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Development of Indonesian Tide Model

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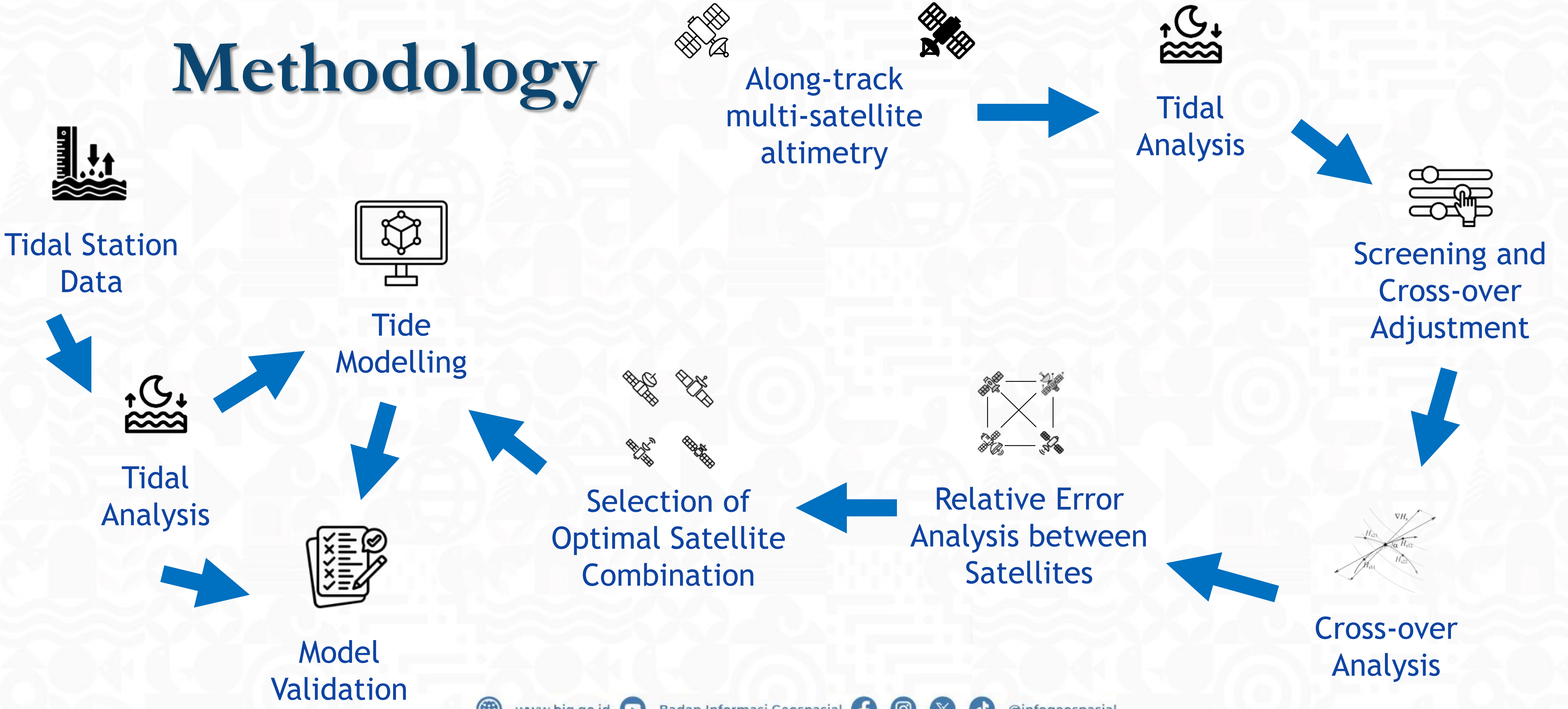
Motivation

- Development of the Indonesian Geoid Model
  - Existing global tide models have an accuracy of >15 cm in shallow water and coastal area
  - Accuracy range of recording of altimetry satellite 2.5 – 7.9 cm
- Development of the Indonesian Tidal Datum Model
  - Determination of Coastline along Indonesian Islands
  - Development of the Indonesian Hydrographic Separation Model

