Solution JPL/GipsyX dans les OVS IPGP

F. Beauducel, P. Boissier, P. Sakic, J.B. de Chabalier, A. Peltier
Institut de physique du globe de Paris

Besoins

- Traitements temps-réel, robustes aux aléas (pannes station / transmission)
- Adapté aux formats de données hétérogènes (formats, arborescence de fichiers, durée, fréquence d'acquisition) et aux métadonnées incomplètes
- Combiner les enregistrements continus et de campagnes
- Séries temporelles brutes, validées, corrigées + vitesses + modélisation + …
- Utilisable en mode batch (Linux) pour intégration dans les chaines automatiques

Solution adoptée depuis les années 2000 : Gamit/Globk

+ excellente précision, adaptée aux études à grande échelle (tectonique)
– dépendance aux données régionales et aux stations de référence
– traitements lourds et difficiles à automatiser

gnss_run_gipsyx.sh

```
Syntax: gnss_run_gipsyx CONF DAYS [options]

Description: runs the automatic GNSS process from raw files to position solution

  Arguments:
     CONF = configuration filename, e.g., /etc/webobs.d/gnss_run_gipsyx.rc
     DAYS = number of days to process (from today)

    Options:
      -s "STA1 STA2..."
           station code or station list with double quotes
           default is all nodes associated with local WebObs proc name
           or a list of nodes  defined in .rc
      -d "yyyy/mm/dd,yyyy/mm/dd"
           choose days to start process; the DAYS argument can still be used to
           process previous days from the selected ones, for instance:
           gnss_run_gipsyx CONF 1 -d 2017/03/17,2018/08/05
           will compute  2017/03/17, 2017/03/16, 2018/08/05 and 2018/08/04
      -final, -rapid, -ultra
           use only final, rapid or ultra orbit
      -force
           forces the process despite existence of final results
      -lock
           creates a lock file to prevent multiple process of gnss_run_gipsyx
      -debug
           verbose mode
```

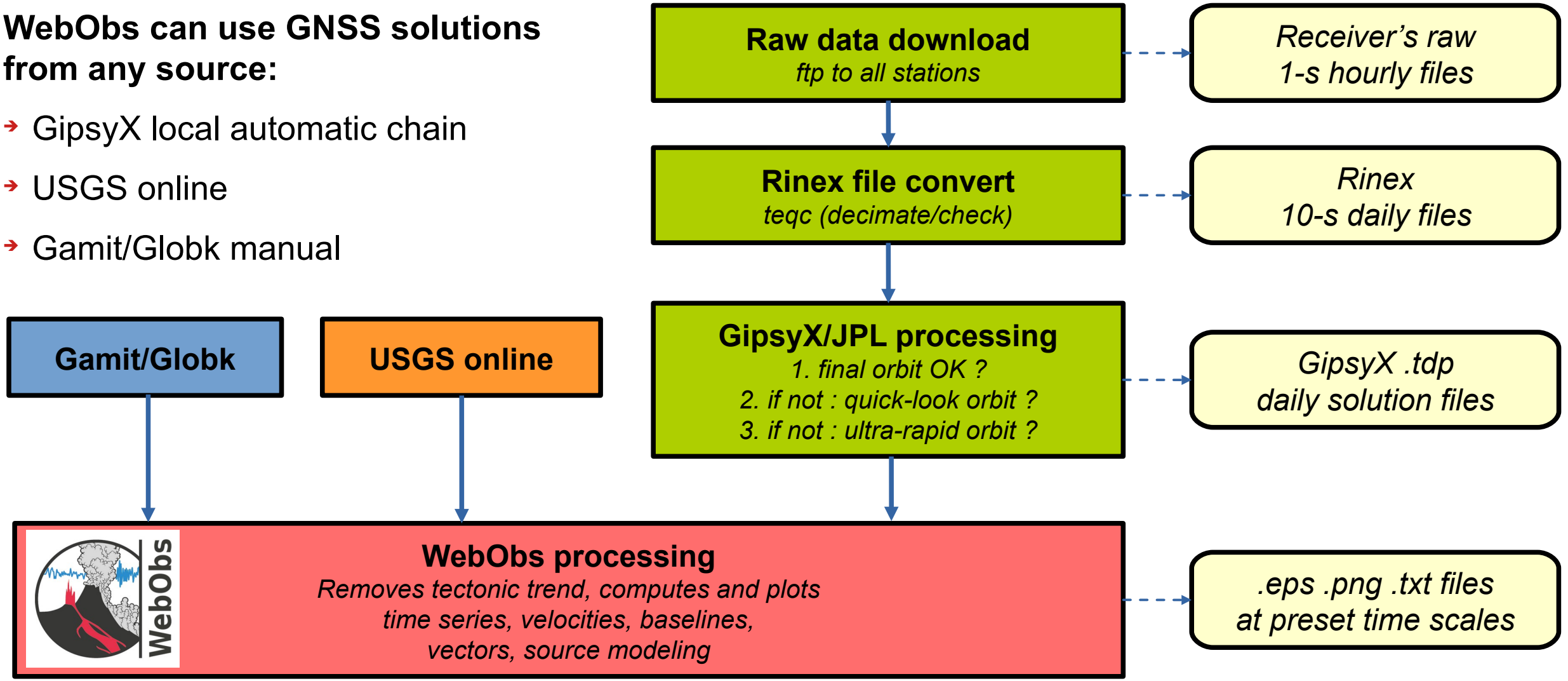
gnss_run_gipsyx.rc

```
# prepares GIPSYX processing
source /home/wo/GipsyX-1.2/rc_GipsyX.sh

# grid of a local WebObs that contains the station list (nodes)
#GRID=PROC.GIPSYX
#NODEROOT=/opt/webobs.d/GRID2NODES/$GRID.
# ... or empty $GRID and default list of station codes (space separated)
NODES=

# optional site logs to overwrite rinex headers (antenna and receiver codes)
# - option 1: station.info file (Gamit)
STATION_INFO=
# - option 2: site log directory (recommended)
SITELOG=

# base directory that contains the raw data
FROM=/home/wo/rawdata/GNSS

# directory structure of the raw data (will be evaluated using eval...)
# valid variables are: $FID, $sta (lowercase FID), $yyyy, $yy, $mm, $dd, $doy,
# $bb. Example for station BABA on September 07, 2022:
#    $FID: BABA
#    $sta: baba
#   $yyyy: 2022
#     $yy: 22
#     $mm: 09
#     $dd: 07
#    $doy: 250
#     $bb: Sep
FMT='$FROM/$FID/$yyyy/$mm/$dd'

# base directory for output results
DEST=/home/wo/GNSS/gipsyx

# base directory to store local orbits (optional)
ORBITSDIR=/home/wo/GNSS/JPL_Local_Orbits

# download_orbit options (see download_orbit)
DOWNLOAD_OPTIONS="-r 30"

# gd2e.py options
GIPSYOPTIONS="-runType PPP"

# teqc options: Please take a deep look at www.unavco.org TEQC tutorial!
TEQCOPTIONS="+quiet -O.pe 0 0 0 -C2 -O.-obs C2 -O.-obs C5 -O.dec 30s -max_rx_SVs 50 -n_GLONASS 27"

# not empty value will add troposphere results in .tdp files (.Trop.*)
TROP_TDP=

# display some rinex header in case of error
ERROR_REGEX_RINEX="REC #|ANT #|# / TYPES OF OBSERV|MARKER NAME|APPROX POSITION XYZ"

# realtime processing (put "Y" if wanted)
REALTIME=""

# data delay for realtime processing
DATA_DELAY="5 min"
```

Real-time automatic GNSS chain connected to the WebObs system

WebObs can use GNSS solutions from any source:

- GipsyX local automatic chain
- USGS online
- Gamit/Globk manual

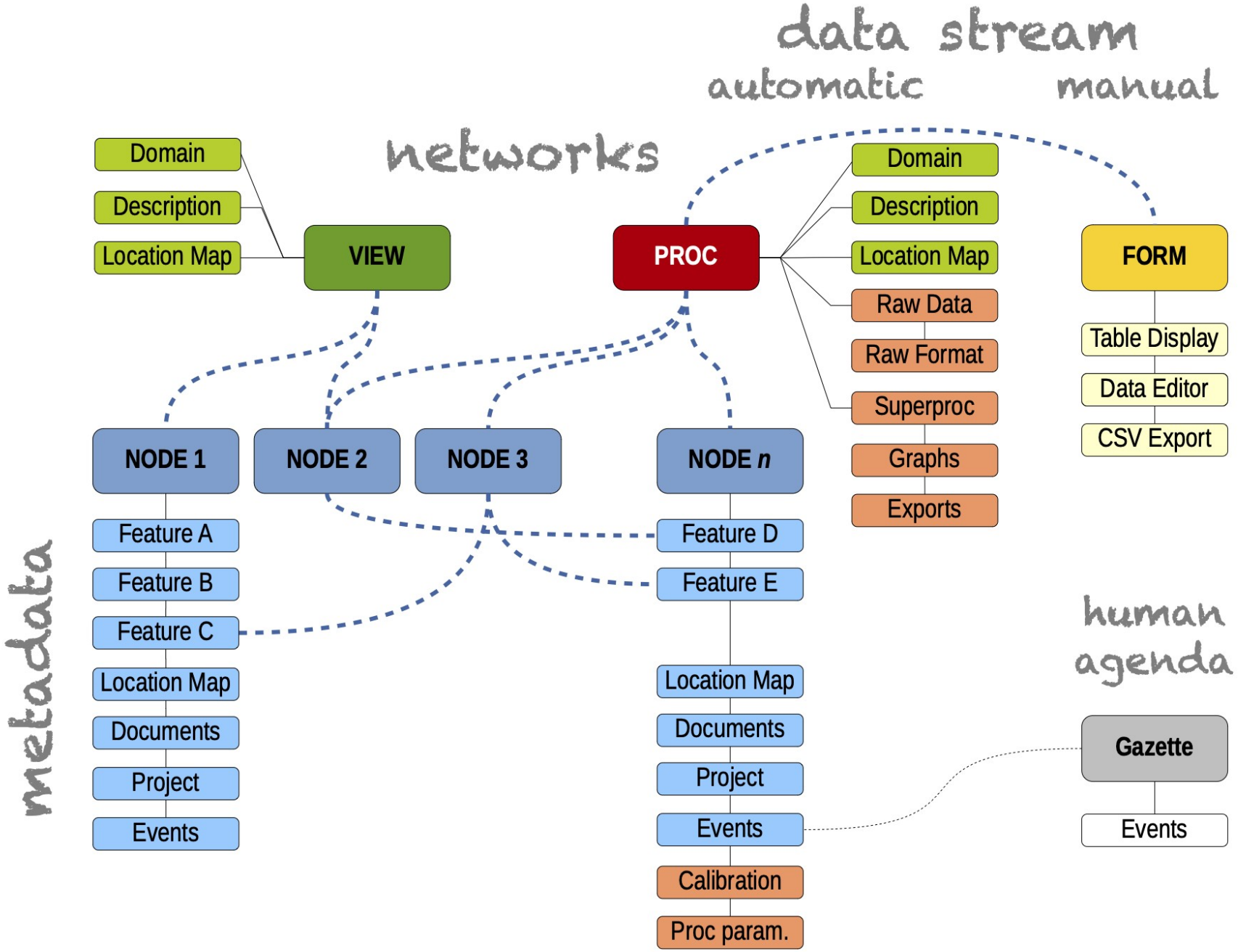


ipgp.github.io/webobs

2001 : conception à l'OVSG

2012 : consolidation du code

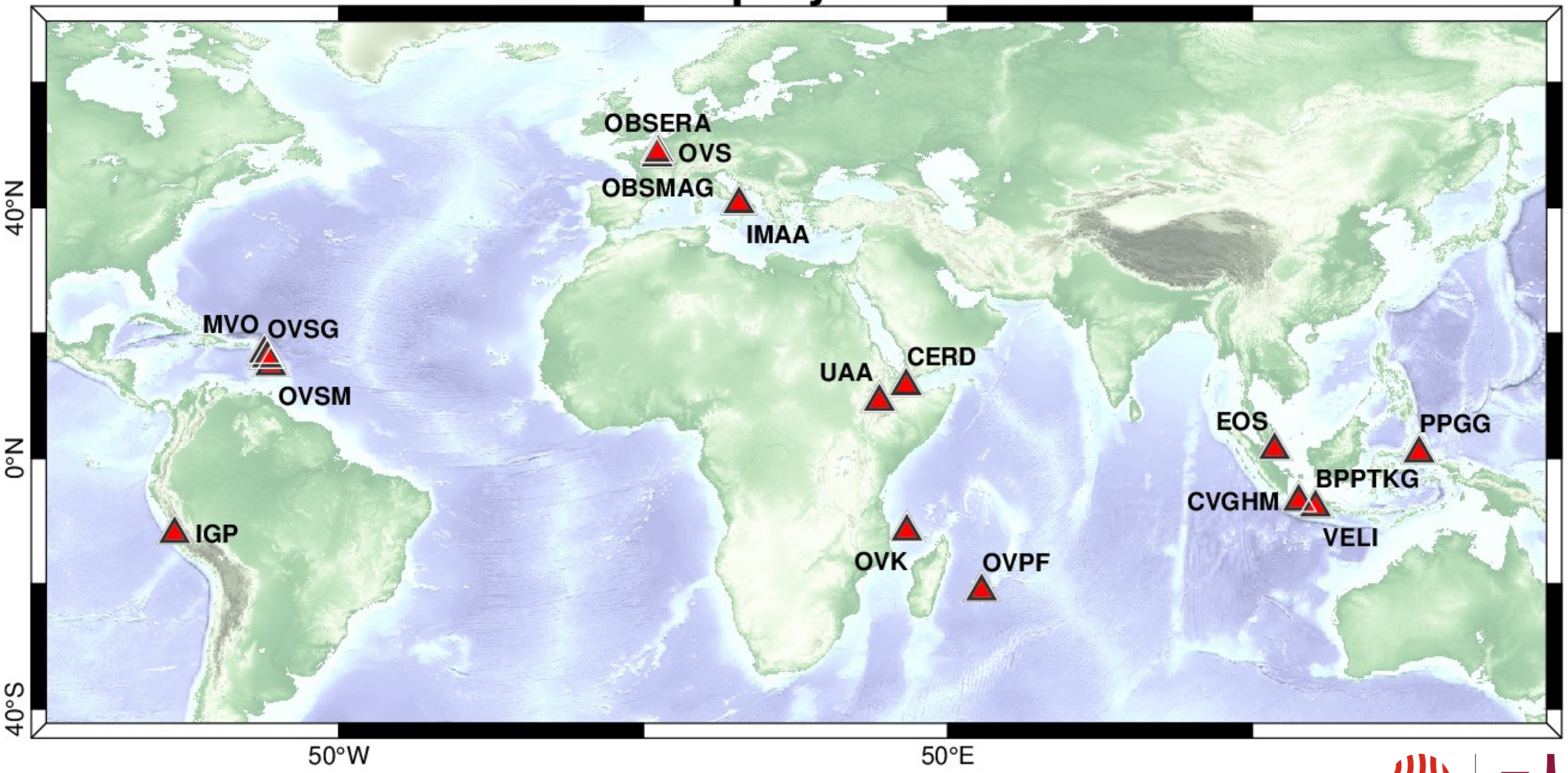
2022 : 1er code communautaire labellisé INSU Terre Solide



IPGP

Université Paris Cité

Known deployed WebObs



WebObs

active (**17**/17)

IPGP

Université Paris Cité

Deformations / I

»» [Procs | | | | | Specificati | ct | Events | References]

Purpose

A first GPS repetition network was setup and measured since 1993, allowing detecting a deep magma reservoir, quantifying magma flux in conduit and identifying shallow discontinuities around the former crater (*Beauducel & Cornet*, 1999; *Beauducel et al.*, 2000; 2006). After the 2010 eruption, when this network was damaged, Indonesian and Japanese teams installed a new continuous GPS network consisting of 3 stations located on the volcano flanks plus a reference at Yogyakarta Observatory (BPPTK) for monitoring purpose.

In the DOMERAPI project we have completed this network with 5 new stations, which are located on the summit area and volcano surrounding. The final network (8 stations + reference), all with 1-Hz sampling and real-time data streaming to the Observatory, will be able to better detect and measure the location and volume variations of possible magma sources, and to follow magma transfer towards the surface. Precise daily solutions automatic algorithms will be set up together with real-time inversion of 3D elastic modelling of deformation sources, using different approaches: 3D-MBEM (*Cayol & Cornet*, 1997) and displacements tomography (*Augier*, 2011).

This is the main automatic processing results for GNSS Merapi network. Results come from local computing (gnss_run_gipsy script) which runs successively: - rinex files convertion (**teqc**) - GipsyX positionning (**gd2e.py**) Daily solutions are performed for each station, in the ITRF08 referential. Time series components are relative to the first position. Vectors are velocity trends on each time period.

Specifications

- Domain: **Deformations**
- Grid code: **PROC.GIPSYX**
- Node(s): **11** "station" [Associate existing node(s) | Create a new node]
- Default data format: **gipsyx**
- Default data source: **/DOMERAPI/data1/GNSS/gipsyx**
- Access to rawdata: **/rawdata/GNSS/gipsyx**
- Events File(s): **CONF/events_World.conf**

Proc Graphs	10d	01m	01y	05y	all
Overview					
SUMMARY					
VECTORS					
BASELINES					
MOTION					
MODELNET					
MODELLING					
MODELTIME					

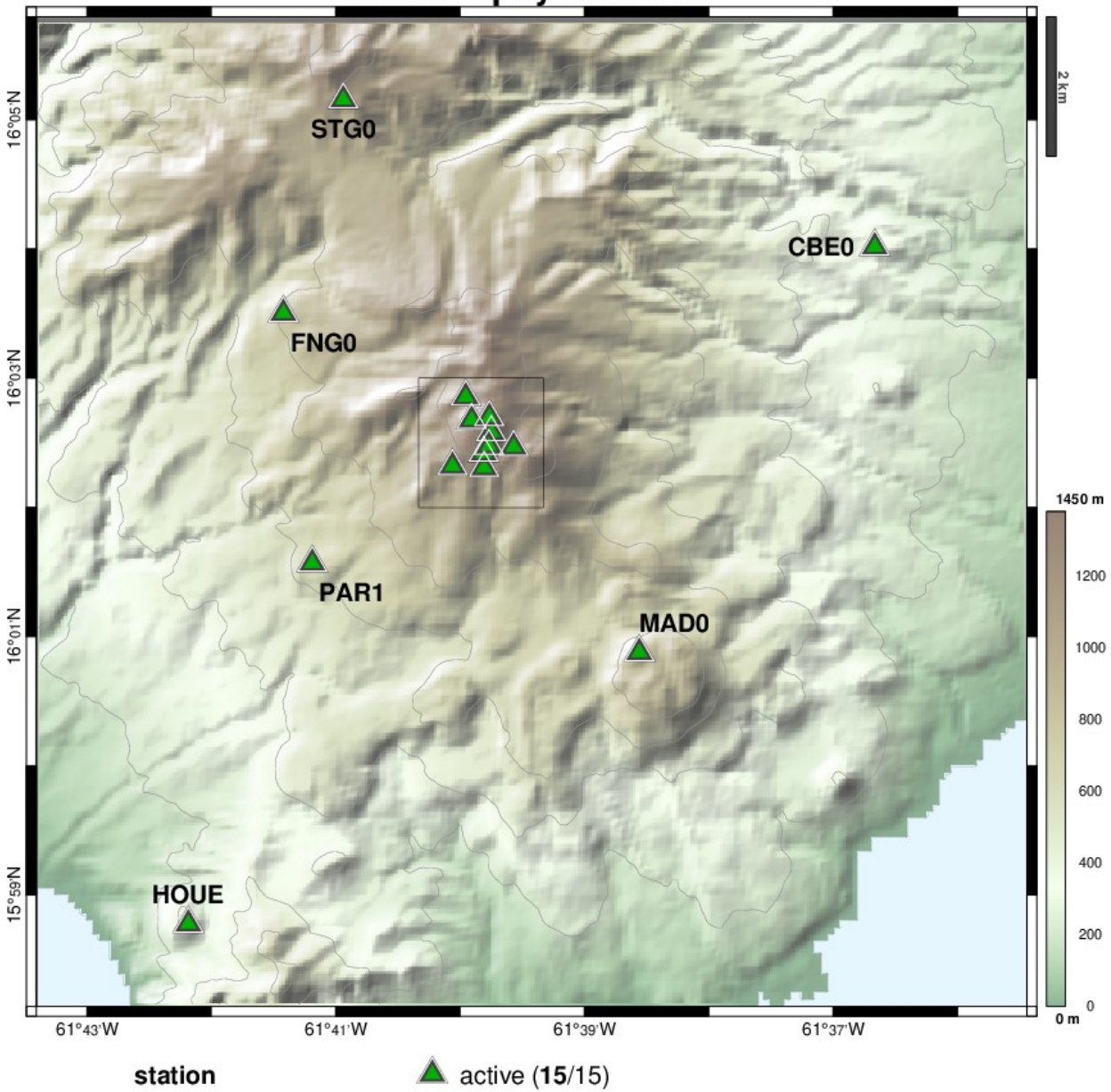
Proc Param.	10d	01m	01y	05y	all
Decimate	*undefined*				
Cumulate	*undefined*				
DateStr	6	6	2	10	10
MarkerSize	6	4	3	2	2
LineWidth	2	.5			
Status	0	1	0	0	0

List of station(s)

Nodes [Active | Valid | **All**] - Coordinates [**Lat/Lon** | UTM | XYZ] - Export [TXT | CSV | KML] - Proc parameters [**On** | Off] - Project [On | **Off**]

