Using independent component analysis (ICA) with time series of InSAR data to monitor volcanoes

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Image: European Space Agency.

COMET

CENTRE FOR OBSERVATION & MODELLING OF EARTHQUAKES, VOLCANOES & TECTONICS

esa

LiCS

LOOKING INSIDE THE CONTINENTS FROM SPACE

DEEPVOLC

ANACONDA

TensorFlow

python™

SciPy

spyder

Matplotlib

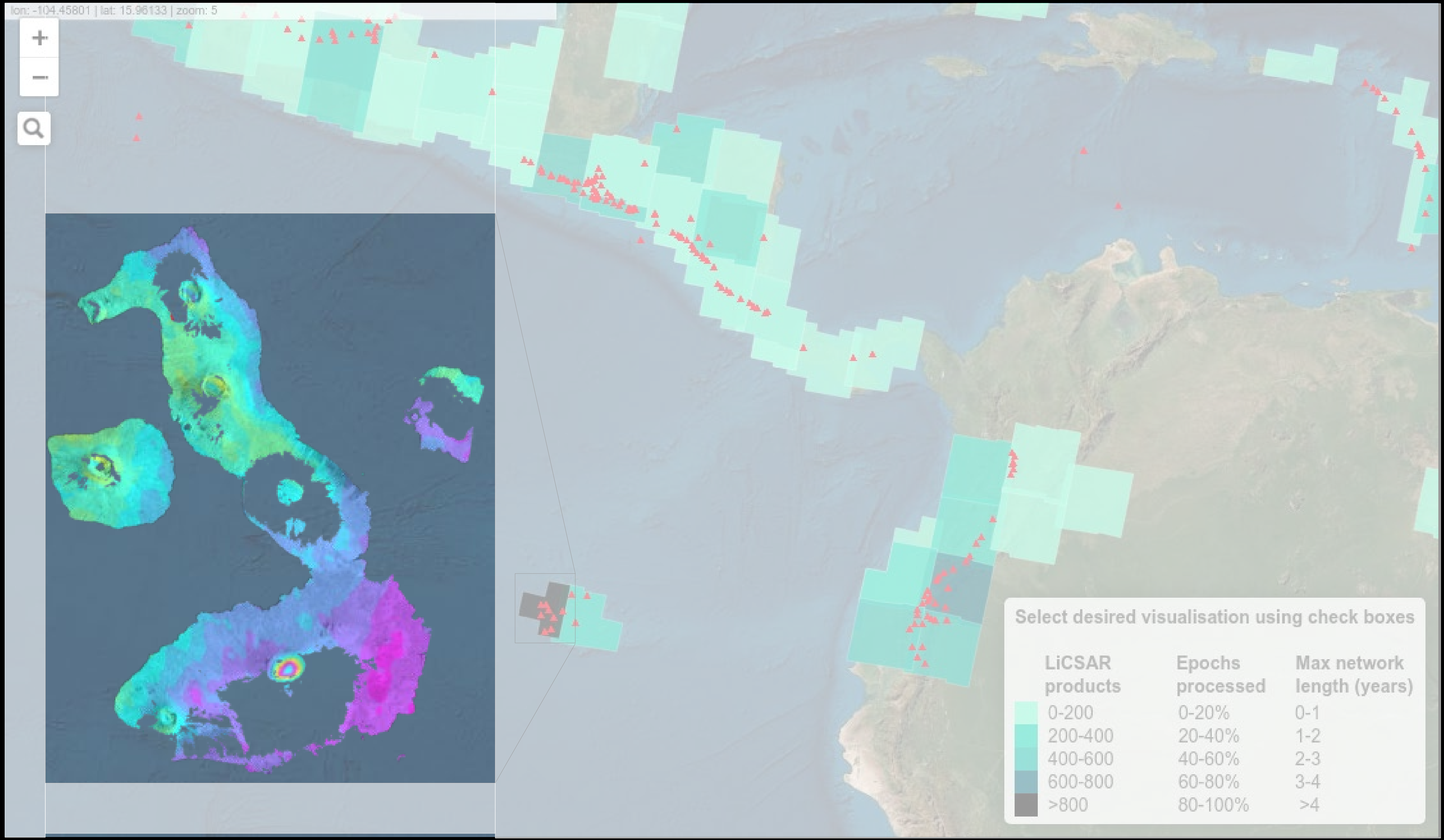
Keras

Ubuntu

NumPy

scikit learn

Why automate the detection of volcanic unrest with Sentinel-1 InSAR data?



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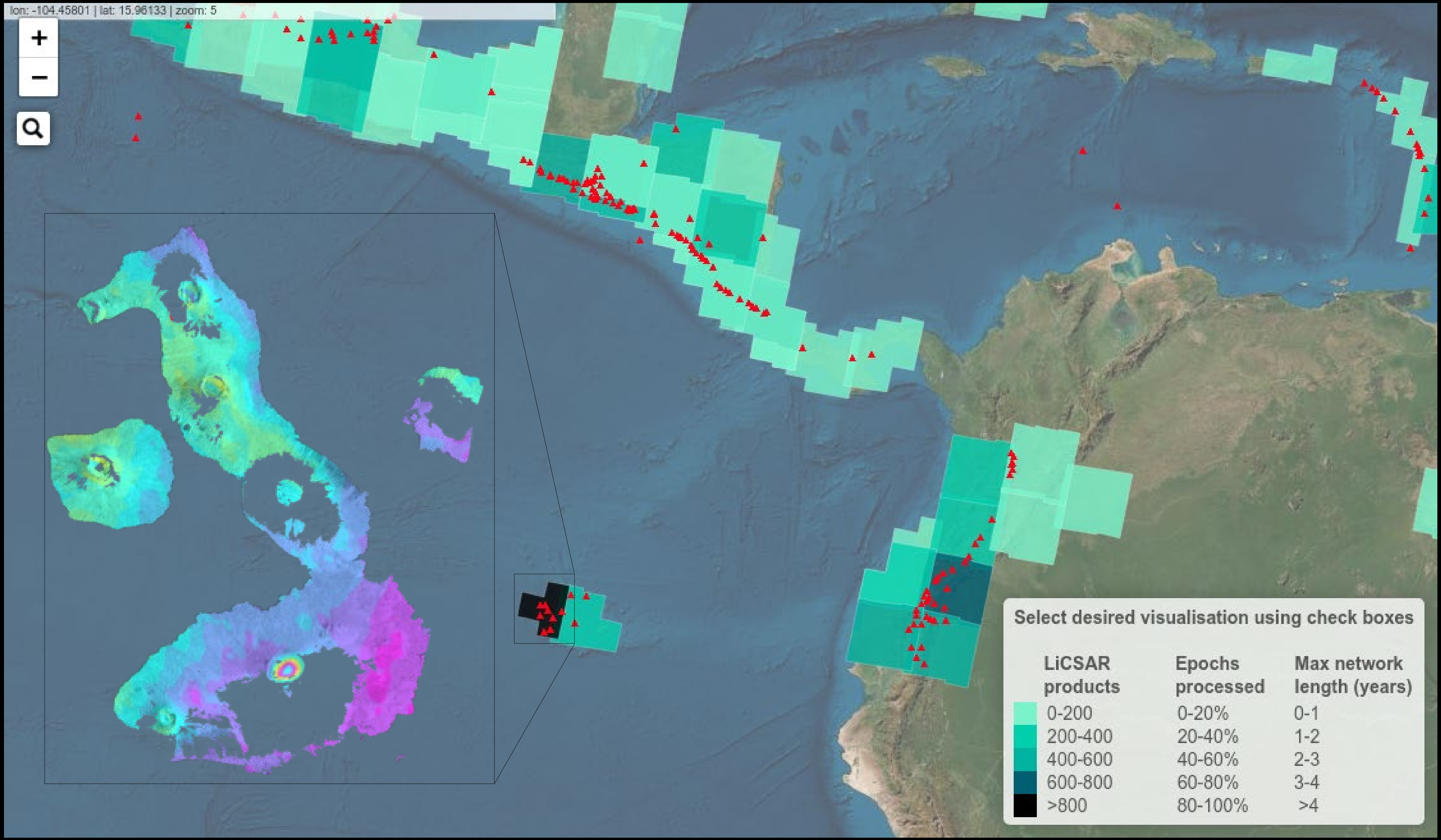
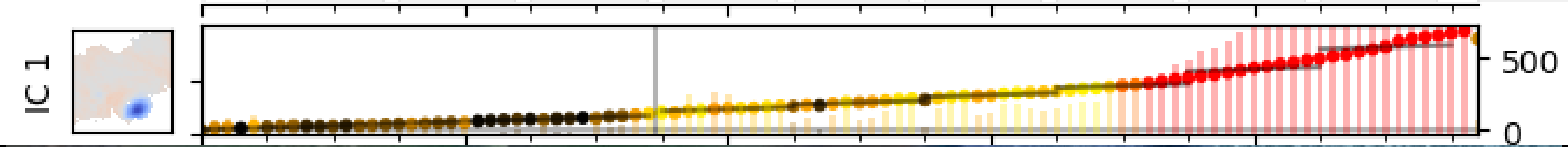


Previous results: isolating large deformation and detecting changes in rate



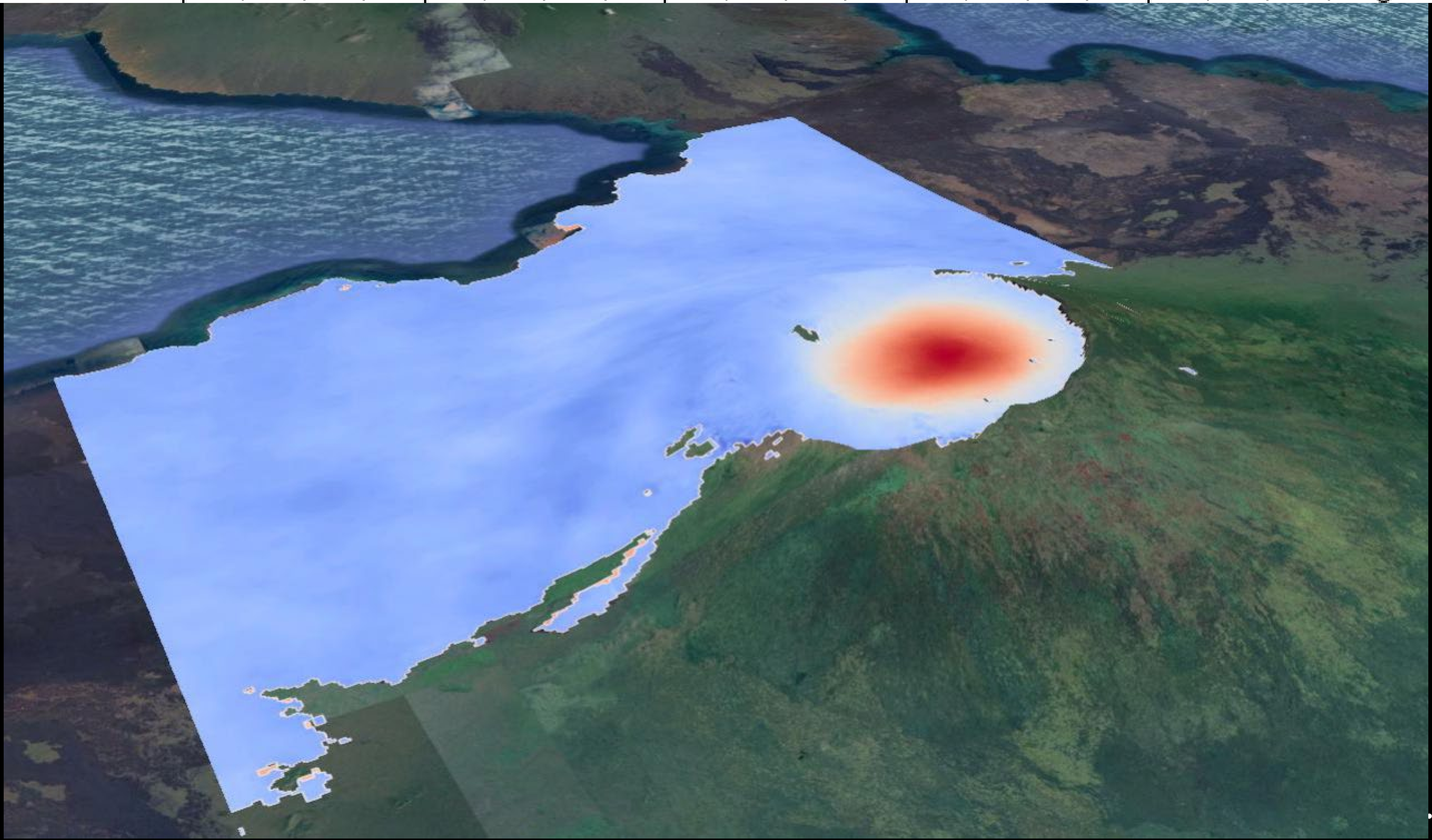
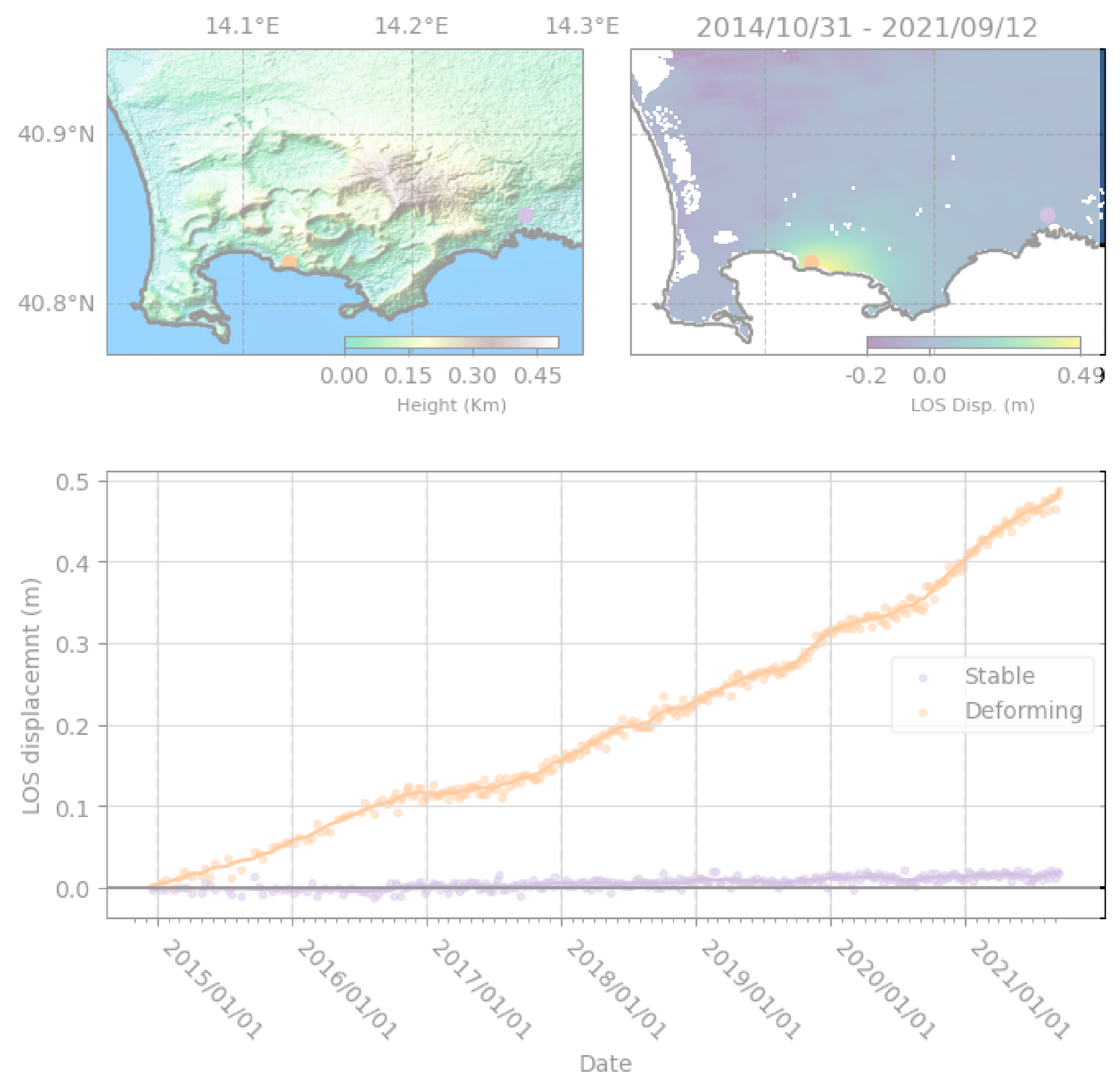


Image: Google Earth

Our new monitoring algorithm: LiCSAlert

- **Increase the variance of deformation signals to recover them.**
- Apply ICA temporally at stratovolcanoes.
- Visualise status for large number of volcanoes (using deep learning).
- Apply globally by implementing on JASMIN computing system



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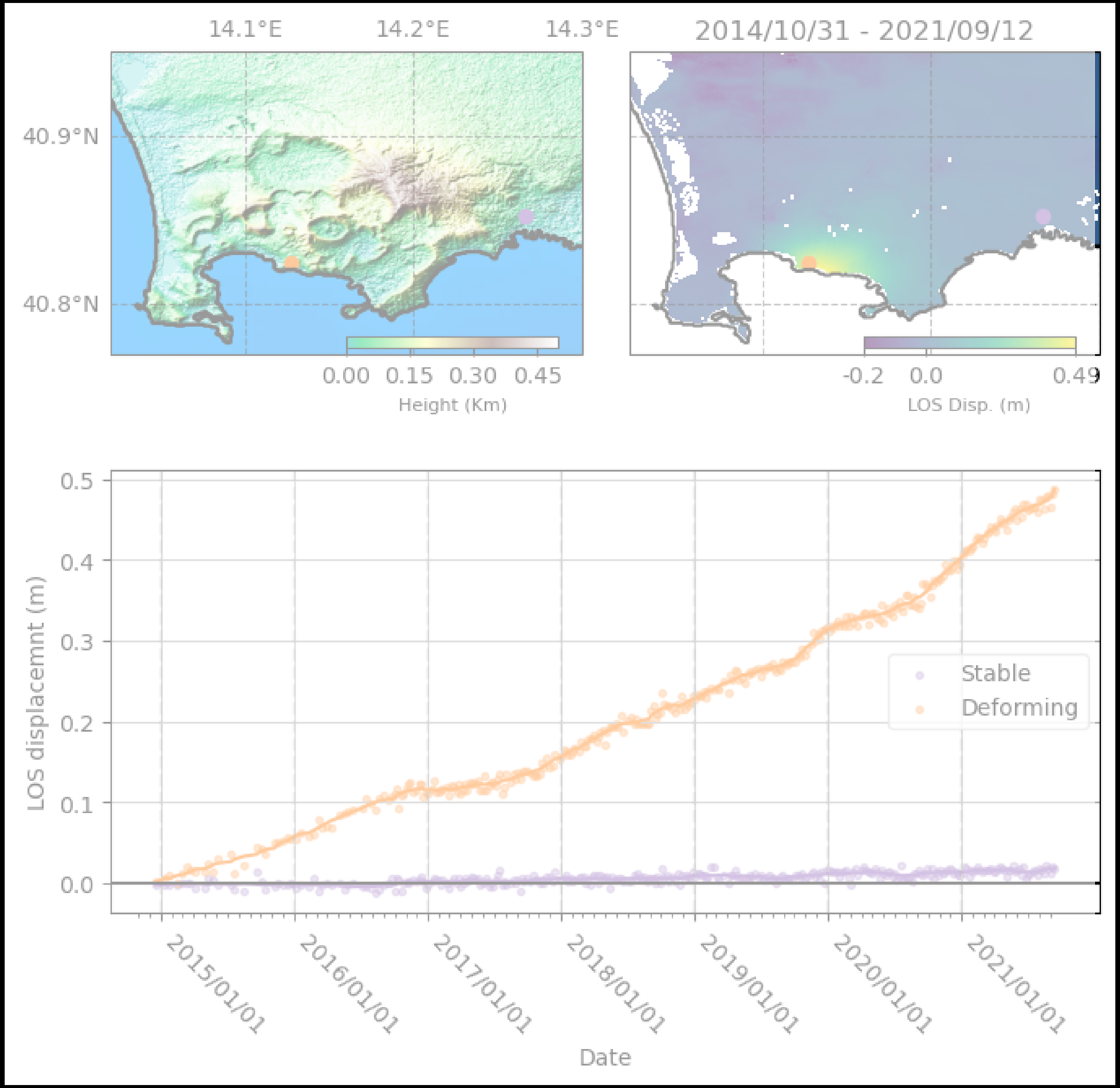

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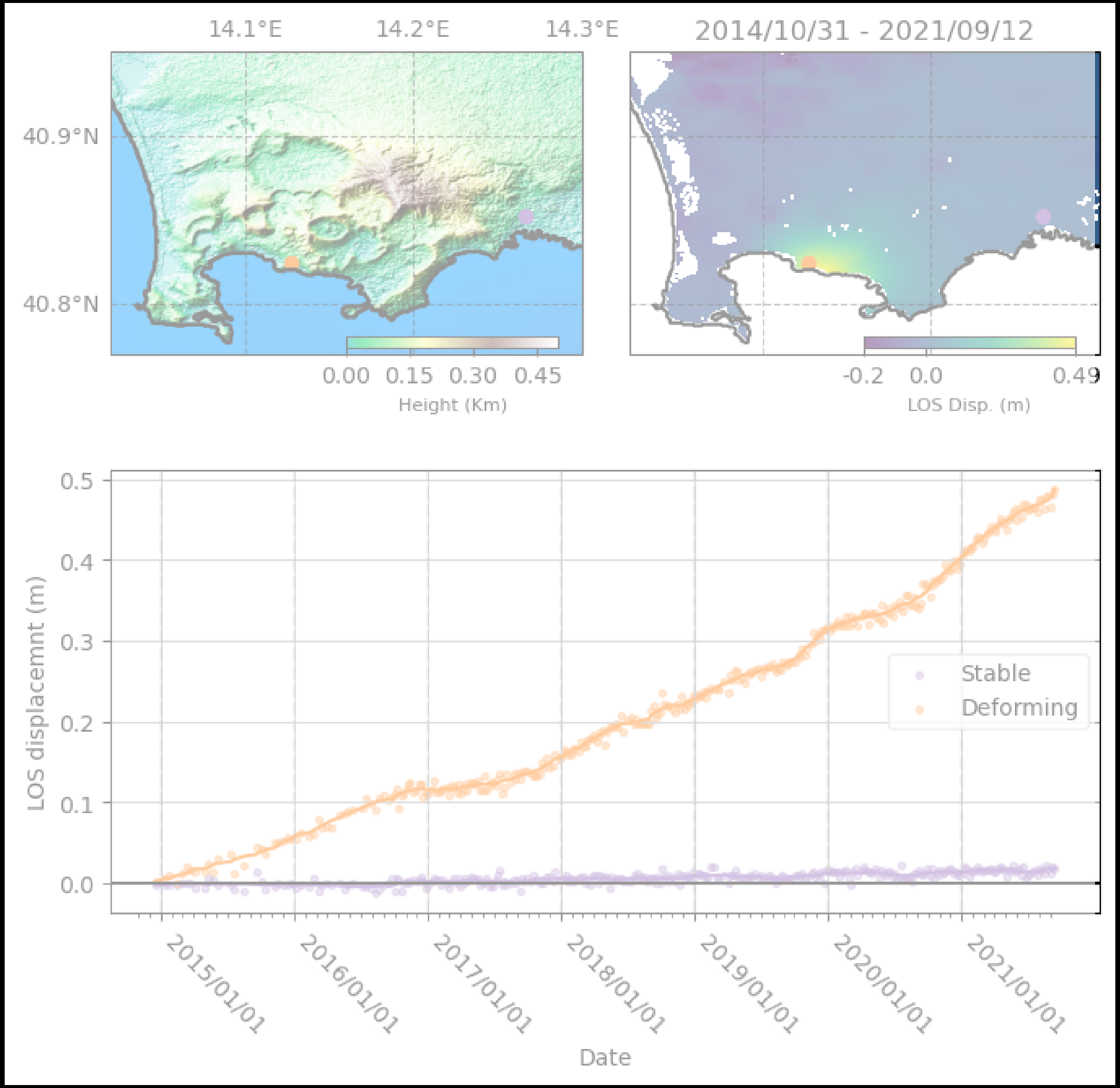

