2024 United Nations/Philippines Workshop
Applications of Global Navigation Satellite Systems
22 - 26 April 2024, Manila, Philippines

GNSS Motions Associated with the 8 Recent Earthquakes in the Philippines

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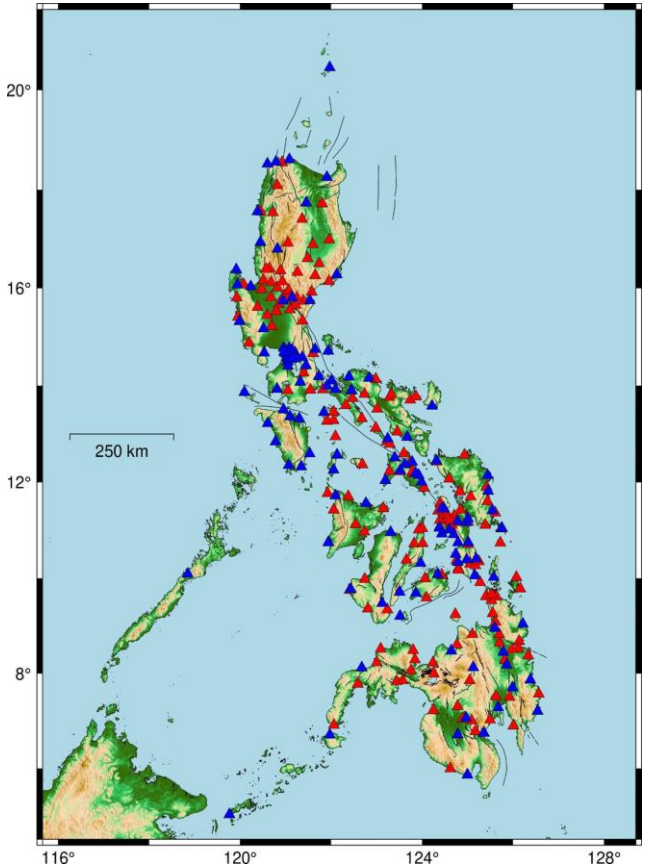
GNSS MOTIONS ASSOCIATED WITH THE RECENT EARTHQUAKES IN THE PHILIPPINES

OUTLINE

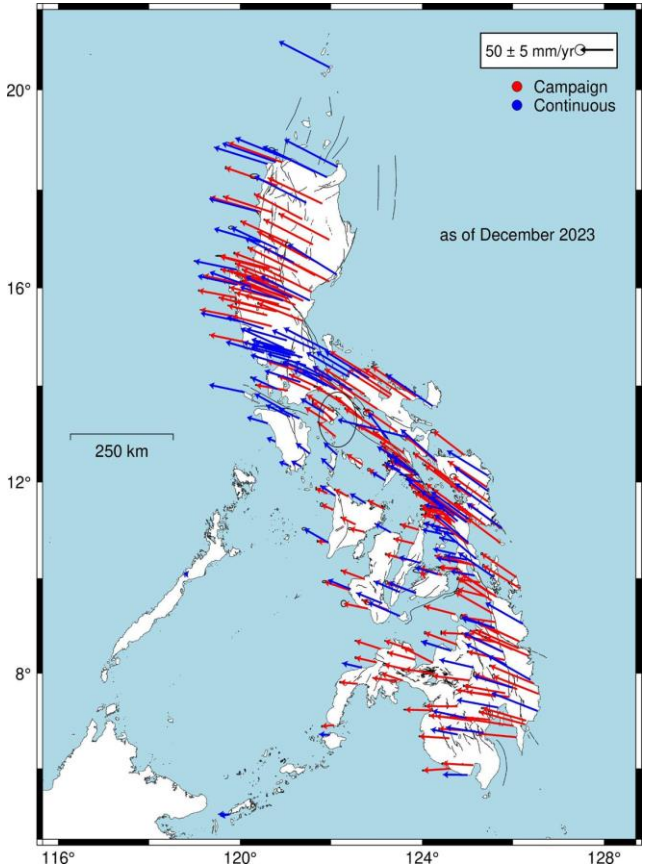
GNSS MOTIONS ASSOCIATED WITH THE RECENT EARTHQUAKES IN THE PHILIPPINES



GNSS continuous and campaign stations established in the Philippine Mobile Belt

- Campaign surveys started in 1997 in the central part of the Philippines in Leyte Island
- Around 200 campaign sites (red) established
  (around 170 sites extant at present)
- 129 active continuous sites (blue) established starting 2008

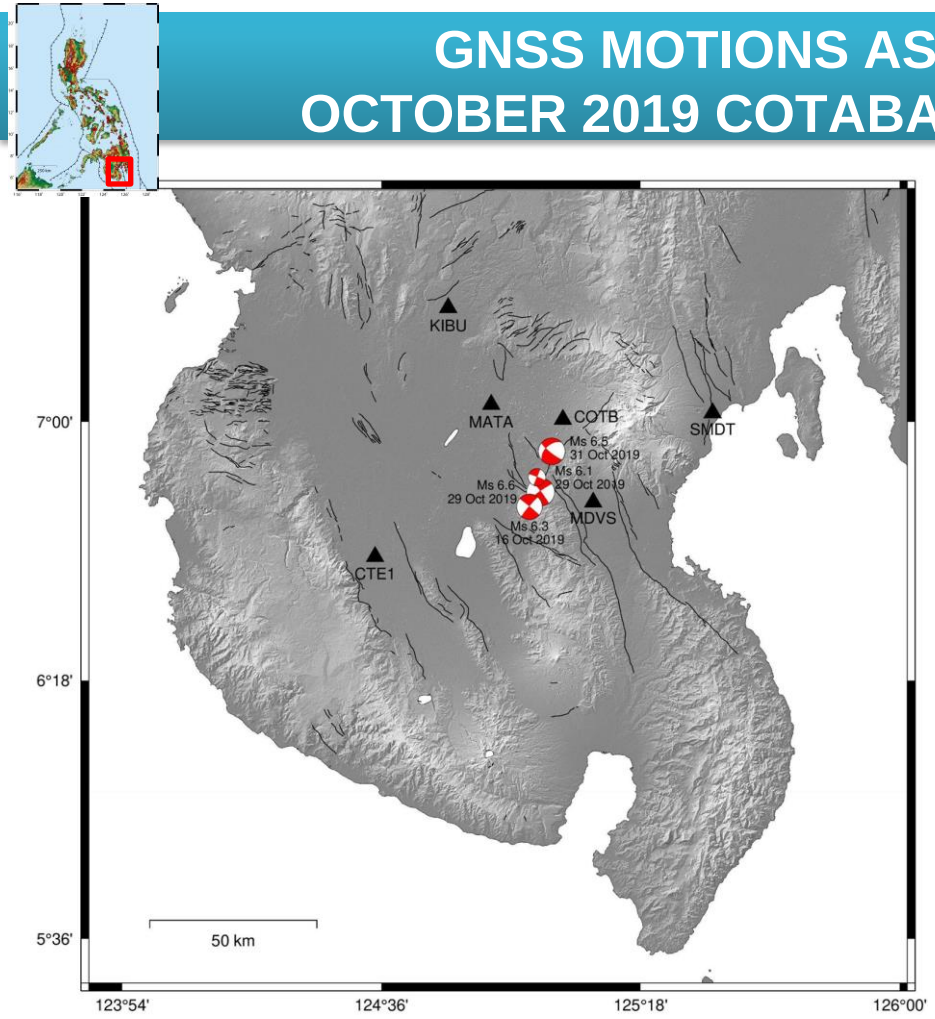
GNSS MOTIONS ASSOCIATED WITH THE RECENT EARTHQUAKES IN THE PHILIPPINES



Data Acquisition and Processing

- Close to 200 points shown from combination of different campaign surveys from 1996 to December 2023
- Each (campaign) site is measured continuously for 2-4 days using dual-frequency geodetic GNSS receivers in a 15/30-second interval
- Also includes around 130 local continuous stations, 12 IGS global and local stations, and one local continuous site in Taiwan (S01R)
- Data processed using Bernese 5.2
- Interseismic velocities across the Philippines vary from 6.32 to 90.28 mm/yr with azimuths ranging from N260.07° to N314.73° degrees, calculated with respect the Eurasian Plate.

GNSS MOTIONS ASSOCIATED WITH THE OCTOBER 2019 COTABATO EARTHQUAKE SERIES



THE EVENTS

Magnitude 6.3

October 16, 2019 at 7:37 PM PhST
Depth: 9 km
Epicenter: 6.76°N, 125.01°E - 023 km
S 62° E of Tulunan, Cotabato
Casualties: 7 dead, 215 injured in Regions XI, XII, and BARMM
Total damage to infrastructures: 7,089 in Regions XI, XII, and BARMM

Magnitude 6.6

October 29, 2019 at 9:04 AM PhST
Depth: 7 km

Magnitude 6.1

October 29, 2019 at 10:42 AM PhST
Depth: 11 km

Magnitude 6.5

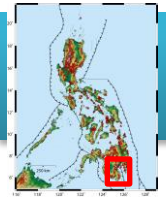
October 31, 2019 at 9:11 AM PhST
Depth: 8 km

Casualties: 23 deaths; 563 injured; 11 missing

Total damage to infrastructures:
49,690 in Regions IX, X, XI, XII, and BARMM

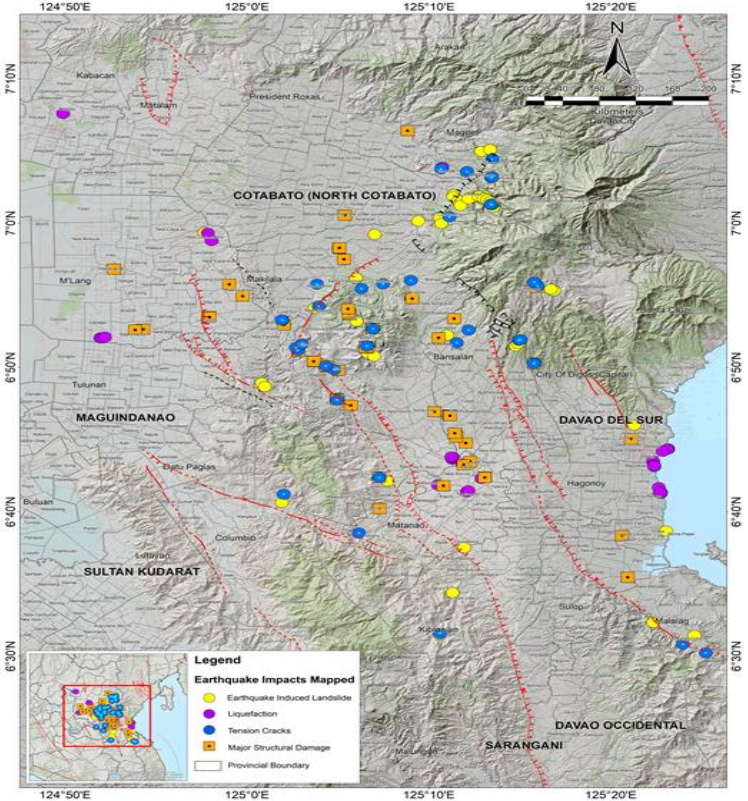
Total Cost of Damage to agricultural infrastructure:
₱ 32,371,295 in Region XI and XII