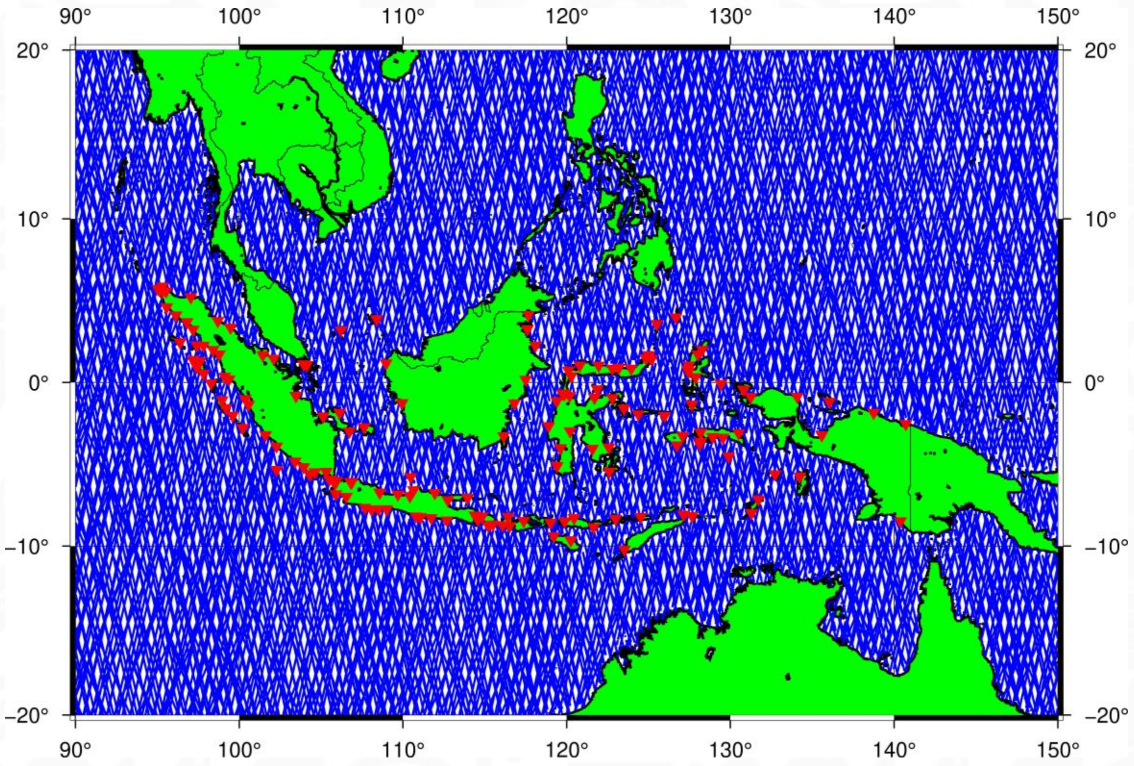
Improvement Strategy

- Selection of optimum satellite combinations
  - Minimize relative error between satellites
- Utilization of along-track altimetry multi-satellite data
  - To improve the resolution

Methodology



Data



Exact Repeat Mission (ERM) Altimetry Satellites

TOPEX/Jason series (TOPEX, Jason-1, Jason-2, Jason-3, SENTINEL-6A), GFO, ENVISAT, ERS2, Sentinel-3A, dan SENTINEL-3B

Tidal Stations

- 160 BIG Permanent Tidal Station Data
- Average Observation Period of 5 years with 1 hour interval

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Tidal Analysis

Response Method (Munk dan Cartwright, 1966; Groves dan Reynolds, 1975)

$$\zeta(\lambda,\phi,t) = \sum_{m=0}^{2}\sum_{s=-S}^{S}[\boldsymbol{P}_{\boldsymbol{2ms}}(\lambda,\phi)a_{2m}(t-s\Delta T)+\boldsymbol{Q}_{\boldsymbol{2ms}}(\lambda,\phi)b_{2m}(t-s\Delta T)]$$

12 *Orthotide components* (Diurnal & Semi-diurnal)
(Cartwright dan Ray, 1990; Groves dan Reynolds,1975)

10 *Orthotide components* (Long Periods)
(Matsumoto dkk., 2000; Desai dan Wahr, 1995)

Equilibrium tide [a,b] (Cartwright dan Ray, 1990) → response weight/orthotide component [P,Q]

Input (equilibrium tide and orthotide component) output (observed tide) ratio → admittance

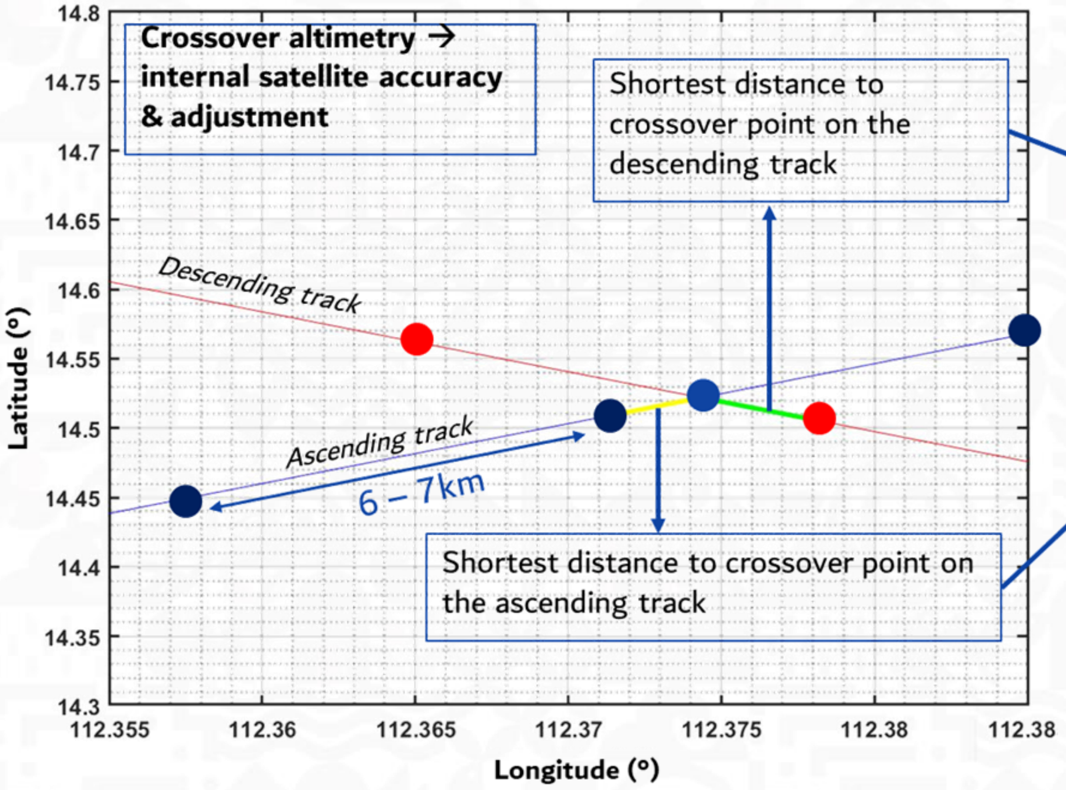
Independent to aliasing frequency

Altimetry Crossover Analysis

→ *Footprint - ascending*

→ *Footprint - descending*

→ *Crossover point*



Shortest distance to *crossover point* → **≤ 5 km** → Empirical results from all satellites

