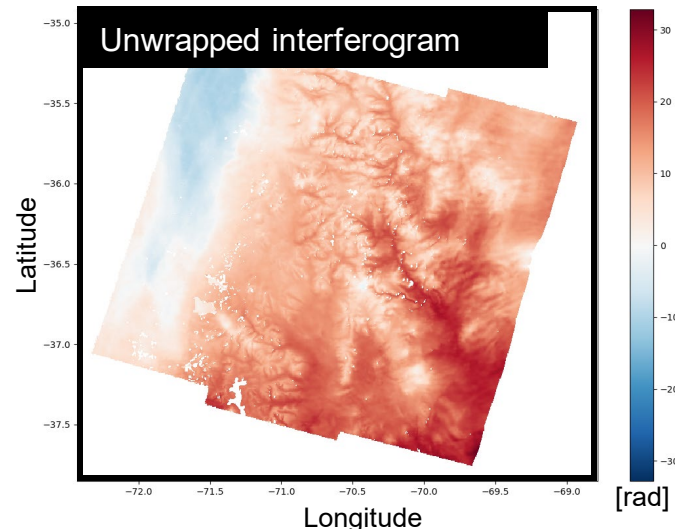
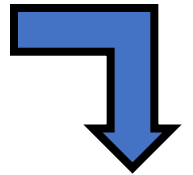
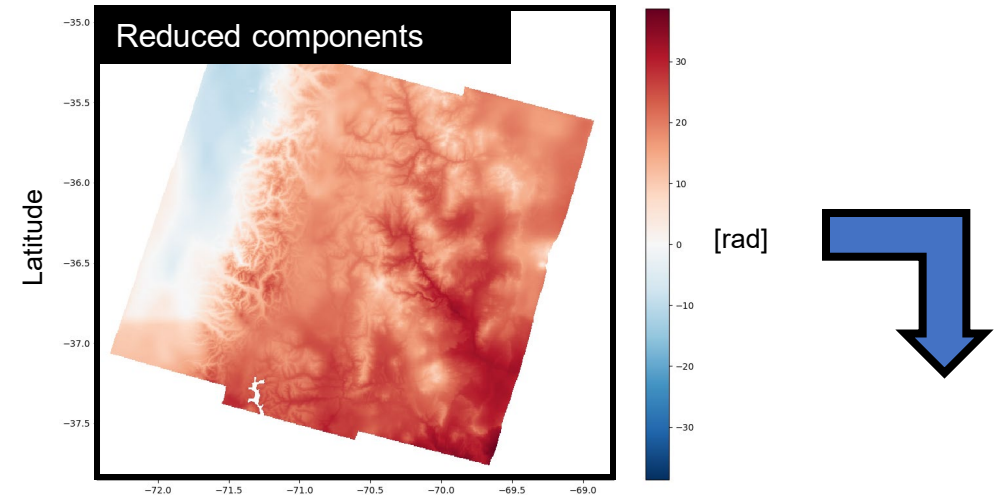
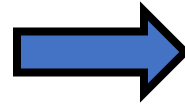
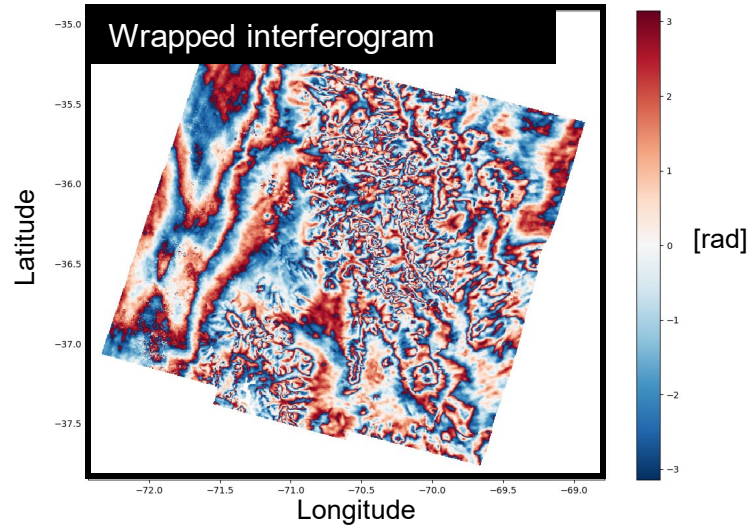


- Short-temporal baseline interferograms
- Three-month interferograms
- Six-month interferograms

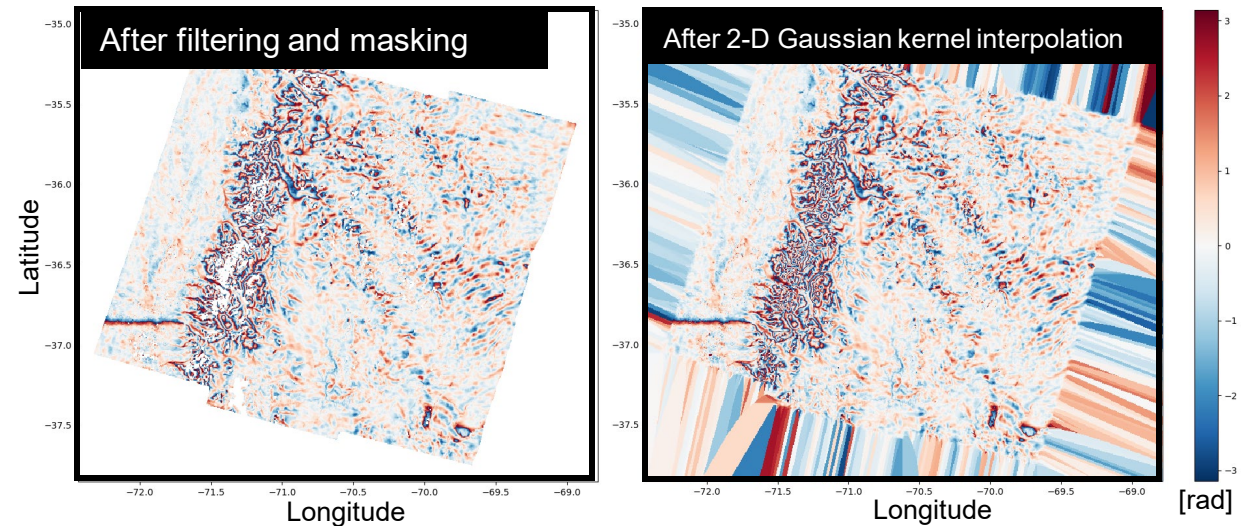
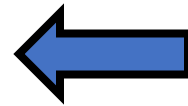
An improved phase unwrapping algorithm

20191208 - 2020101, Nevados de Chillán

A. Reducing phase gradients before unwrapping



Unwrapping results

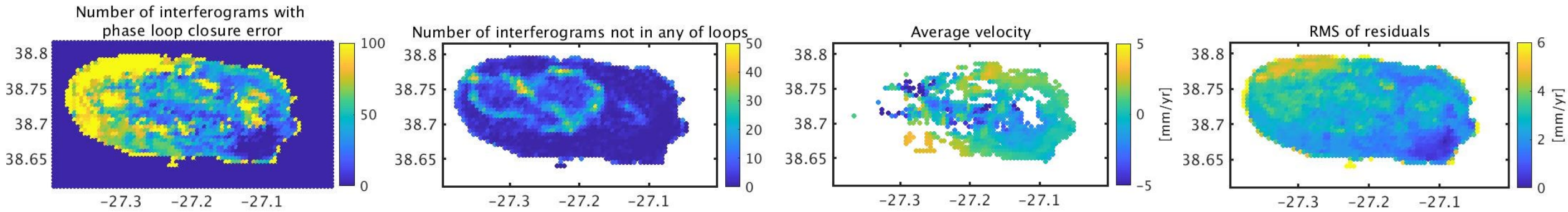


B. Spatial gaussian filtering, masking and interpolation

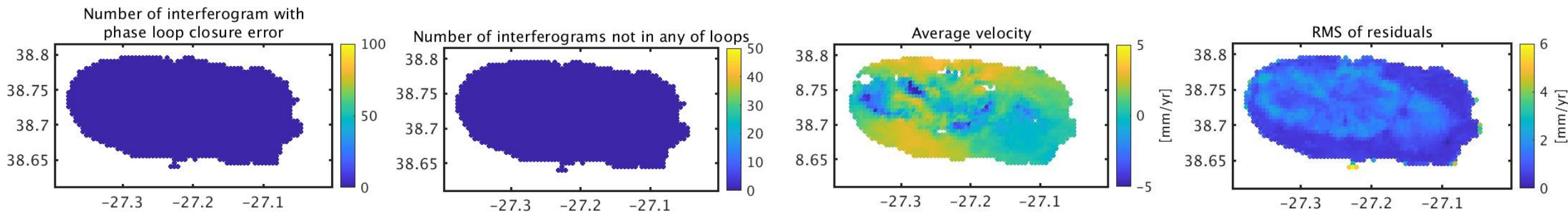
A novel algorithm for phase loop closure error check

- ❖ Identify individual pixels that fail each phase loop closure error check
- ❖ Exclude non-redundant interferograms not in any of loops for each pixel

Without pixel-wise phase loop closure error check



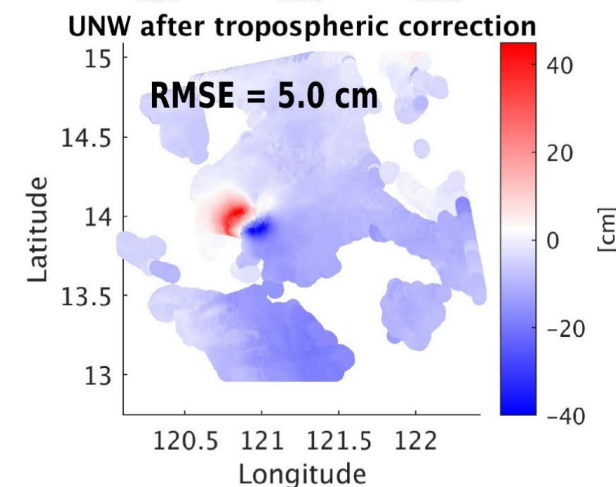
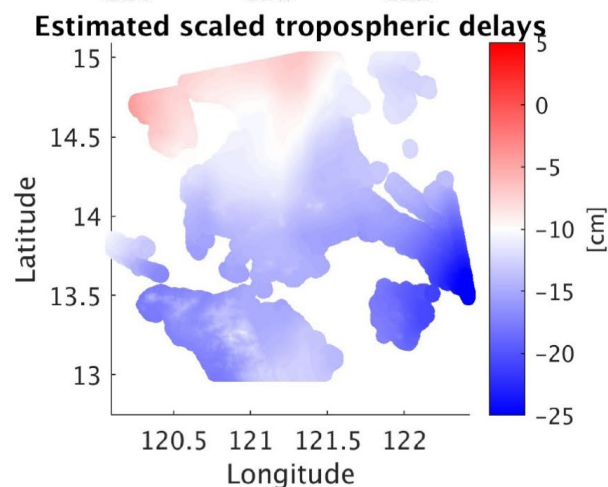
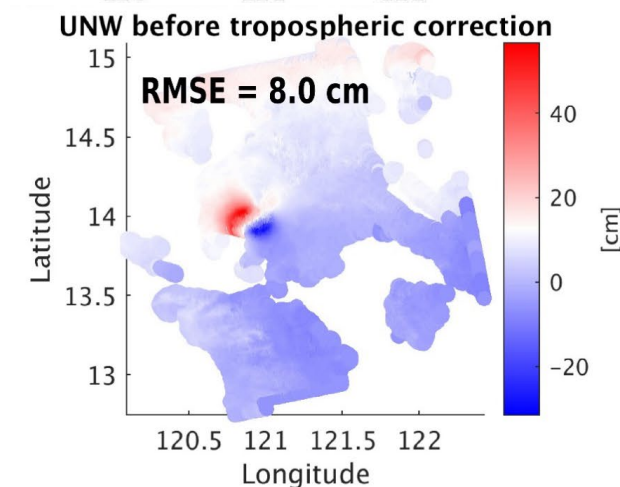
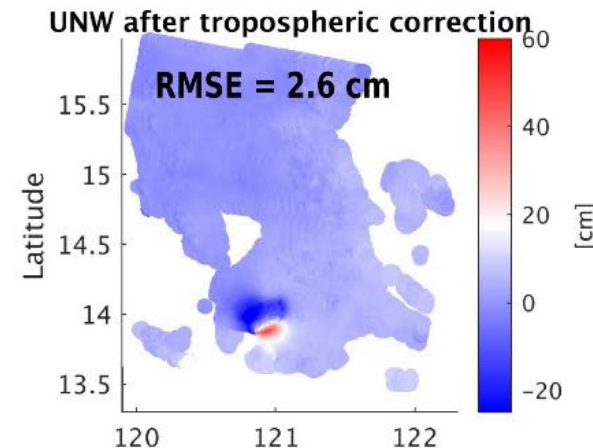
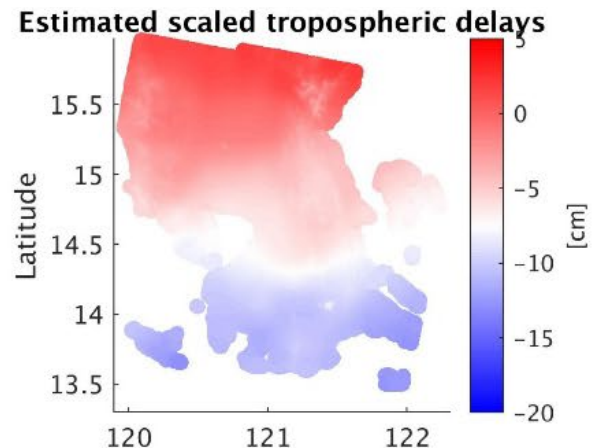
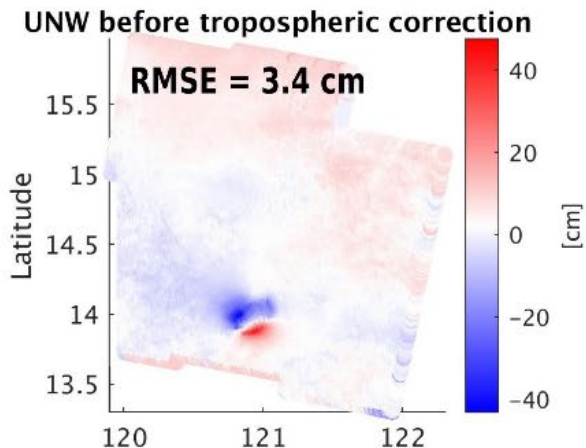
VS.



With pixel-wise phase loop closure error check

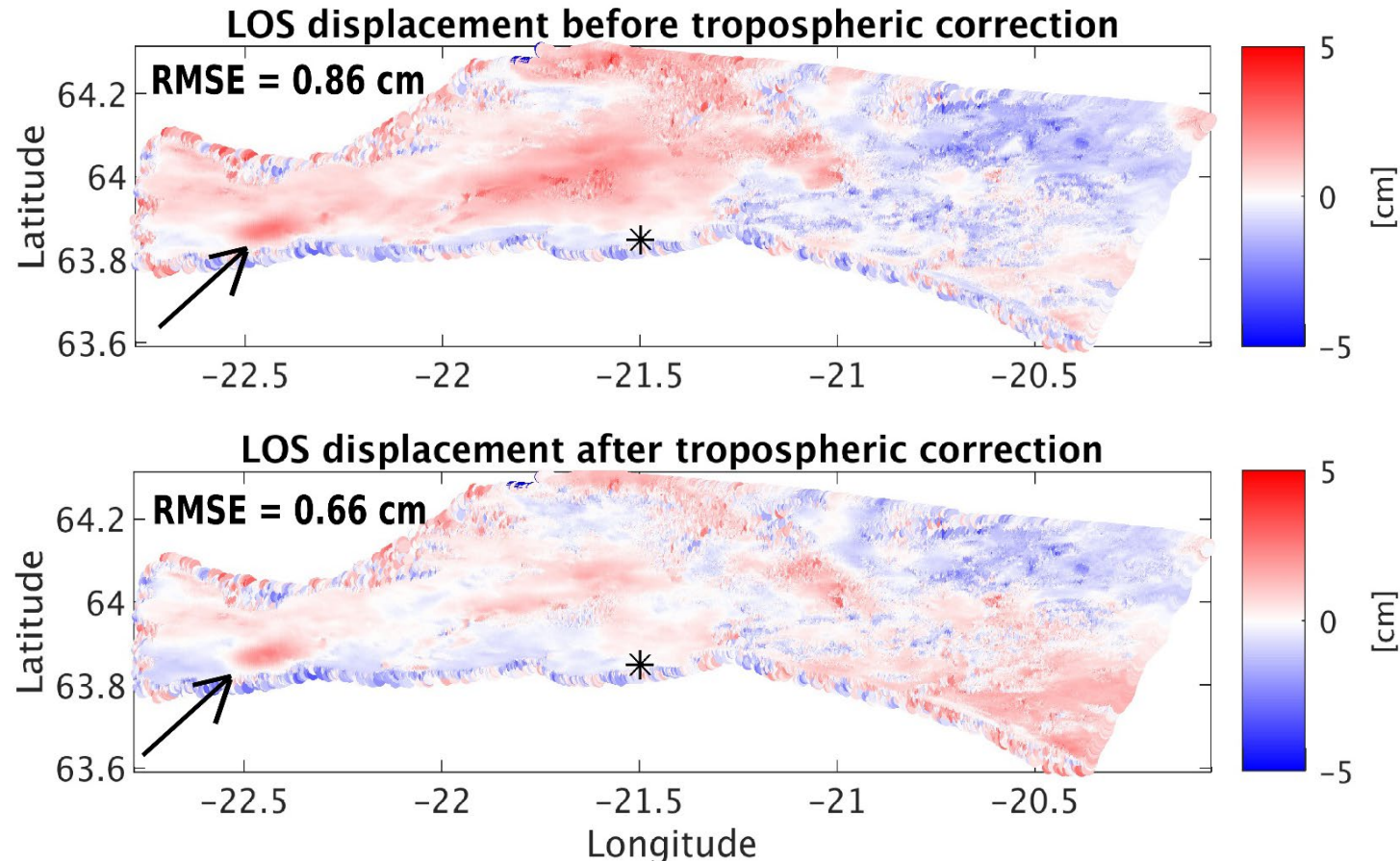
Tropospheric correction with a spatially varying scaling method - co-eruptive signals

- ❖ Use high-resolution ECMWF data to define the form of the relationship between tropospheric delay and height [Shen et al., 2019]
- ❖ Use interferometric phase to refine the interpolation of weather model data in time and space



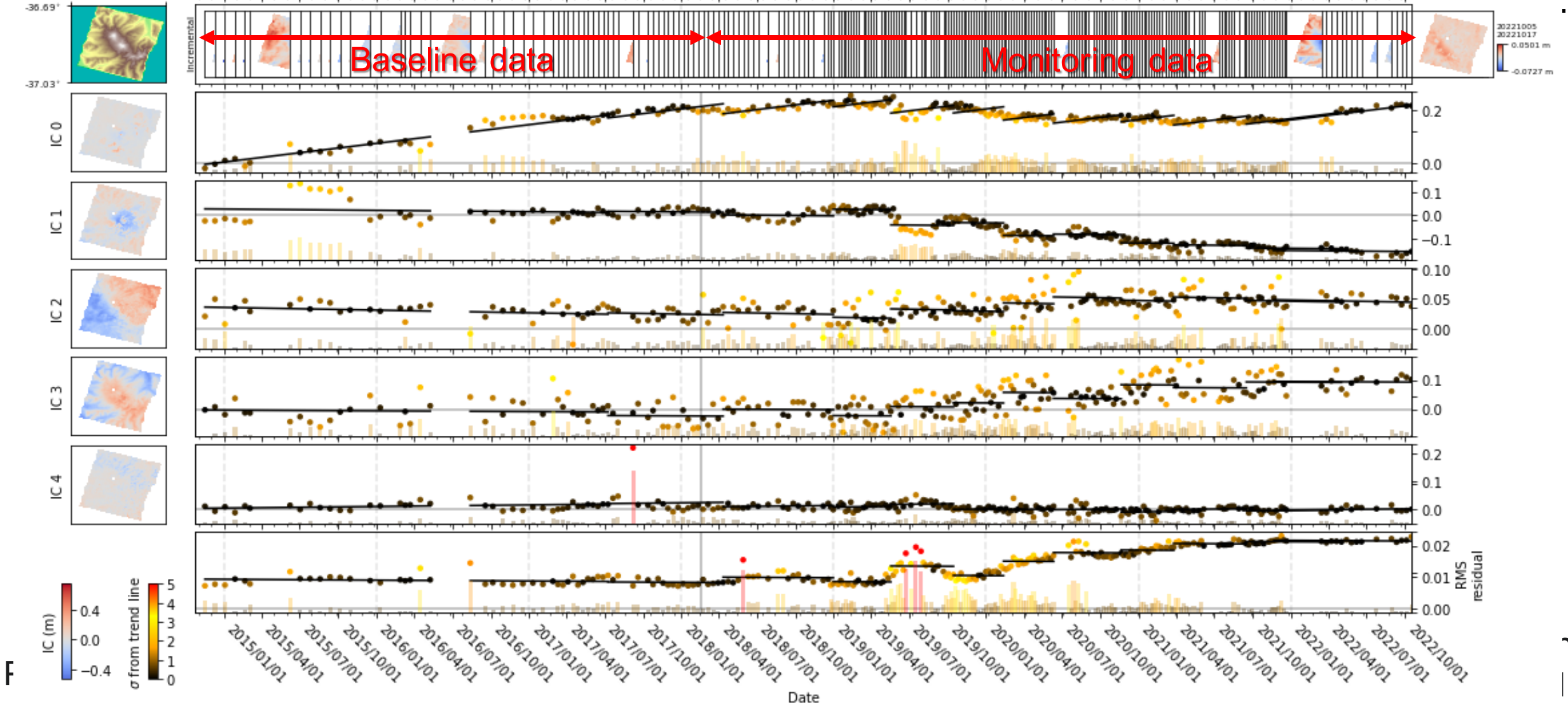
Tropospheric correction with a spatially varying scaling method - inter-eruptive signals

- ❖ Use high-resolution ECMWF data to define the form of the relationship between tropospheric delay and height [Shen et al., 2019]
- ❖ Use interferometric phase to refine the interpolation of weather model data in time and space