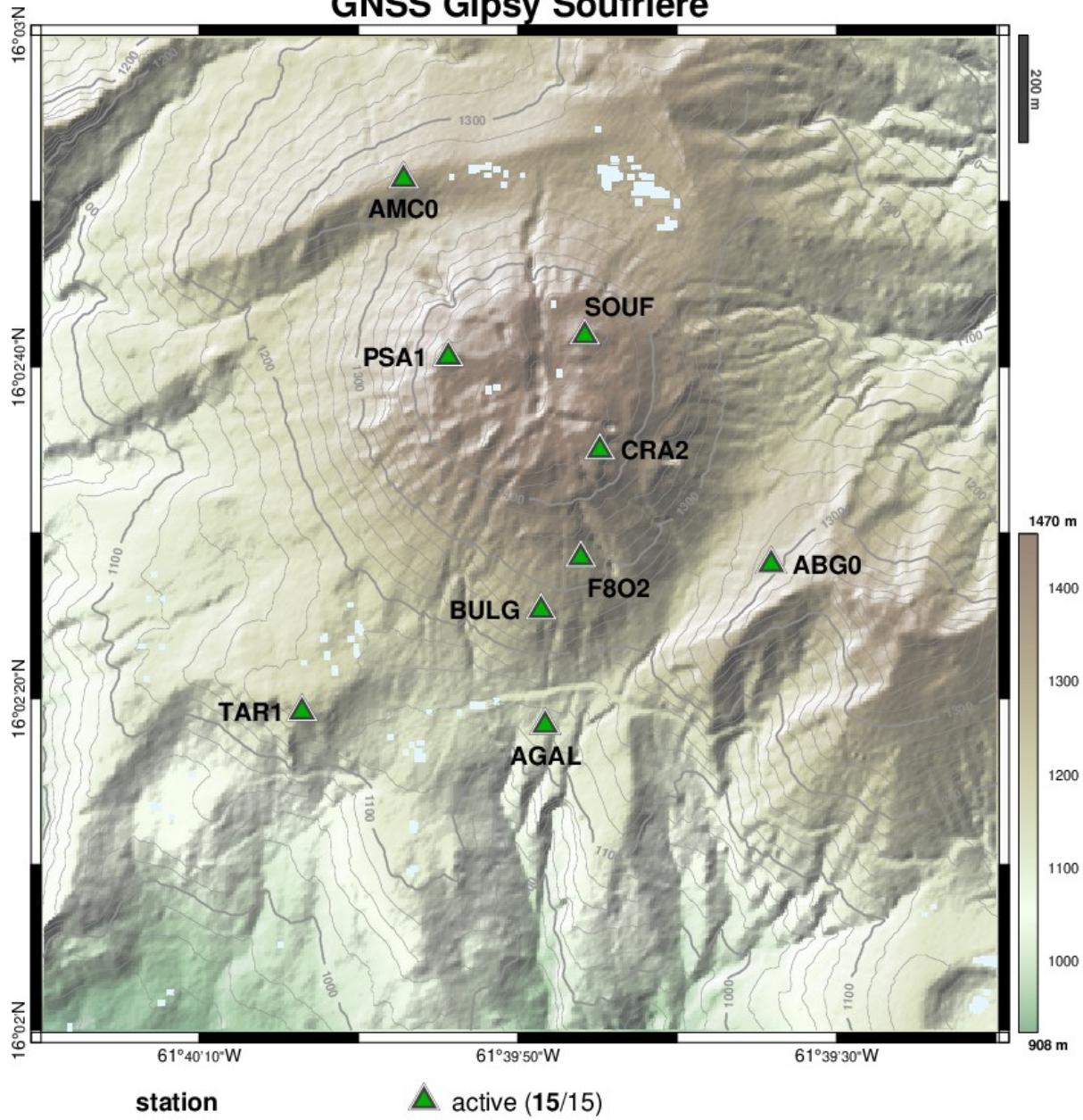
	Alias	Name	Coordinates			Lifetime and Validity		Type	Nb Evnt	Proc Parameters			Proc Graphs					Proc Status (01m)		
			Lat. (WGS84)	Lon. (WGS84)	Elev. (m)	Start / Installation	End / Stop			FID	Raw Format	Chan.	10d	01m	01y	05y	all	Last Data (TZ +0)	Sampl.	Status
	BABA	"Pos Babadan"	-7.52621	110.41067	1274	2013-06-13		DOMERAPI GR25 @1s	27	BABA	gipsyx							2022-09-20 07:55:00+00.00	68 %	0 %
	BPTK	"BPPTKG Yogyakarta"	-7.79868	110.38384	111	2010-12-25		BPPTKG GX1220 @1s	0	BPTK	gipsyx							2022-09-29 09:55:00+00.00	86 %	0 %
	DELS	"Deles"	-7.56783	110.46469	1399	2011-11-01	2020-02-13	BPPTKG GR10 @1s	1	DELS	gipsyx							2020-02-13 04:55:00+00.00	*Stopped*	
	GRWH	"Jurang Grawah"	-7.52160	110.45150	2045	2011-09-26		BPPTKG GR10 @1s	0	GRWH	gipsyx							2022-10-02 07:55:00+00.00	100 %	100 %
	JRAK	"Pos Jrakah"	-7.49723	110.42158	1281	2013-06-09		DOMERAPI GR10 @1s	8	JRAK	gipsyx							2022-10-02 07:55:00+00.00	100 %	100 %
	KLAT	"Klatakan"	-7.53470	110.42800	1640	2011-12-01		BPPTKG GR10 @1s	1	KLAT	gipsyx							2022-10-02 07:55:00+00.00	100 %	100 %
	KNDT	"Kendit"	-7.54912	110.44525	2308	2018-04-27	2020-03-03	DOMERAPI GR30	7	KNDT	gipsyx							2020-03-02 21:55:00+00.00	*Stopped*	
	LABH	"GPS Labuhan"	-7.55703	110.44507	1844	2020-09-04		BPPTKG Leica GR30	0	LABH	gipsyx	4						2022-10-02 07:55:00+00.00	100 %	100 %
	PASB	"Pasar Bubar"	-7.53666	110.44865	2676	2013-06-22		DOMERAPI GR10 @1s	11	PASB	gipsyx	4						2022-10-02 07:55:00+00.00	100 %	100 %
	PLAW	"Plawangan"	-7.58794	110.43148	1235	2013-06-27		DOMERAPI GR10 @1s	5	PLAW	gipsyx							2022-10-02 07:55:00+00.00	100 %	100 %
	SELO	"Pos Selo"	-7.49894	110.45717	1646	2013-06-10		DOMERAPI GR10 @1s	16	SELO	gipsyx							2022-10-02 07:55:00+00.00	100 %	100 %

GNSS Gipsy Soufrière

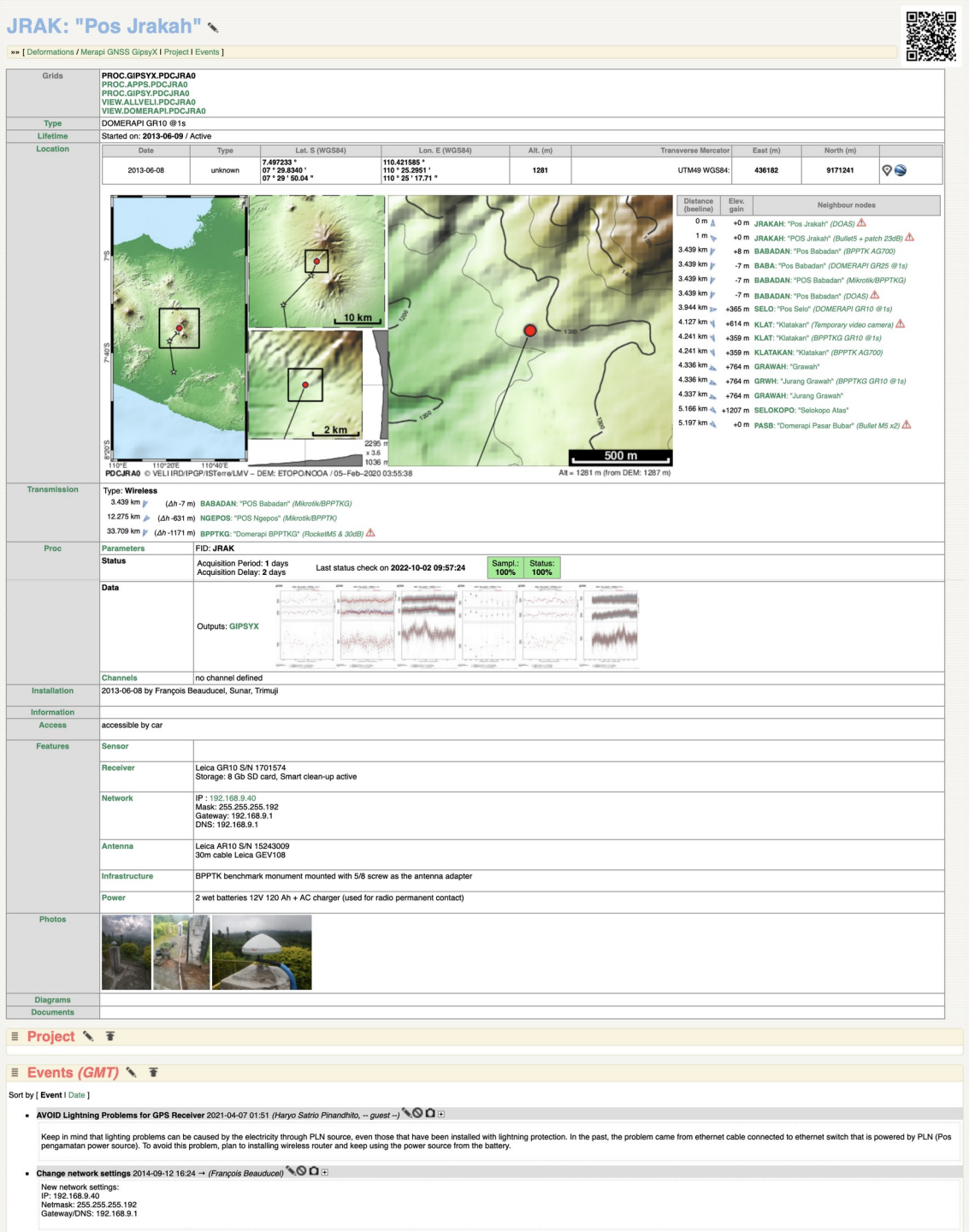


© WEBOBS MASTER-DEV / IPGP – PROC.GIPSYSOUF – DEM: SRTM/NASA / 18-Dec-2020 18:53:17

GNSS Gipsy Soufrière



© WEBOBS MASTER-DEV / IPGP – PROC.GIPSYSOUF – DEM: LIDAR / 18-Dec-2020 18:53:18



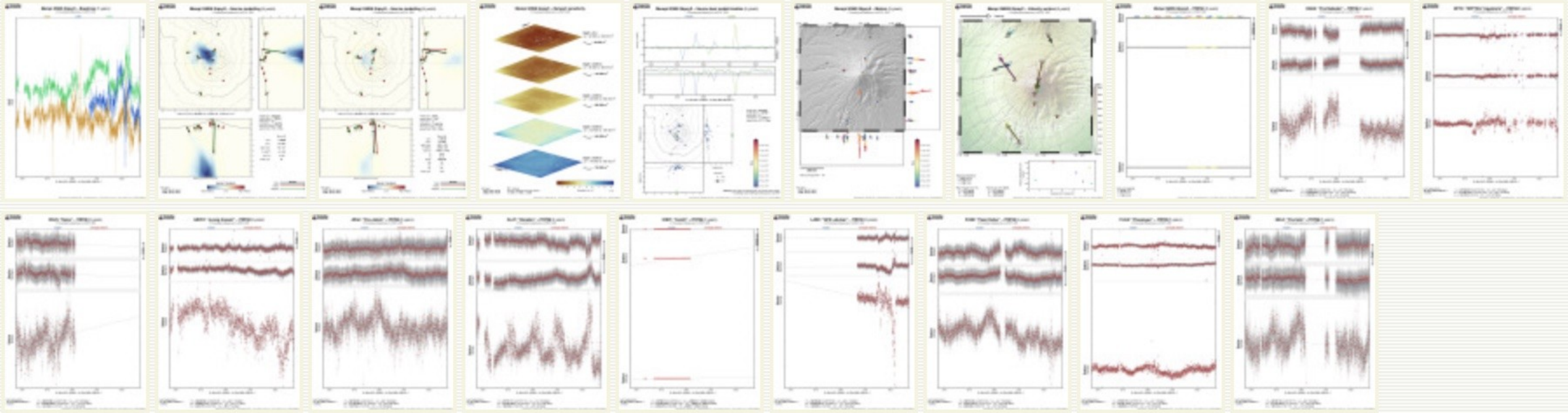
Le “NODE” webobs : une structure d’élément bien adaptée à une station GNSS permanente