Sources: NDRRMC Update SitRep No. 39 regarding Magnitude 6.6 and 6.5 Earthquakes & Situational Report No. 19 regarding Magnitude 6.3 Earthquake in Tulunan, North Cotabato



GNSS MOTIONS ASSOCIATED WITH THE OCTOBER 2019 COTABATO EARTHQUAKE SERIES

Impacts of October 2019 Cotabato Earthquake Series

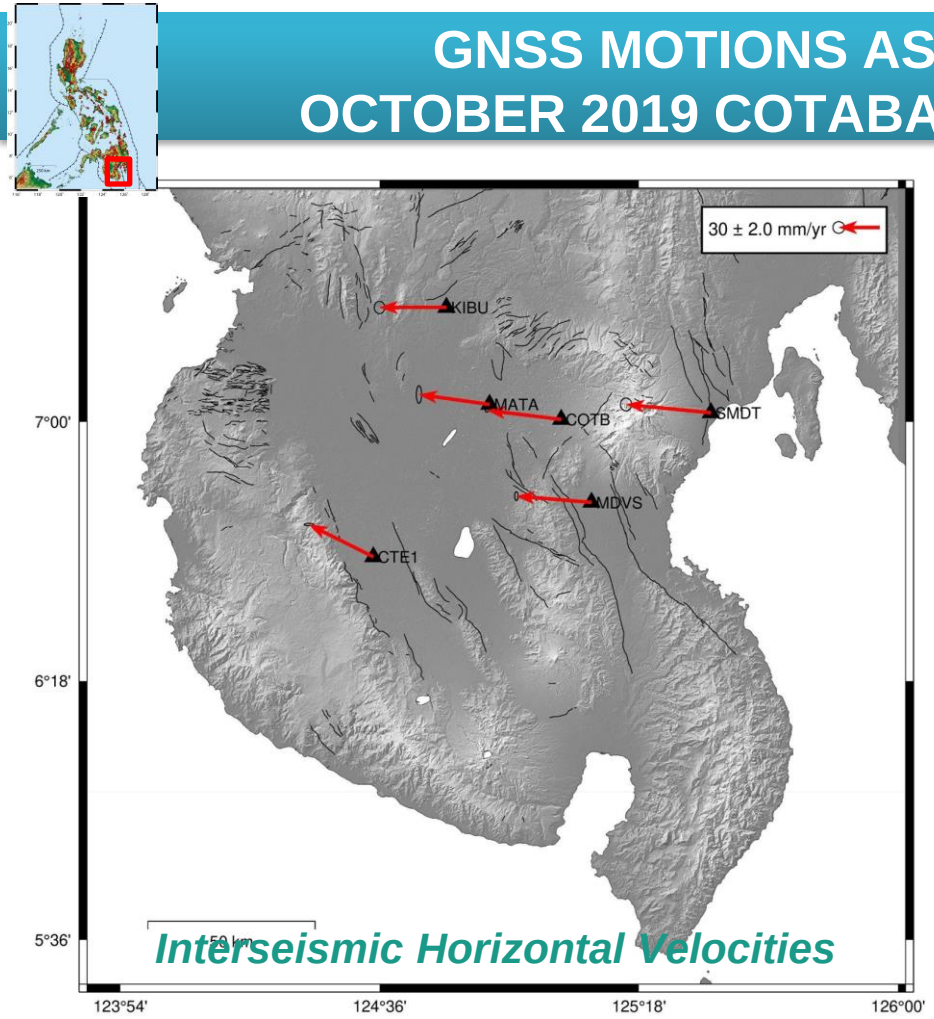


Landslide in Brgy. Bato and Malabuan

Eva's Building damaged during the October 31 2019 M6.5 event

Lateral spread that appeared in Brgy. Tamlangon after the M6.6 earthquake that has worsened after the M6.5 earthquake

GNSS MOTIONS ASSOCIATED WITH THE OCTOBER 2019 COTABATO EARTHQUAKE SERIES

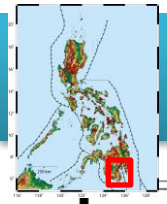


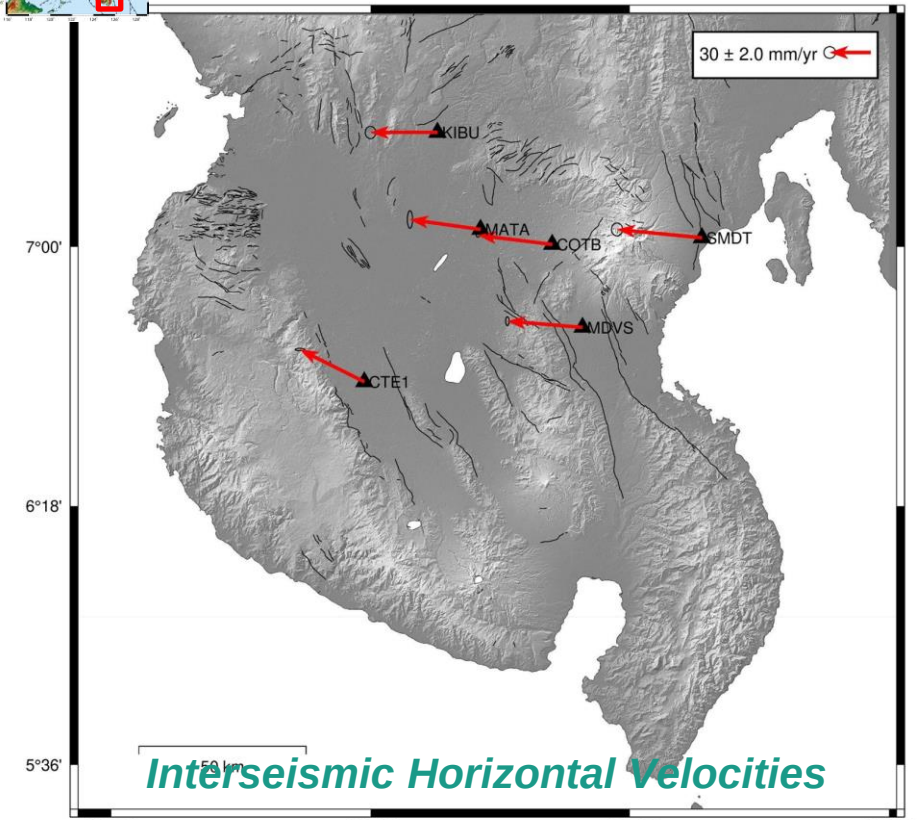
Interseismic Horizontal Velocities

INTERSEISMIC VELOCITIES

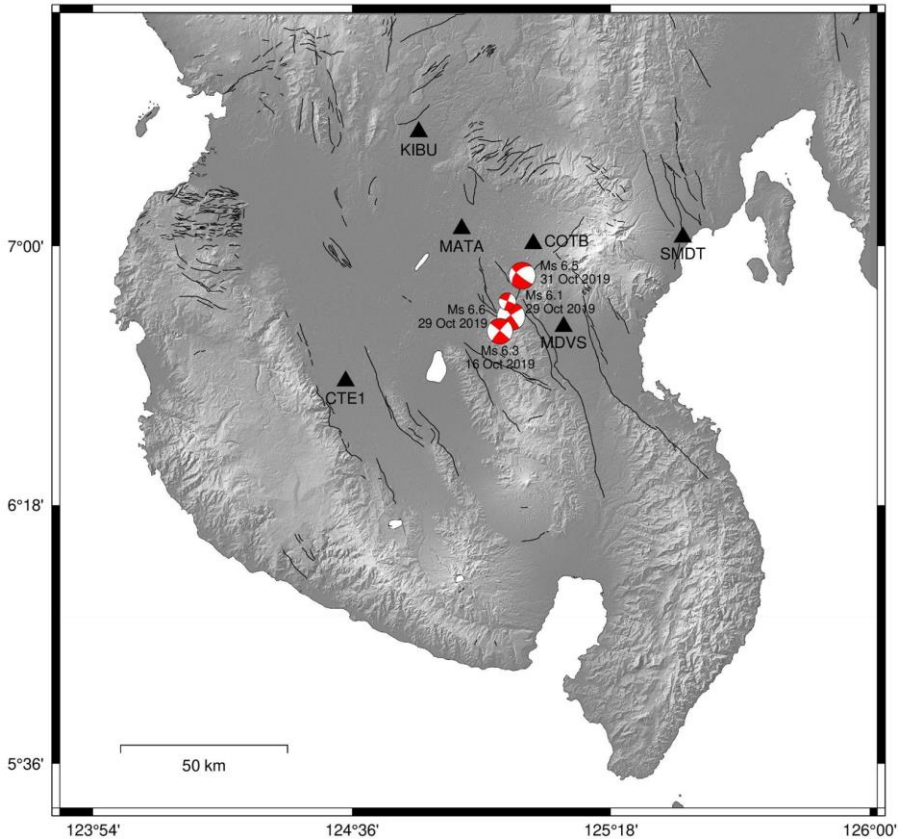
- From a combination of GNSS campaigns from 2009 to 2018
- NW-directed movements
- The interseismic horizontal velocities ranges from 49.10 mm/yr (KIBU) to 62.53 mm/yr (SMDT)
- With azimuths from 270 degrees (KIBU) to 297 degrees (CTE1)

