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Realizing a Single Vertical Reference System in Archipelago Country

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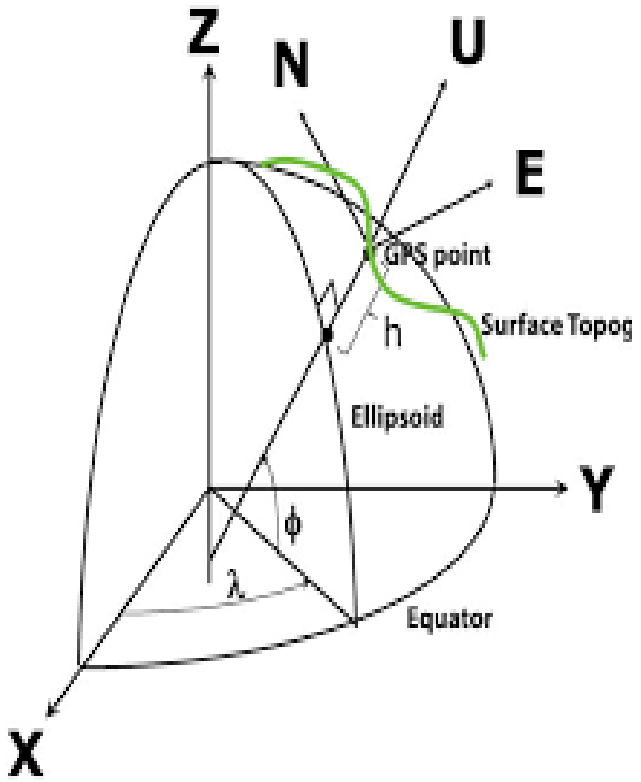
1. Background

Background

- Archipelago as a group of islands, interconnecting waters, and other natural features that are closely interrelated and form an intrinsic geographical, economic, and political entity[2].
- Coastal are become centre of existing, extension and further development, where 60% of the population lives (Case of Indonesia)
- The coast area has highly complex spatial conditions, especially now due to climate change, which accelerates and intensifies hydro-meteorological disasters and environmental damage, such as land subsidence, high waves, extreme weather, and more.
- Valid, seamless geospatial data/information are very crucial as basis of sustainable development over the coastal areas

Background



- Rapid development of geospatial technology has enable 3D positioning and mapping with high speed and accuracy.
- However, only horizontal positioning has been fully fulfilled, while vertical positioning still faces challenges due to the complexity of Earth's physic and concept.
- The vertical datum is defined as a reference plane used to determine the elevation of an object (Yazid et al., 2021). The elevation of an object is the vertical distance of the object on Earth's surface relative to a specific reference plane (Featherstone & Kuhn, 2006).

- Vertical reference are currently use: the ellipsoid, geoid, mean sea level (MSL), and local ground surface height (Hofmann-Wellenhof & Moritz, 2005).

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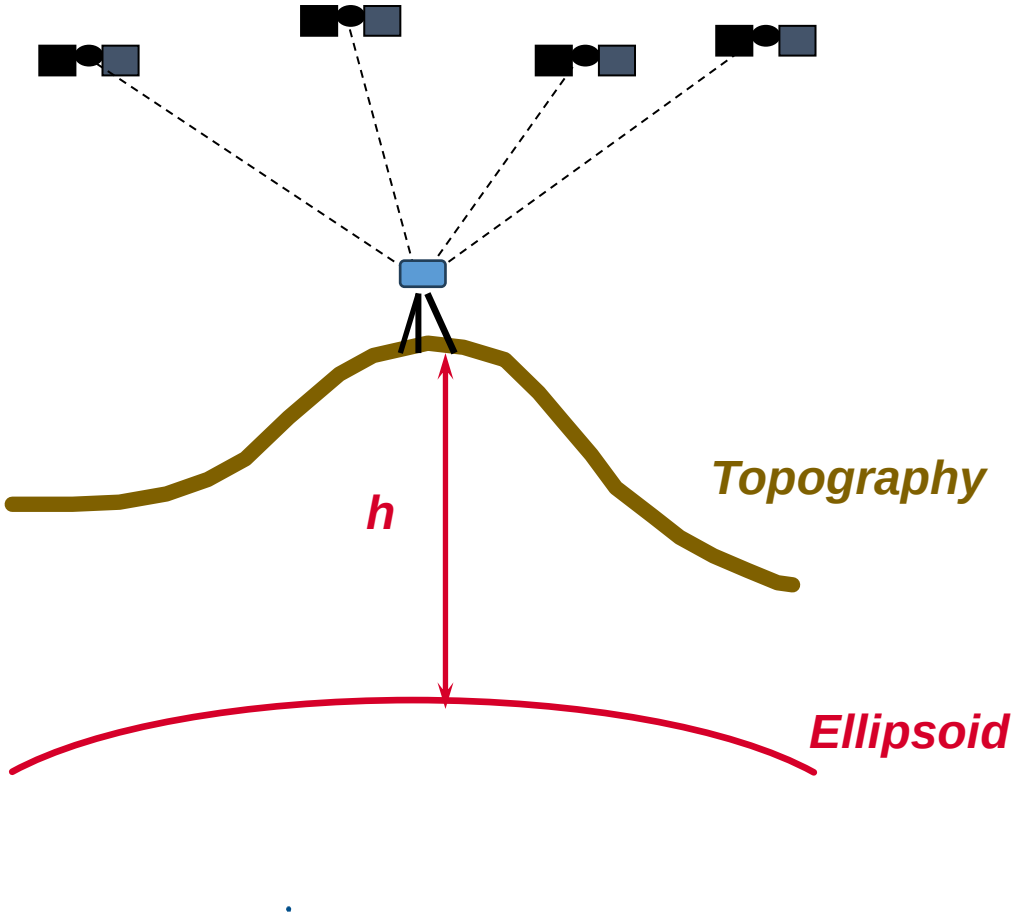
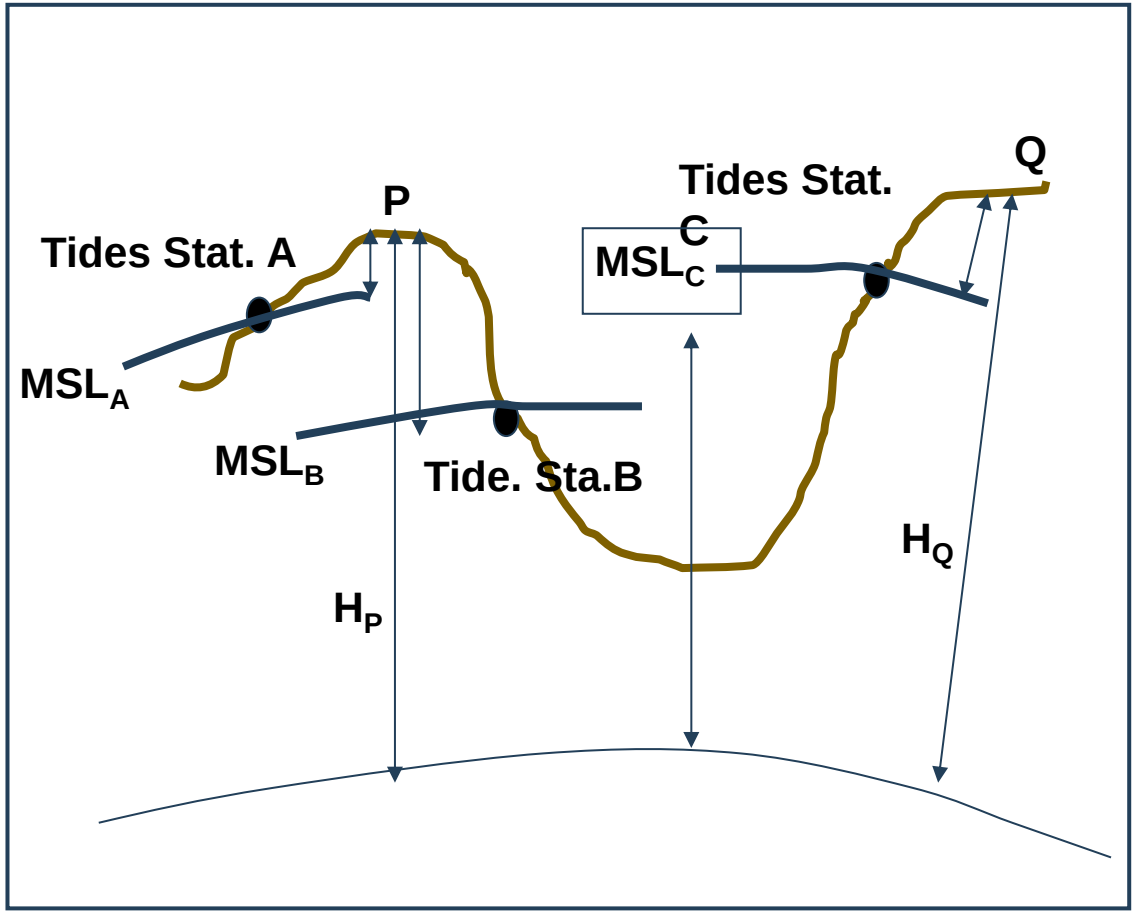
2. Vertical Reference System

