**KL GeoHydro 2019**

**Kuala Lumpur, Malaysia**

**18 – 19 November 2019**

*"Empowering Marine Knowledge Through Hydrography"*

# Advances in Satellite Altimetry for the Ocean Exploration

**By:**

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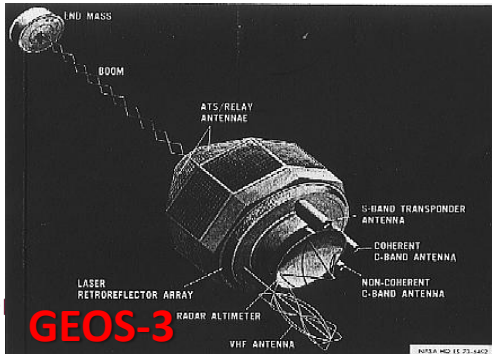
# CONTENTS

# Historical of Satellite Altimetry

- The principle of radar altimetry measurements was envisaged in the sixties and recognized as a high priority measurement at the Williamstown Symposium in 1969.
- The development of altimeter technology was a constant effort, which gave birth to a series of early missions : Skylab (1973), GEOS-3 (9 April 1975 – December 1978) and SeaSat (June 1978 – October 1978).
- With the advent of more precise instruments flying on a much better known trajectory, radar altimetry began to supply invaluable information in Geodesy, Oceanography, Geophysics, Hydrography, and Hydrology.

(Vignudelli *et al.*, 2011)