Auto-crossover adjustment → lowest orbit bias (asc or dsc)
Dual-crossover adjustment → Satellite with the best internal accuracy

Relative Error between Satellites

Satellite with the best accuracy

$$RSSIQ = \sqrt{\frac{1}{2N}\sum_{j=1}^{M}\sum_{i=1}^{N}\left[C_k^{ref}(i)\right]^2 + \left[S_k^{ref}(i)\right]^2}$$

The other satellite

$$RSS = \sqrt{\sum_{k=1}^{M} RMS_k^2}$$

Discrepancy (D)

$$D = \frac{RSS}{RSSIQ} \times 100\%$$

Classification and selection of satellite combinations

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Single-Satellite Cross-over Adjustment

Altimetry Satellite	Internal Precision (cm)
SENTINEL-3A	30,19
SENTINEL-3B	109,40
ERS-2	64,50
GFO	33,75
ENVISAT	13,68
TOPEX/Jason series	2,72

Reference Satellite

Determining Multi-satellite Combinations

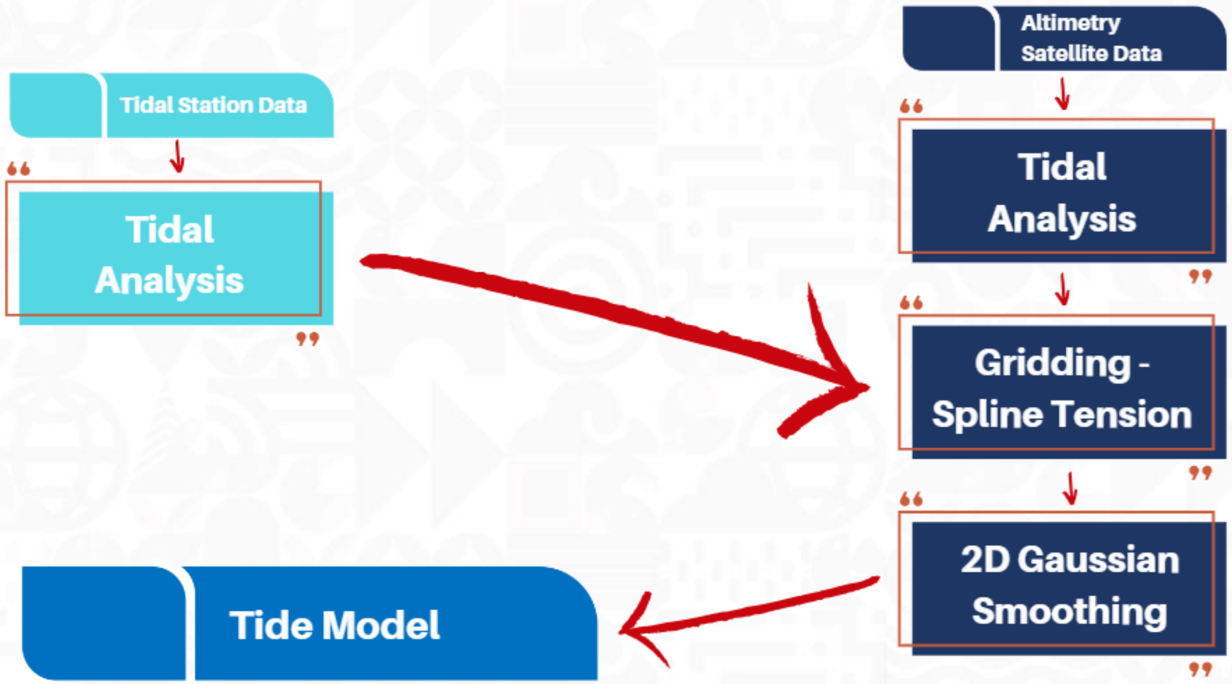
Altimetry data	RSS2 (cm)	D (%)	Satellite Group		
			D < 100%	D < 25%	D < 1%
SENTINEL-3A	0.70	1.73	✓	✓	×
SENTINEL-3B	12.41	29.45	✓	×	×
ERS-2	21.20	53.15	✓	×	×
Geosat Follow-On (GFO)	0.06	0.16	✓	✓	✓
ENVISAT	0.34	0.85	✓	✓	✓

(1) Satellite Group-1/SG-1 with the discrepancy $D < 100\%$, including TOPEX/Jason series, ERS-2, ENVISAT, GFO, SENTINEL-3A, and SENTINEL-3B.

