GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS) CO-LOCATED TIDE STATIONS: PURPOSE AND PROSPECTS IN THE PHILIPPINES

Presented during: United Nations / Philippines Workshop on the Applications of Global Navigation Satellite Systems
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Outline of Presentation

01 *Geographical Setting*

02 *Physical Oceanography Division (POD)*

03 *Primary Tide Stations of the Philippines*

04 *Co-located Global Navigation Satellite Systems (GNSS) Tide Stations*

05 *Purpose: Vertical Land Motion Monitoring*

06 *Coastal Sea Level Rise (CSLR) Project: Discussions, Results and Conclusions*

07 *Development of GNSS Tide Gauge and Float Buoy*

08 *Prospects: GNSS Interferometric Reflectometry (GNSS-IR)*

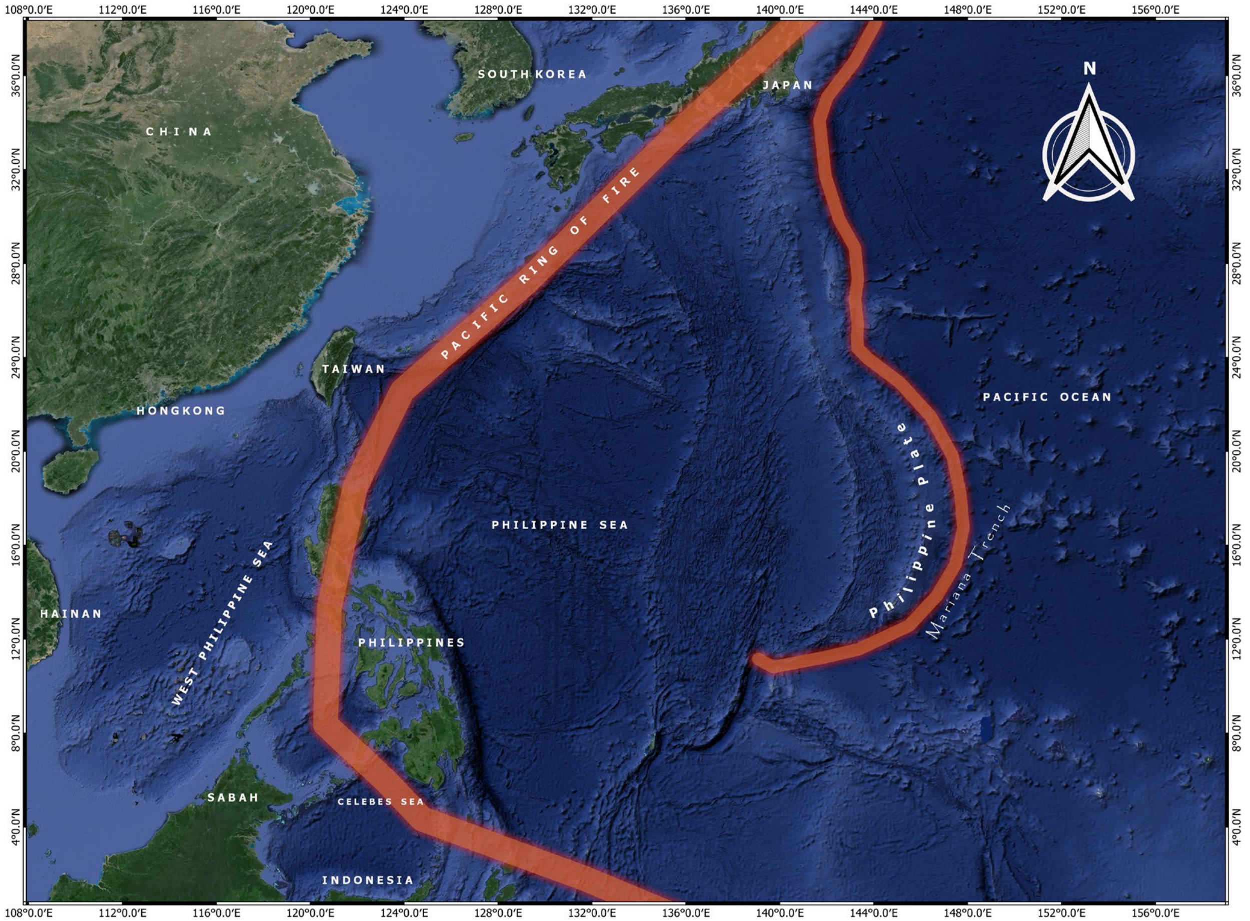
09 *Preliminary Activities: GNSS-IR Analysis Software (GIRAS) Initial Data Evaluation*

10 *Issues and Concerns*

11 *Ways Forward*

Geographical Setting

- ✓ *The Philippine archipelago lies in the middle of the Philippine Sea adjacent to the Pacific Ocean to the east and to its west coast, West Philippine Sea.*
- ✓ *Geographically an archipelago and geologically sits on various tectonic plates, the Philippine Plate and particularly part of the so-called "Pacific Ring of Fire".*
- ✓ *The Philippines mapping and charting agency, the NAMRIA is responsible for the establishment and maintenance of reliable geodetic reference datum.*
- ✓ *For the vertical component of this geodetic reference datum, the NAMRIA's Physical Oceanography Division operates and maintains at least 60 tide stations throughout the country.*



Physical Oceanography Division

Physical Oceanography Division

Main Responsibilities

- *Responsible for the establishment and determination of a reliable vertical reference datum primarily used in hydrographic surveys, nautical charting & topographic mapping.*
- *Operates and maintains a network of permanent tide stations throughout the country that continuously collects and records sea level data*
- *Responsible for the publication of the annual Tide and Current Tables (TCT).*
- *Ensures the stability of tide gauges by establishing and maintaining tide gauge benchmarks (TGBM's) to monitor tidal datum variations or changes through time.*

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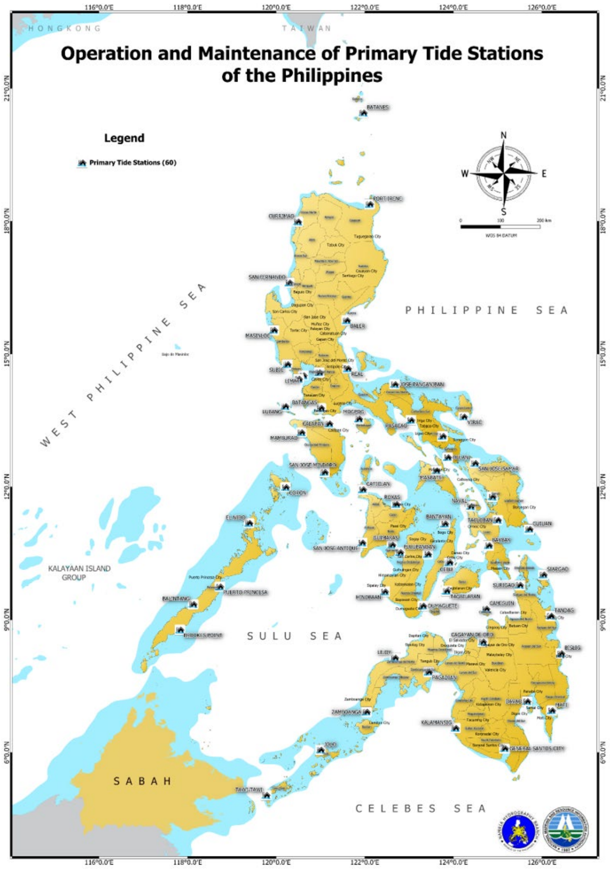

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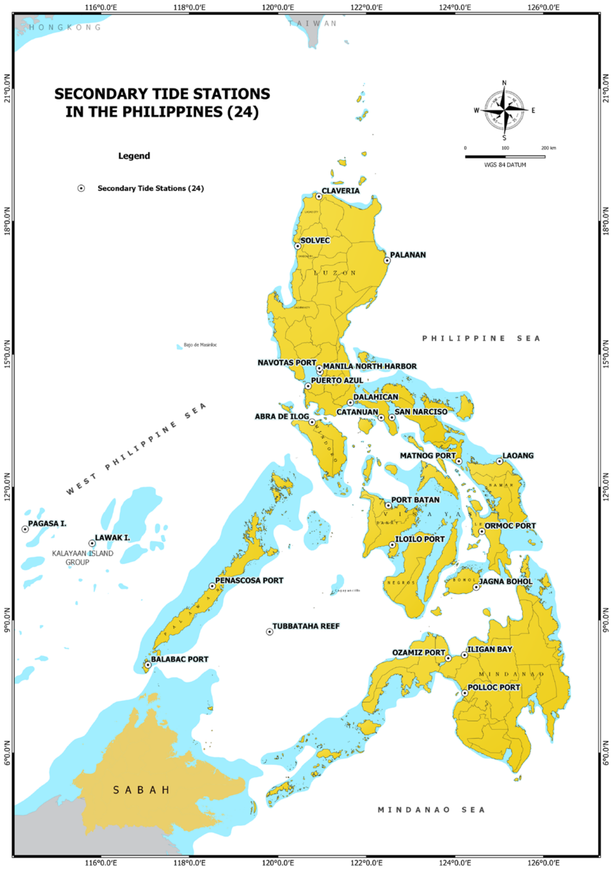