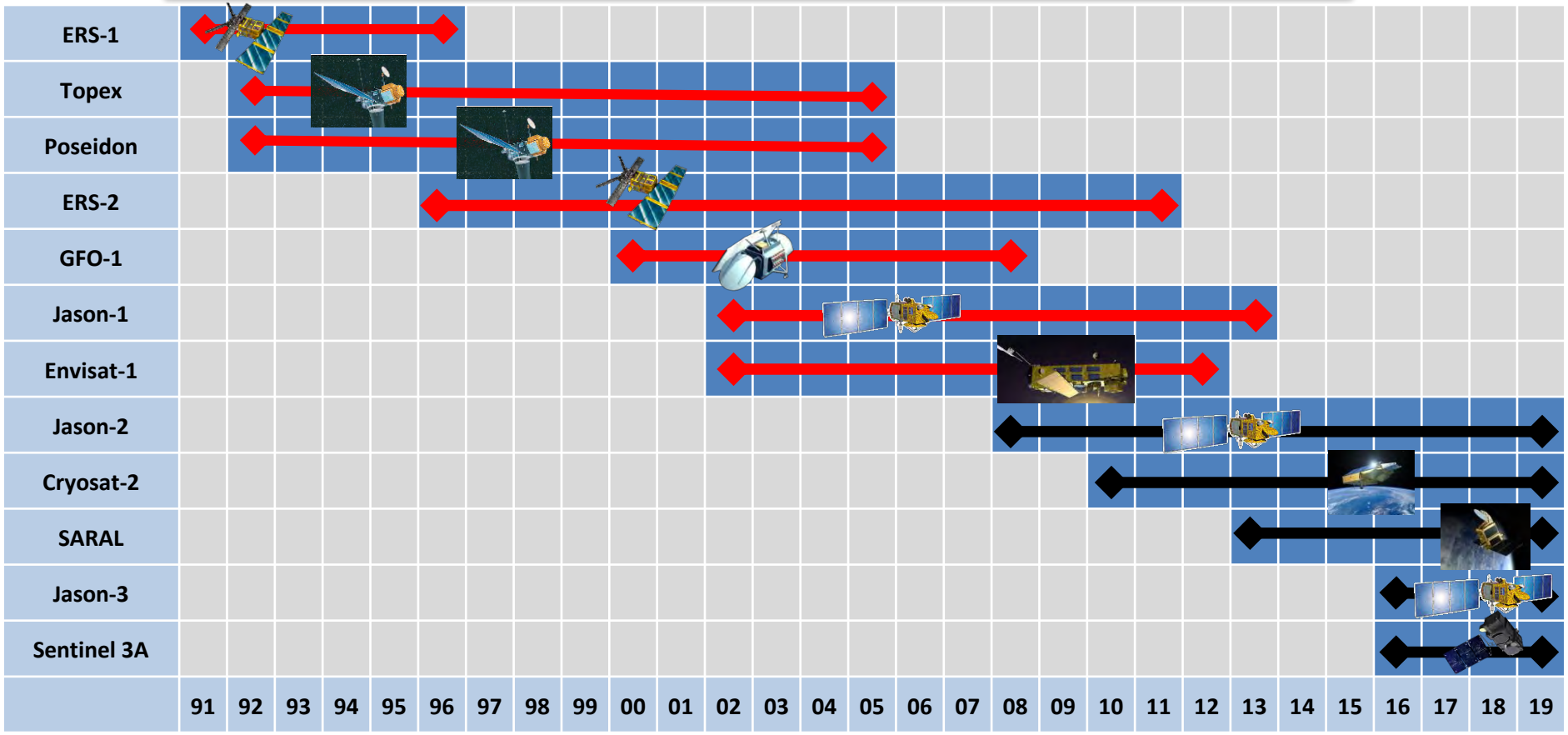

Skylab



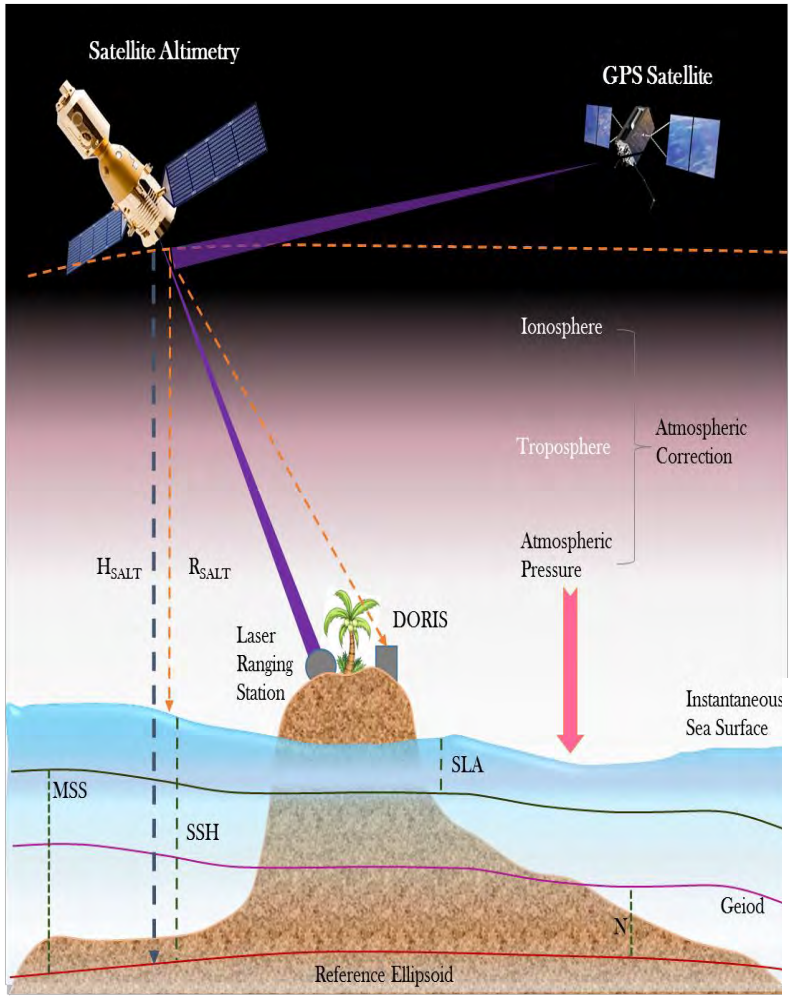
GEOS-3


SeaSat

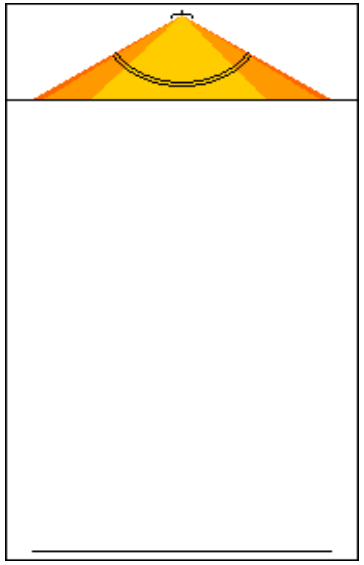
## Satellite Altimetry Missions



# Satellite Altimetry Principle




**Radar pulse reflecting at the sea surface**



$$SSH = H_{SALT} - R_{SALT}$$

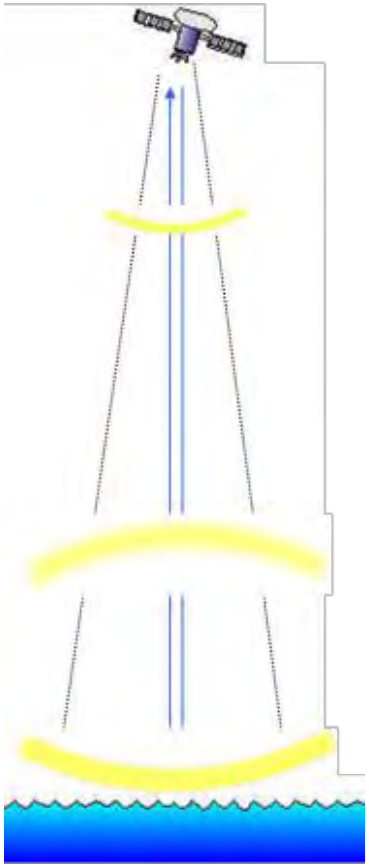
$$SLA = SSH - MSS$$

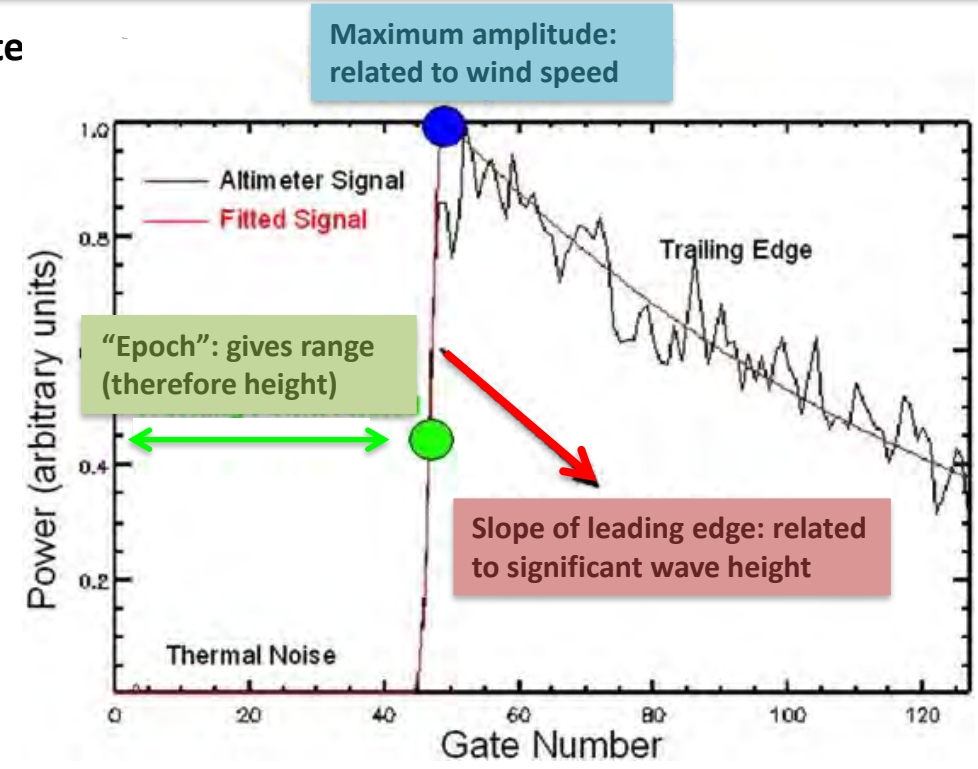
**SLA**: The diff. between the time-independent sea surface height (SSH) and the mean sea surface (MSS)

$H_{SALT}$ = Satellite Orbit Height
$R_{SALT}$ = Altimeter Range
SSH = Sea Surface Height
MSS = Mean Sea Surface
SLA = Sea Level Anomaly
N= Geoid Height