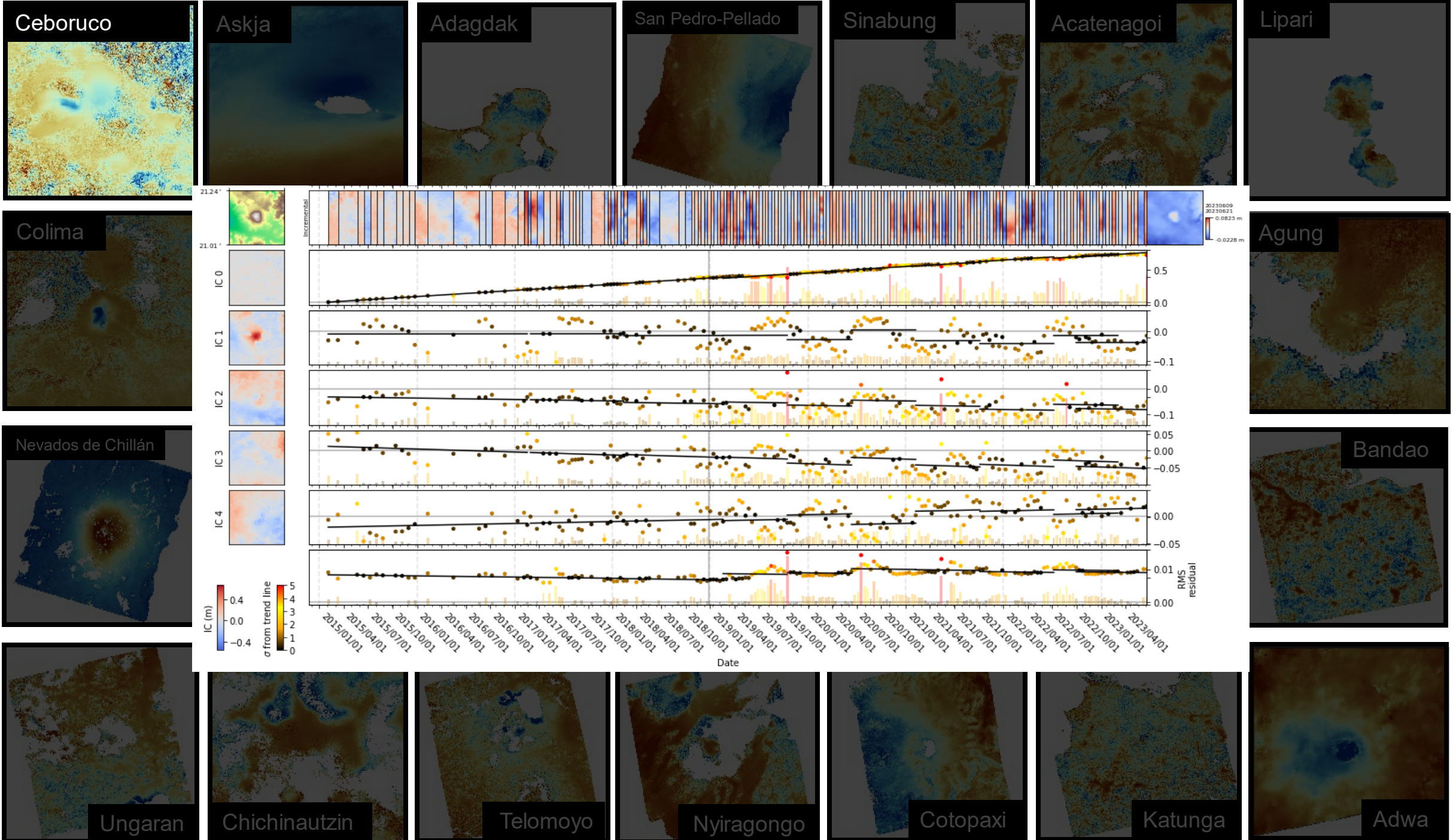


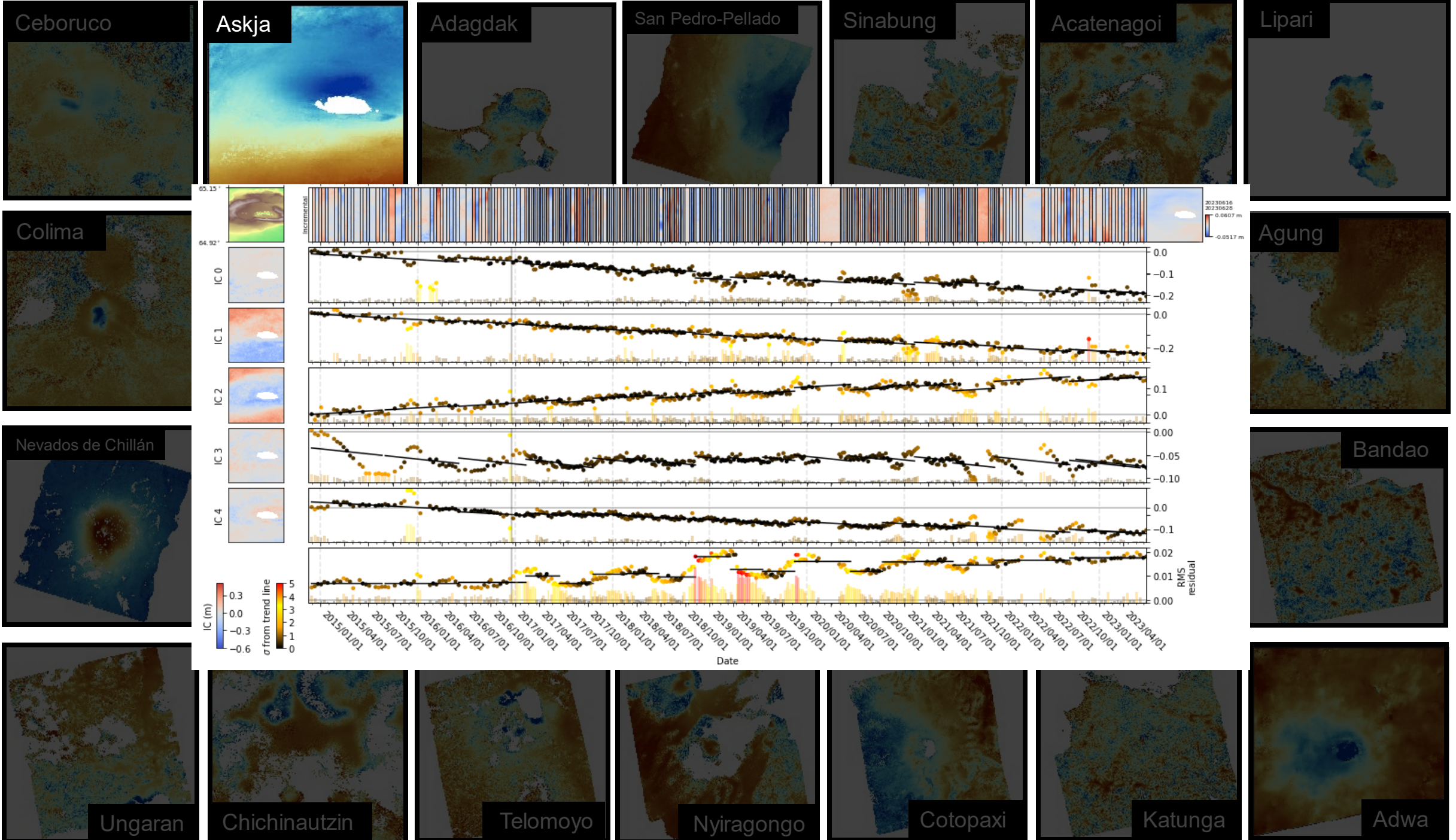
Automatic detection of changes in deformation signals using independent component analysis

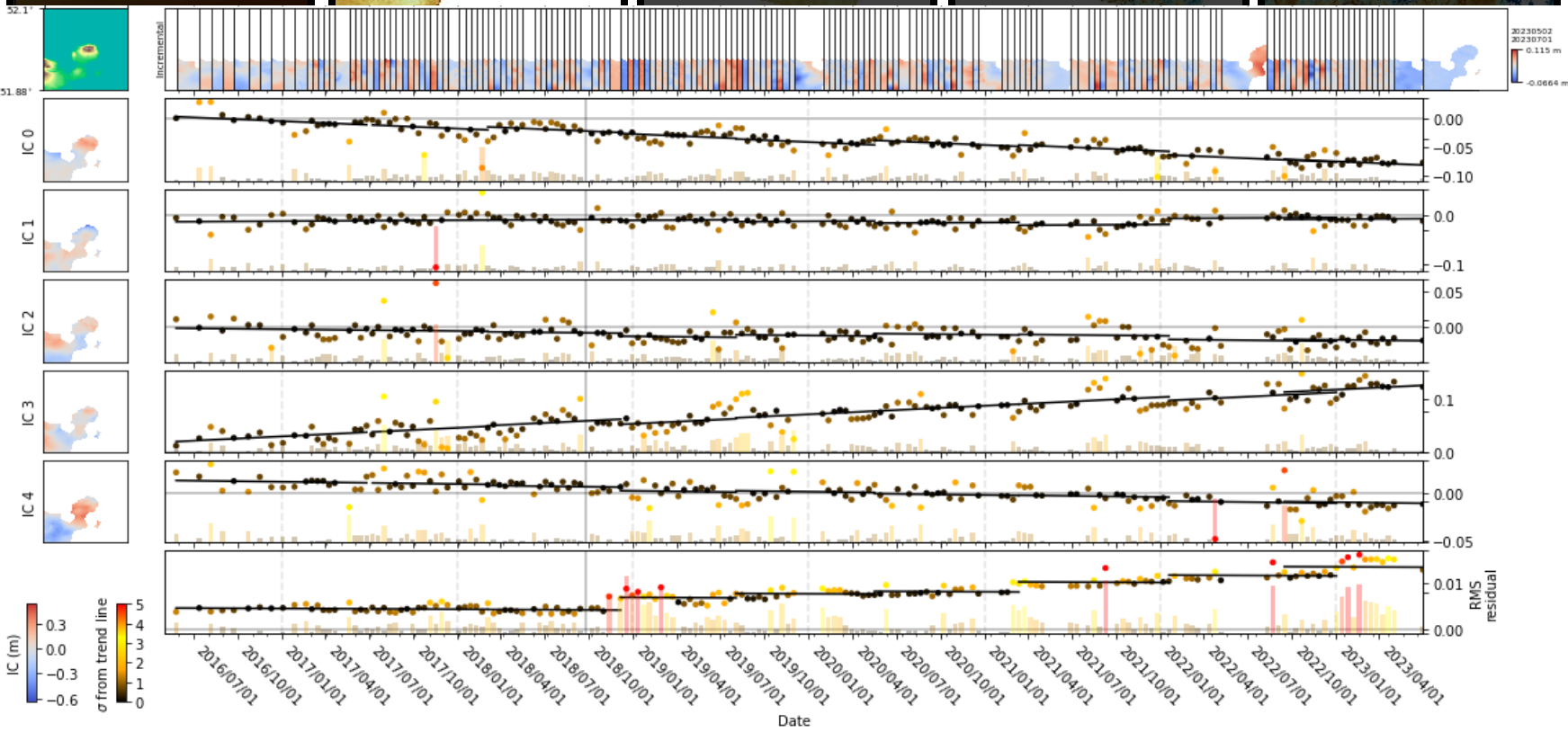
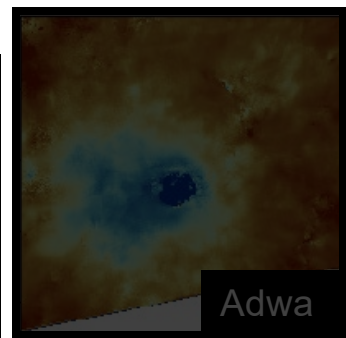
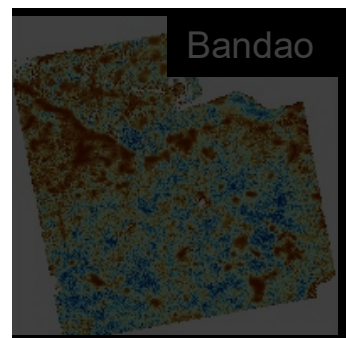
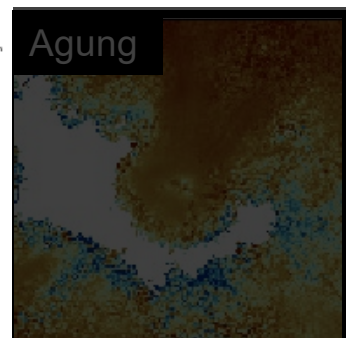
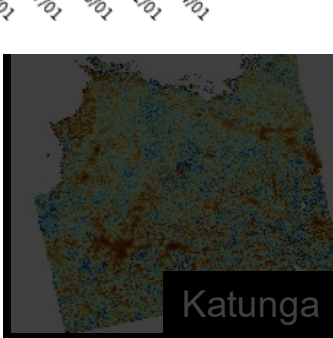
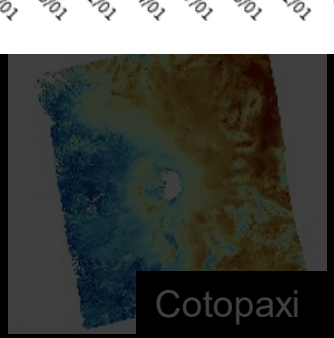
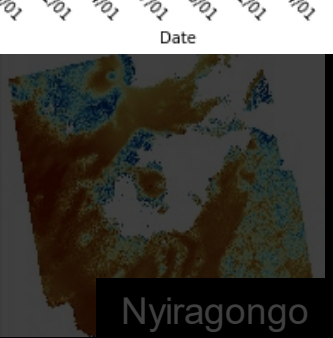
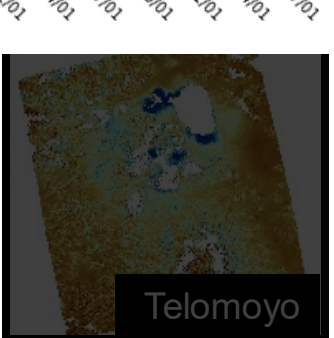
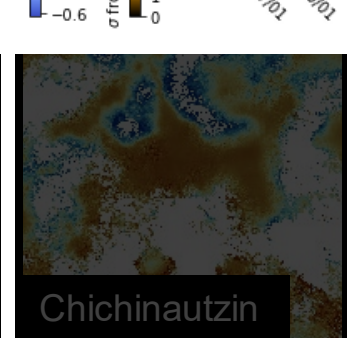
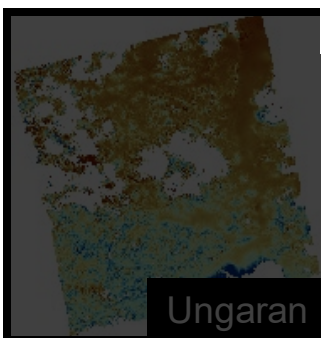
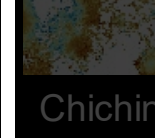
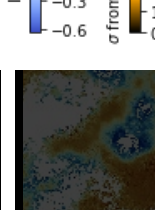
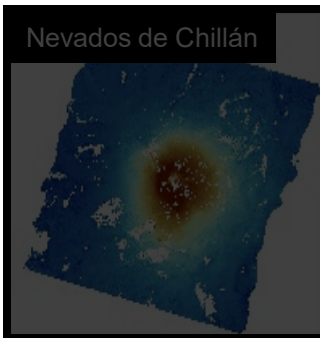
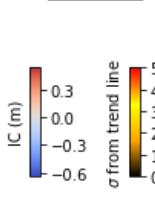
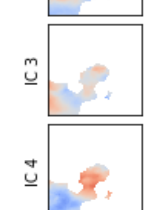
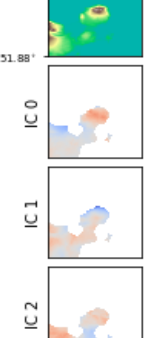
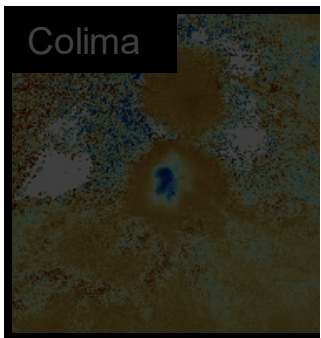
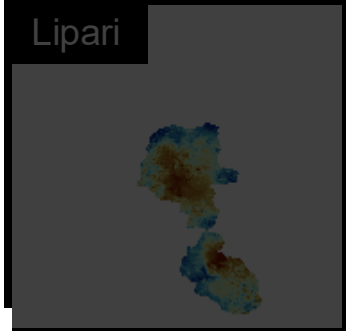
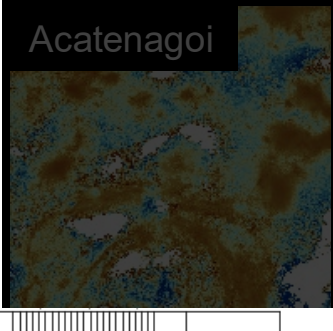
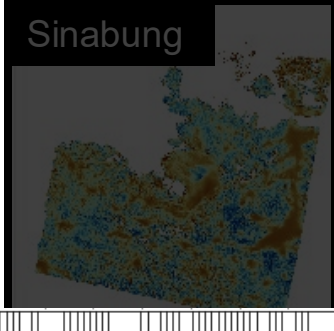
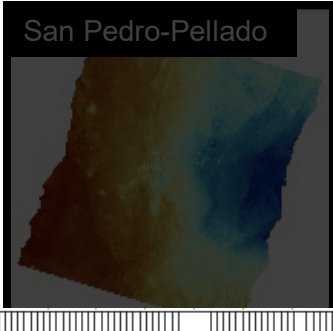
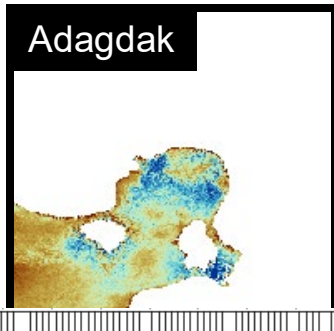
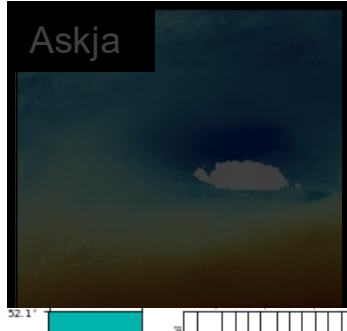
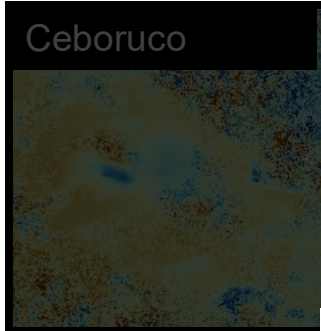
Clustering and manifold learning results of displacement time series using LICSA-Met [Cadedo et al., 2022]

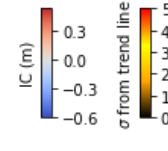
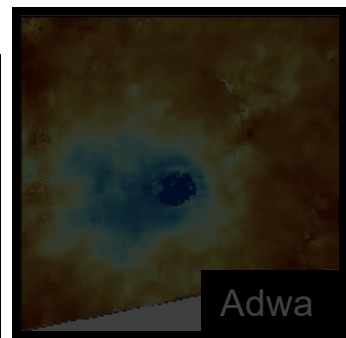
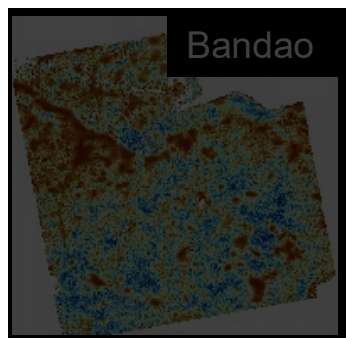
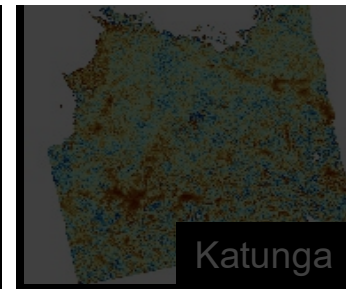
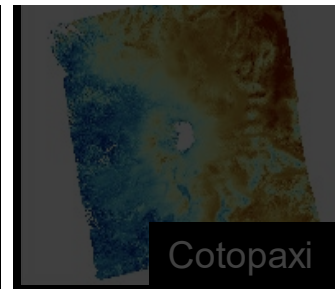
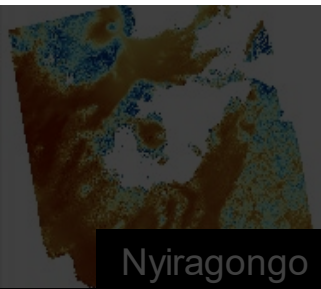
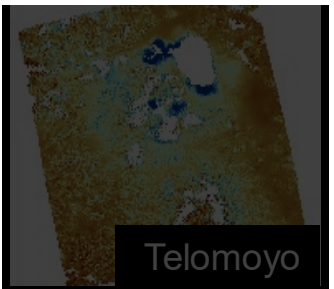
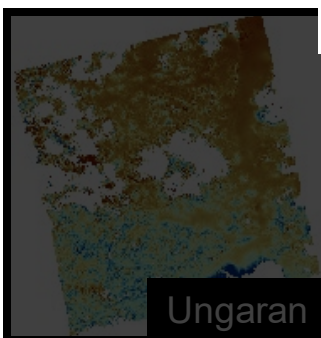
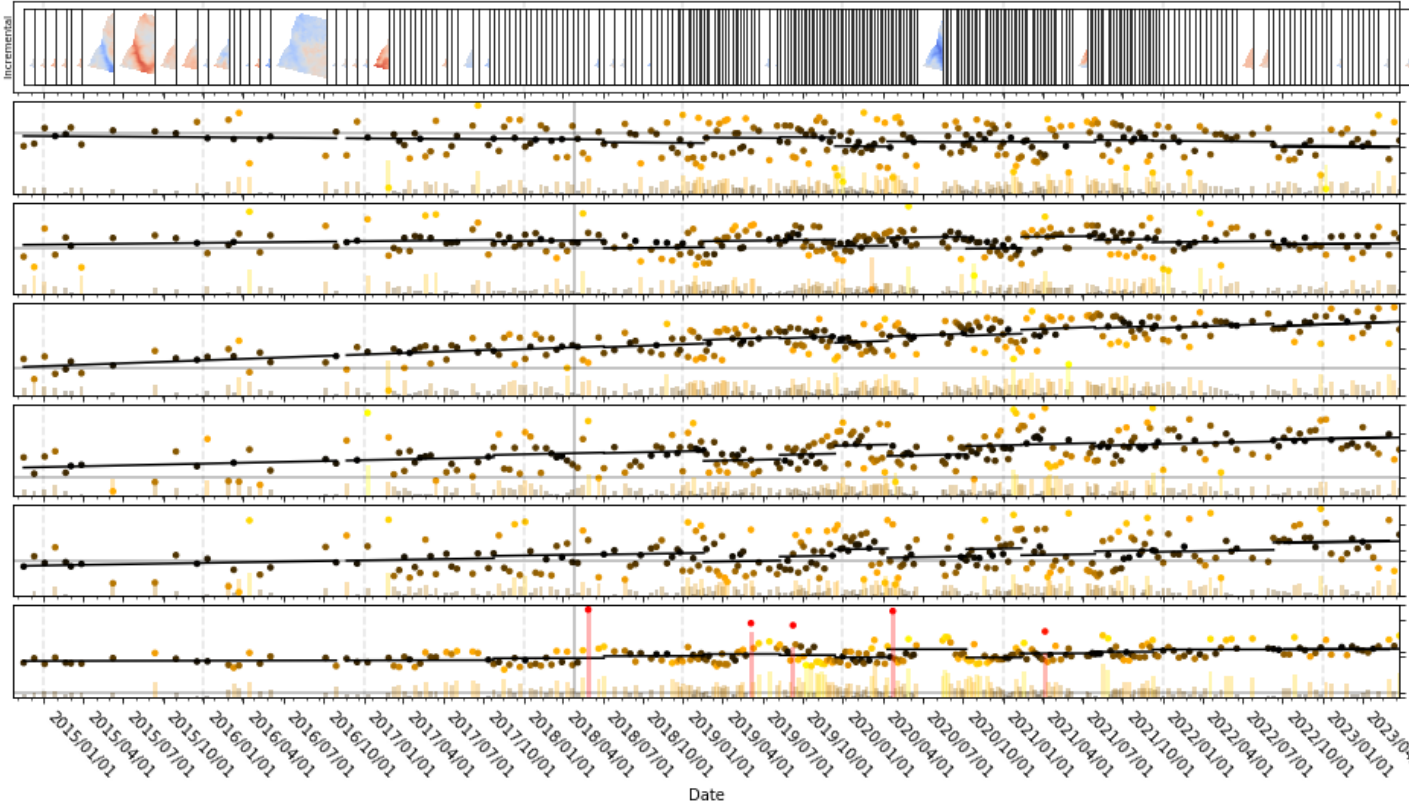
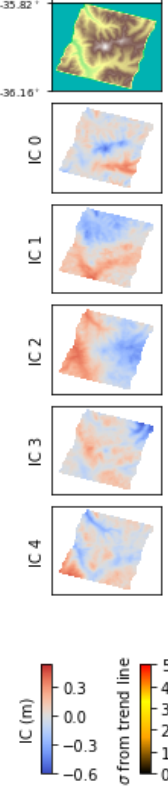
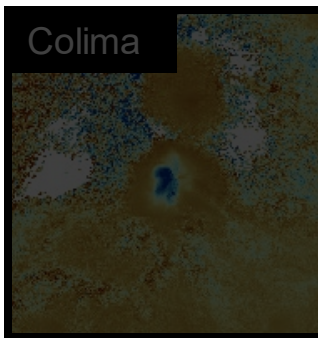
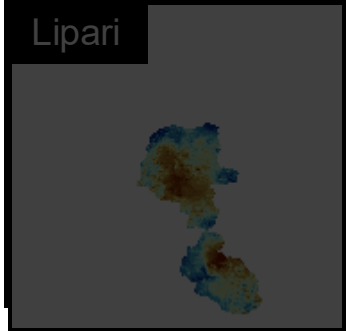
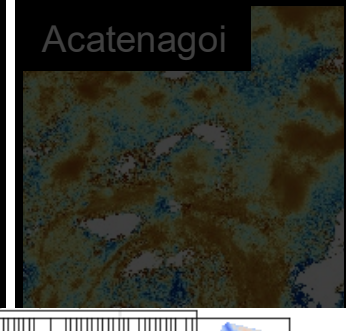
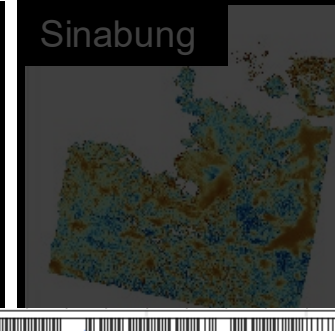
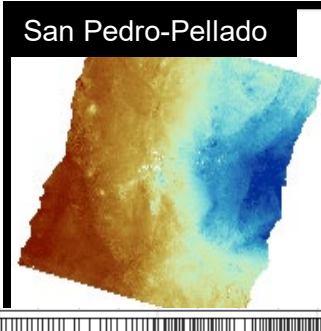
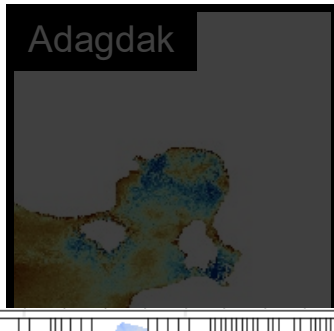
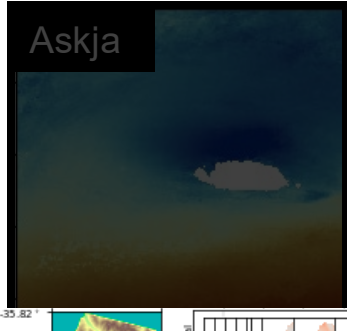
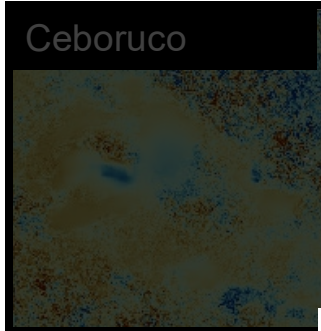