1. Ellipsoid Vertical Reference

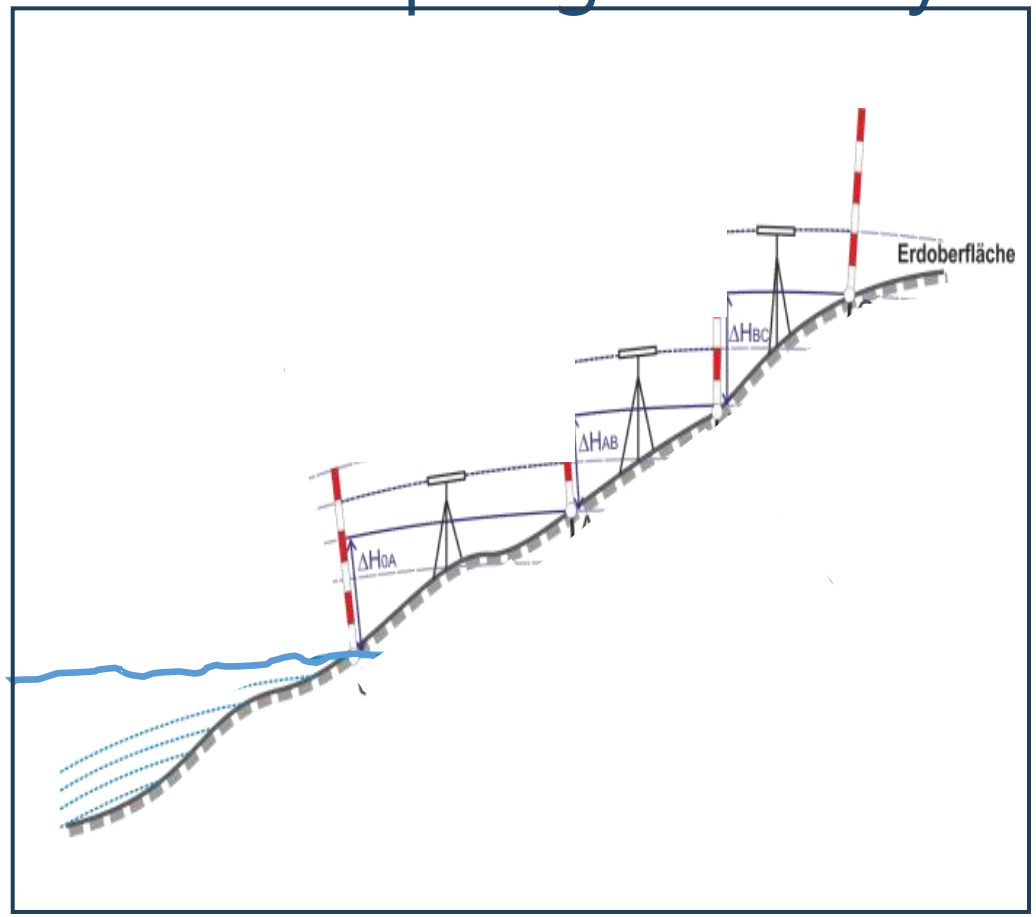


- There are no issues with consistency and unification in the use of the ellipsoid reference in archipelagic countries, as the ellipsoid reference surface consistently encompasses the entire territory of the archipelago.
- The ellipsoid height, only for conceptual and relative application, due to no physical realization on Earth's surface

2. Mean Sea Level Vertical Reference & Archipelago country

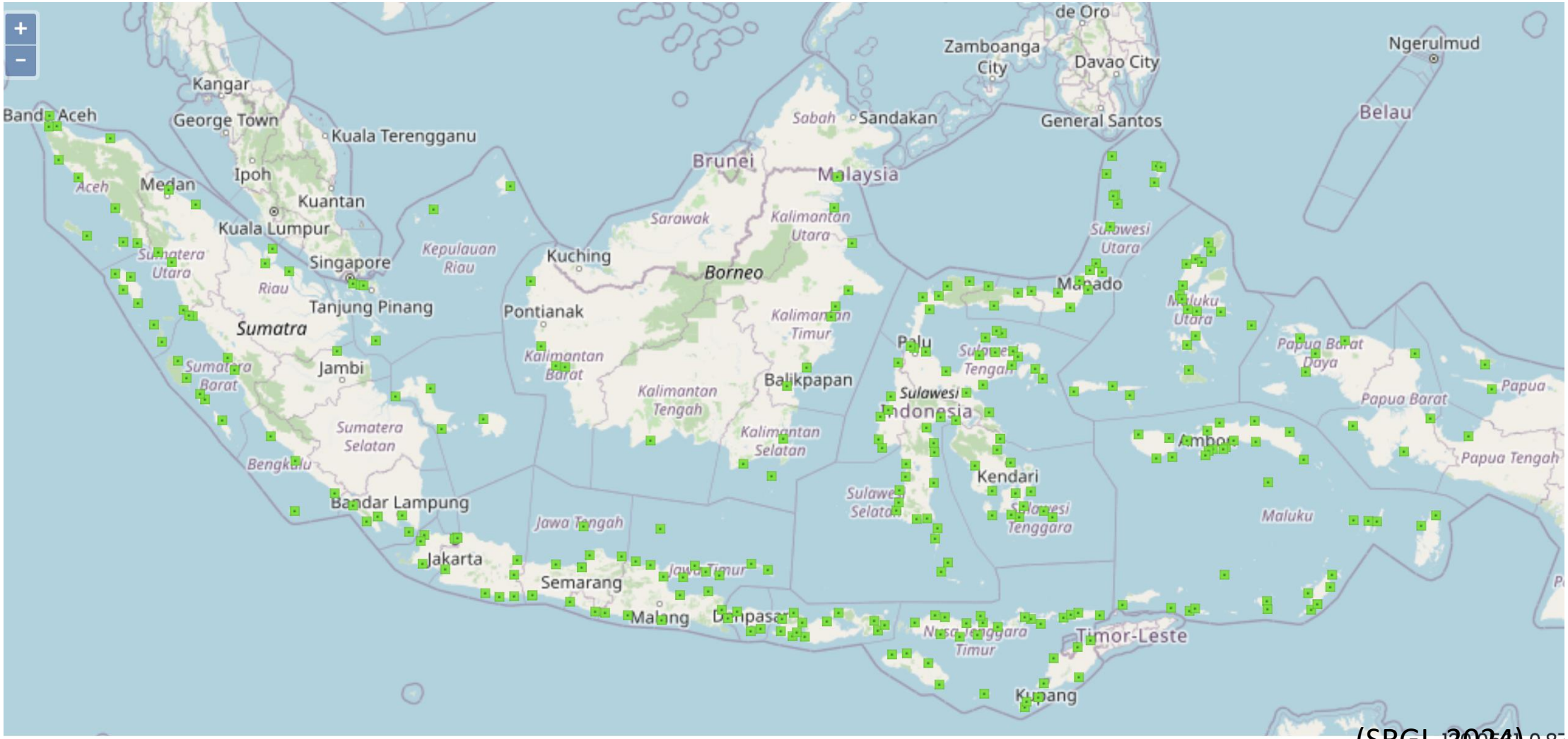


Due to SST, each tide gauge station defines an MSL that does not lie on the same equipotential surface, resulting a local height system. In the archipelago country, it cannot be connected, caused separated by the ocean



Un-convenient, as it has to bring the MSL/tidal benchmark (BM) height through levelling networks as the control points of vertical measurement.