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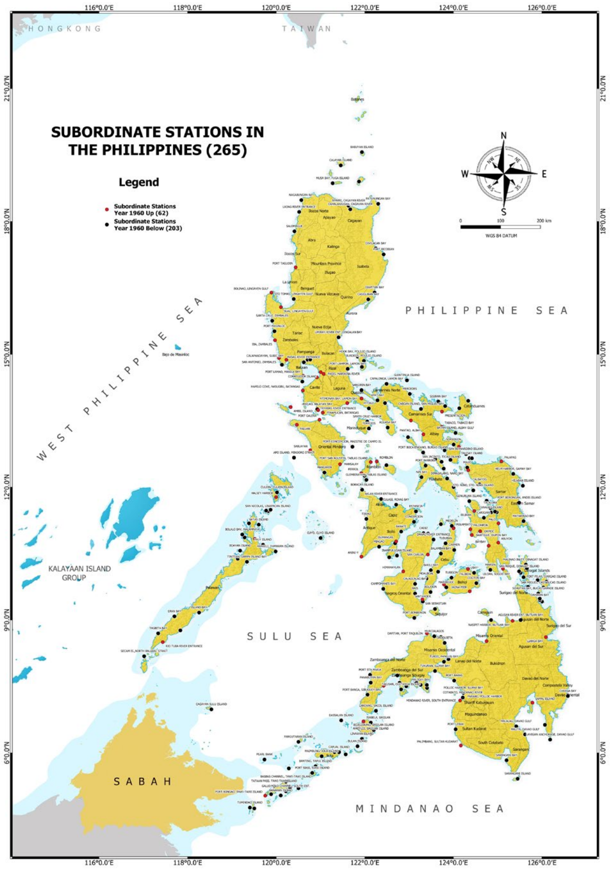
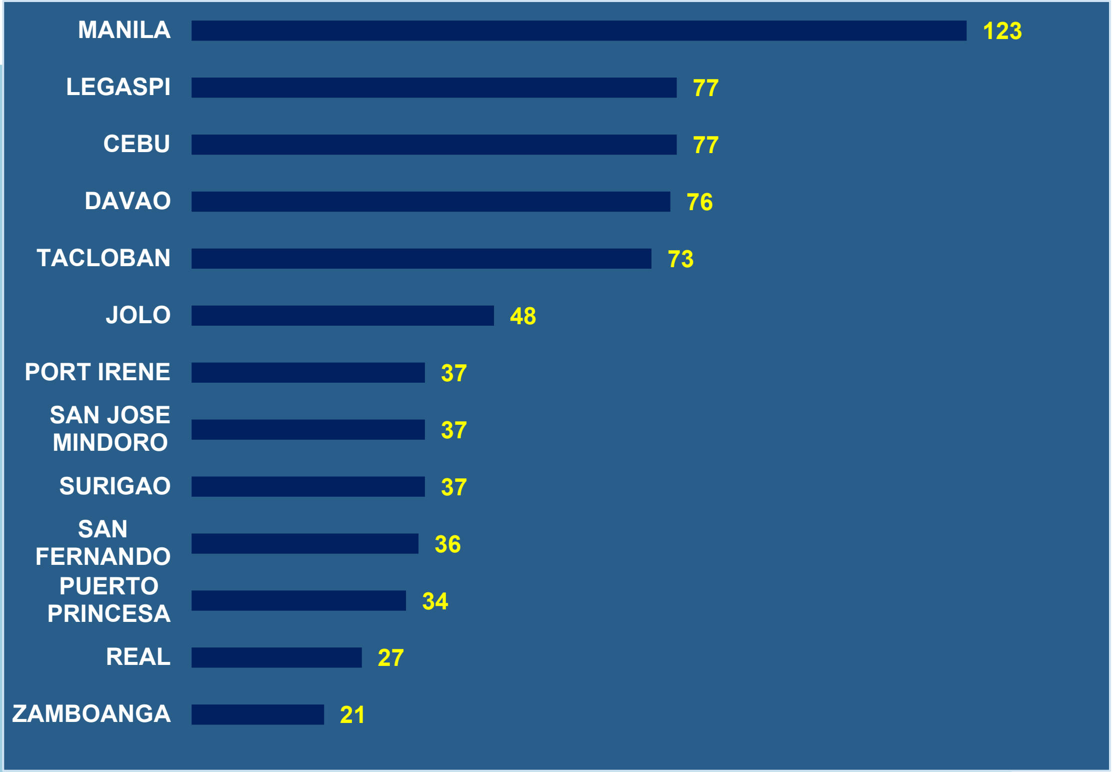


LONG-TERM TIDE STATIONS IN THE PHILIPPINES (13)

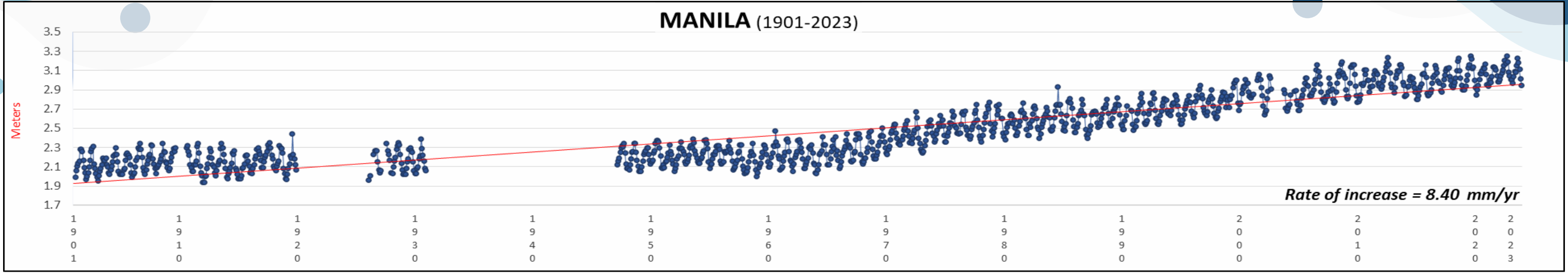


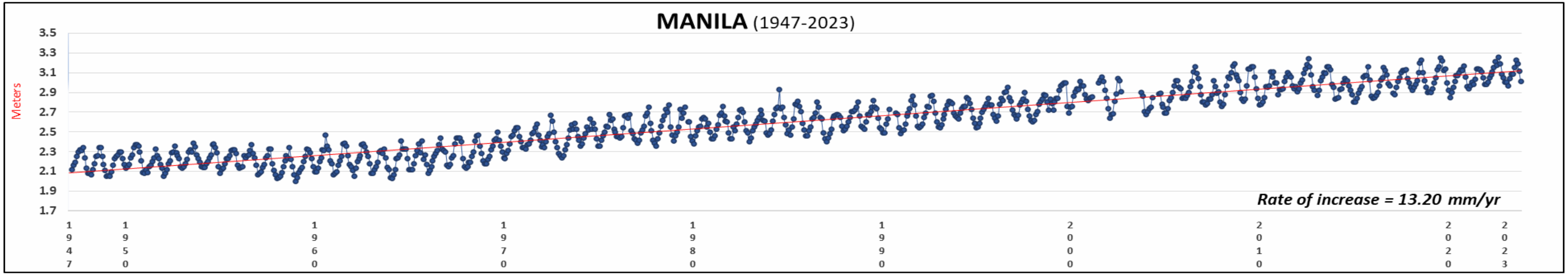
(Note: as of 2023)

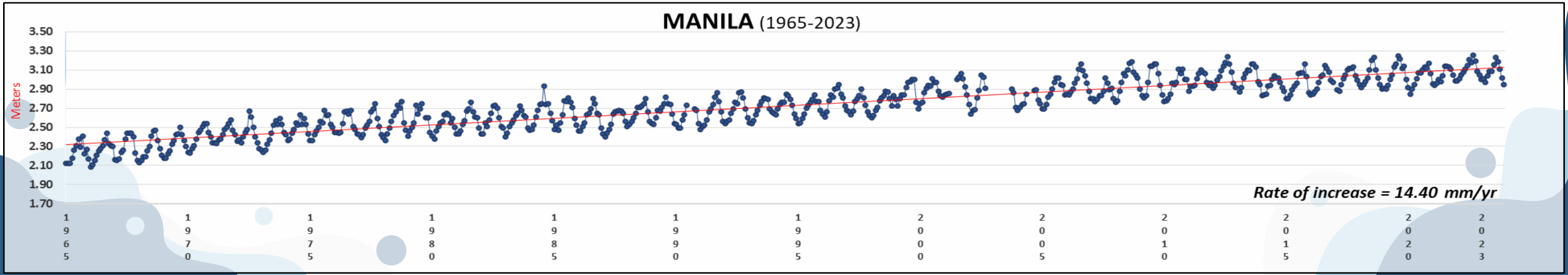
TIDE STATION	RATE OF INCREASE/ DECREASE (mm/yr)	TREND Rising/Falling	PERIOD	NO. OF YEARS
MANILA	8.4/13.2/14.4	R	1901-2023	123
LEGASPI	6.00	R	1947-2023	77
CEBU	1.20	R	1947-2023	77
DAVAO	3.60	R	1948-2023	76
JOLO	0.24	R	1949-1996	48
PORT IRENE	4.80	R	1987-2023	37
SAN JOSE MINDORO	2.40	R	1987-2023	37
SURIGAO	4.80	R	1987-2023	37
SAN FERNANDO	-1.20	F	1988-2023	36
PUERTO PRINCESA	4.80	R	1990-2023	34
TACLOBAN	0.06	R	1951-2023	34
REAL	3.60	R	1996-2023	28
ZAMBOANGA	-1.20	F	2003-2023	21