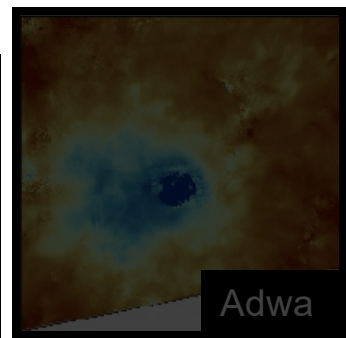
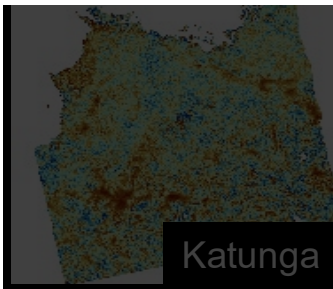
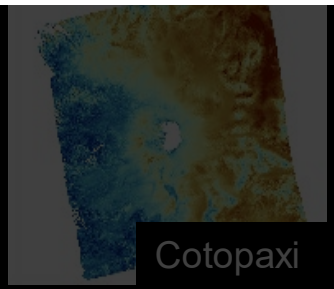
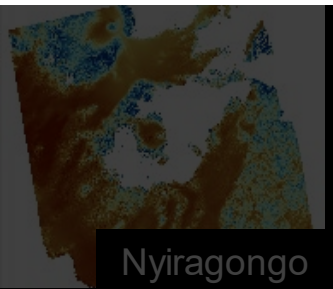
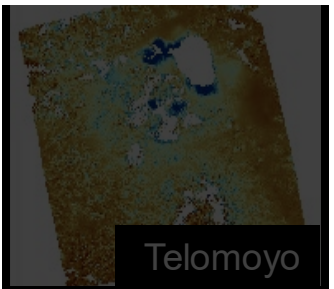
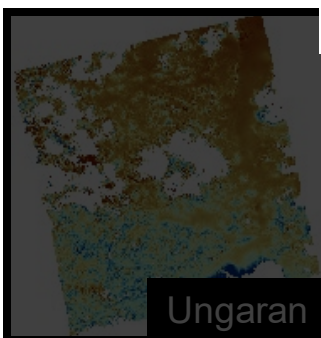
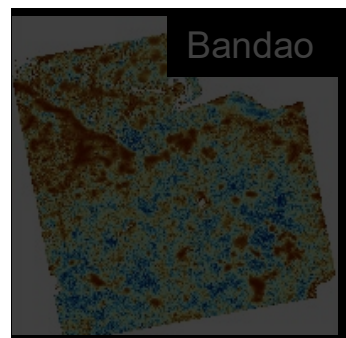
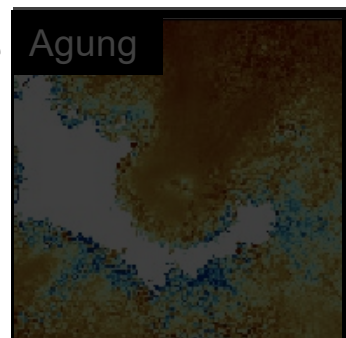
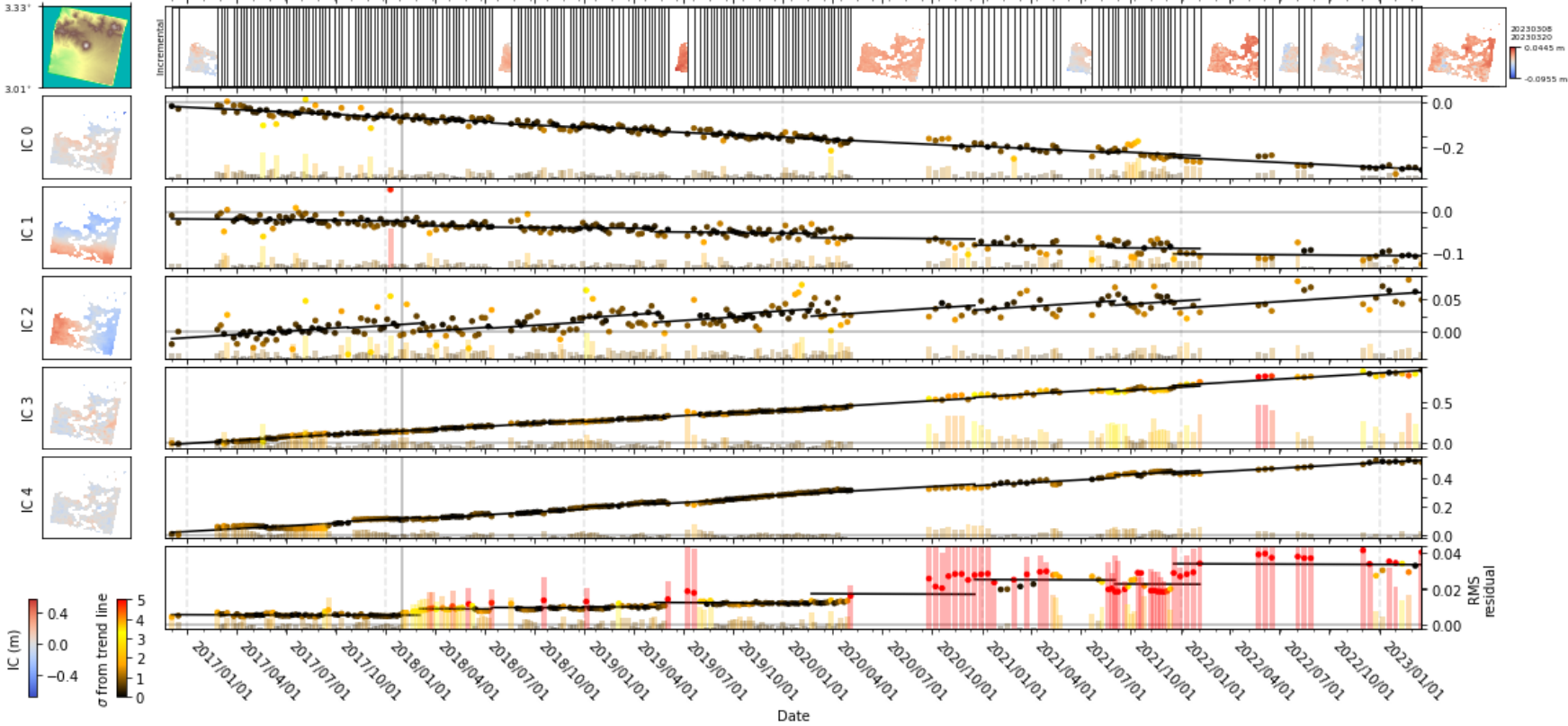
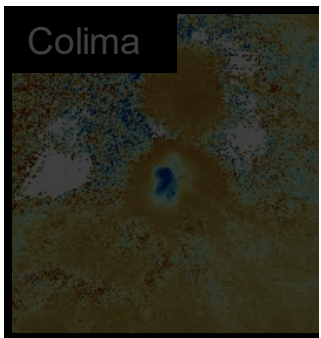
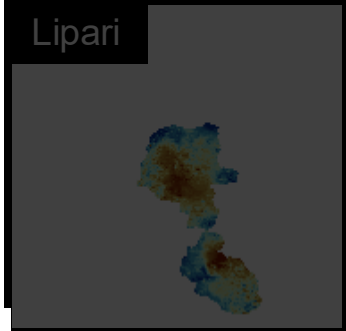
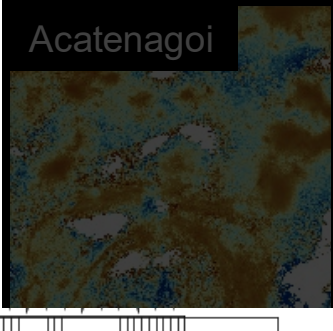
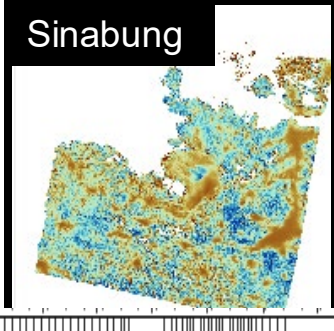
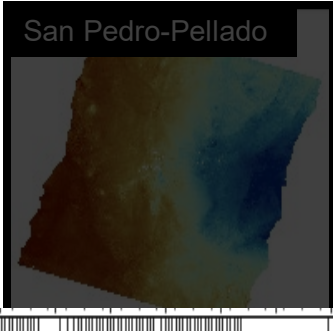
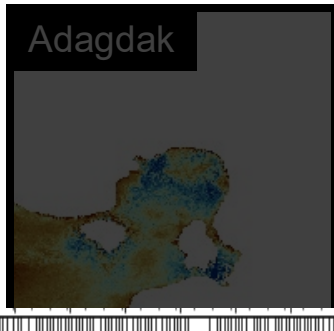
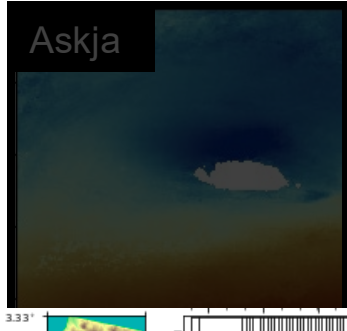
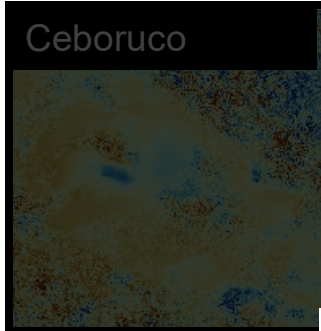
Distributed stochastic neighbor embedding

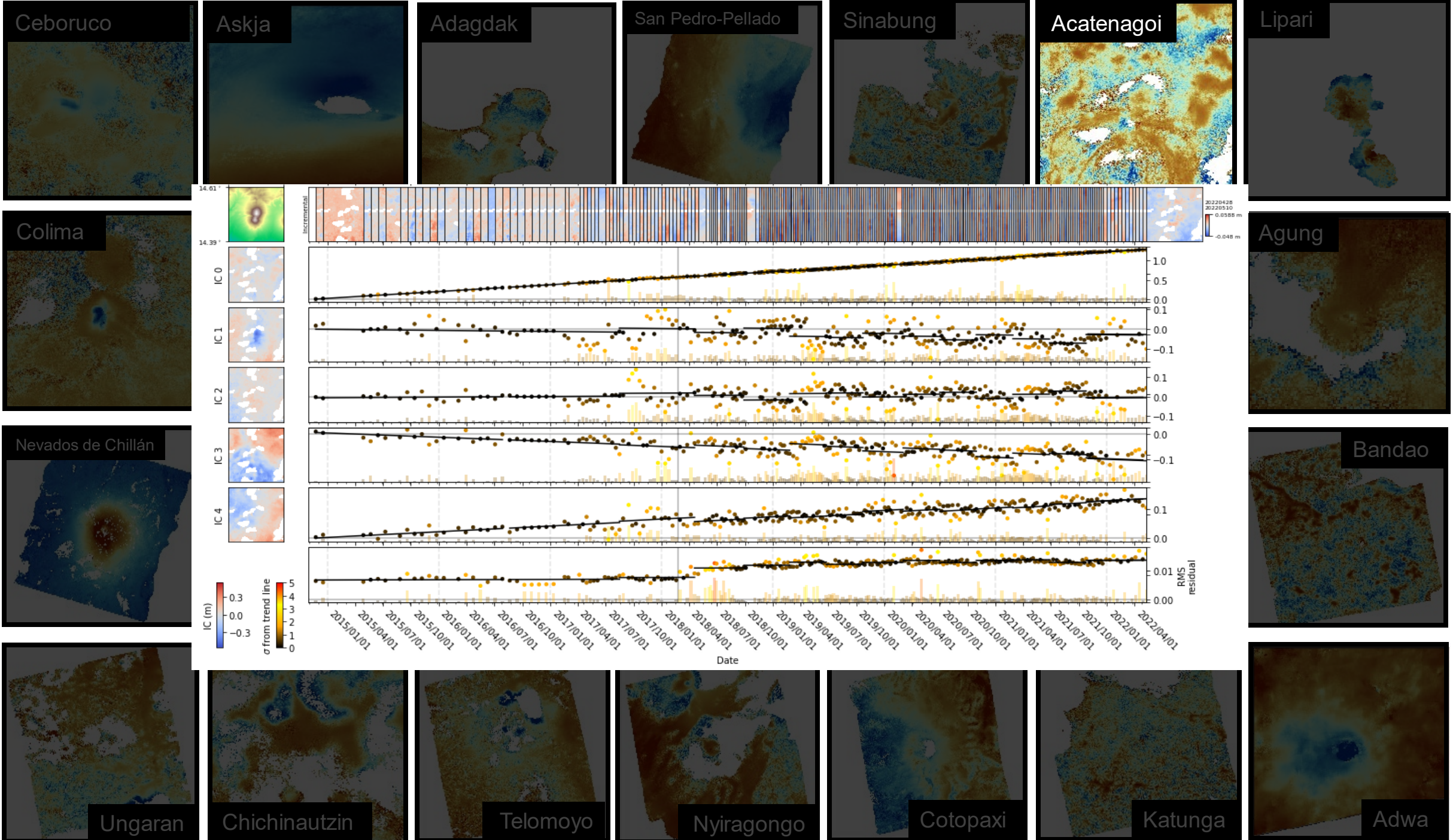


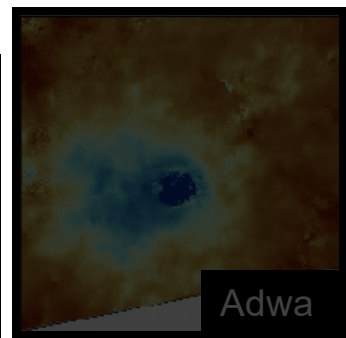
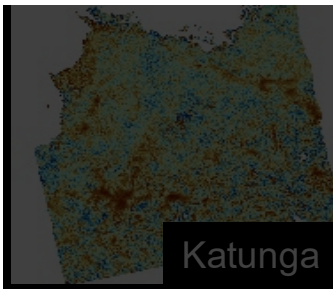
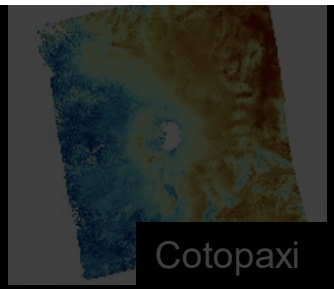
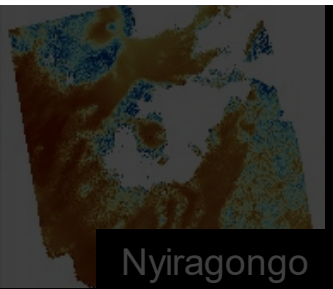
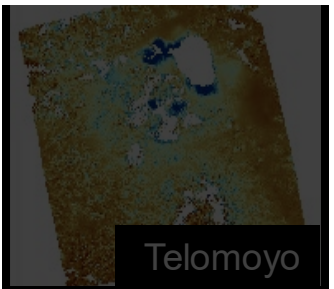
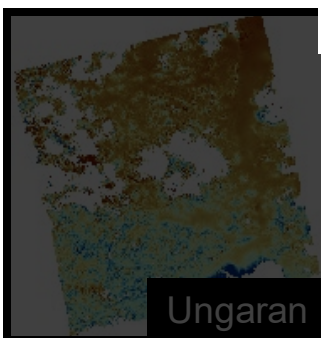
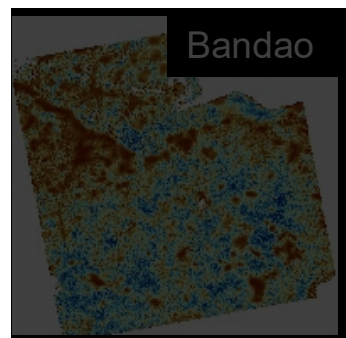
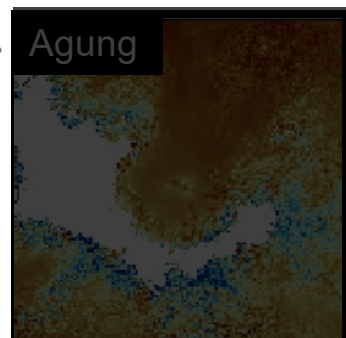
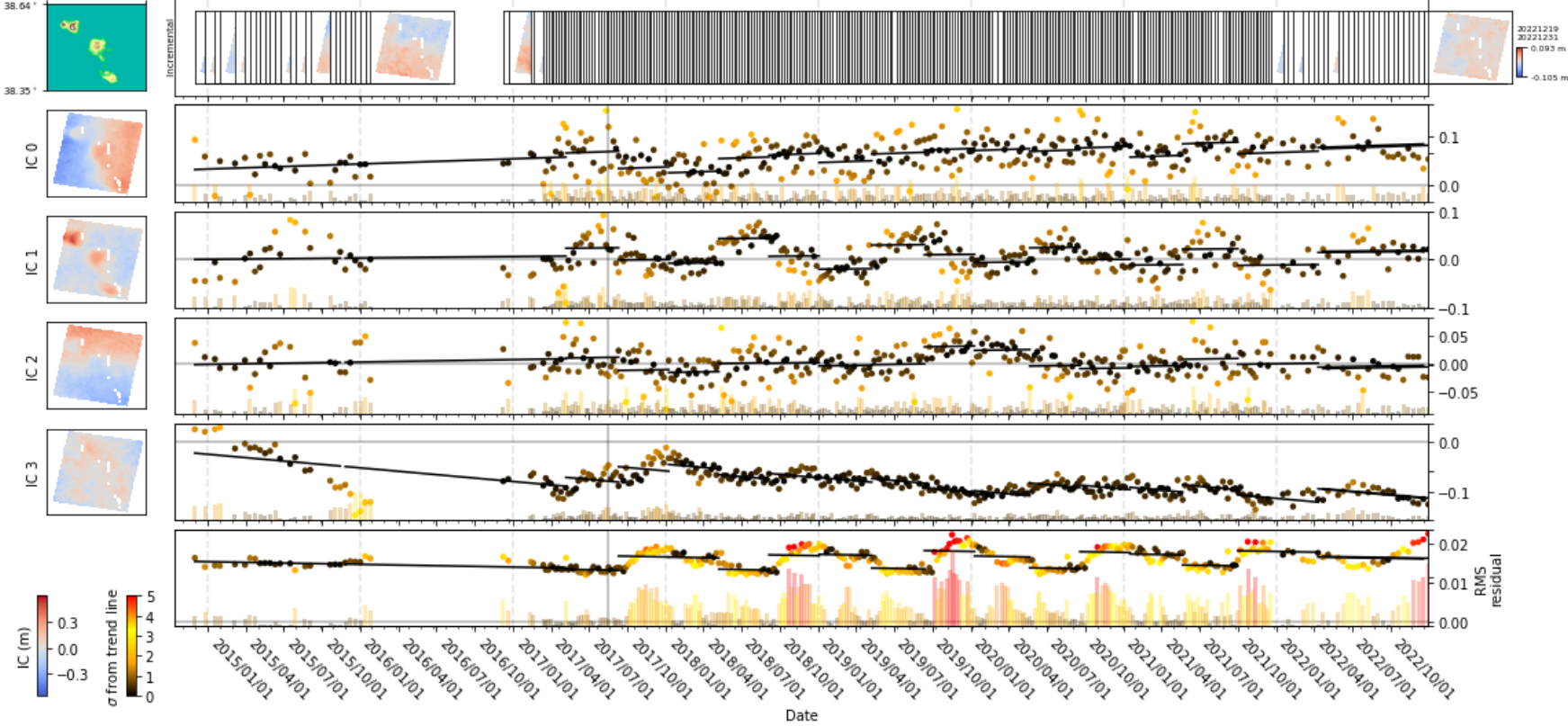
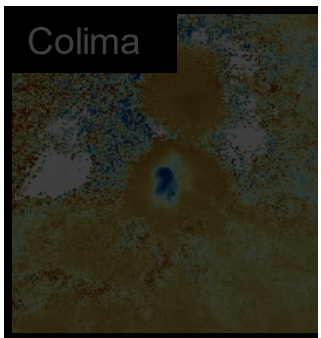
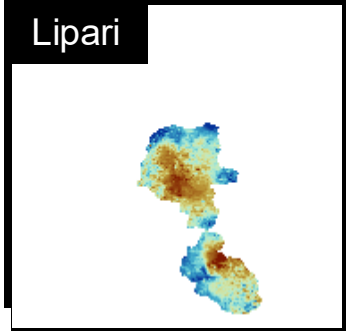
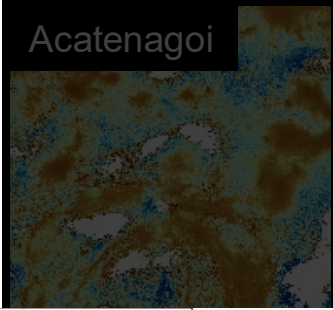
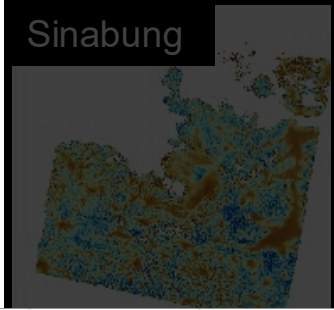
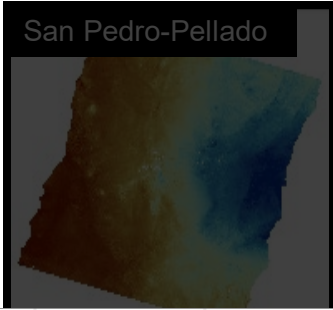
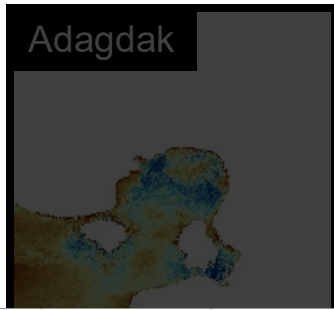
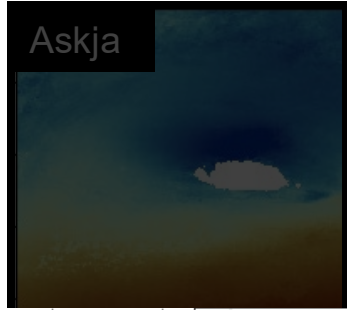
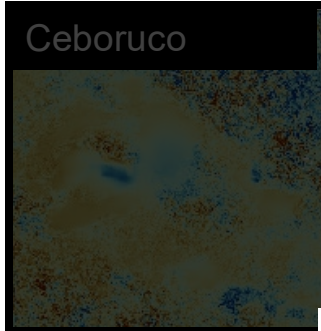