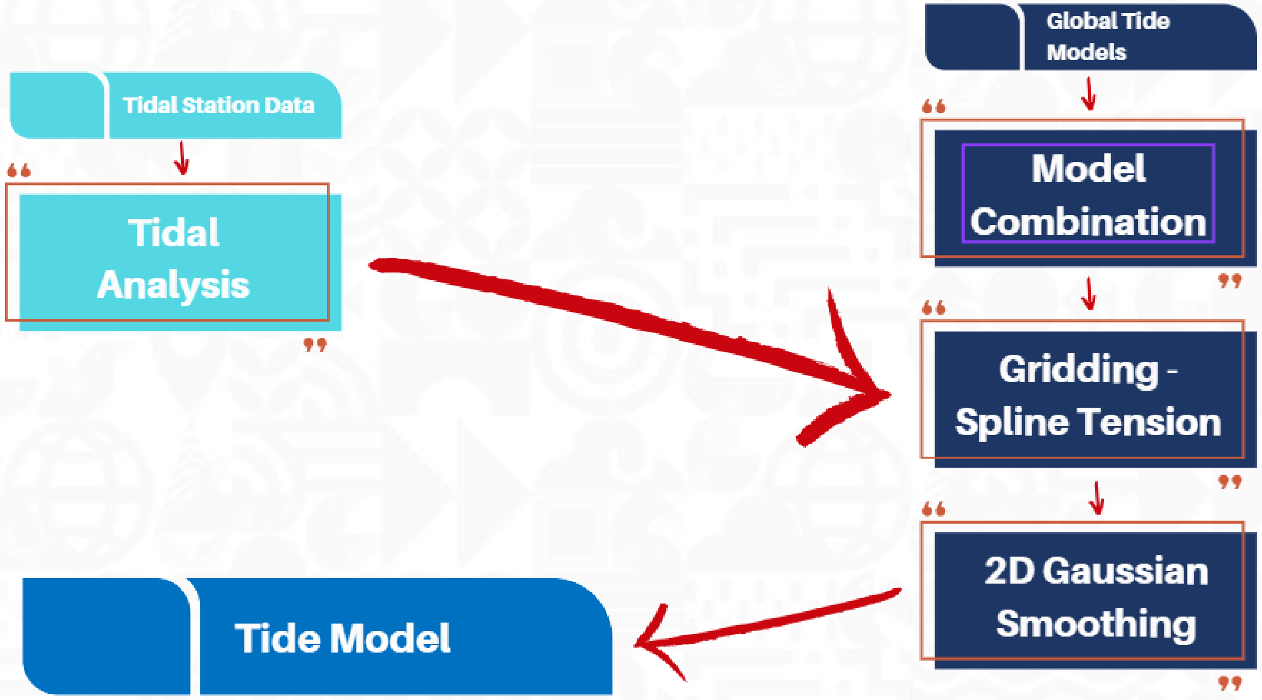
(2) Satellite Group-2/SG-2 with the discrepancy $D < 25\%$. According to Fok (2012), this discrepancy threshold is effective to remove insignificant satellites. The satellites include TOPEX/Jason series, ENVISAT, GFO, and SENTINEL3A.

(3) Satellite Group-3/SG-3 with the discrepancy $D < 1\%$. This group is intended to accommodate satellites with very low discrepancy, which include TOPEX/Jason series, ENVISAT, and GFO.

Tide Modelling – Diurnal & Semi-Diurnal Tide Model



Tide Modelling – Shallow Water Tide Model



Validation of Tide Model

Altimetry Satellite	Altimetry Satellite or Tidal Station
Amplitude dan phase	Amplitude dan phase
Cosinus *argument* (C^1)	Cosinus *argument* (C^0)
Sinus *argument* (S^1)	Sinus *argument* (S^0)

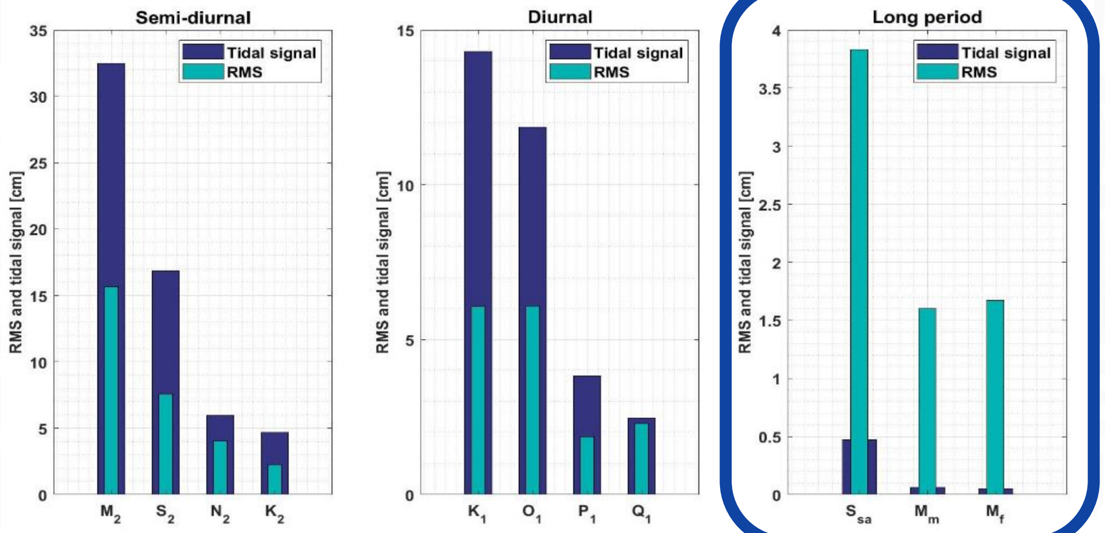
$$RMS_k = \sqrt{\frac{1}{2N}\Sigma_{i=1}^{N}[C_k^1(i) - C_k^0(i)]^2 + [S_k^1(i) - S_k^0(i)]^2}$$

