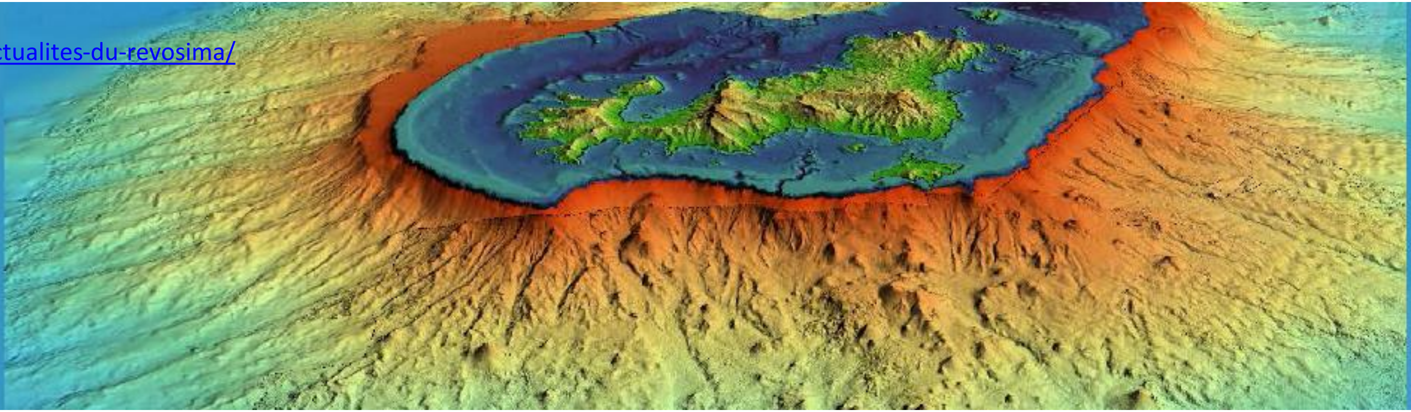
How to best account for crustal deformation in Mayotte?

Image source:
https://www.ipgp.fr/actualites-du-revosima/



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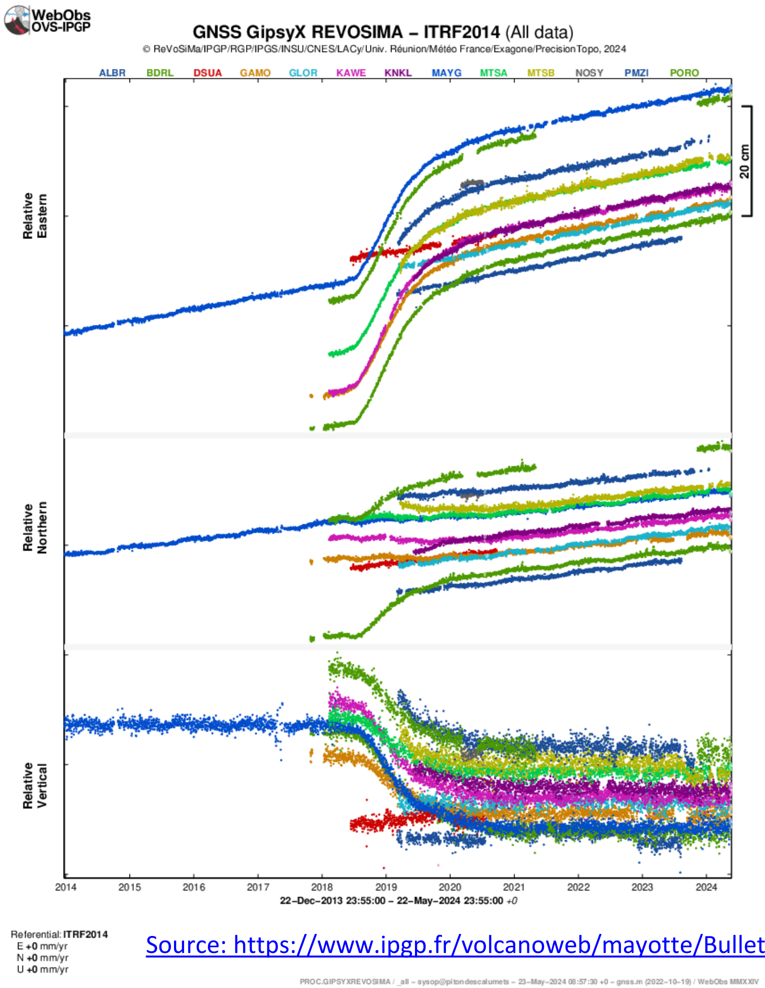
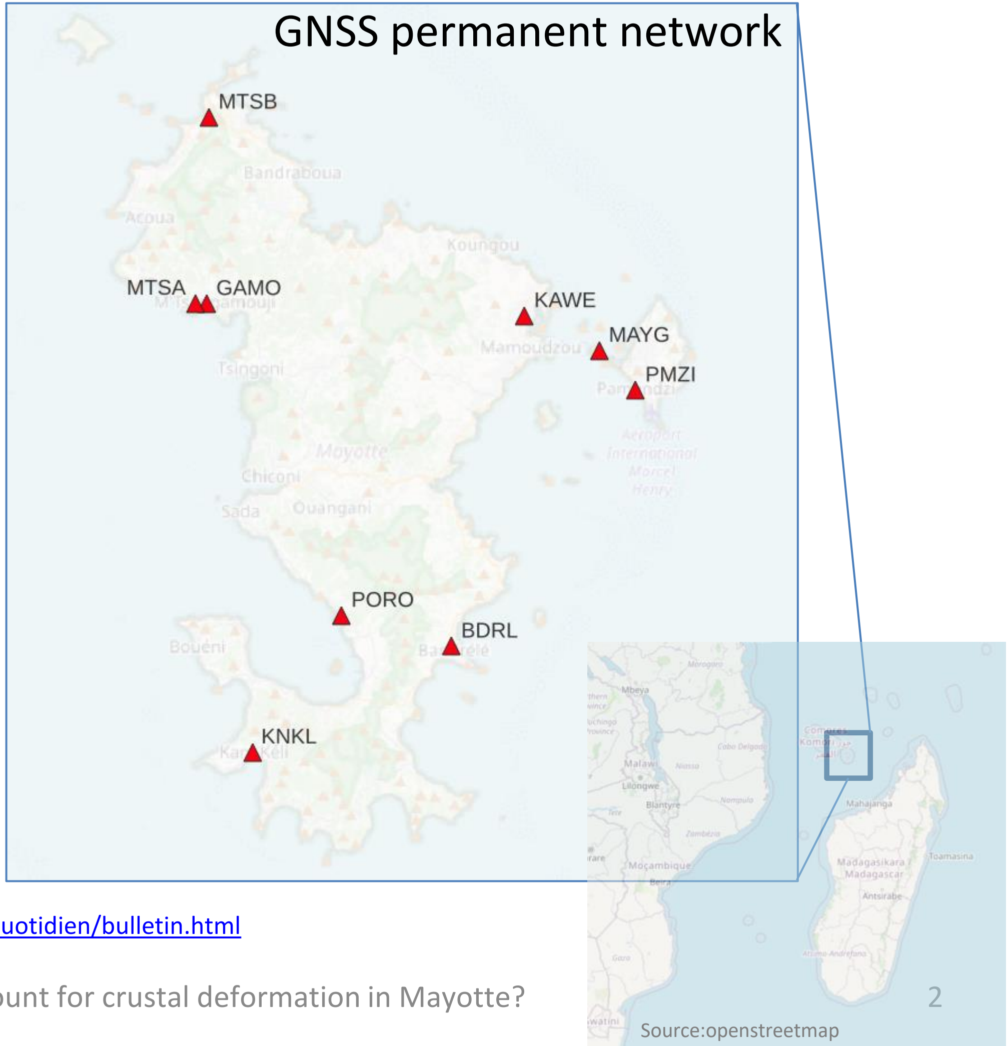
Acknowledgment: Kristel Chanard, Bruno Garayt, Didier Bouteloup
[1] IPGP, [2] ENSG-Géomatique/Université Gustave Eiffel, [3] IGN