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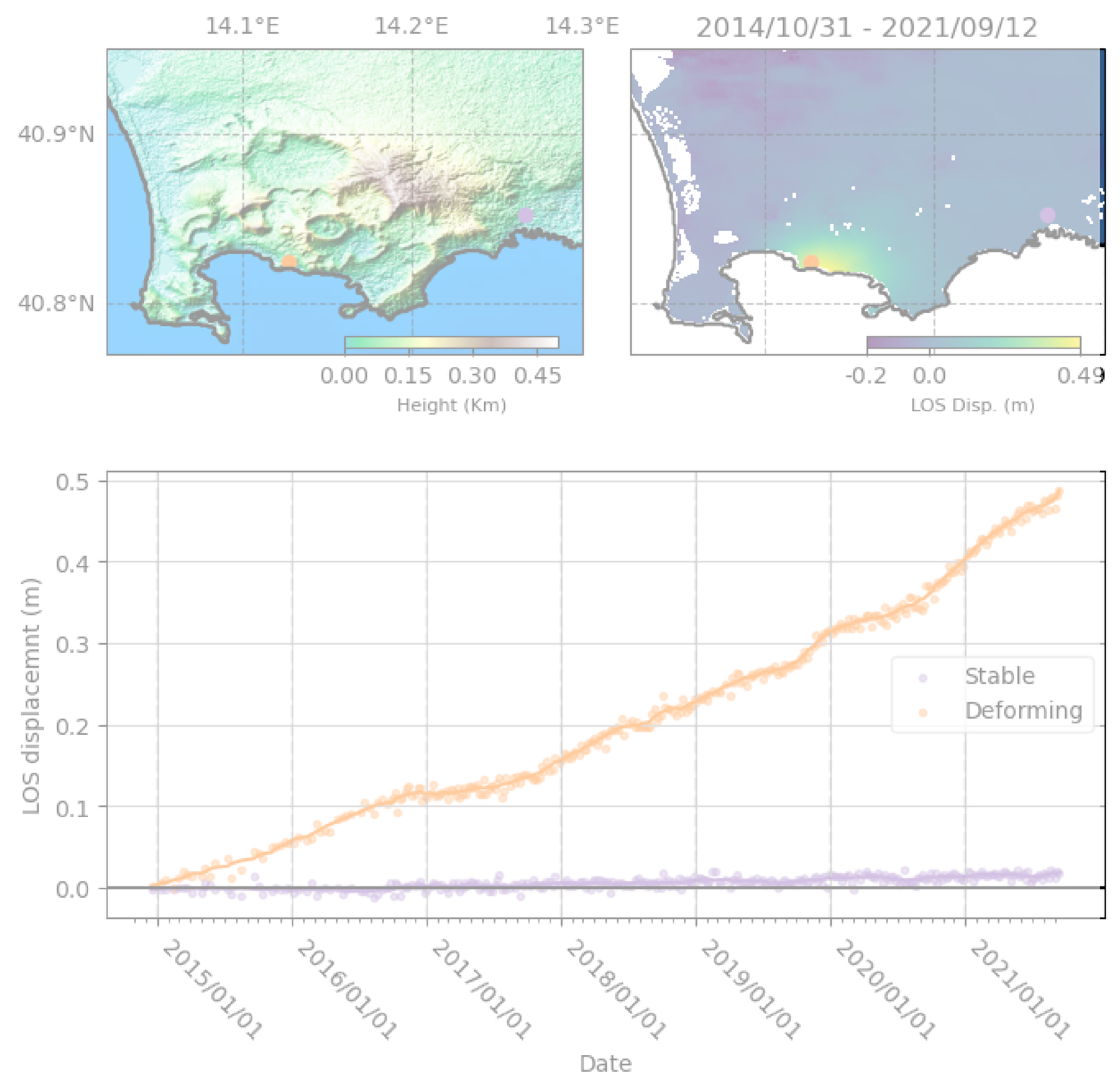

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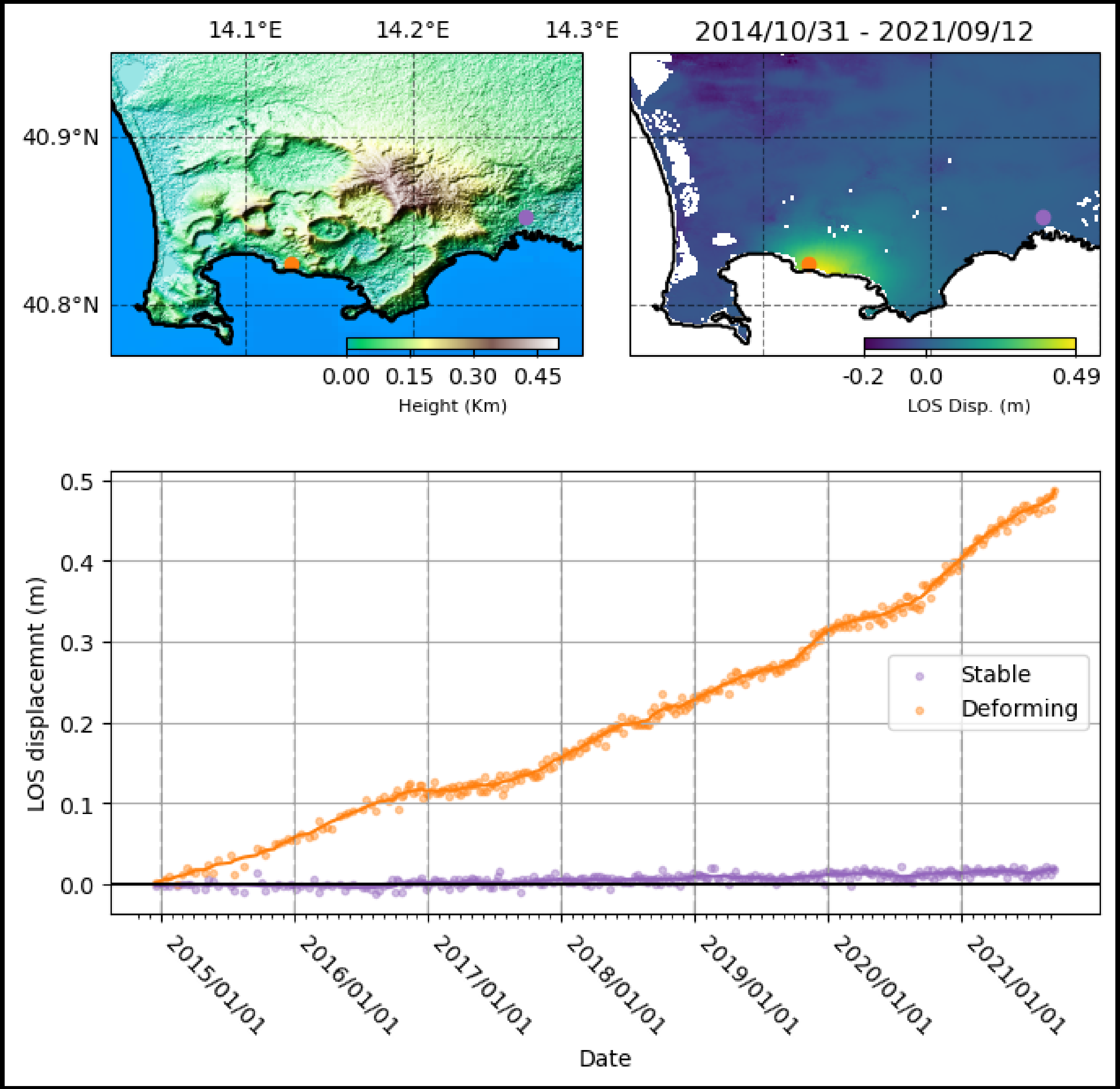

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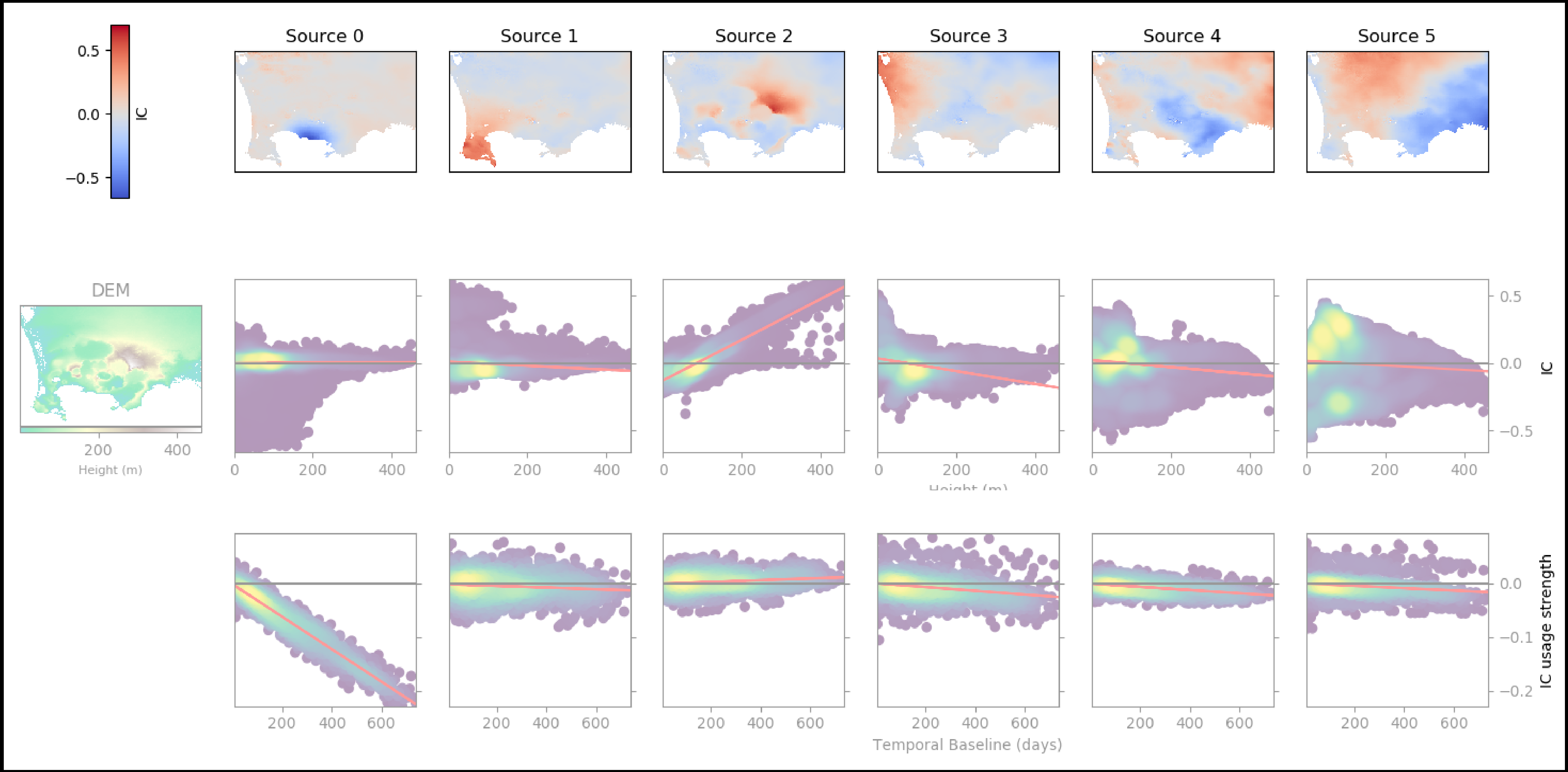
LiCSAlert: ICA to isolate deformation from noise (atmosphere)

- Create a network of interferograms that maximises deformation variance.



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IC to DEM correlations

IC use vs temporal baseline

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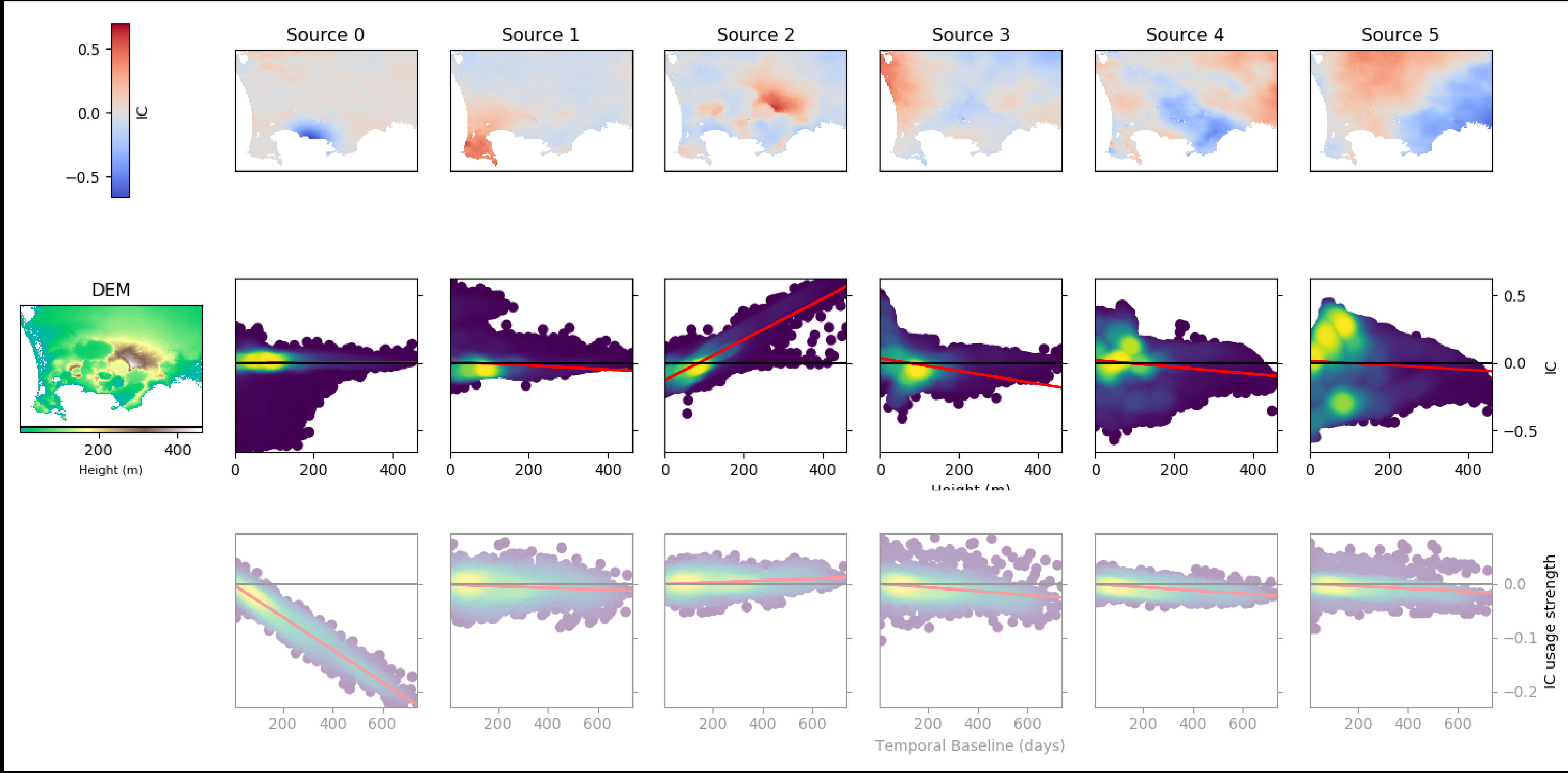

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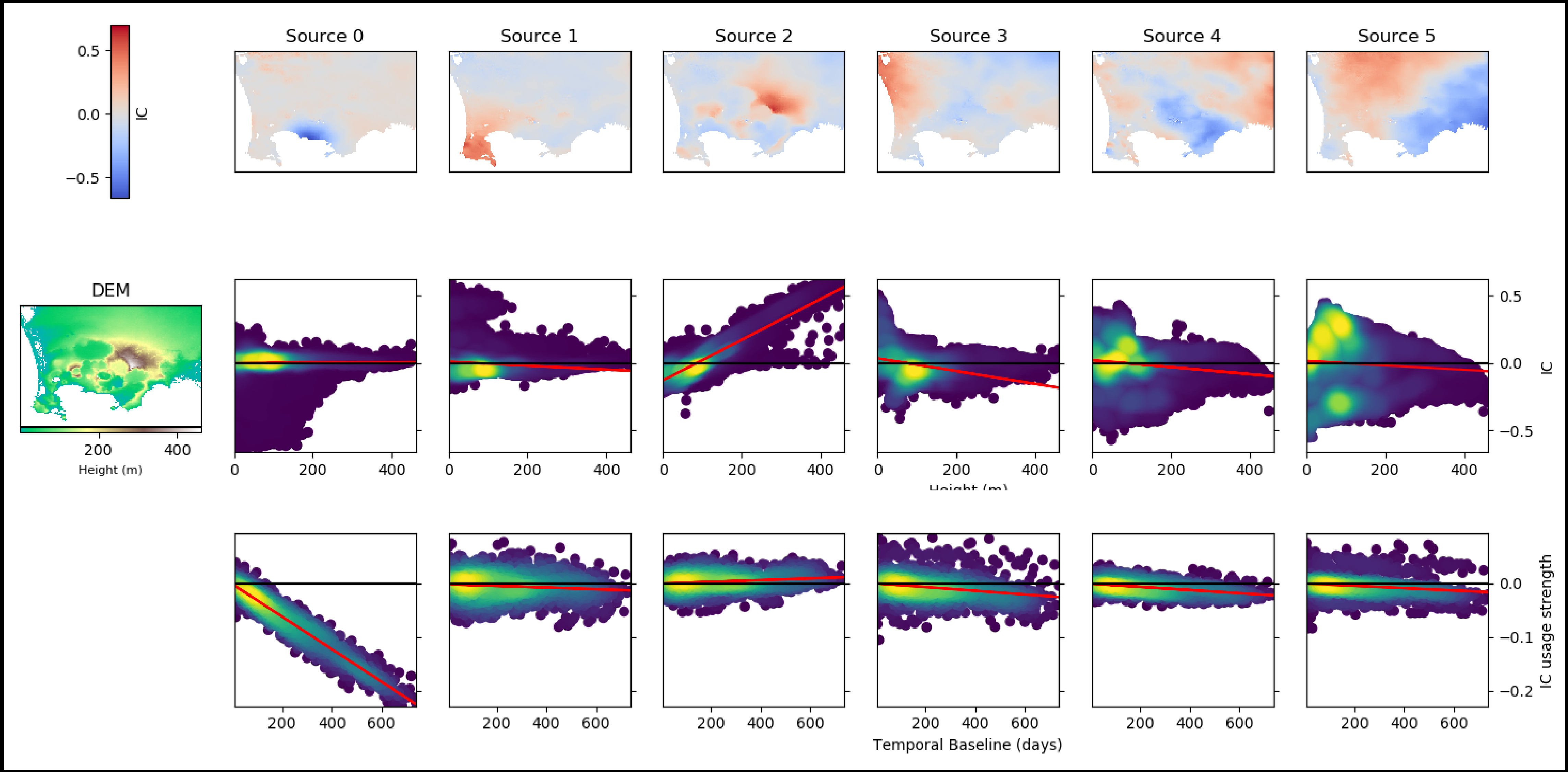

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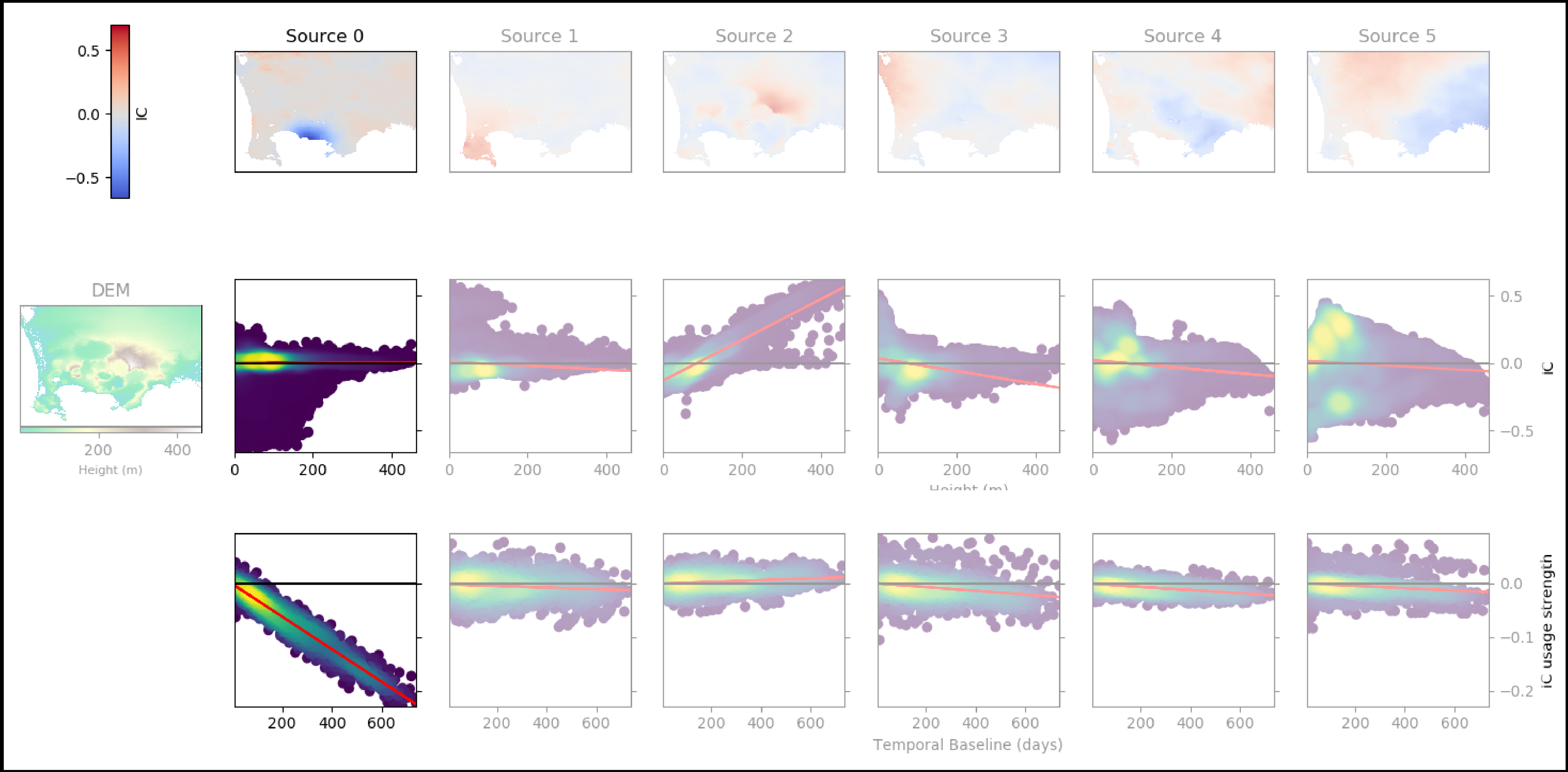

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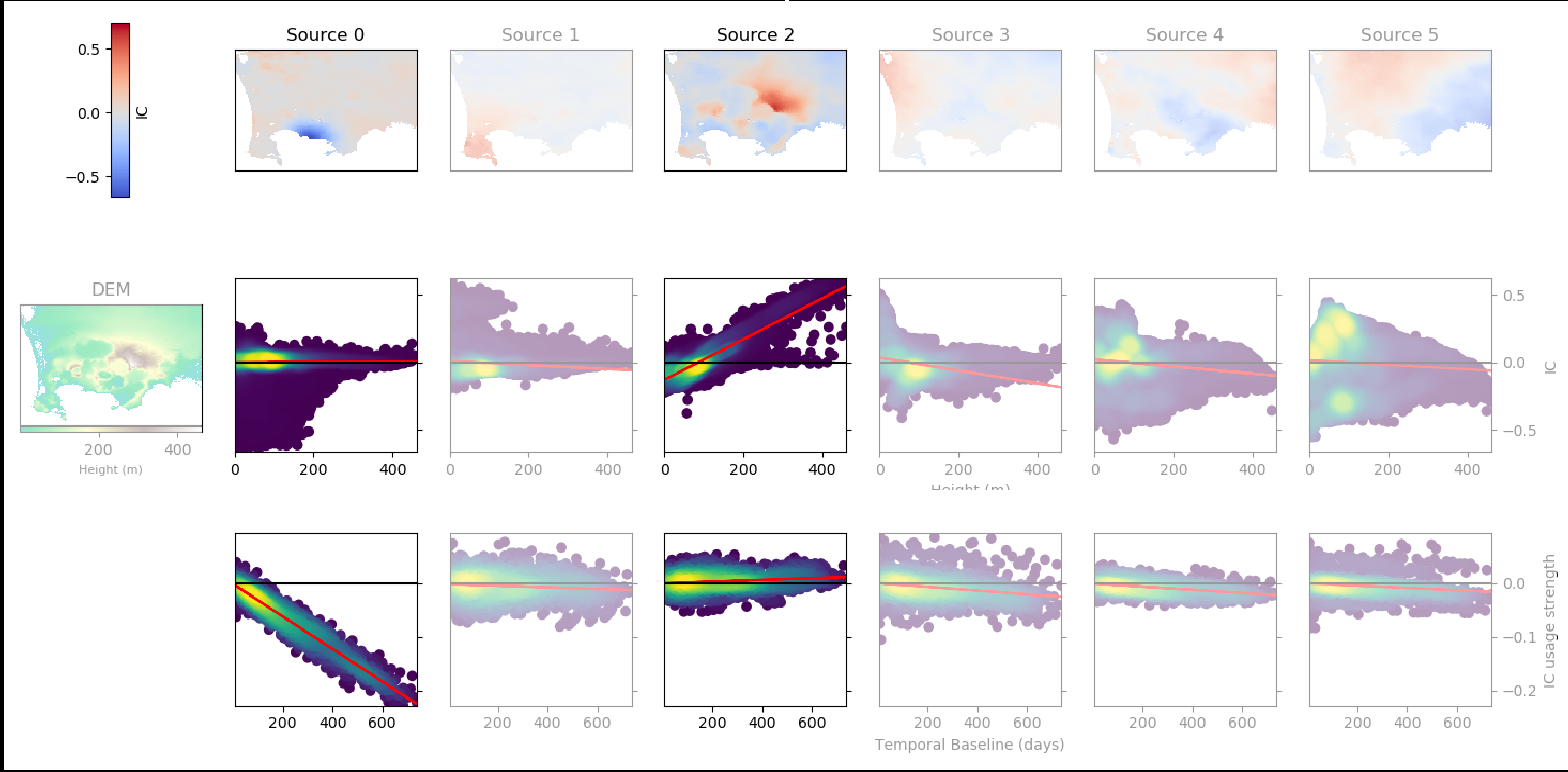
Deformation