# Satellite Altimetry Principle

**Radar on board satellite looking at nadir**





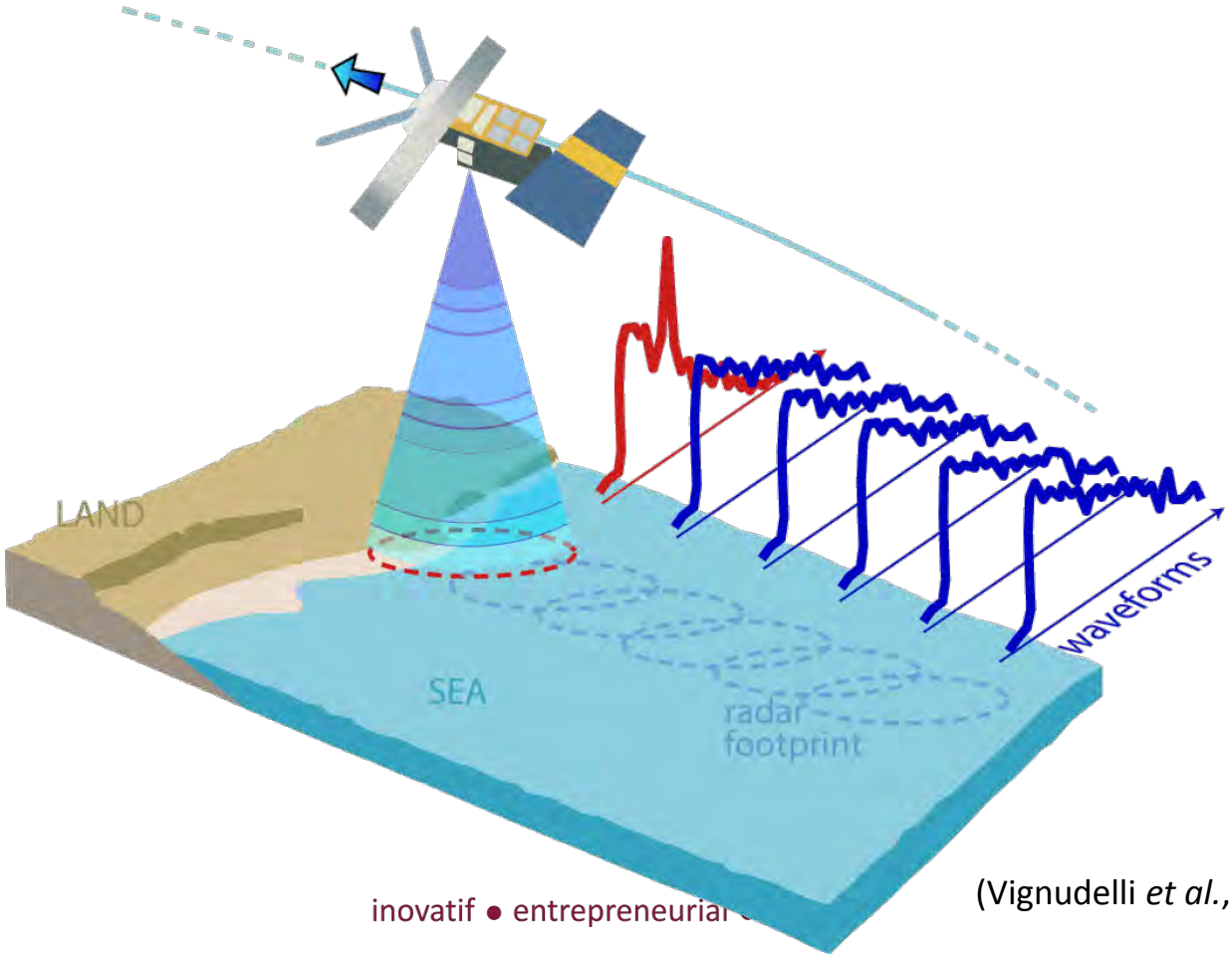

*(Gomez-Enri, Vignudelli et al., SPIE, 2009)*

Fitting the waveforms with a model (waveform retracking): **Brown Model**

Estimate the range (from the computed surface height), wave height and wind from waveforms

Generally done at 18 Hz (**~350 m** along-track) and then in open ocean altimetry averaged at 1 Hz (**~7km**) to improve precision

# Satellite Altimetry Principle

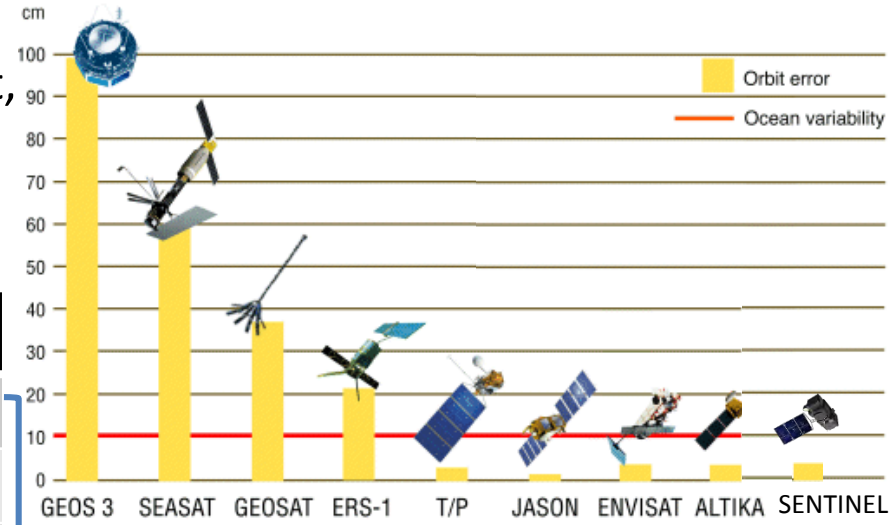



(Vignudelli *et al.*, 2011)

# Satellite Altimetry Characteristics

- Topex, Jason-1/2/3, ERS-1/2, EnviSat, Cryosat, Saral/AltiKa and Sentinel-3A
- 1 August 1991 – 2019 (current)

| Satellite | Sponsor | Repeat Period | Track Spacing | Inclination | Perigee |
|---|---|---|---|---|---|
| TOPEX | NASA & CNES | 9.9156 days | 315 km | 66° | 1340 km |
| Jason-1 | NASA & CNES | 9.9156 days | 315 km | 66° | 1336 km |
| Jason-2 | NASA & CNES | 9.9156 days | 315 km | 66° | 1325 km |
| Jason -3 | NASA & CNES | 9.9156 days | 315 km | 66° | 1328 km |
| ERS-1 | ESA | 35 days | 80 km | 98.5° | 780 km |
| ERS-2 | ESA | 35 days | 80 km | 98.5° | 785 km |
| EnviSat | ESA | 35 days | 80 km | 98.5° | 796 km |
| Cryosat - 2 | ESA | 30 days | 250 km | 92° | 717 km |
| SARAL | ISRO/CNES | 35 days | 75 km | 98.5° | 800 km |
| Sentinel-3A | ESA | 27 days | 104 km | 98.6° | 814.5 km |