GNSS MOTIONS ASSOCIATED WITH THE OCTOBER 2019 COTABATO EARTHQUAKE SERIES

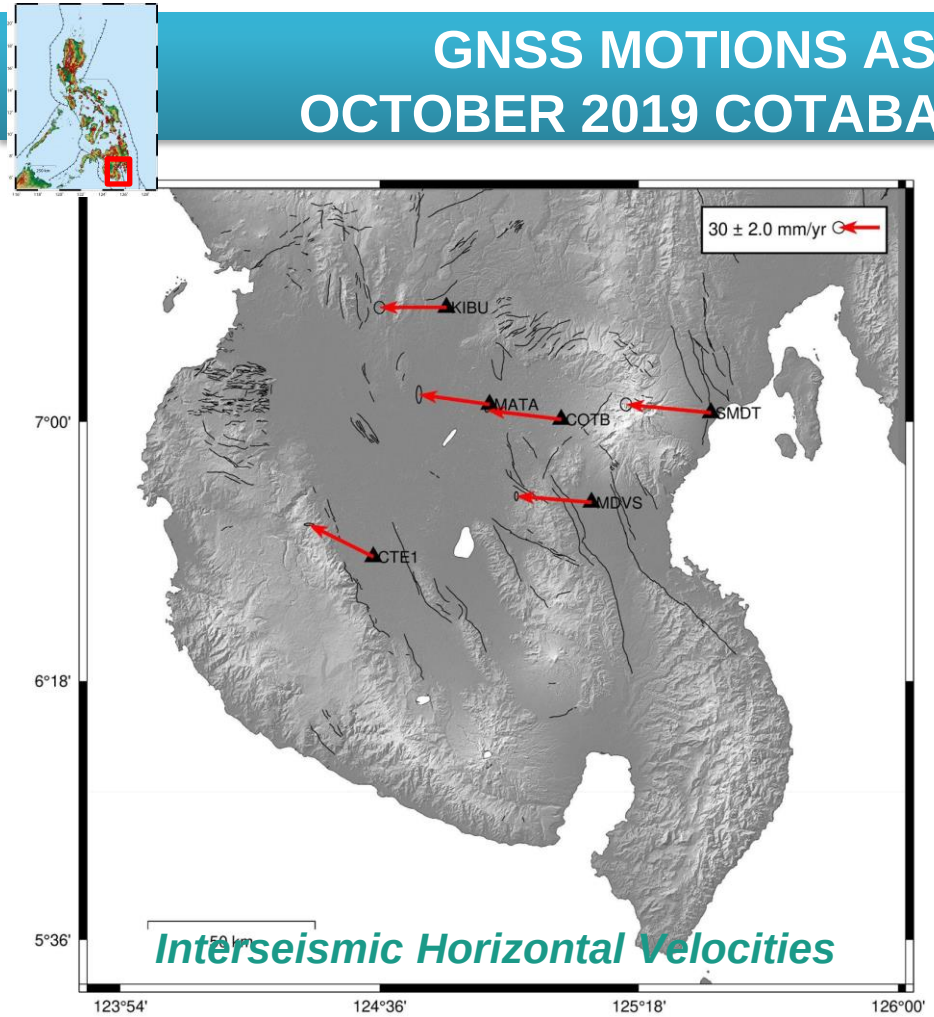




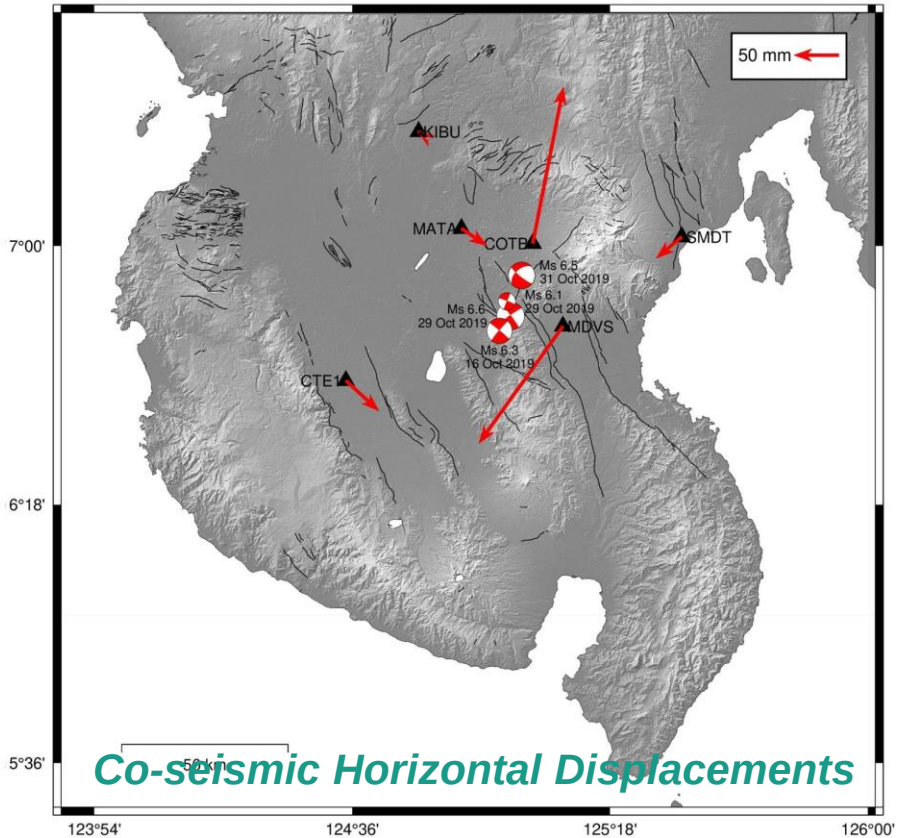
Interseismic Horizontal Velocities



GNSS MOTIONS ASSOCIATED WITH THE OCTOBER 2019 COTABATO EARTHQUAKE SERIES

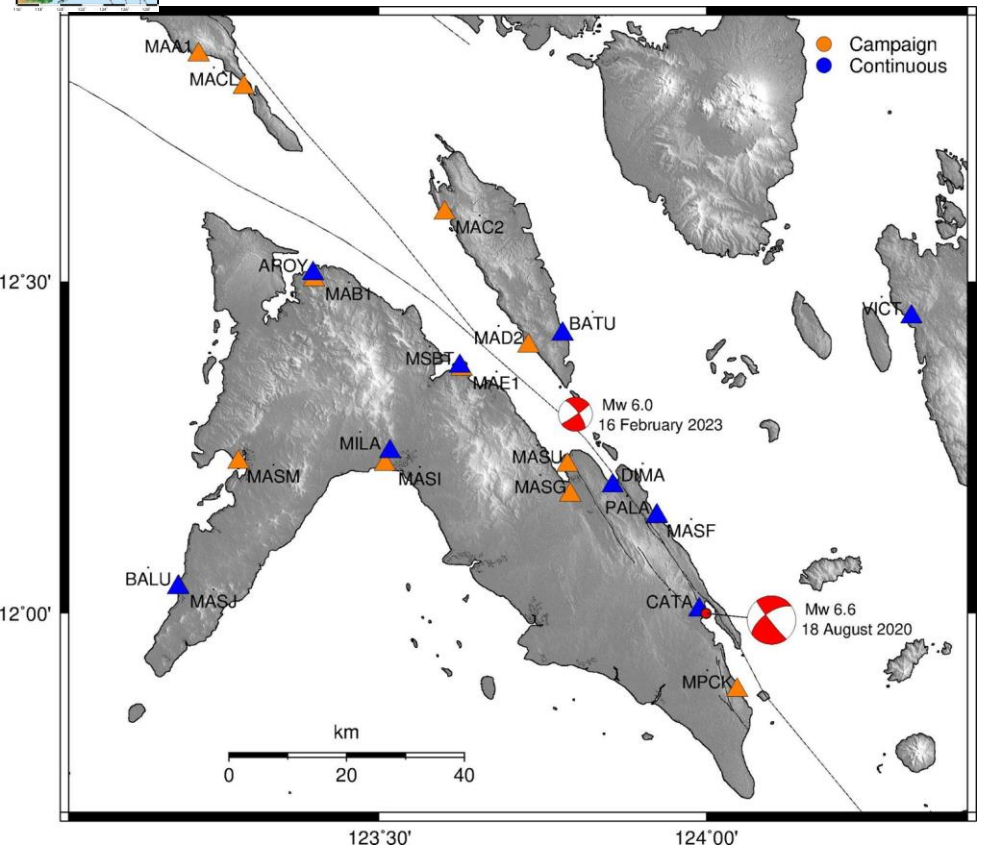


Interseismic Horizontal Velocities



Co-seismic Horizontal Displacements

GNSS MOTIONS ASSOCIATED WITH THE 2020 M6.6 AND 2023 M6.0 MASBATE EARTHQUAKES



THE EVENTS

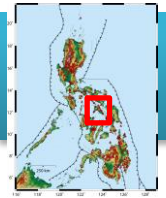
Magnitude 6.6

August 18, 2020 at 8:03 AM PhST
Depth: 13 km
Epicenter: 11.98°N, 124.01°E - 005 km S 20° E of Cataingan, Masbate
Casualties: 1 dead, 50 injured
Cost of total damage (NDRRMC estimate): 30 M Pesos or 600T USD