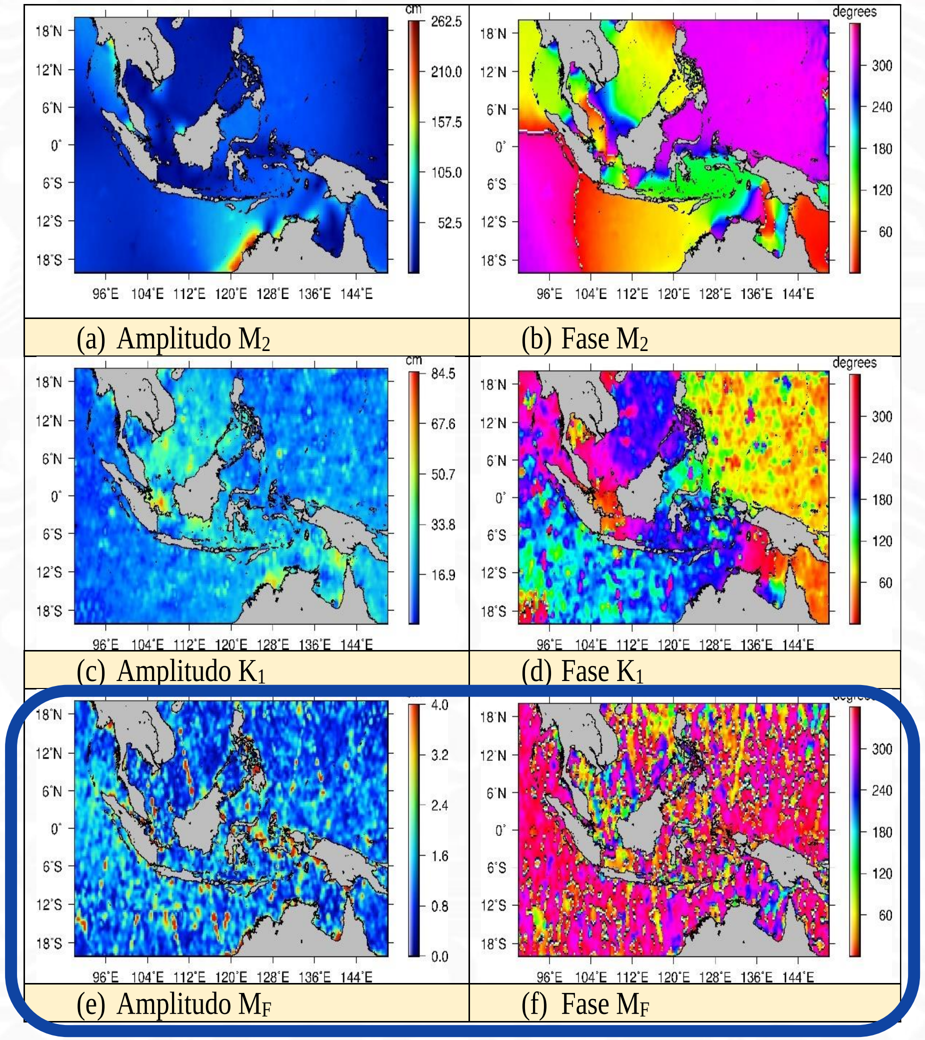
$$RSS = \sqrt{\sum_{j=1}^{M} RMS_j^2}$$

Validation Results

- **Each tidal component**
- **All tidal components**

Result





Energy of long period is very low, distorted by *ocean general circulation* and interaction with the currents

(Desai dan Wahr, 1995; Proudman, 1960; Kantha, 1995; Wunsch dkk., 1997; Wunsch, 1967)

Accuracy Assessment

Tidal component	Tidal models		
	SG-1	SG-2	SG-3
M_2	14.57	14.81	15.66
S_2	20.77	15.08	7.54
N_2	4.44	4.42	4.03
K_2	6.28	4.58	2.22
K_1	35.13	16.62	6.07
O_1	7.50	6.38	6.08
P_1	10.51	5.08	1.87
Q_1	2.55	2.47	2.29
S_{sa}	6.46	5.12	3.83
M_m	25.94	4.45	1.60
M_f	24.98	3.53	1.67

Comparison with Global Tide Model

	Tidal models					
Tidal component	SG-3[a]	SG-3[b]	FES2014[c]	TPXO9[c]	EOT20[c]	GOT4.8[c]
M_2	15.66	8.84	7.94	11.96	7.93	9.93
S_2	7.54	3.82	4.03	7.23	4.01	6.40
N_2	4.03	2.35	1.44	2.72	1.57	2.43
K_2	2.22	1.13	1.17	2.68	1.26	1.85
K_1	6.07	3.65	7.43	6.75	8.28	9.17
O_1	6.08	3.51	3.44	5.50	3.91	4.57
P_1	1.87	1.12	2.92	2.81	3.16	3.68
Q_1	2.29	1.23	0.88	0.93	0.93	1.10
RSS	20.14	11.31	12.61	17.16	13.33	16.38

[a]results without combination with tidal stations.
[b]results of the combination with tidal stations.
[c]current global tidal model.