Topographically correlated atmosphere



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- **Use ICs (latent sources) from ICA step.**
- Take a baseline stage of 1-2 years.
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- Record residual of fit.
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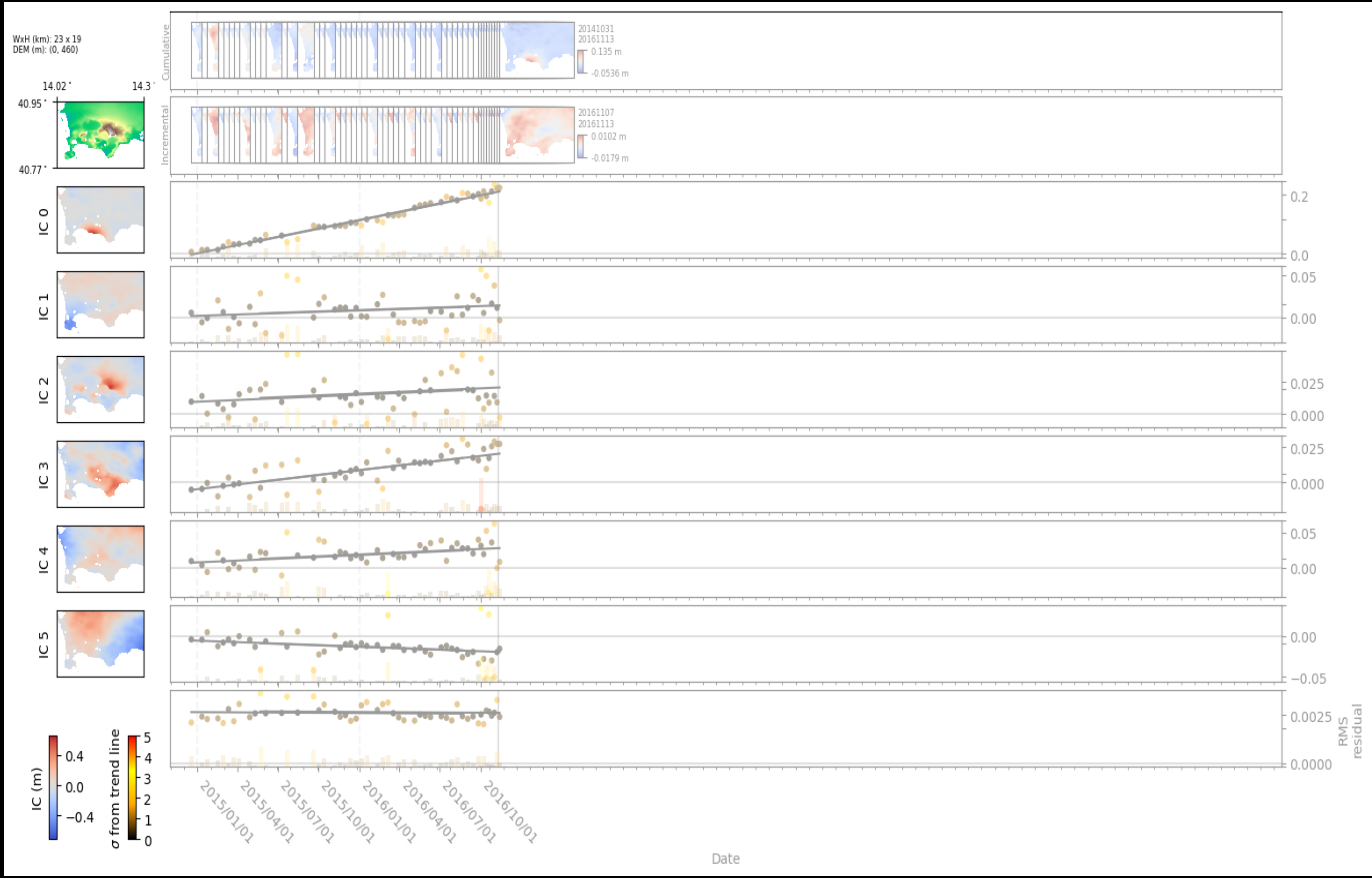

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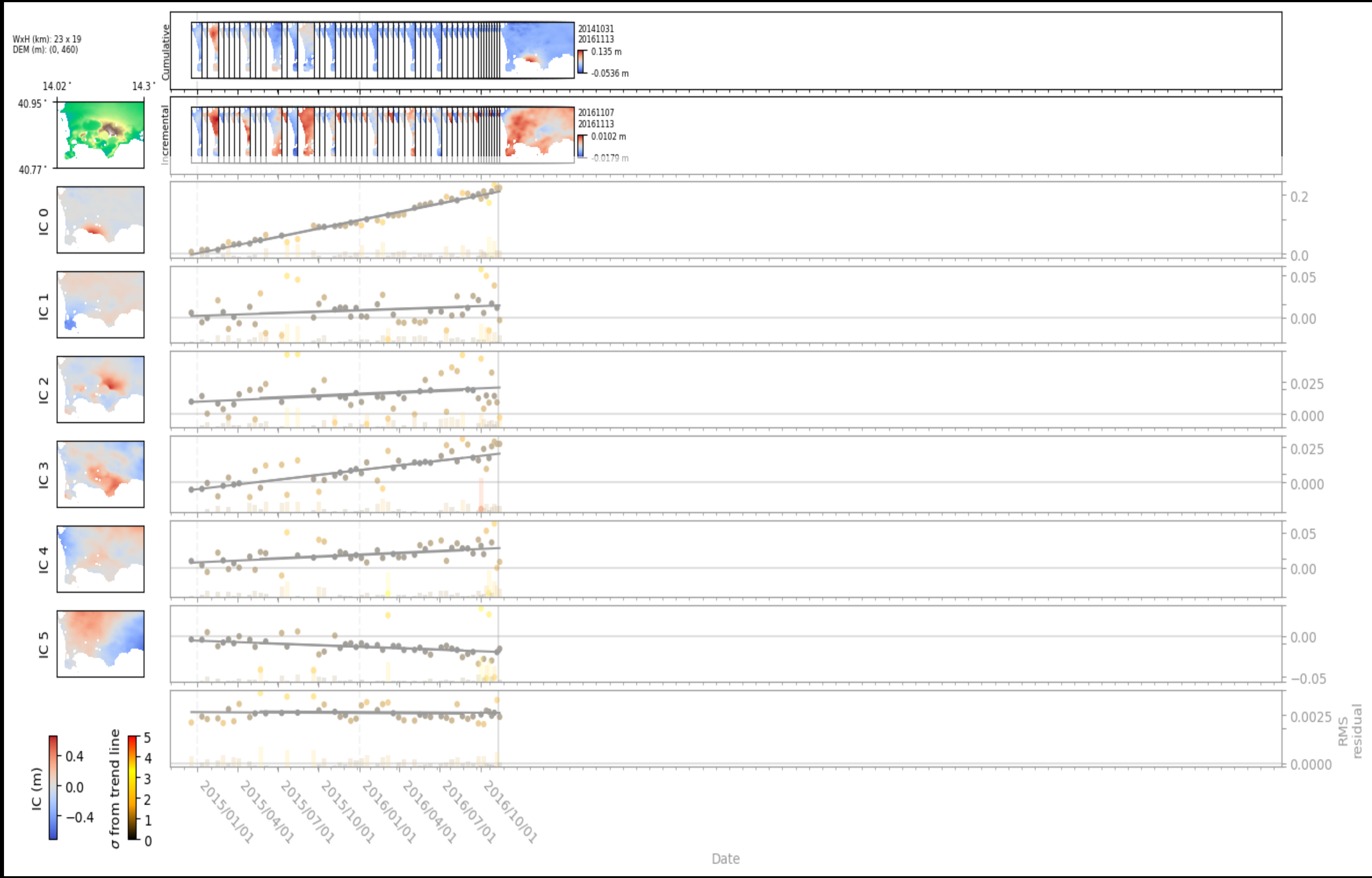

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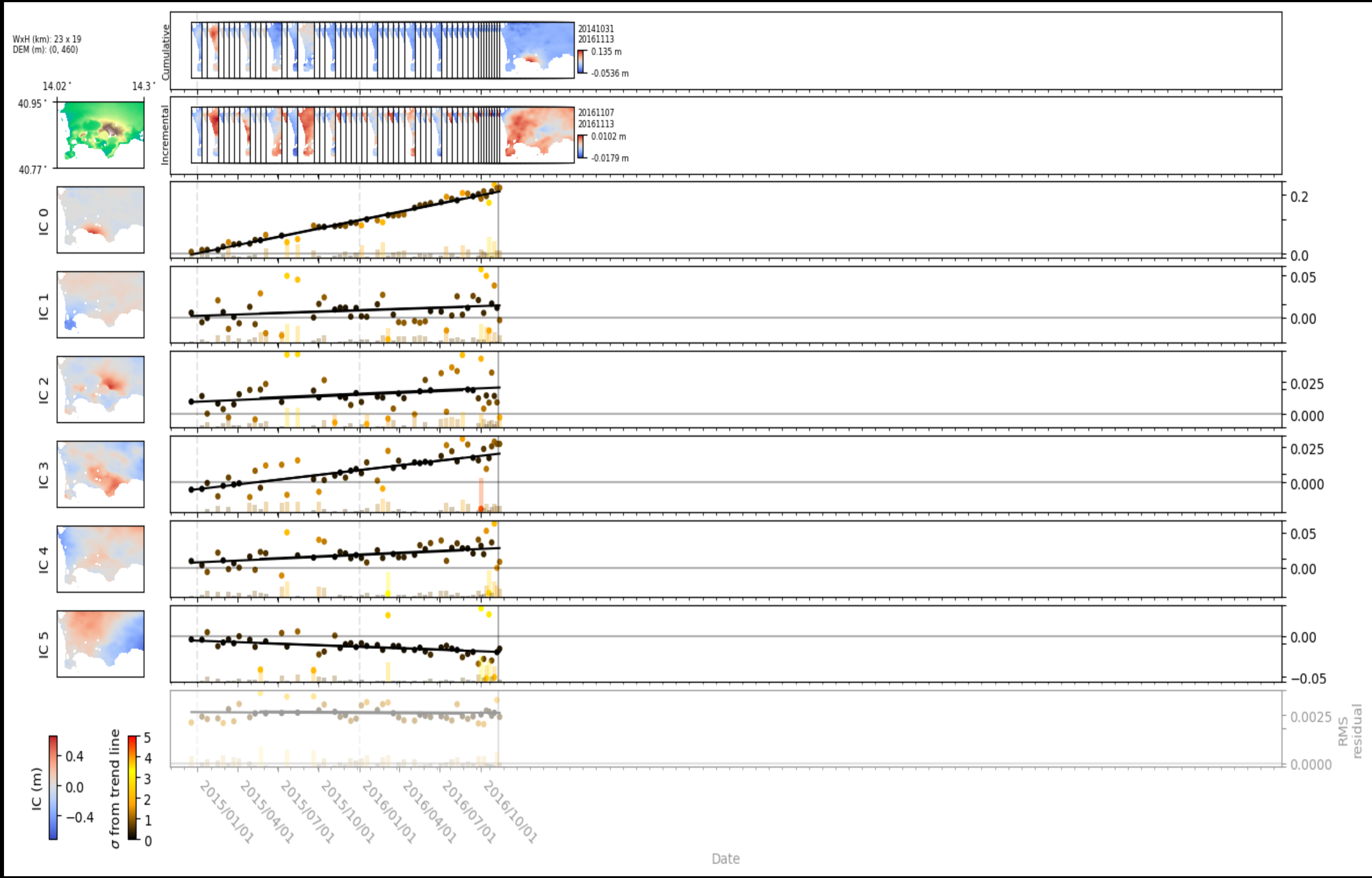

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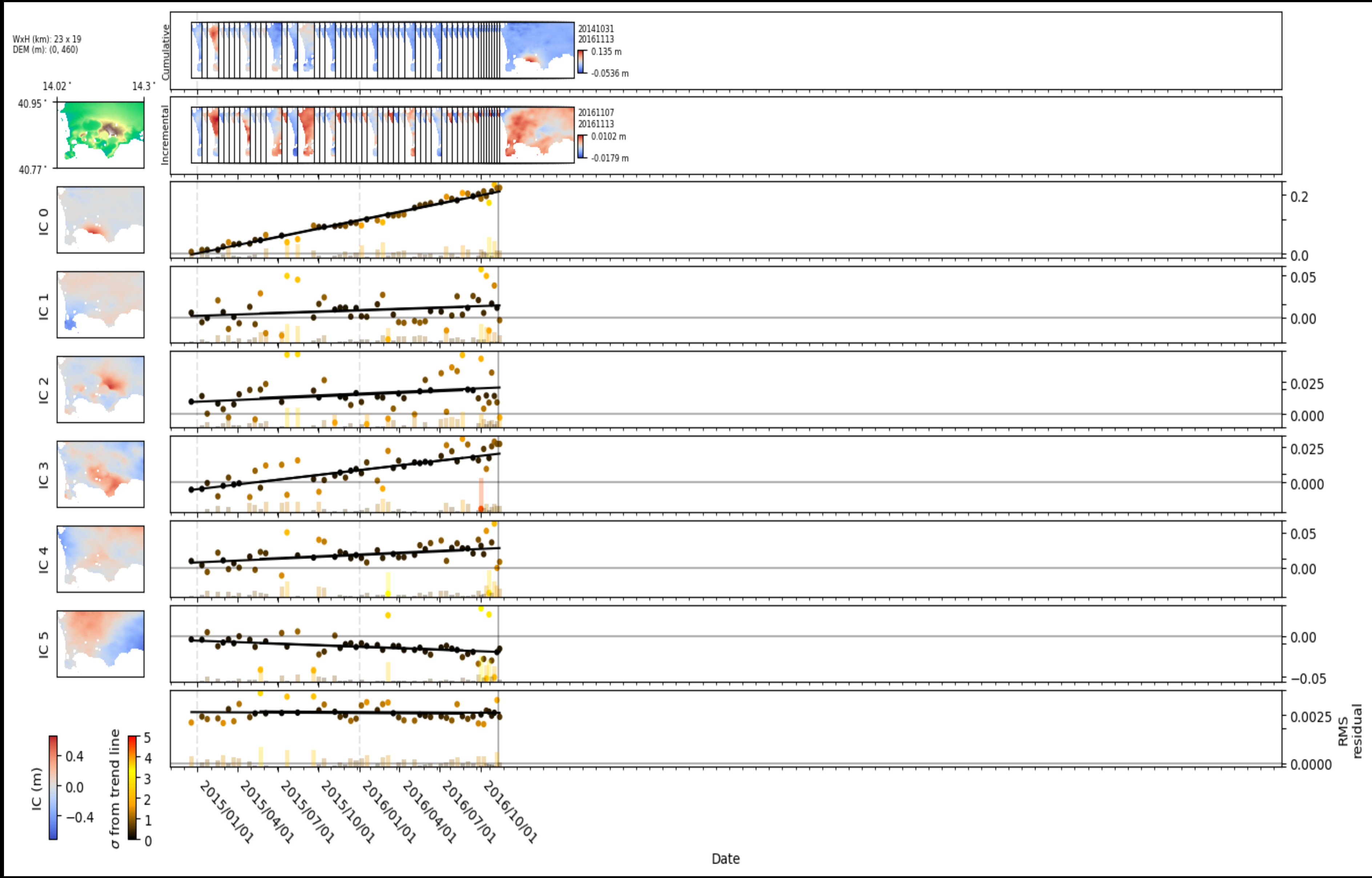

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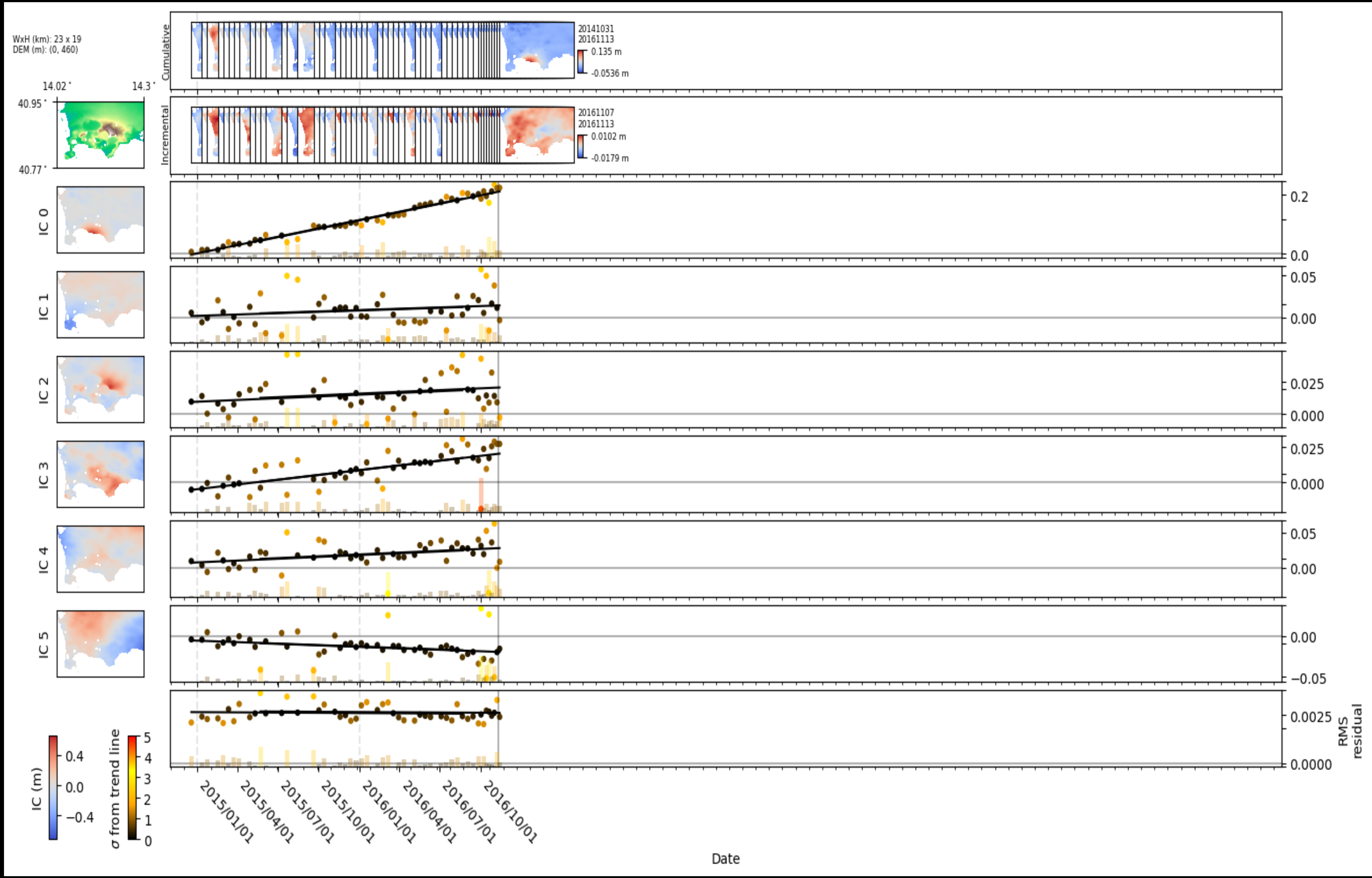

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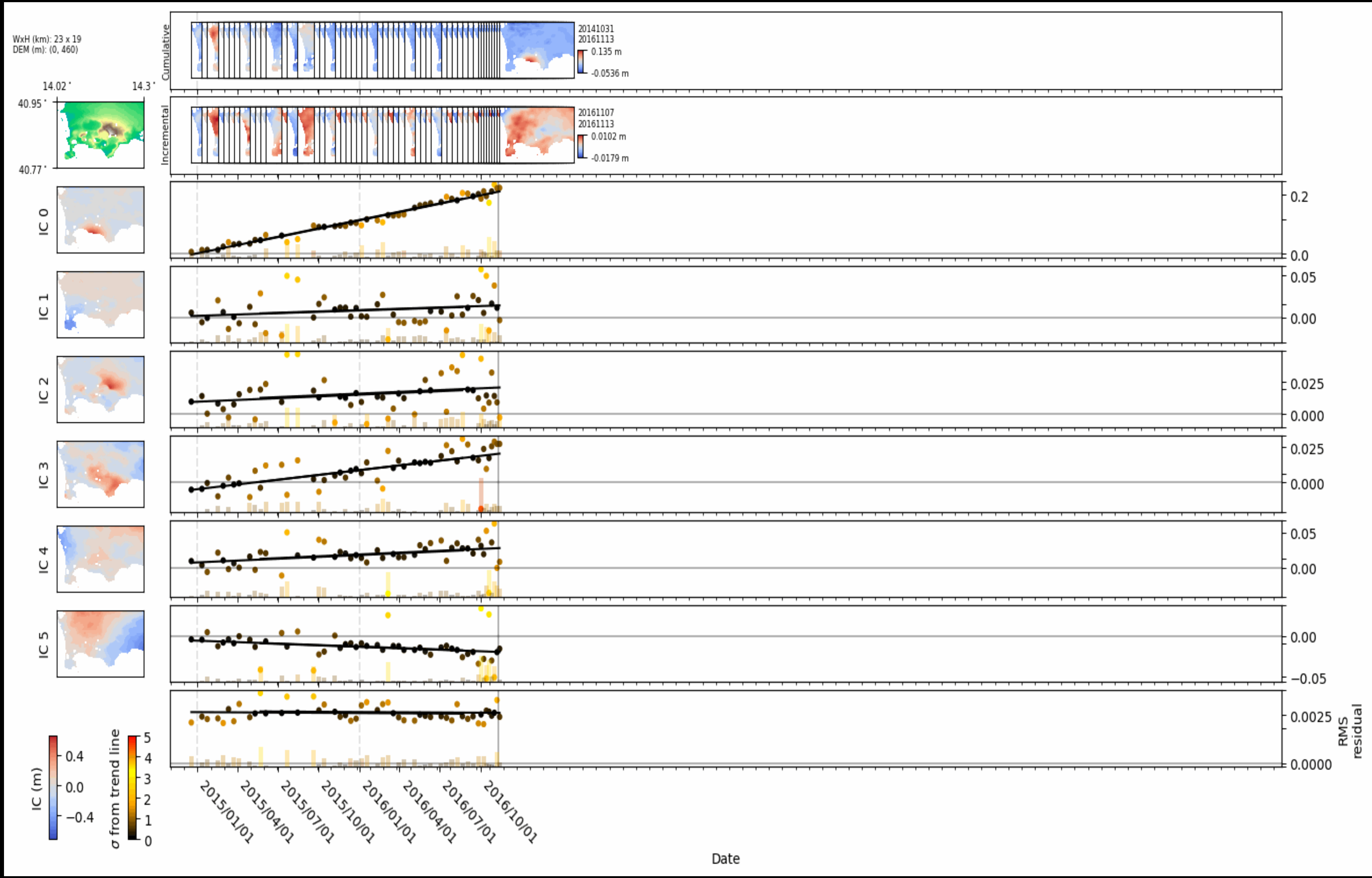

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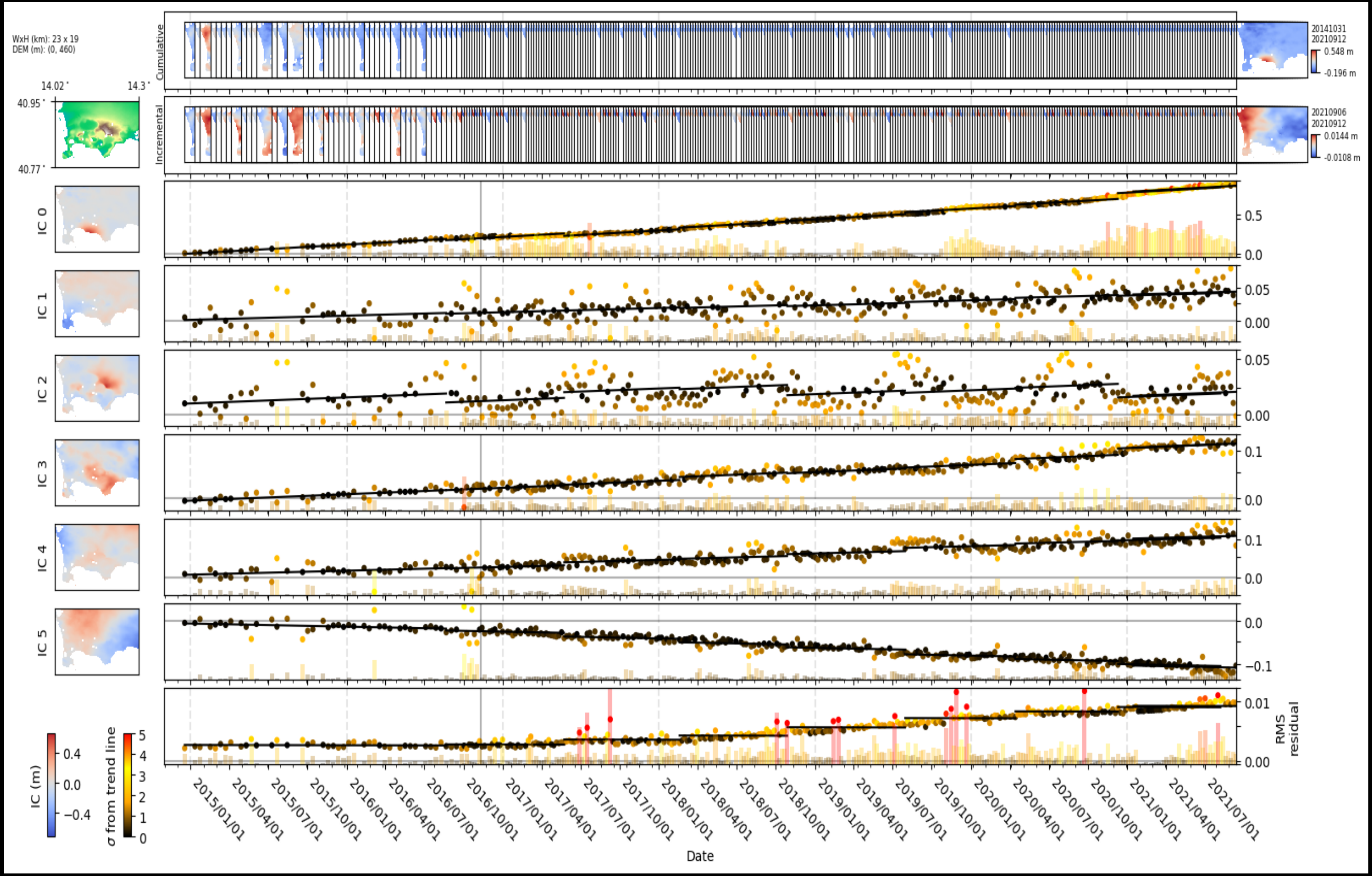