Magnitude 6.0

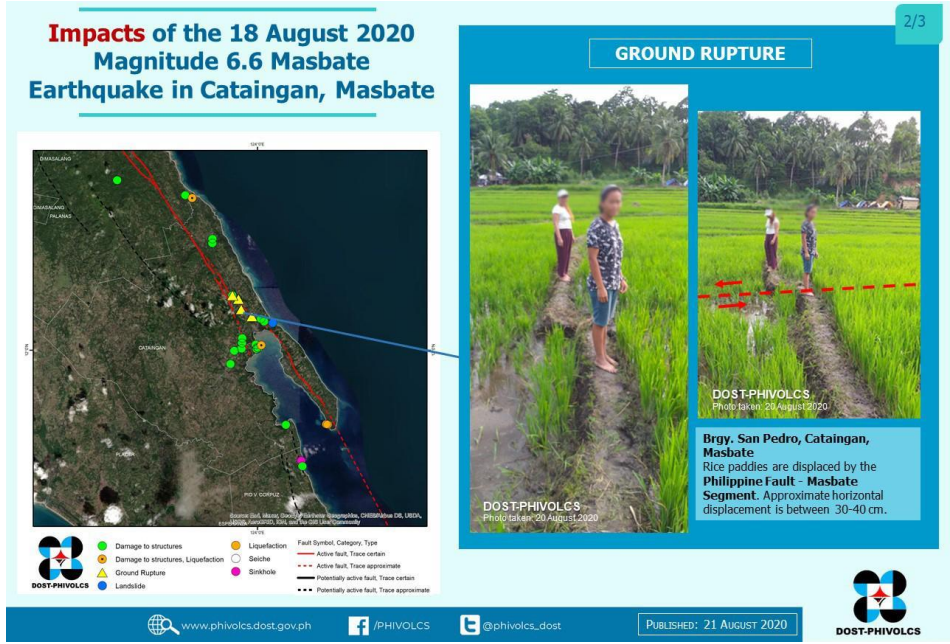
February 16, 2023 at 2:10 AM PhST
Depth: 10 km
Epicenter: 12.32°N, 123.75°E - 011 km S 20° W of Batuan, Masbate
Affected population: 96 families/440 individuals
Damaged houses: A total of 148 houses (3 totally and 145 partially)
Damage to infrastructure: A total of 94 damaged infrastructure
Road and bridges: 1 road affected with one-lane passable

Sources: NDRRMC Update SitRep No. 10 regarding Magnitude 6.6 Earthquake in Cataingan, Masbate & https://reliefweb.int/report/philippines/philippines-m60-earthquake-masbate-region-v-16-feb-2023; PDRRMC Official Report No. 2 as of 12 NN, February 17, 2023