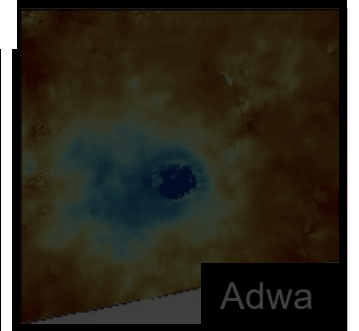
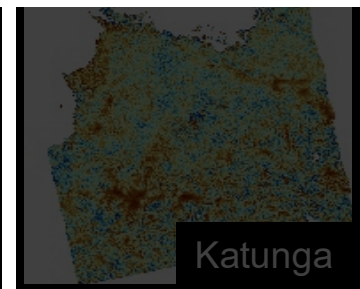
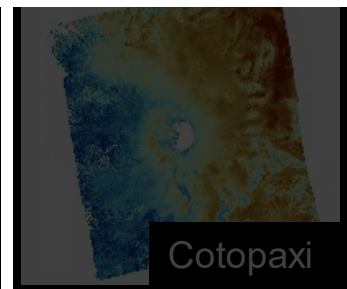
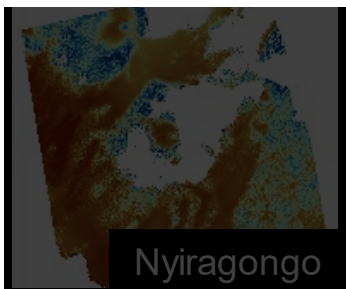
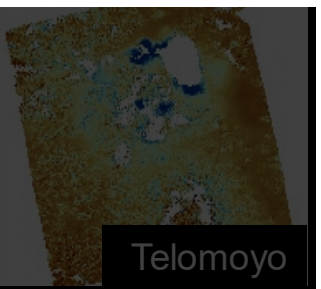
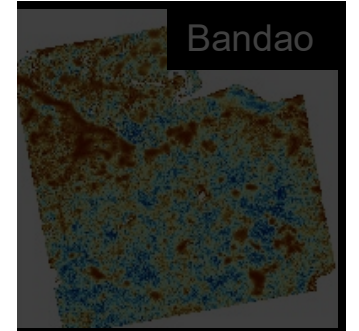
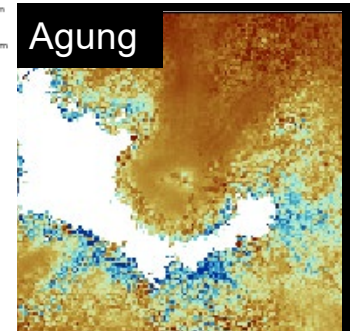
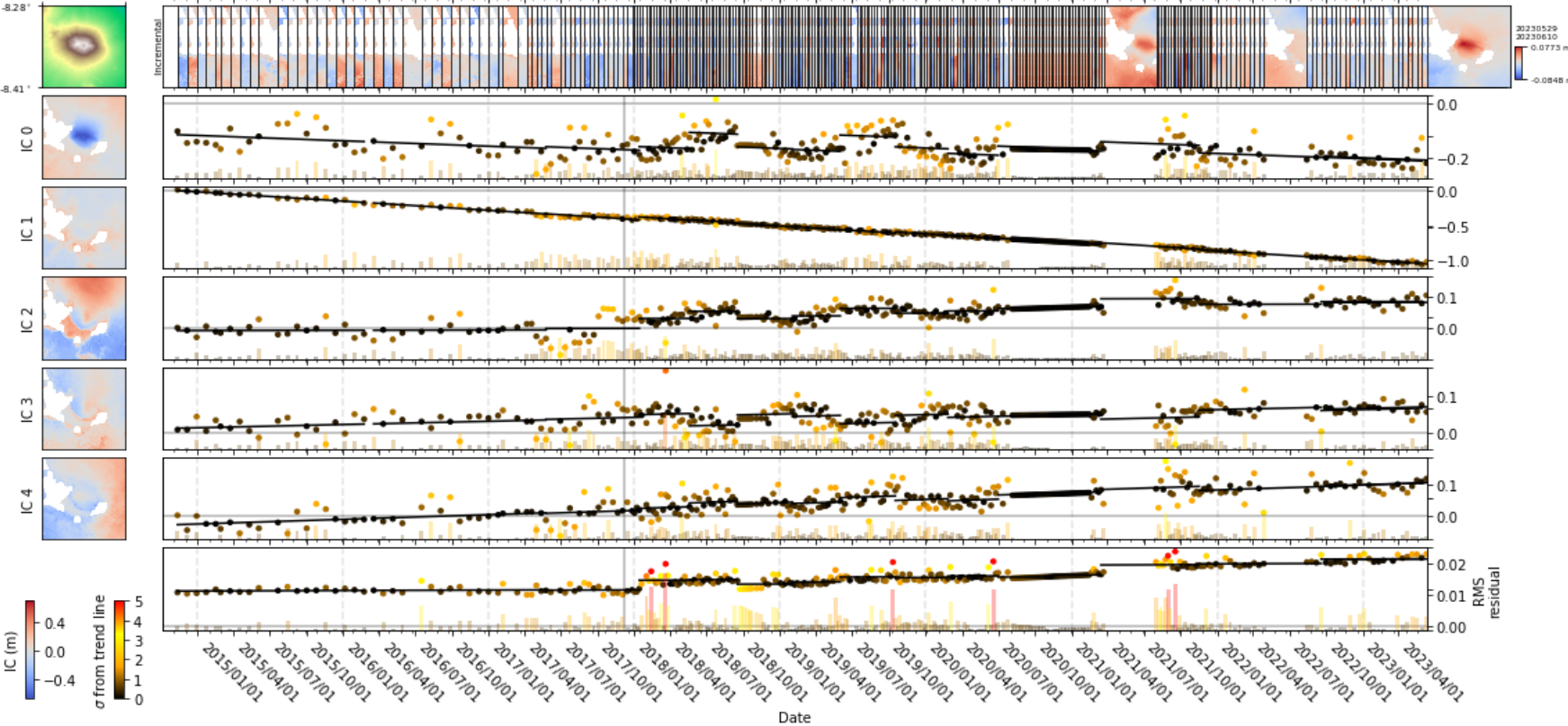
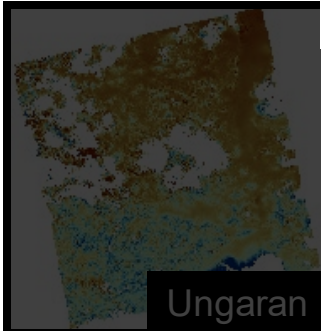
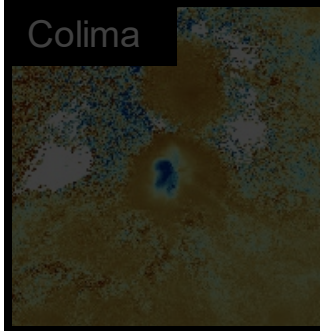
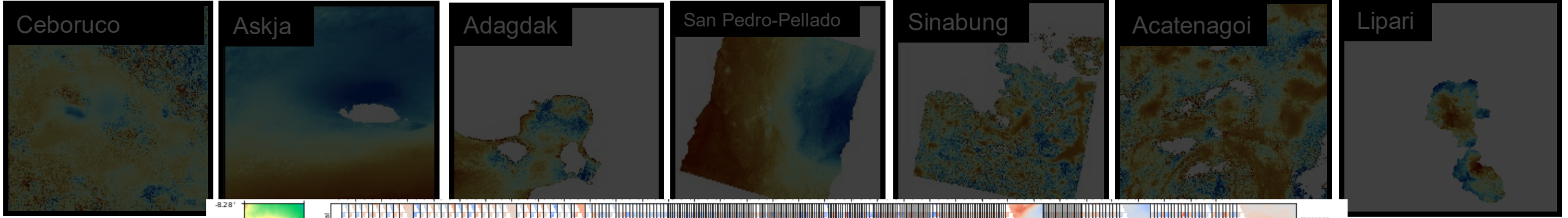


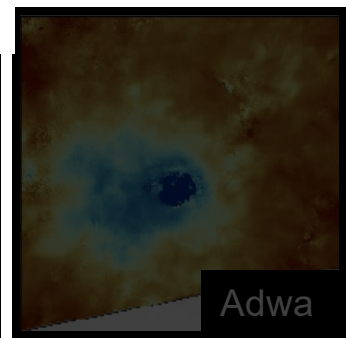
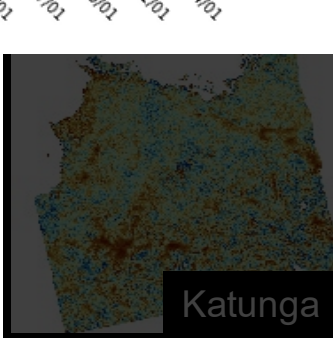
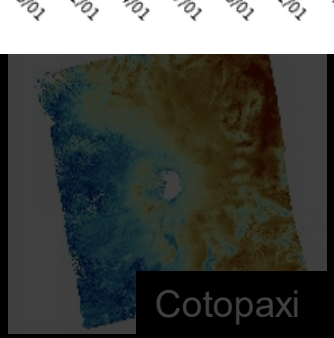
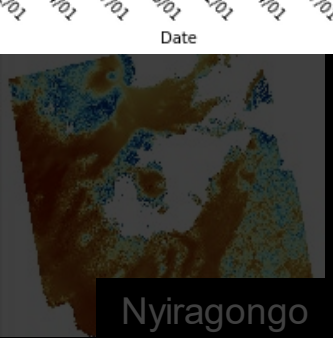
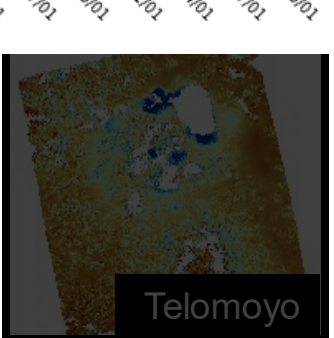
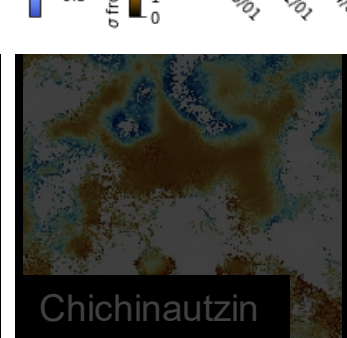
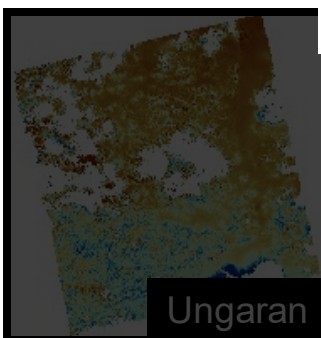
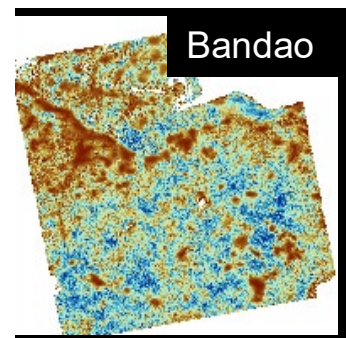
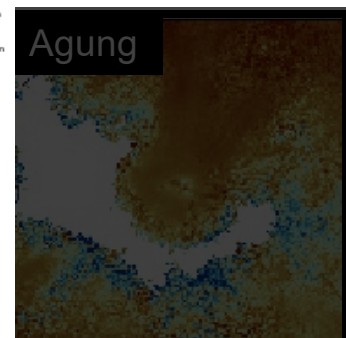
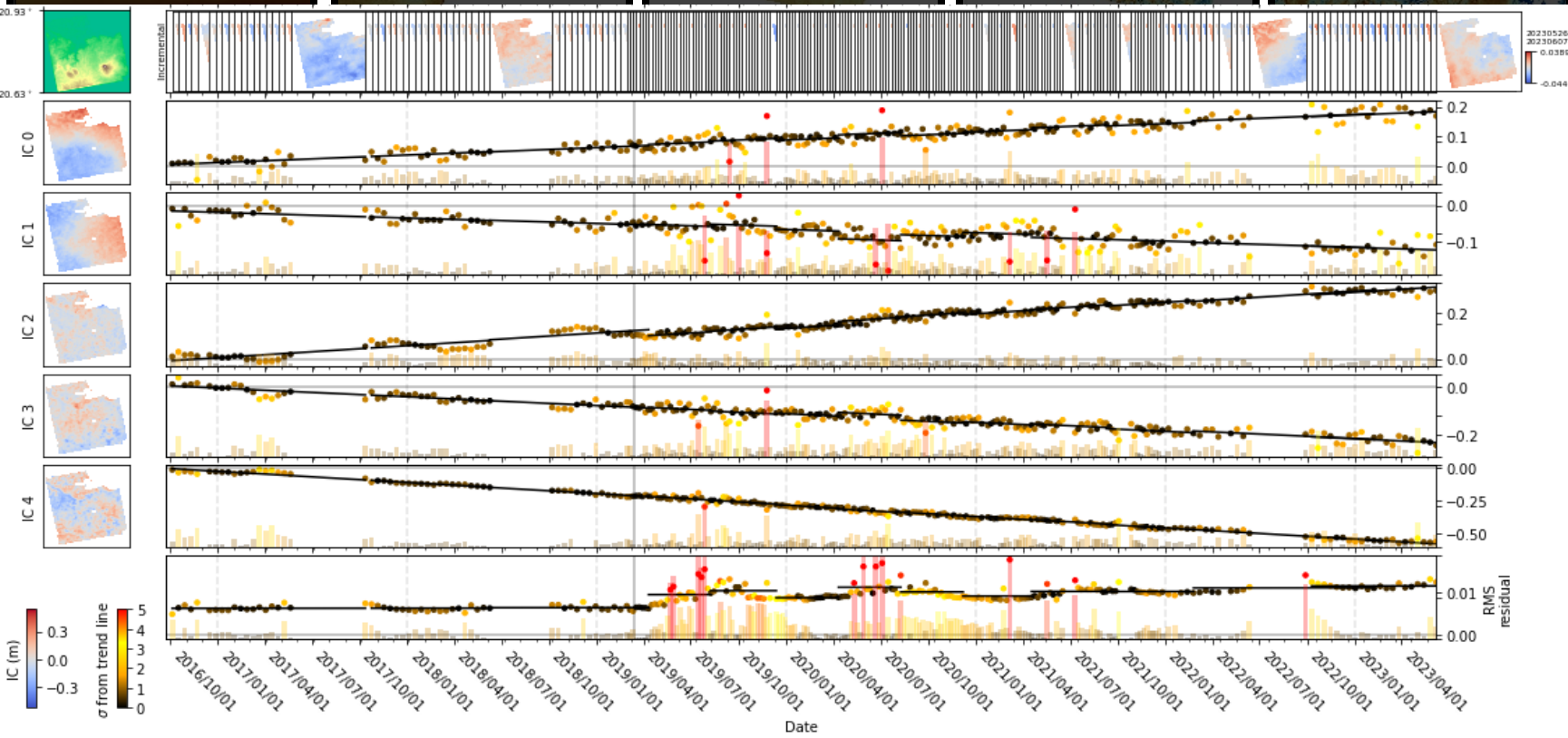
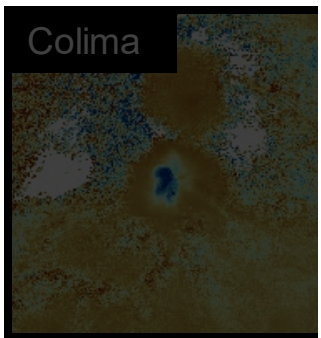
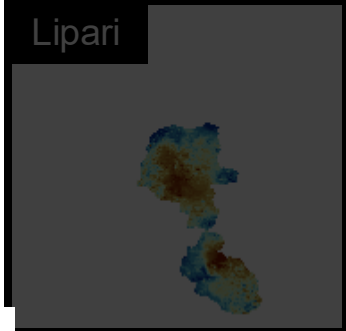
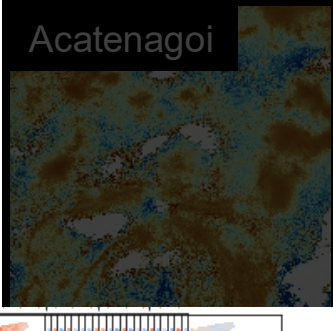
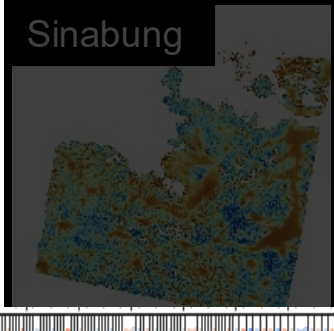
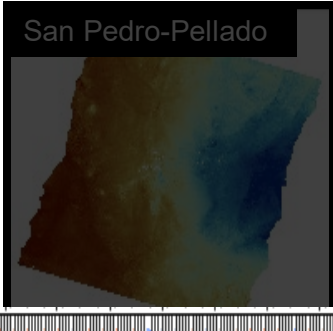
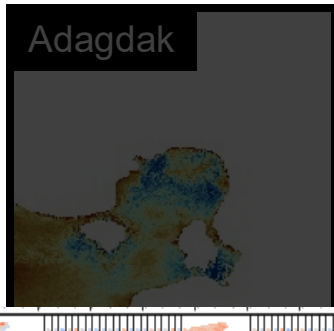
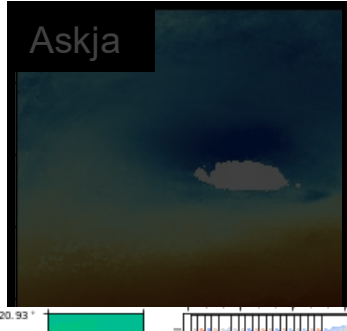
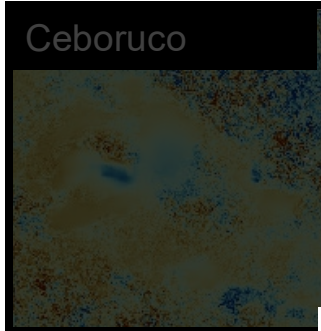