Tidal Datum

Highest Astronomical Tide (HAT)
20-years predictions

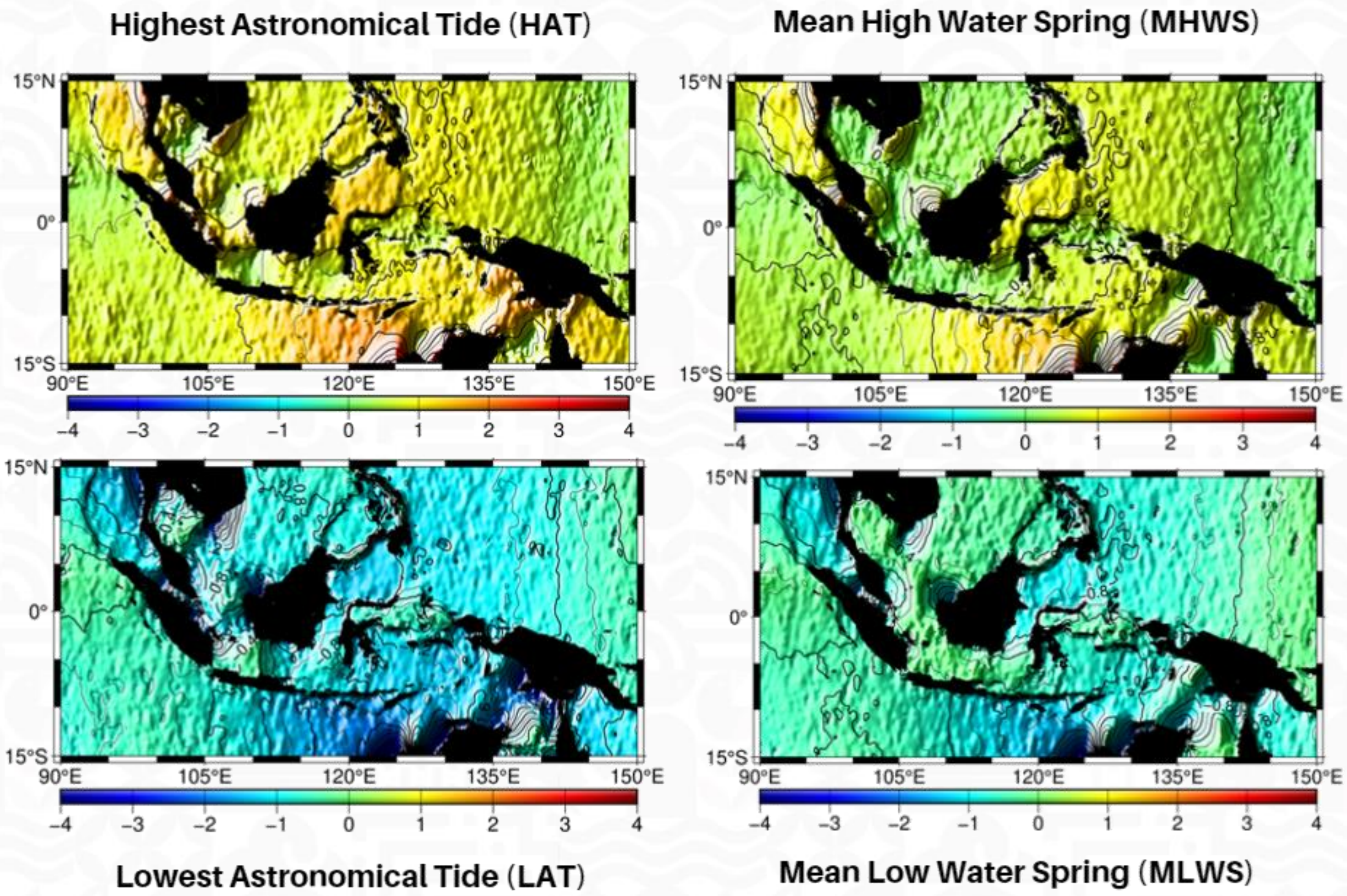
Mean High Water Spring (MHWS)
Tidal Components

Mean Sea Surface (MSS)
MSSH Model

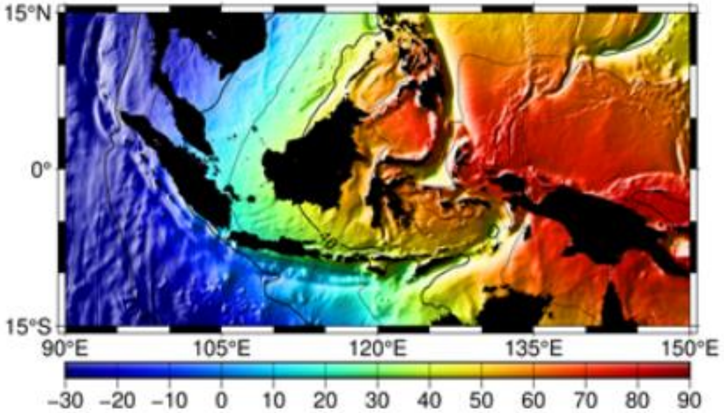
Mean Low Water Spring (MLWS)
Tidal Components