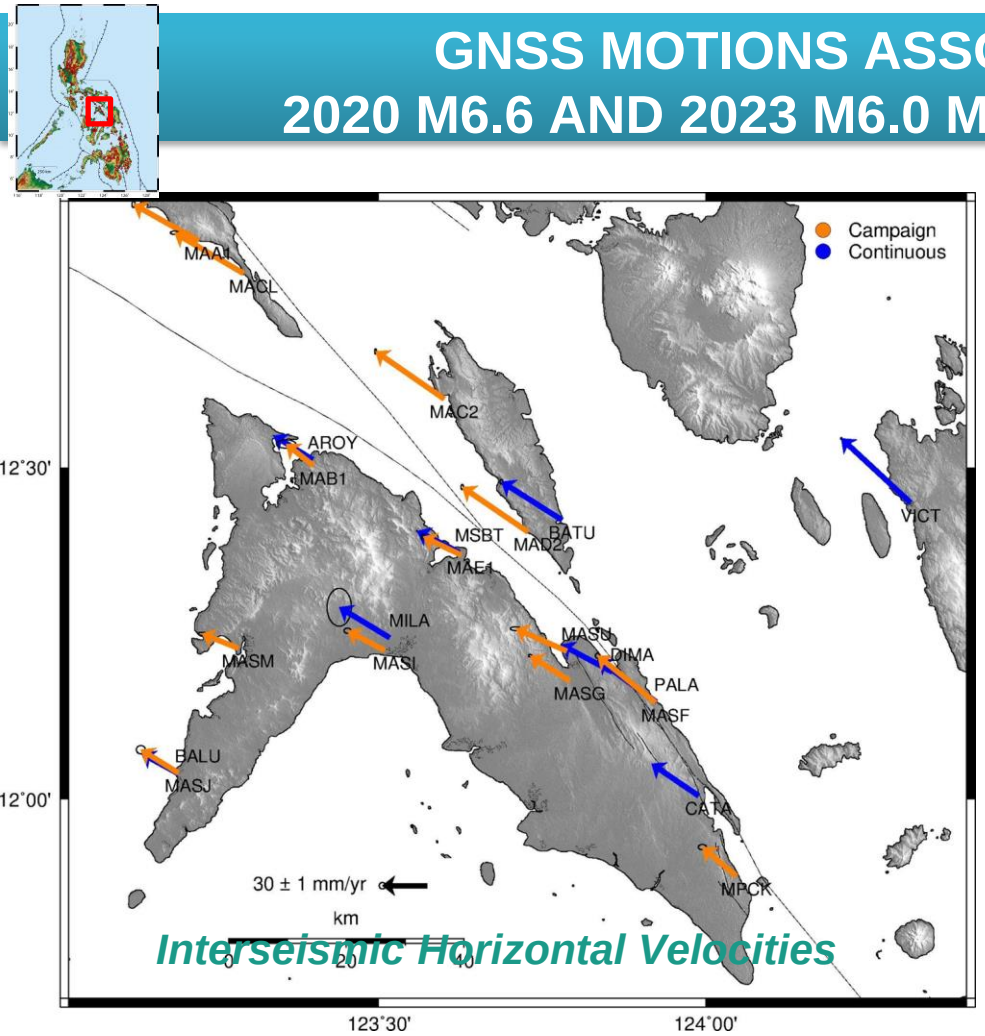


GNSS MOTIONS ASSOCIATED WITH THE 2020 M6.6 AND 2023 M6.0 MASBATE EARTHQUAKES

Impacts of August 2020 M6.6 Masbate Earthquake



GNSS MOTIONS ASSOCIATED WITH THE 2020 M6.6 AND 2023 M6.0 MASBATE EARTHQUAKES

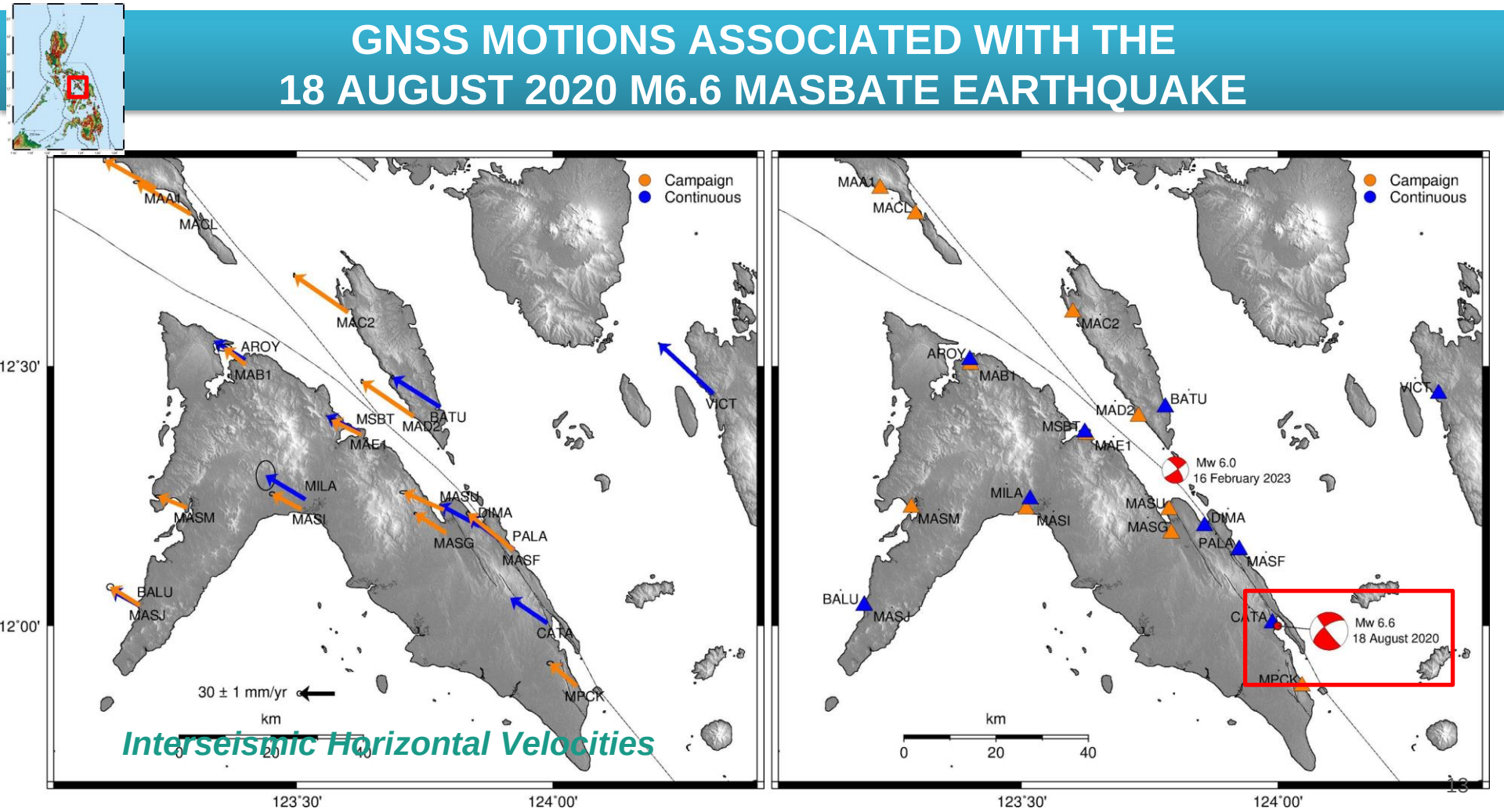


Interseismic Horizontal Velocities

INTERSEISMIC VELOCITIES

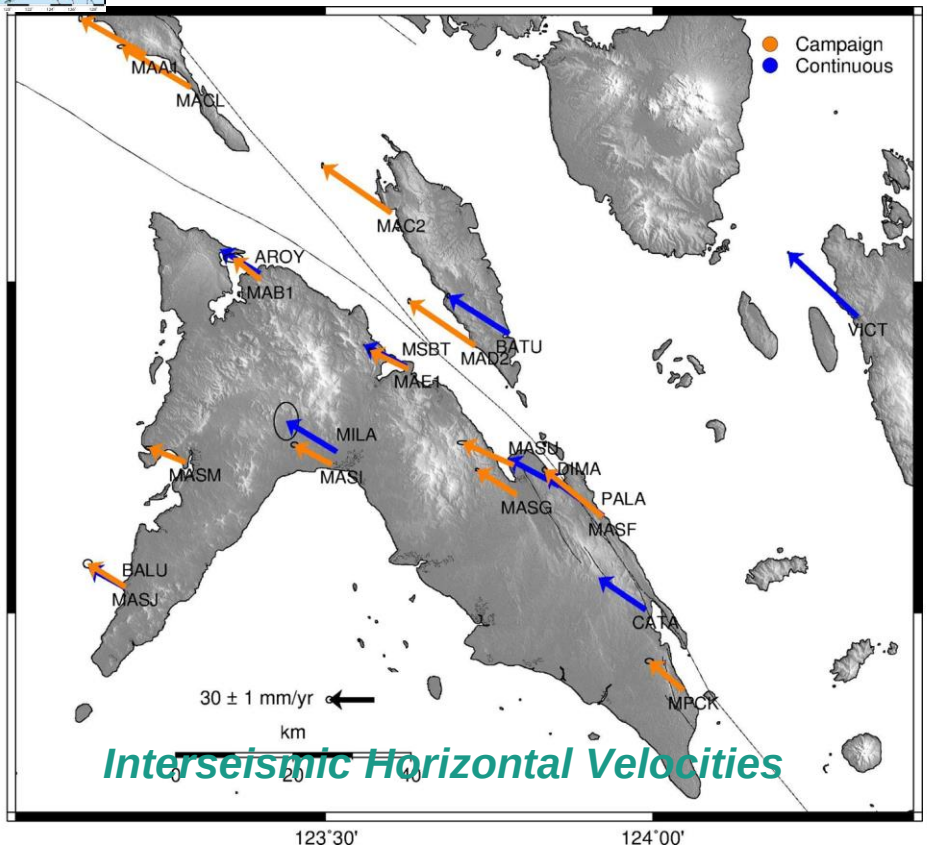
- From a combination of GNSS campaign and continuous sites from 2004 to 2020
- NW-directed movements
- The interseismic horizontal velocities ranges from 23.39 mm/yr (MAB1) to 55.79 mm/yr (MAC2)
- With azimuths from 291.63 degrees (MASM) to 310.56 degrees (MPCK)