- dates de validité, localisation
- métadonnées libres sur récepteur, antenne, connectique, alimentation, transmission, accès au site, etc.
- photos, documents, journal des interventions, projet technique
- fichier de calibration (correction de sauts non renseignés dans les sitelogs)
- format des données / solutions (gamit, gipsyx, …)

➔ permet aussi de renseigner les points de répétition (caractéristiques libres)

Merapi GNSS GipsyX

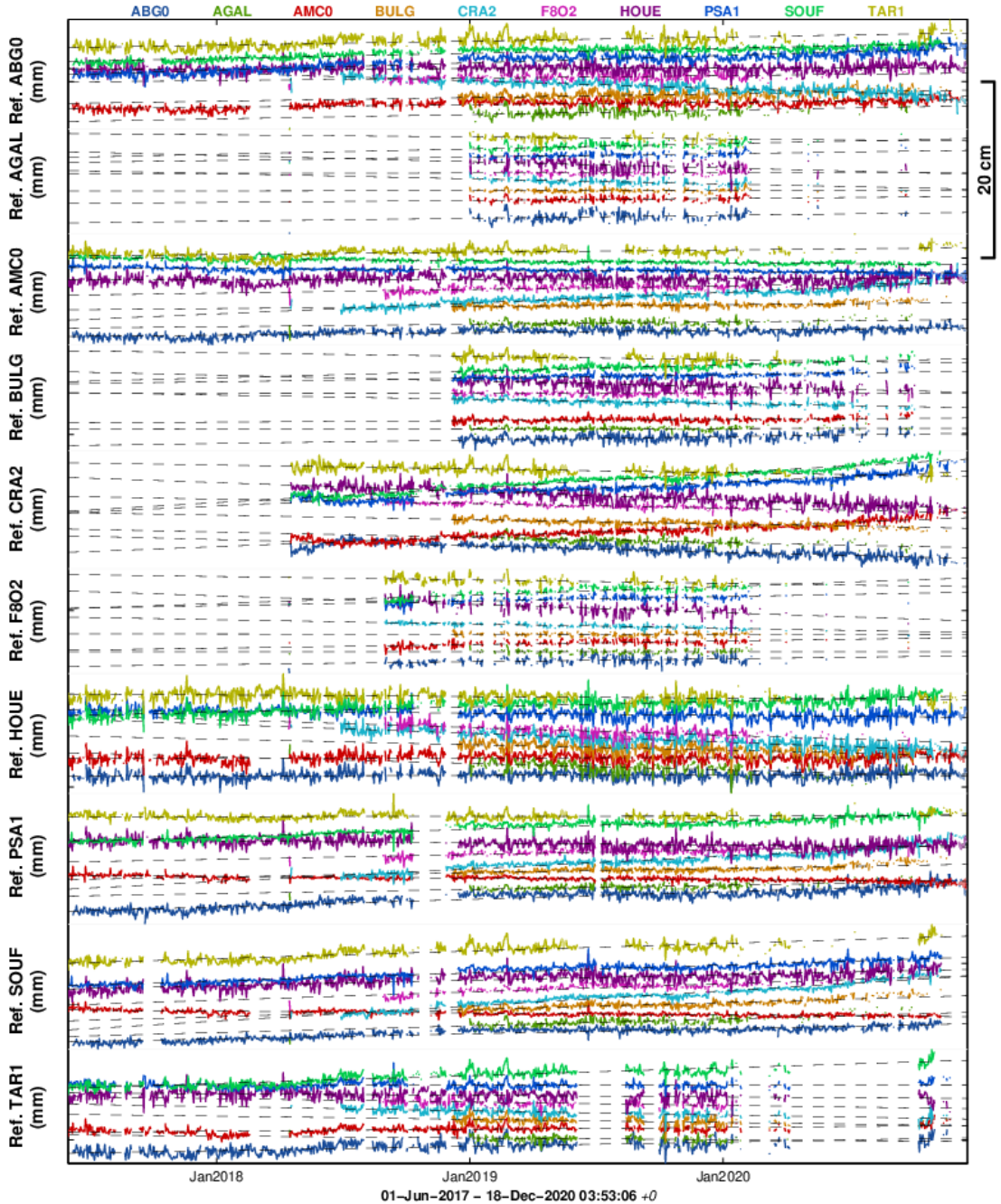
»» [Proc | Map | Time scales: 10 days | 1 month | 1 year | **5 years** | All Data | ⟳]
[Overview | Column | BASELINES | MODELLING | MODELLING_pCDM | MODELNET | MODELTIME | MOTION | VECTORS | SUMMARY | BABA | BPTK | DELS | GRWH | JRAK | KLAT | KNDT | LABH | PASB | PLAW | SELO]



WebObs OVS-IPGP

GNSS Gipsy Soufrière – Baselines (Ref. 01)

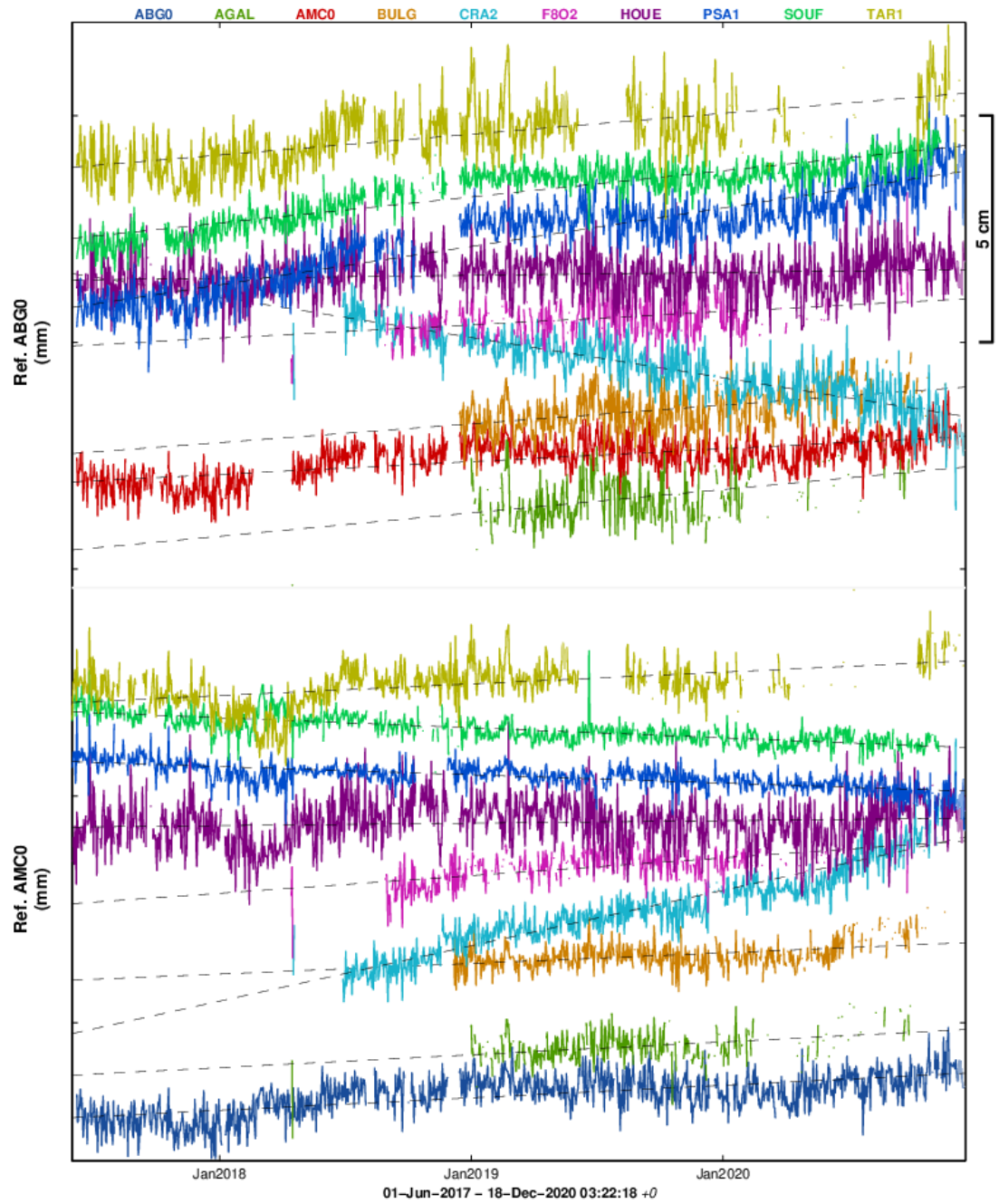
© OVSG–IPGP, 2020



WebObs OVS-IPGP

GNSS Gipsy Soufrière – Baselines (Ref. 01)

© OVSG–IPGP, 2020

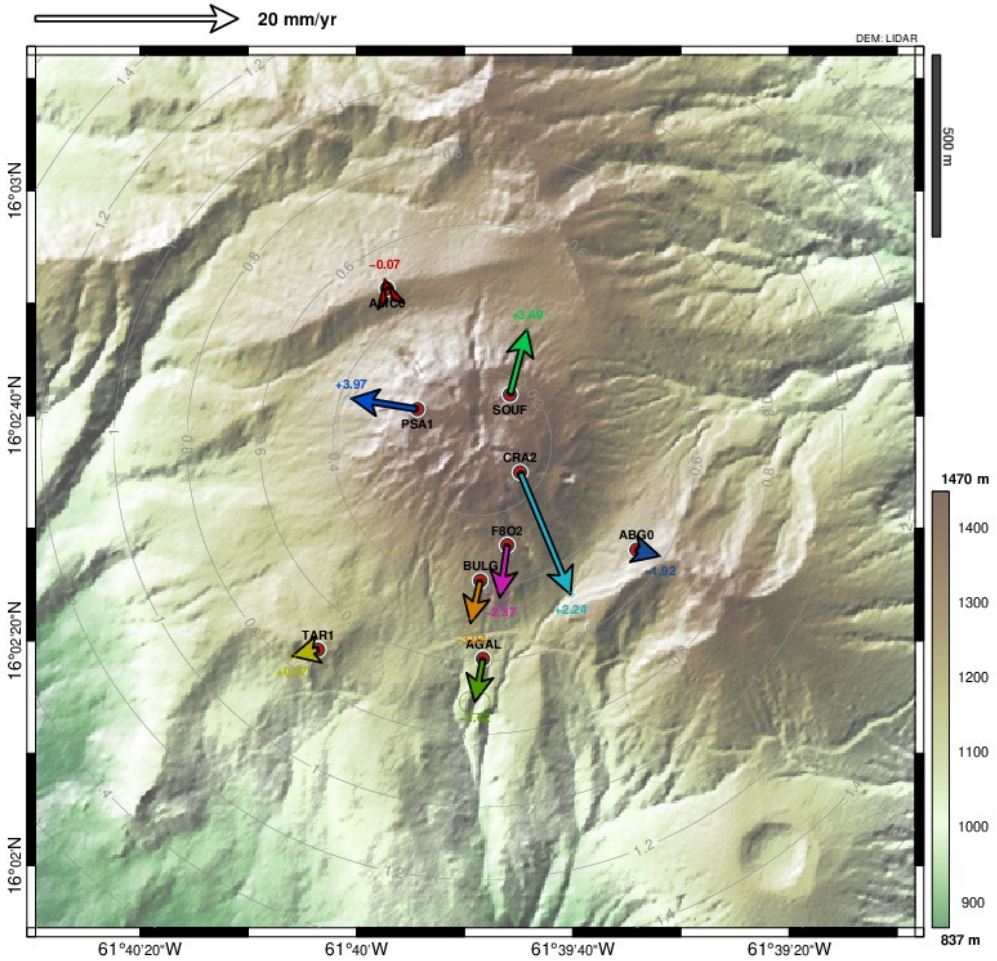


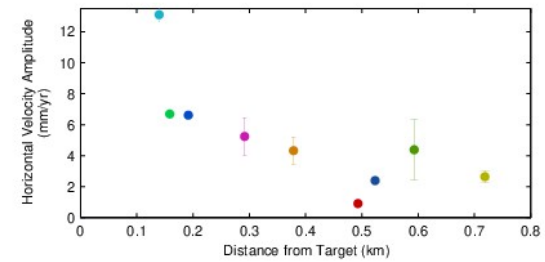
IPGP | Université Paris Cité

WebObs OVS-IPGP

GNSS Gipsy Soufrière – Velocity vectors (Ref. 01)