Indonesian Tide gauge stations (256 station)



(SRGI, 2024)

3. Geoid Vertical Reference

Concept of Physical Height

Physical height realization: water flows.

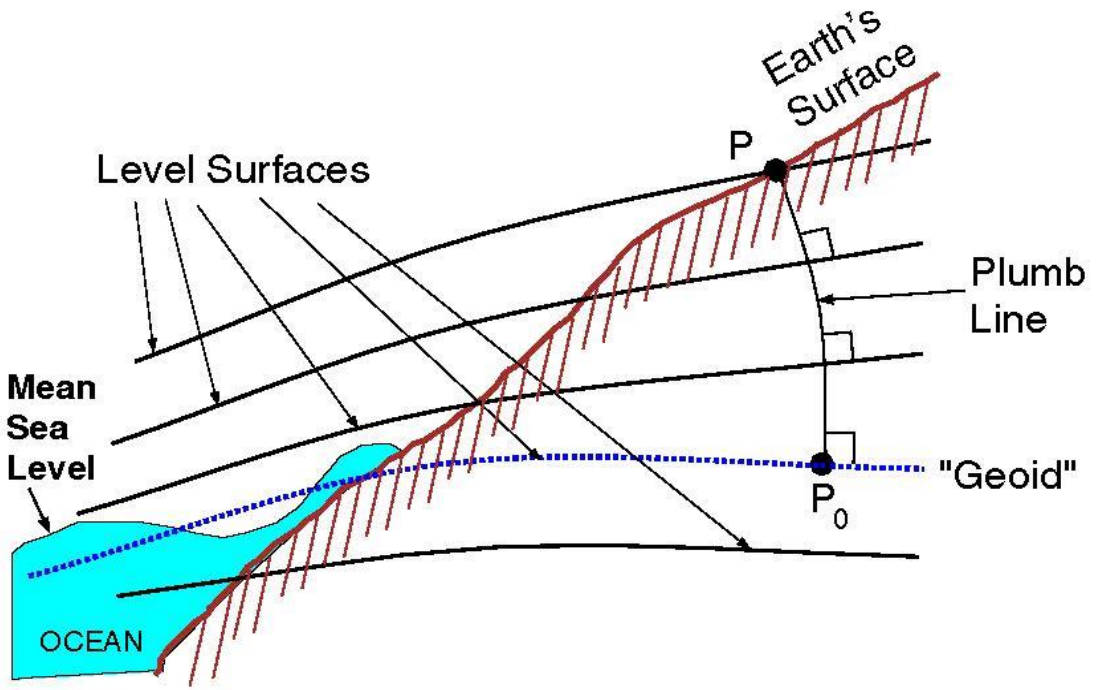
Water flows from low gravitational potential to high gravitational potential.

The height difference is not just the vertical distance, but the difference in gravitational potential

Geoid as ideal vertical Referensi

The Gravity equipotential surface which assumed to be coincide with the global mean sea level.

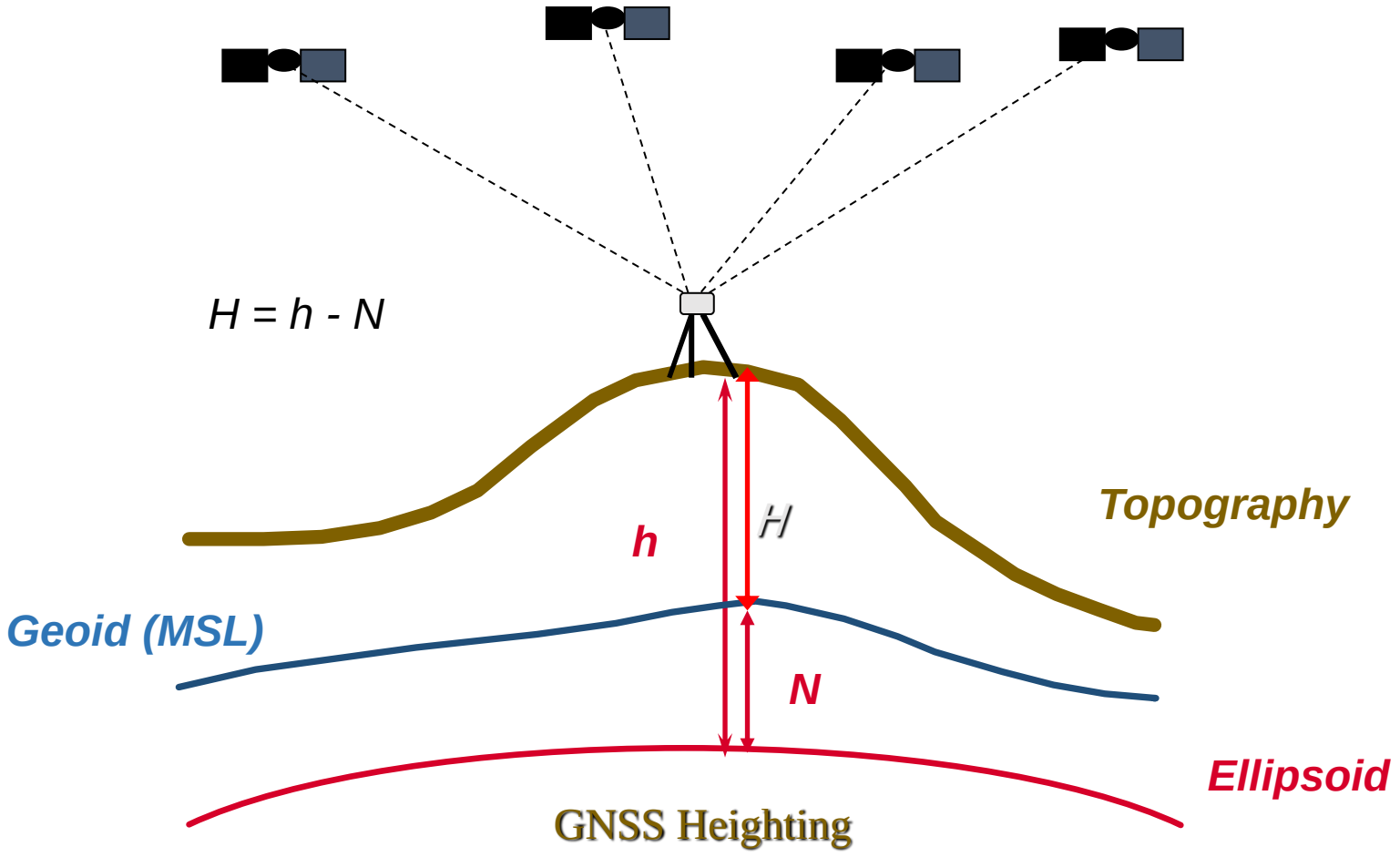
The geoid is to define a physically meaningful equipotential surface that can be used as a vertical datum to ensure the continuity of heights across borders, coastline areas, and the Globe (Vaníček, 1994; Jekeli, 2000)