GNSS MOTIONS ASSOCIATED WITH THE 18 AUGUST 2020 M6.6 MASBATE EARTHQUAKE

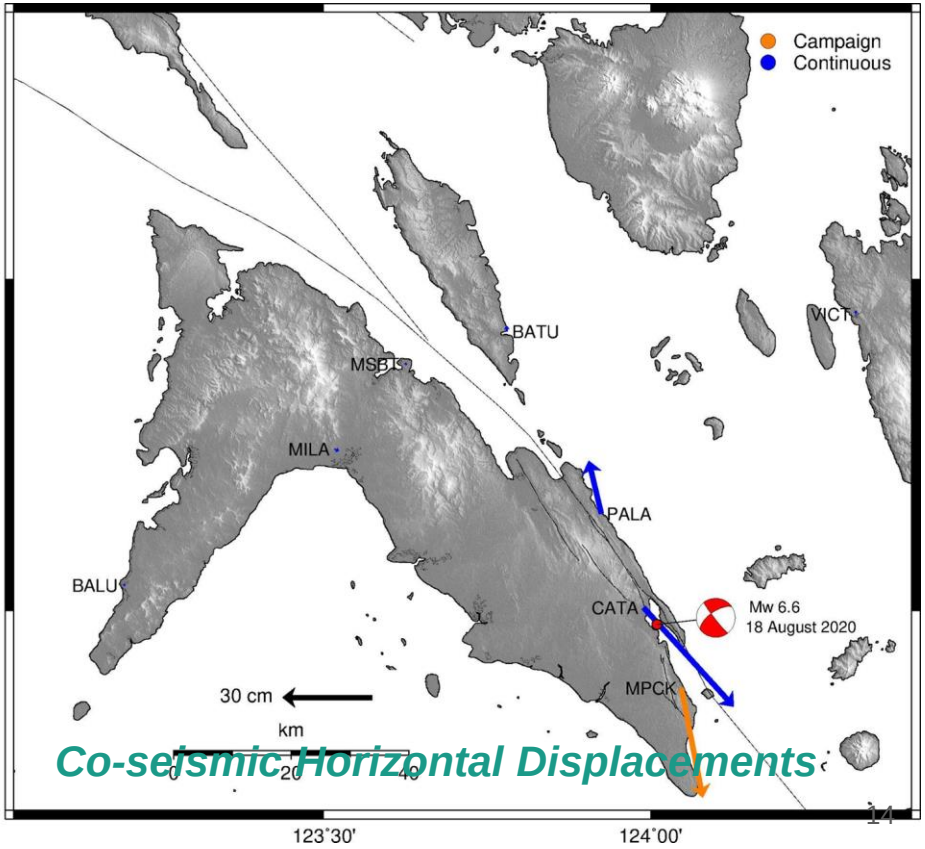


Interseismic Horizontal Velocities

GNSS MOTIONS ASSOCIATED WITH THE 18 AUGUST 2020 M6.6 MASBATE EARTHQUAKE



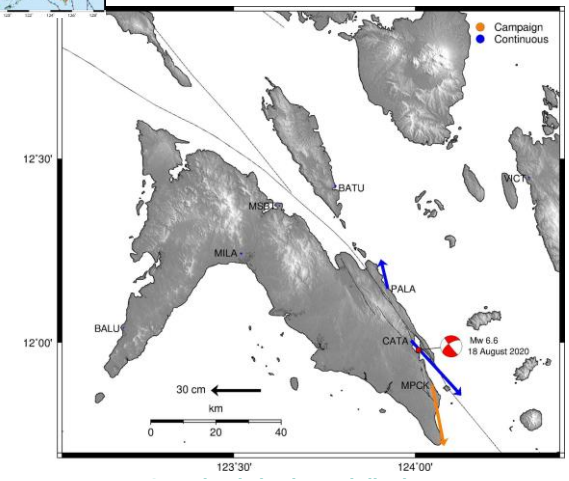
Interseismic Horizontal Velocities



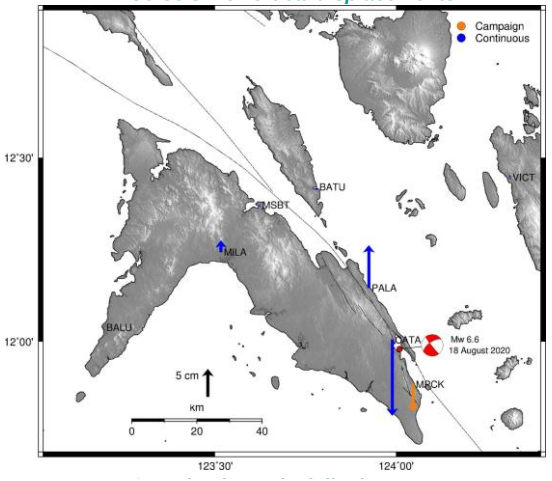
Co-seismic Horizontal Displacements

GNSS MOTIONS ASSOCIATED WITH THE 18 AUGUST 2020 M6.6 MASBATE EARTHQUAKE

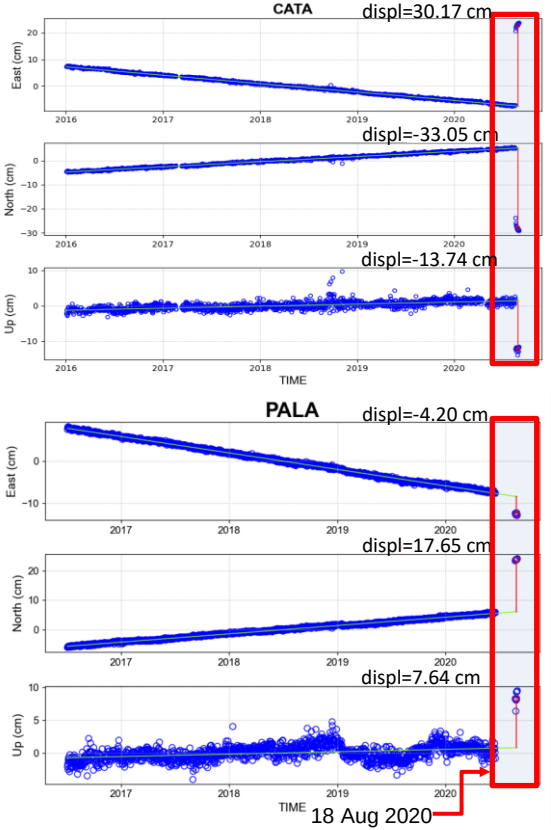
Co-seismic horizontal displacements



Co-seismic vertical displacements

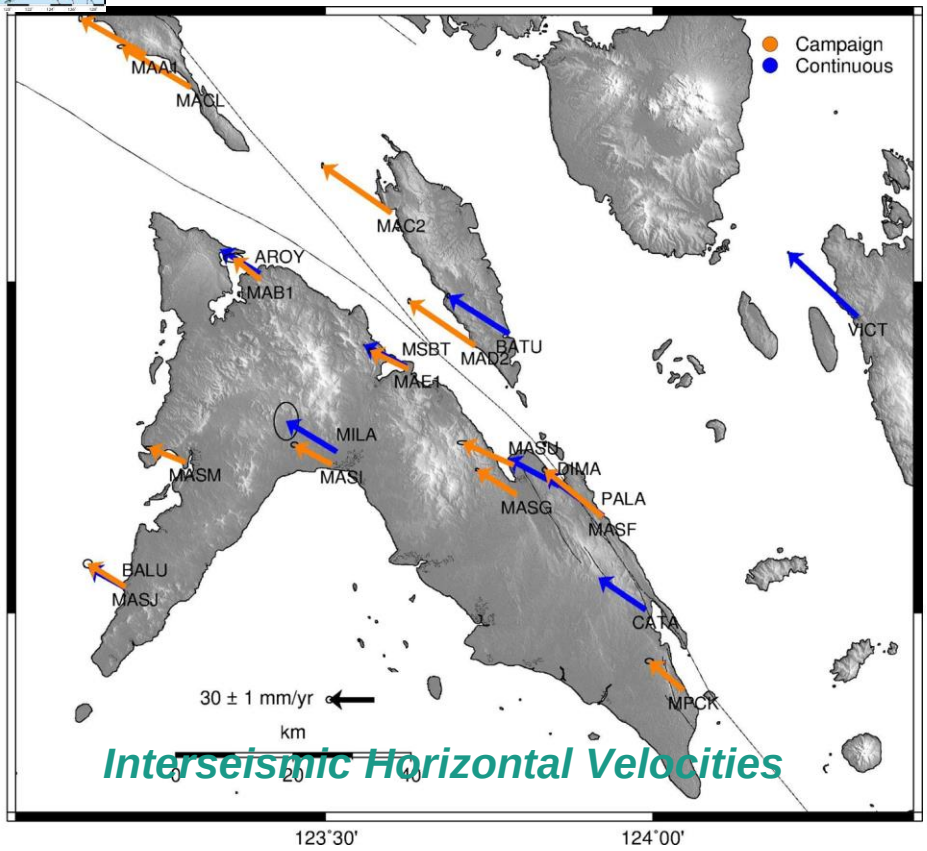


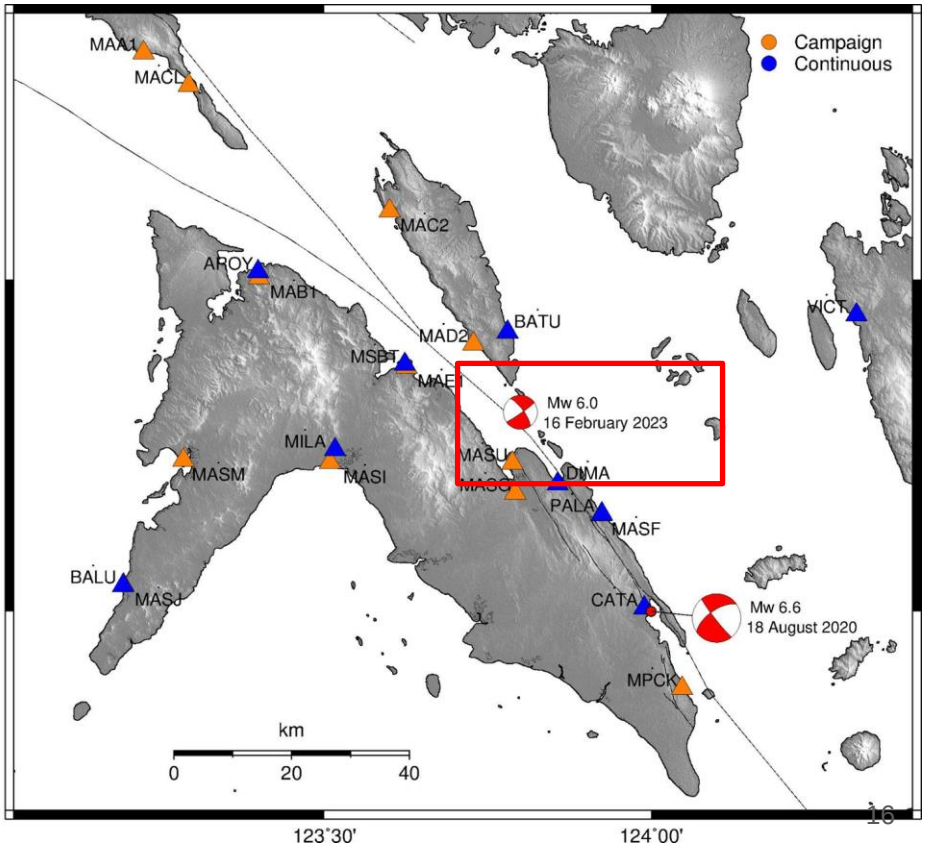
Point	Horizontal Displ (cm)	Vertical Displ (cm)	Azimuth (degree)
CATA	44.75	-13.74	137.61
MPCK	37.24	-4.94	168.94
PALA	18.14	7.64	346.60
BATU	1.86	-0.61	354.84
VICT	1.16	0.37	8.34
MILA	1.51	2.07	110.07
MSBT	0.98	-0.34	93.70
BALU	0.89	-0.12	86.12