Lowest Astronomical Tide (LAT)
20-years predictions

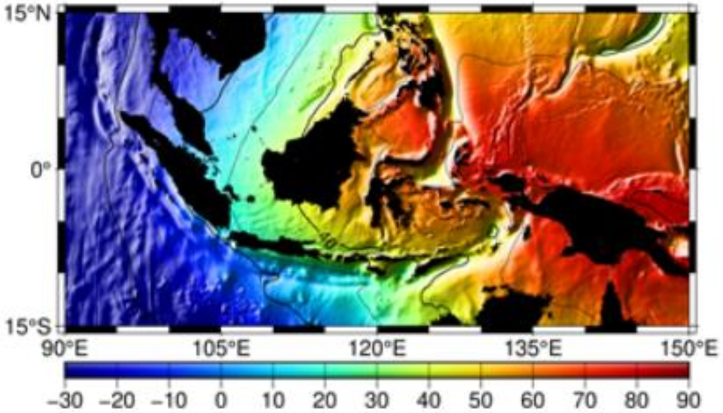
Refer to MSS


Highest Astronomical Tide (HAT)
Mean High Water Spring (MHWS)
Lowest Astronomical Tide (LAT)
Mean Low Water Spring (MLWS)
15°N
0°
15°S
90°E
105°E
120°E
135°E
150°E
−4
−3
−2
−1
0
1
2
3
4