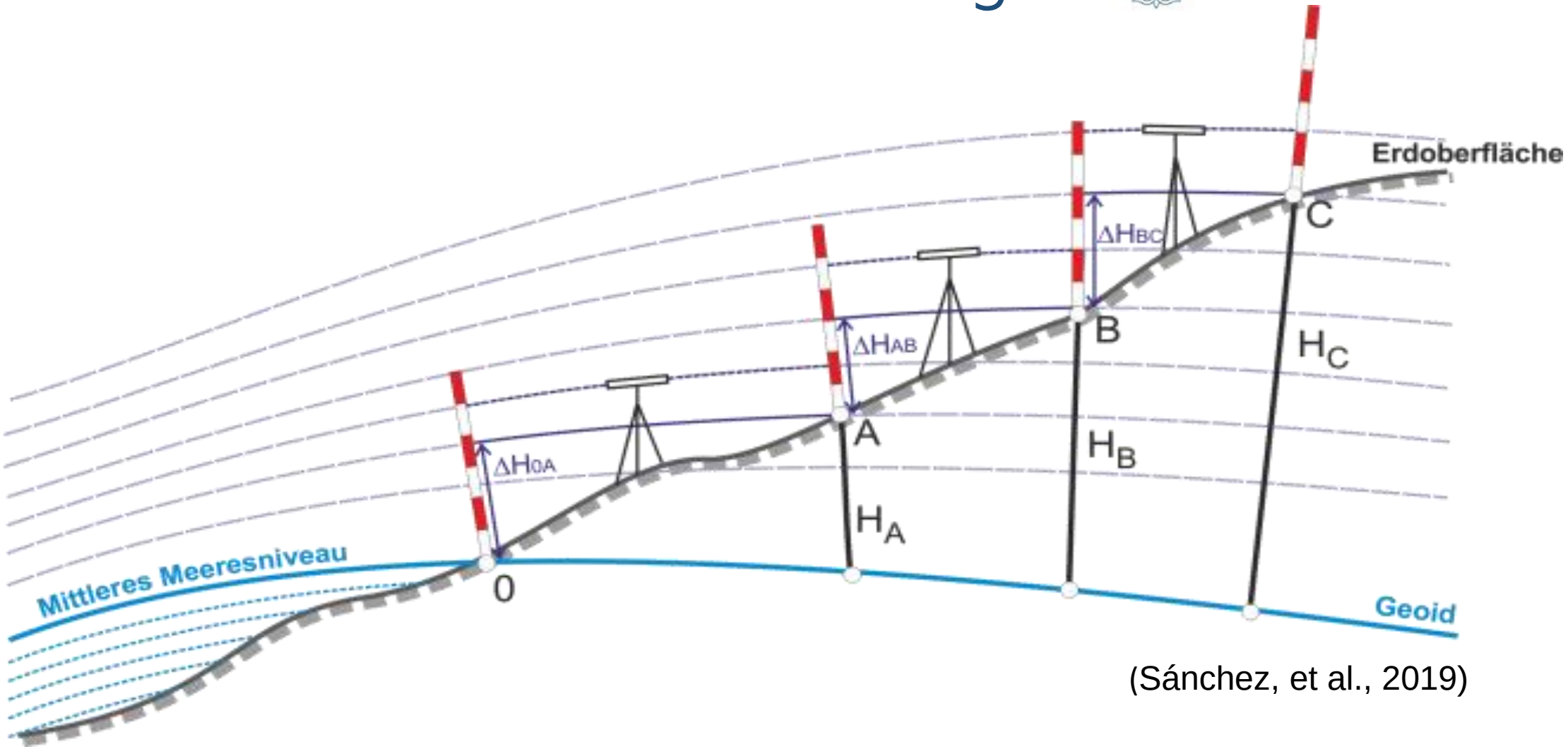
Level Surface = Equipotential Surface

H (Orthometric Height) = Distance along Plumb line (P_0 to P)

Geoid: transform the ellipsoid to orthometric Height

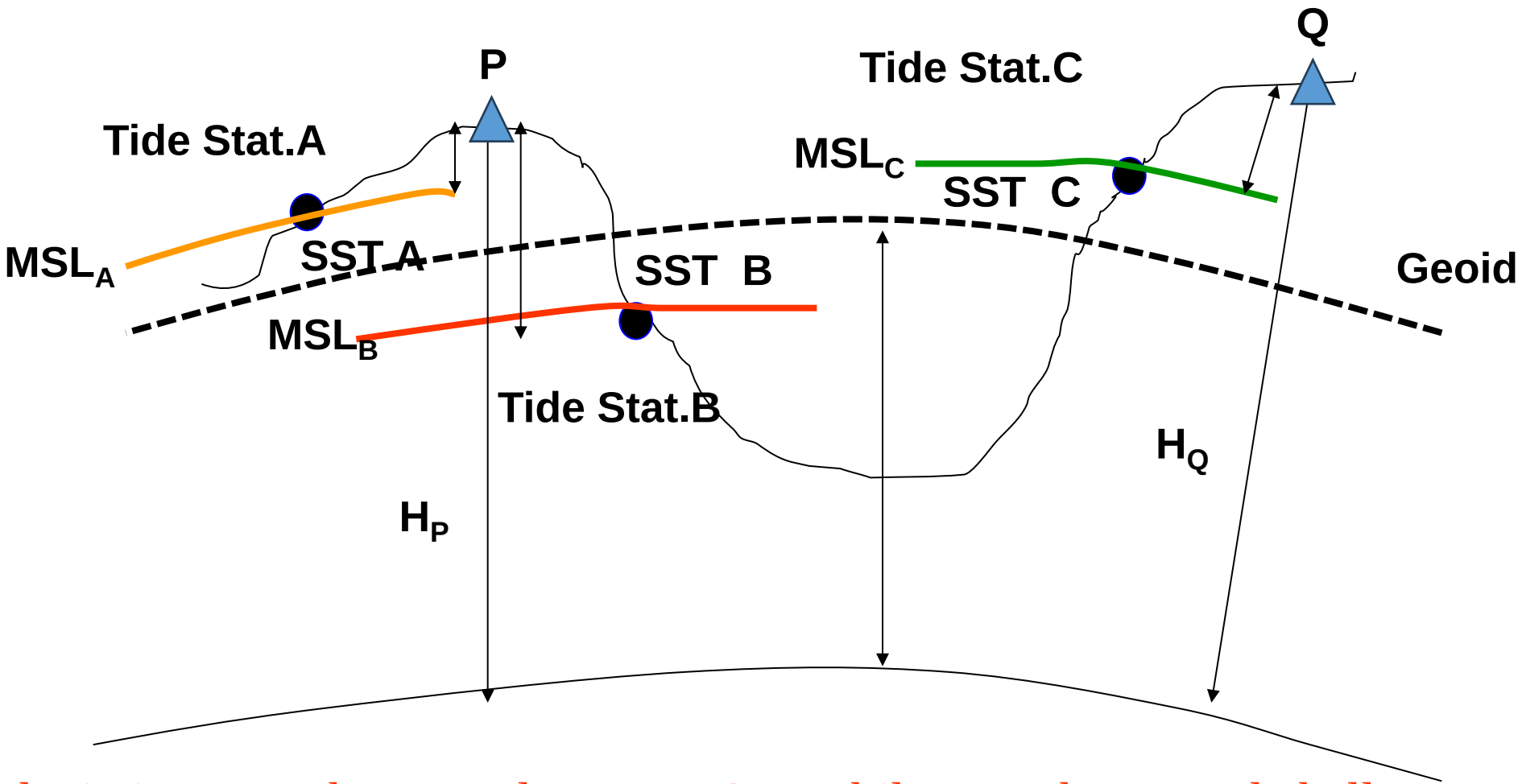


Geoid: Consistent orthometric height



(Sánchez, et al., 2019)

Geoid: Unification vertical reference system of Archipelago Country



SST : the deviation over the open/deep sea <2m, while over the coastal/shallow sea > 2 meter