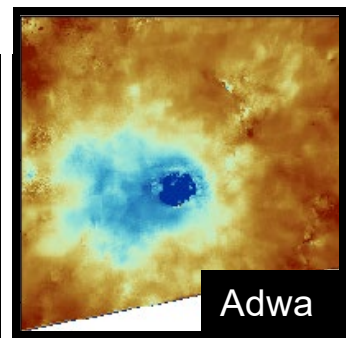
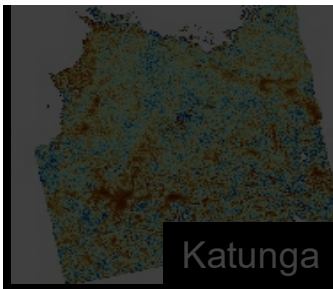
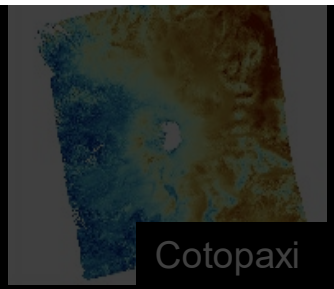
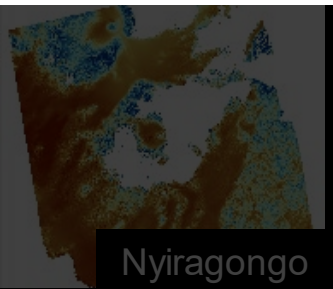
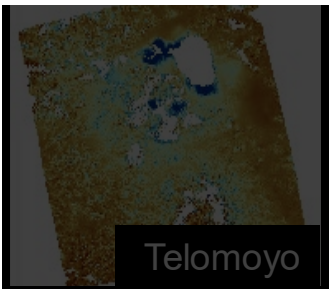
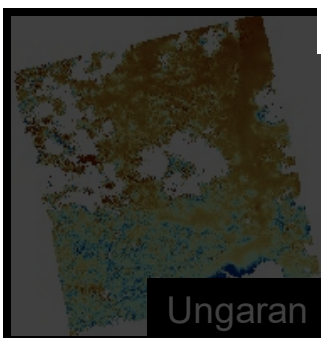
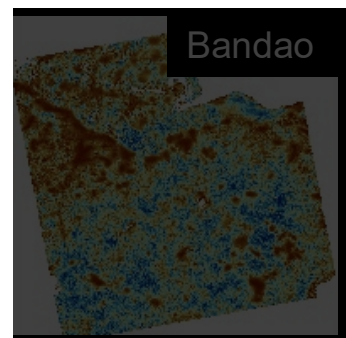
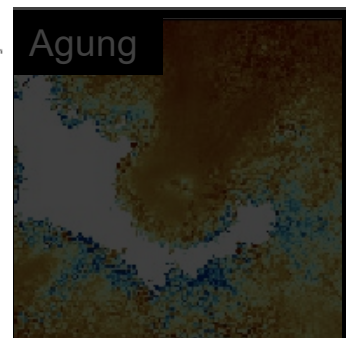
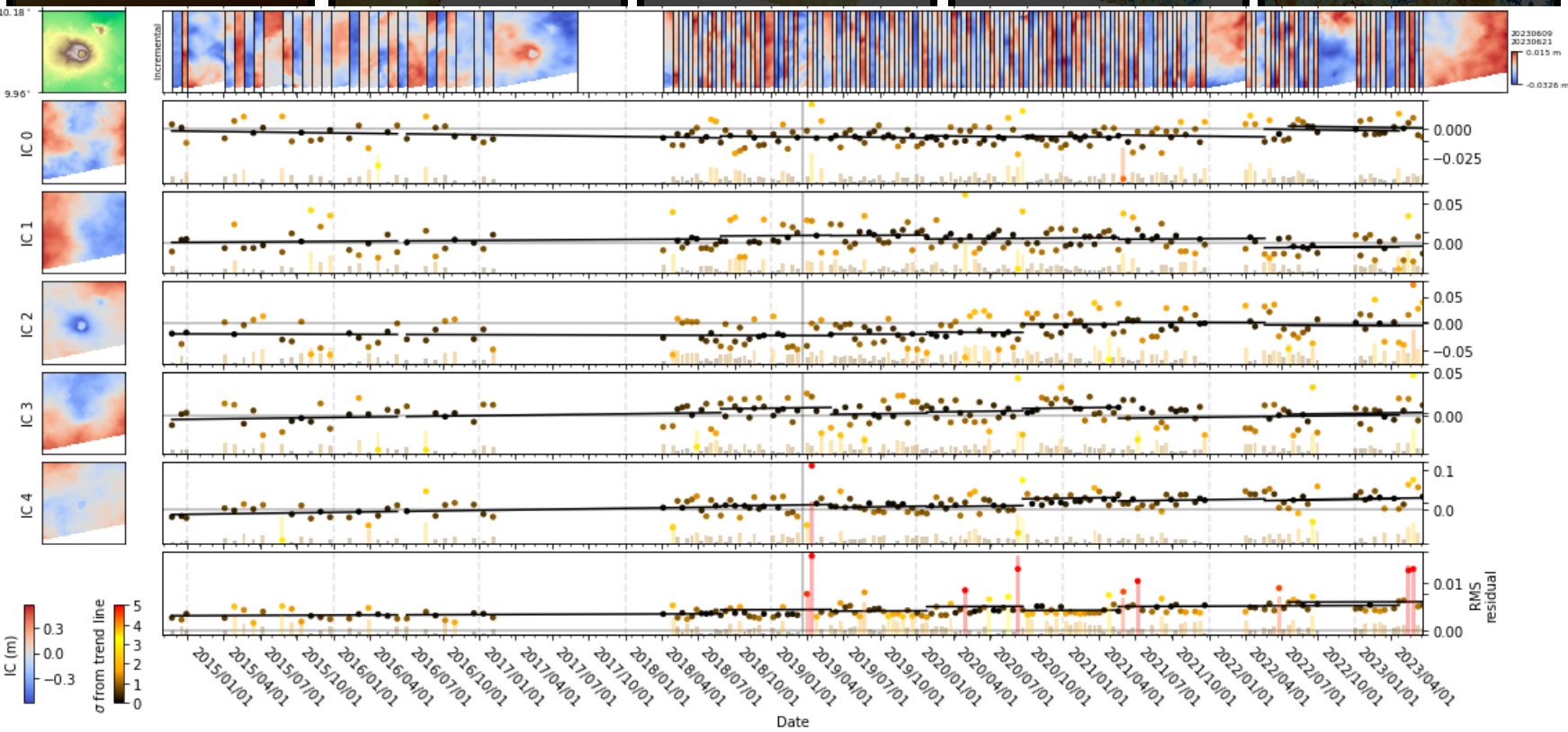
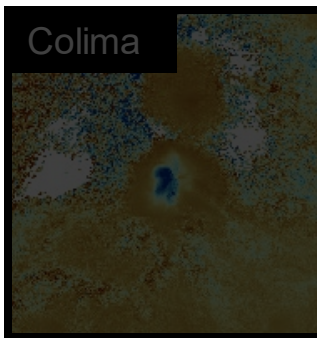
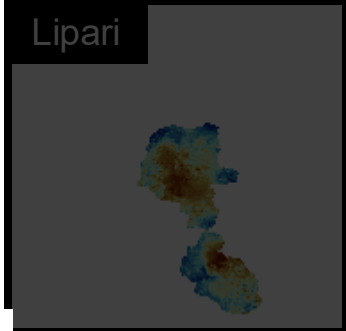
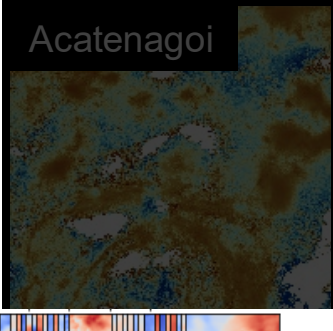
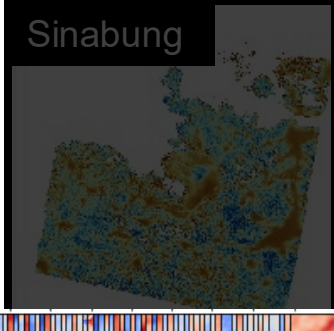
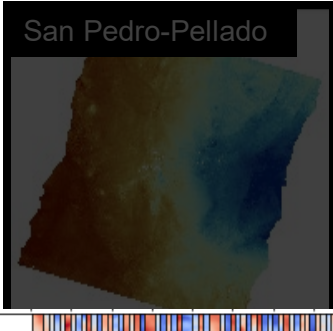
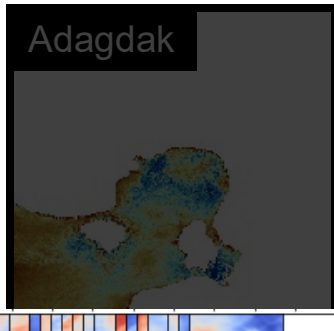
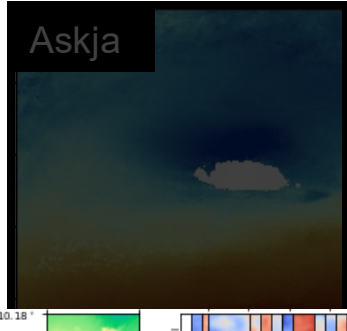
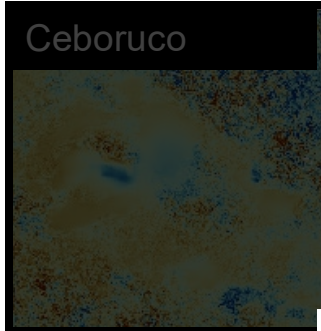


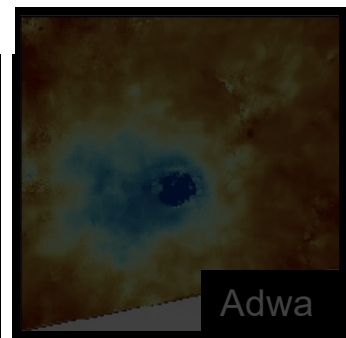
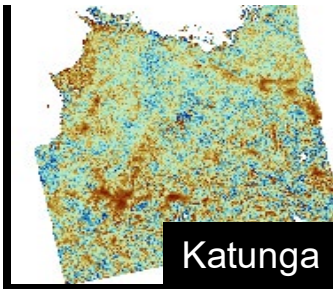
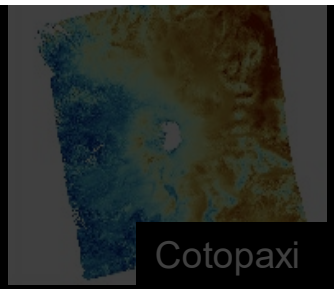
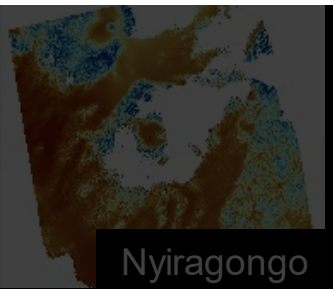
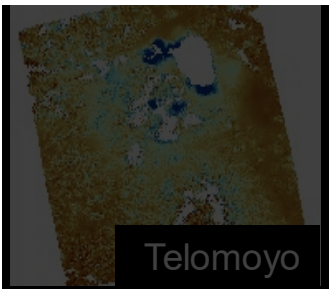
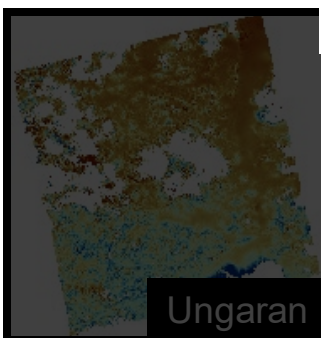
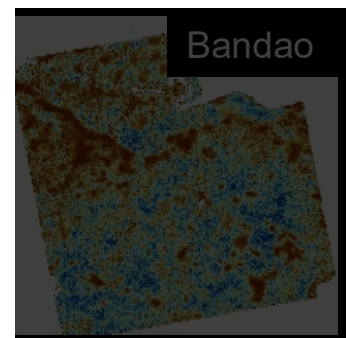
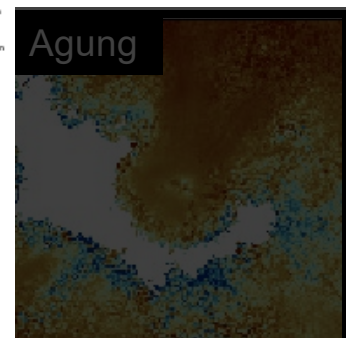
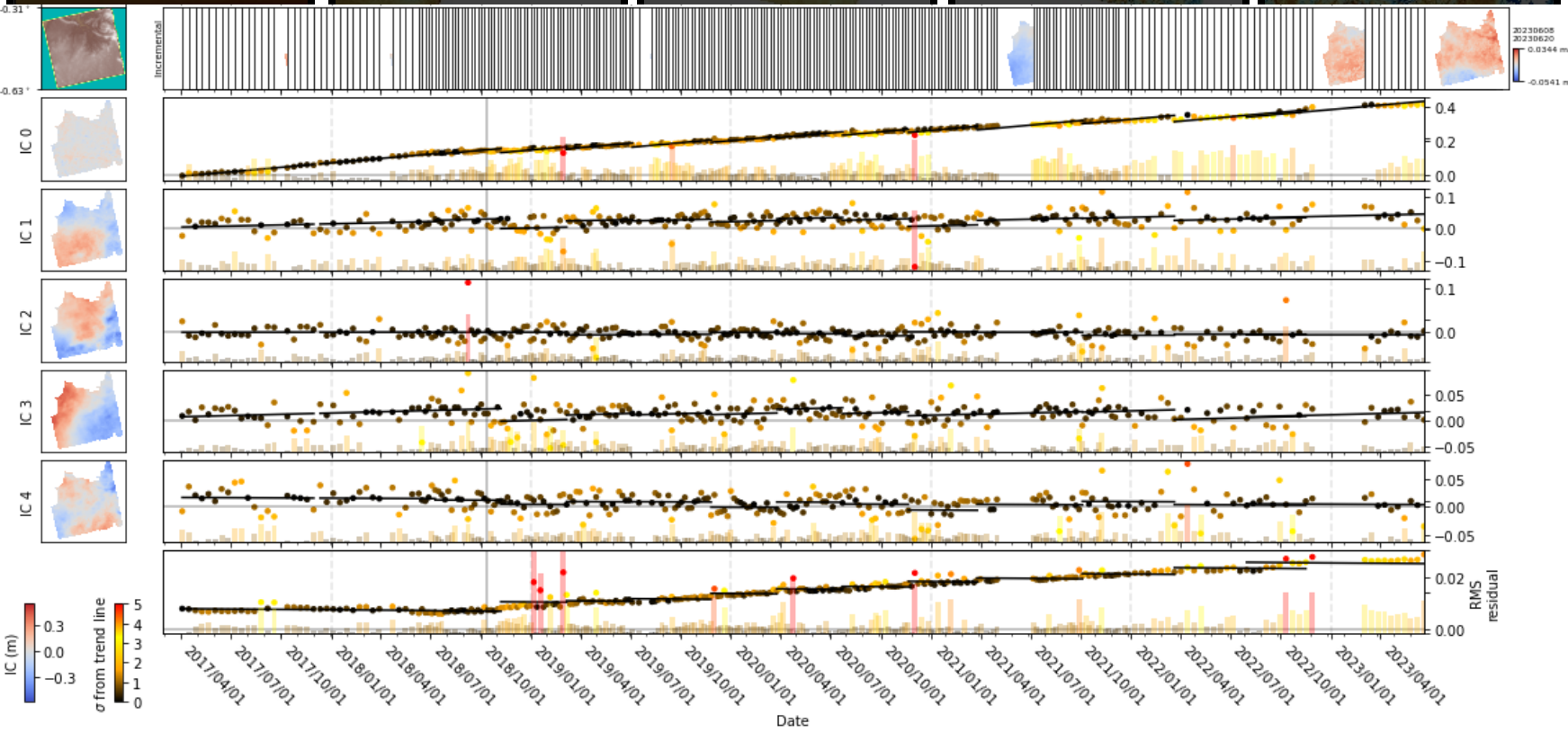
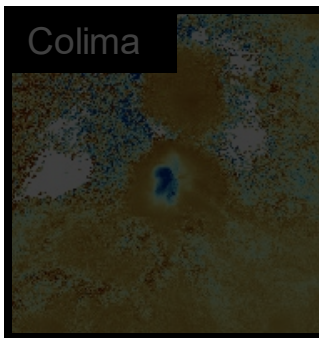
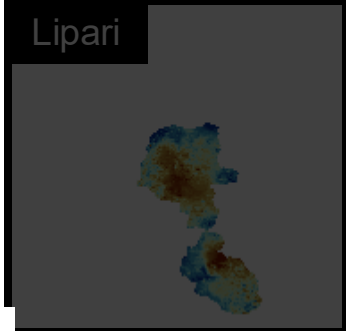
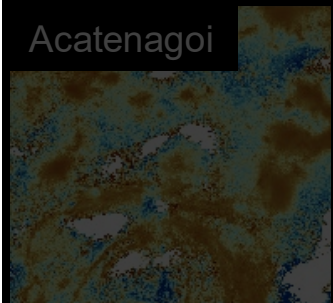
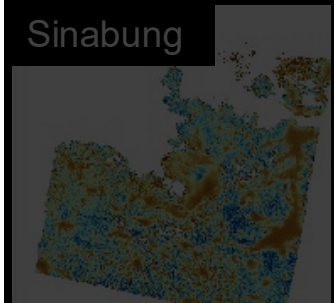
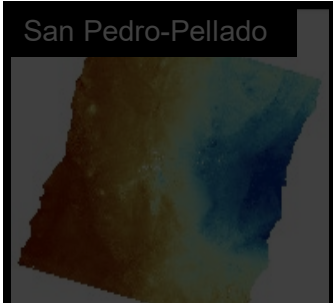
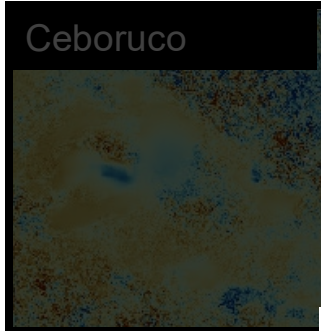


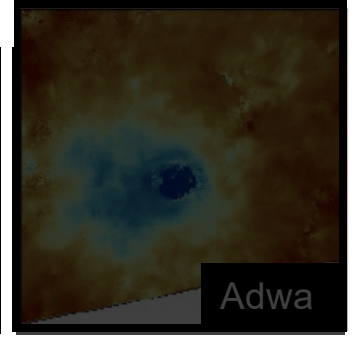
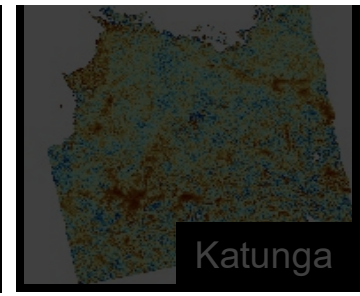
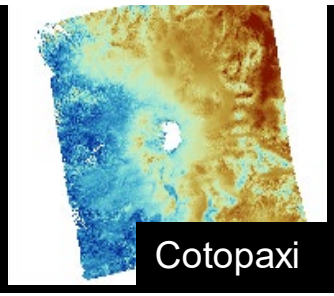
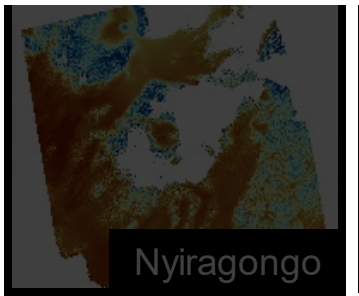
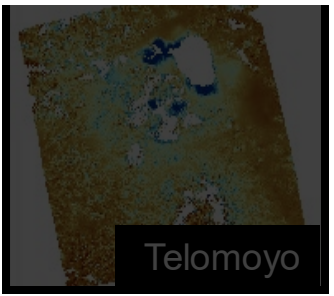
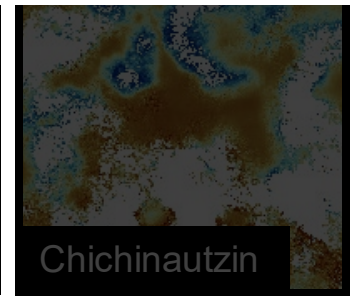
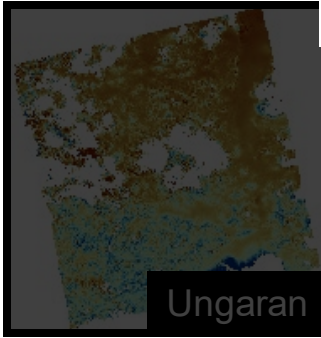
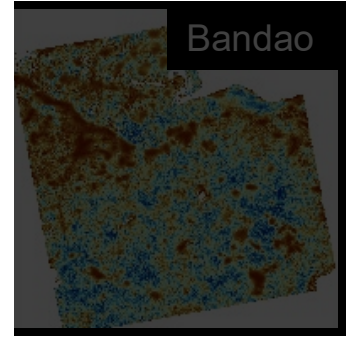
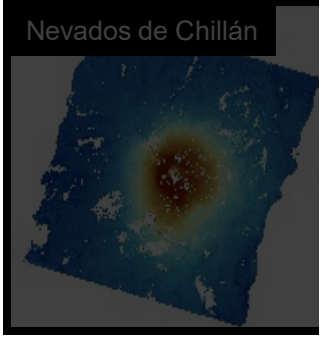
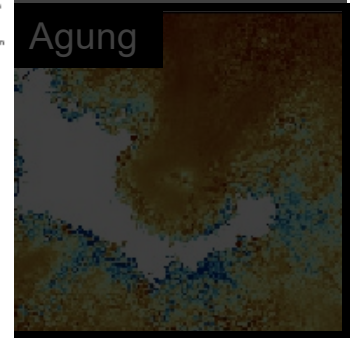
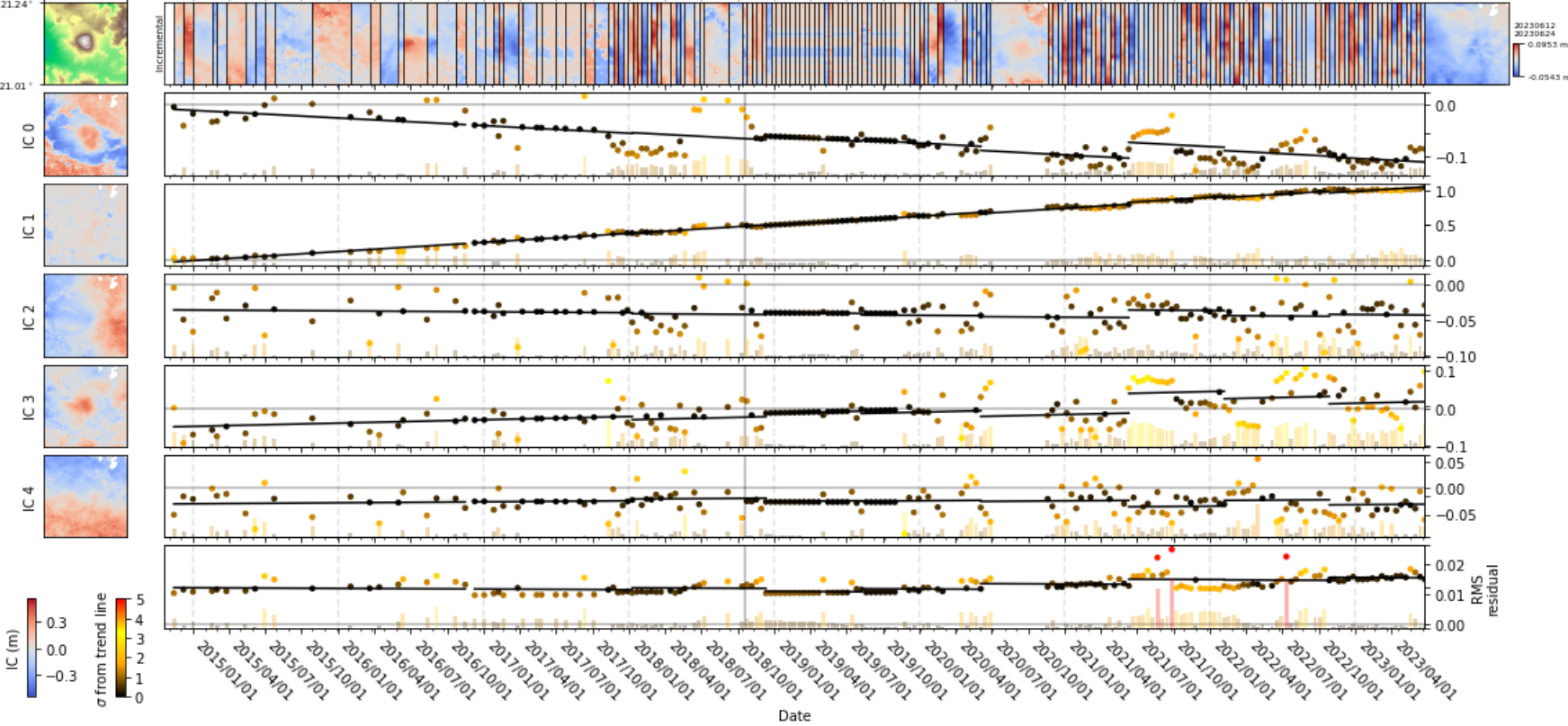
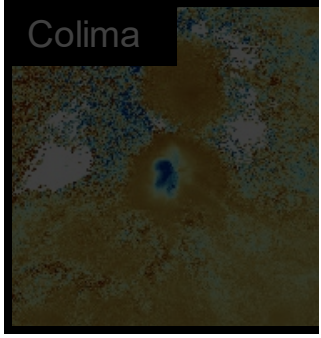
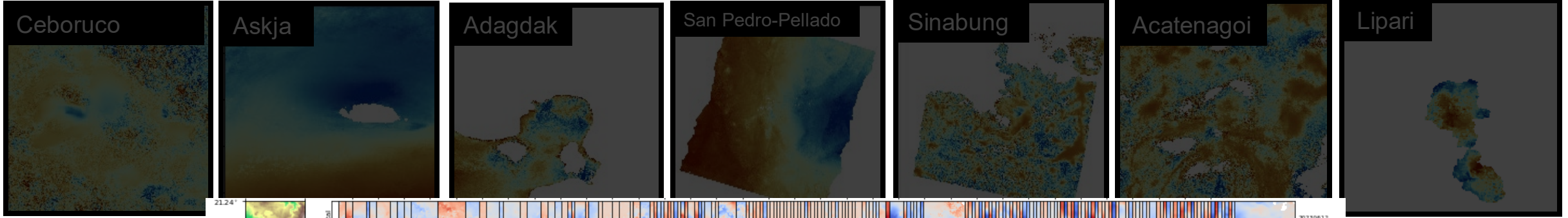