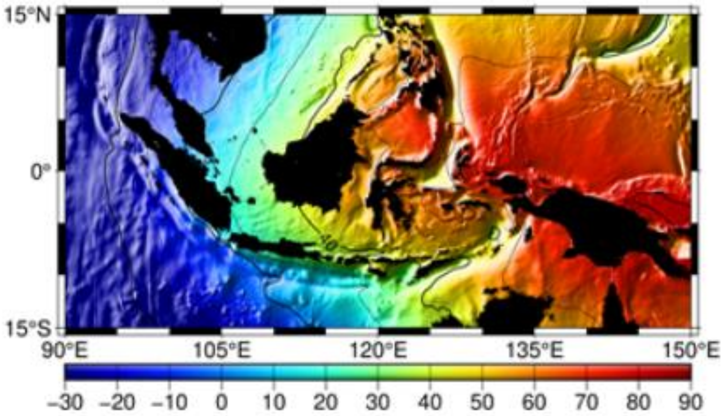
Refer to Ellipsoid



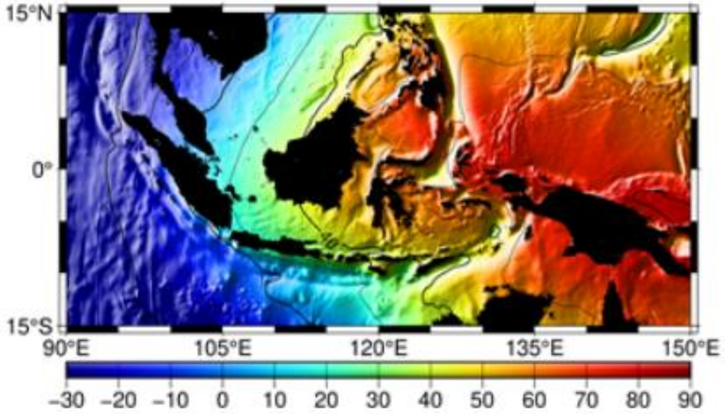
HAT



MHWS

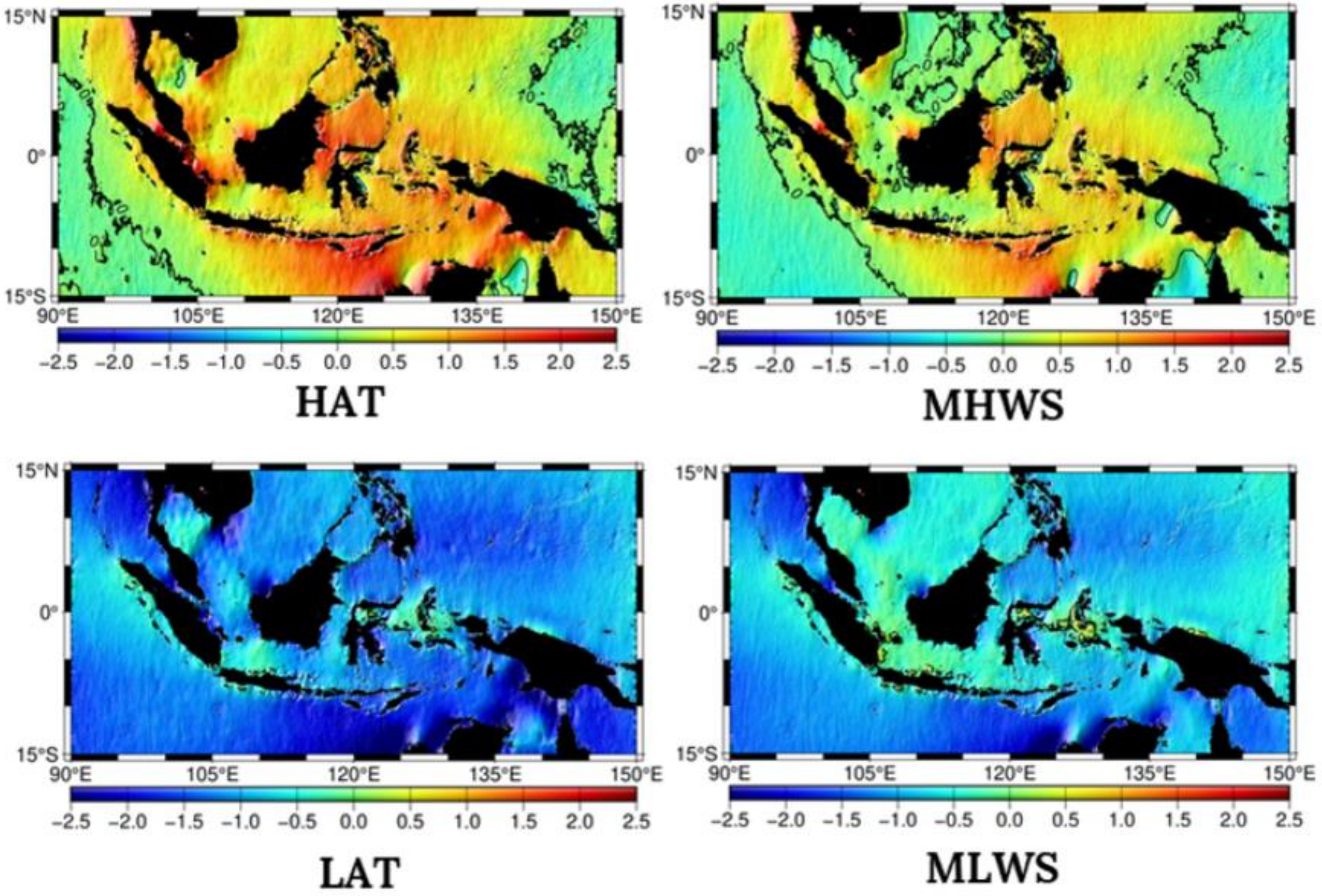


LAT



MLWS

Refer to Geoid



Verification of Tidal Datum

HAT

RMSE total = 0.125 m
RMSE outlier removal = 0.113 m

LAT

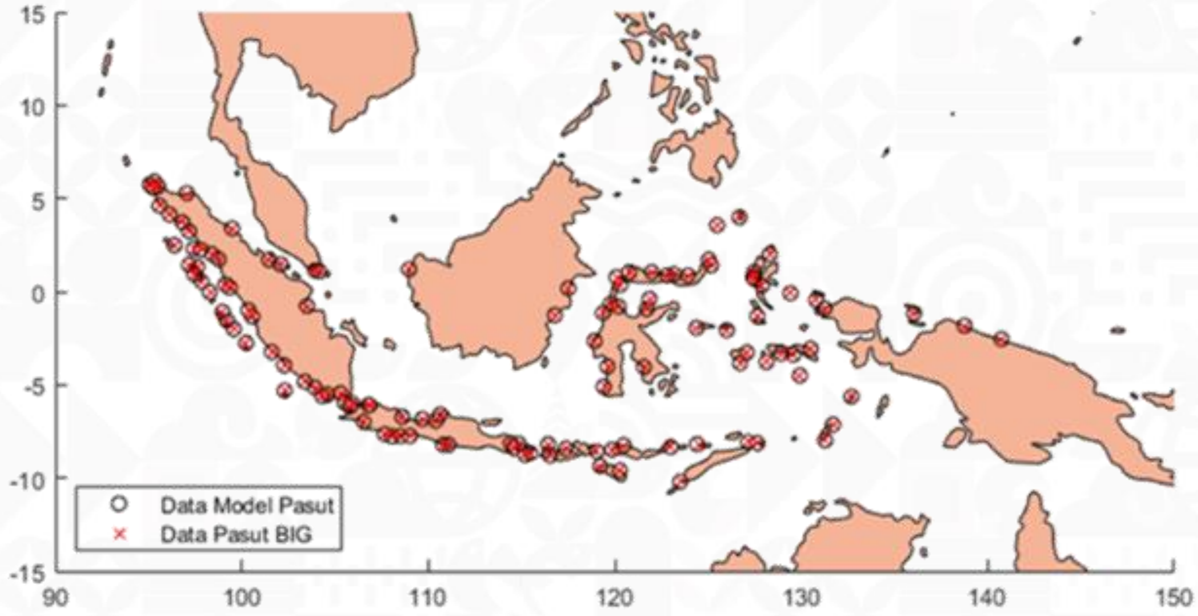
RMSE total = 0.155 m
RMSE outlier removal = 0.139 m

MHWS

RMSE total = 0.099 m
RMSE outlier removal = 0.084 m

MLWS

RMSE total = 0.099 m
RMSE outlier removal = 0.084 m



“Outlier” Tidal Stations

No	Nama	Lat	Lon	HAT	MHWS	MLWS	LAT
1	0011PLPO02	-2.98351	120.21014	0.219	0.238	0.238	0.176
2	0036PTLN02	-0.71126	119.85835	0.213	0.155	0.155	0.161
3	0039LWUK02	-0.95294	122.79634	0.236	0.166	0.166	0.162
4	0050BLWN01	3.78773	98.69433	0.158	0.170	0.170	0.181
5	0134NNKN01	4.14518	117.66555	0.318	0.429	0.429	0.742
6	0182PIRU03	-3.06704	128.17956	0.255	0.187	0.187	0.154
7	0190NBRE03	-3.23002	135.58403	0.251	0.170	0.170	0.252
8	0194BGAI02	-1.59000	123.49836	0.310	0.195	0.195	0.179

Thank You

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