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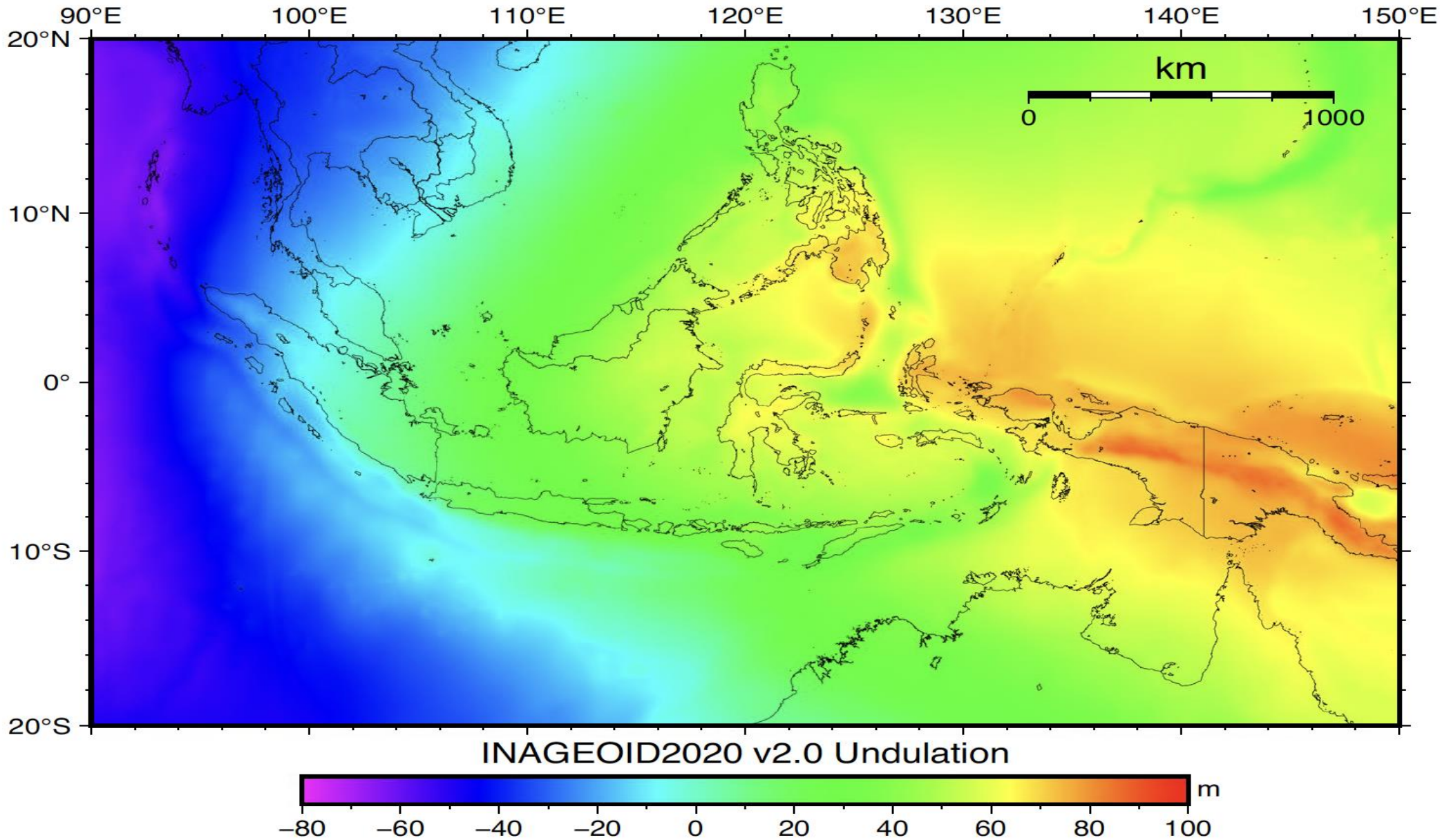
3. Vertical Reference: National Geoid of Indonesia

Indonesian Geoid: InaGeoidV2.0

- Regulation of BIG No. 15/2013, Article 10, states that the national vertical geospatial reference system, which is the geoid, is determined based on gravity surveys tied to Geodetic control network
- InaGeoidV2.0 created based on terrestrial gravity data measured from 2018-2023 (5 km spacing)l. Airborne gravity data covers Islands of Java, Sumatra, Kalimantan, Sulawesi, Bali, Maluku, and parts of Nusa Tenggara (spacing track ~15 km) with an FAA RMS of 1.5 to 4.65 mGal.
- The ocean region uses DTU17, SRTM15, and EGM2008 at 360-degree resolution.
- Using the Stoke's method, the Remove-Compute-Restore (RCR) - FFT solution, obtained geoid with a spatial resolution of 0.01 x 0.01 degrees (+/- 1.11 km).


90°E
100°E
110°E
120°E
130°E
140°E
150°E
20°N
10°N
0°
10°S
20°S
km
0
1000
INAGEOID2020 v2.0 Undulation
m
−80
−60
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0
20
40
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80
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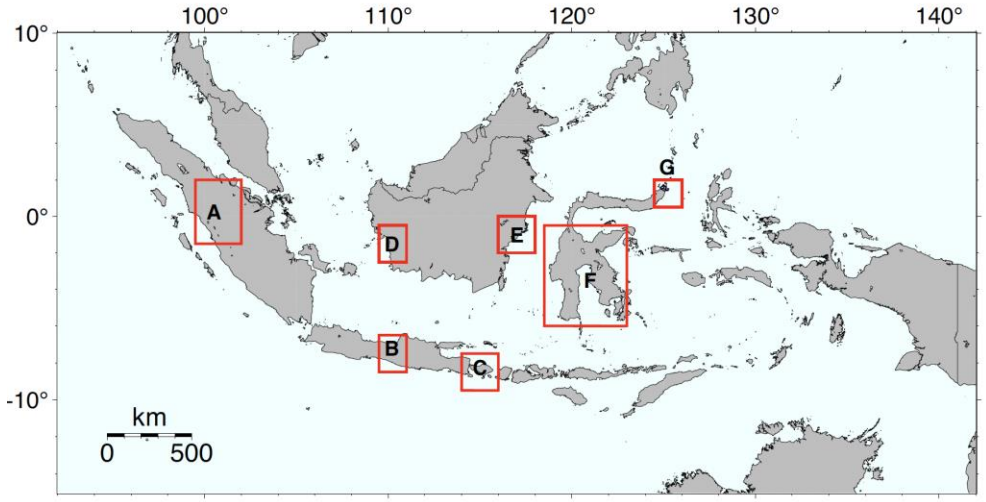

Validation: Co-site GNSS-levelling

Areas	Number of data	Before Fitting (m)				After Fitting (m)			
		ΔN_{min}	ΔN_{max}	ΔN_{mean}	ΔN_{stdev}	ΔN_{min}	ΔN_{max}	ΔN_{mean}	ΔN_{stdev}
Java	186	1.769	2.321	2.053	0.122	−0.243	0.301	0.008	0.118
Bali	178	1.768	2.798	2.316	0.200	−0.560	0.367	−0.106	0.167
West Kalimantan	284	1.489	1.958	1.766	0.070	−0.538	−0.001	−0.269	0.064
East Kalimantan	264	1.640	2.160	1.944	0.073	−0.196	0.206	0.020	0.059
South part of Sulawesi	53	1.380	2.655	2.015	0.272	−0.005	0.753	−0.040	0.251
North part of Sulawesi	220	1.673	2.281	1.994	0.116	−0.355	0.270	−0.034	0.121
Sumatra	21	0.881	2.222	1.610	0.293	−0.934	0.372	−0.219	0.286