GNSS permanent network

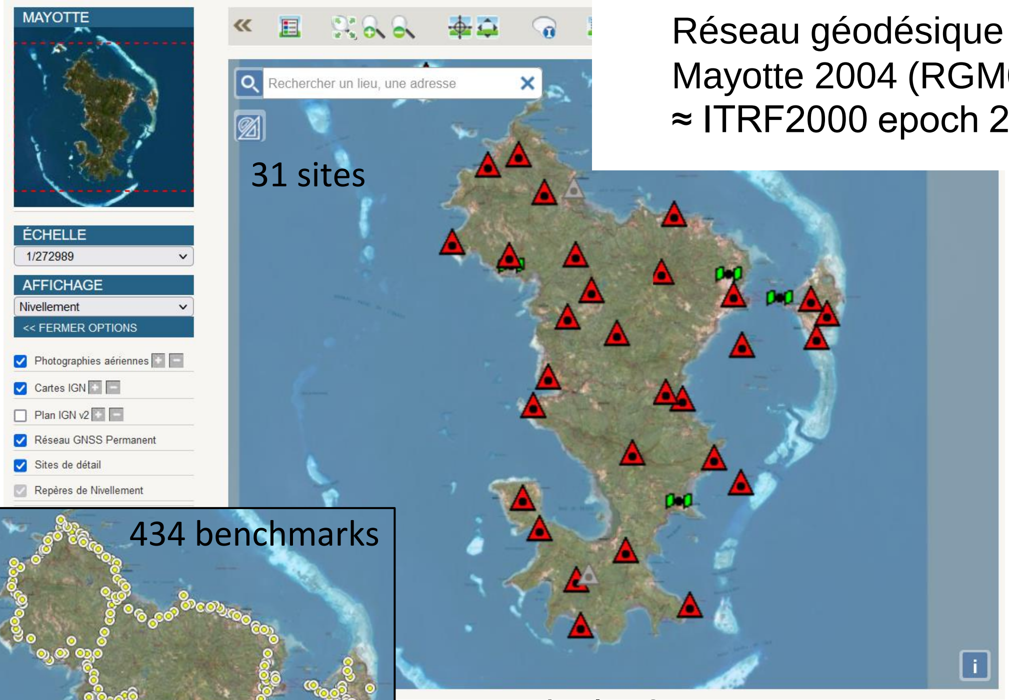


[Source: https://www.ipgp.fr/volcanoweb/mayotte/Bulletin_quotidien/bulletin.html](https://www.ipgp.fr/volcanoweb/mayotte/Bulletin_quotidien/bulletin.html)

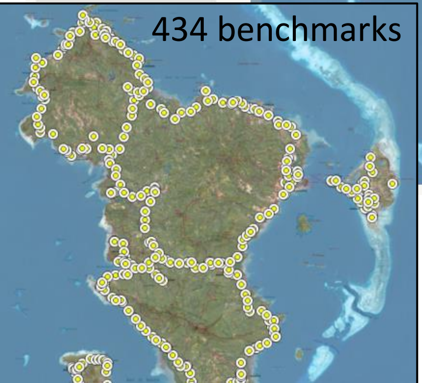
Reference Frame in Mayotte

- Terrestrial Reference Frame : Réseau géodésique de Mayotte 2004 (RGM04) ≈ ITRF2000 epoch 2004.0

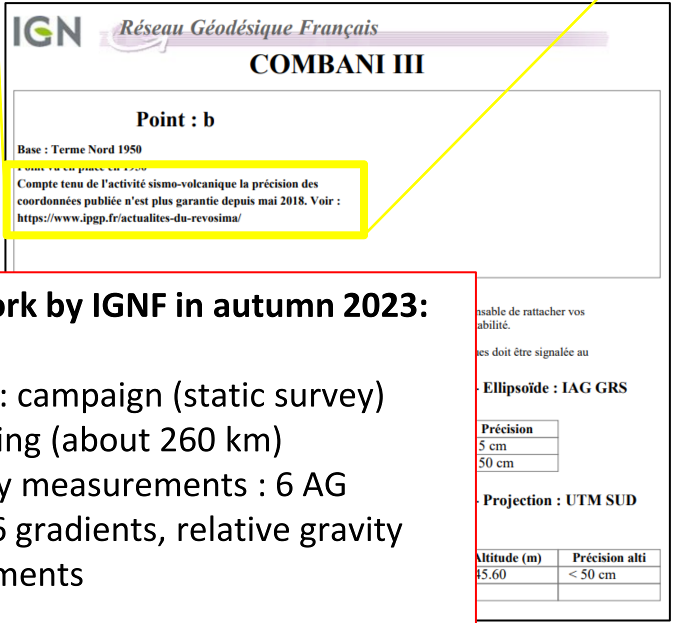
Given the seismo-volcanic activity, the accuracy of the published coordinates is no longer guaranteed since Mai 2018. See : https://www.ipgp.fr/actualites-du-revosima



31 sites



434 benchmarks



web site.