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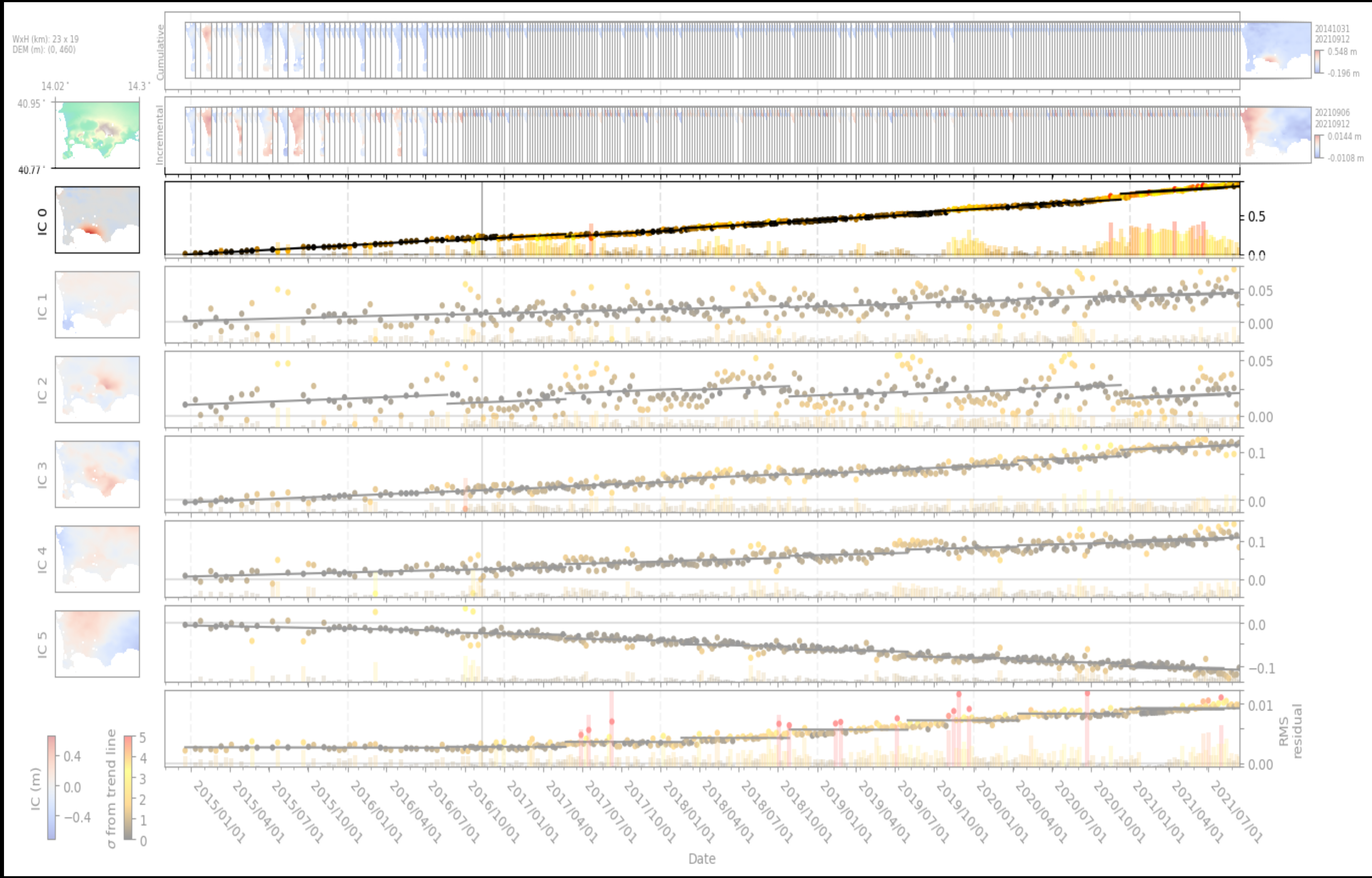

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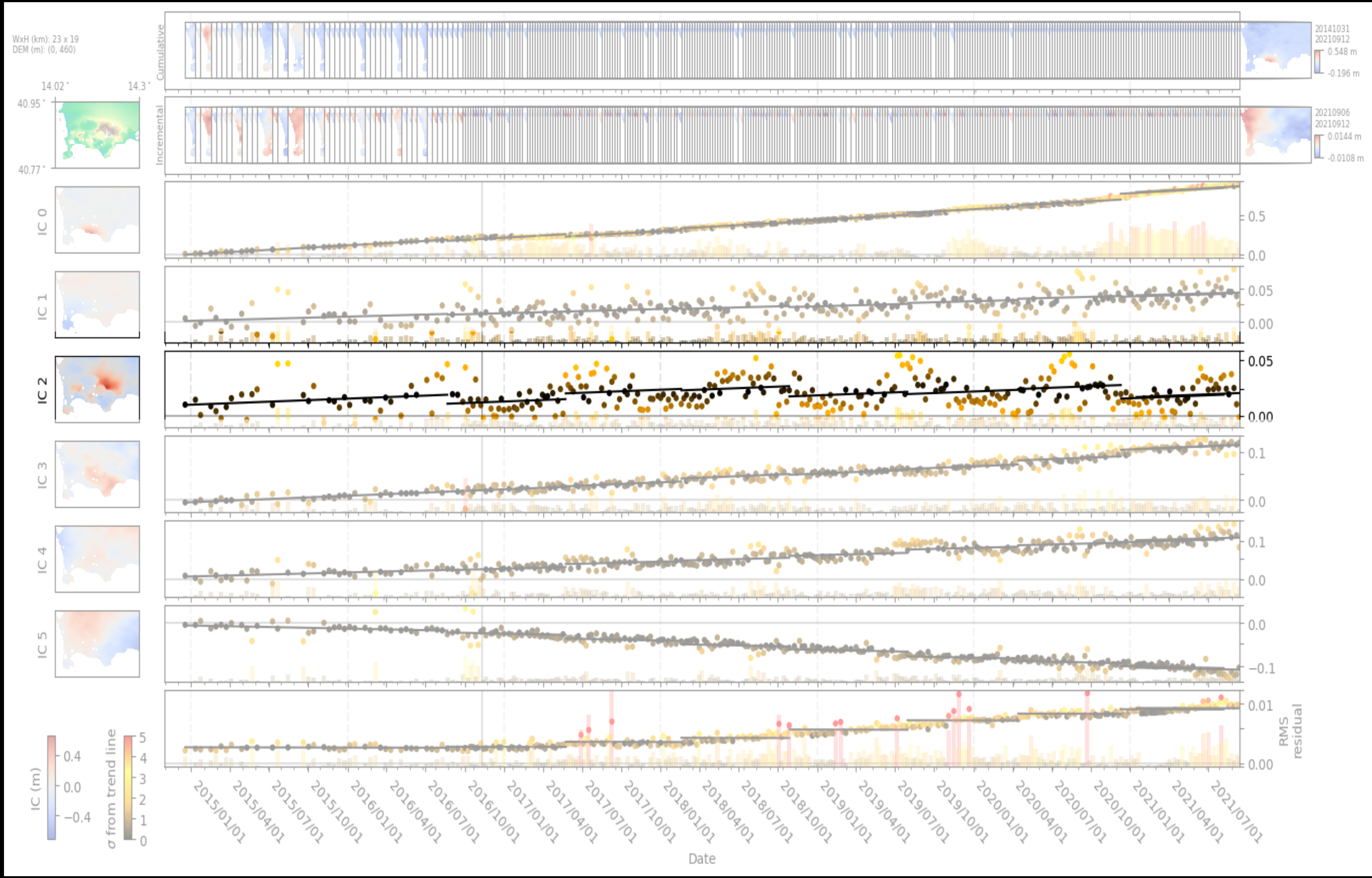

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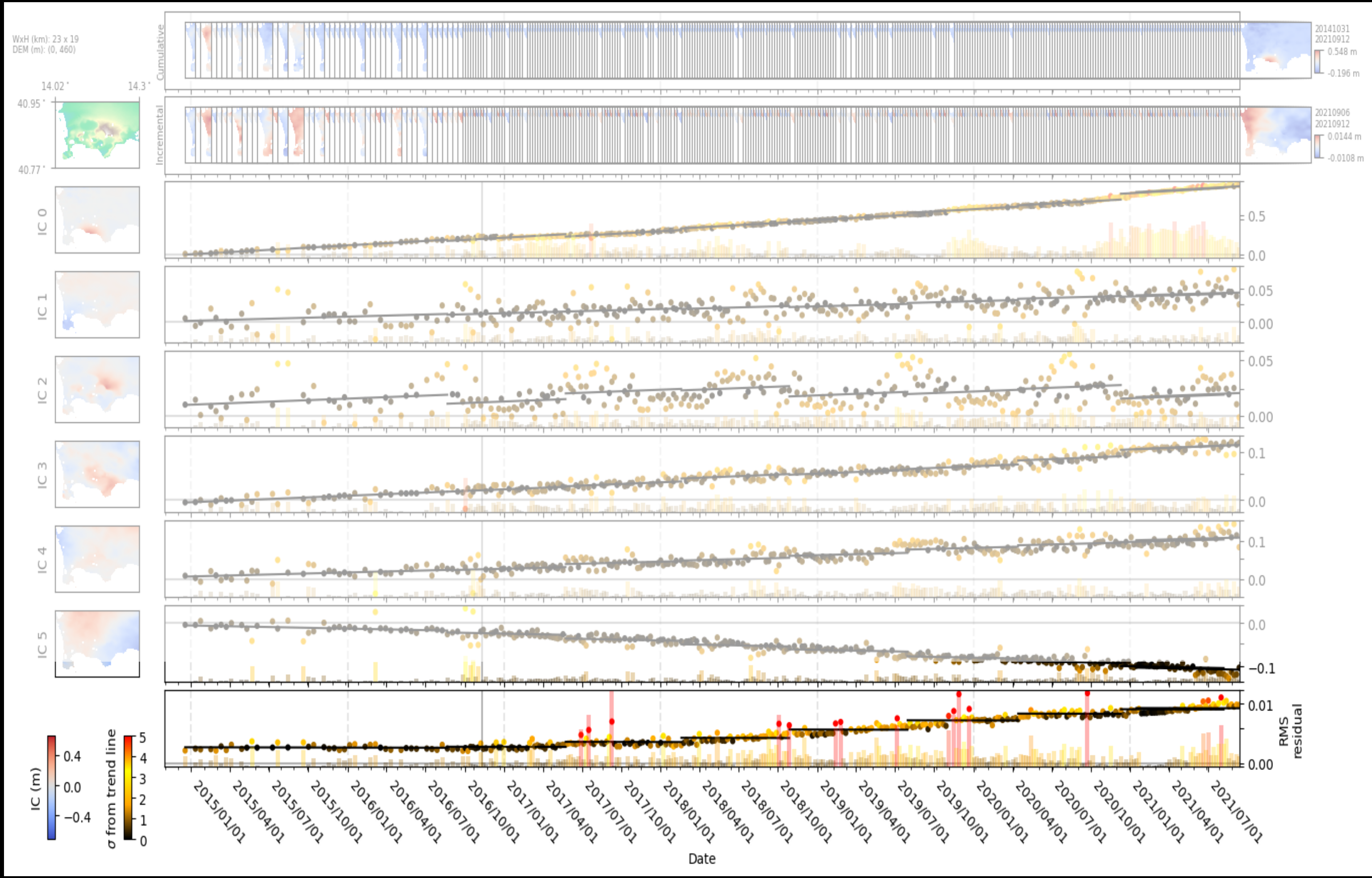

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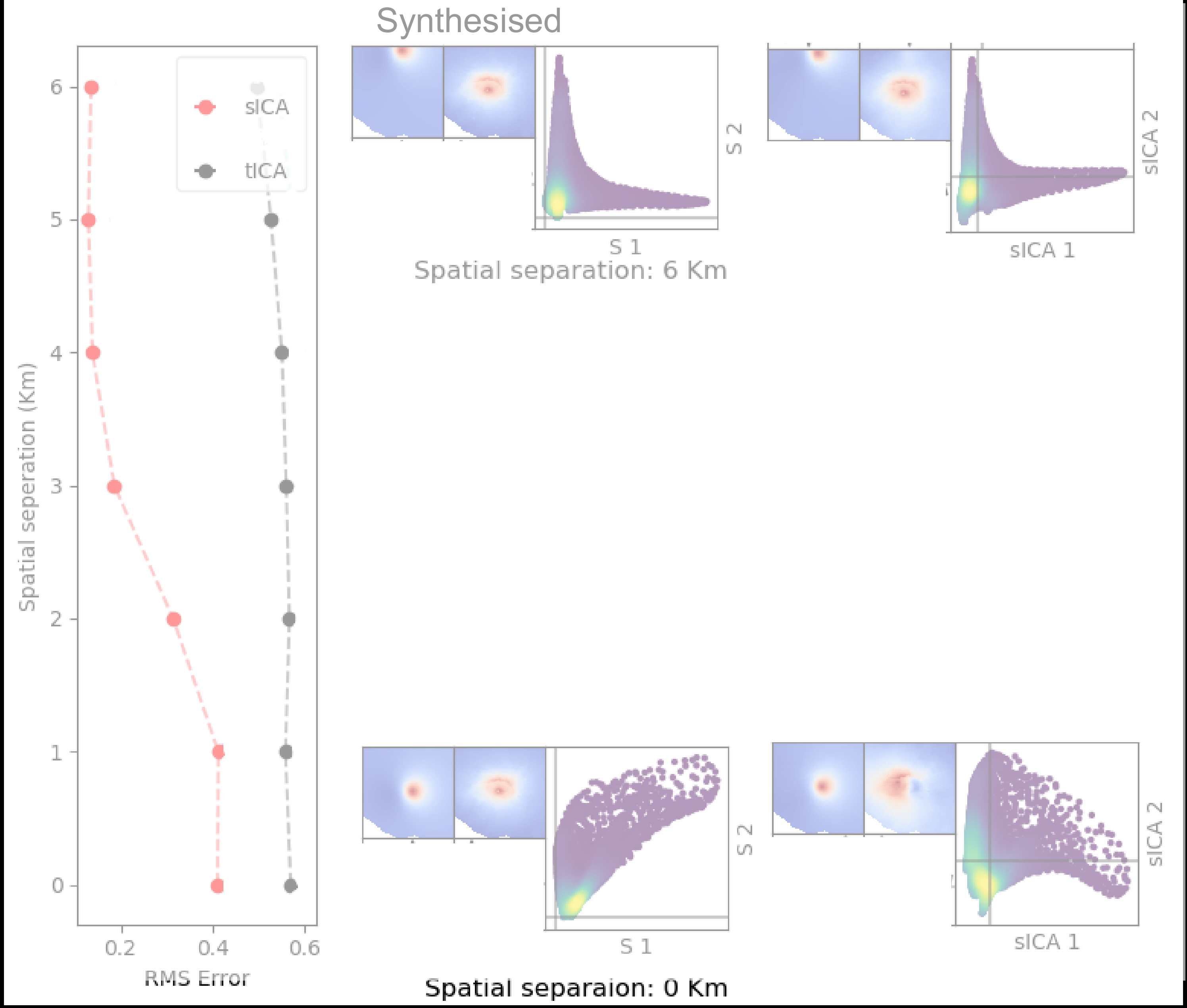
At stratovolcanoes, sICA often works poorly

- **How non-Gaussian are signals in time/space?**
- How independent are signals in time/space?
- How many samples do we have in space (pixels) vs in time (acquisitions)?
- Synthetic example where we vary the spatial independence.

  → Non-overlapping (independent) signals work well with sICA.

  → When signals overlap, sICA is not accurate.



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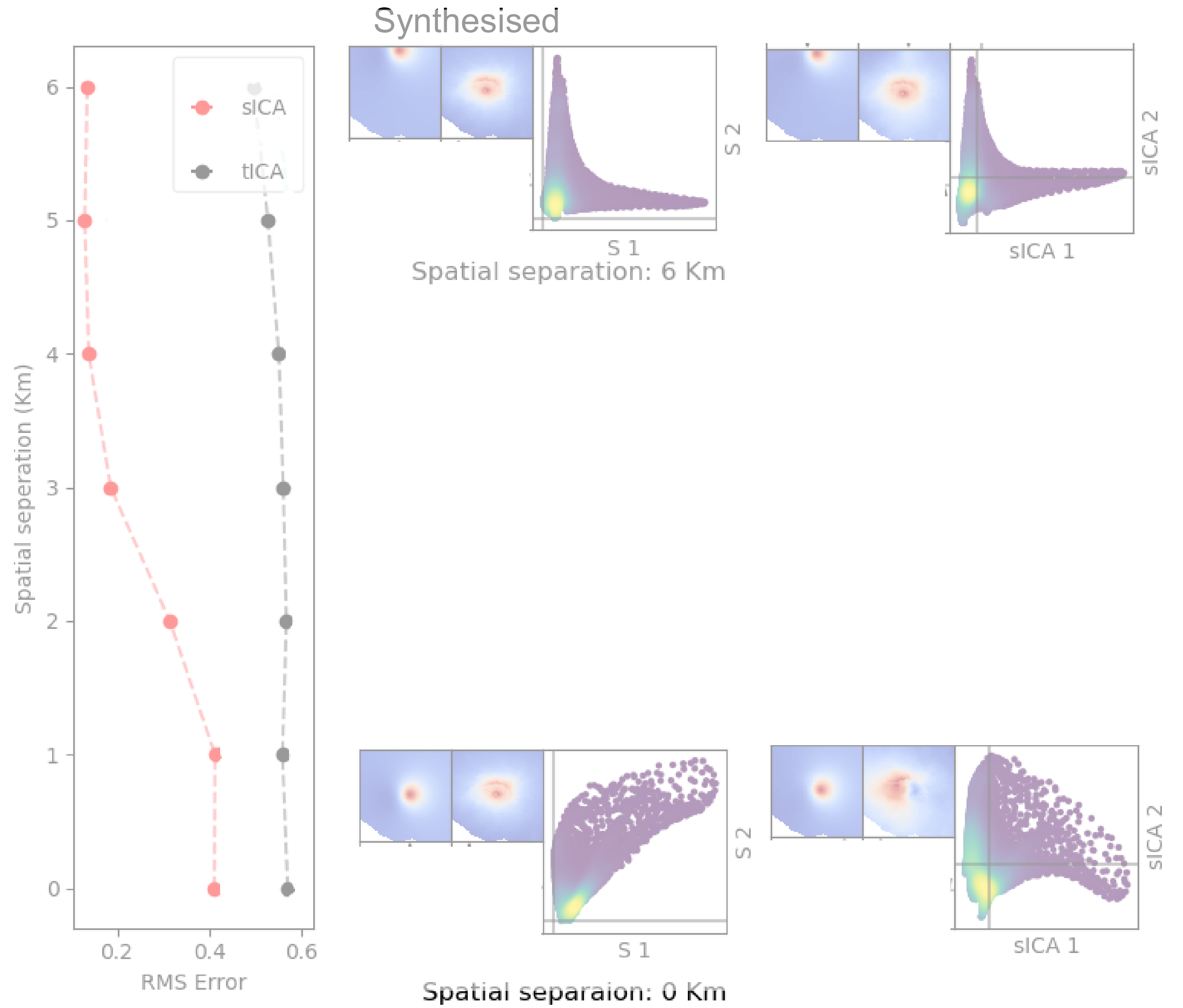

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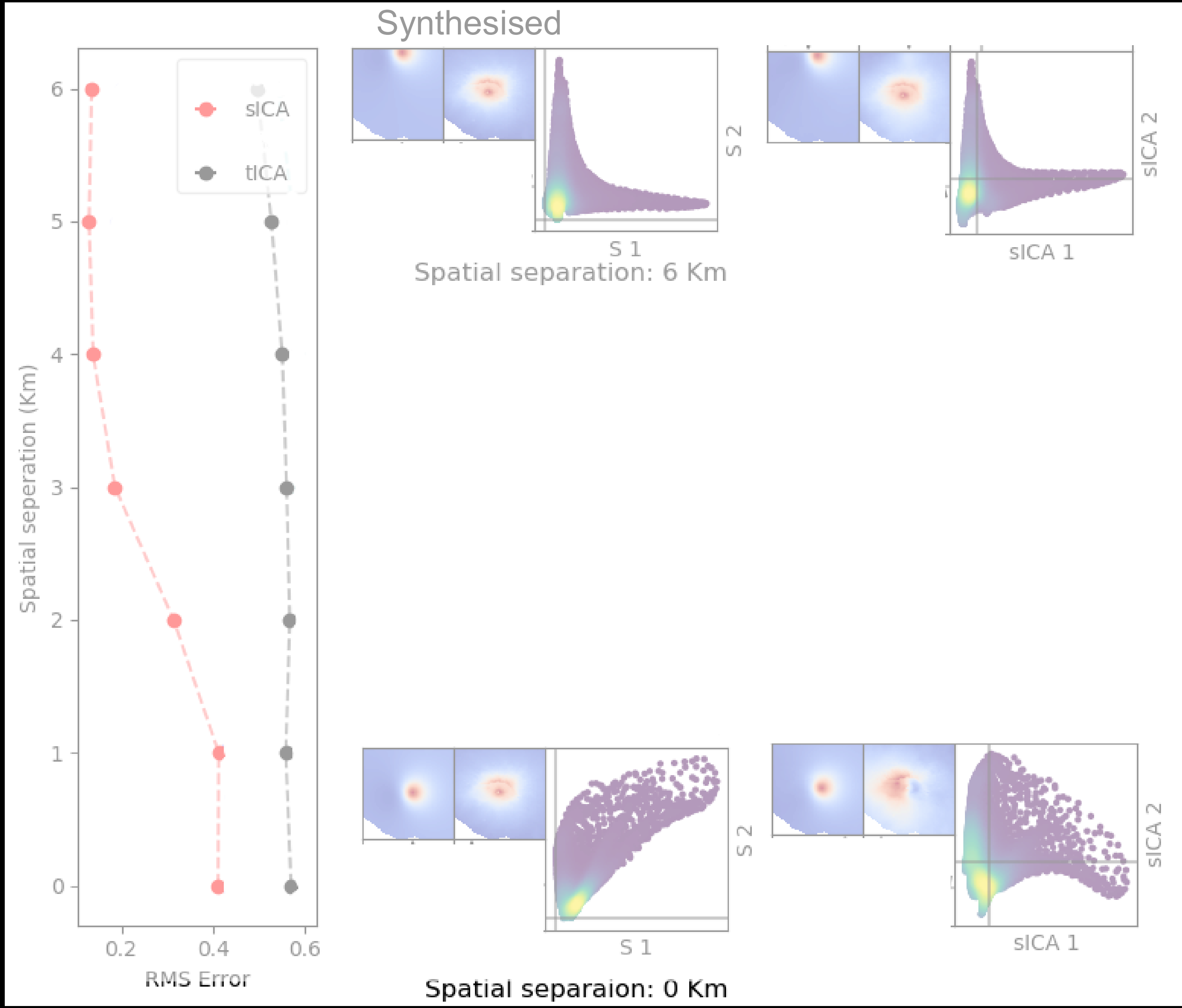

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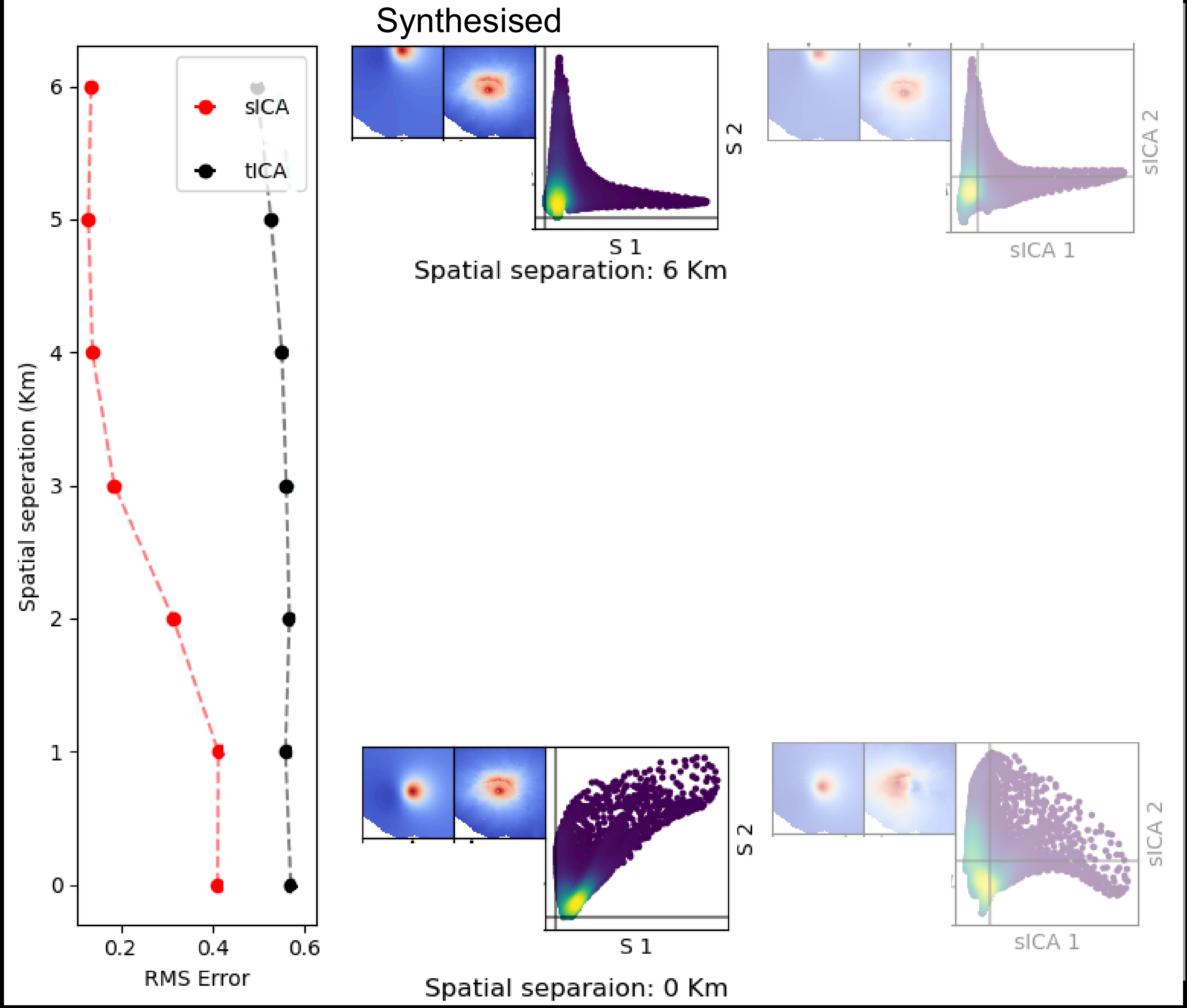