© OVSG–IPGP, 2020





Referential: **local ref.**
E **+11** mm/yr
N **+15** mm/yr
U **+0** mm/yr

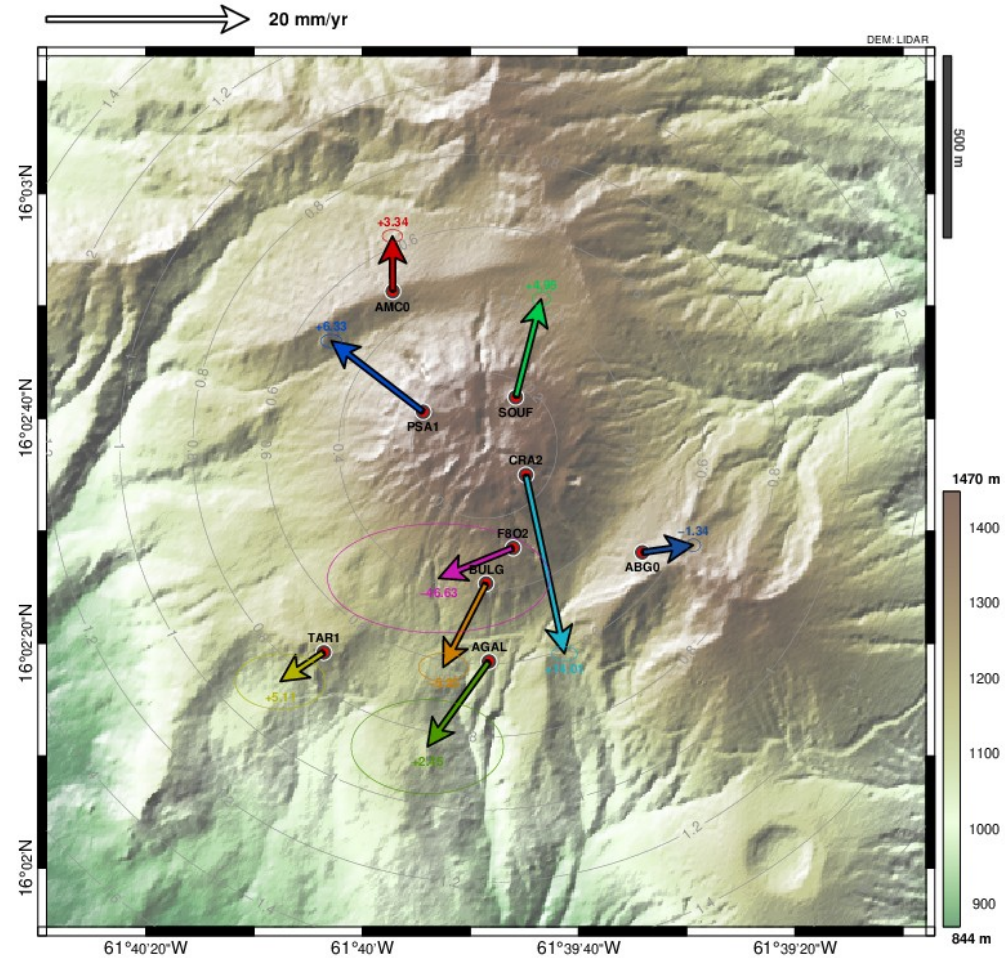
Mean velocity (local ref.):
E = **−0.16 mm/yr**
N = **+0.07 mm/yr**
U = **+1.11 mm/yr**

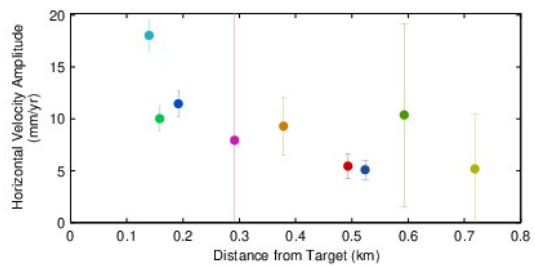
Velocity ref. vector (**auto**):
E = **−0.16 mm/yr**
N = **+0.07 mm/yr**
U = **+0.00 mm/yr**

WebObs OVS-IPGP

GNSS Gipsy Soufrière – Velocity vectors (1 year)

© OVSG–IPGP, 2020





Referential: **local ref.**
E **+11** mm/yr
N **+15** mm/yr
U **+0** mm/yr

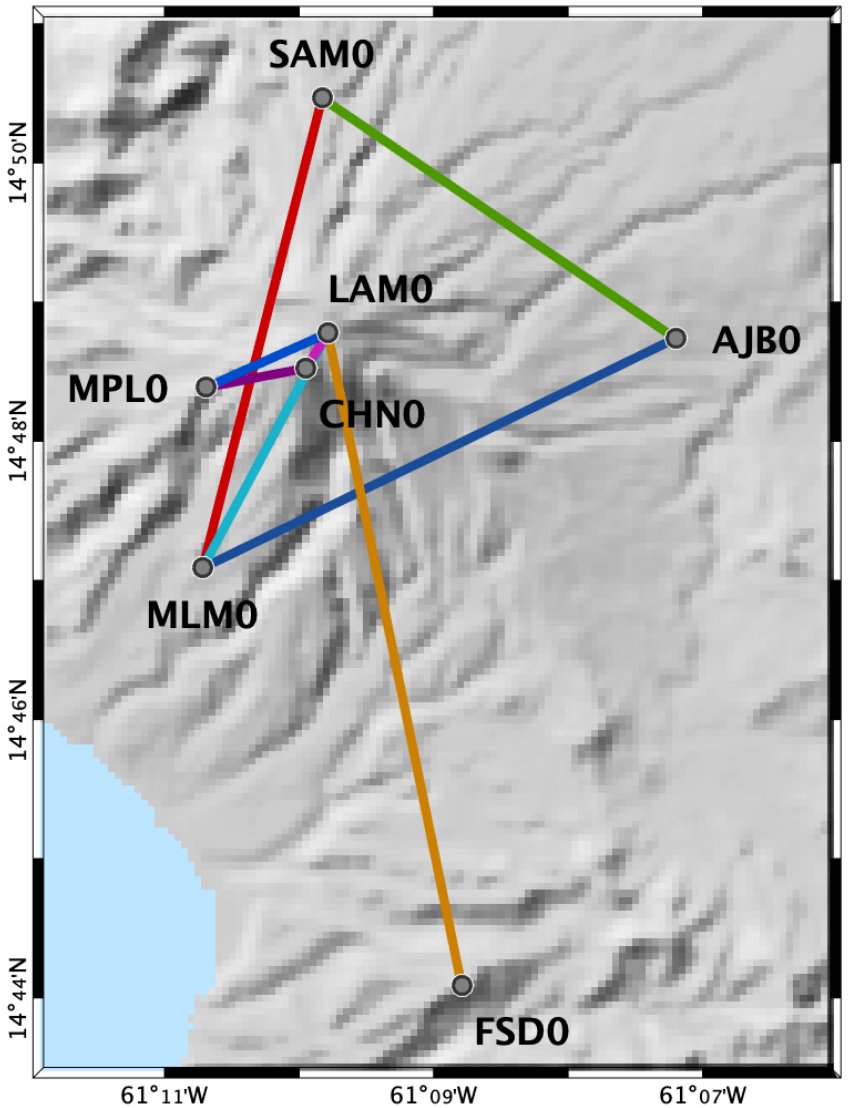
Mean velocity (local ref.):
E = **−0.38 mm/yr**
N = **−3.04 mm/yr**
U = **+3.42 mm/yr**

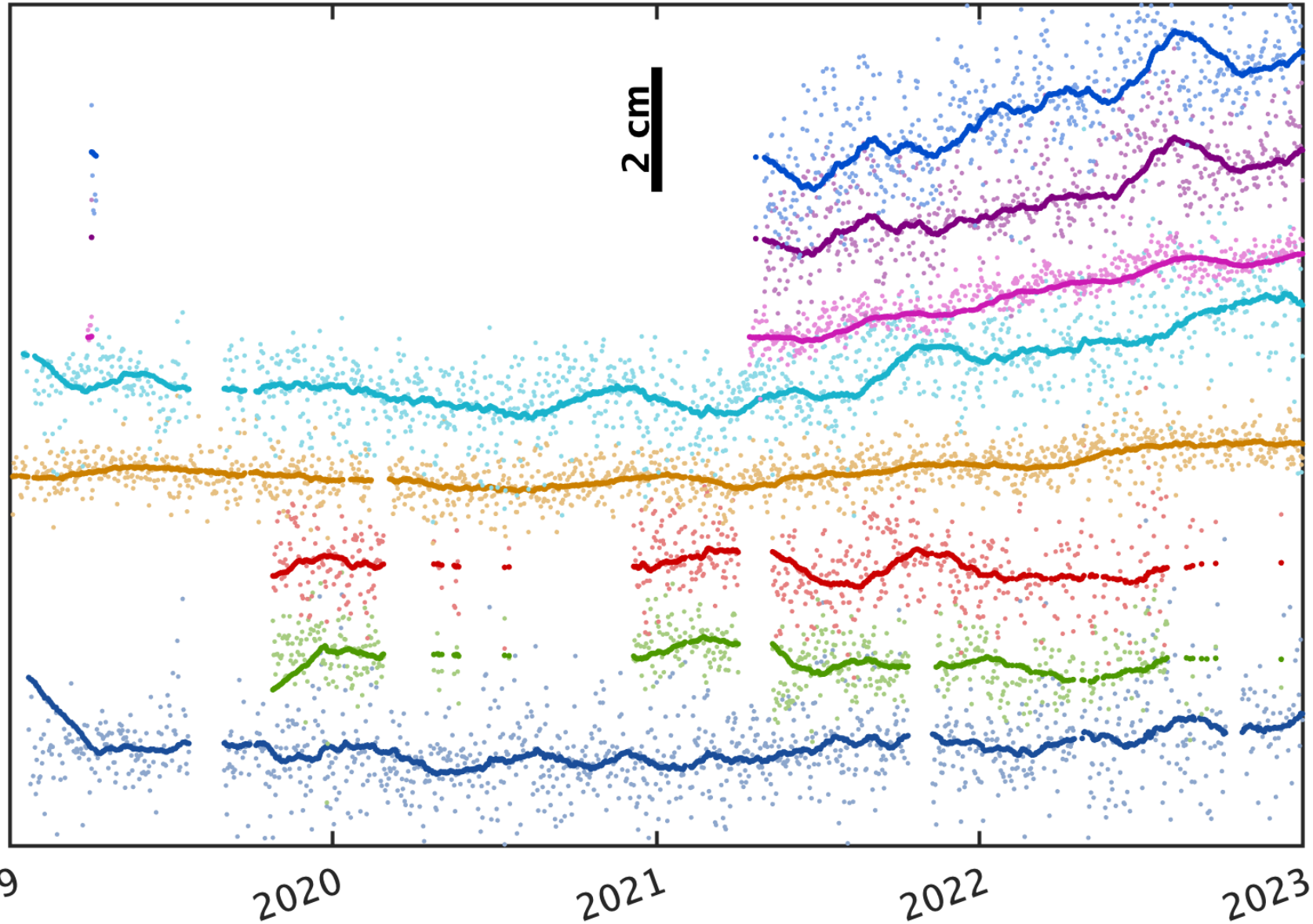
Velocity ref. vector (**auto**):
E = **−0.38 mm/yr**
N = **−3.04 mm/yr**
U = **+0.00 mm/yr**