HỊGĂ̂ ĦĐĂBLHĂ NỊBĦẢĂỊNH HẮLÒ

OBSERVED MONTHLY MEAN SEA LEVEL TRENDS

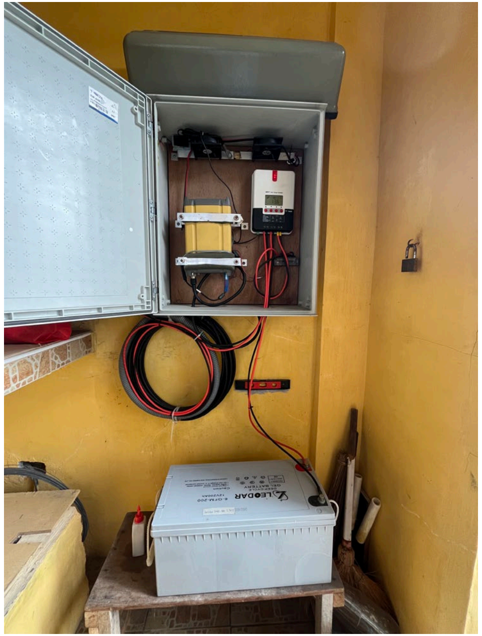


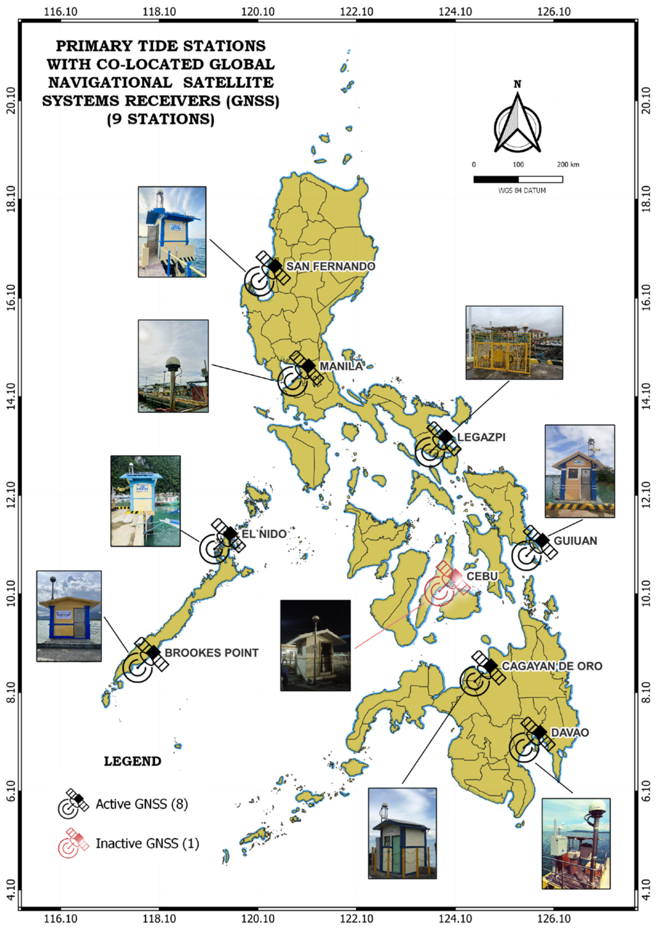




GNSS Co-located Tide Stations

- Year installed (2016-2017)
- GNSS Receiver: Topcon Net-G5
- GNSS Antenna: TPSCR.G5 TPSH (Choke Ring)
- Data Access: via FTP
- Data Logging: 1 second
- Antenna Height: 4.14 meters above "SFD GNSS" station mark





Purpose

- ✓ *Continuous GNSS observations at tide stations to determine the contribution of Vertical Land Motion (VLM) to sea level rise.*

- ✓ *Input data for the collaborative research project on Coastal Seal Level Rise (CSLR) with the University of the Philippines Department of Engineering (UPDGE).*

The CSLR Research Project

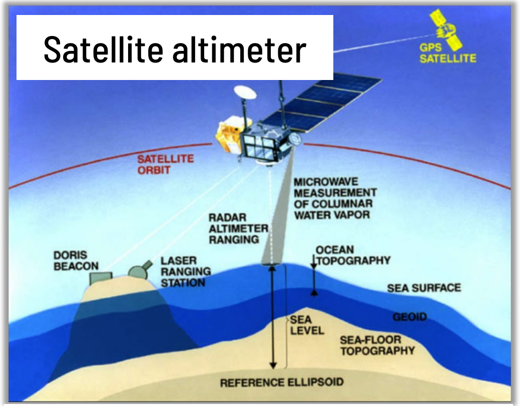
- ✓ *The project was conceptualized to determine relative sea level changes at the coasts using tide gauge and satellite altimetry data. The correlation of the satellite altimetry data to tide gauge measurement will determine its usability on areas without tide gauges.*

- ✓ *Vertical Land Motion (VLM) was investigated on tide stations where co-located with Global Navigational Satellite Systems (GNSS) receivers. The data from GNSS were post-processed to determine the VLM rates.*

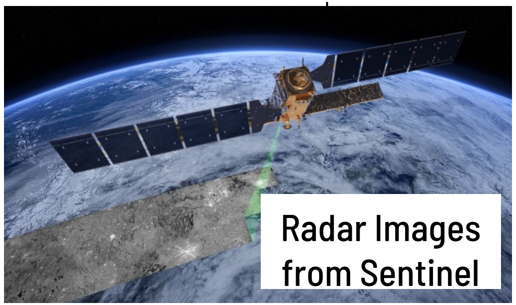
- ✓ *In addition, the project also developed a low-cost GNSS tide gauge float and buoy for sea level monitoring.*

Data Sources

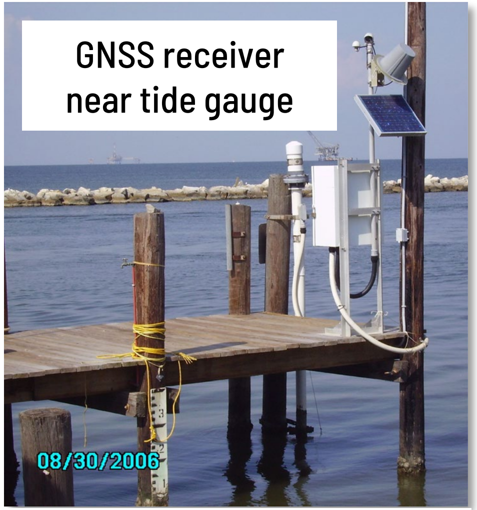
Affected by ground movement



Not affected by ground

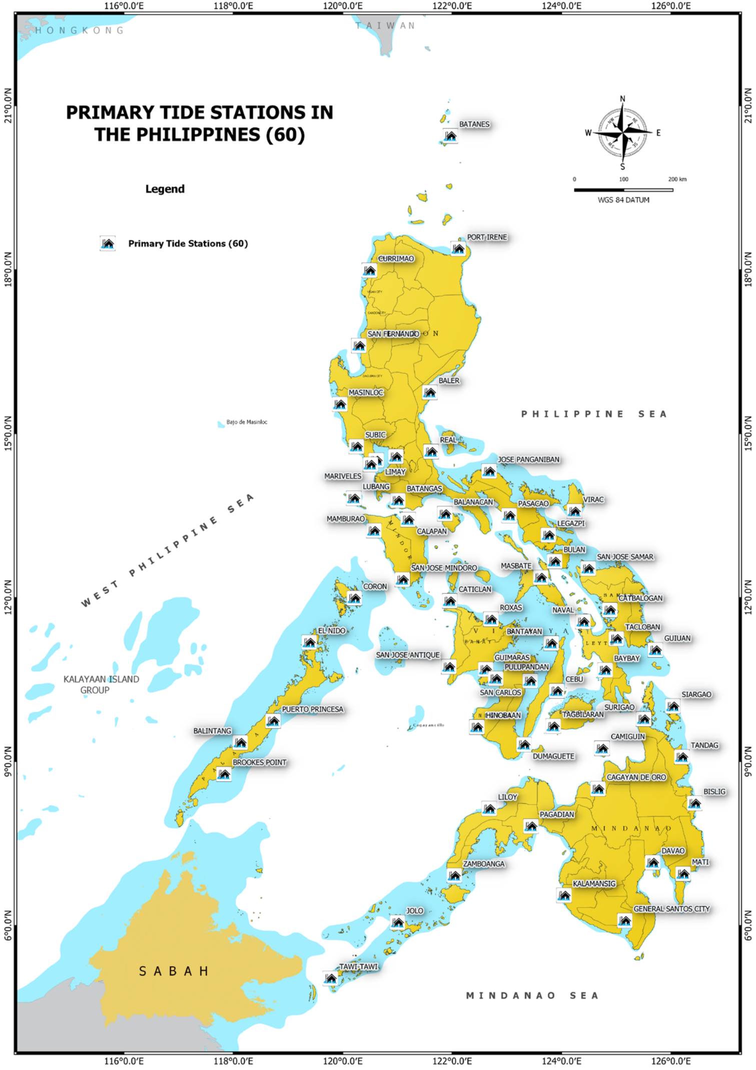


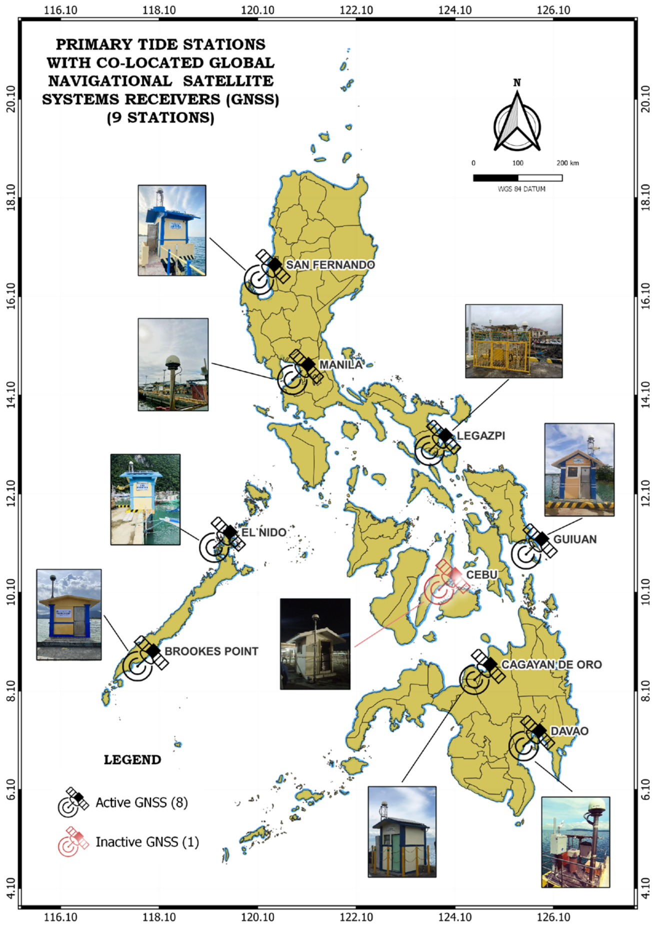
Detects ground movement



Detects ground movement

Study Sites





- ✓ *25 tide stations were selected as study sites*
- ✓ *9 of these tide stations were collocated with GNSS receivers (Manila, San Fernando, Legaspi, Cebu, Guiuan, Cagayan de Oro, Davao, Brookes Point and El Nido)*

Determining the contribution of VLM to sea level rise using PSInSAR, GNSS and SSH-TGSL difference

- *PSInSAR (Permanent Scatterer Interferometric Synthetic Aperture Radar) uses radar signals from satellite to measure ground displacement.*
- *GNSS data at TG or nearby Active Geodetic Network Station (AGN).*
- *SSH-TGSL difference – Sea Surface Height (SSH) from SA minus the TG sea level*