- Vertical reference system: IGN 1950 / SHOM 1953 (MAYO53)

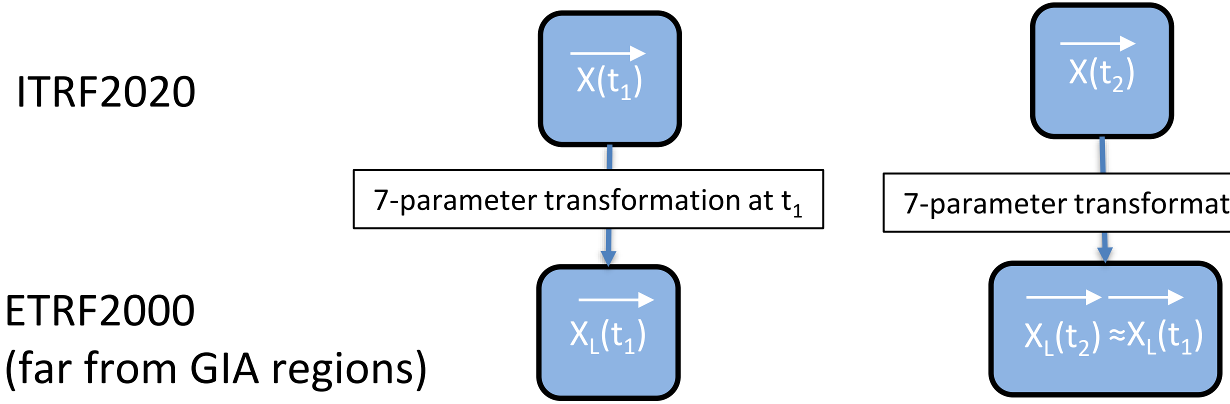
Field work by IGNF in autumn 2023:

O GNSS : campaign (static survey)
O Levelling (about 260 km)
O gravity measurements : 6 AG points, 6 gradients, relative gravity measurments

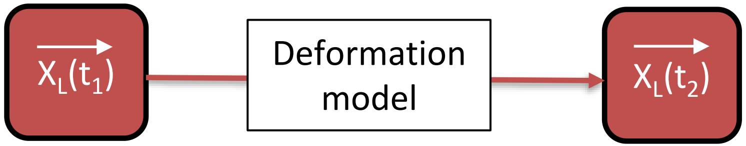
Data processing in progress

Deformation model in geodesy

In the stable part of a tectonic plate, a terrestrial reference system which co-rotates with the tectonic plate can be defined. Ex: ETRS89



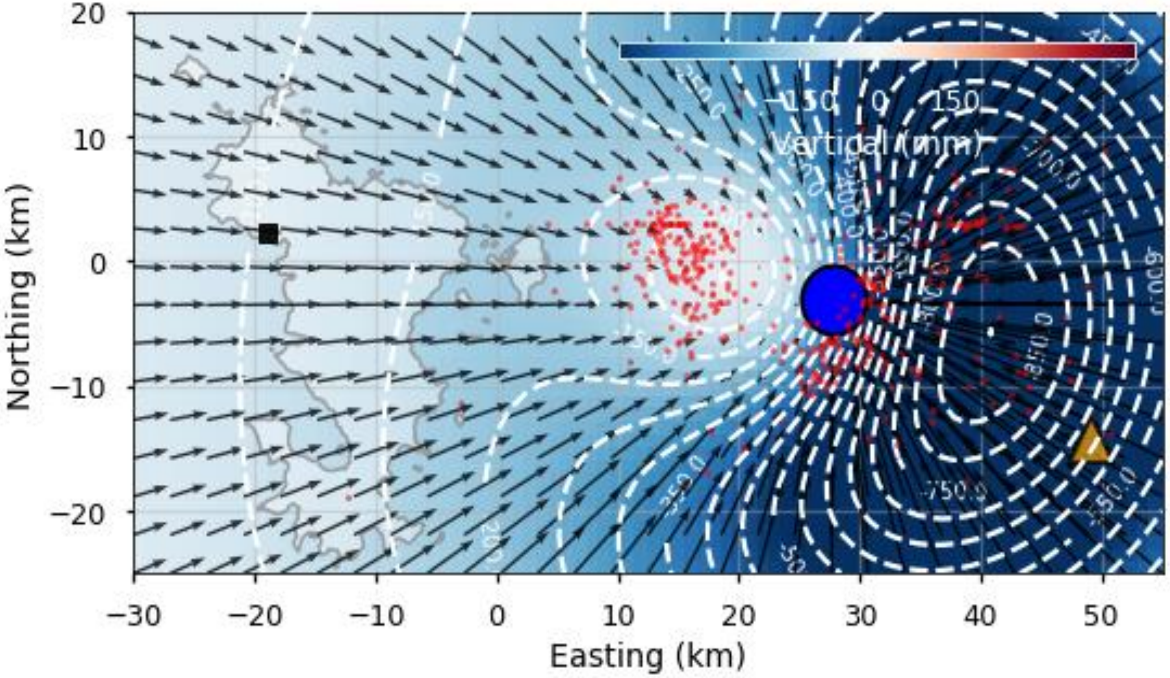
In a deformation zone: $X_L(t_2) \neq X_L(t_1)$