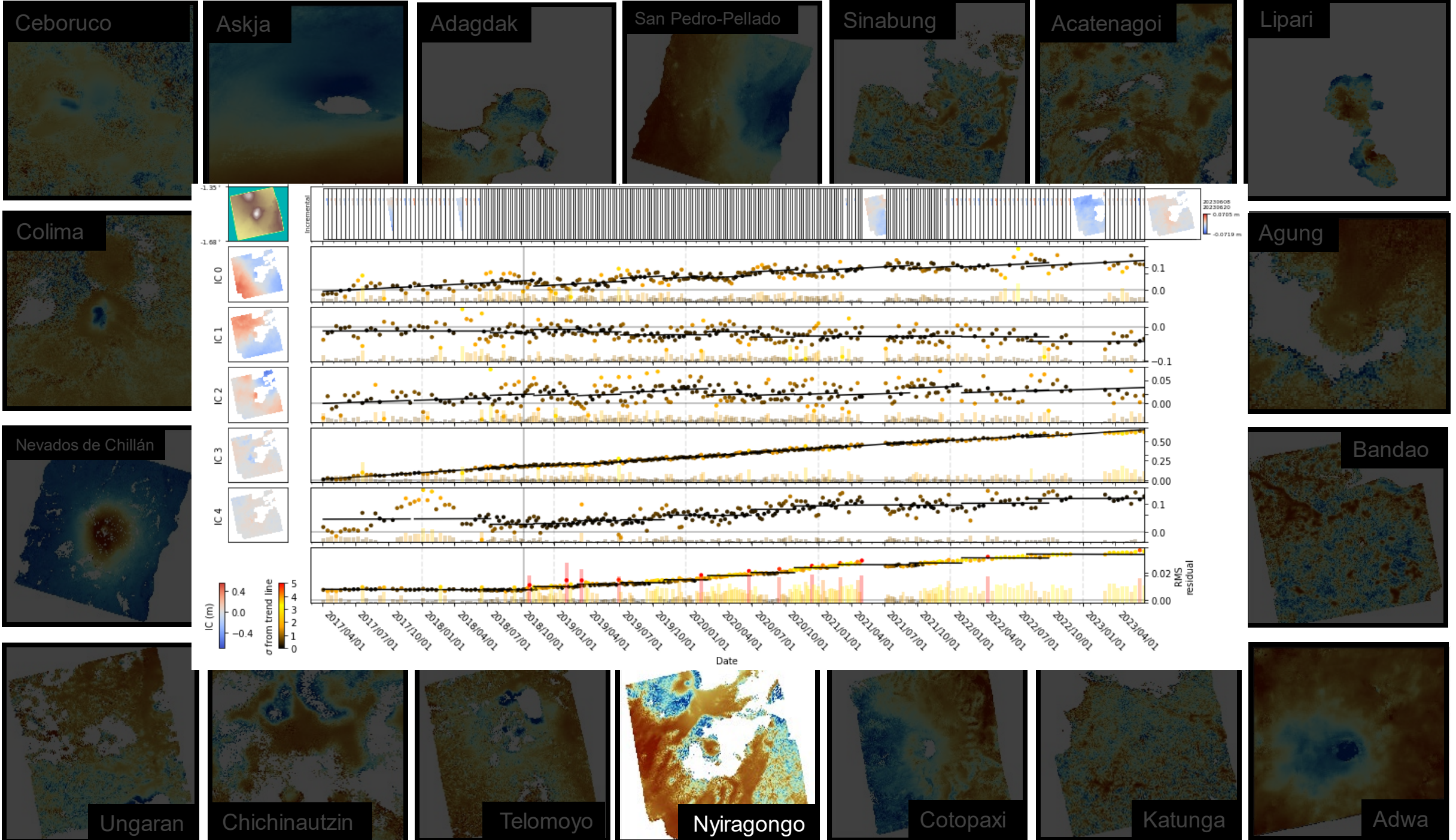


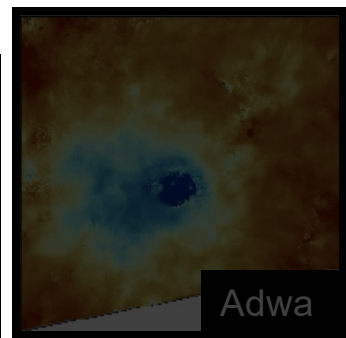
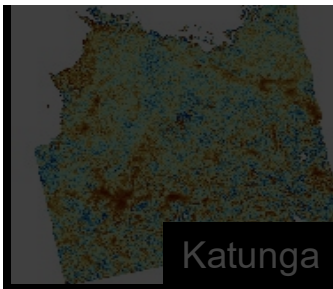
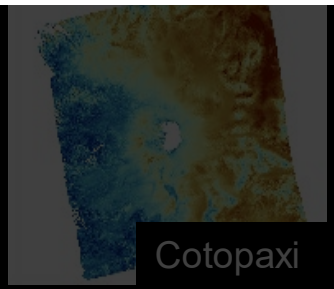
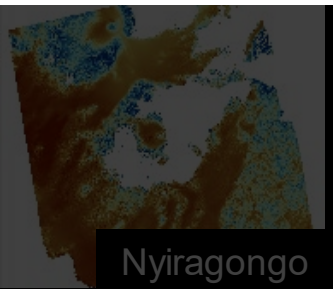
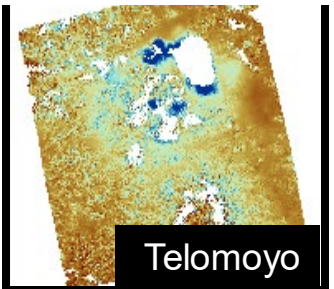
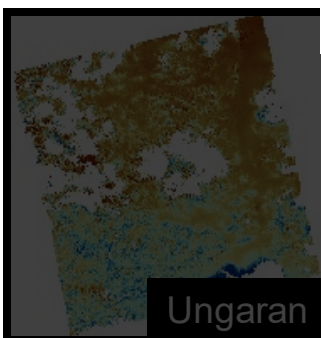
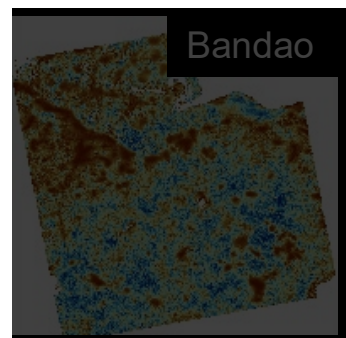
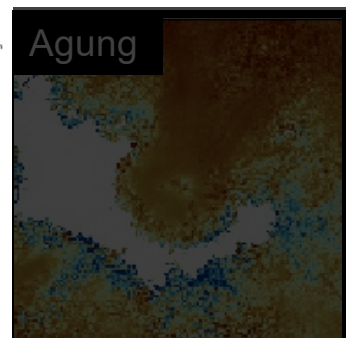
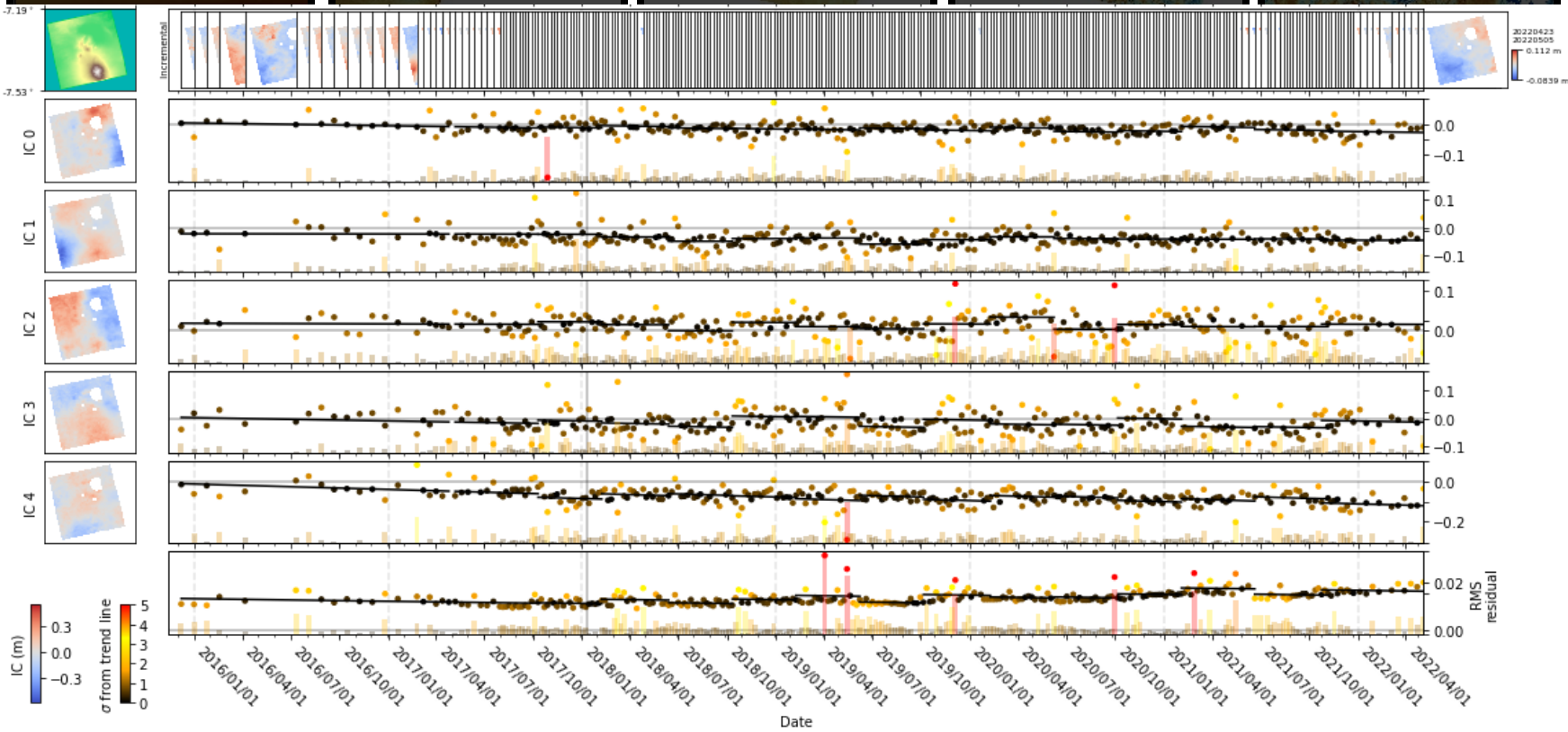
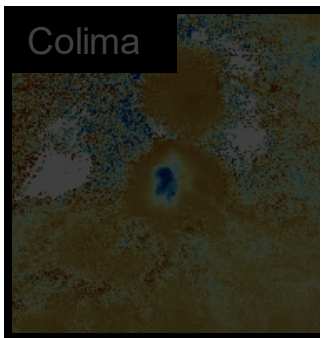
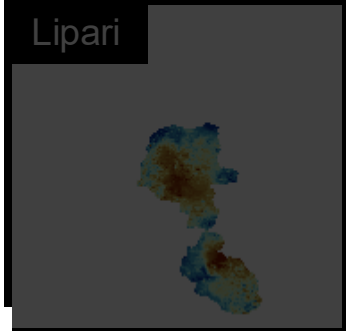
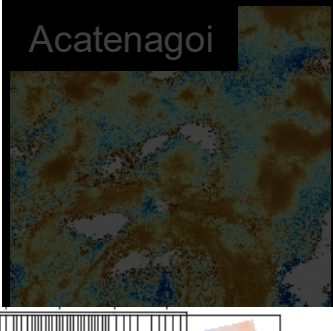
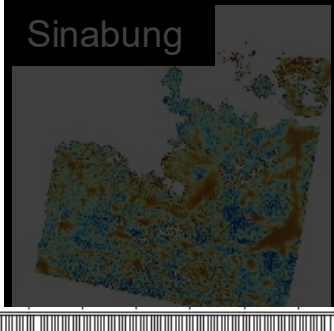
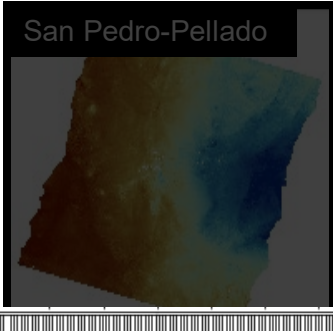
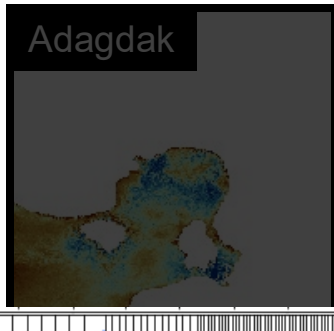
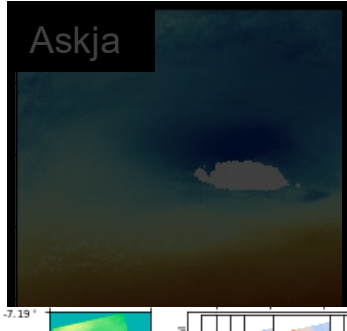
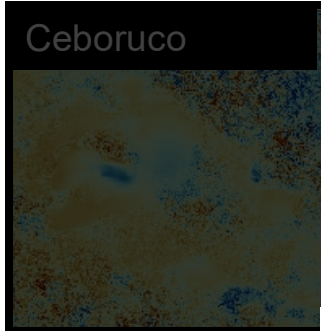


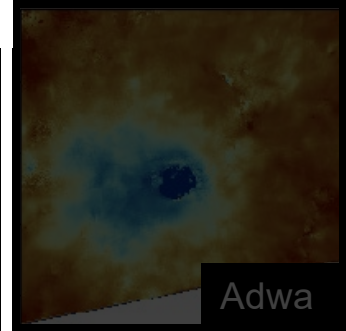
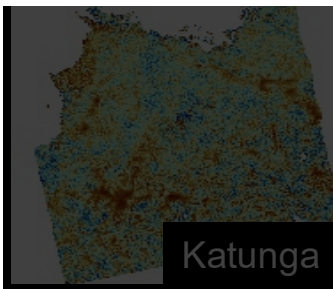
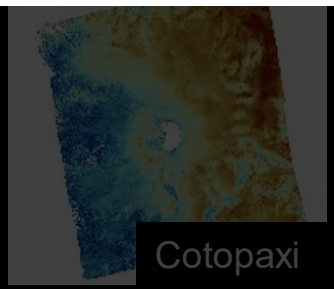
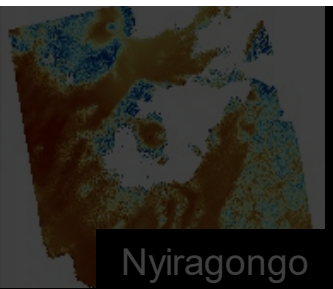
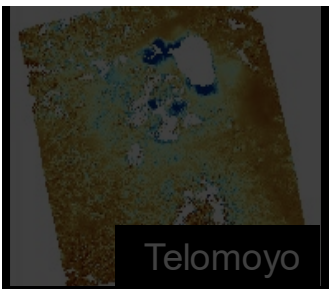
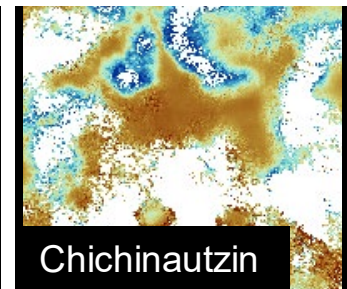
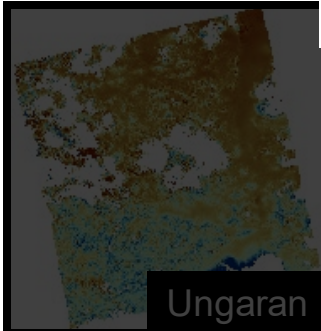
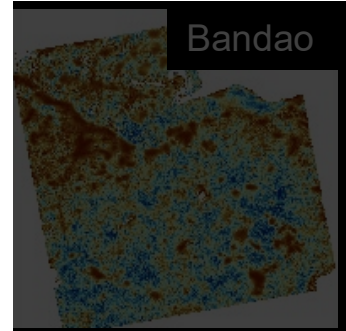
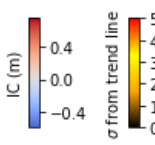
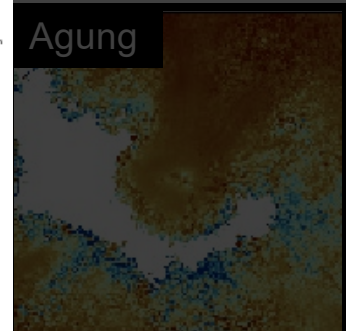
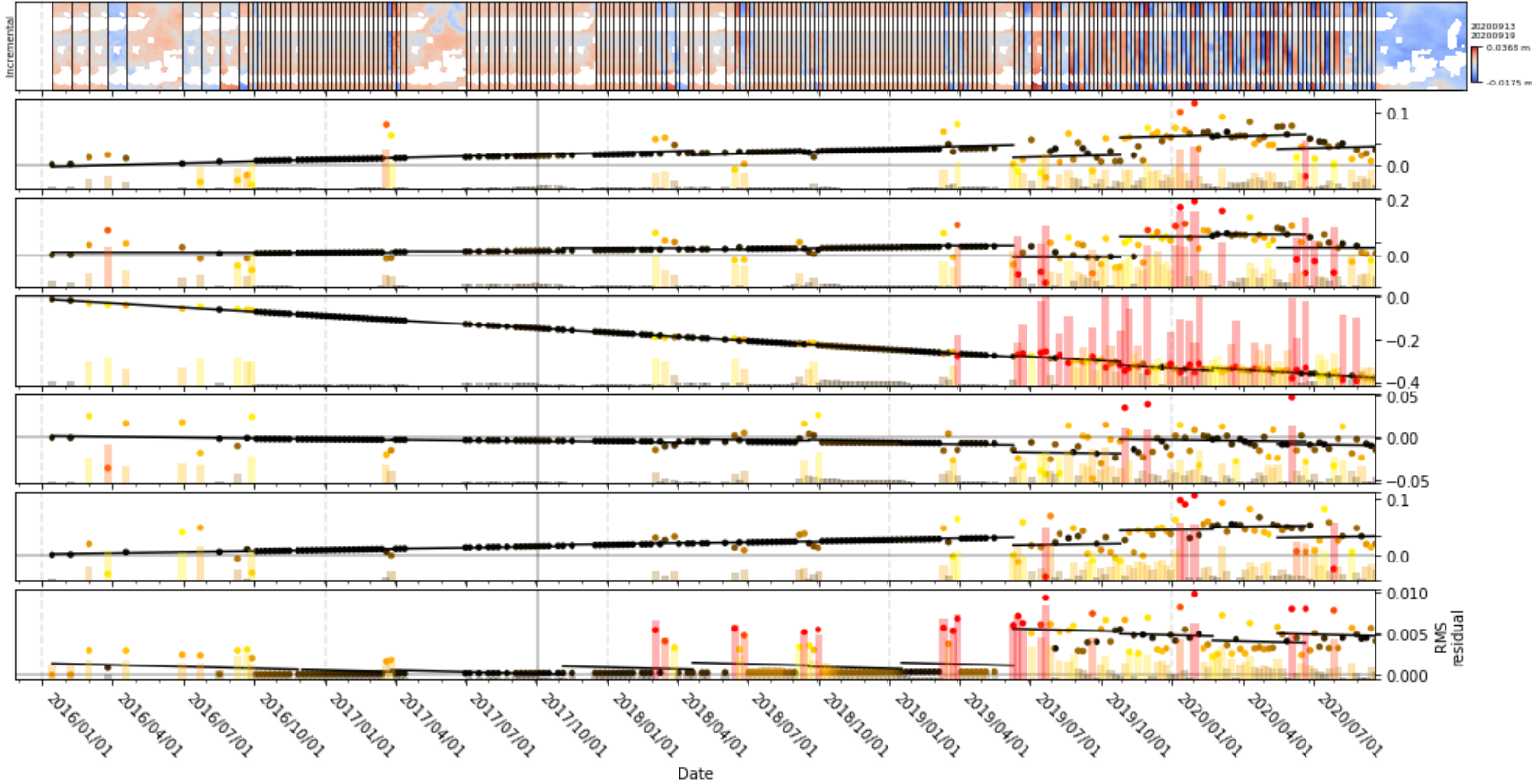
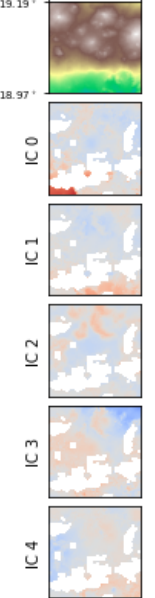
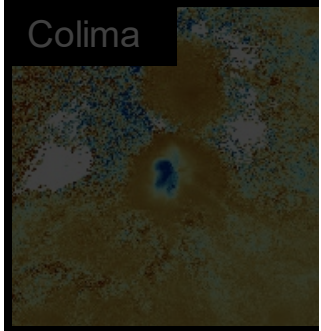
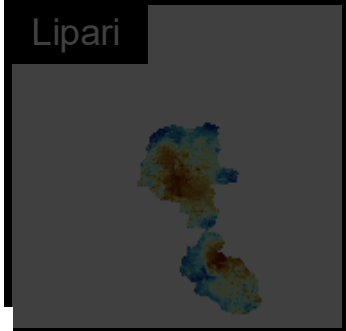
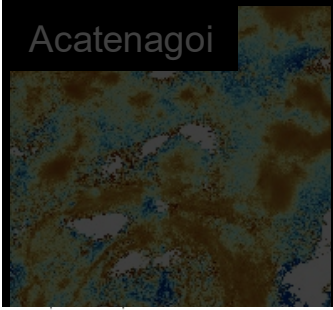
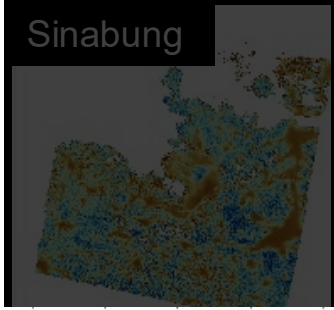
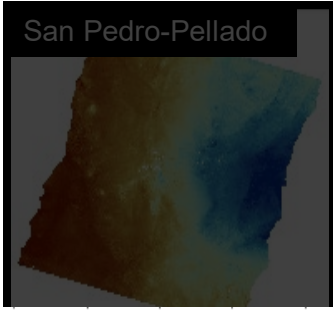
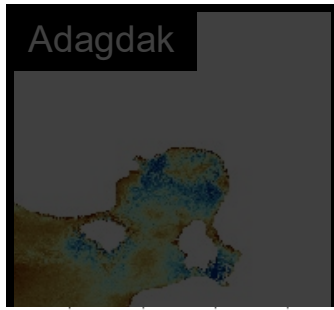
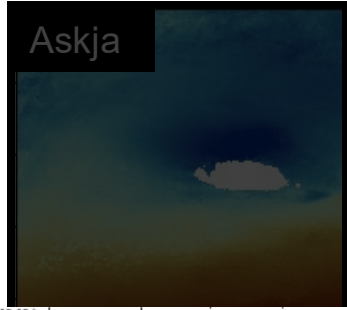
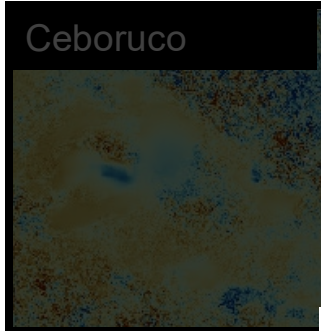