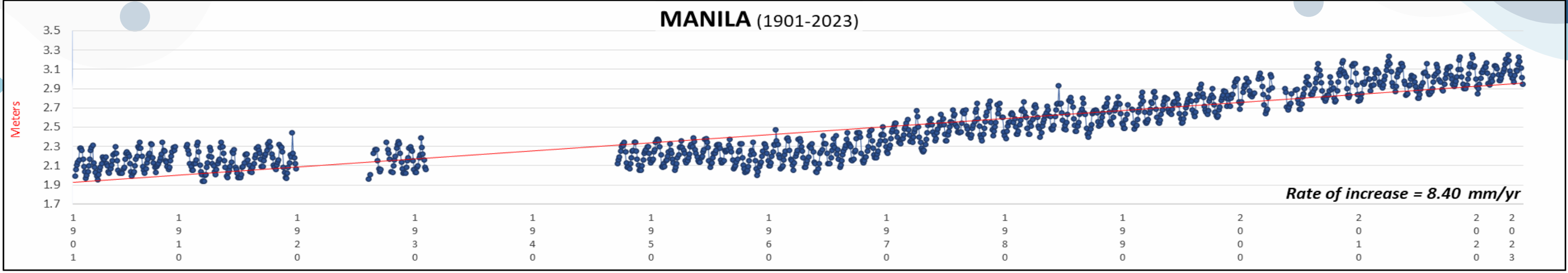
Vertical Land Motion (VLM) rates (mm/yr)

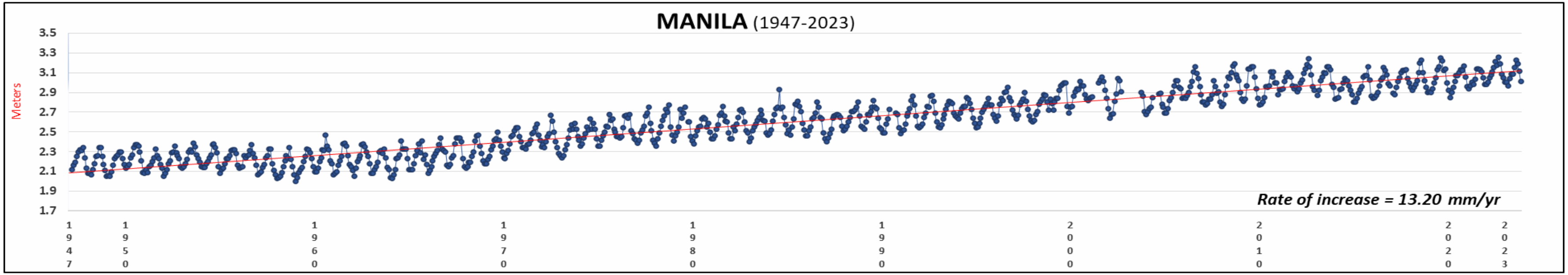
Location	PSInSAR	CGNSS Tide Stations
Manila	-1.40	-1.00
San Fernando	-1.10	-0.62
Cagayan de Oro	-6.80	-5.43
Guiuan	-1.40	-0.91
Cebu	-0.90	-1.11
El Nido	-5.20	-5.20
Davao	-1.40	-1.59

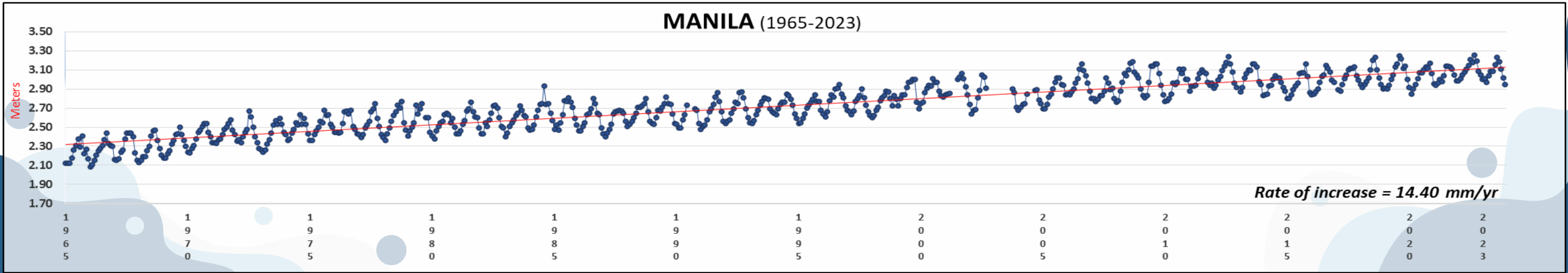
Results: Net local SLR (mm/yr)

Location	SLR	VLM	Net SLR
Manila	14.4	-1.00	13.4
San Fernando	-1.2	-0.62	-1.82
Cagayan de Oro	6.0	-5.43	0.57
Guiuan	3.6	-0.91	2.69
Cebu	1.2	-1.11	0.09
El Nido	6.0	-5.20	0.8
Davao	3.6	-1.59	2.01

OBSERVED MONTHLY MEAN SEA LEVEL TRENDS





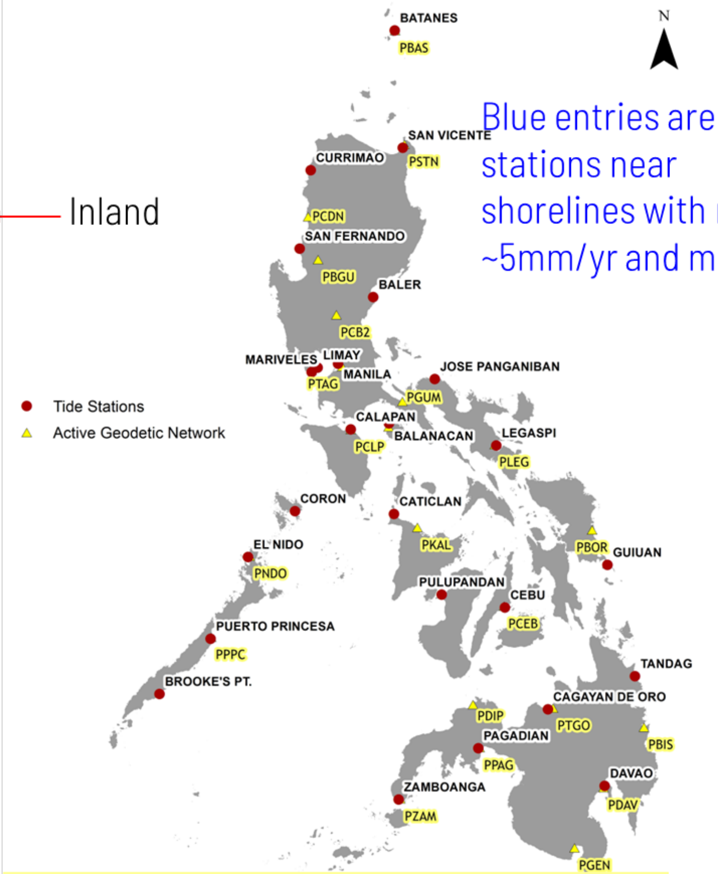


VLM from GNSS observations in the Philippine Active Geodetic Network (AGN)

AGN	Location	Period	CSLR-Phil	NAMRIA
PBAS	Basco, Batanes	2014-10 to 2019-12	-2.98	-3.35
PMOG	Mogpog, Marinduque	2014-08 to 2019-12	-2.58	-2.23
PCB2	Cabanatuan, Nueva Ecija	2012-08 to 2019-12	-16.57	-15.48
PTGO	Tagoloan, Misamis Oriental	2013-11 to 2019-12	-2.08	-2.40
PCLP	Calapan City, Oriental Mindoro	2015-12 to 2019-12	-3.62	-5.74
PKAL	Kalibo, Aklan	2015-01 to 2019-12	-17.99	-17.55
PCEB	Cebu City, Cebu	2014-04 to 2019-12	-5.23	-4.97
PDAV	Davao City, Davao del Sur	2013-04 to 2019-12	-5.01	-4.95
PNDO	El Nido, Palawan	2014-08 to 2019-12	-2.74	-2.13
PGEN	Gen. Santos City, South Cotabato	2010-04 to 2019-12	-4.98	-4.05
PBOR	Borongan, Eastern Samar	2018-01 to 2019-12	-14.53	-21.25
PGUM	Gumaca, Quezon	2018-09 to 2019-12	-19.32	-22.27
PLEG	Legazpi City, Albay	2011-03 to 2019-12	-3.58	-3.77
PTAG	NAMRIA Office, Taguig City, MM	2008-09 to 2019-12	1.02	3.11
PDIP	Dipolog City, Zamboanga del Norte	2015-09 to 2019-10	-3.54	-4.78
PPAG	Pagadian City, Zamboanga del Sur	2018-07 to 2019-12	-19.69	-12.9
PPPC	Puerto Princesa City, Palawan	2010-12 to 2019-12	-1.28	-1.15
PILC	Iloilo City, Iloilo	2010-04 to 2019-12	-3.31	-4.31
PBGU	Baguio City, Benguet	2016-09 to 2019-12		-5.79
PCDN	Candon City, Ilocos Sur	2016-09 to 2019-12	-5.31	-5.5
PSTN	Sta Ana, Cagayan	2015-06 to 2019-11	-4.42	-5.01
PBIS	Bislig City, Surigao del Sur	2016-10 to 2019-10	-9.37	-8.3
PZAM	Zamboanga City, Zamboanga del Sur	2014-04 to 2019-12	-1.65	-1.29