Outline

- Deformation model
- Model evaluation
- Perspectives

3D displacement model



Deformation model

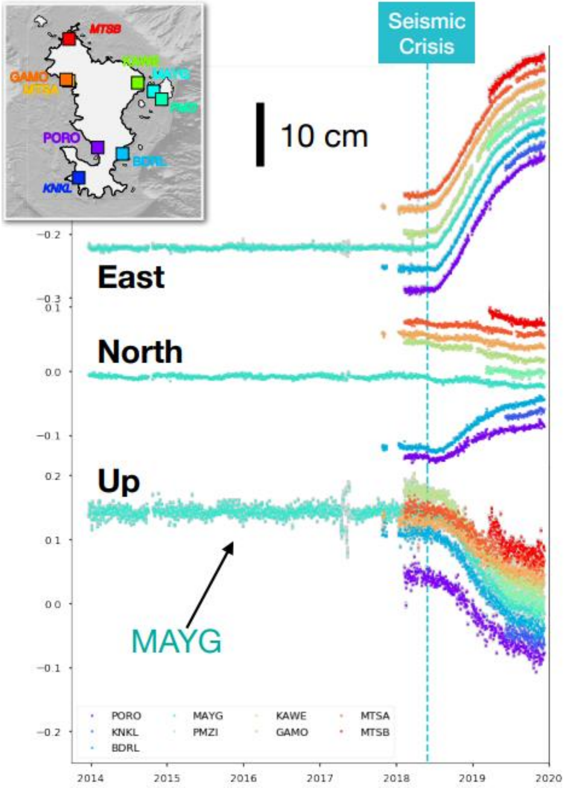


Figure: Used GNSS position time series. Grandin et al. (2019)

Principal component analysis (PCA) of GNSS displacements

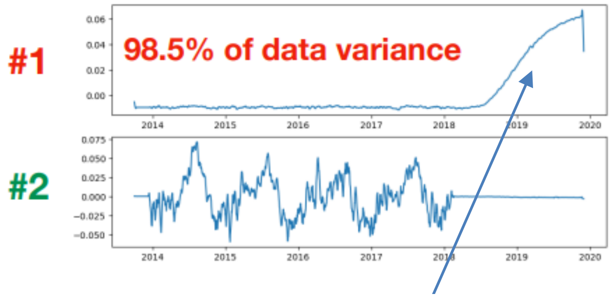


Fig. Two first temporal components

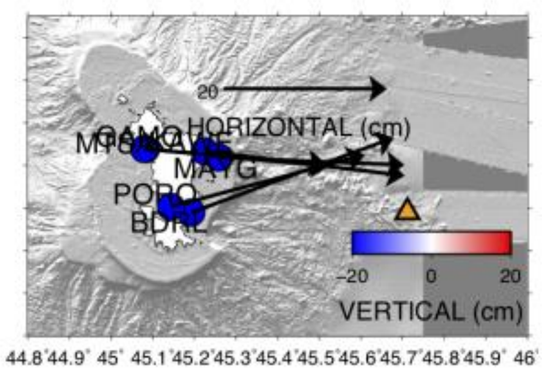


Fig. Spatial component associated to the first temporal component.

Deformation model

Can be explained by a fluid-filled cavity (reservoir) whose outlet is connected to a pipe. The reservoir gradually equilibrates its pressure by expelling material through the pipe. A function that makes use of two exponential functions can model such a behavior (Le Mével et al., 2016)

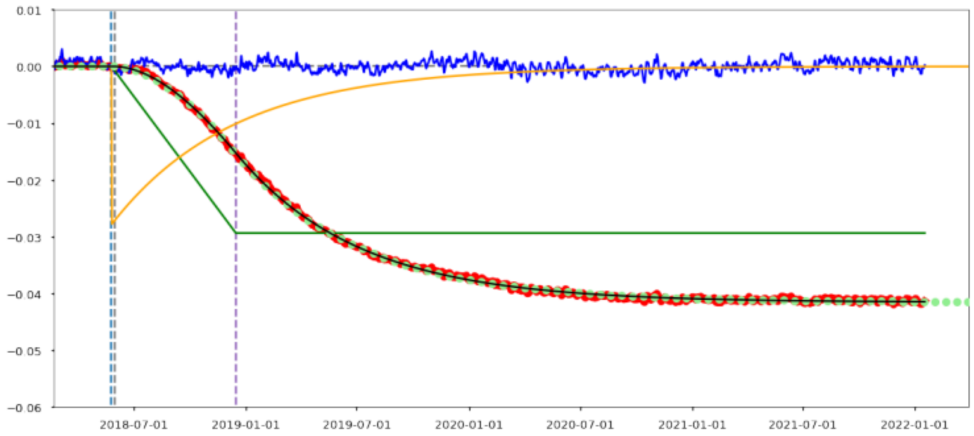
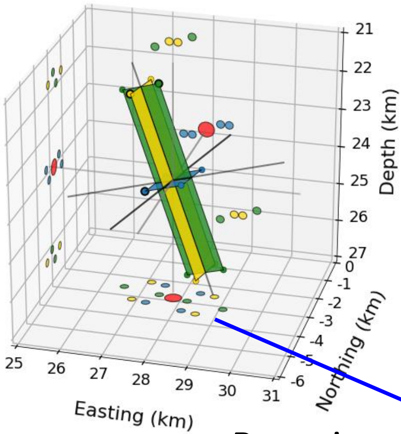
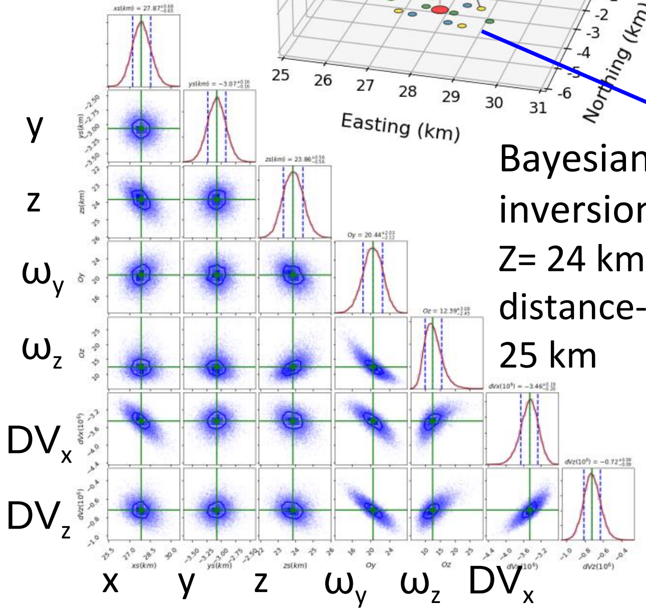