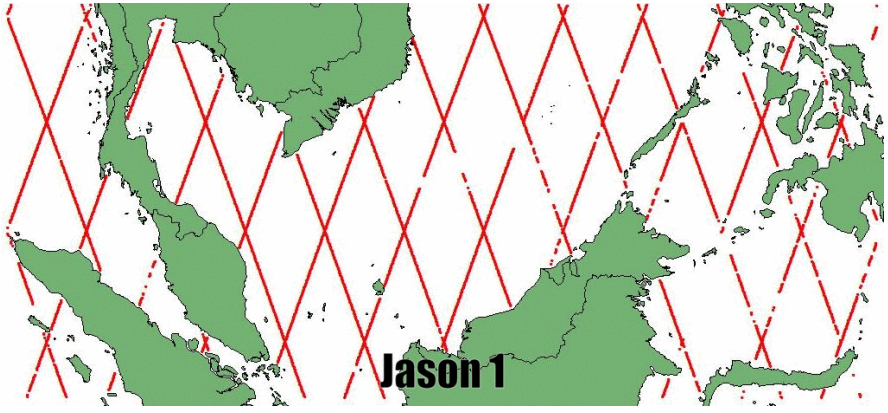

*TOPEX Class*

*ERS Class*

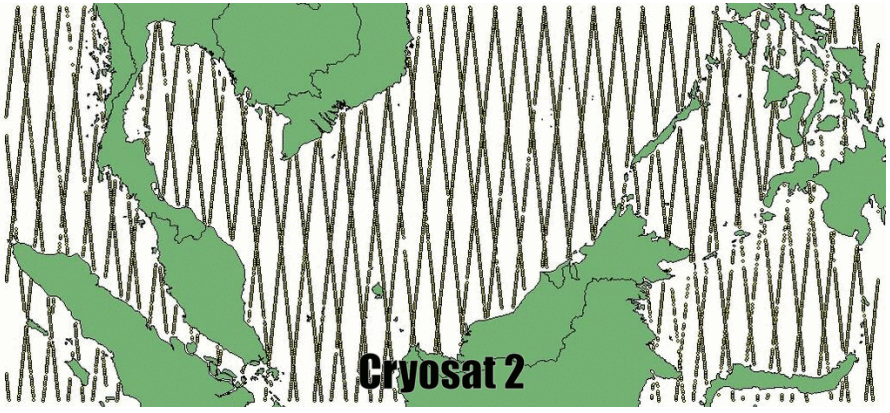
*(AVISO, 2019)*

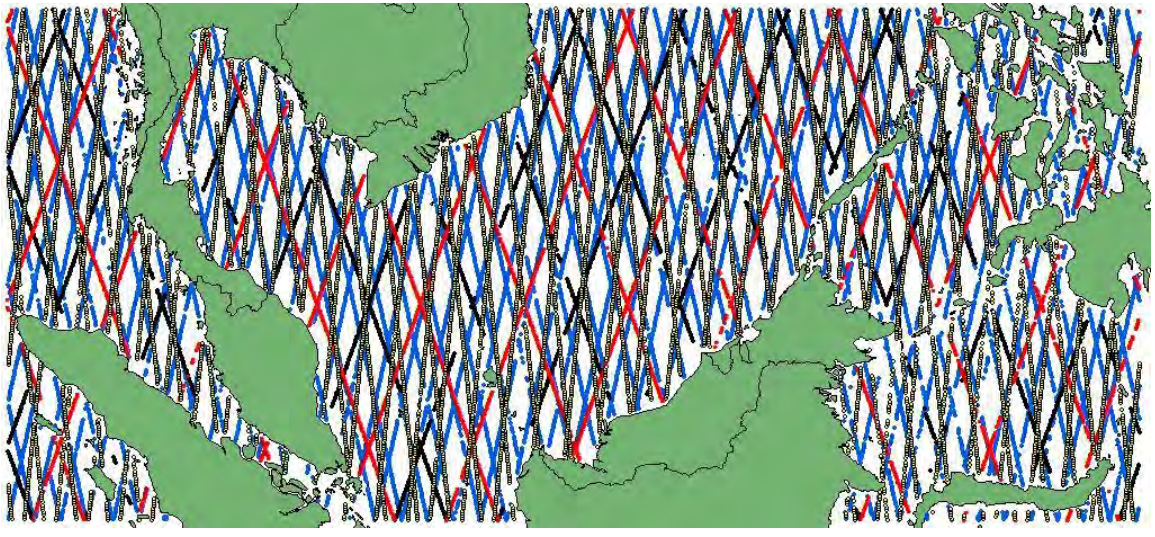
# Merit of Multi-missions Satellite Altimetry

*TOPEX-Class*




*ERS-Class*



Combination of **Jason-1**, **Jason-2**, **Cryosat-2** and **SARAL**

# Satellite Altimetry Data Access

RADS
RADAR ALTIMETER DATABASE SYSTEM

UTM
UNIVERSITI TEKNOLOGI MALAYSIA

TU Delft
Delft University of Technology

- RADS : The archiving and processing initiative of TU Delft, NOAA and Altimetrics LLC.
- This system has been installed in Malaysia at UTM since 2005 in the frame of the SEAMERGES project (www.deos.tudelft.nl/seamerges)
- Funded under the ASEAN-EU University Network programme (AUNP).

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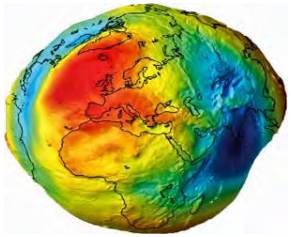
# Applications of Satellite Altimetry