Inland

Blue entries are AGN stations near shorelines with rates ~5mm/yr and more



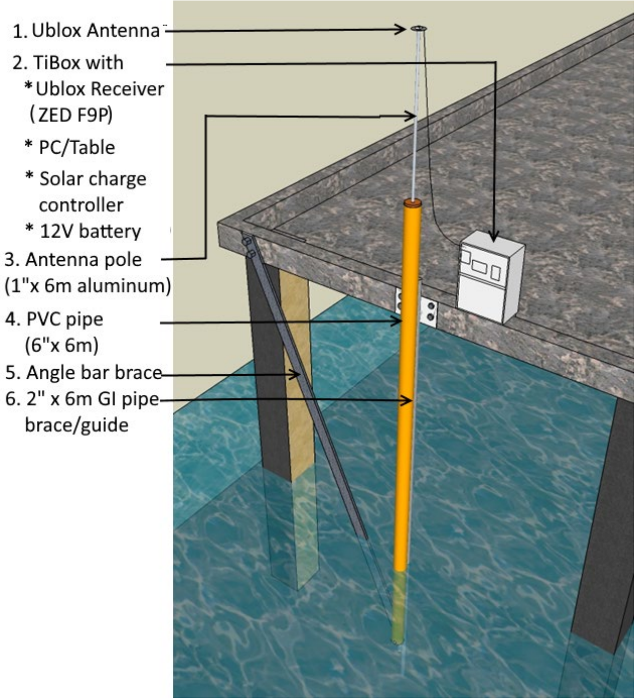
Short period of observation

DEVELOPMENT OF A GNSS FLOAT AND BUOY TIDE GAUGES

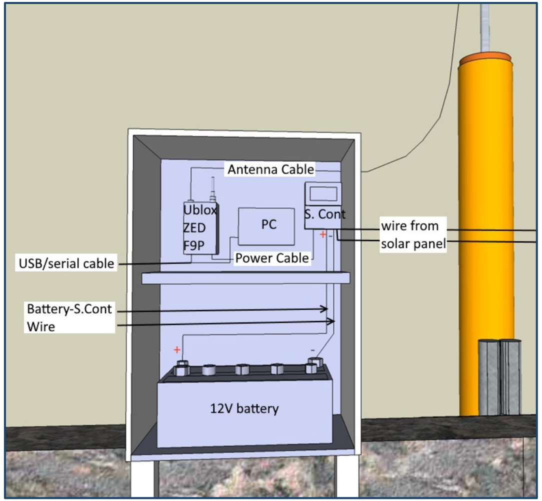
- *NAMRIA was able to design and develop two (2) types of tide gauges (float & buoy) using GNSS receivers as sensors in monitoring variations of sea level.*

- *The tide gauges could record sea level heights in terms of the ellipsoidal heights and showed acceptable differences with in-situ tide gauge data.*