Fig. Red : First component of the PCA. **Black**: Estimated model. Blue : residuals. Green : pressure history imposed at the extremity of the pipe

Deformation model

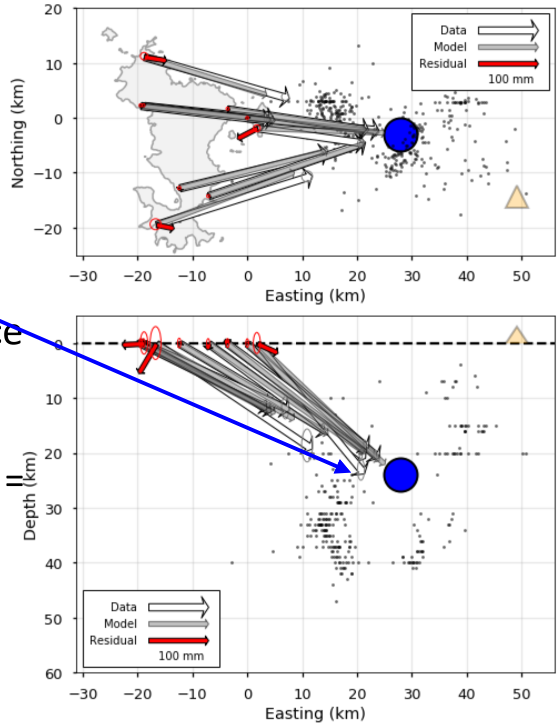
Compound Dislocation Model : «deflating pipe » (–5 km3)

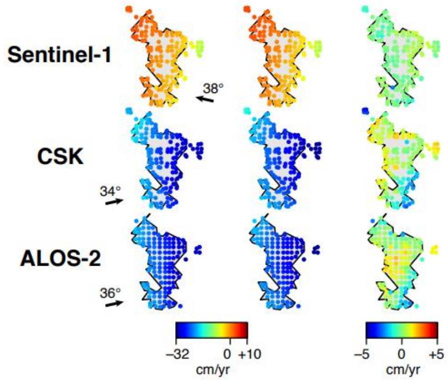




Bayesian source inversion :
Z= 24 km /
distance-MAYG = 25 km

Adjustment of cumulated displacements (2018–2022) : residuals < 1 cm





Deformation model

➡ Implementation in « proj » library (https://proj.org)

Deformation can be represented with such a decomposition

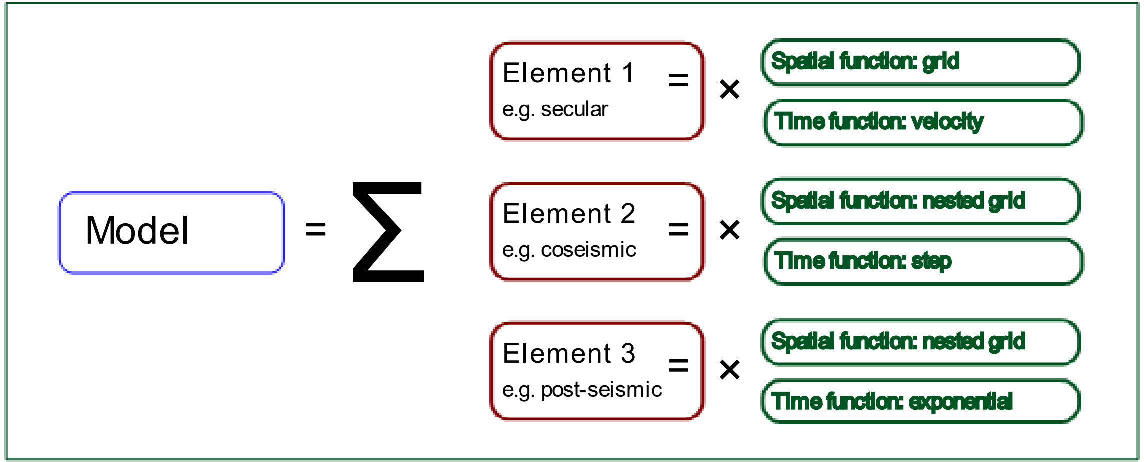


Fig. Adapted from Crook C. (2019)

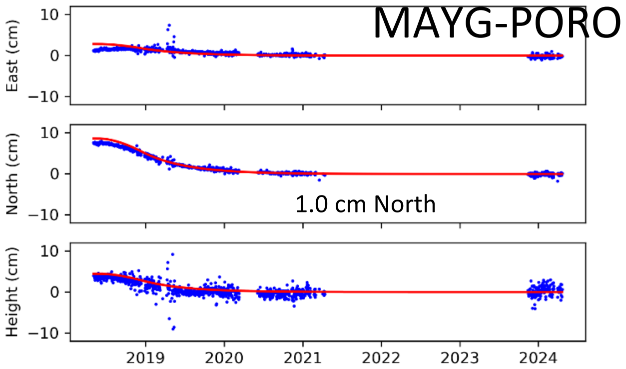
$ cct +proj=defmodel +model=path/RGM23_defmod.json coord.txt