IPGP

Université Paris Cité

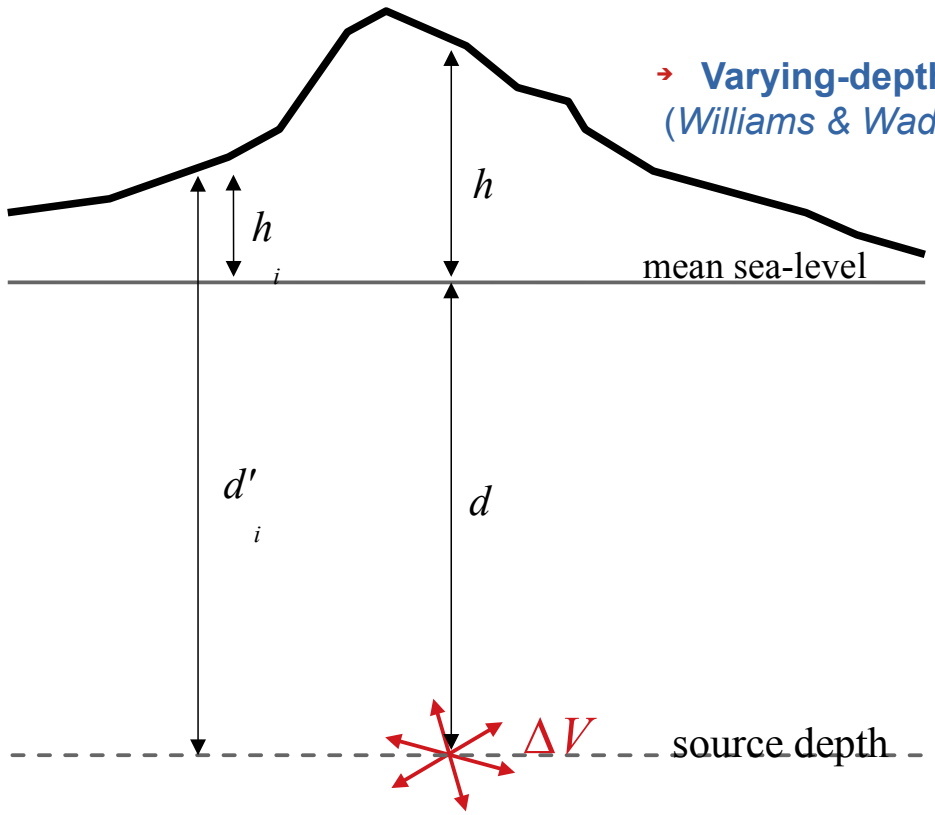
GNSS horizontal baselines at Mount Pelée

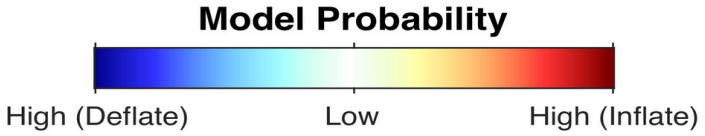




Simple source model without (too much) a priori using Bayesian inversion

F. Beauducel et al. (2014)





- Single isotropic point source in elastic medium using ΔV formulation (no elastic parameter dependency)
- Topographic approximation using the varying-depth method
- Likelihood :

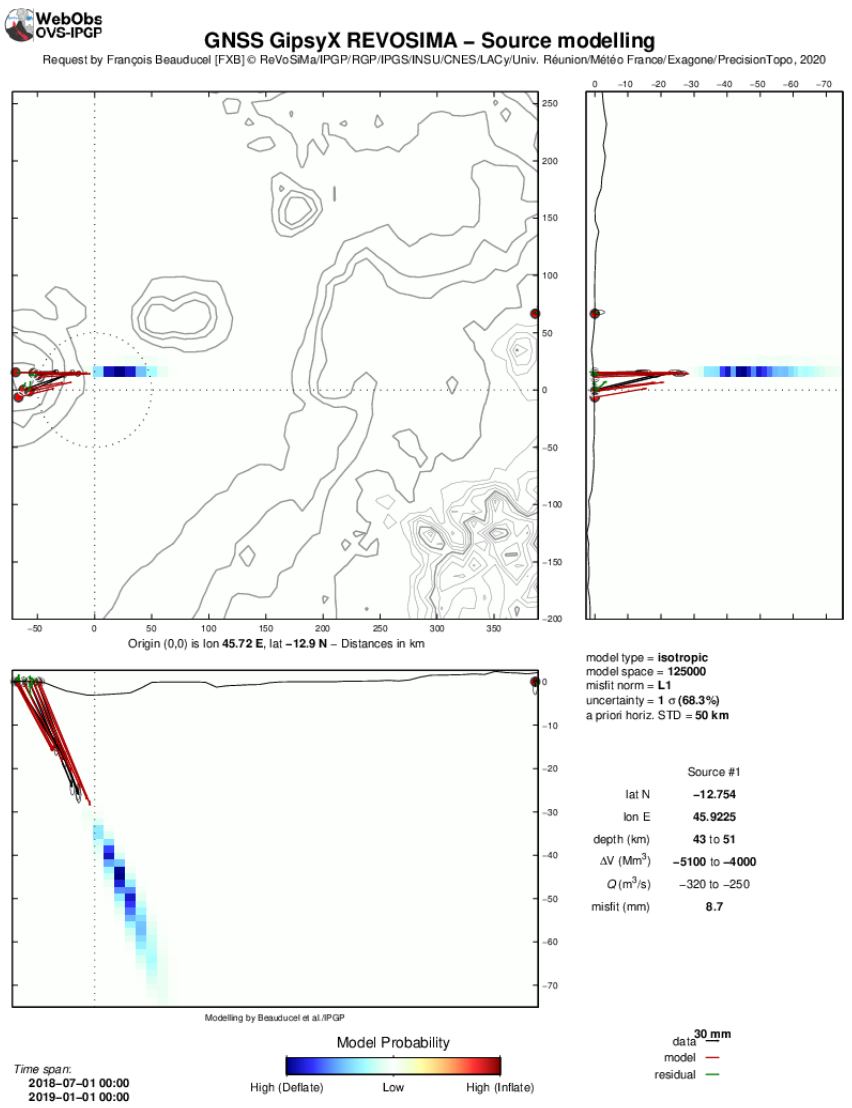
$$P(m_{x,y,z,\Delta V}) = \prod \frac{1}{\sigma_i \sqrt{2\pi}} \exp \frac{-\left(d_i^{obs} - d_i^{calc}\right)^2}{2\sigma_i^2}$$

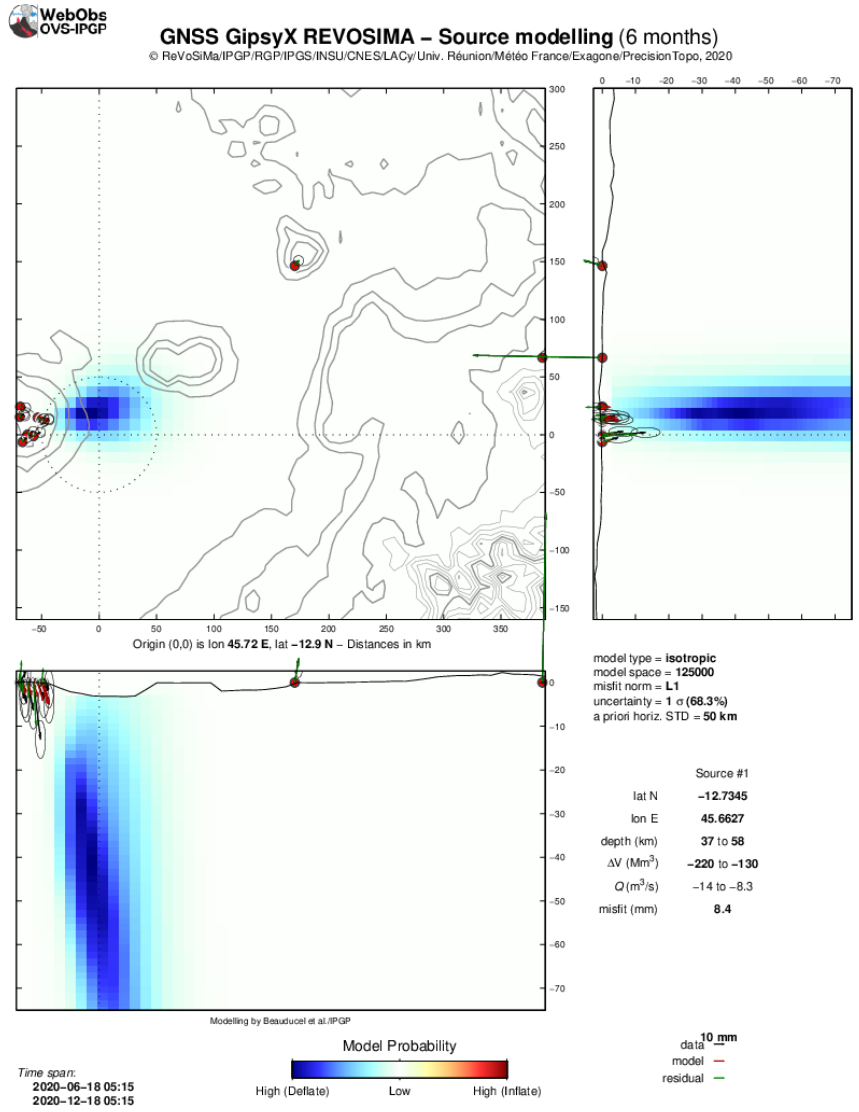
- Plots the entire model space in a 4-D grid, using a colorscale mixing probability and inflation/deflation sign
- **Unsupervised modeling adapted to real-time monitoring**

Qu’est-ce qu’une modélisation « robuste » ?