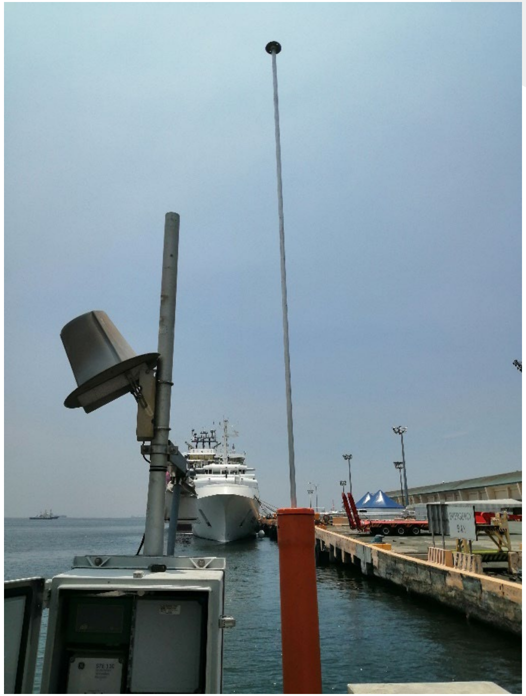
GNSS FLOAT TIDE GAUGE INSTALLATION



a) Float Tide Gauge Design

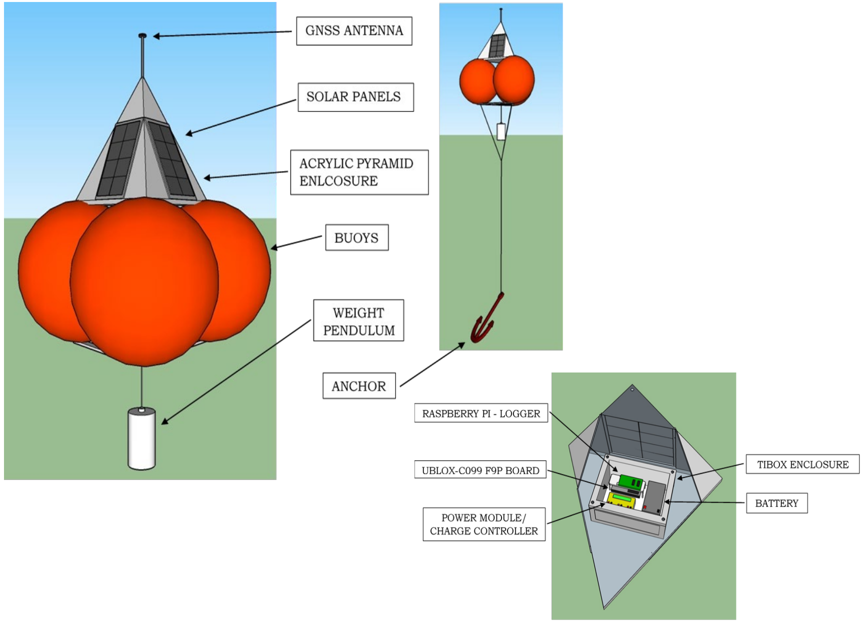


b) Control & Power Supply Panel

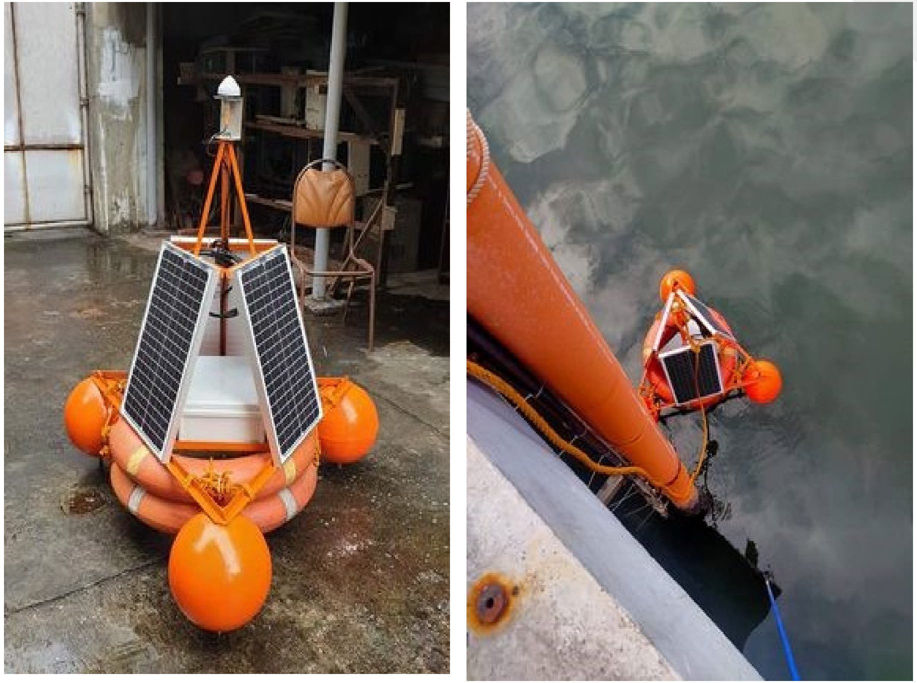


c) Actual installation of Float Tide Gauge at Manila Bay

GNSS TIDE GAUGE BUOY

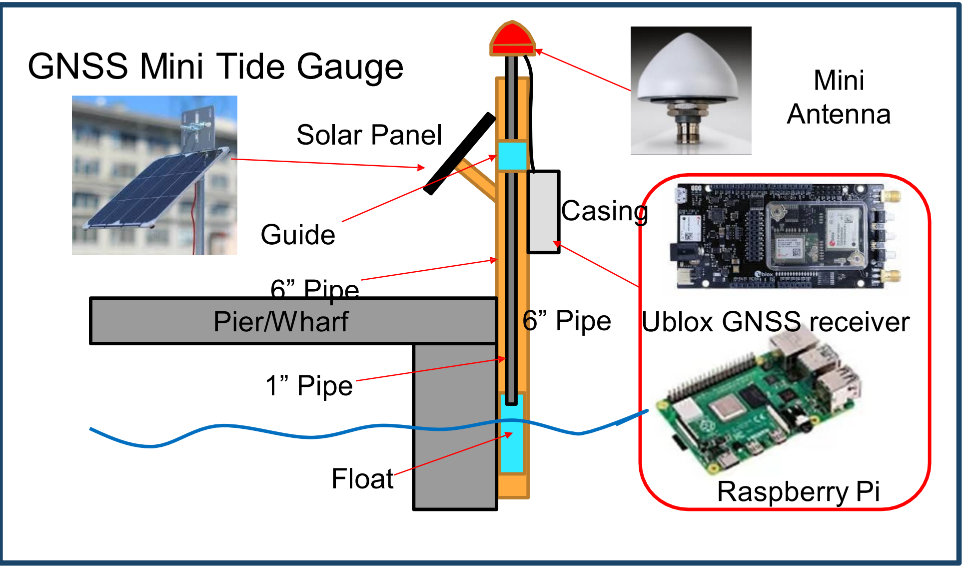


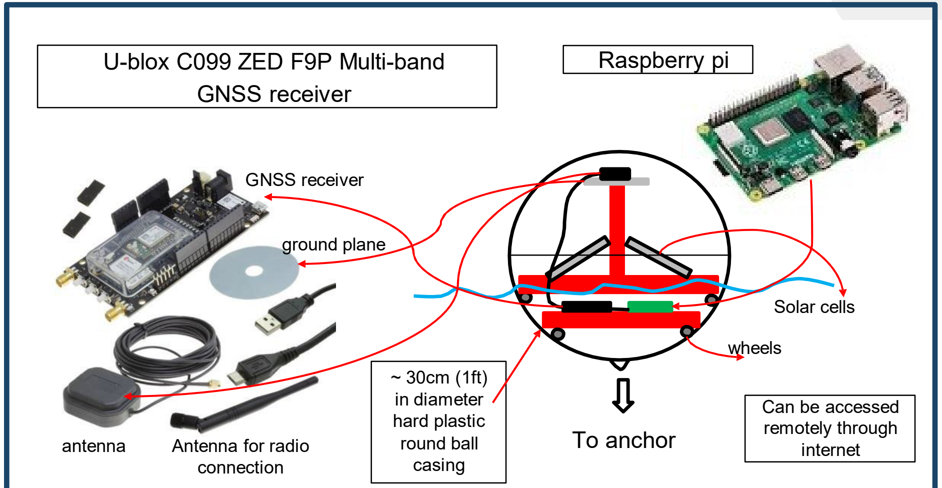
a) Buoy Tide Gauge Design



b) Buoy Tide Gauge

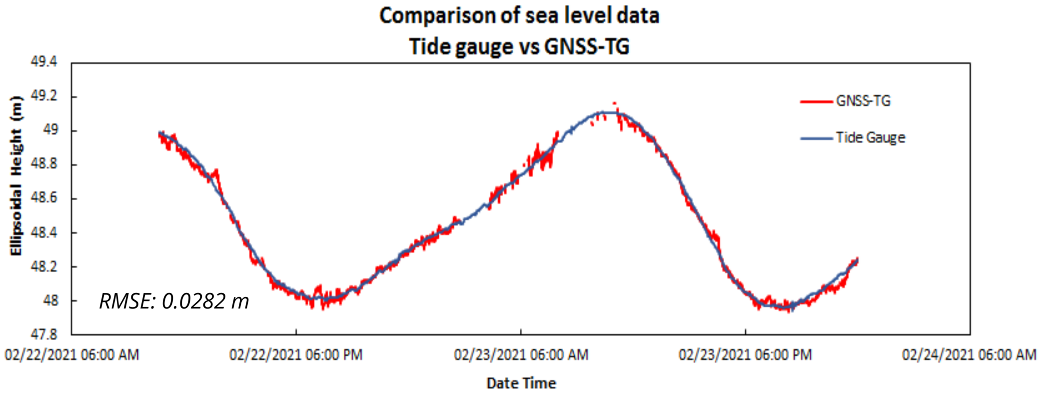
Schematic Diagram

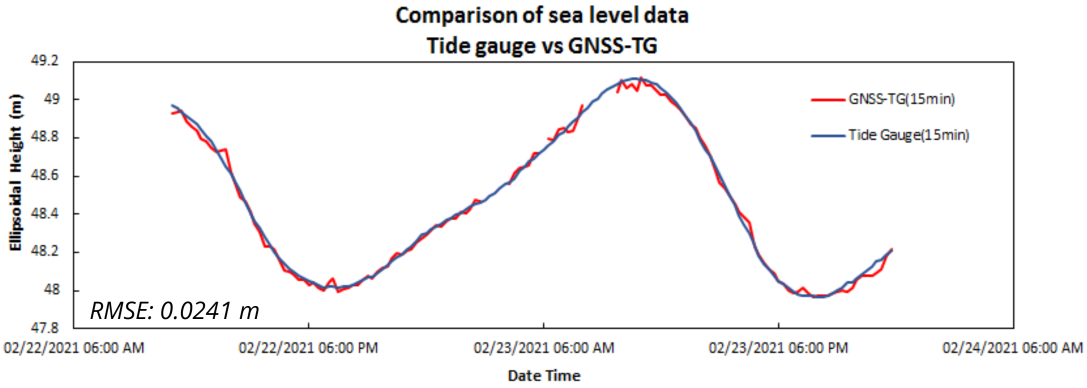




Prototype of low cost miniWsurfer buoy

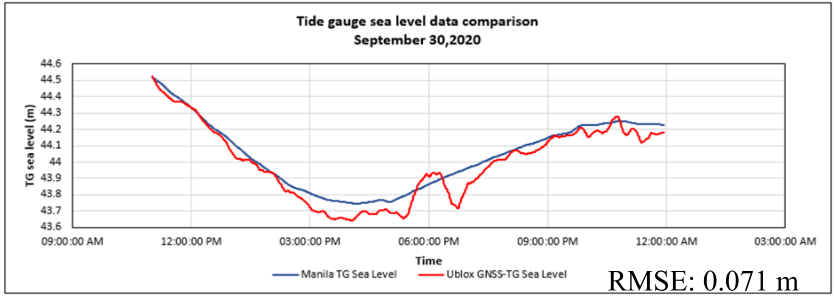
GNSS Float Tide Gauge



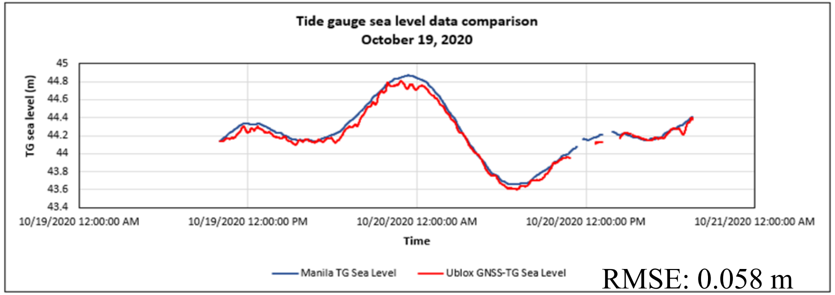


GNSS Tide Gauge Buoy

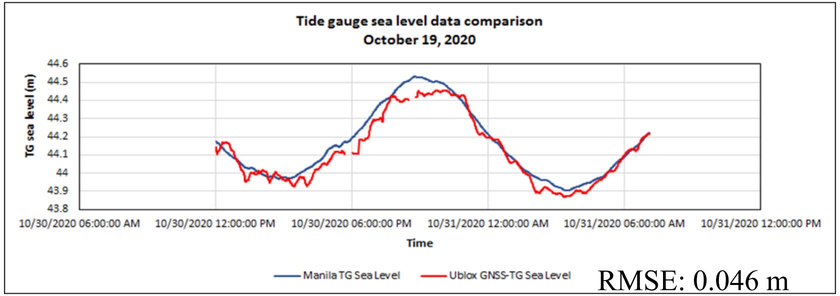
Plotted results of TG²NSS VS TGSL



RMSE: 0.071 m



RMSE: 0.058 m



RMSE: 0.046 m

CSLR Project: Conclusions

1. *The TGs with long period of observations (more than 19 years) exhibit a sea level rise. The SA data also showed the same trend.*

2. *In Manila Bay where sea level rise is accelerating at 14.4 mm/year. The influence of VLM is very minimal at -1 mm/year (~5 yrs data). This means that there are other factors contributing to the sea level increase.*

3. *The low-cost GNSS tide gauge showed promising results as its post processed solutions showed an average of around 5 cm compared with the TG sea level observed using Radar sensor. Continuously improving the design.*

CLSR Project Published Research Papers

- ✓ *Rise Or Fall? How Local Factors Influence Coastal Sea Level in The Philippines*
- ✓ *Influence of the El Niño Southern Oscillation to the Interannual Sea-level Variability in the Philippine Sea*
- ✓ *Local Tide and Geoid Corrections Significantly Improve Coastal Retracked Jason Sea Surface Heights in the Philippines*
- ✓ *Estimation of Net Absolute Sea Level Change in Mogpog, Marinduque Using Persistent Scatterer Interferometric Synthetic Aperture Radar-derived Vertical Land Motion and Tide Gauge Measurements.*
- ✓ *Quantifying Vertical Land Motion at Tide Gauge Sites Using Permanent Scatterer Interferometric Synthetic Radar and Global Navigation Satellite System Solutions*

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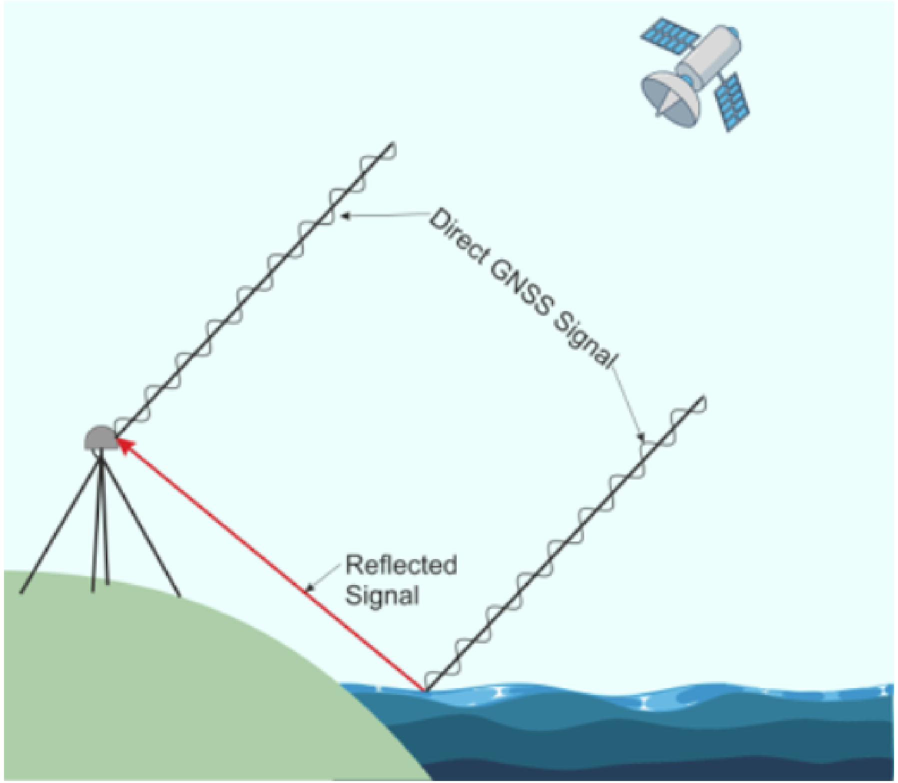


Multipath caused by GNSS signals reflecting off a body of water. Image: Simon Williams