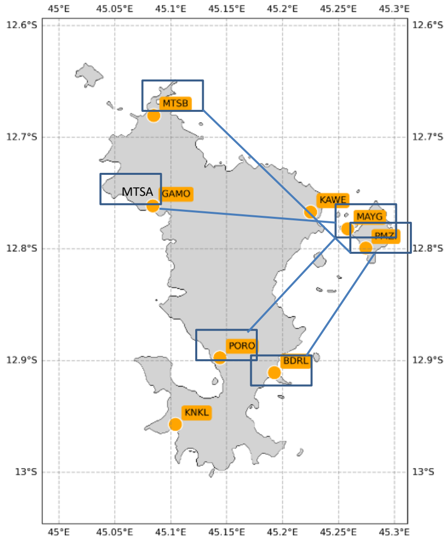
Model evaluation

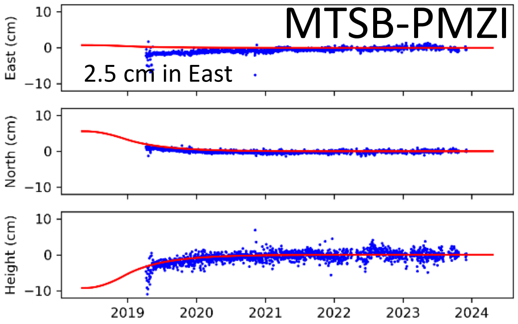
Internal deformation

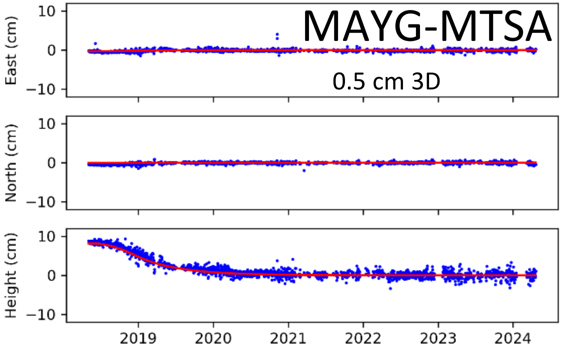
- Comparison with an independant processing at GNSS permanent stations (IGNF, Bernese)

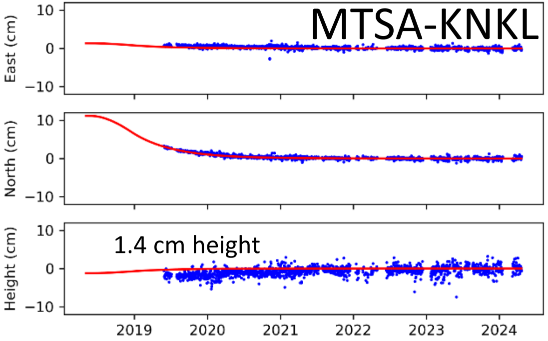
Maximum difference among all possible baselines in East / North / Up :
2.5 cm/ 1.1 cm/ 2.0 cm











Model evaluation

GNSS: campaign sites

New GNSS observations (campaign sites):

- 2 obs. sessions (2 h) from 11/09/2023 to 04/12/2023
- Stacked coordinates computed in IGS20@2023.75

RGM04 coordinates converted to ITRF2020 and propagated to epoch 2023.75 to compute the 2004-2023.75 displacements.

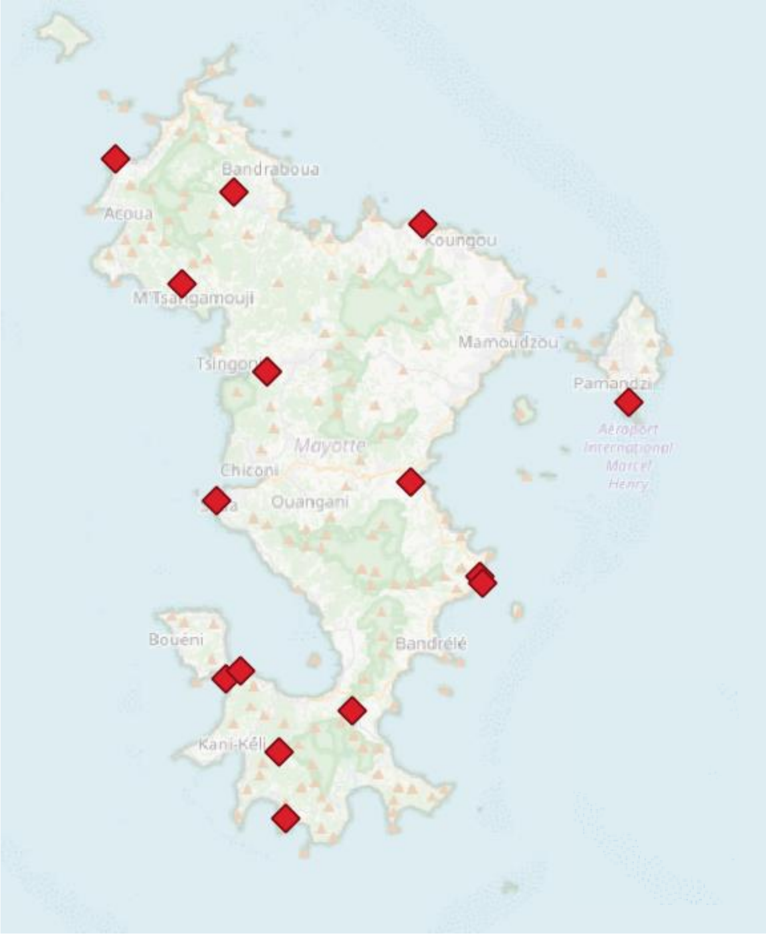


Fig. 16 common sites

Model evaluation

GNSS: campaign sites

New GNSS observations (campaign sites):

- 2 obs. sessions (2 h) from 11/09/2023 to 04/12/2023
- Stacked coordinates computed in IGS20@2023.75

RGM04 coordinates converted to ITRF2020 and propagated to epoch 2023.75 to compute the 2004-2023.75 displacements.