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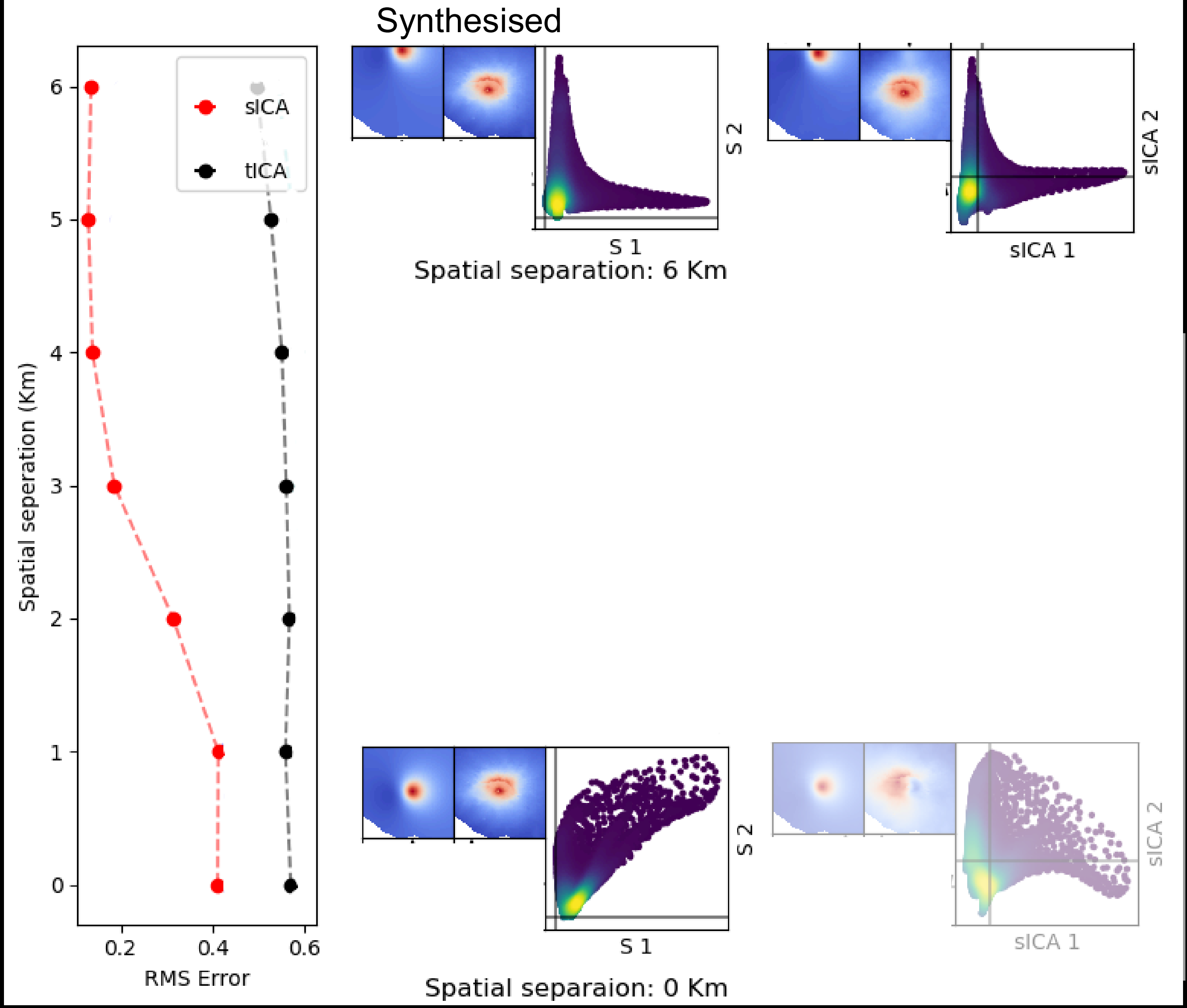

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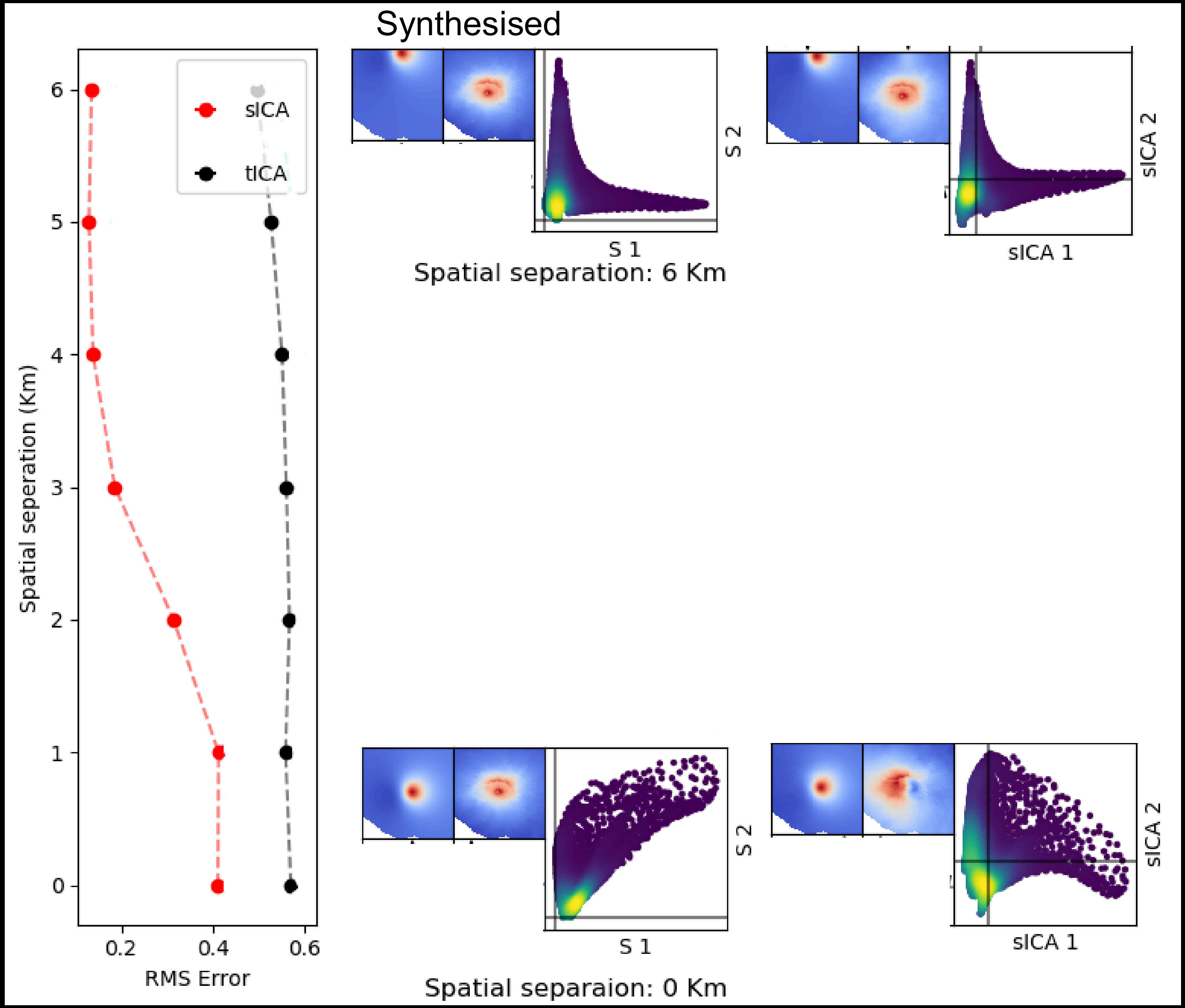

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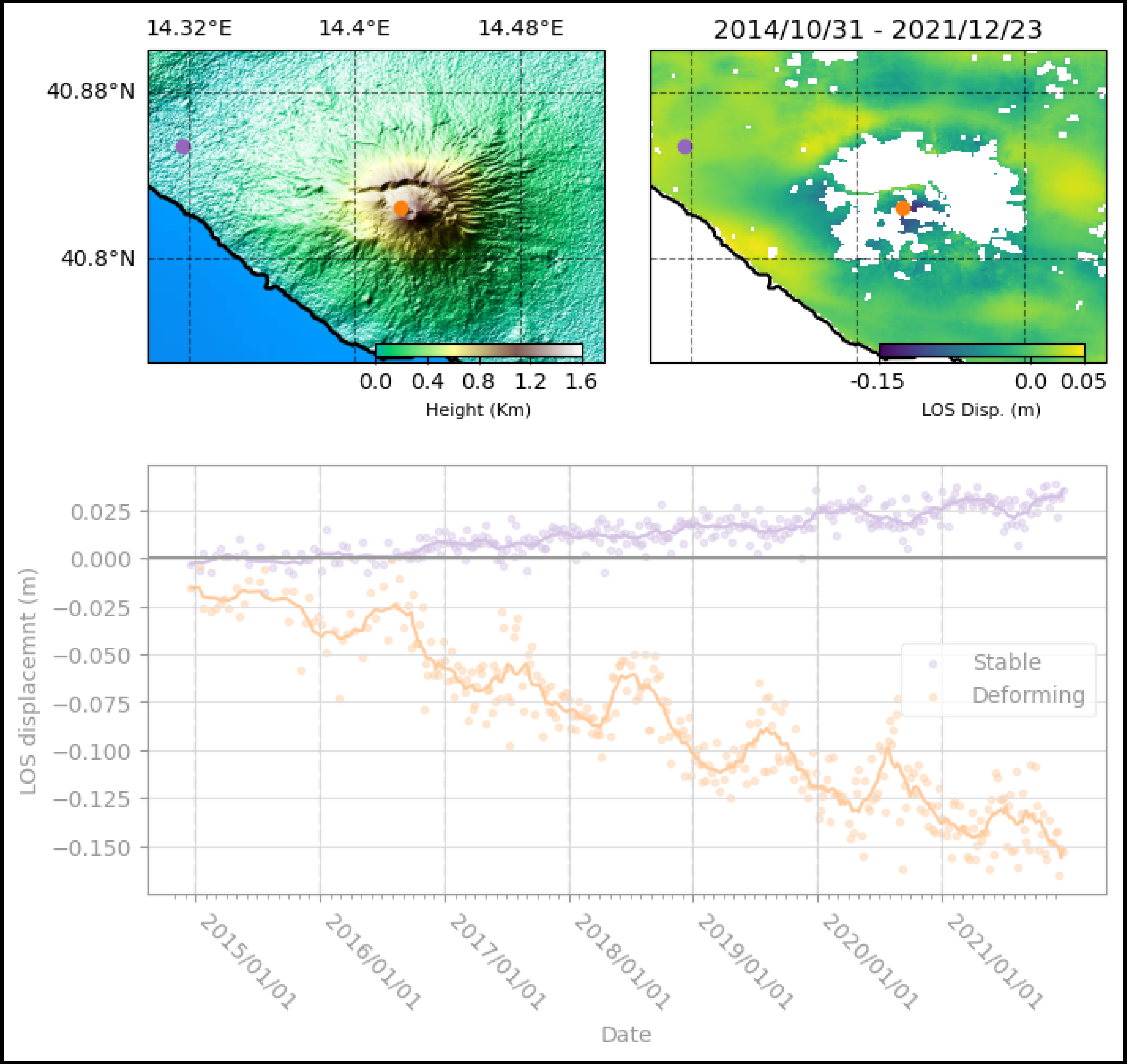
LiCSAlert: temporal ICA at Vesuvius

- **In 2018, ~100 acquisitions, but now ~300.**
- LiCSBAS time series shows highly variable deformation (direction reversal).
- Challenging to monitor without separating deformation from atmosphere.



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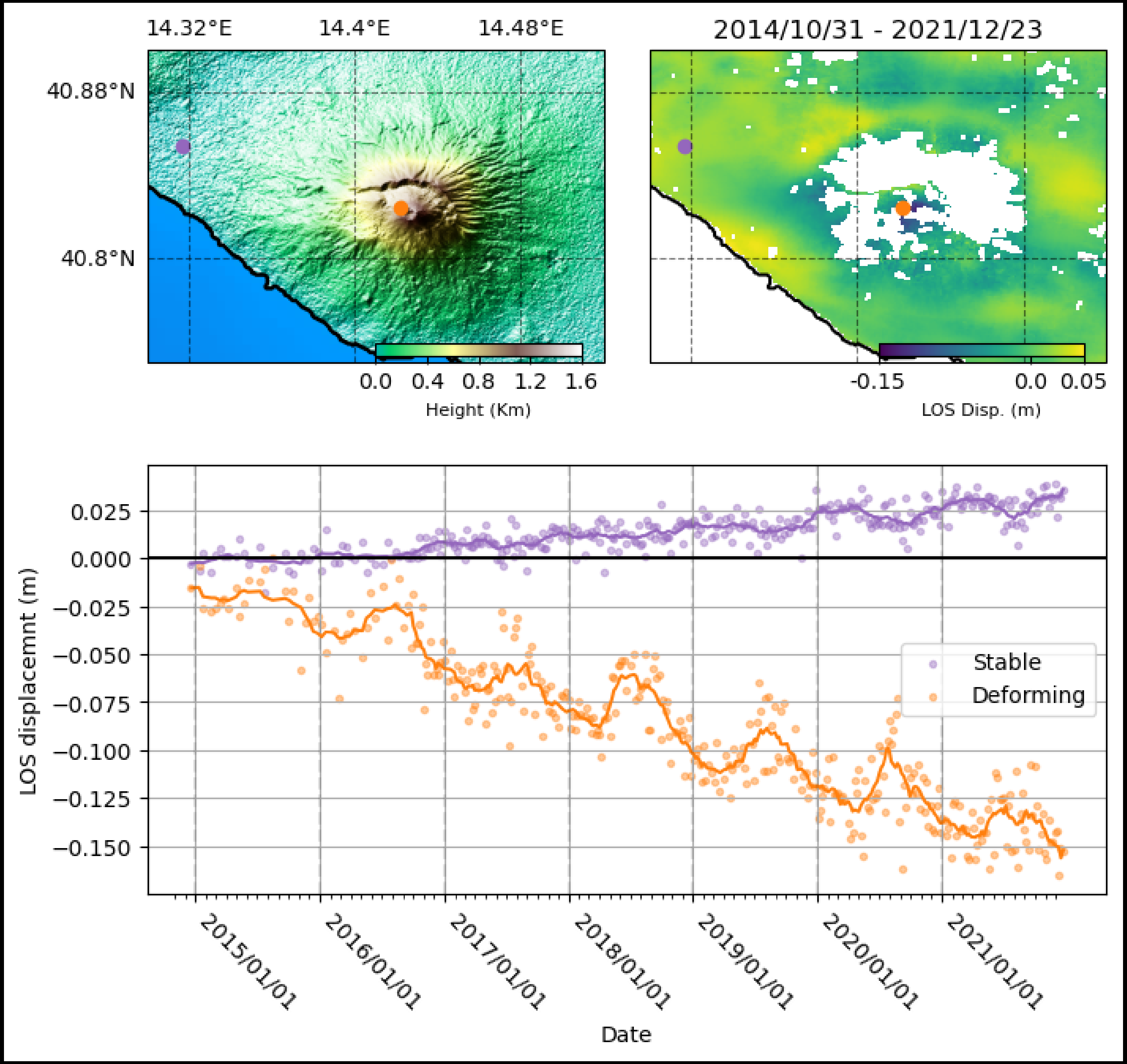

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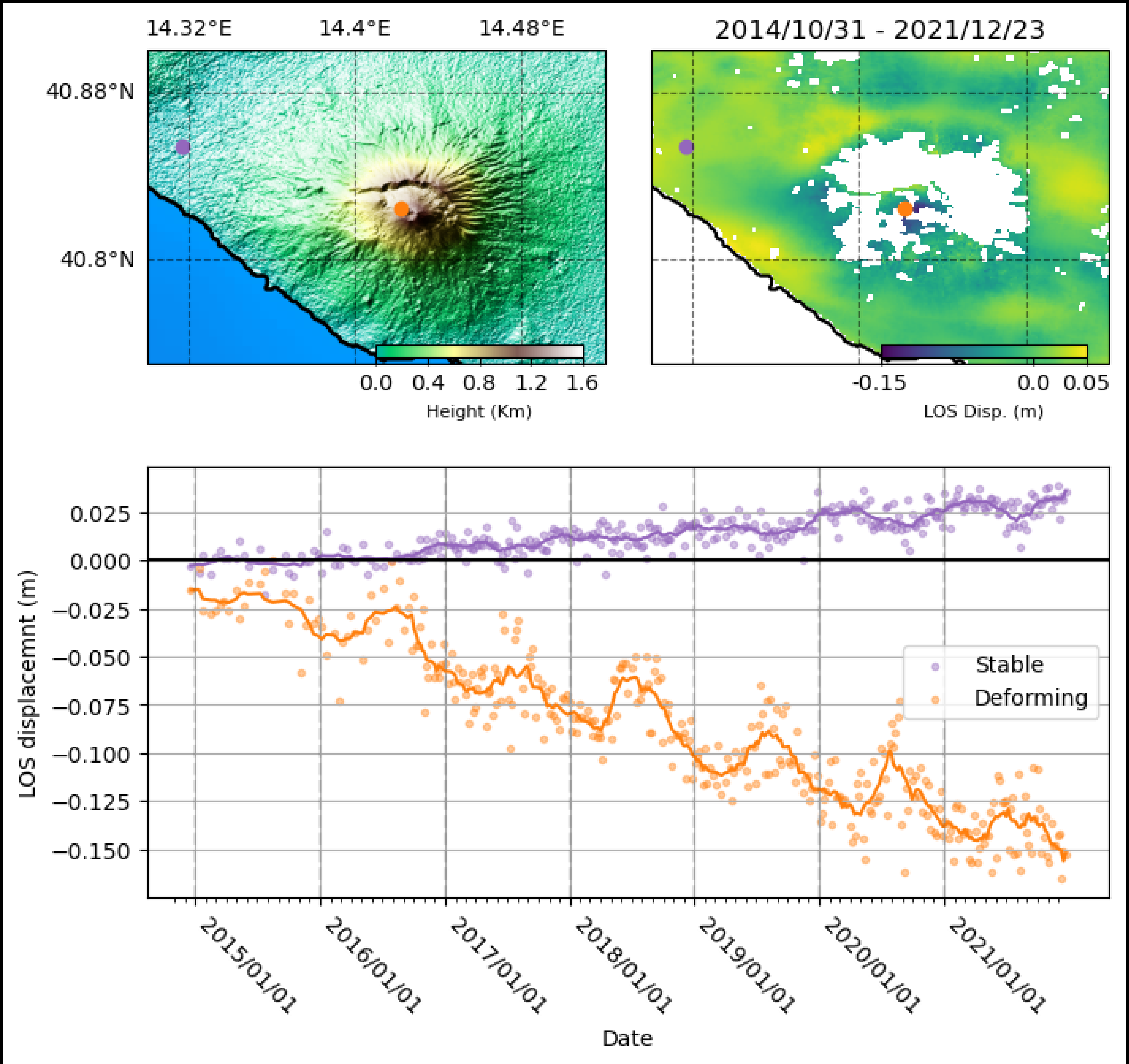

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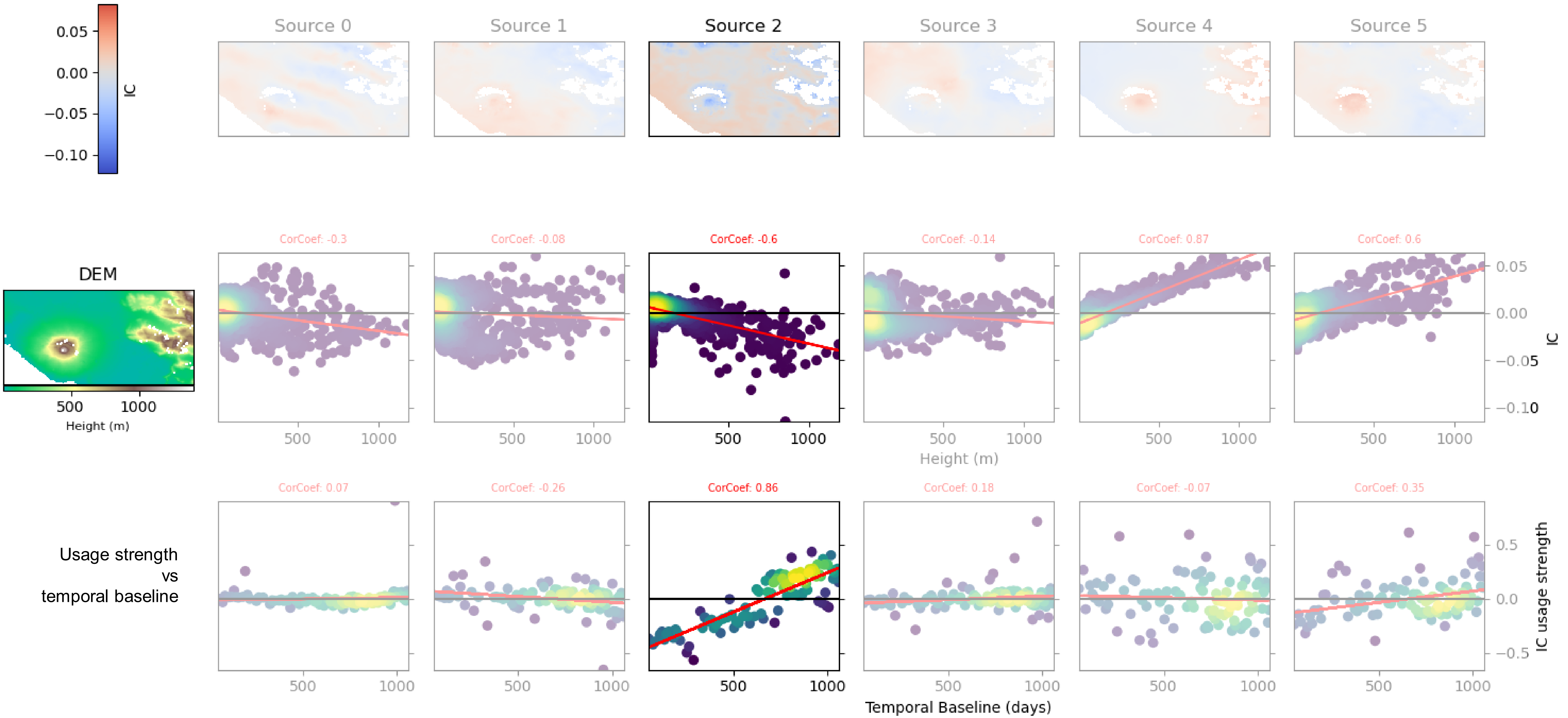
- IC4 is strongly correlated with the DEM.