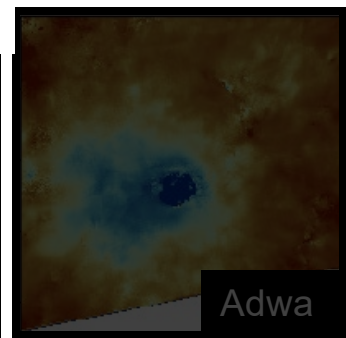
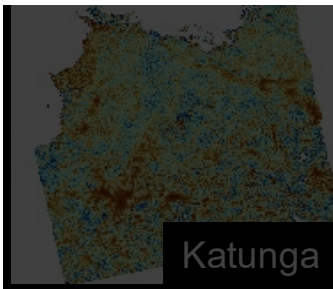
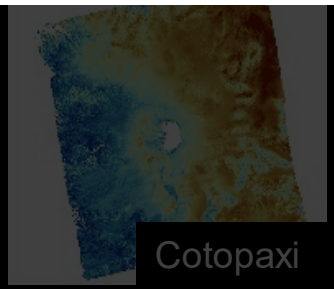
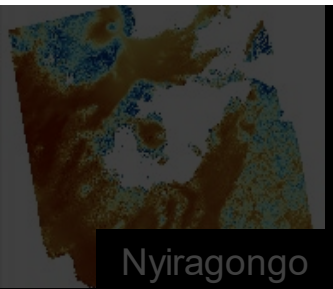
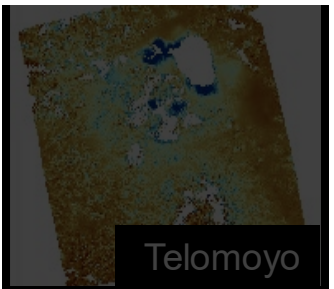
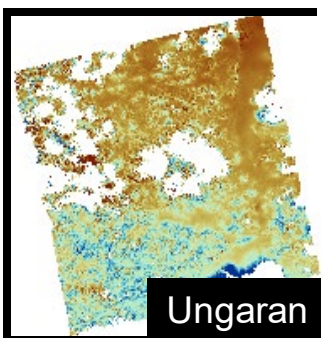
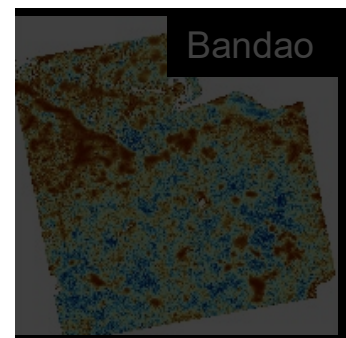
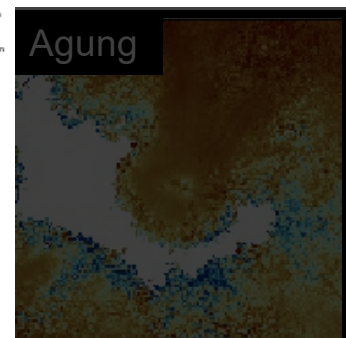
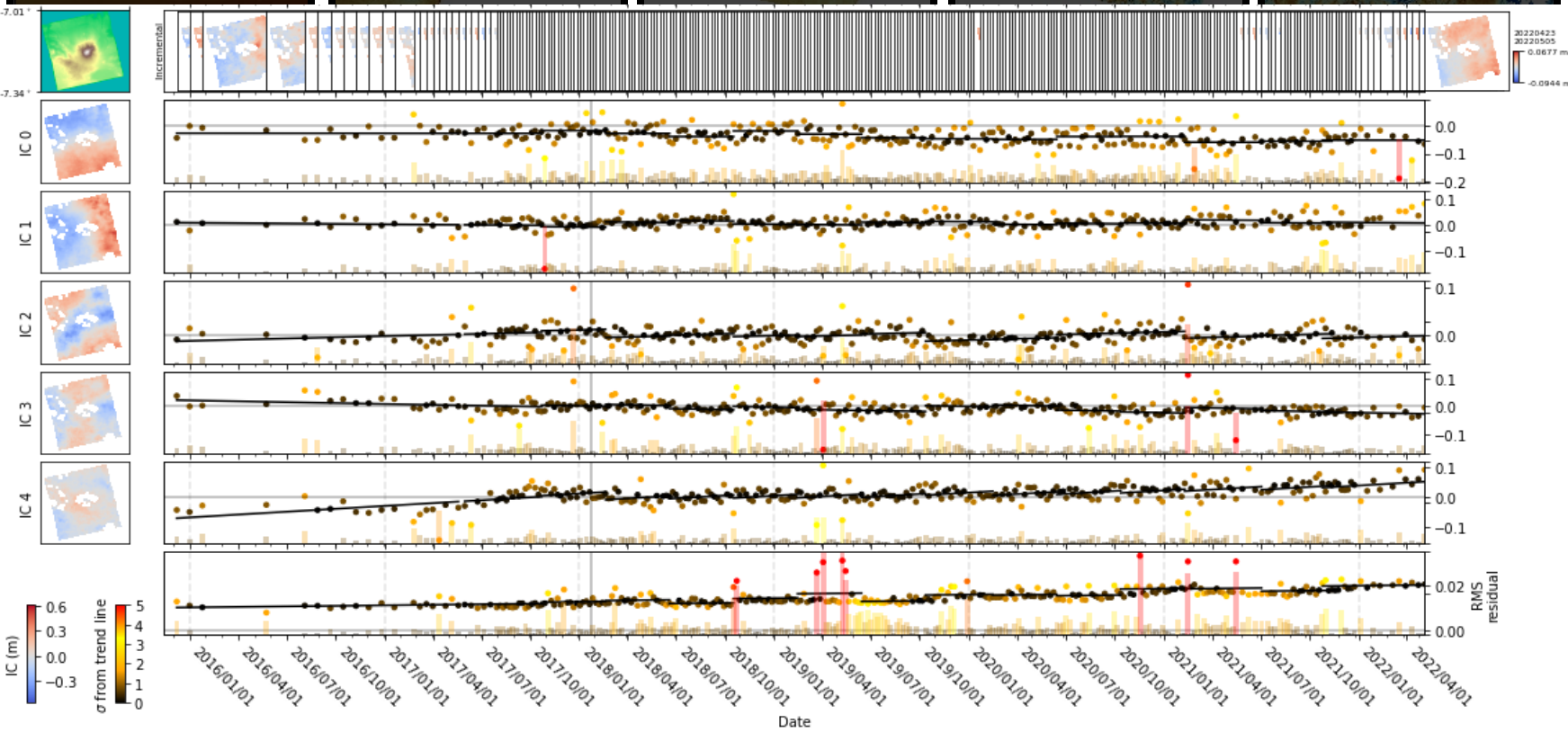
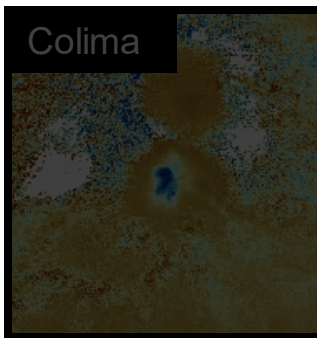
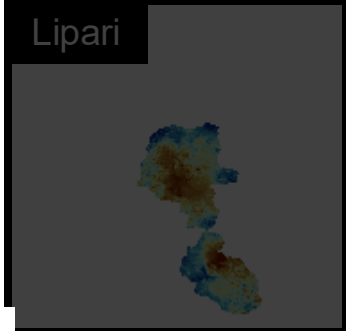
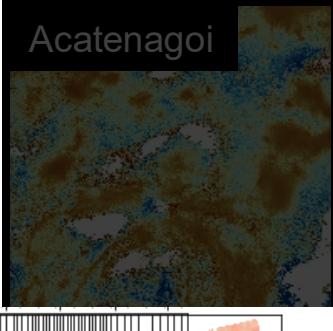
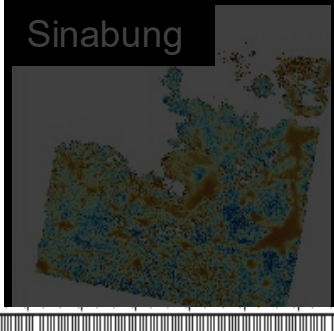
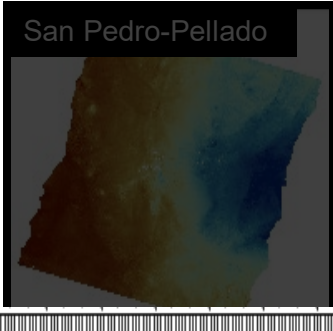
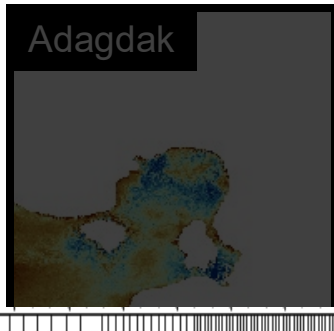
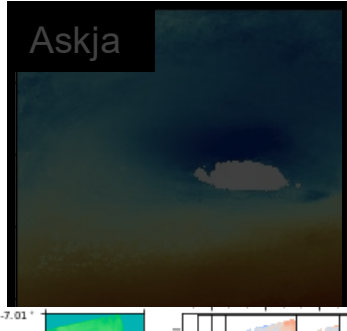
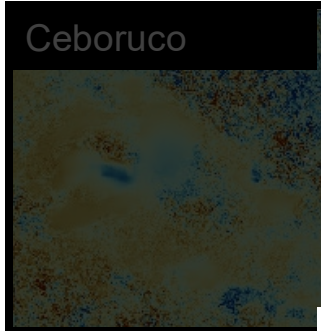


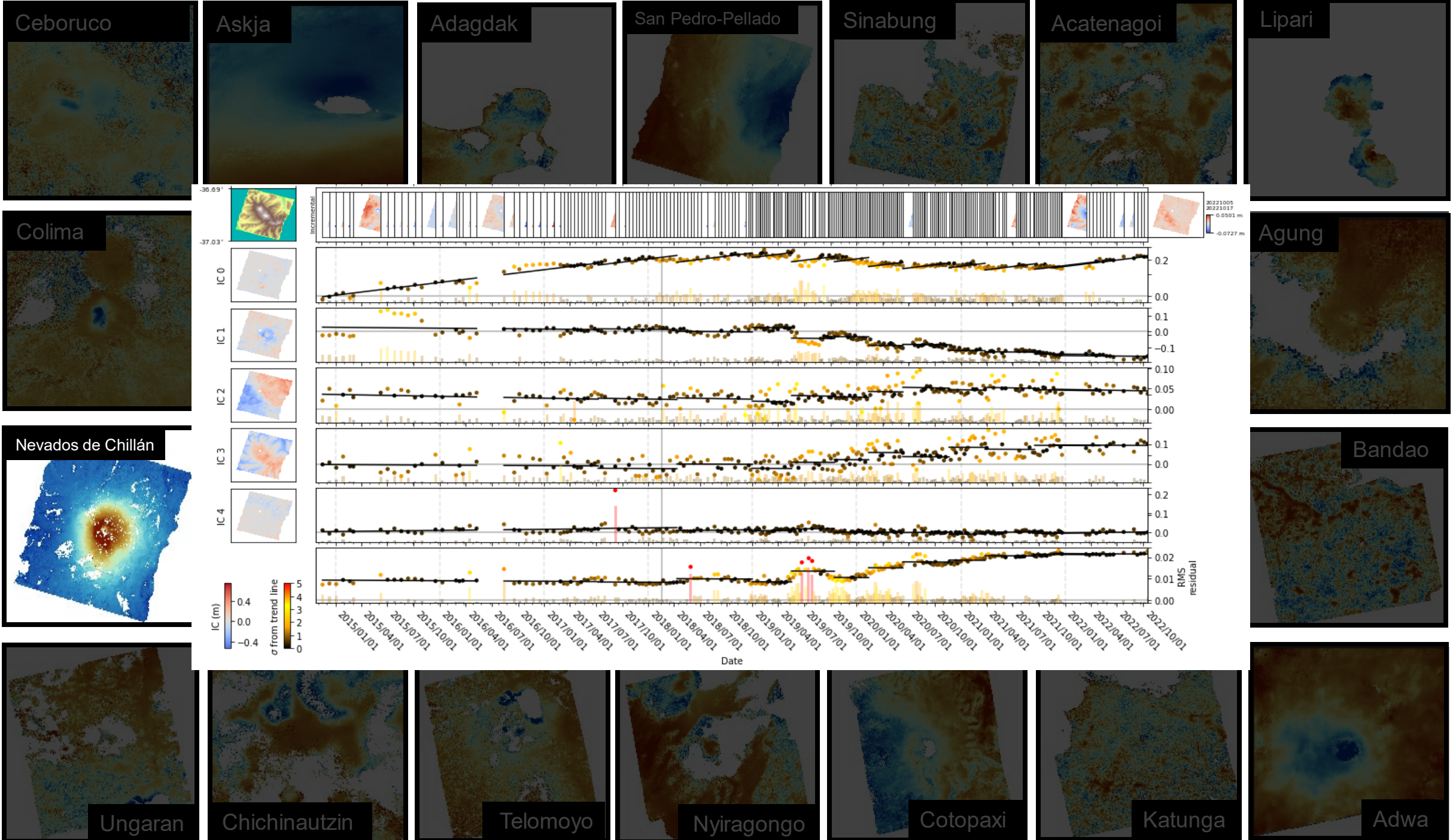


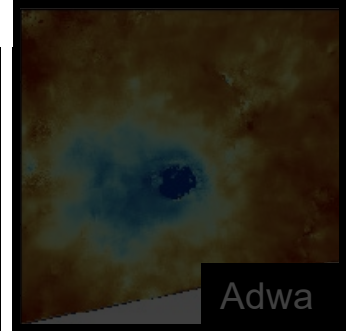
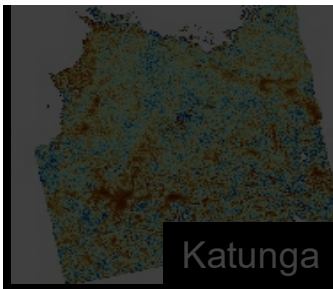
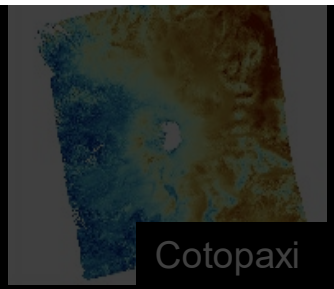
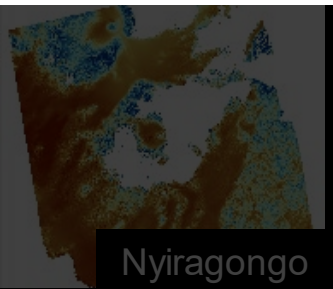
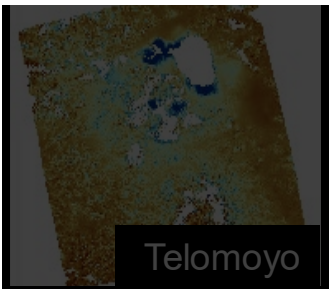
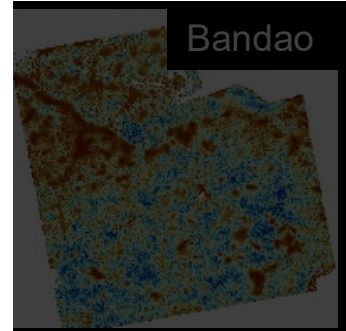
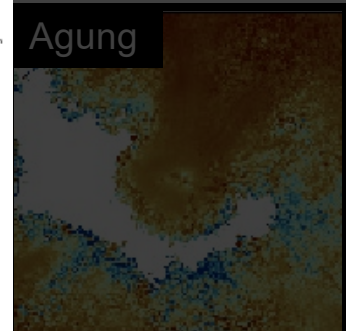
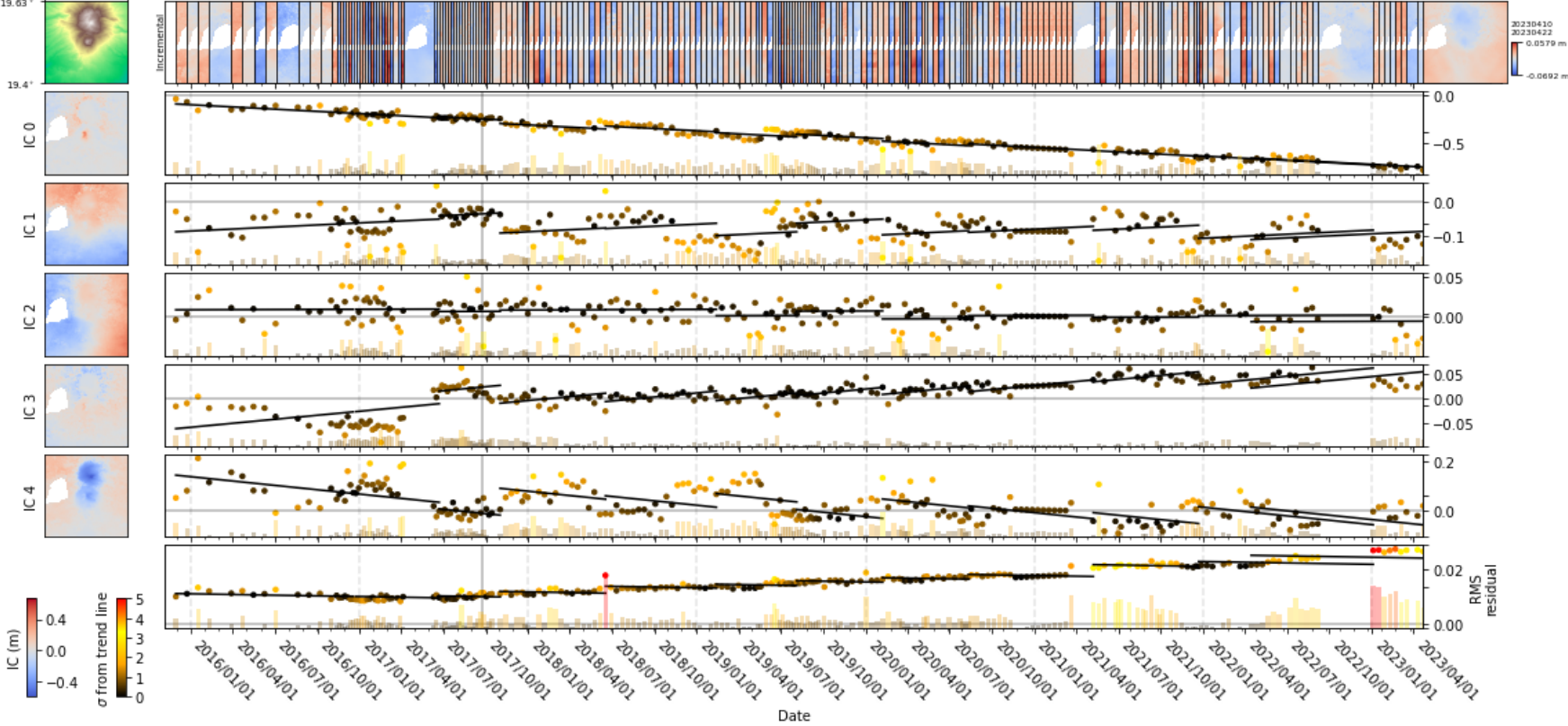
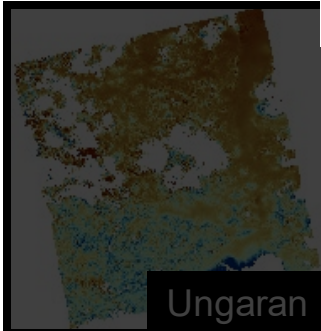
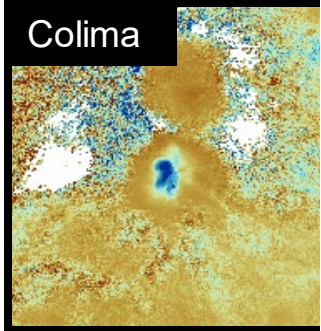
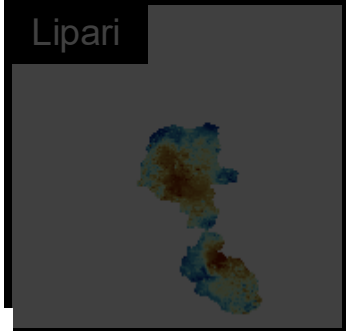
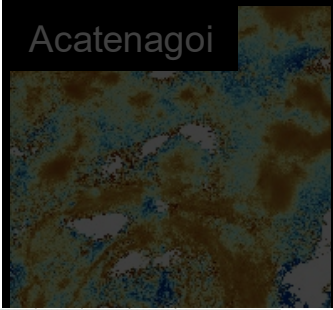
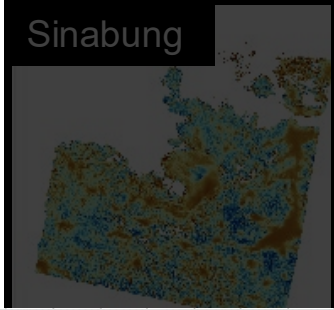
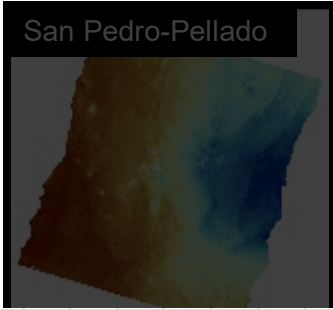
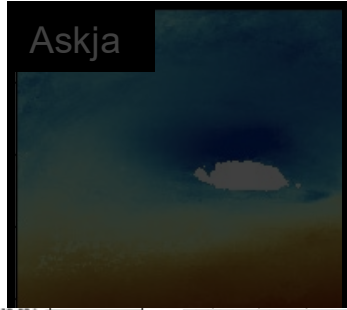
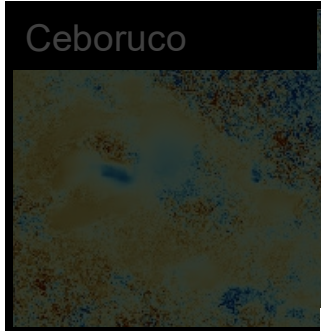




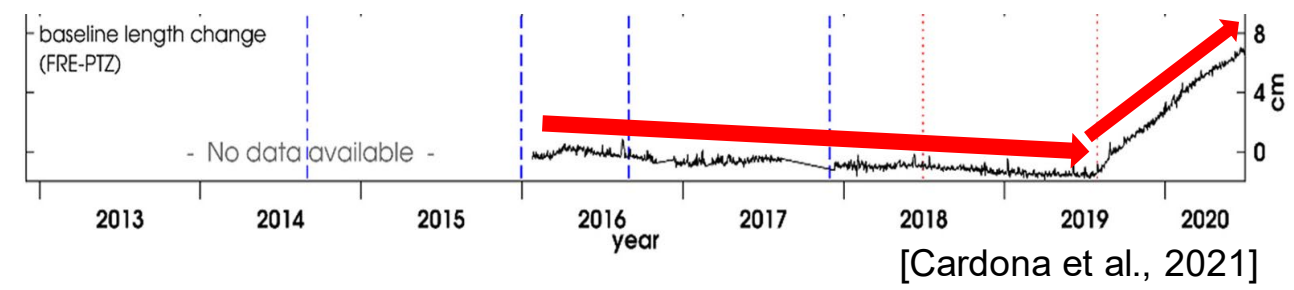
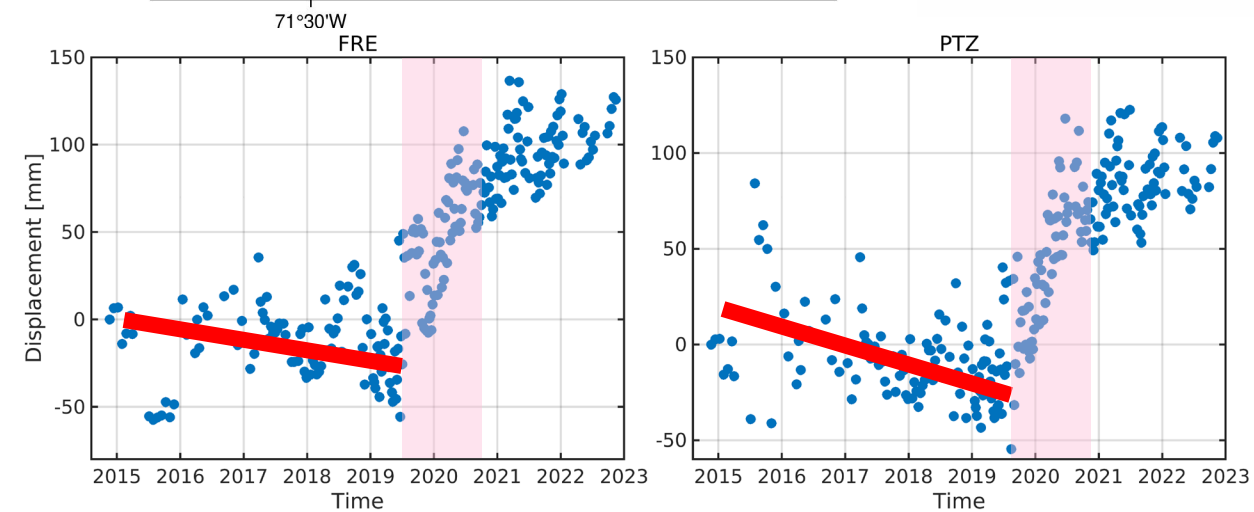
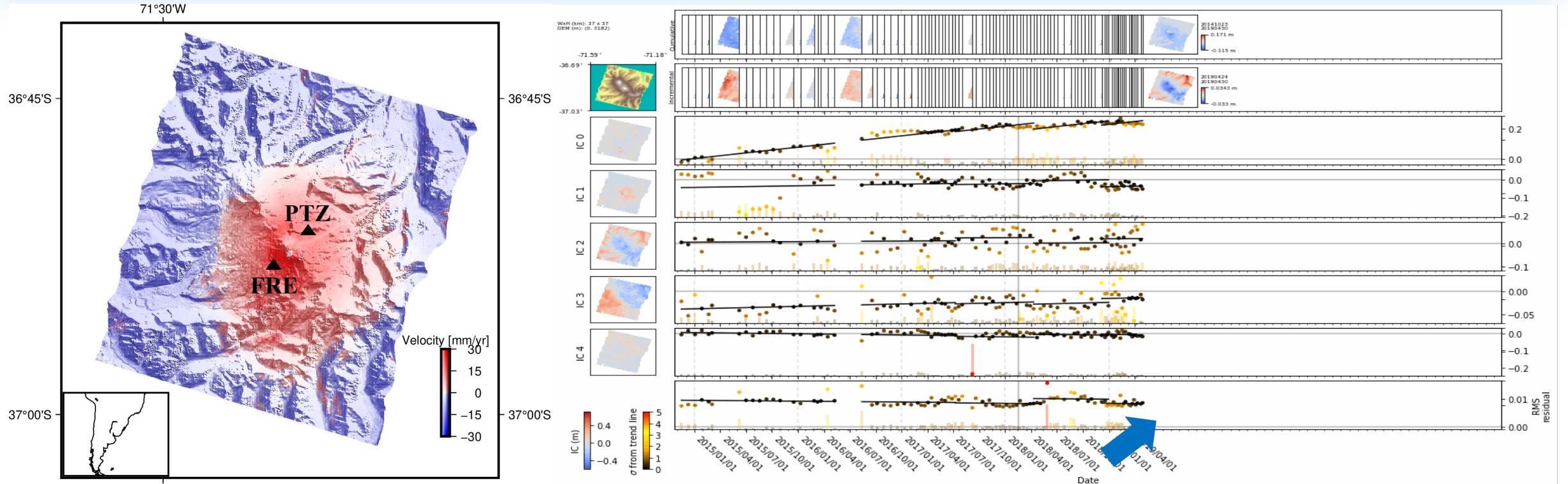