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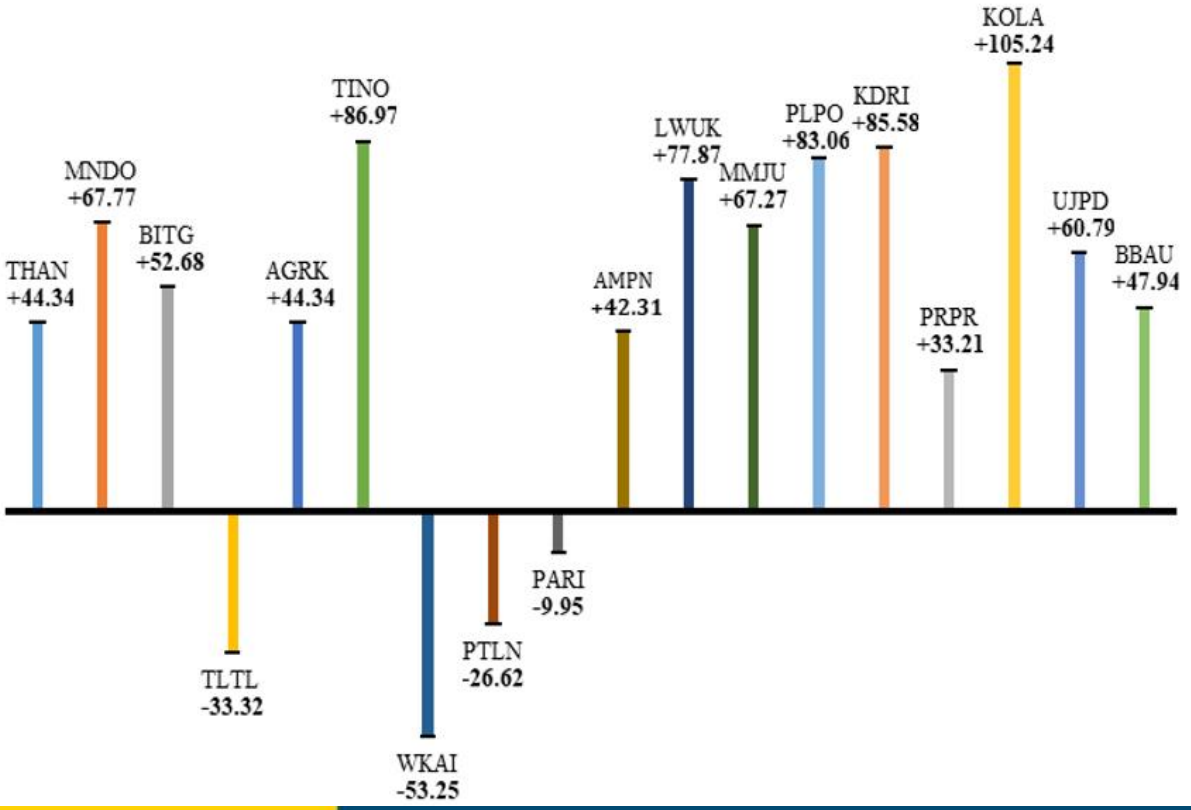
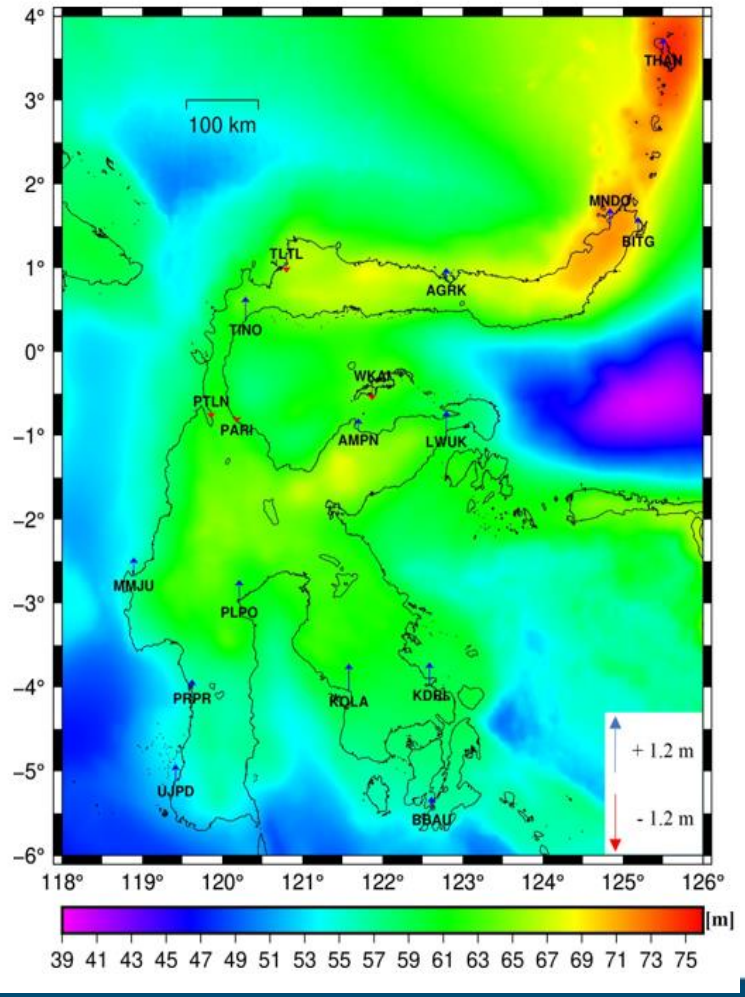
4. Application : Geoid as Vertical Reference System