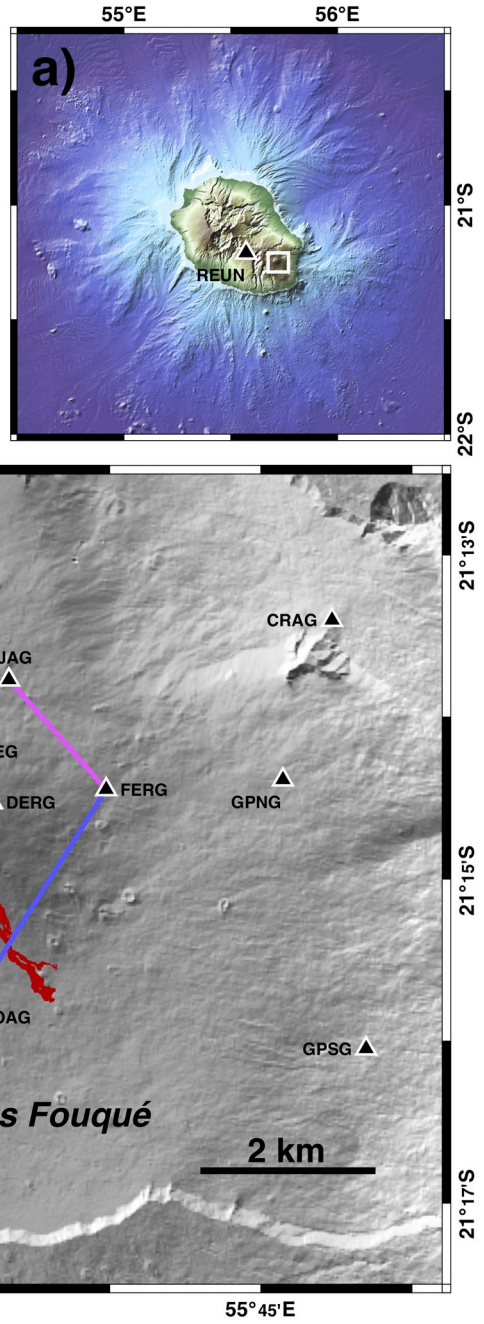
- La robustesse est la capacité à correctement estimer la **probabilité** et l’**erreur a posteriori** des modèles proposés.

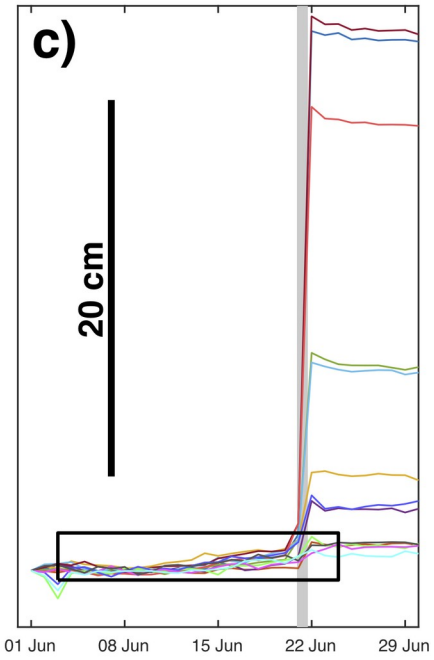
- Exemple sur Mayotte avec la probabilité de localisation d’une source de déformation sur 2 ans de données (gauche) et 6 mois (droite)

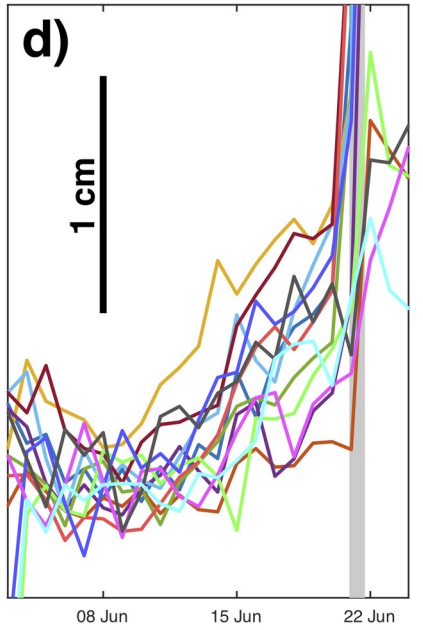




Piton de la Fournaise
La Réunion Island







Point-source model, homogeneous elastic half-space, with 9 parameters (modified from *Nikkhoo et al.*, 2016):