Time series of CATA and PALA indicating co-seismic displacement

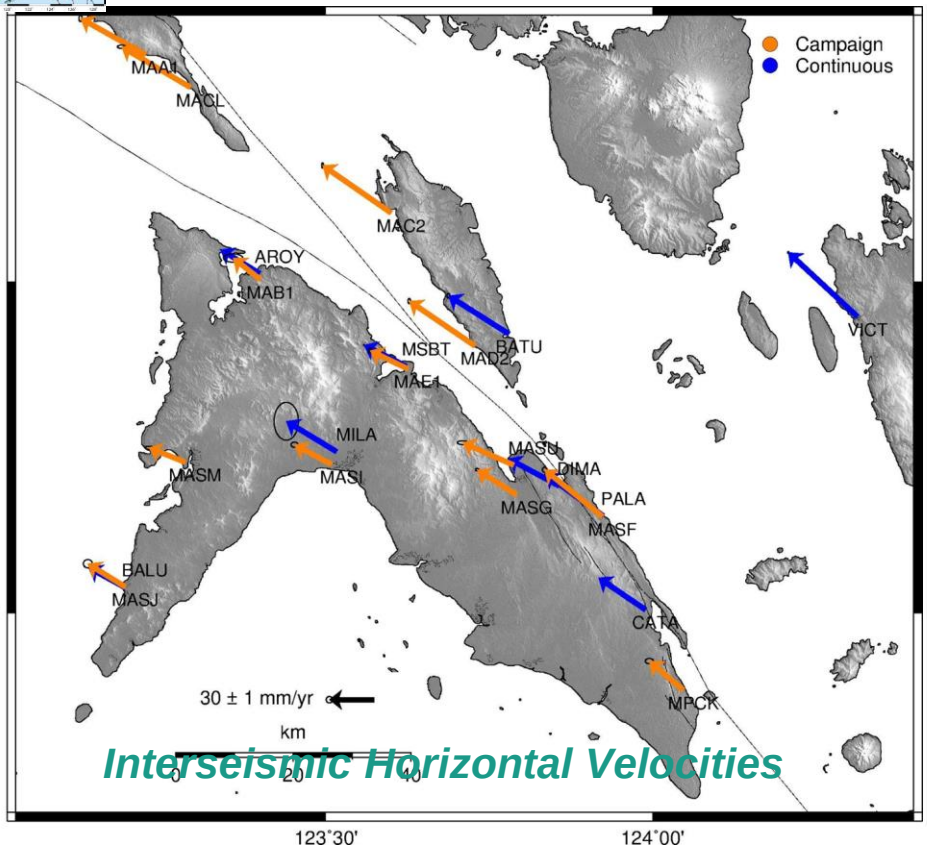
GNSS MOTIONS ASSOCIATED WITH THE 16 FEBRUARY 2023 M6.0 MASBATE EARTHQUAKE



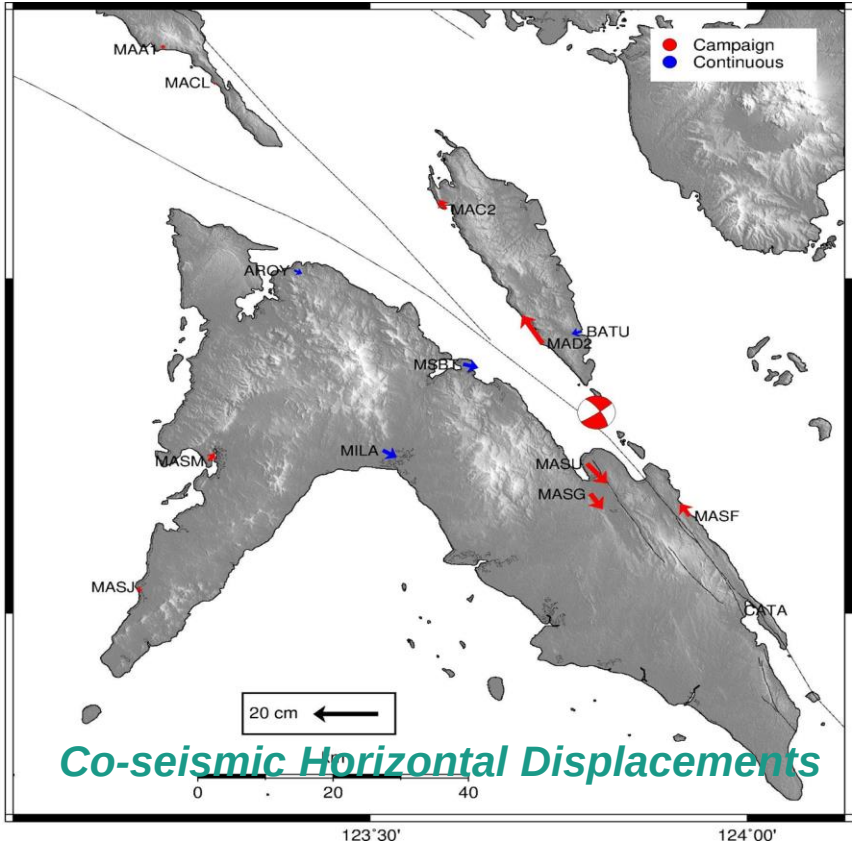


Interseismic Horizontal Velocities

GNSS MOTIONS ASSOCIATED WITH THE 16 FEBRUARY 2023 M6.0 MASBATE EARTHQUAKE

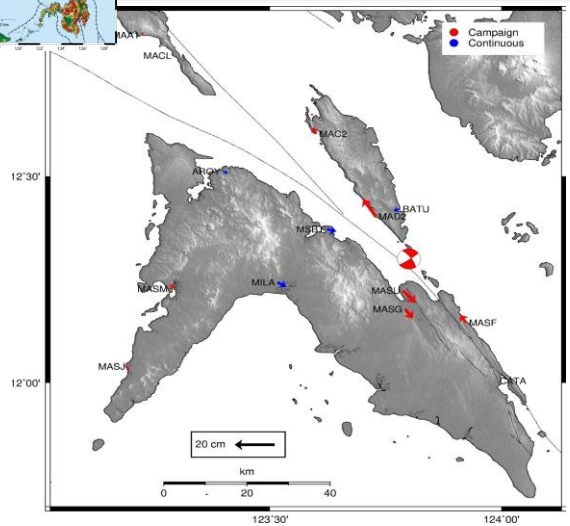


Interseismic Horizontal Velocities

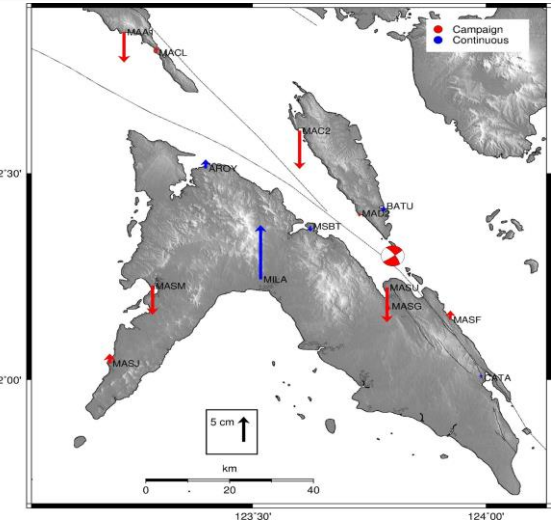


Co-seismic Horizontal Displacements

GNSS MOTIONS ASSOCIATED WITH THE 16 FEBRUARY 2023 M6.0 MASBATE EARTHQUAKE

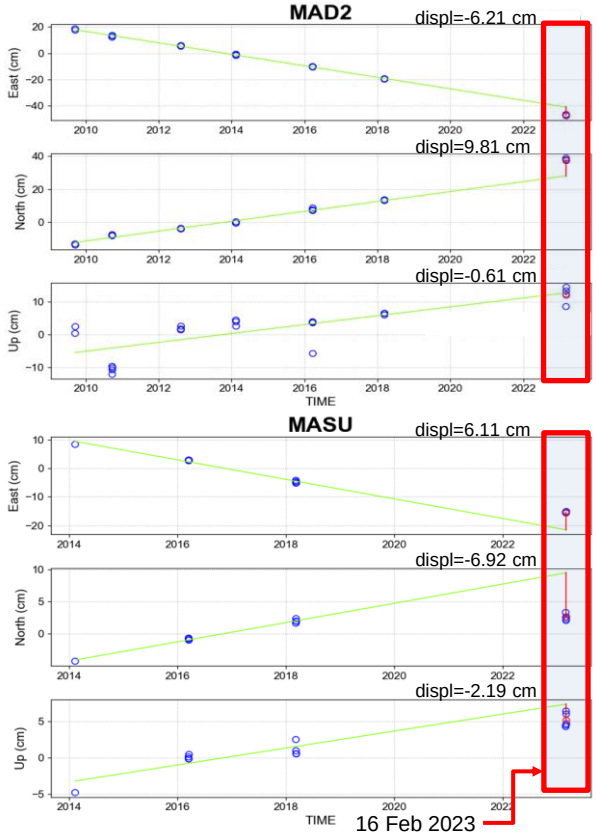


Co-seismic horizontal displacements



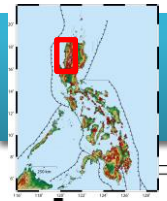
Co-seismic vertical displacements

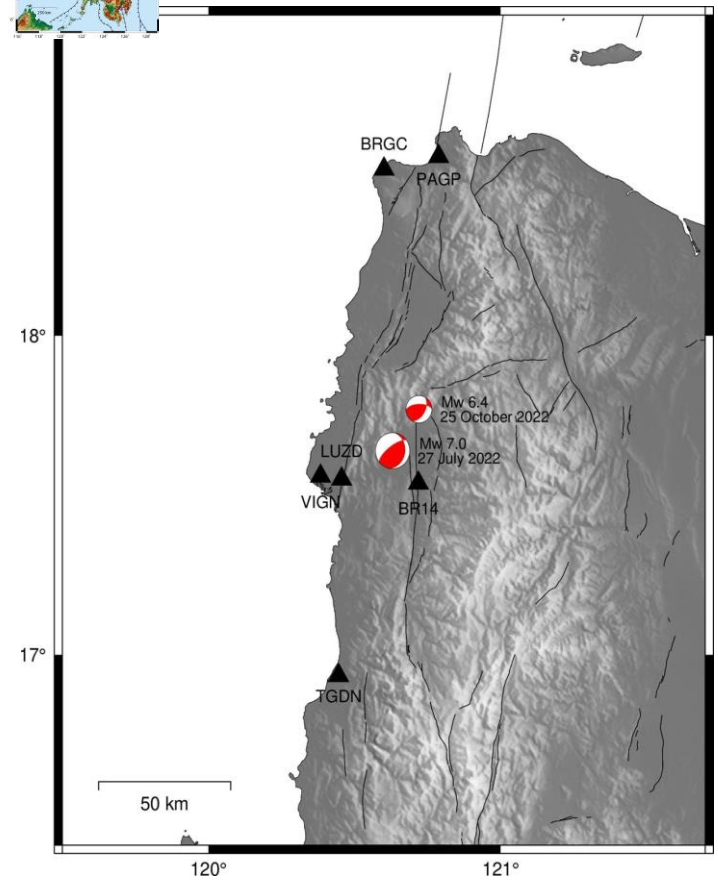
Point	Horizontal Displ (cm)	Vertical Displ (cm)	Azimuth (degree)	Point	Horizontal Displ (cm)	Vertical Displ (cm)	Azimuth (degree)
MAD2	11.61	-0.61	327.65	**MSBT**	4.74	-1.02	105.40
MASU	9.23	-2.19	138.58	**MAC2**	3.81	-7.66	327.75
MASG	6.51	-0.78	145.40	**BATU**	3.19	-1.14	255.05
MASF	5.12	1.77	326.16	**MASM**	3.27	-5.78	36.70
MILA	4.85	10.83	121.66	**AROY**	2.57	1.76	116.19
MASJ	1.89	1.90	178.44	**MACL**	0.86	1.07	164.18
MAA1	1.58	-6.03	6.99	**CATA**	0.10	0.59	354.81

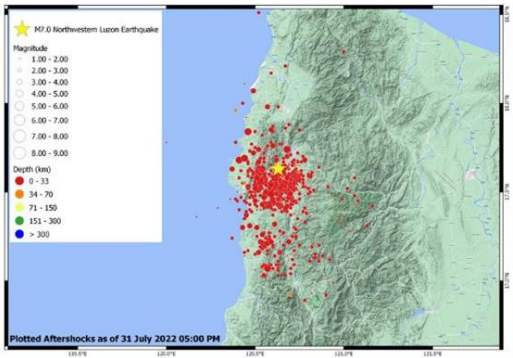


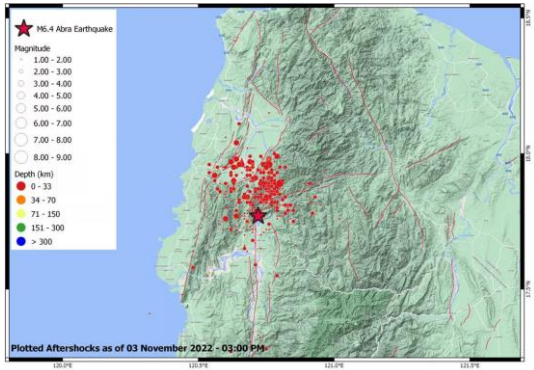
Time series of MAD2 and MASU indicating co-seismic displacement

GNSS MOTIONS ASSOCIATED WITH THE 2022 NORTHWESTERN LUZON EARTHQUAKES









THE EVENTS

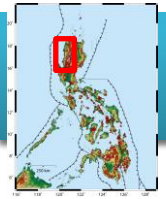
Magnitude 7.0

July 27, 2022 at 8:43 AM PhST
Depth: 17 km
Epicenter: 17.64°N, 120.63°E - 003 km N 45° W of Tayum (Abra)
Casualties: 11 dead, 574 injured
Cost of total damage (NDRRMC estimate): P1.6 B Pesos or 80 B US Dollars)

Magnitude 6.4

Oct 25, 2022 at 10:59 PM PhST
Depth: 16 km
Epicenter: 17.77°N, 120.72°E - 005 km N 21° E of Lagayan, Abra
Casualties: 139 injured
Cost of total damage (NDRRMC estimate): P85 M Pesos or 1.7 M US Dollars)

Sources: NDRRMC Update SitRep No. 12 regarding Magnitude 7.0 Earthquake in Tayum, Abra and Final Report for Magnitude 6.4 Earthquake in Lagayan, Abra



GNSS MOTIONS ASSOCIATED WITH THE 2022 NORTHWESTERN LUZON EARTHQUAKES

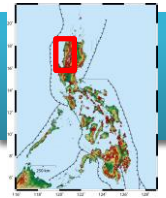
Impacts of the 2022 Northwestern Luzon Earthquakes