Geoid: Unification of Vertical Reference system

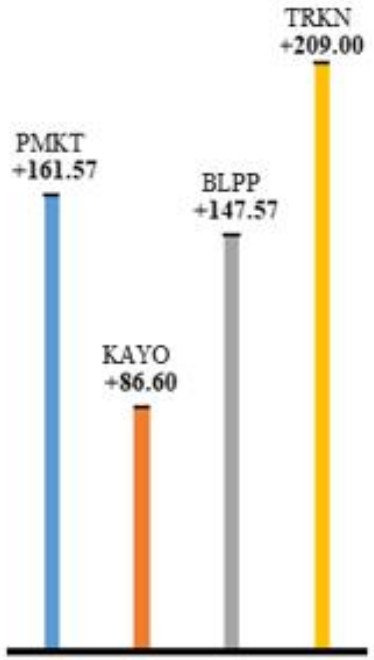
- Sulawesi Vertical Reference system

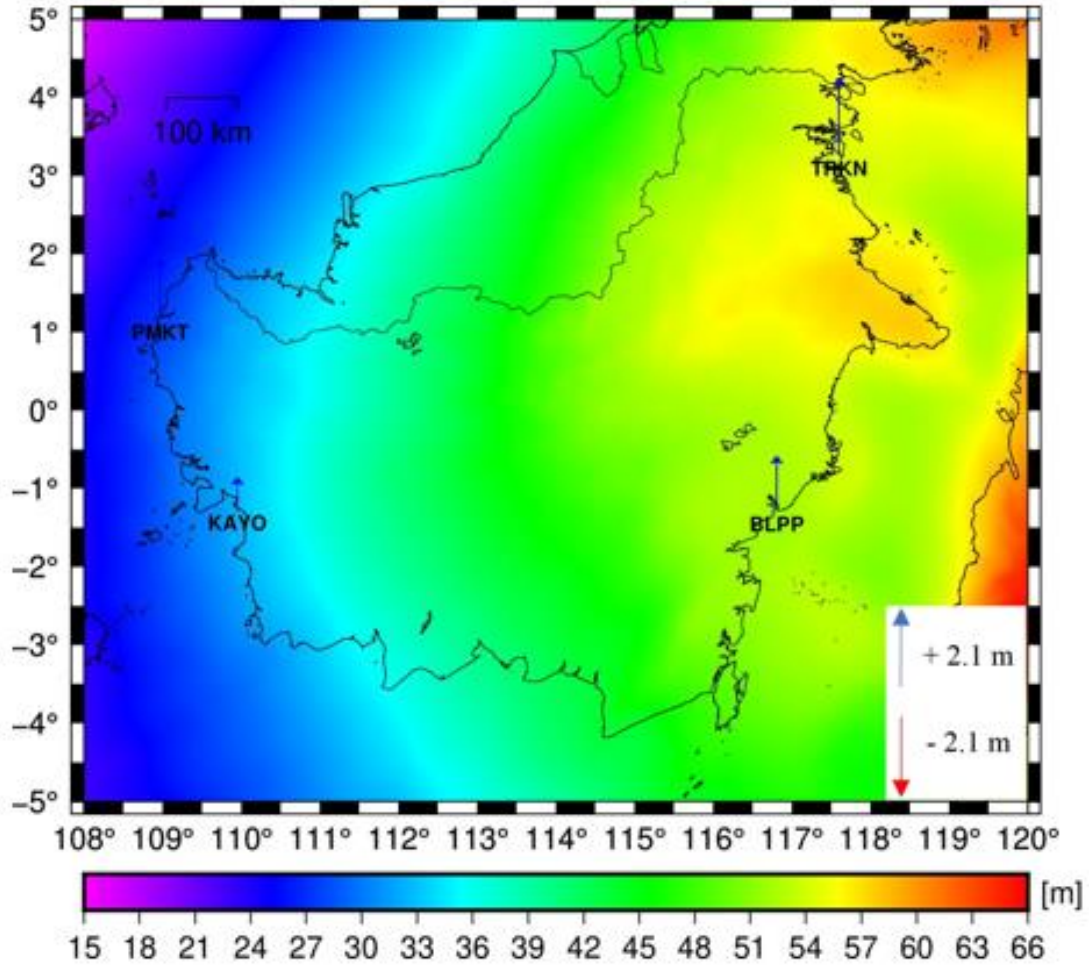




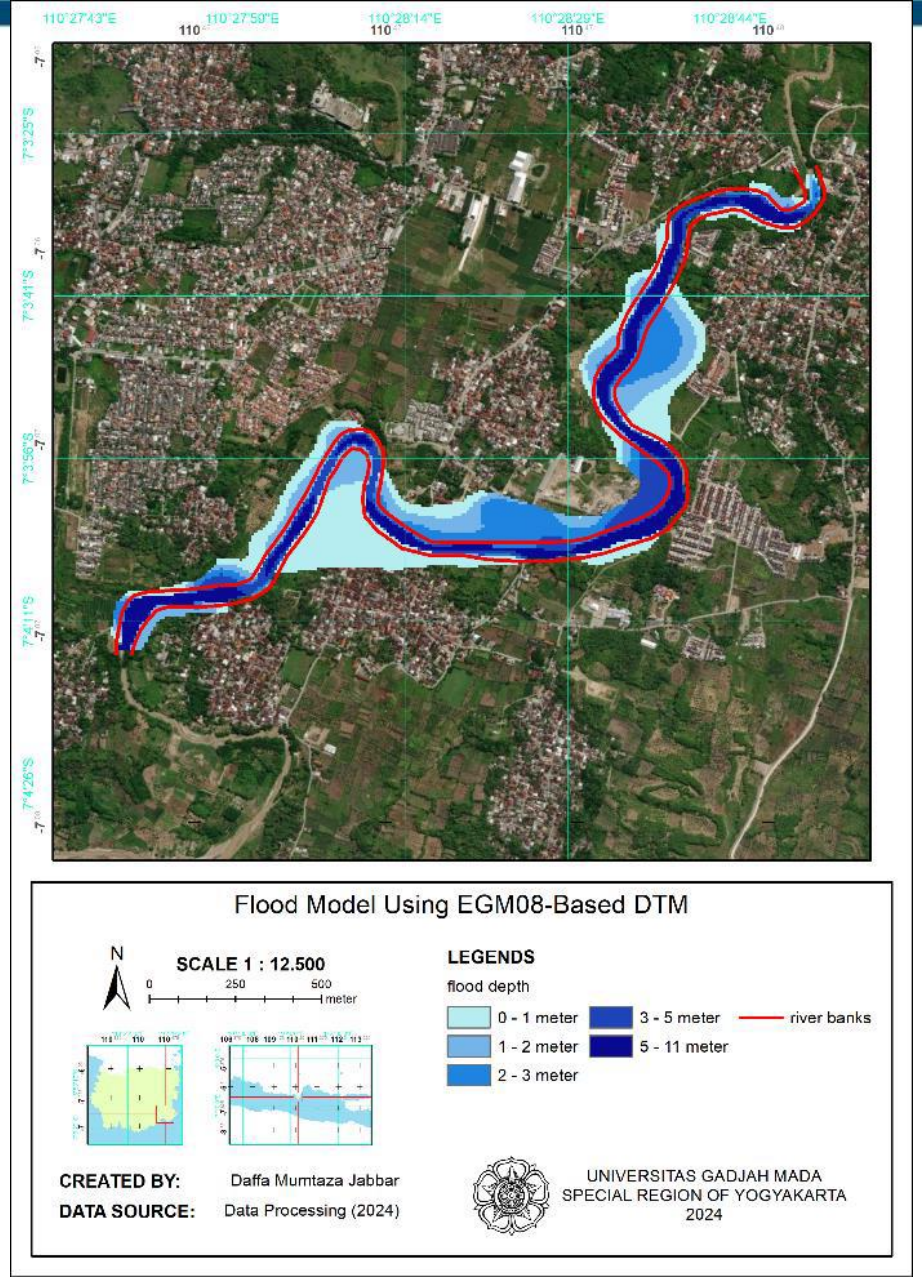
Geoid: Unification of Vertical Reference system

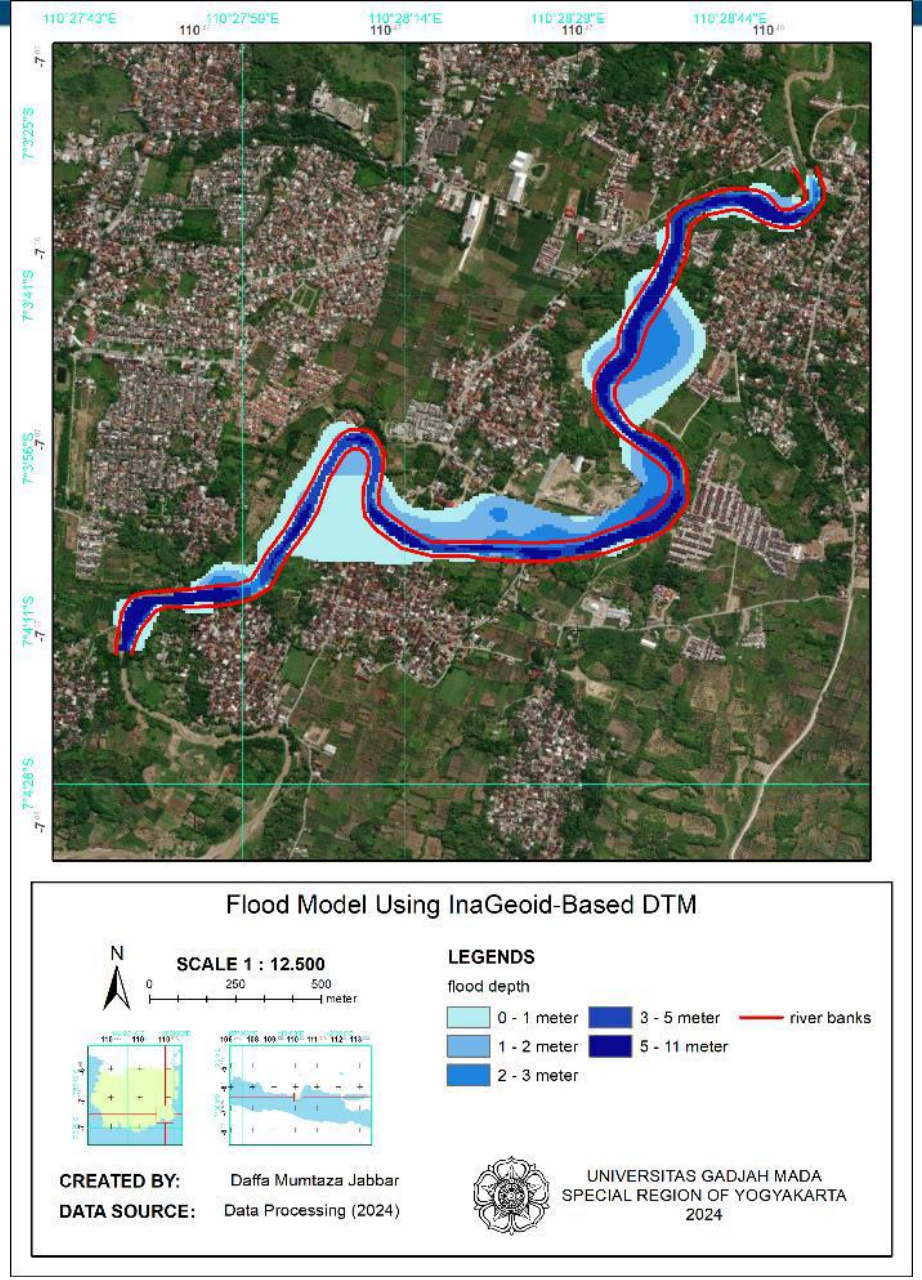
- Kalimantan Vertical Reference system





Flood modeling





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5. Seamless Geoid Model Land and Sea