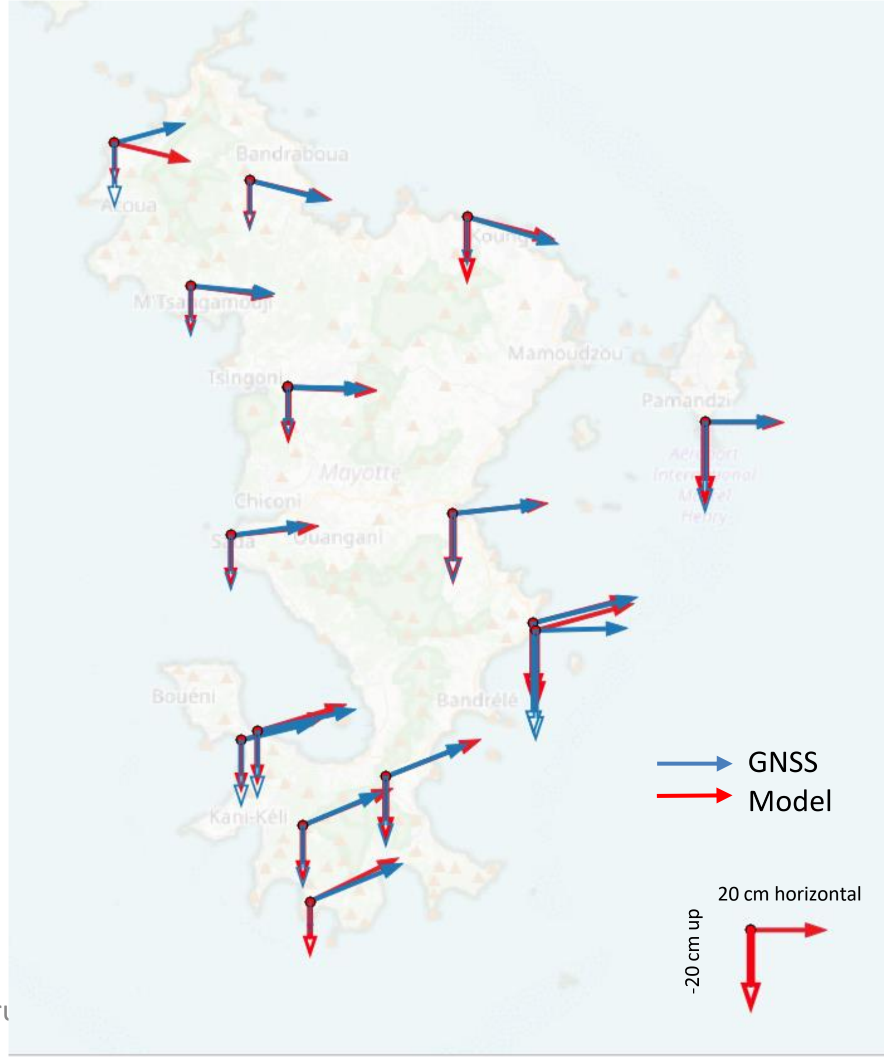


Fig. Estimated displacements of the 16 common sites

Model evaluation

GNSS: campaign sites

New GNSS observations (campaign sites):

- 2 obs. sessions (2 h) from 11/09/2023 to 04/12/2023
- Stacked coordinates computed in IGS20@2023.75

RGM04 coordinates converted to ITRF2020 and propagated to epoch 2023.75 to compute the 2004-2023.75 displacements.

Fig. GNSS displacements minus model

Model evaluation

Levelling

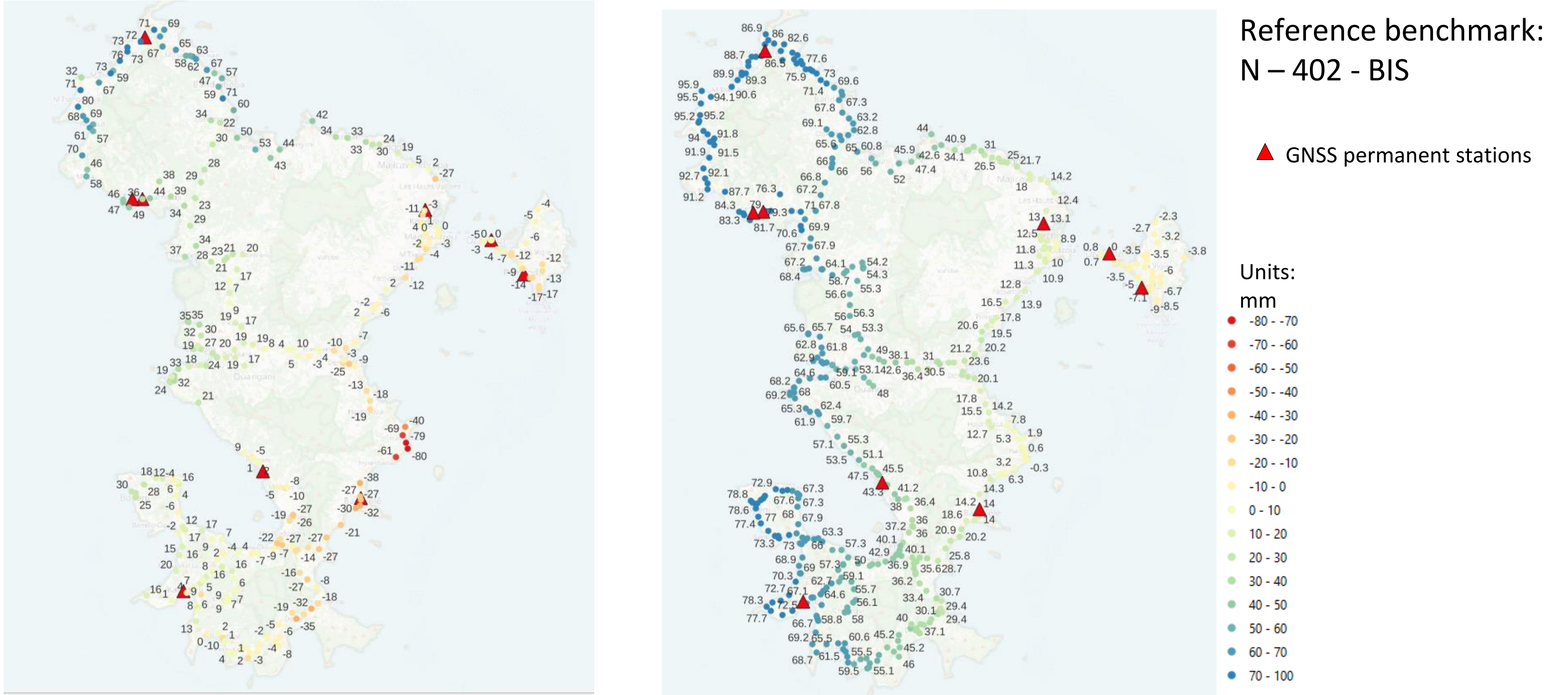


Fig. Left) Difference btw levelling campaigns 2006 and 2023. No gravity correction applied. Right) Model prediction.