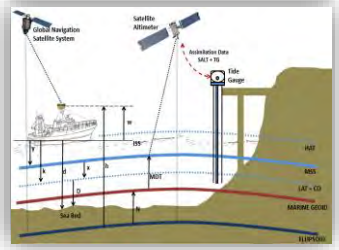
## Coastal Inundation

## Marine Geoid

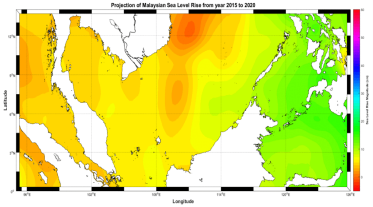


## Maritime Boundary

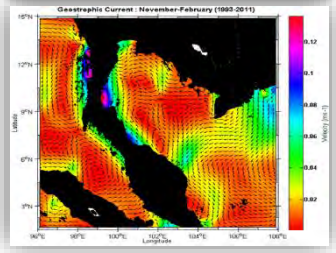
## Ellipsoidal Reference Survey



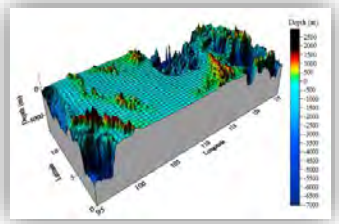
## Sea Level Rise



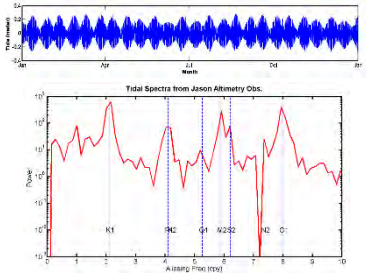
## Current Circulation



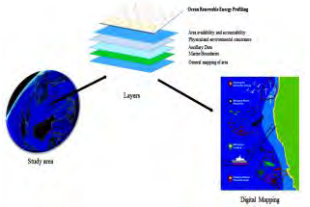
## Sea Floor Mapping



## Tidal Modelling



## Ocean Renewable Energy



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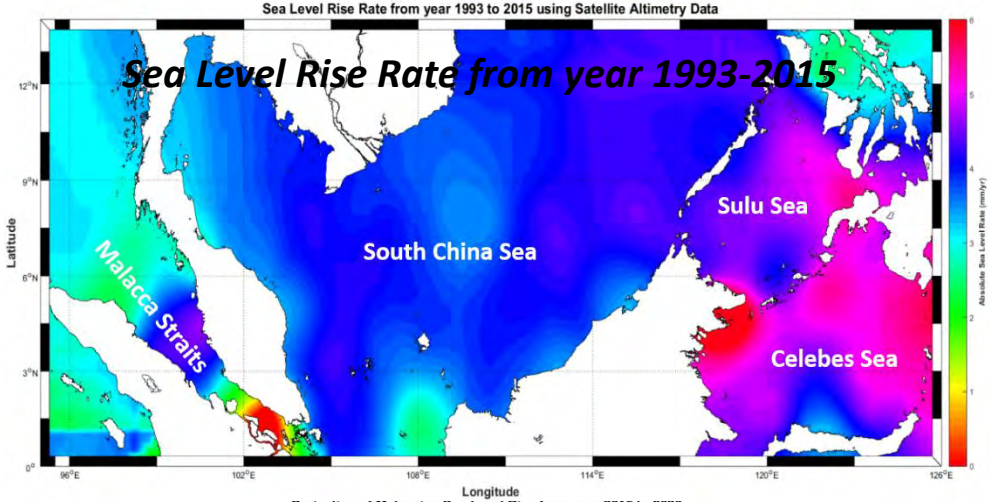
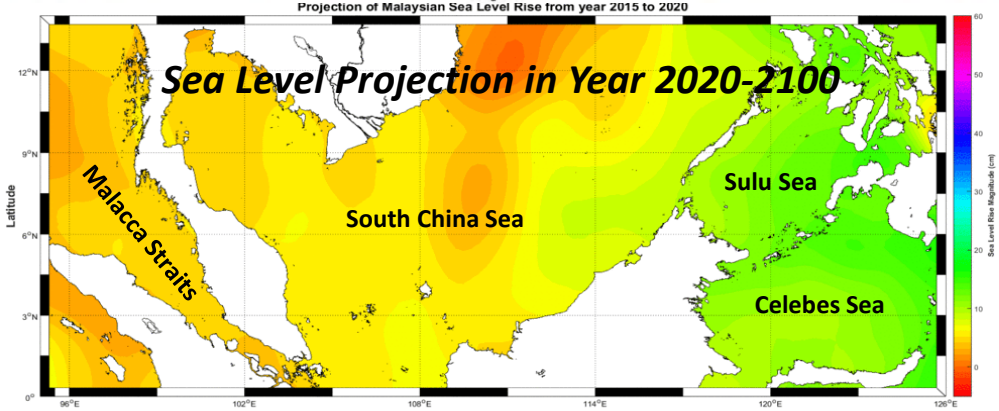
# Applications of Satellite Altimetry

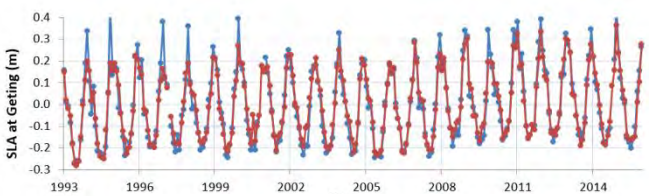
## *"Sea Level Rise"*

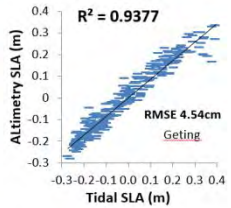
Sea level rise interpretation in the Malaysian region using multi-mission satellite altimeter.



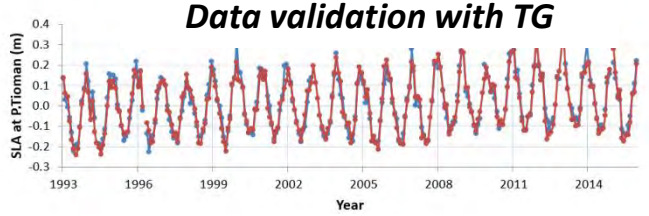



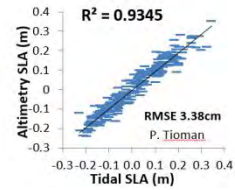

*Data Validation (Tidal Data )*




*Data validation with TG*




| Group | SLR rate (mm/yr) | Sea Level Projection in Year 2100 (cm) |
|---|---|---|
| Malacca Strait | $3.27 \pm 0.12$ | 32 |
| South China Sea | $3.88 \pm 0.05$ | 38 |
| Sulu Sea | $4.77 \pm 0.14$ | 48 |
| Celebes Sea | $4.95 \pm 0.15$ | 50 |
| Mean | $\mathbf{4.22 \pm 0.12}$ | **42** |

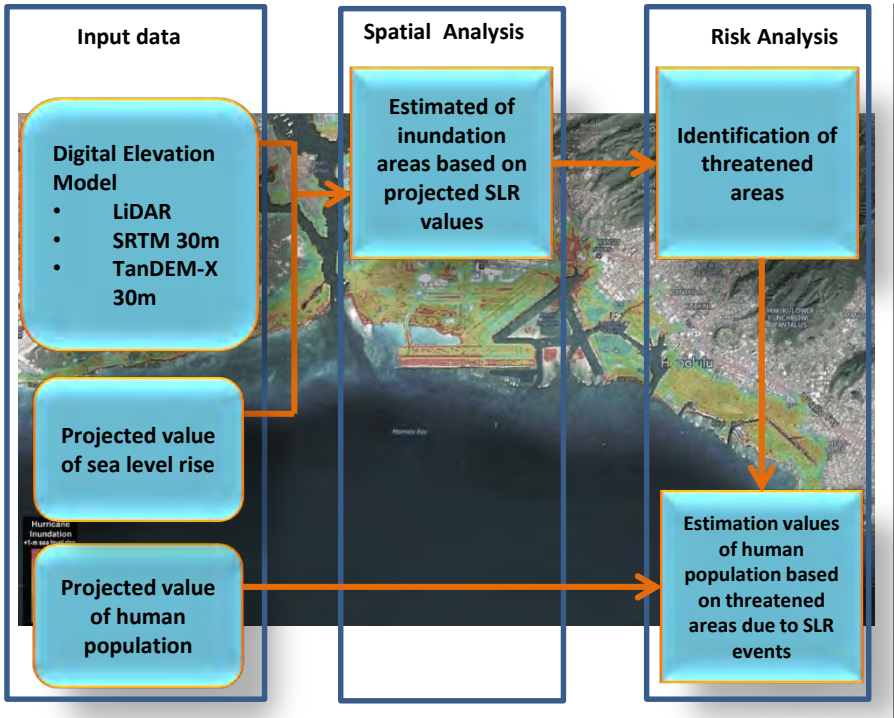
*Sea Level Rise Rate from year 1993-2015*