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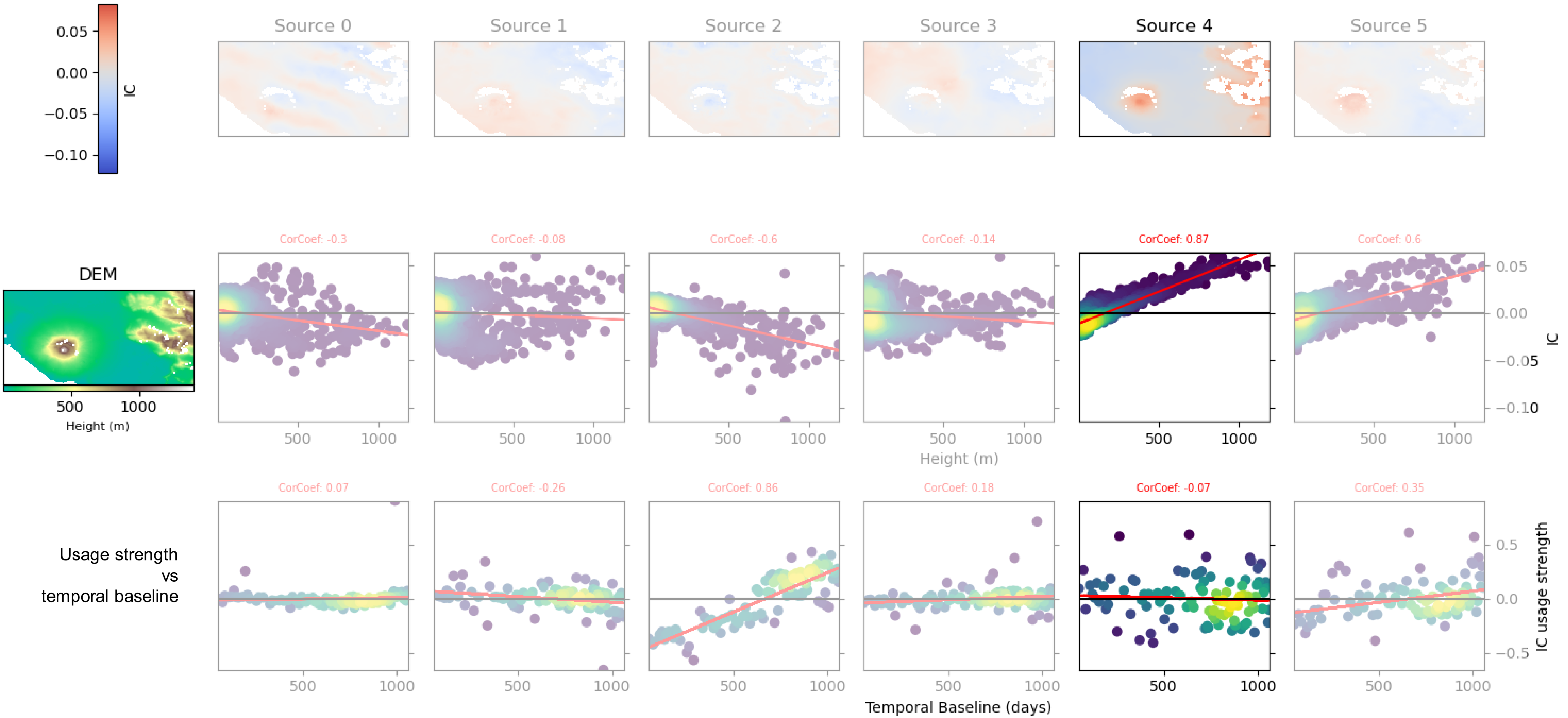

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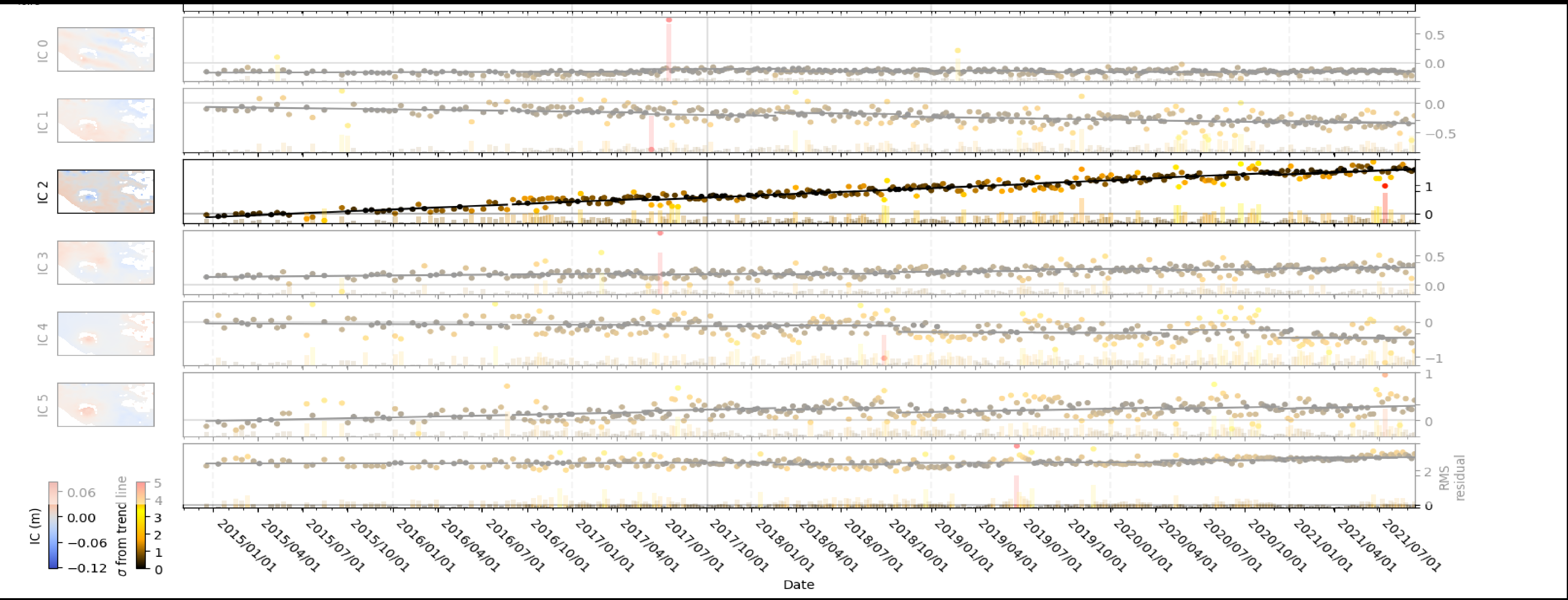
- IC4 (and IC5) show sinusoidal motion with little linear trend.



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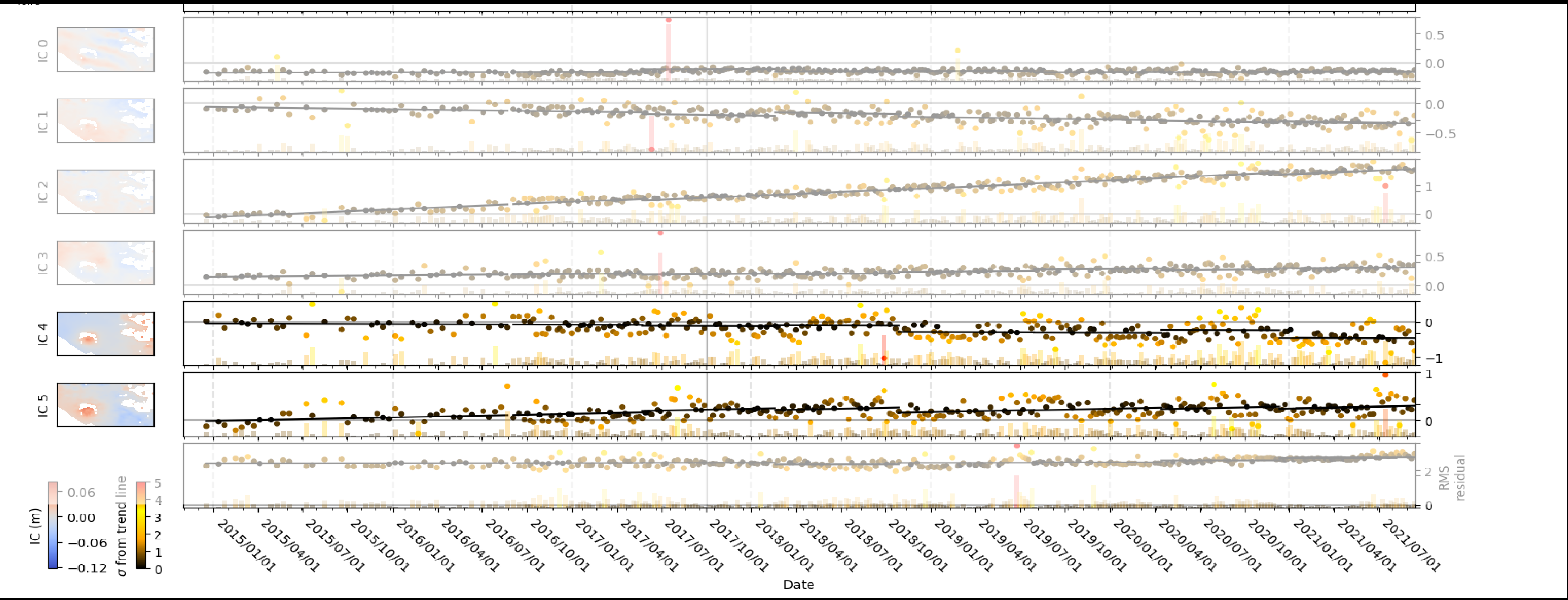

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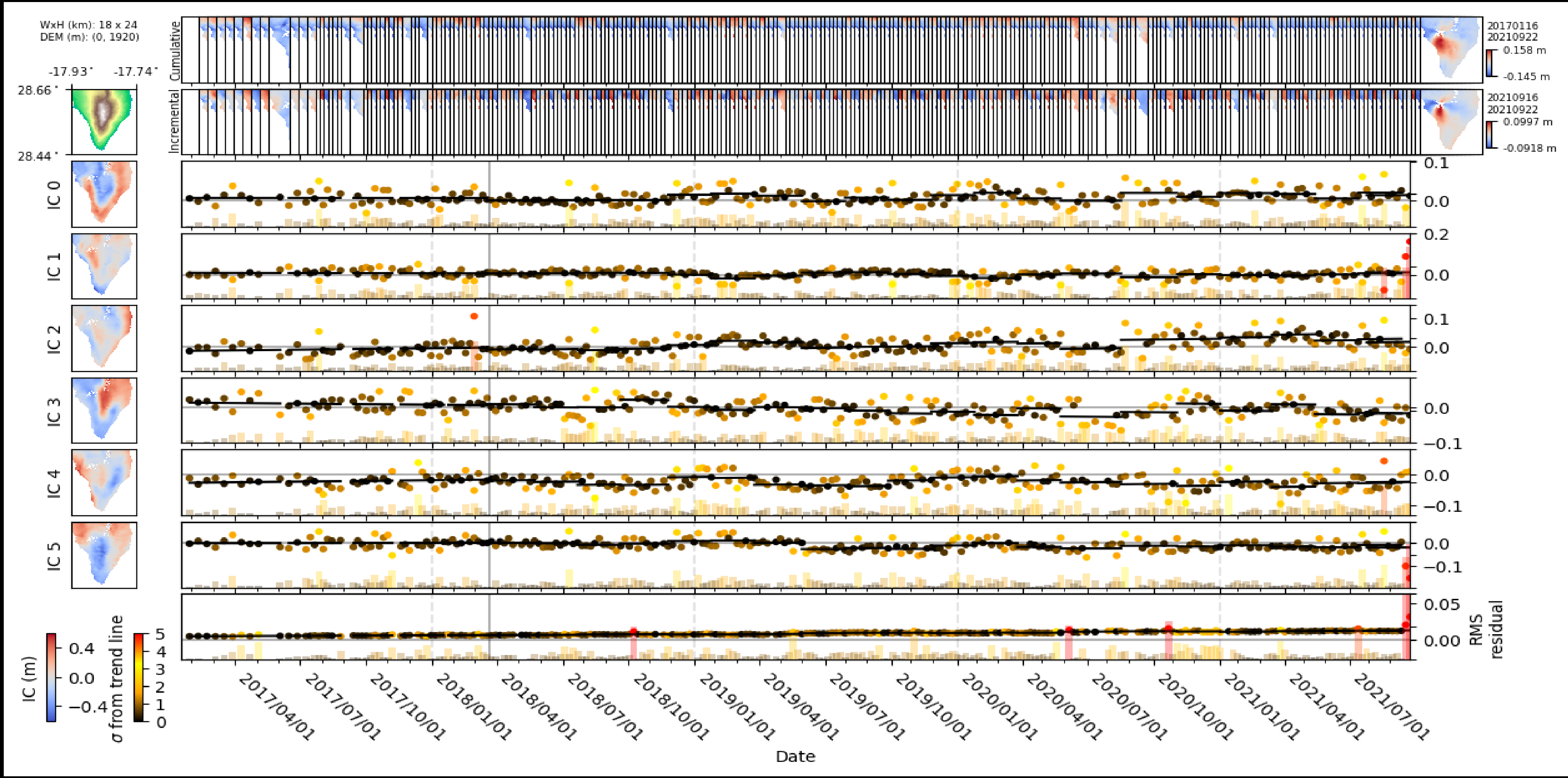
(Near) global application: results

- La Palma, Canary Islands:
  → Flagging of the new deformation associated with 2021 eruption.
- 

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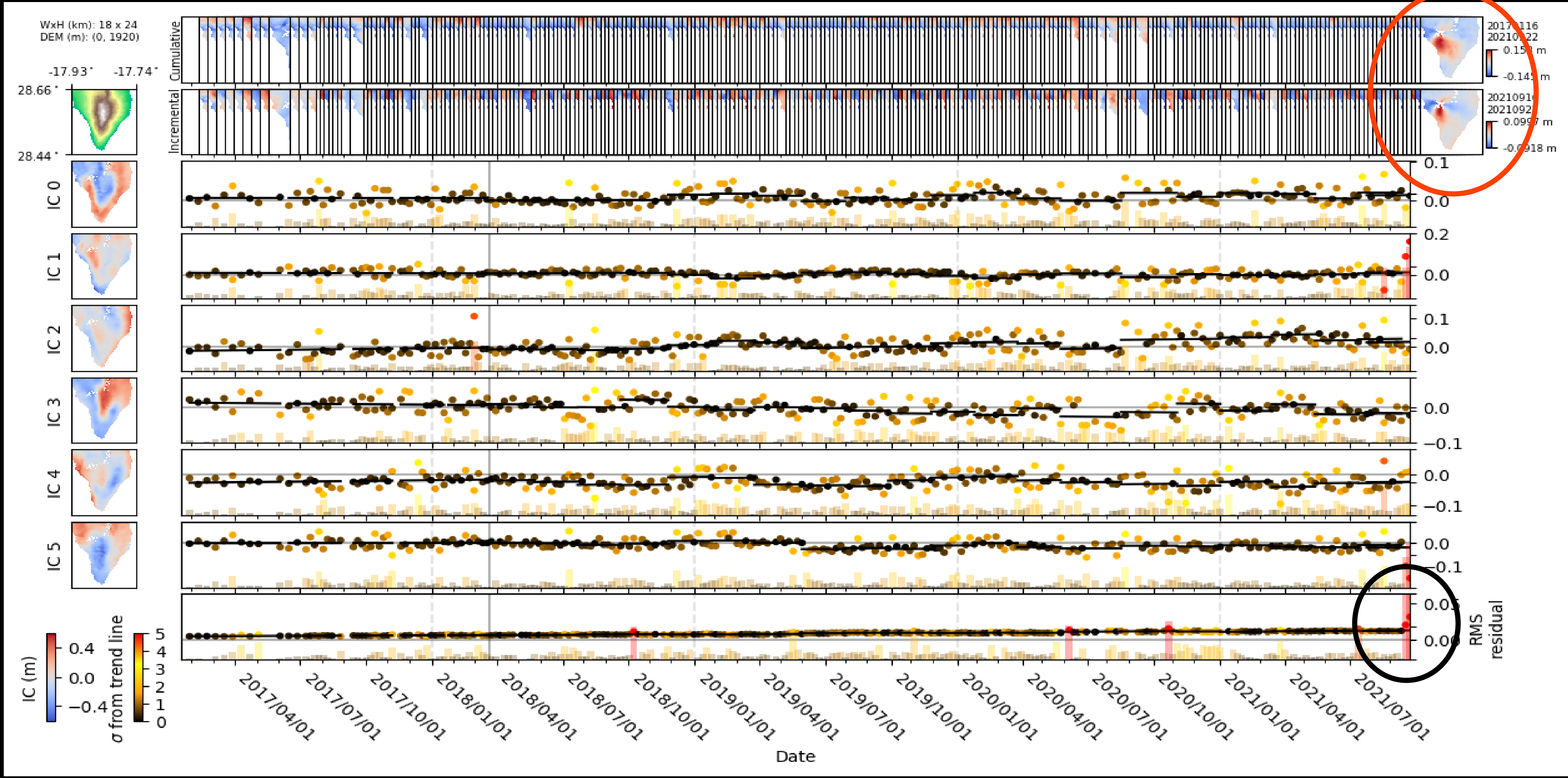

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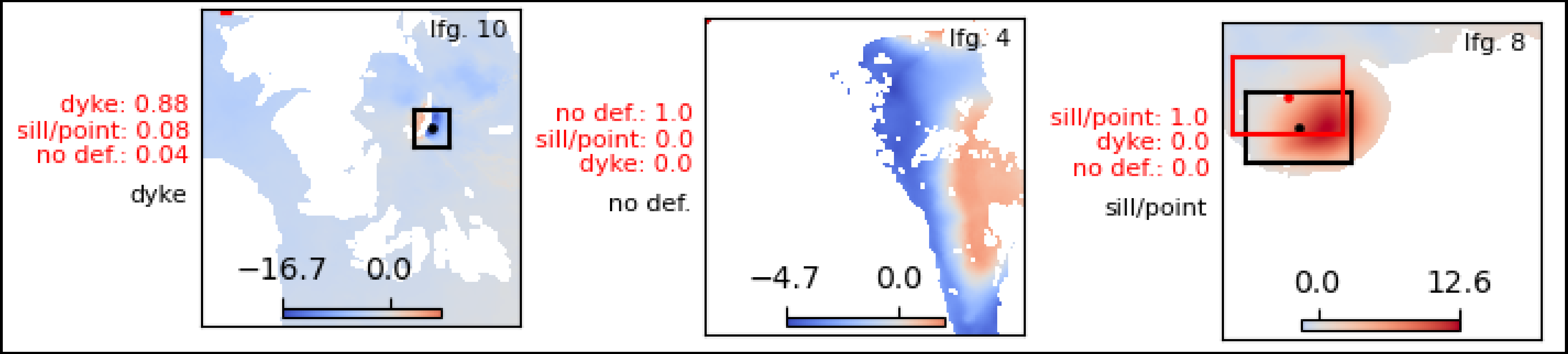
How to visualise thousands of results?

- **Condense our LiCSAlert figure into 2 values:**
  → Changes in existing deformation
  → New deformation.

- But, we have to first identify deformation source.

  → Use deep learning (CNN):

  → Red: model predictions, black: human label:



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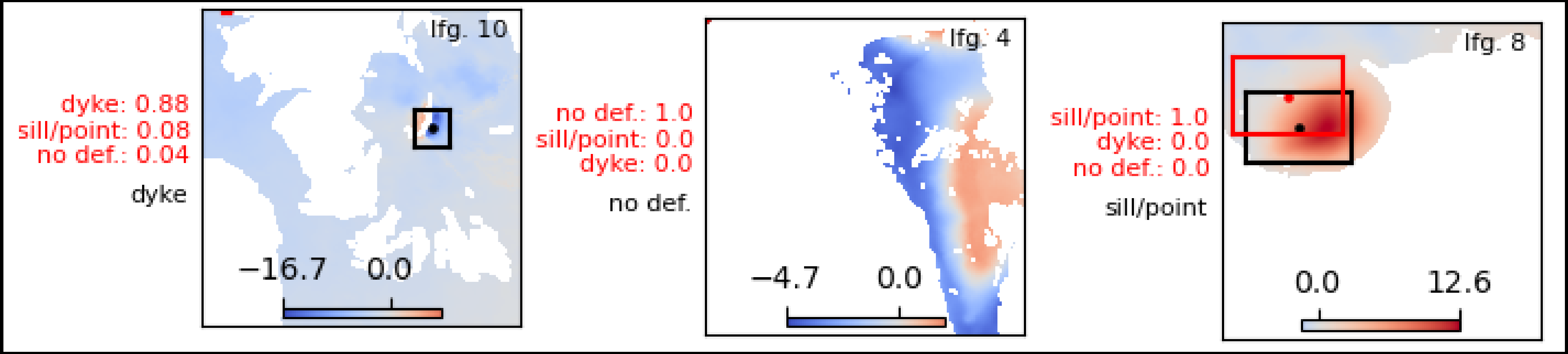

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Visualising the status: 1 volcano, many times

- Sierra Negra - Change to existing deformation prior to eruption (x axis).
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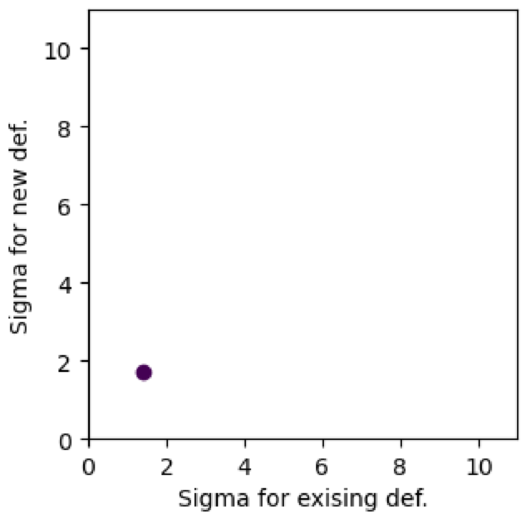

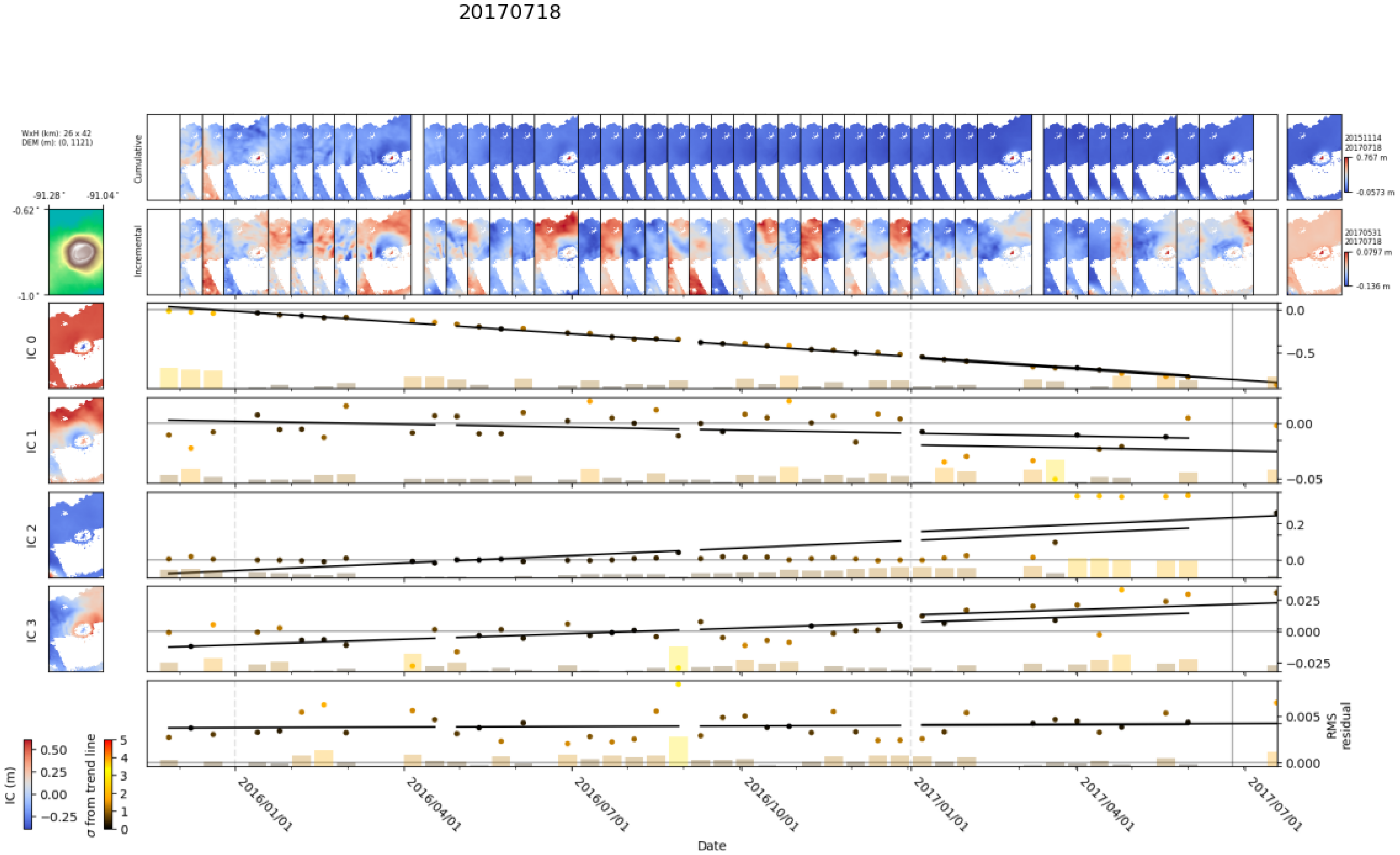

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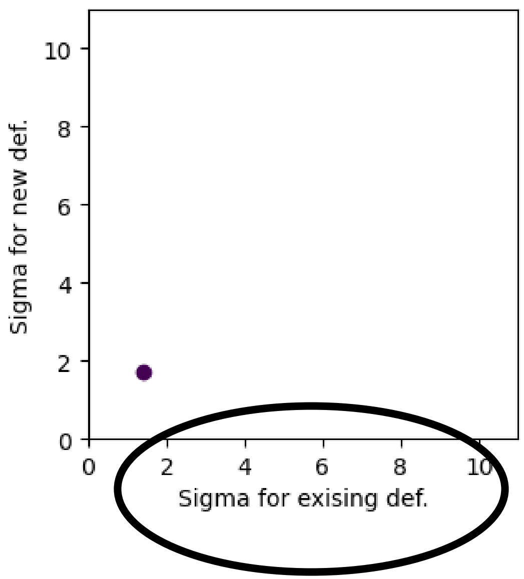