Model evaluation

Levelling

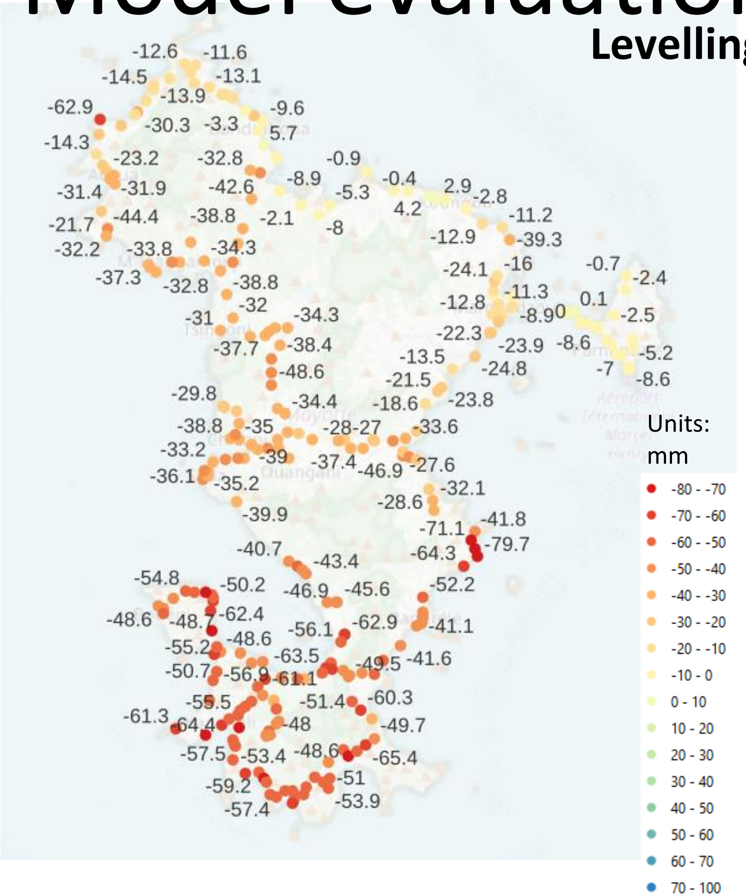
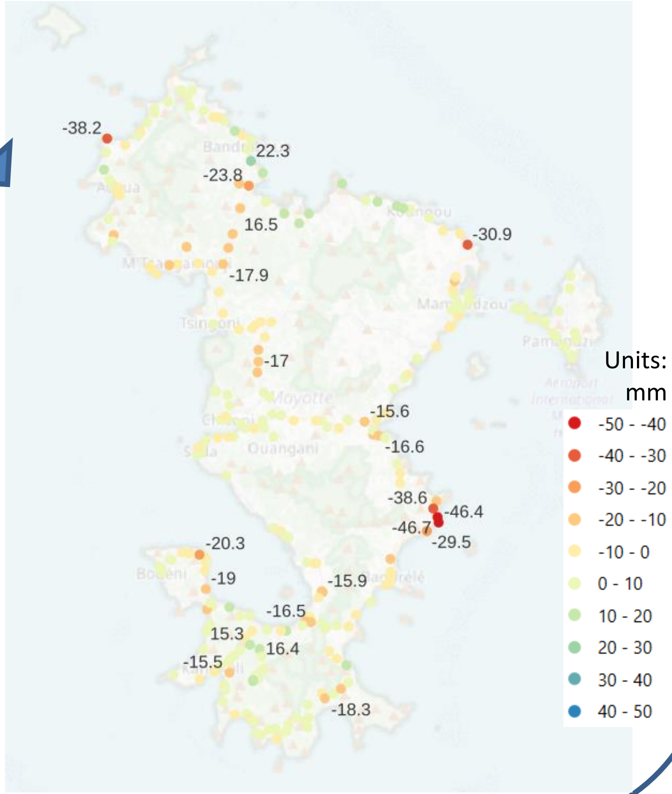


Fig: Levelling (no gravity correction) minus model

Linear model (Fitted in UTM 39 S)
Residual std : 9.7 mm

```
A (east)   (mm/km):   1.30 +/-   0.10
B (north)  (mm/km):   1.54 +/-   0.06
```



Perspectives

- Publication of the deformation model and its 'proj' implementation

- Release of the new frame « RGM23 » (by IGN survey department)

- Make use of the deformation model to provide a grid transformation between RGM04 and RGM23?

- Release of a transformation from ITRF2020 @ epoch t to « RGM23 » @epoch 2023.75 ?

- Upgrade of « RGM23 » to a semi-dynamic frame in a second step ?
  Important: no need of the model after 2023.75.
  Advantage: All data acquired during the crisis (2018-2020) could be rigourously transformed to RGM23.

References

- Crook C. (2019), Proposal for encoding of a Deformation Model, Land Information New Zealand
- FIG (2014), Reference Frames in Practice Manual, Commission 5 Working Group 5.2 Reference Frames, publication n°64
- Grandin, R., Beauducel, F., Peltier, A., Ballu, V., Chanard, K., Valty, P., ... & Komorowski, J. C. (2019, December). Surface deformation during the 2018-19 mayotte seismo-volcanic crisis from gnss, synthetic aperture radar and seafloor geodesy. In *AGU Fall Meeting Abstracts* (Vol. 2019, pp. V52D-03).
- Kierulf, H. P., Valsson, G., Evers, K., Lidberg, M., Häkli, P., Prizginiene, D., ... Poutanen, M. (2019). Towards a dynamic reference frame in Iceland. Geophysica, 54(1), 3-17.
- Le Mével, H., Gregg, P. M., and Feigl, K. L. (2016). Magma injection into a long-lived reservoir to explain geodetically measured uplift: Application to the 2007–2014 unrest episode at laguna del maule volcanic field, chile. Journal of Geophysical Research: Solid Earth, 121(8):6092–6108.
- Nikkhoo, M., Walter, T. R., Lundgren, P. R., and Prats-Iraola, P. (2016). Compound dislocation models (cdms) for volcano deformation analyses. Geophysical Journal International, page ggw427.
- Peltier, A., Saur, S., Ballu, V., Beauducel, F., Briole, P., Chanard, K., ... & Van Der Woerd, J. (2022). Ground deformation monitoring of the eruption offshore Mayotte. *Comptes Rendus. Géoscience*, *354*(S2), 1-23.