*Sea Level Projection in Malaysia in Year 2100*

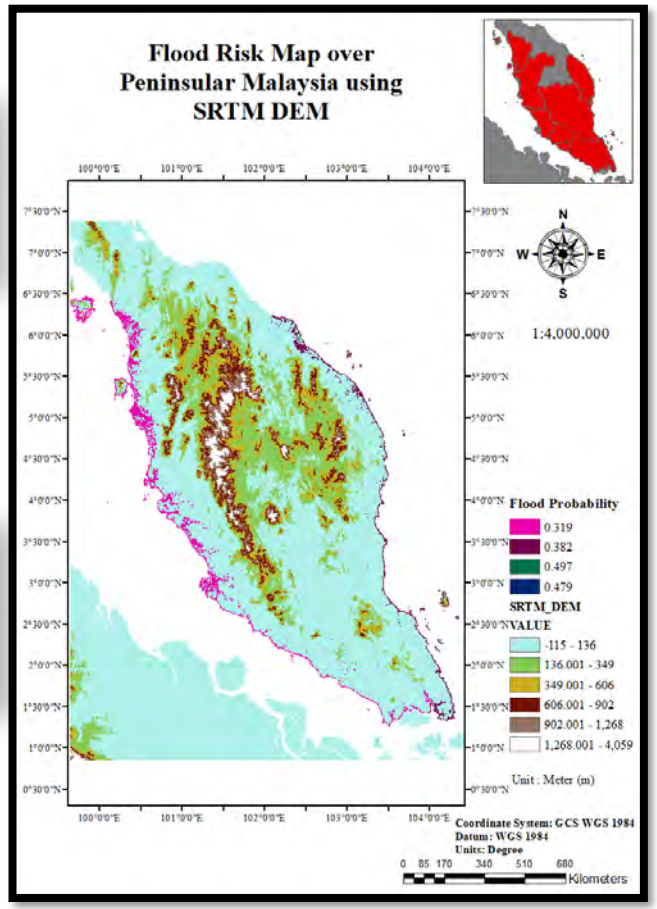
# Applications of Satellite Altimetry

## "Coastal Inundation"

Determining the coastal inundation area due to sea level changes from multi-mission satellite altimeter.




*Coastal vulnerable assessment based on the inundation risk map*




*Simulation of inundation risk map of Peninsular Malaysia with inundation probability levels by the year 2100. Units are in meter (m).*

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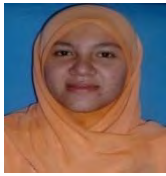
# Applications of Satellite Altimetry

## *"Current Circulation"*

Collaboration with

UNIVERSITI TEKNOLOGI MARA

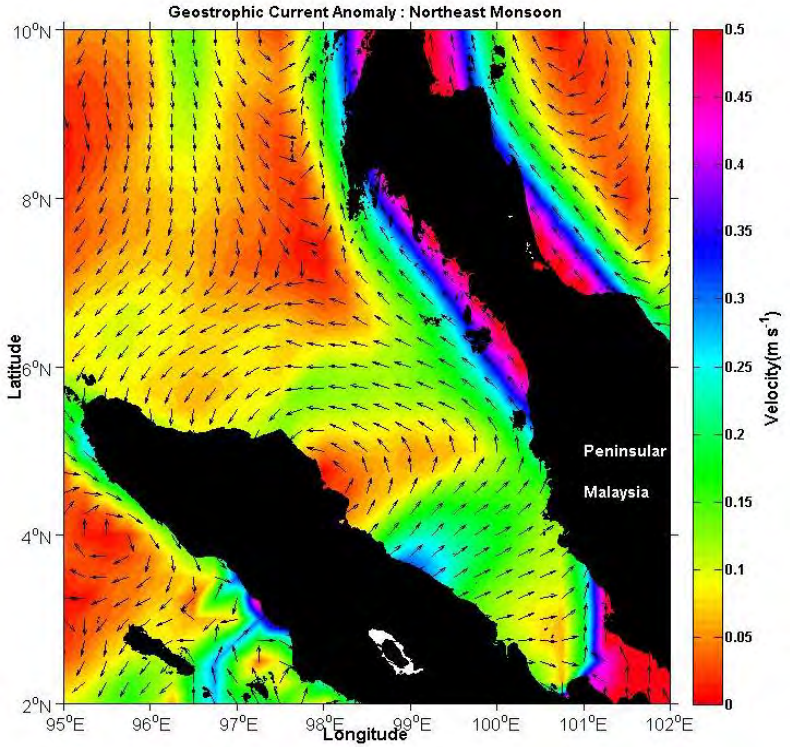


*Altimetry Processing in RADS*

MATLAB
The Language of Technical Computing

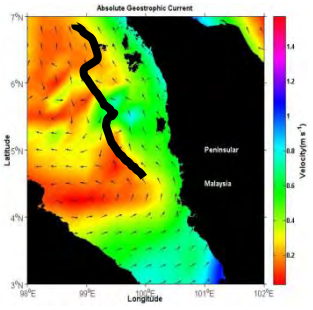
***Computation of surface current***

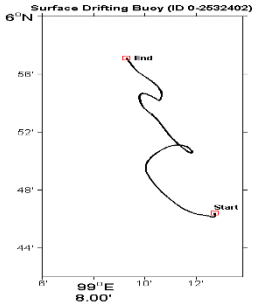
$$ug = -g / f (\delta\zeta / \delta y)$$
$$vg = g / f (\delta\zeta / \delta x)$$




***Map of surface current***

***Ground Truth Data***

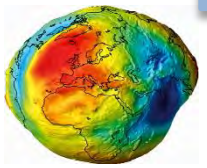


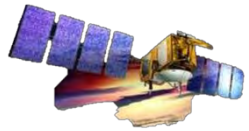

**Low Cost Surface Drifting Buoy**

inovatif ● entrepreneurial ● global

# Applications of Satellite Altimetry

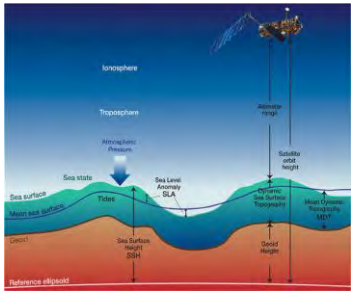


## *"Marine Geoid"*

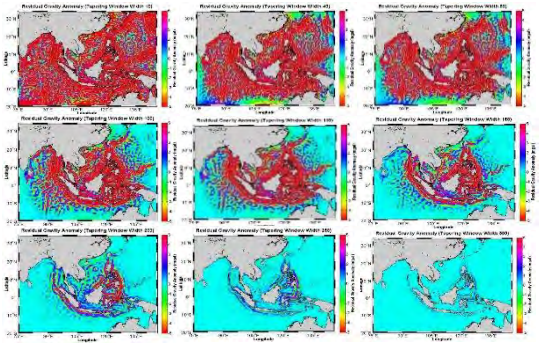


Marine geoid determination over Malaysian seas using multi-mission satellite altimeter.