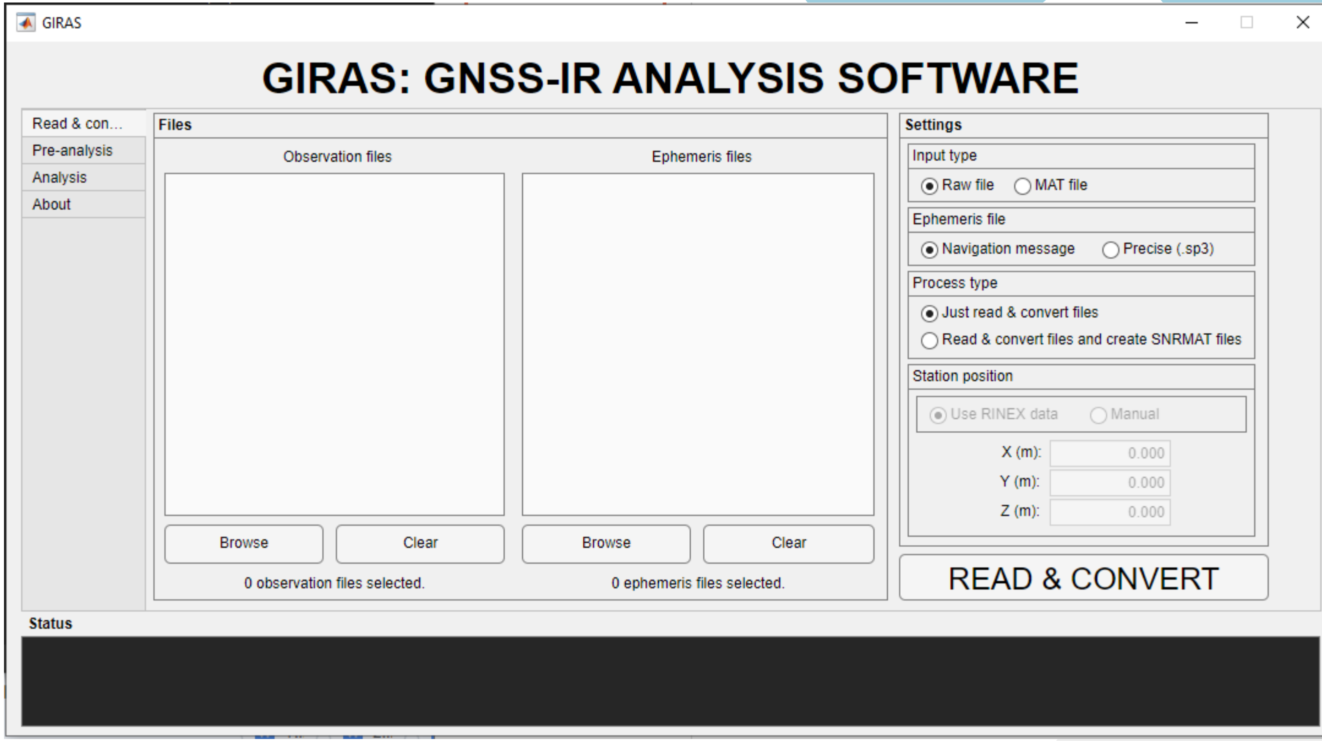
The GNSS-IR is a technique that uses signals from GNSS satellites reflected off surfaces, such as the ocean surface, to make measurements. When applied to tide gauge measurements, GNSS-IR can provide valuable information about sea surface height variations, complementing traditional tide gauge measurements.

Feasibility

- ✓ *Input data: Data from co-located GNSS tide station from Cagayan De Oro.*
- ✓ *Raw data of 7 days (January 1 – 7, 2024) with interval of 1 and 30 secs.*
- ✓ *Converted from raw data to Rinex 2.11 or 3.04.*
- ✓ *Preliminary assessment using GNSS-IR Analysis Software (GIRAS), an open-source software developed by United States' National Oceanic and Atmospheric Administration (NOAA)*

GIRAS

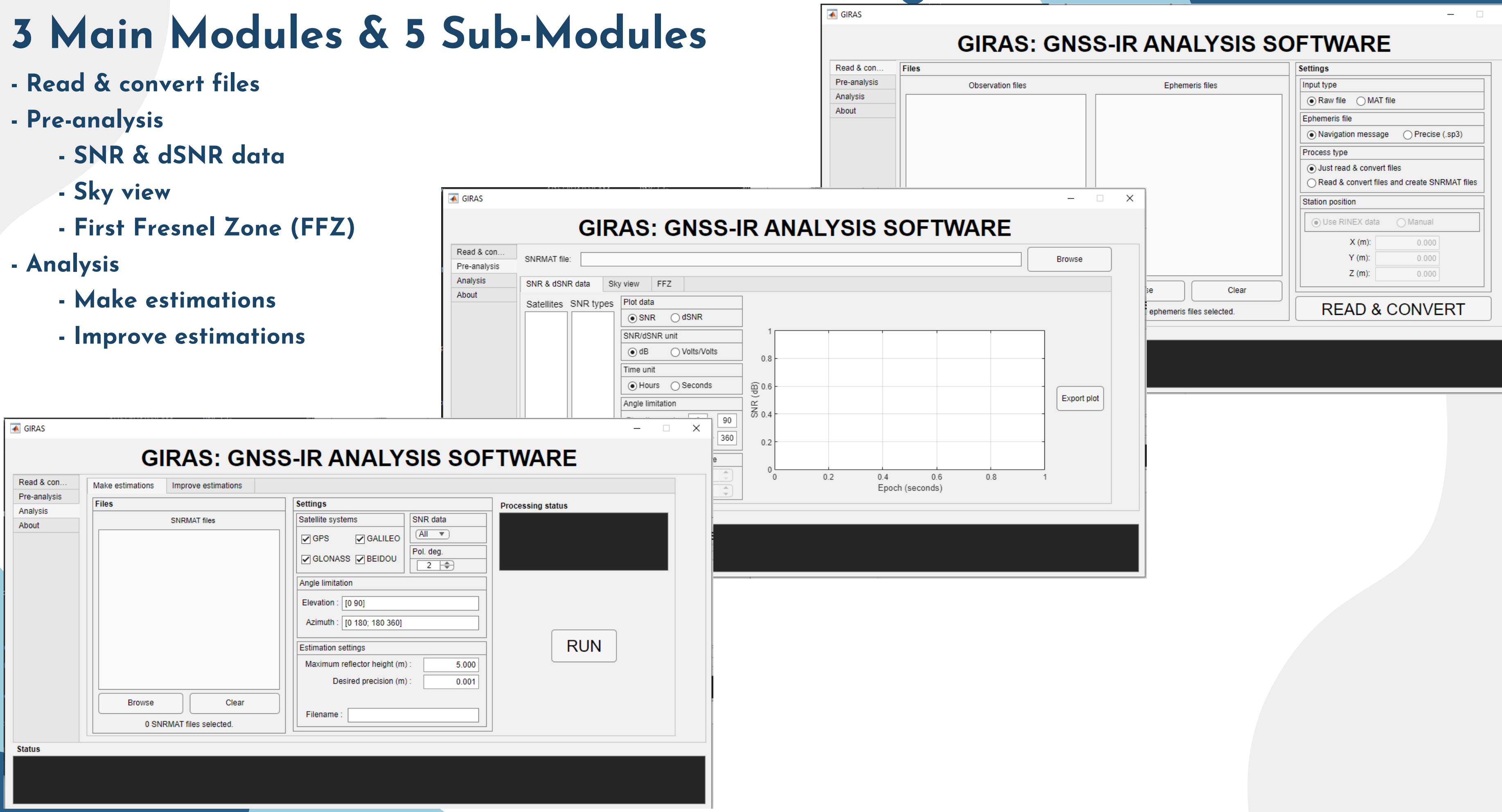
- is an open-source MATLAB-based software, with file reading, data analysis and data visualization tools.
- It consist of 3 main modules & 5 sub-modules.



https://geodesy.noaa.gov/gps-toolbox/GIRAS.shtml

3 Main Modules & 5 Sub-Modules

- Read & convert files
- Pre-analysis
  - SNR & dSNR data
  - Sky view
  - First Fresnel Zone (FFZ)
- Analysis
  - Make estimations
  - Improve estimations



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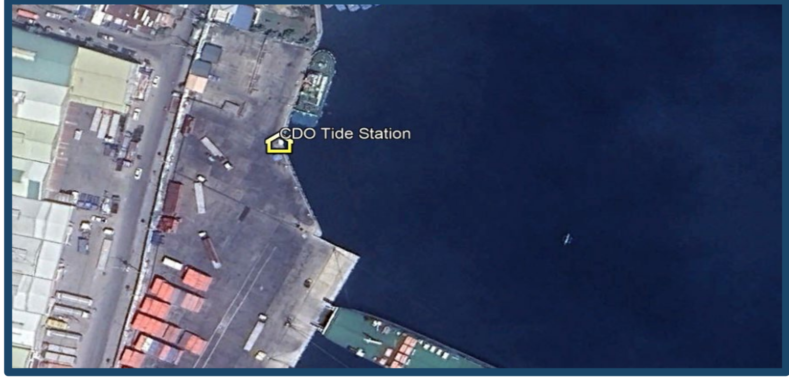
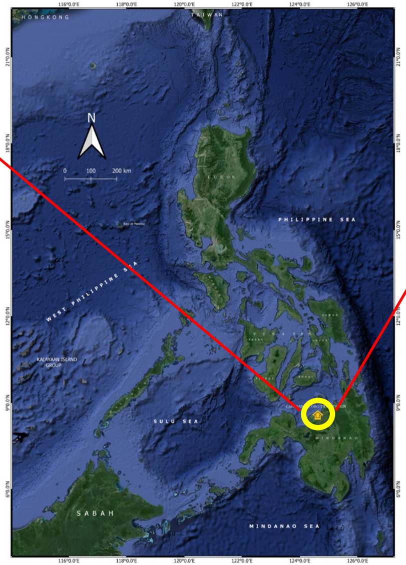
Location Map of CDO Tide Station

Cagayan De Oro Primary Tide Station - *is located in Macabalan Port Cagayan De Oro City established in 2007 and operating 24/7. The tide station is made of concrete structure with dimension 2.1x1.9x2.95 m situated at Northern part of Macabalan Port.*

OTT Tide Gauge and GNSS Receiver.