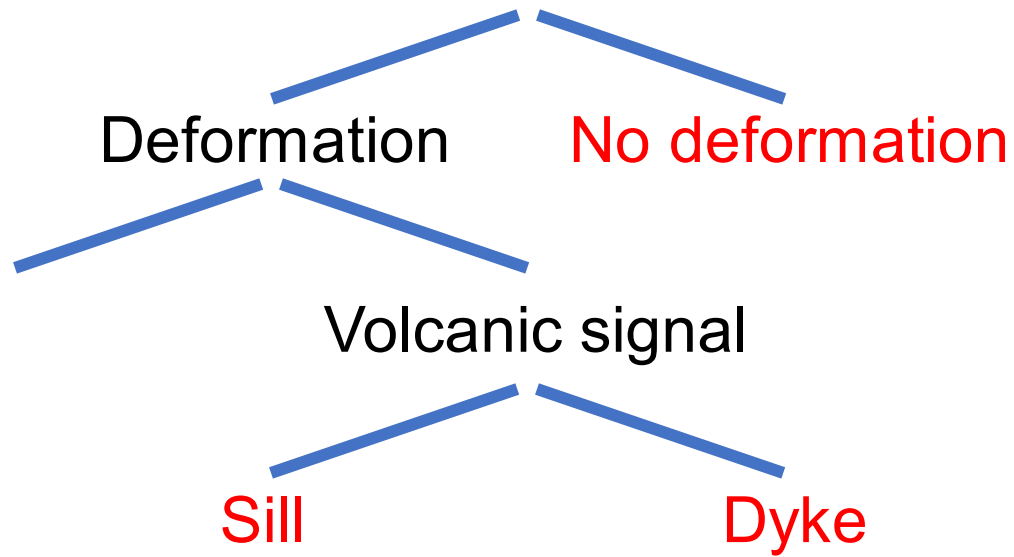


Automatic detection of changes in deformation signals

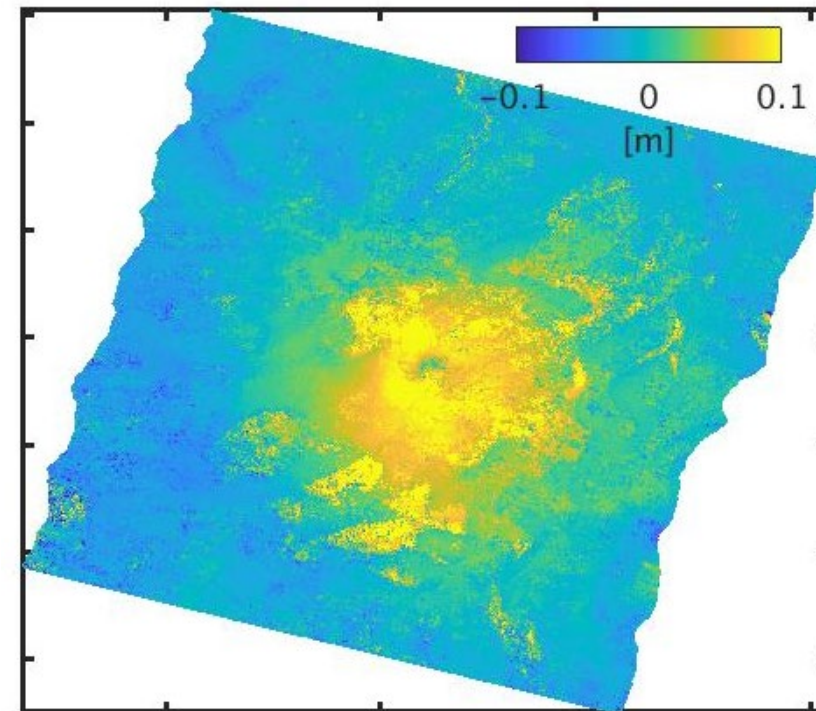


GNSS data recorded from 2015 to 2020 evidenced an uplift event beginning in July 2019

Volcanic deformation detection and classification using a developed convolutional neural network (CNN)



Cumulative displacement
[20141023 – 20221017]



sill: 0.65
dyke: 0.34
no.def: 0.01
sill

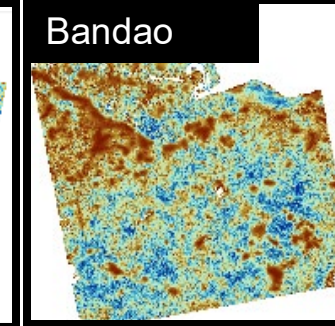
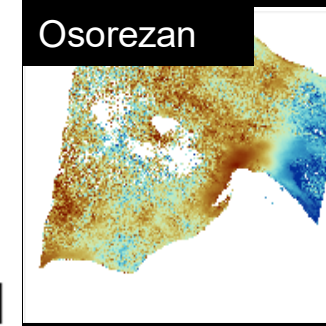
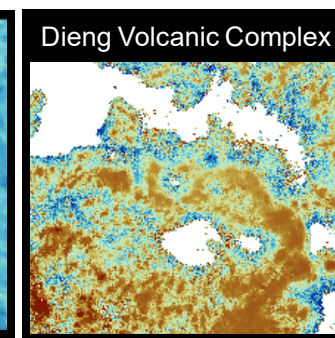
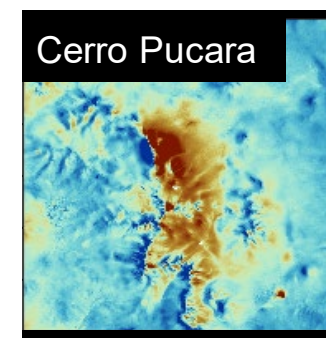
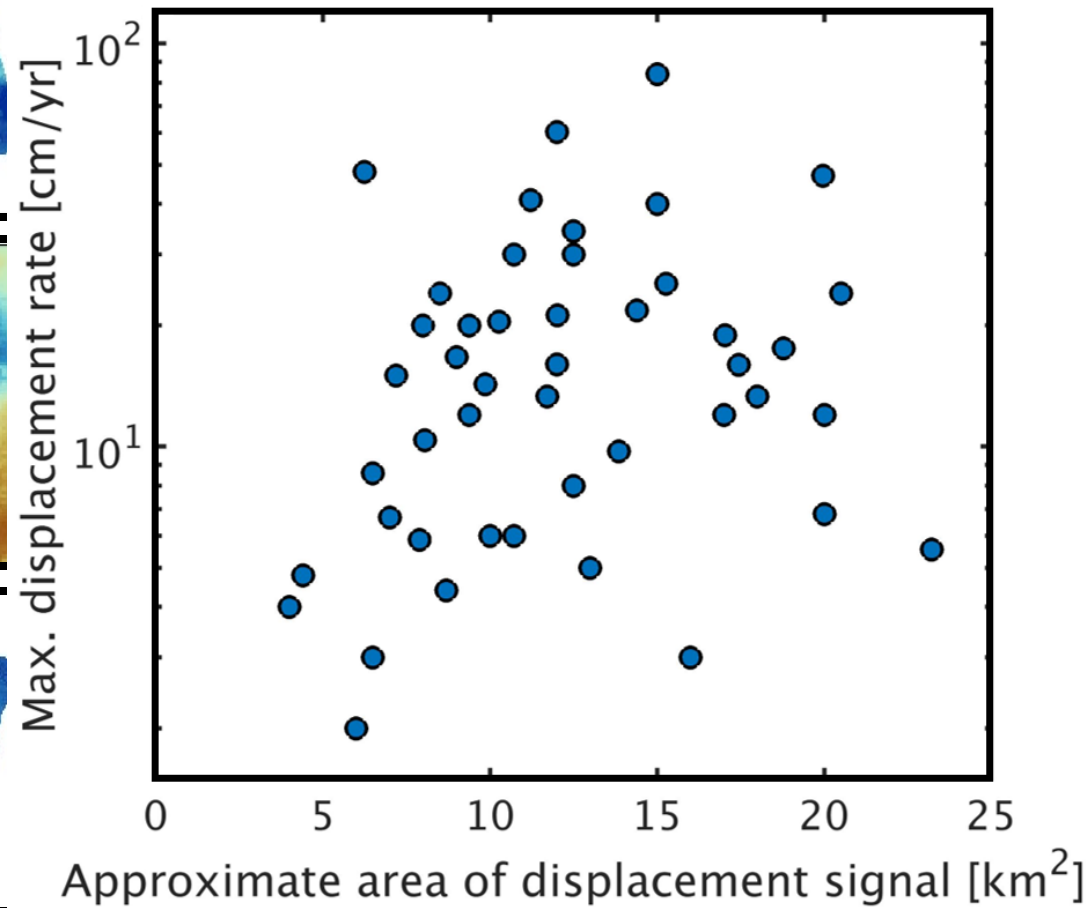
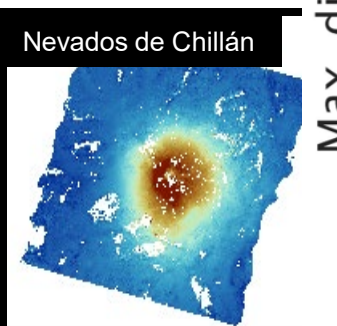
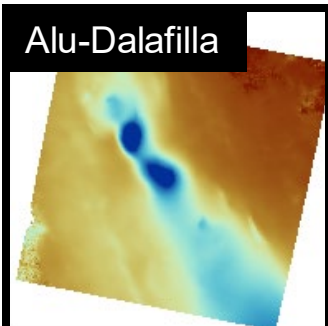
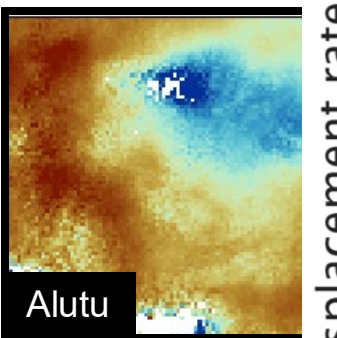
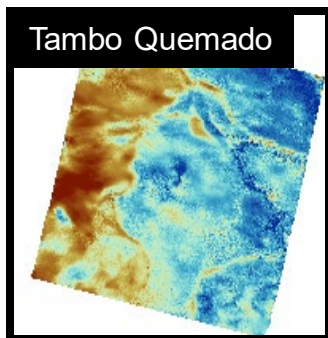
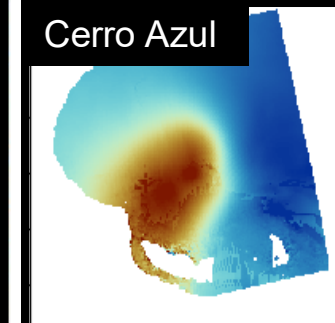
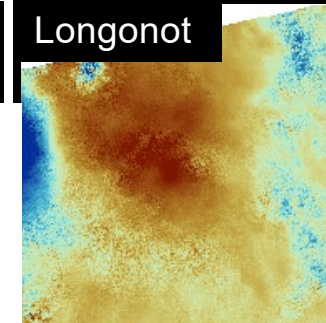
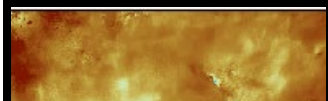
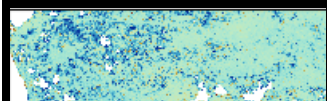
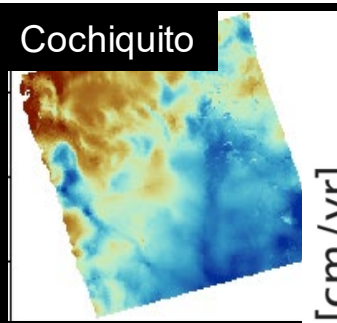
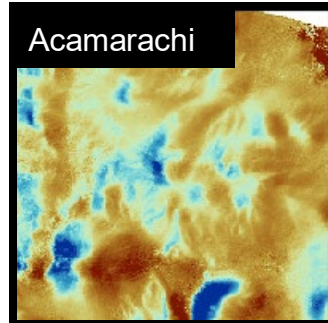
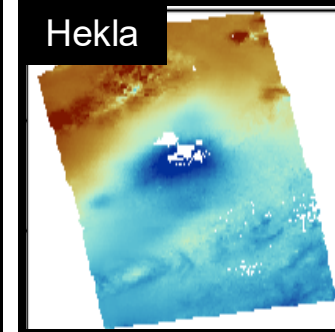
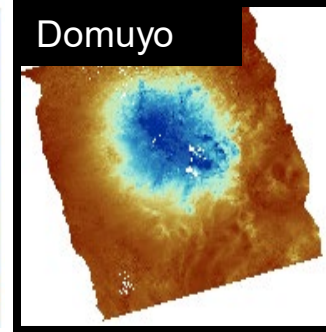
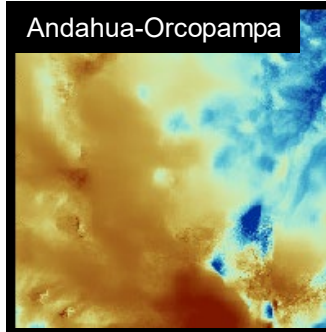
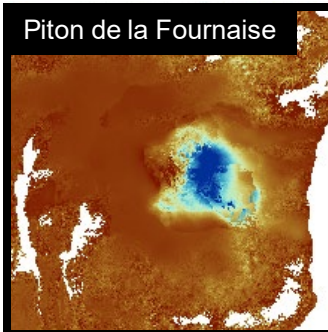
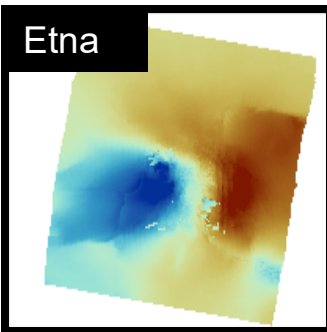
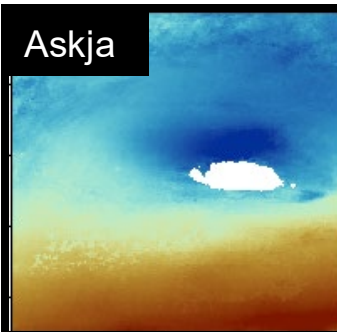
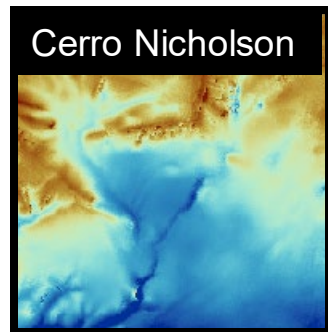
❖ VUDLNet_21 [Gaddes et al., in review]

https://github.com/matthew-gaddes/VUDLNet_21

500,000 labelled Sentinel-1 interferograms

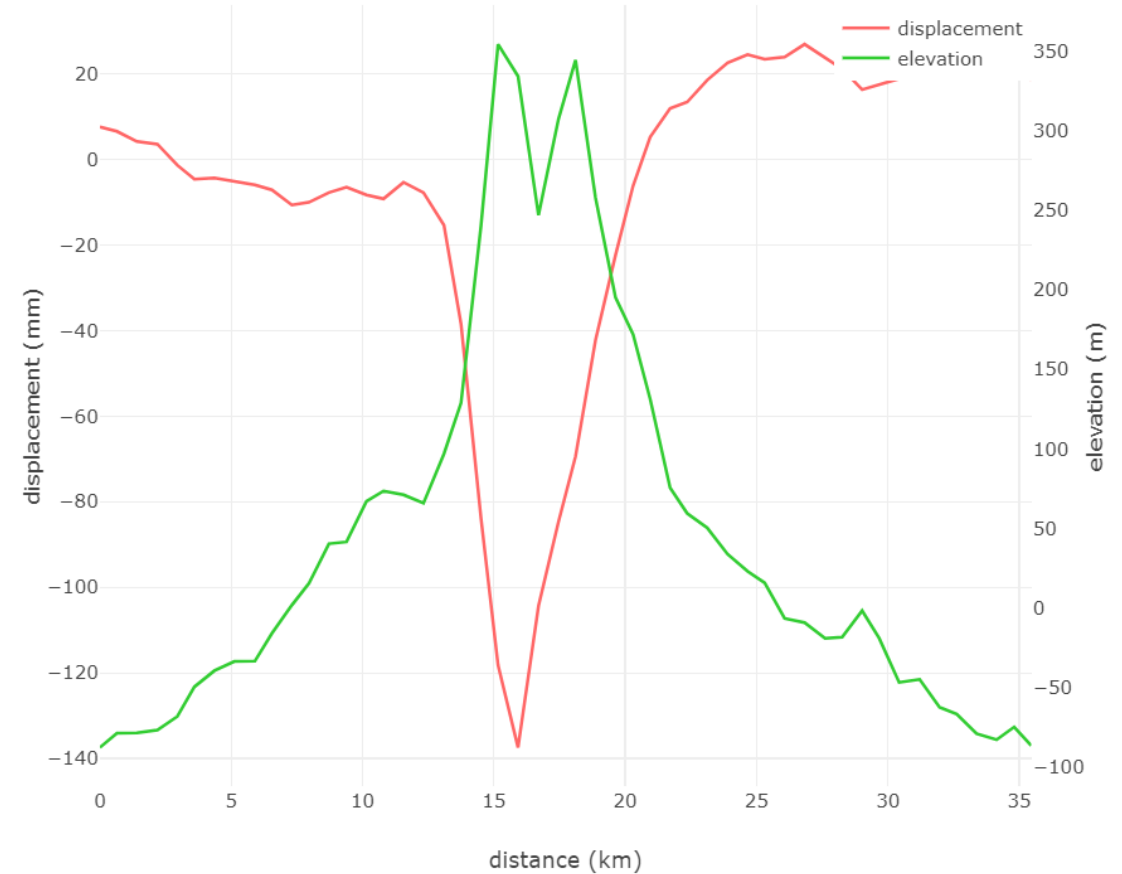
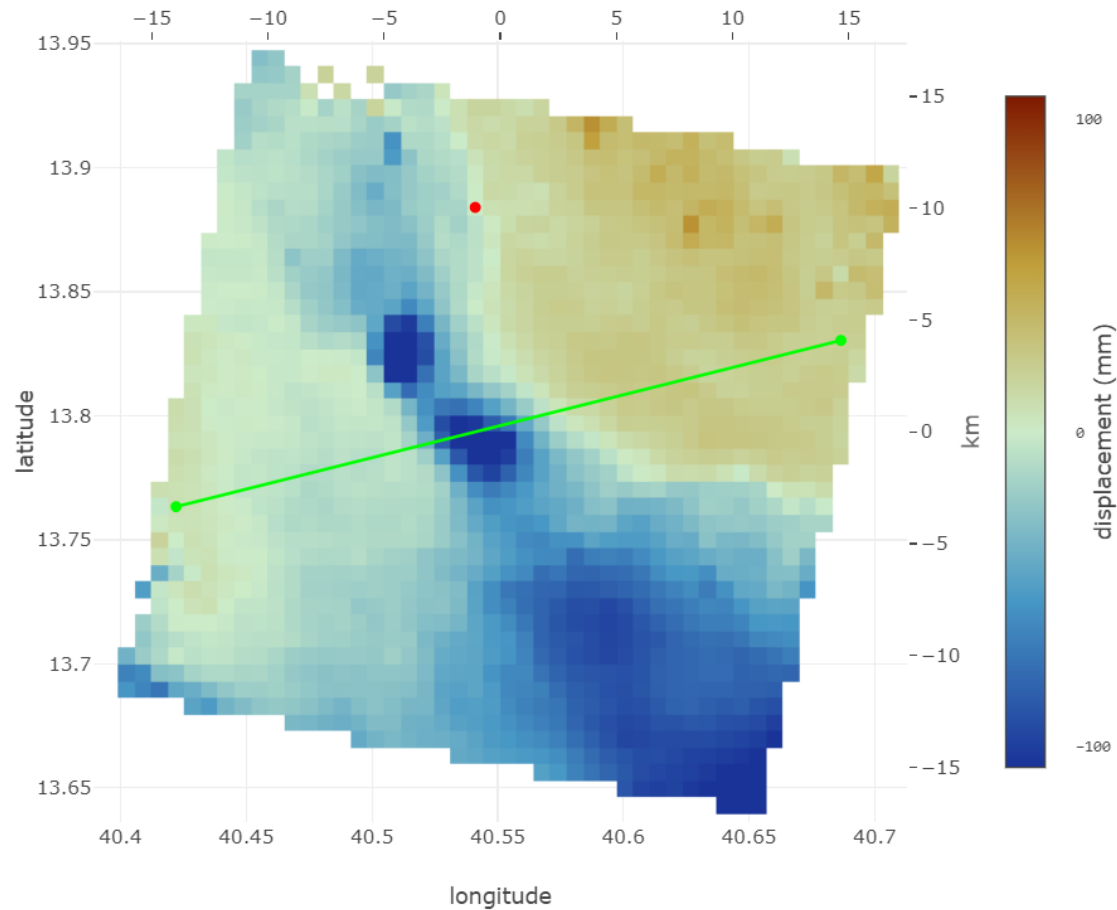
- Synthetic interferograms
- Real dataset of 15 volcanoes from Volcnet

This observational database makes a significant increase in the number of volcanoes for network training



Data visualization in the COMET volcanic and magmatic deformation portal

❖ <https://comet.nerc.ac.uk/comet-volcano-portal>



<input checked="" type="checkbox"/> displacement	<input type="checkbox"/> coherence
<input checked="" type="checkbox"/> points to plot	<input type="checkbox"/> reference area
<input type="checkbox"/> save data as csv	<input type="checkbox"/> surface plot

<input checked="" type="checkbox"/> plot	<input type="checkbox"/> sentinel-2 map
<input type="checkbox"/> time series	<input checked="" type="checkbox"/> profile
<input type="checkbox"/> save data as csv	

Take home messages

- ❖ We developed an approach to automatically derive high-resolution displacement time series for global subaerial volcanoes
- ❖ We provided a database for machine learning to automatically detect, classify and potentially forecast volcano deformation
- ❖ Online interactive visualization and data request are supported by the COMET Volcanic and Magmatic Deformation Portal
- ❖ The database will be shared publicly under an open source license, and made available through other relevant projects such as the European Plate Observing System (EPOS) and the Global Volcano Model (GVM)