5. Improvement of geoid model

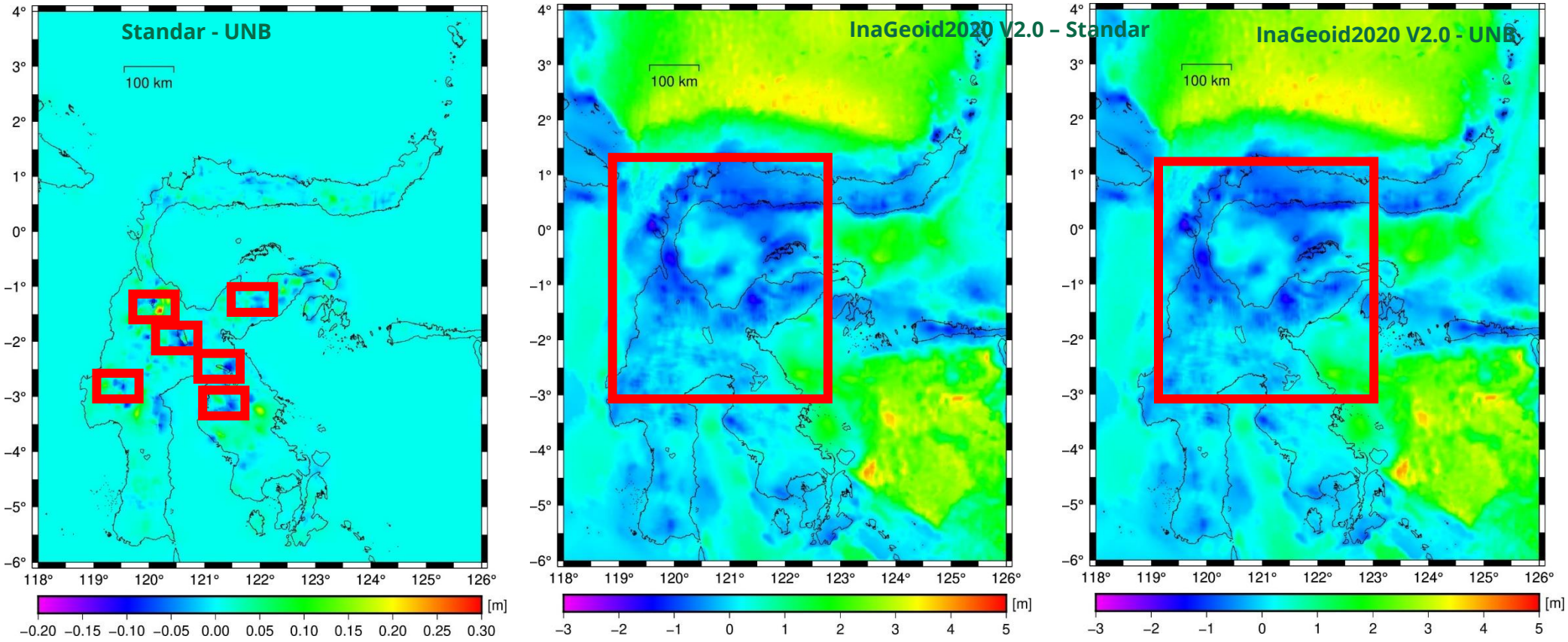
Realization of vertical reference for archipelago country based on geoid:

➔Accurate and Seamless geoid model over land – sea area.

➔The seamless geoid is consistent between land and sea, so it can be used as a height reference for surveys or mapping on land and a depth reference for surveys or mapping at sea.

➔Accuracy of geoid affected by: accuracy of gravity data, gravity densitas data, *Digital Terrain Model(DTM)*, accuracy of GNSS/leveling dan topographic variation

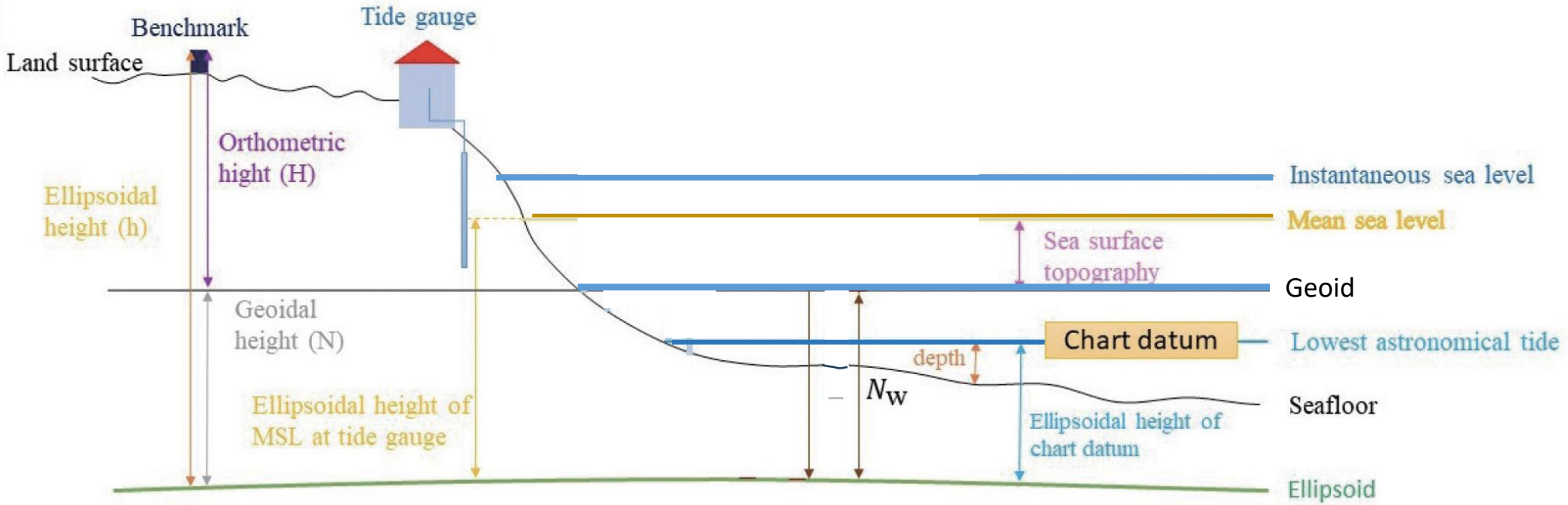
Geoid with density variation



1. **The difference in geoid values, especially in mountainous areas, with value differences ranging from -20 to 30 cm (Standard – UNB).**
2. **The difference in geoid values between InaGeoid2020 V2.0 and the Standard/UNB model ranges around ±1 m.**

Seamless vertical datum: Land and Sea

➔ Clear connection among reference system used on land and sea positioning and mapping



(Modification Huang et al., 2021)

Conclusions

- Vertical reference systems are essential for defining elevations and depths in geospatial applications. Archipelagic nations face unique challenges due to the scattered nature of islands, variations in tidal regimes, and tectonic activities. Traditional approaches relying on local mean sea level as a vertical datum often lead to inconsistencies. the establishment of a unified vertical reference system is critical for achieving geospatial consistency across disparate islands.
- The geoid is to define a physically meaningful equipotential surface that can be used as a vertical datum to ensure the continuity of heights across borders, coastline areas, and the Globe
- The seamless and accurate geoid is needed so it can be used as a height reference for surveys or mapping on land and a depth reference for surveys or mapping at sea.

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LOCALLY ROOTED, GLOBALLY RESPECTED