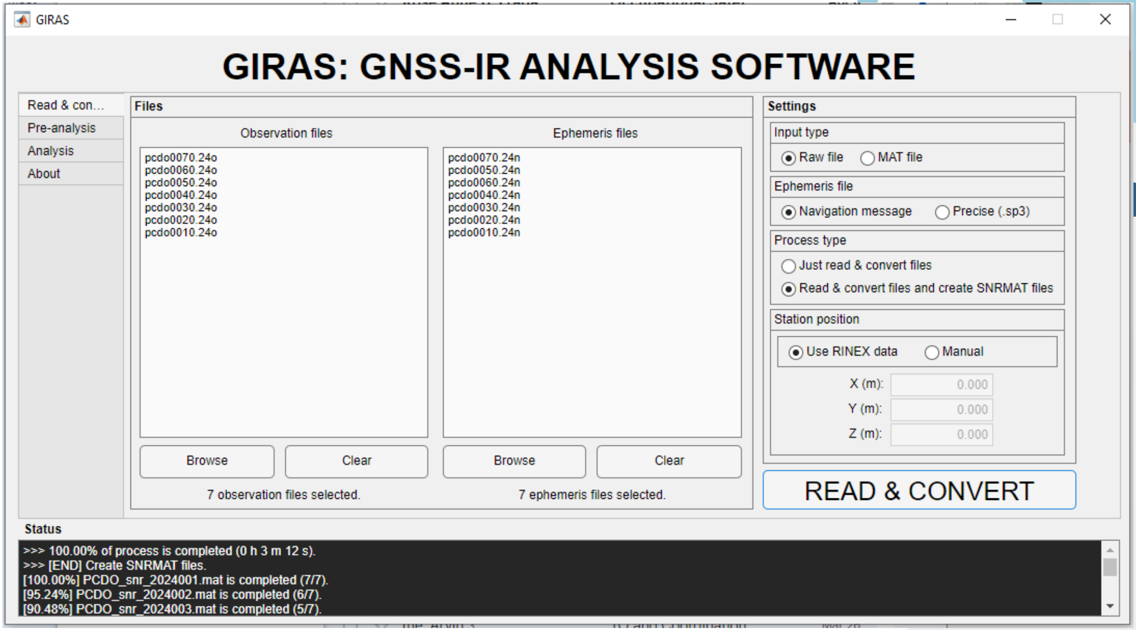
Main module 1: Read & convert files

INPUT

- *GNSS raw data converted into RINEX 2.11 or 3.04 versions are supported as observation file.*
- *Broadcast ephemeris (navigation file) or precise ephemeris (sp3) files can be read to obtain orbit information.*

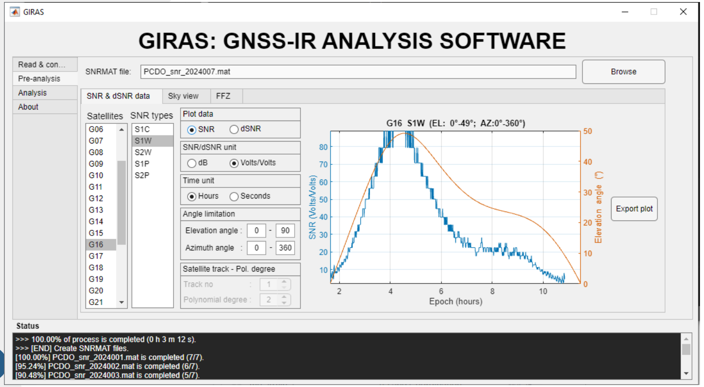
OUTPUT

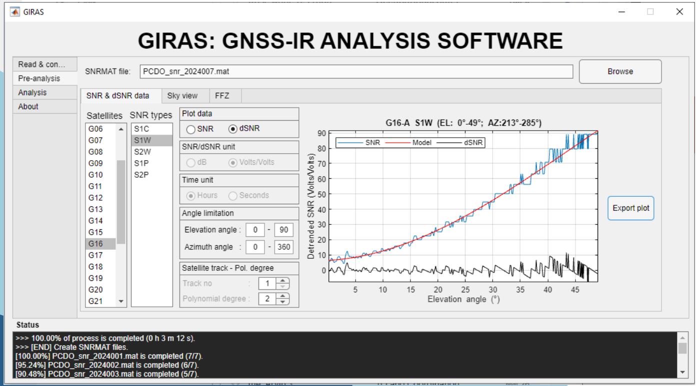
- *In the process type both options will generate Matlab files containing Signal-to-ratio (SNR) of each satellite.*

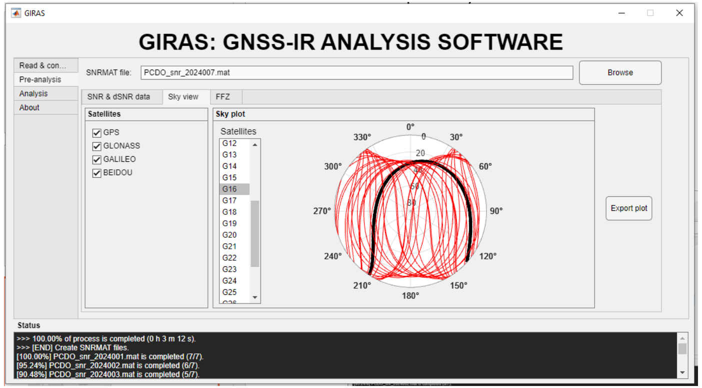


Main module 2: Pre-analysis

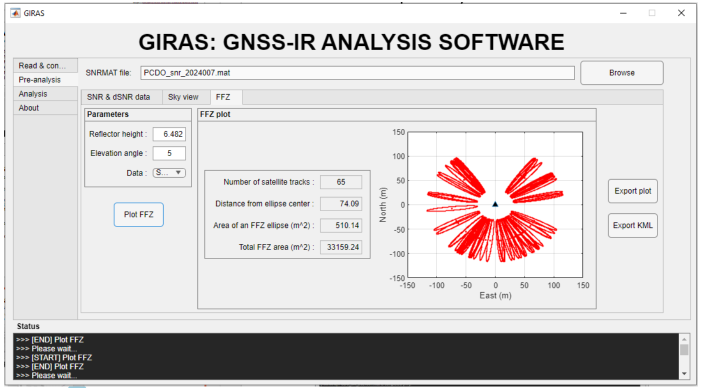
SNR & dSNR data *- visualizes and pre-analyzes the SNR data from each satellite in the SNRMAT file.*







- *Sky view*
- *prepares the sky plot for the satellites found in the SNRMAT file.*

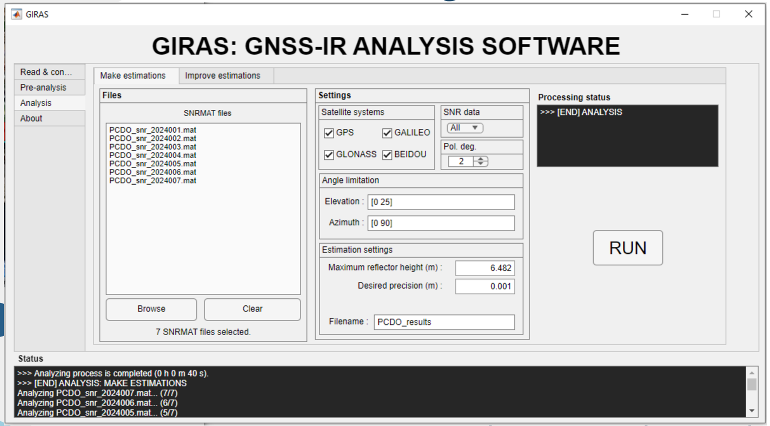


- *provides the First Fresnel Zone (FFZ) graphic & quantities for observed satellites in the SNRMAT file.*

Main module 3: Analysis

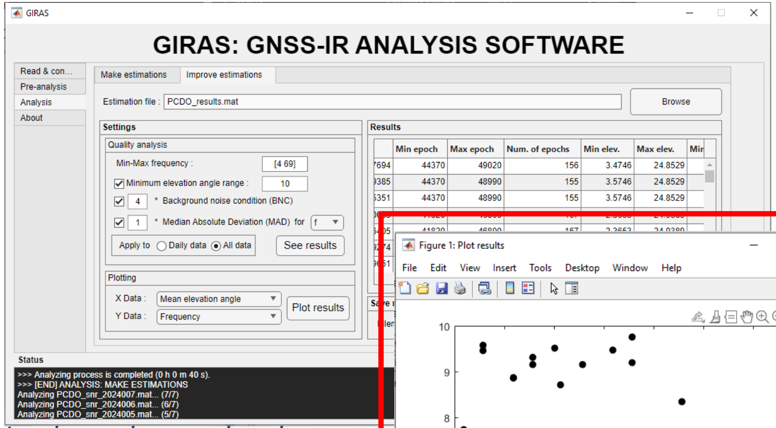
➤ *Make estimations*

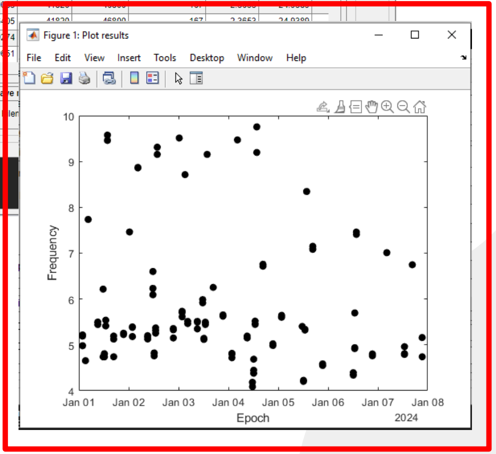
- *SNRMAT files are selected first, then input the desired angle limitation and estimation settings.*



➤ *Improve estimations*

- *The result file is used as input. Final settings will be input and display the plot result.*





The output do not show the desired result, maybe due to the following factors:

- ✓ *wrong configuration of GNSS receiver*
- ✓ *antenna location*
- ✓ *elevation mask*
- ✓ *multipath mitigation*
- ✓ *limited capability/specification of receiver*
- ✓ *First Fresnel Zone coverage.*

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- ✓ *Appropriate GNSS Receiver*
- ✓ *Set-up and configuration of GNSS Receiver*
- ✓ *Proper conversion of raw data to RINEX format*
- ✓ *Data processing techniques in particular multipath mitigation*
- ✓ *Lack of training, technology transfer needed*

Ways Forward

- ✓ *Continue research collaboration with the academe*
  - *Project proposal: Sea Level Monitoring using GNSS-IR*
- ✓ *Seek training on GNSS-IR data processing techniques*
  - *GIRAS, GNSS REFL Applications, etc.*
- ✓ *Procurement of new and upgraded multi-frequency GNSS Receivers*
- ✓ *Concept of GNSS Meteorology (?)*

Thank you!

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