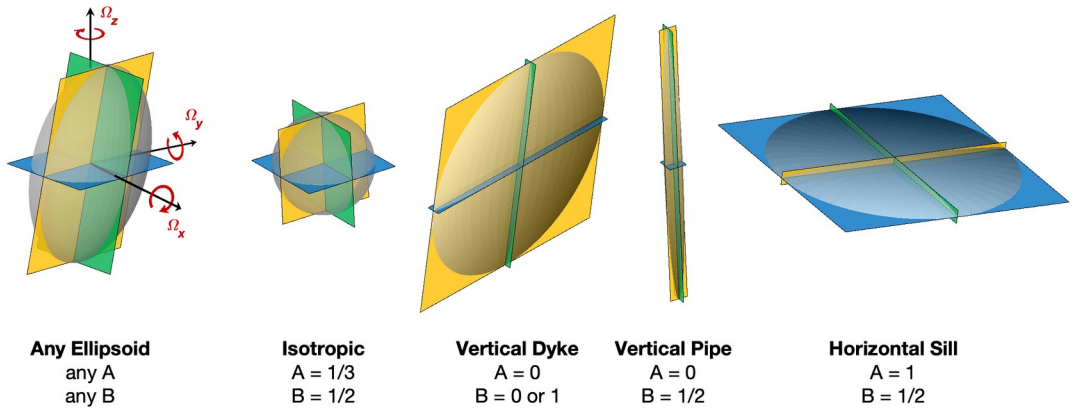
X, Y, Z, ΔV,

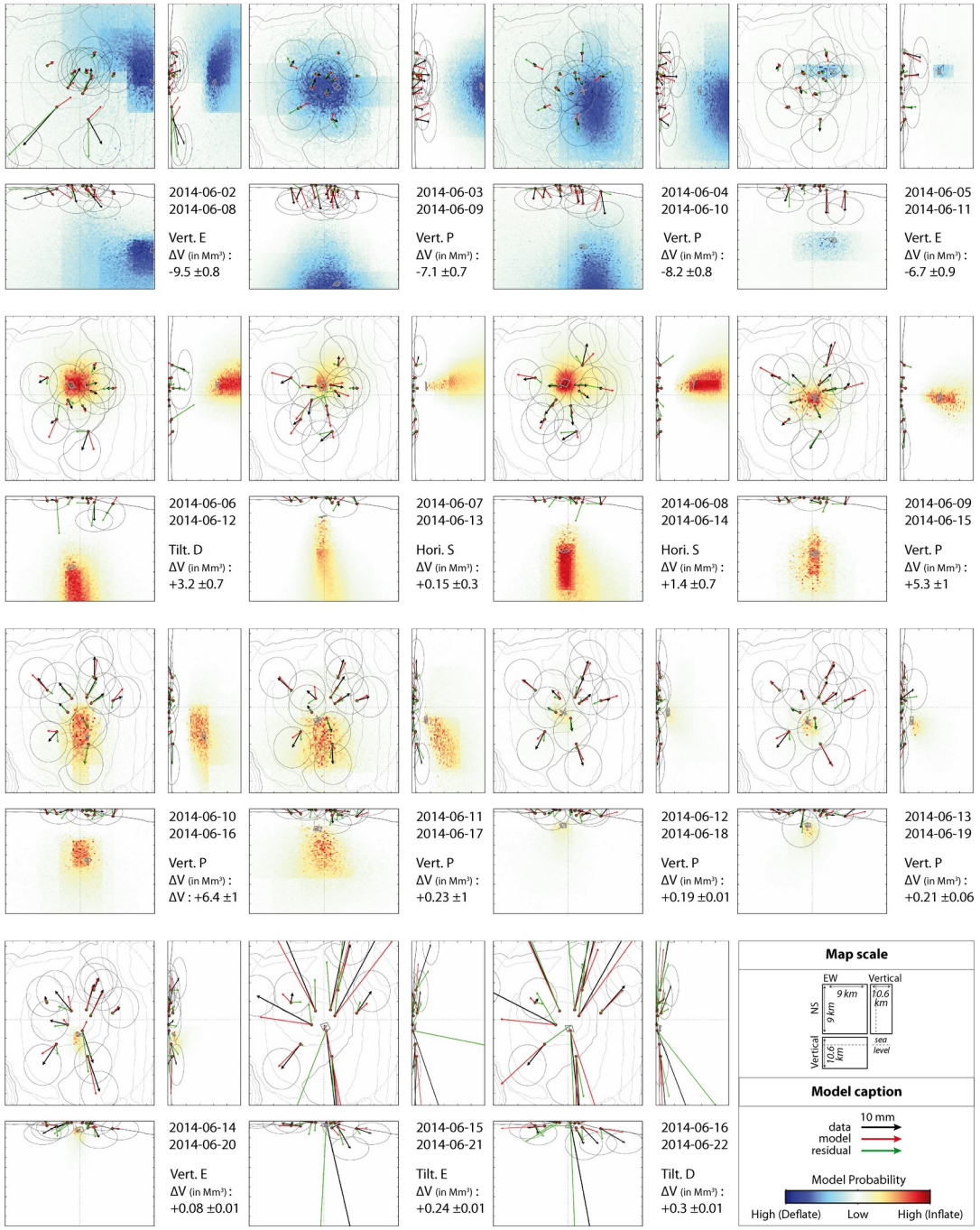
A, B (shape), Ω_X, Ω_Y, Ω_Z

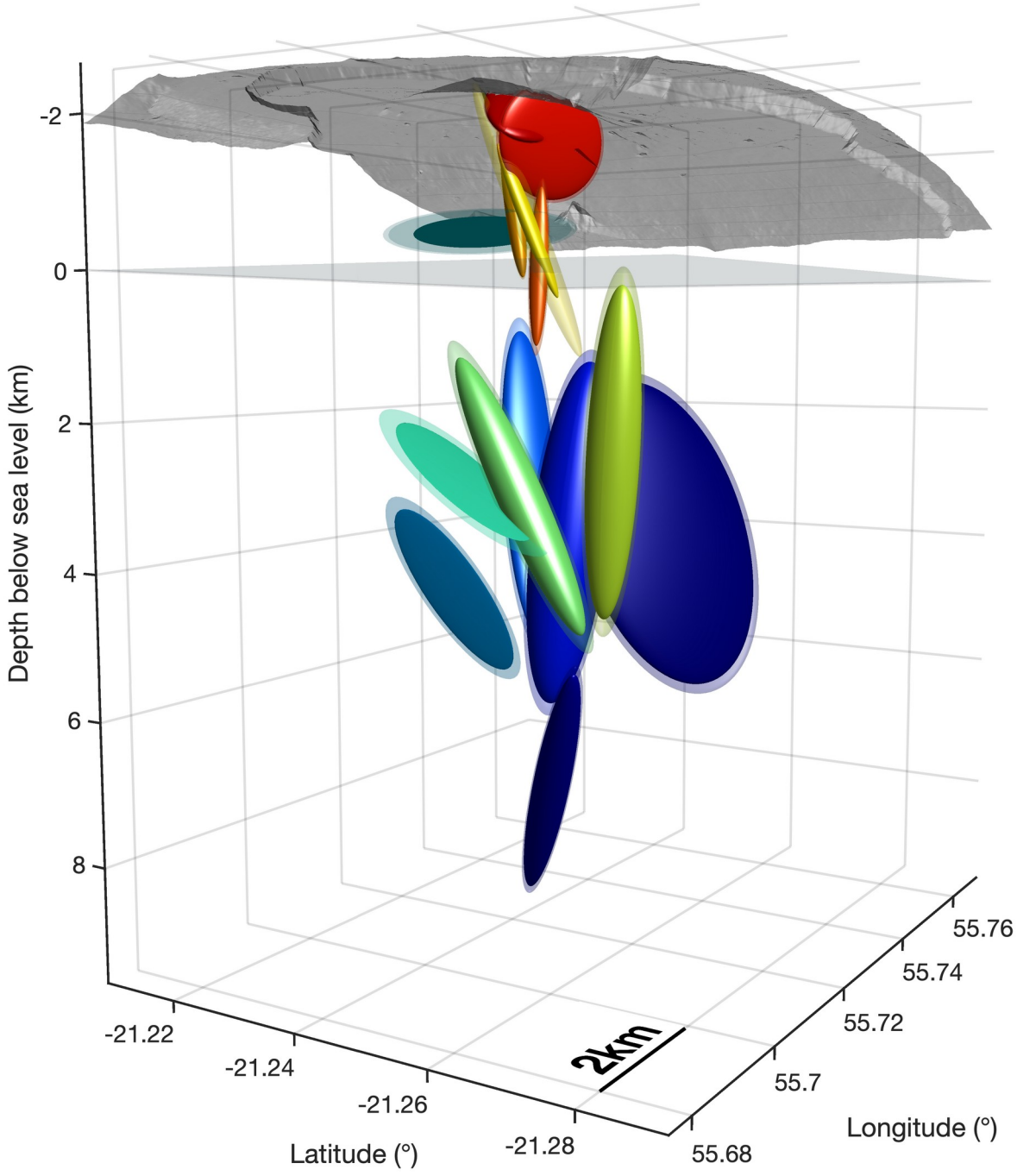
Full vectorized and optimized code, topography approximation (*Williams & Wadges*, 1998)

Unsupervised bayesian inversion without (too much) a priori, using a monte-carlo sampling approach

Beauducel et al., GRL, 2020




2014-06-02
2014-06-08
Vert. E
ΔV (in Mm³) :
-9.5 ±0.8
2014-06-03
2014-06-09
Vert. P
ΔV (in Mm³) :
-7.1 ±0.7
2014-06-04
2014-06-10
Vert. P
ΔV (in Mm³) :
-8.2 ±0.8
2014-06-05
2014-06-11
Vert. E
ΔV (in Mm³) :
-6.7 ±0.9
2014-06-06
2014-06-12
Tilt. D
ΔV (in Mm³) :
+3.2 ±0.7
2014-06-07
2014-06-13
Hori. S
ΔV (in Mm³) :
+0.15 ±0.3
2014-06-08
2014-06-14
Hori. S
ΔV (in Mm³) :
+1.4 ±0.7
2014-06-09
2014-06-15
Vert. P
ΔV (in Mm³) :
+5.3 ±1
2014-06-10
2014-06-16
Vert. P
ΔV : +6.4 ±1
2014-06-11
2014-06-17
Vert. P
ΔV (in Mm³) :
+0.23 ±1
2014-06-12
2014-06-18
Vert. P
ΔV (in Mm³) :
+0.19 ±0.01
2014-06-13
2014-06-19
Vert. P
ΔV (in Mm³) :
+0.21 ±0.06
2014-06-14
2014-06-20
Vert. E
ΔV (in Mm³) :
+0.08 ±0.01
2014-06-15
2014-06-21
Tilt. E
ΔV (in Mm³) :
+0.24 ±0.01
2014-06-16
2014-06-22
Tilt. D
ΔV (in Mm³) :
+0.3 ±0.01
Map scale
EW
Vertical
NS
9 km
9 km
10.6 km
Vertical
10.6 km
sea level
Model caption
10 mm
data
model
residual
Model Probability
High (Deflate)
Low
High (Inflate)


Depth below sea level (km)
-2
0
2
4
6
8
-21.22
-21.24
-21.26
-21.28
Latitude (°)
55.68
55.7
55.72
55.74
55.76
Longitude (°)
2km
22 Jun
20 Jun
18 Jun
16 Jun
14 Jun
12 Jun
10 Jun
08 Jun

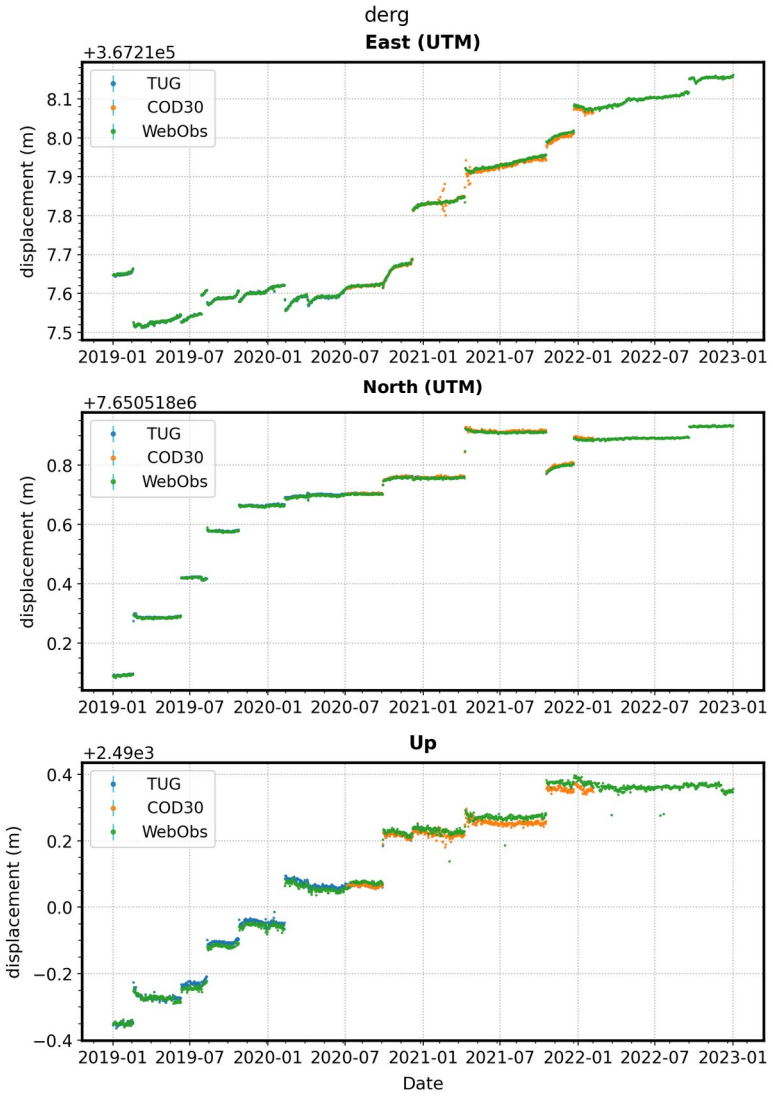
GROOPS comme alternative ?

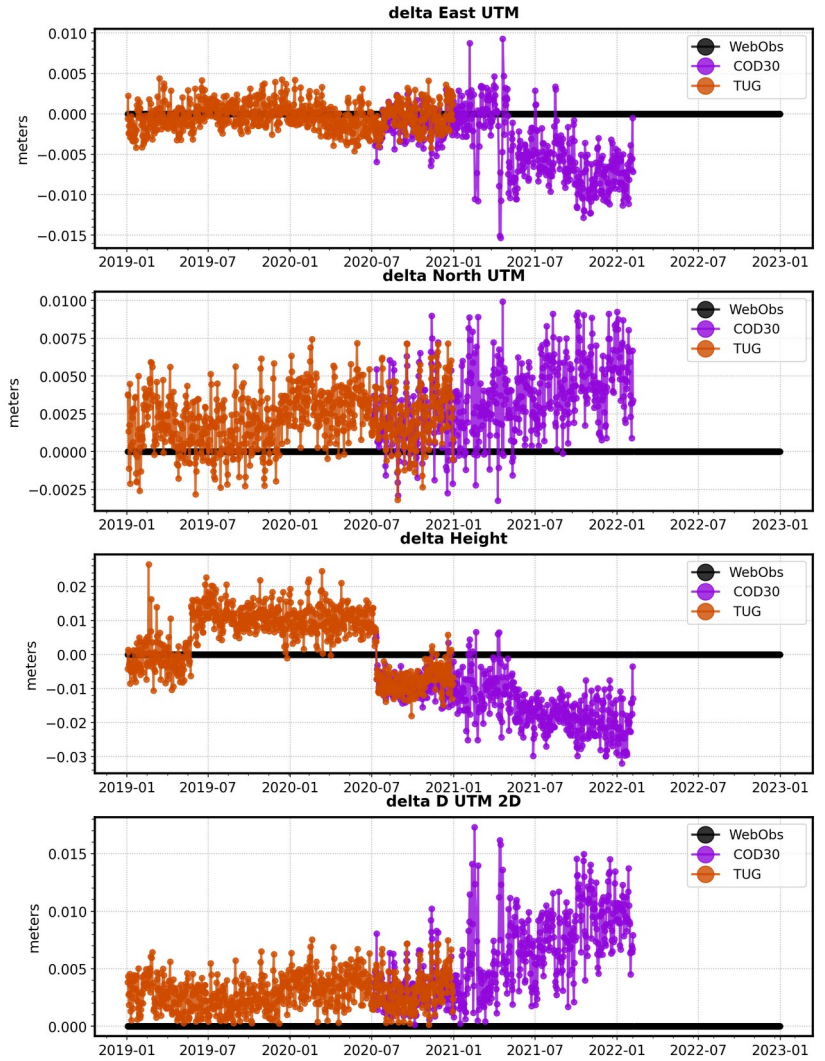
- The *Gravity Recovery Object Oriented Programming System* Developpé par l'Université Technique de Graz, Autriche
- Fonctionnalité de détermination de position GNSS (PPP et réseau)
- Meilleures produits orbites/horloges des centres d'analyses IGS ayant participé à la campagne Repro3 (c.f. travaux de comparaison de e.g. *Mansur et al.* 2022)
- Gratuit et open source (licence GPLv3) vs. GipsyX en code fermé et licence restrictive

Principales limitations

- Pas d'orbites proposées en routine (uniquement pour la période IGS-Repro3 1994-2020). Tests en cours pour trouver la meilleur alternative (COD, GRG envisagés en remplacement)
- Pas de scripts haut niveau pour lancer automatiquement et simplement le calcul d'une station pour une journée. Développement de tels scripts en cours, bêta disponible ici: https://github.com/GeodeZYX/geodezyx-toolbox/blob/master/geodezyx/operational/groops_frontend.py

GROOPS – quelques résultats





- Station DERG, Piton de la Fournaise, La Réunion
- Très bonne cohérence avec les positions déterminées par GipsyX (<5mm en plani., <10mm en vertical) (modulo une transformation en aval réalisé par le module GNSS de WebObs)
- Test de l'utilisation des produits « GROOPS » TUG en rouge et CODE MGEX en Violet :
- produits CODE légèrement plus bruité mais test a re-réaliser avec les nouvelles orbites CODE multi-GNSS IGS standard (depuis décembre 2022)