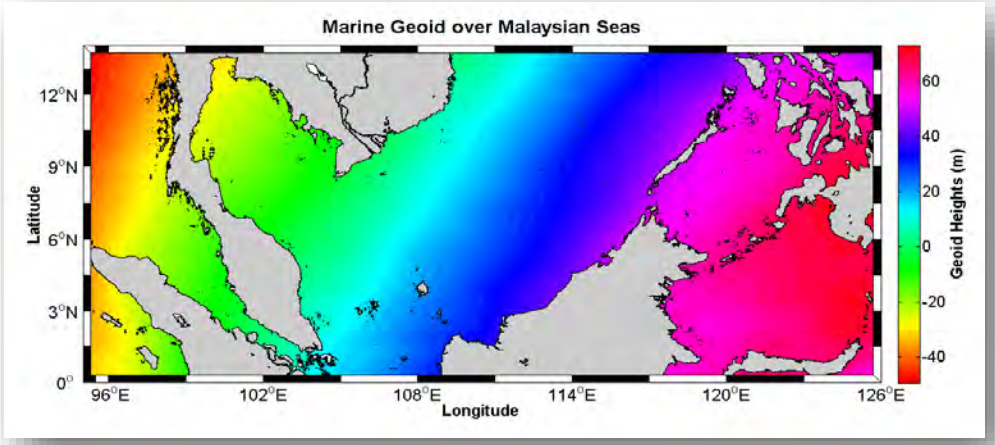
### *MSS Derivation*



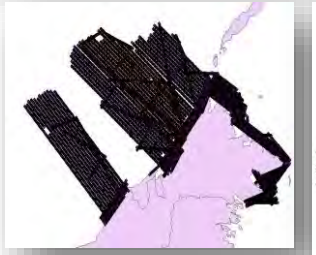

### *Gravity Anomaly Derivation*

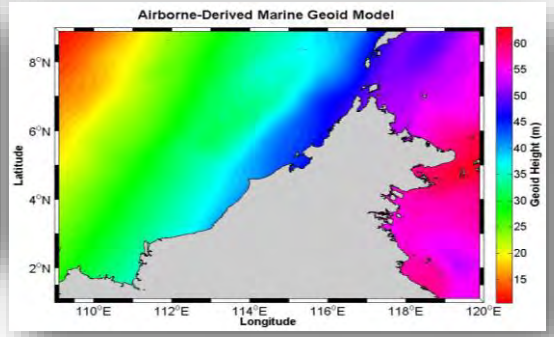


### *UTM18 Marine Geoid Model*




### *Data Validation (Airborne Gravity)*



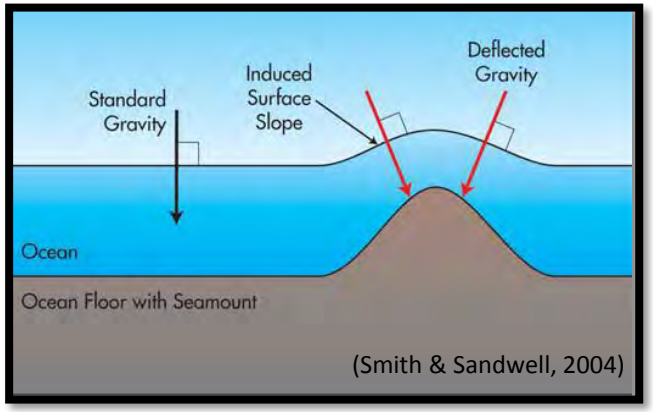



JUPEM

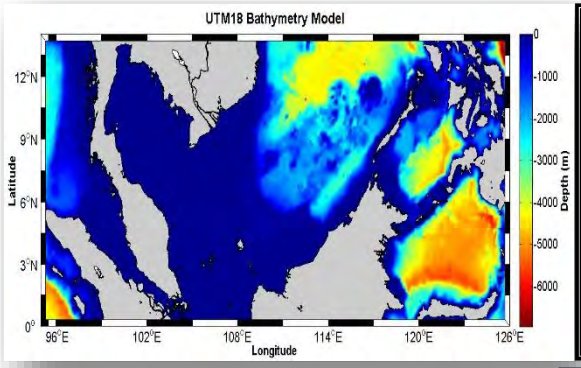
# Applications of Satellite Altimetry

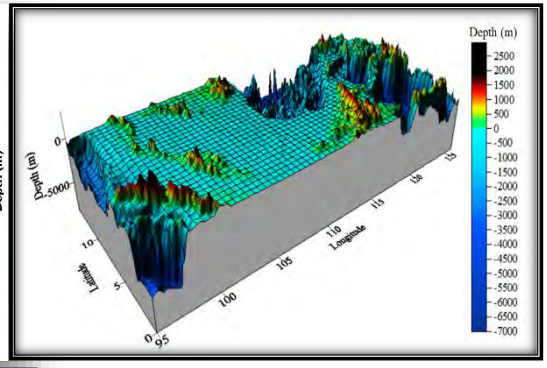
## "Sea Floor Mapping"

Estimating bathymetry using multi-missions satellite altimeter and gravity satellite missions.