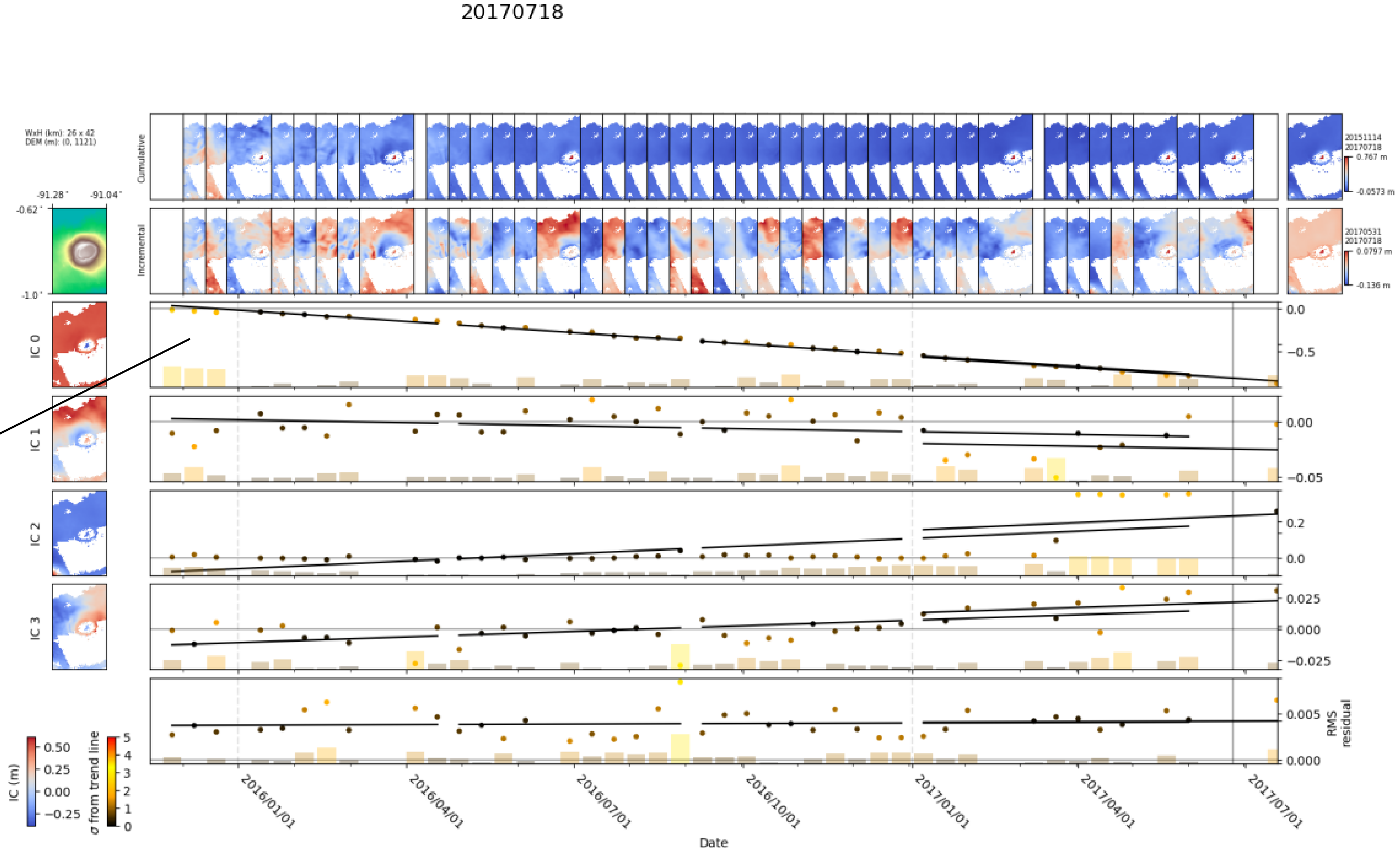

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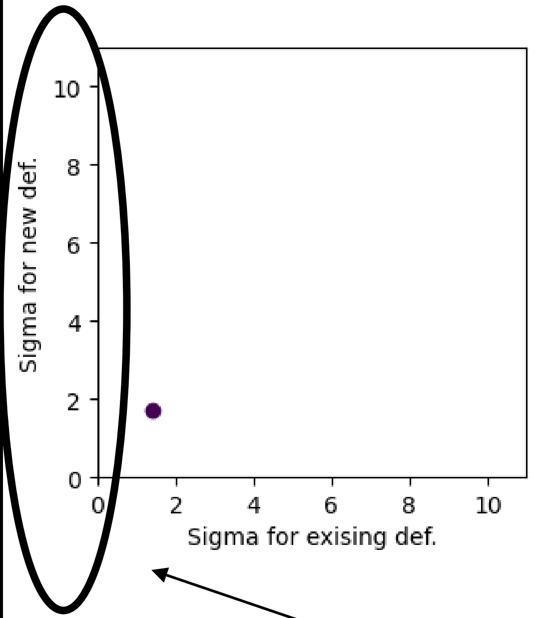

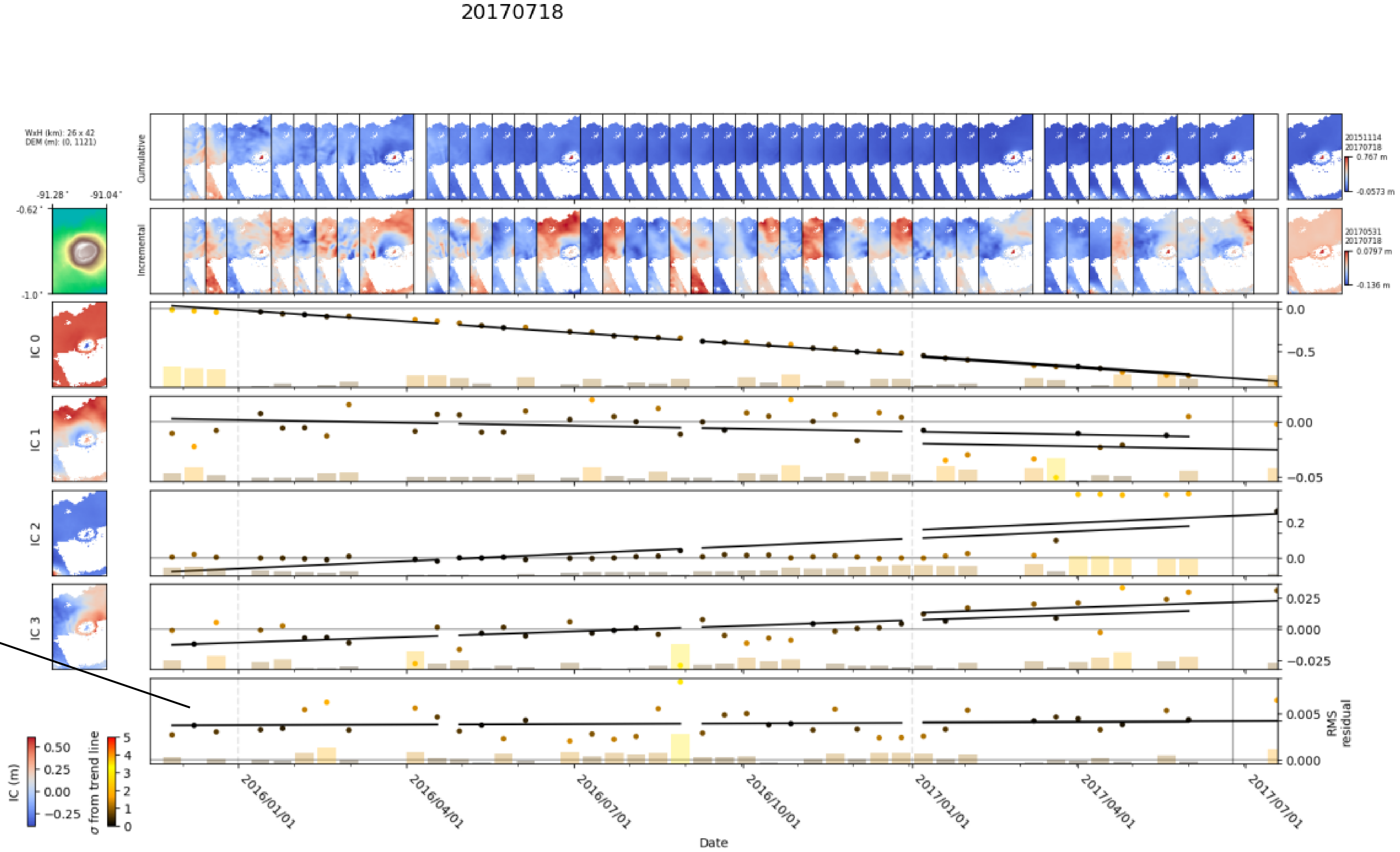

Visualising the status: 1 volcano, many times

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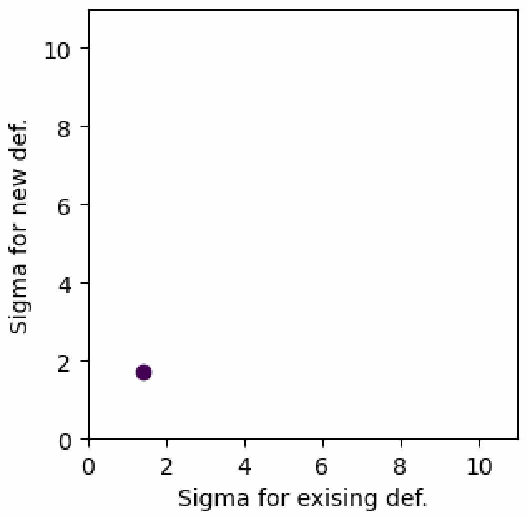

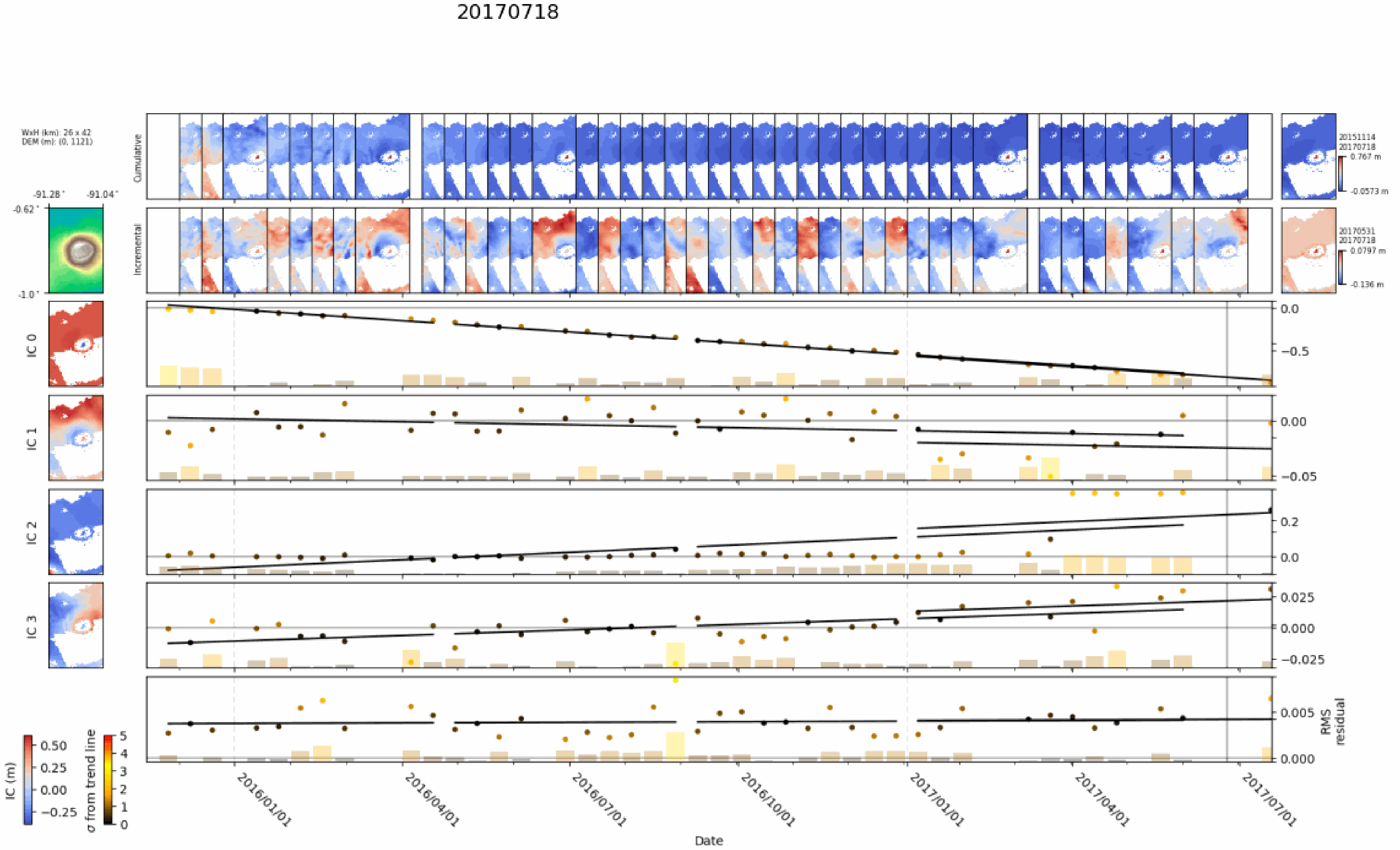

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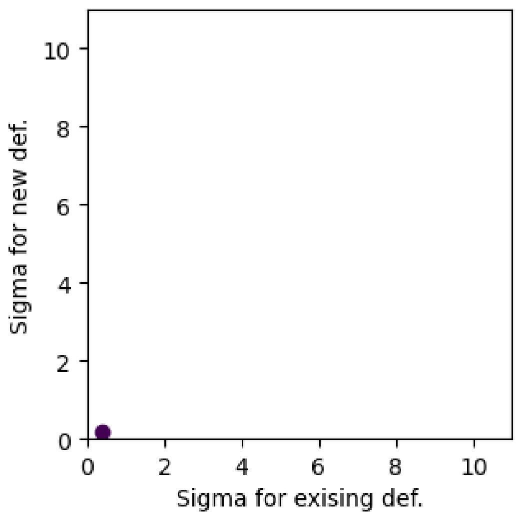

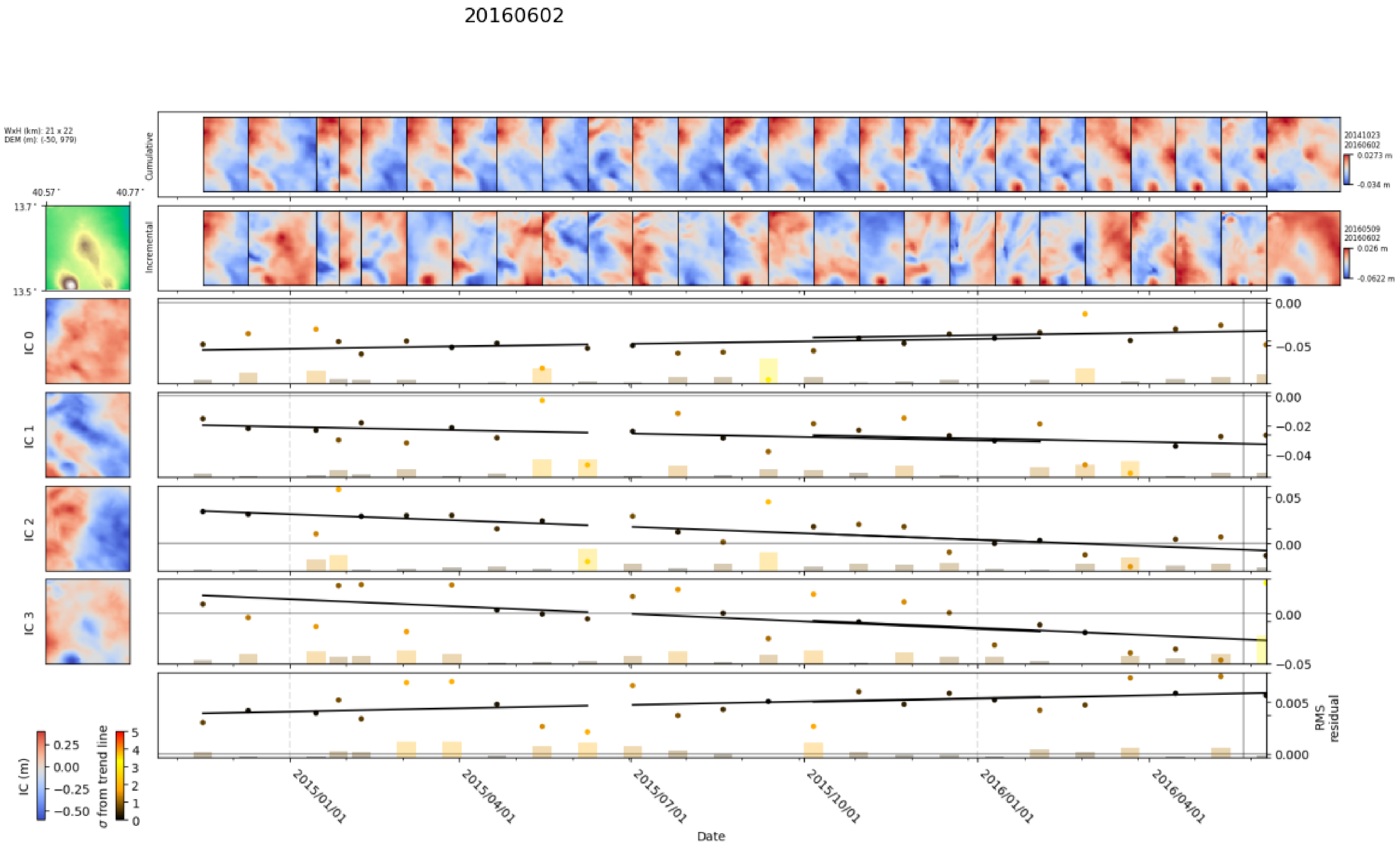

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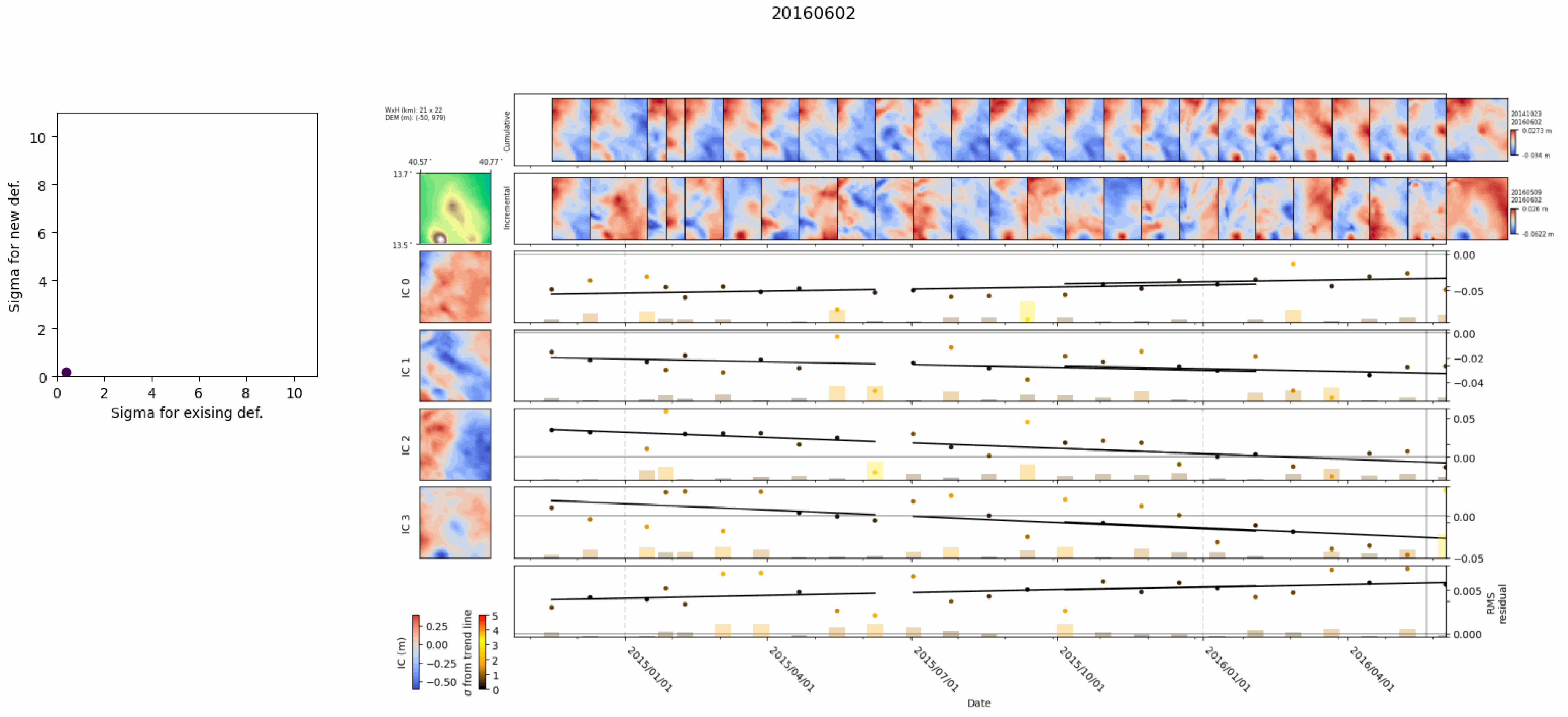
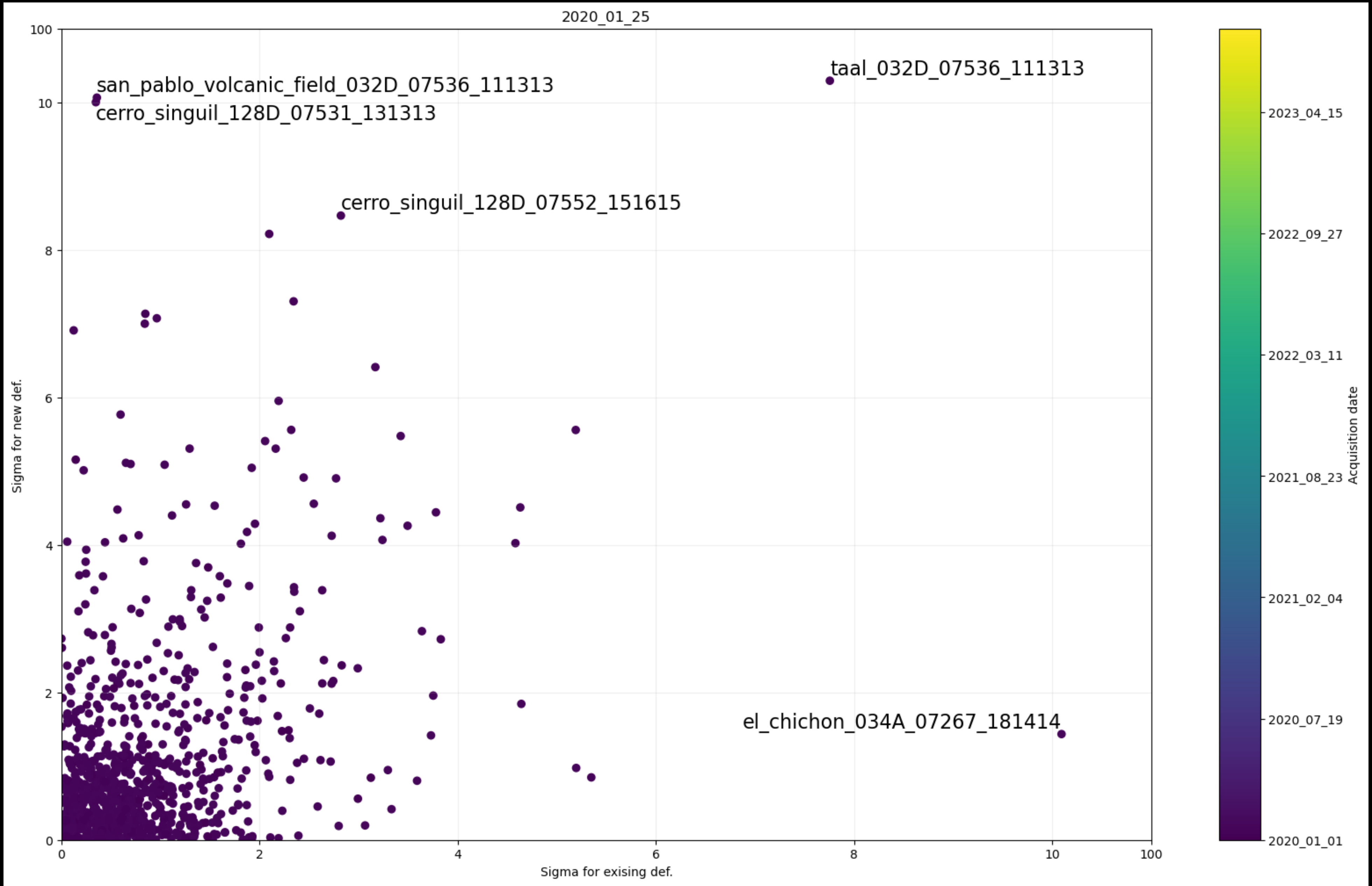