Landslide in Mt. Data Cliff, Mankayan

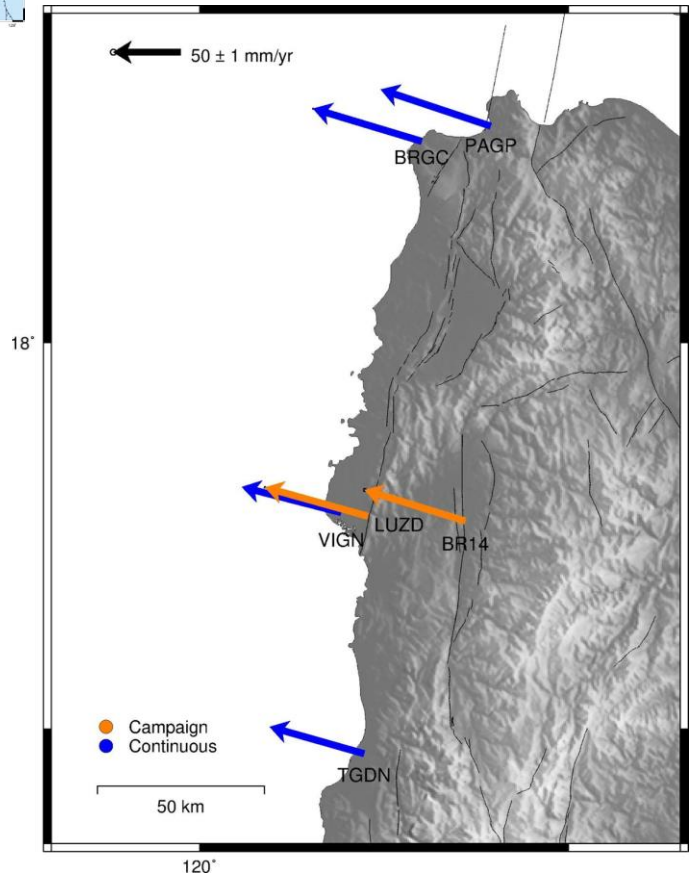
Before

After

Collapsed house foundation at Balay idiay Brgy. Lapting, San Juan

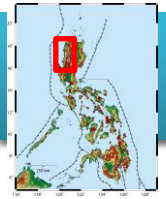


GNSS MOTIONS ASSOCIATED WITH THE 2022 NORTHWESTERN LUZON EARTHQUAKES



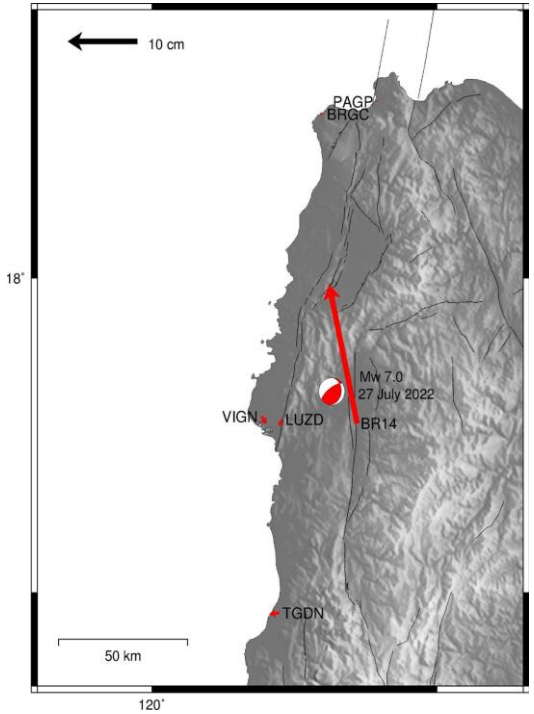
INTERSEISMIC VELOCITIES

- From a combination of GNSS campaigns and continuous sites from 2000 to 2022
- NW-directed movements
- The interseismic horizontal velocities ranges from 72.72 mm/yr (TGDN) to 85.87 mm/yr (PAGP)
- With azimuths from 284 degrees (VIGN) to 288 degrees (PAGP)

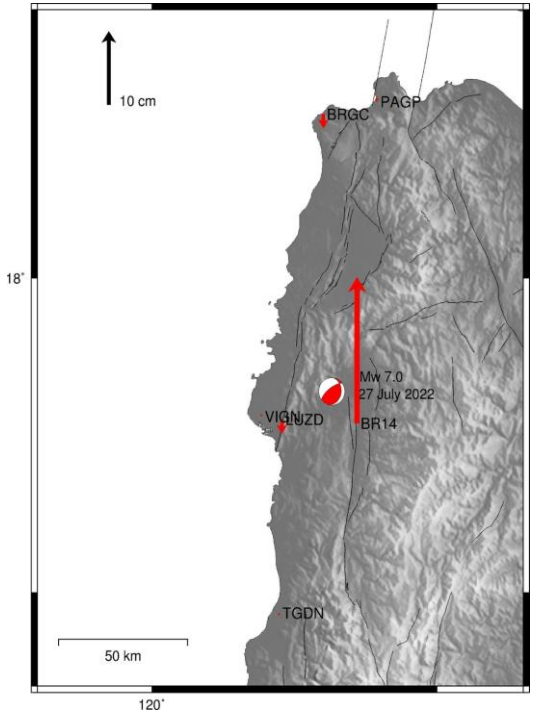


GNSS MOTIONS ASSOCIATED WITH THE 27 JULY 2022 M7.0 NORTHWESTERN LUZON EARTHQUAKE

CO-SEISMIC DISPLACEMENTS

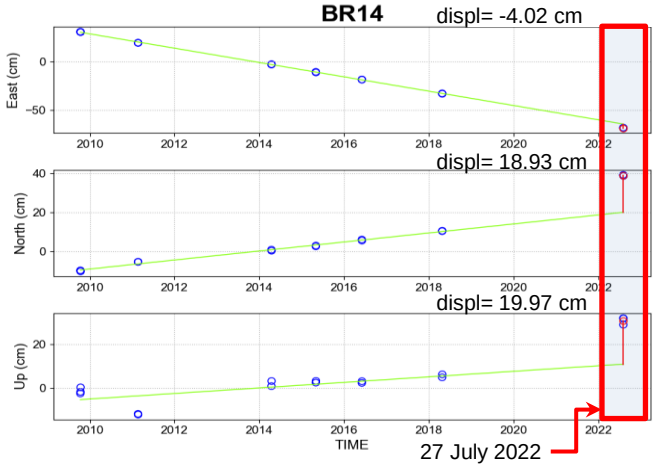


Co-seismic horizontal displacements



Co-seismic vertical displacements

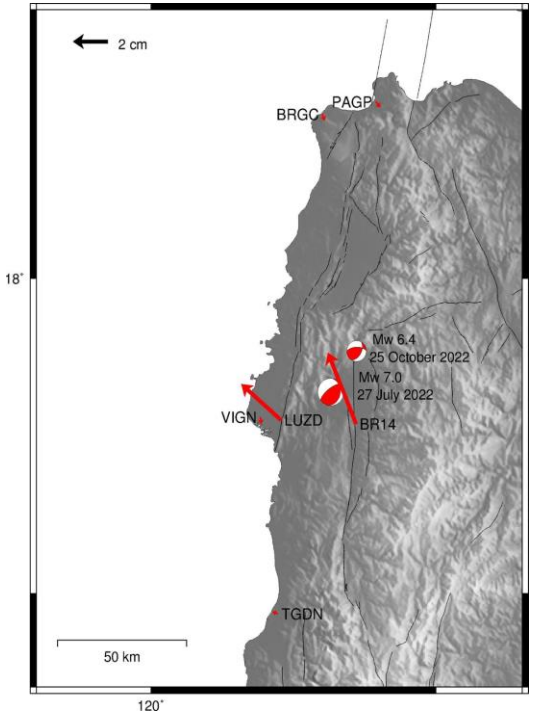
Point	Horizontal Displ (cm)	Vertical Disp (cm)	Azimuth (degree)
PAGP	0.270	0.581	57.61
BRGC	0.495	-1.921	277.22
VIGN	1.265	0.339	143.00
TGDN	1.369	-0.376	262.87
LUZD	1.009	-1.928	203.58
BR14	19.351	19.974	348.01



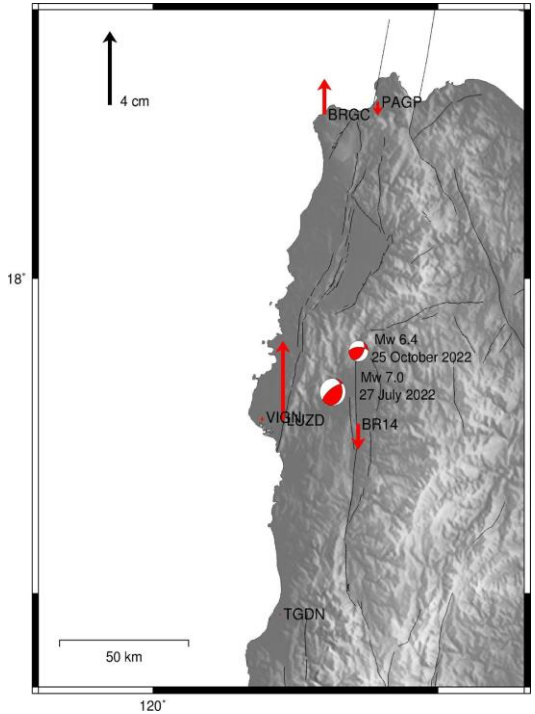
Time series of BR14 indicating co-seismic displacement

GNSS MOTIONS ASSOCIATED WITH THE 25 OCT 2022 M6.4 NORTHWESTERN LUZON EARTHQUAKE

CO-SEISMIC DISPLACEMENTS

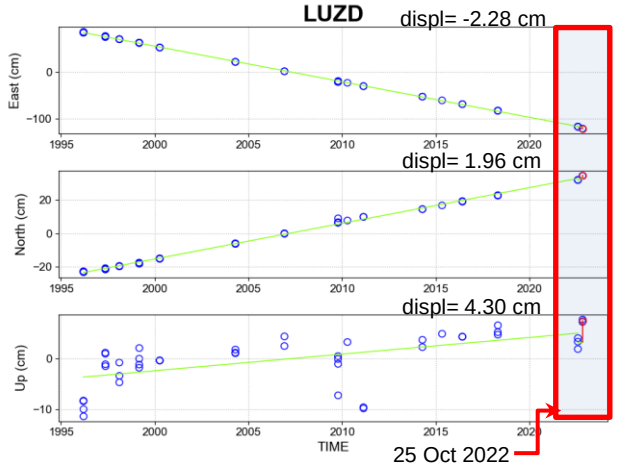


Co-seismic horizontal displacements



Co-seismic vertical displacements

Point	Horizontal Displ (cm)	Vertical Disp (cm)	Azimuth (degree)
PAGP	0.398	-0.730	138.26
BRGC	0.367	1.912	159.99
VIGN	0.391	-0.219	172.63
TGDN	0.332	-0.103	286.09
LUZD	3.006	4.304	310.62
BR14	4.209	-1.390	337.33



Time series of LUZD indicating co-seismic displacement

SUMMARY

- **Interseismic velocities**: Ranging from 6.32 mm/yr to 90.28 mm/yr with azimuths varying from N260.07° to N314.73° degrees
- **2019 M6.0+ Cotabato earthquake series**: total cumulative co-seismic horizontal displacement: 335.40 mm; indicate right-lateral motions
- **2020 M6.6 Masbate earthquake**: at least 620 mm co-seismic horizontal displacement; with elastic rebound indications similar to the 2003 Masbate event.
- **2023 M6.0 Masbate earthquake**: at least 200 mm co-seismic horizontal displacement;with elastic rebound indications; recurrence interval consistent with the dislocation modeling done in 2012
- **2022 M7.0 and M6.4 Northwestern Luzon earthquakes**: 235 mm cumulative co-seismic horizontal displacements

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