Visualising the status: ~500 volcanoes, 1 time

- Applied to ~1500 LiCSAR frames



LiCSAlert: Plans

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- Web-based interactive LiCSAlert figure (possibly on COMET Volcano Portal).
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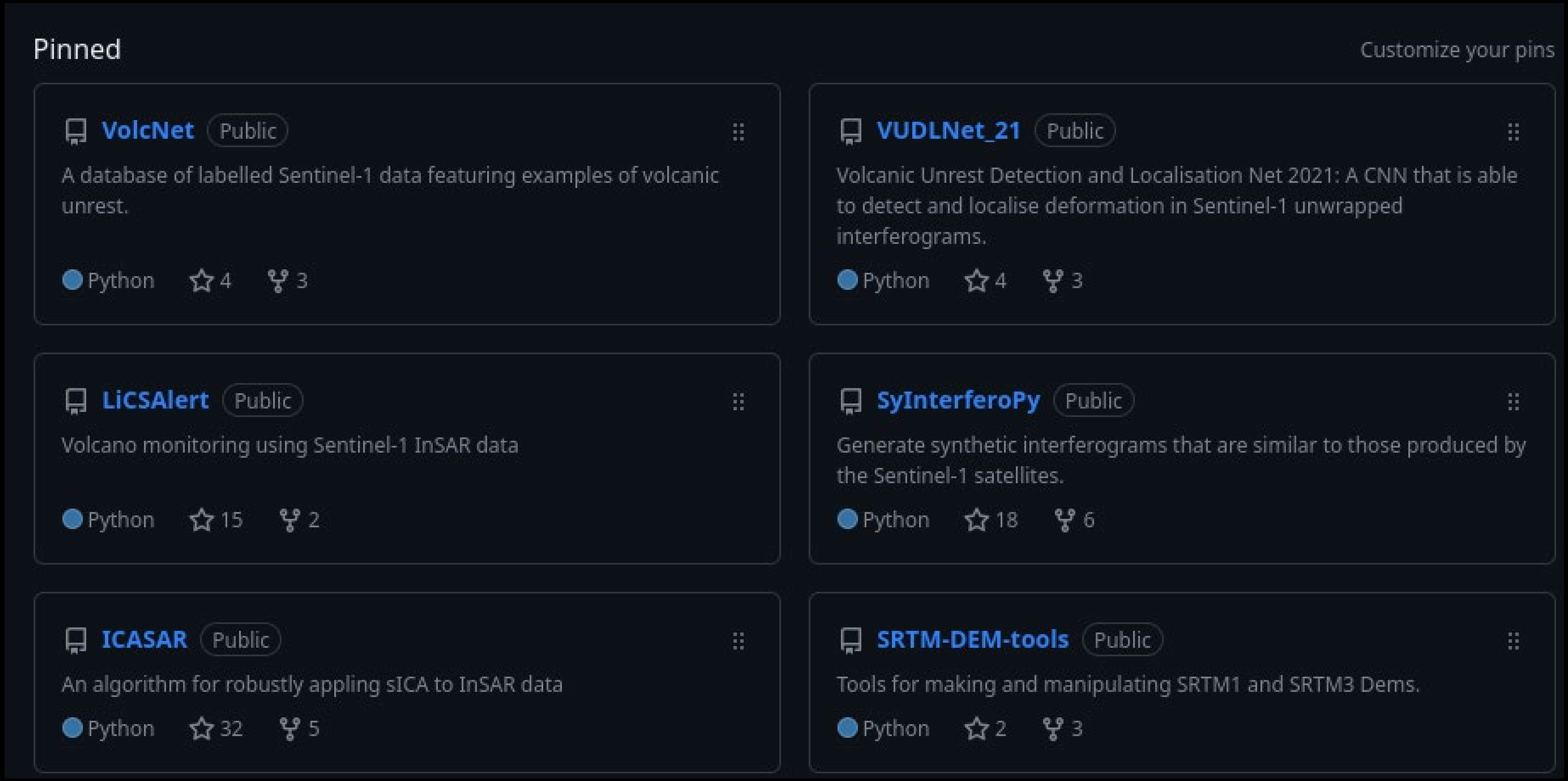

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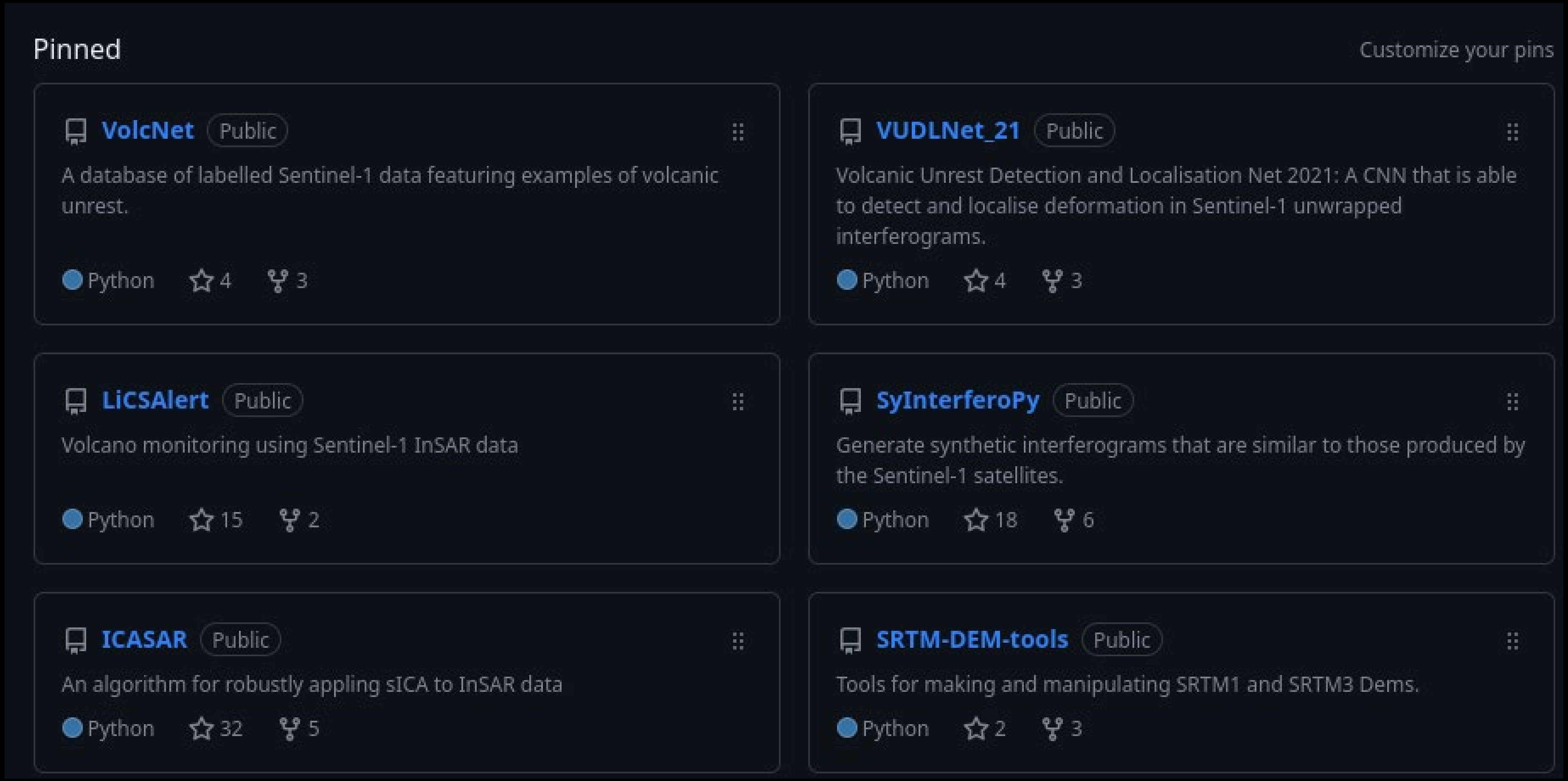

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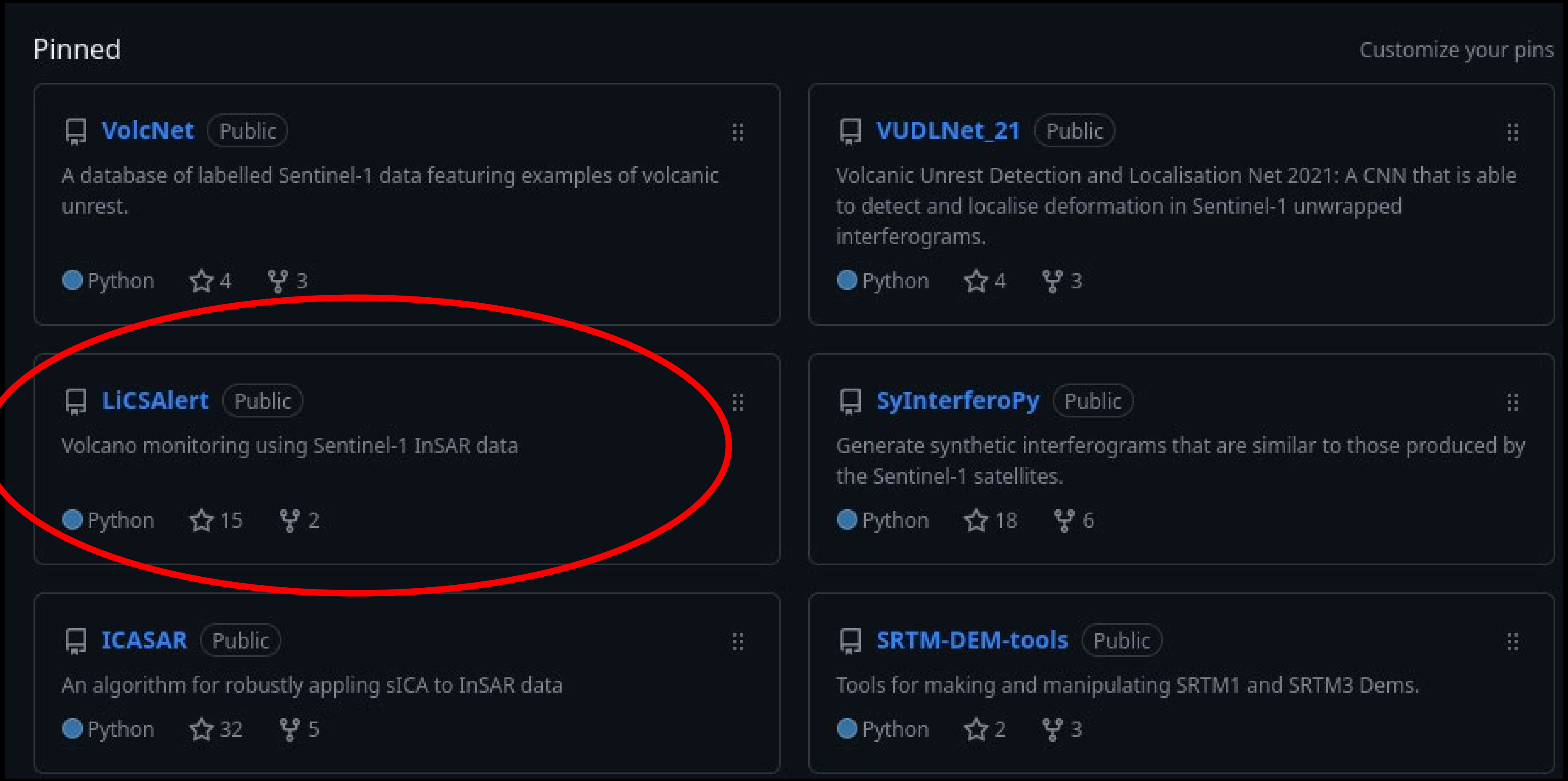

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- **Conclusions**

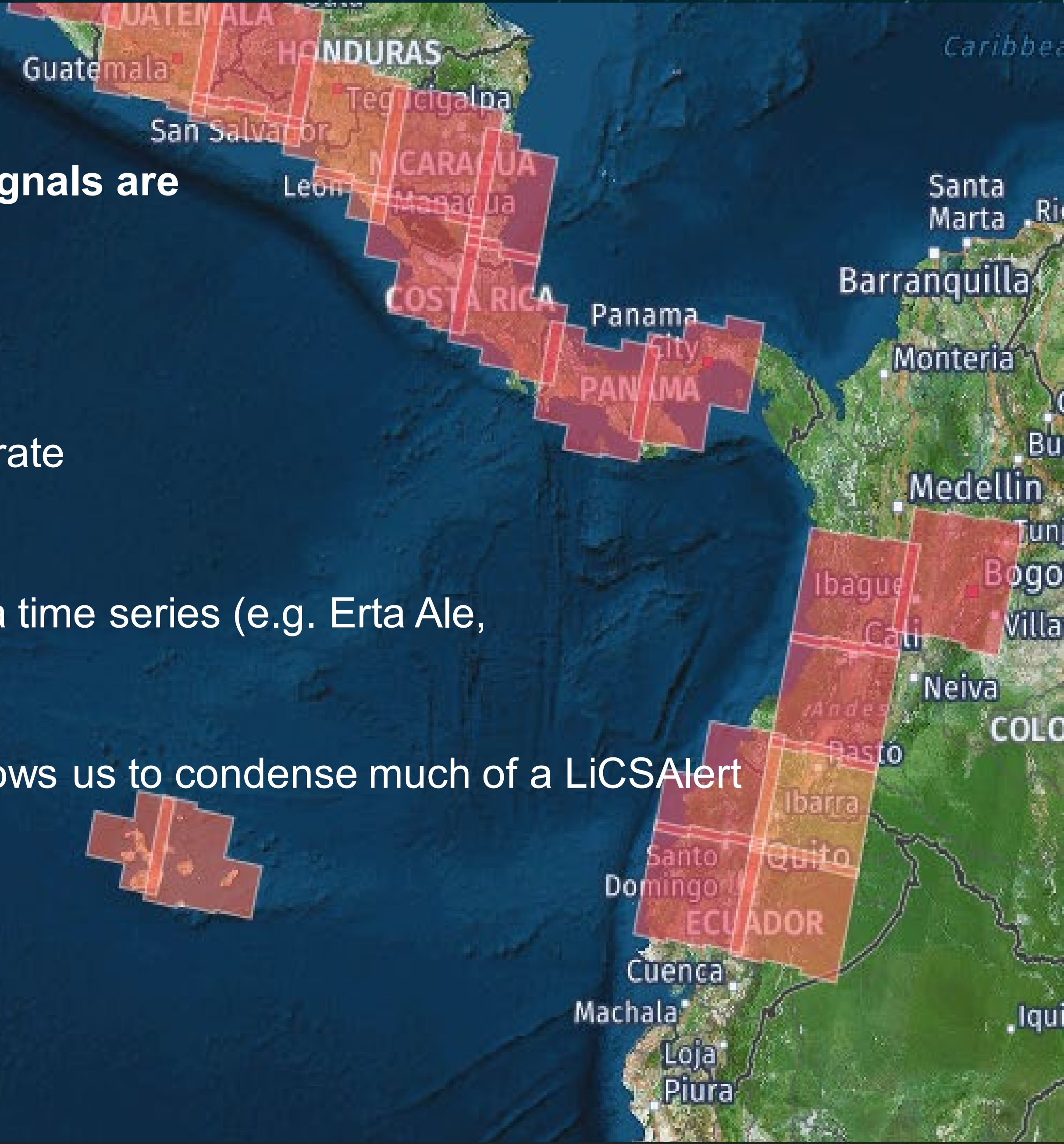
- **Networks that increase the variance of deformation signals are needed when using sICA at most volcanoes.**

- At stratovolcanoes, tICA outperforms sICA.

- LiCSAlert is able to detect subtle changes in deformation rate (e.g. Campi Flegrei).

- LiCSAlert is able to detect when new deformation enters a time series (e.g. Erta Ale, La Palma).

- Using deep learning to identify the deformation source allows us to condense much of a LiCSAlert figure into a simple 2D plot.



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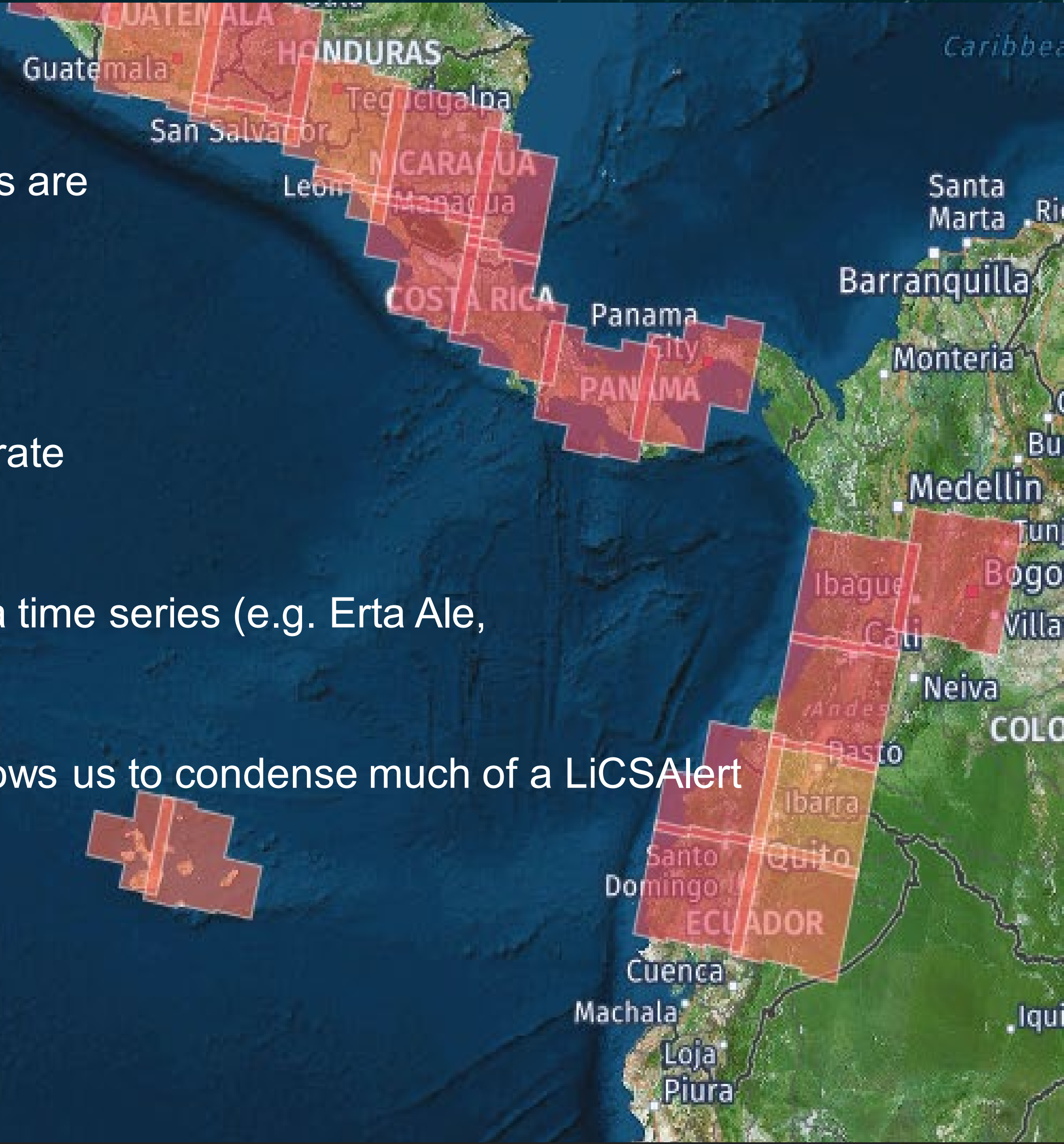

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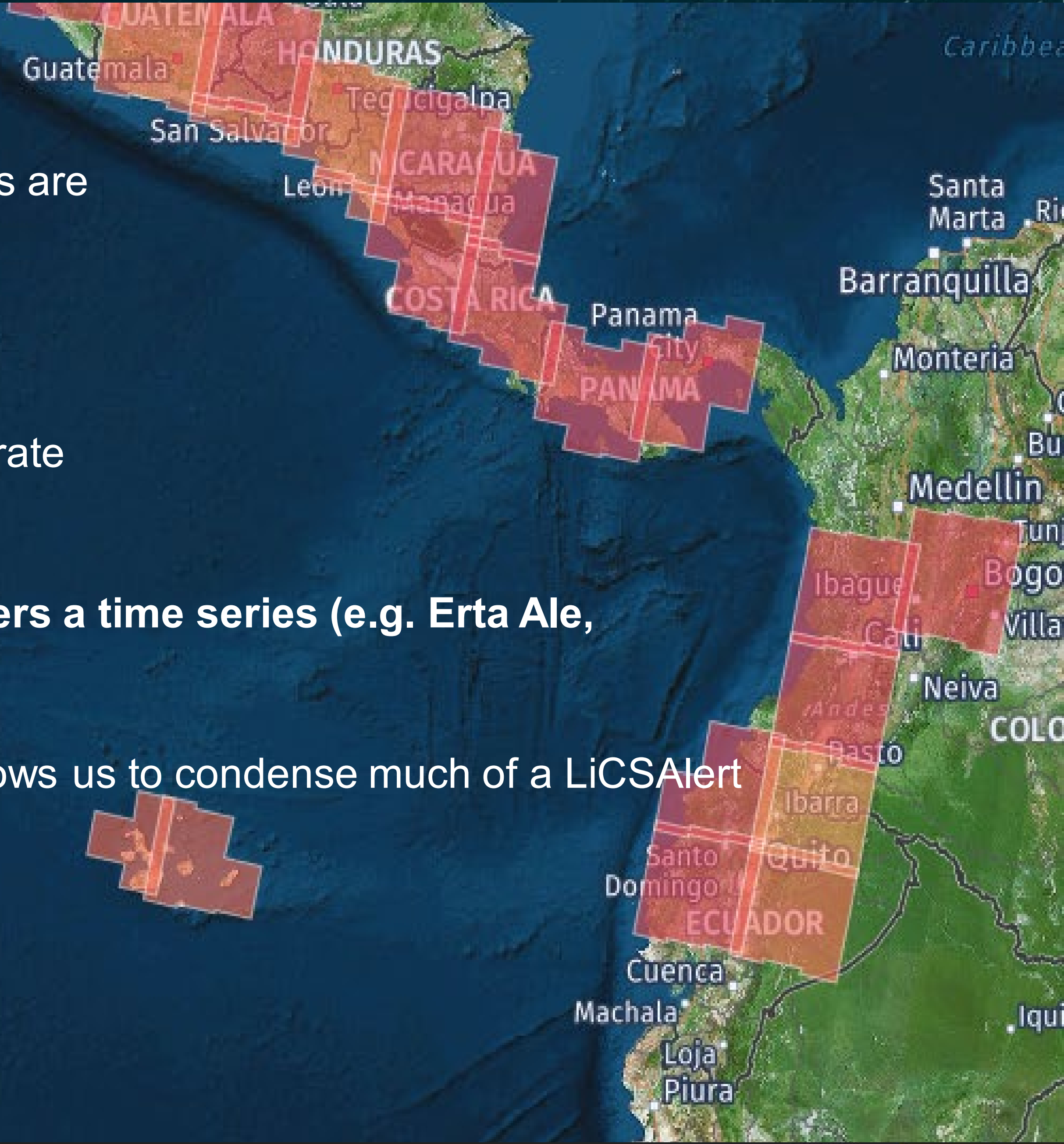

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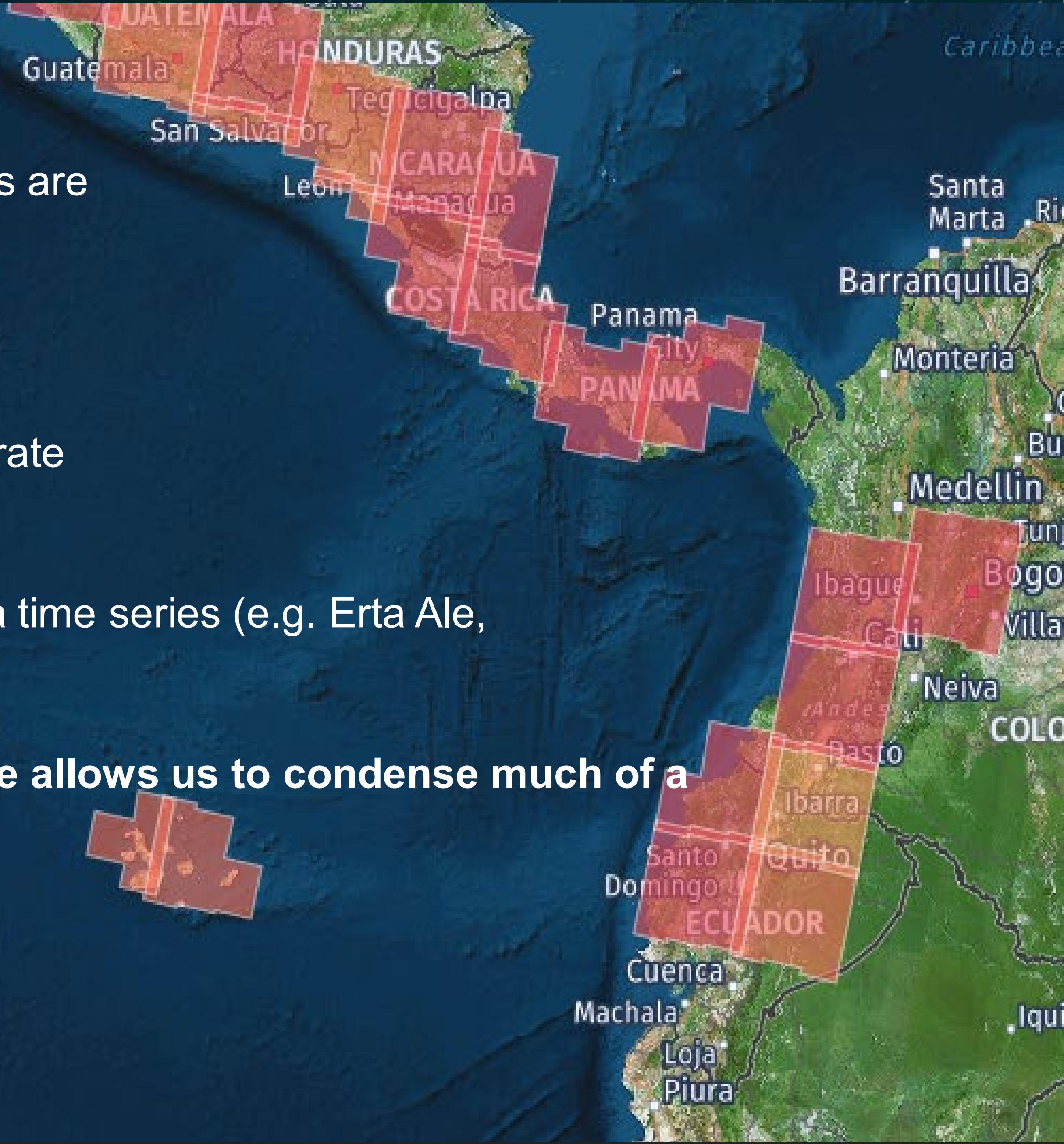

Title

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