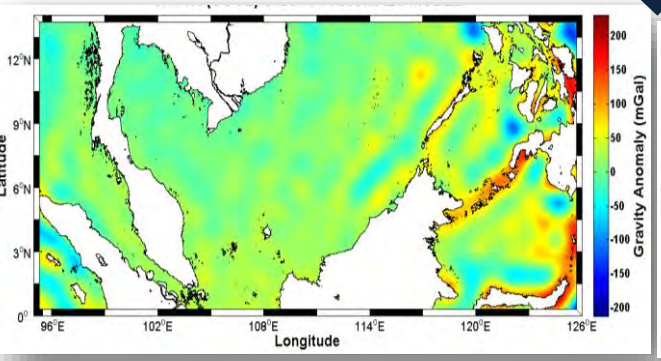



***UTM18 Bathymetry Model***

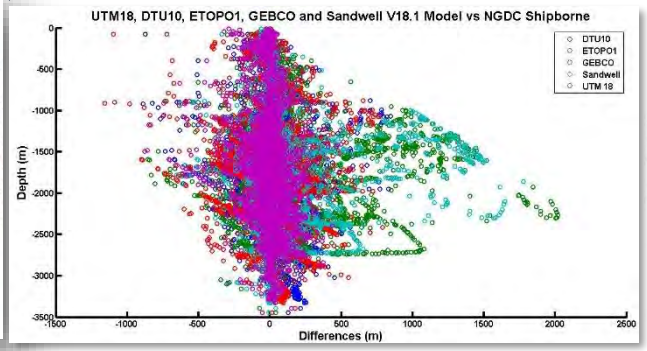


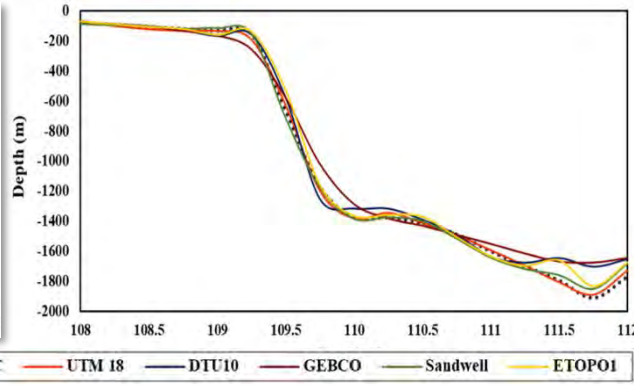




***Data Validation with NGDC Shipborne (NOAA)***




***Gravity Anomaly***

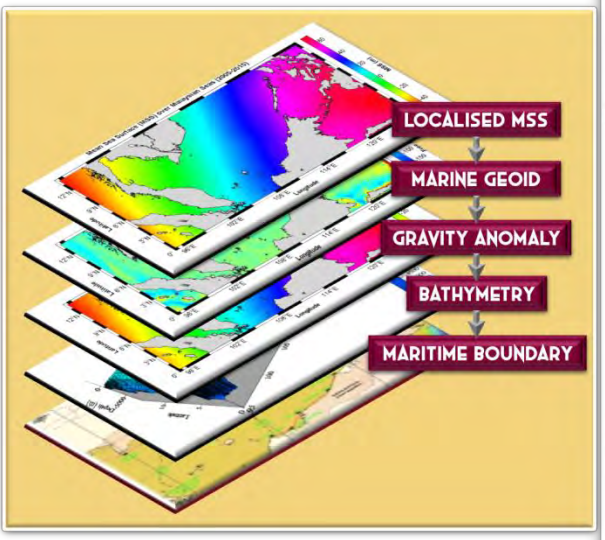


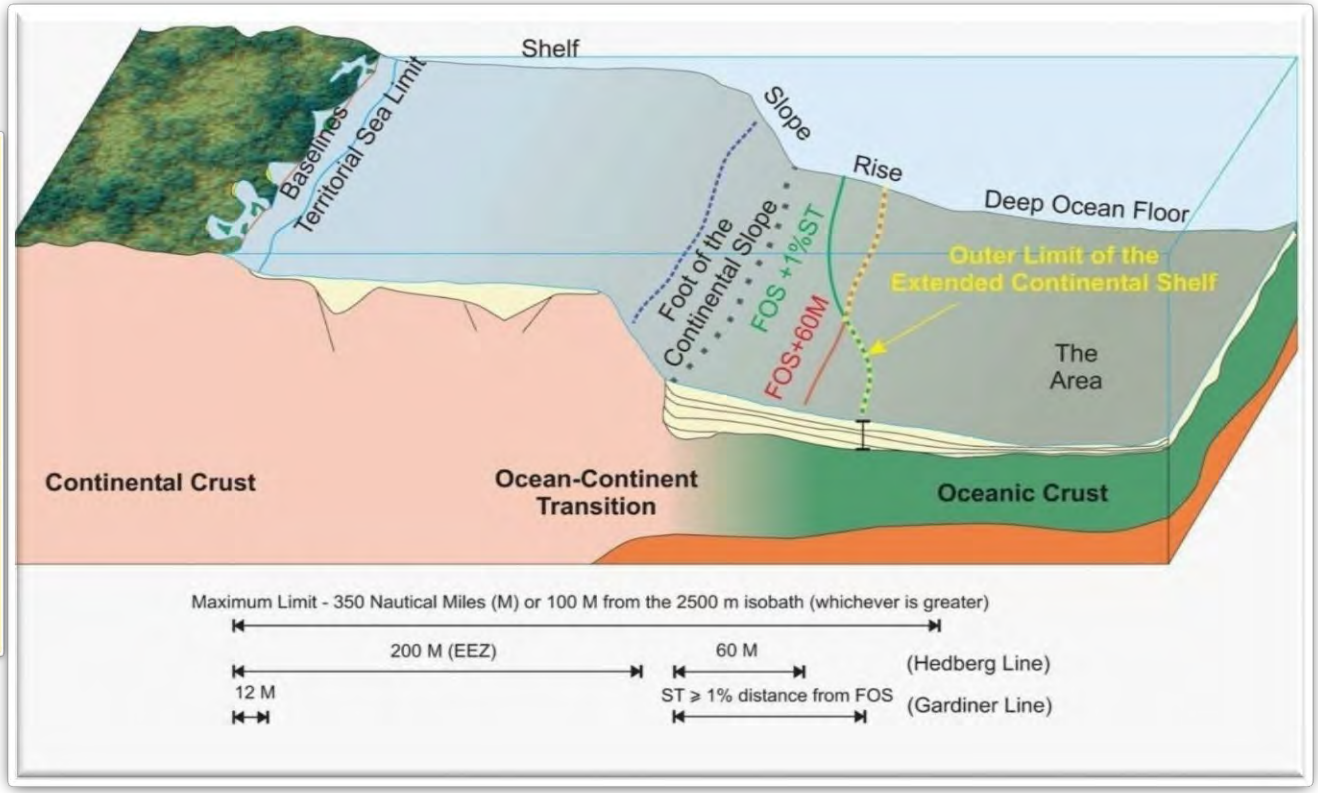



# Applications of Satellite Altimetry

## "Maritime Boundary"

Determine the maritime boundary of continental shelf's seabed from multi-mission satellite altimeter



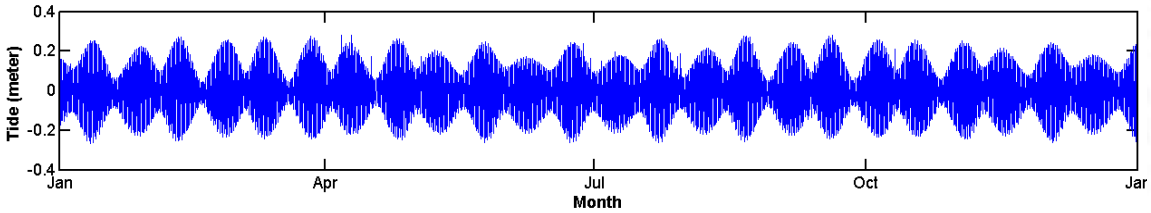



# Applications of Satellite Altimetry

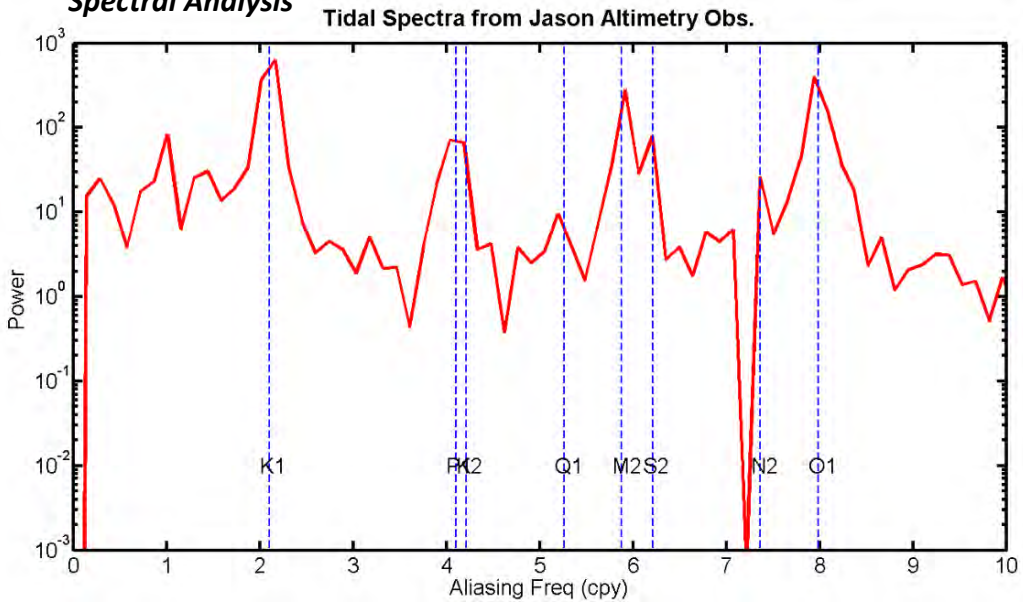
## "Tidal Modelling"

$$f(t) = A_o + \sum_{n=1}^{\infty} A_n \cos(\omega_n t - \theta_n)$$

### Harmonic Analysis




### Spectral Analysis

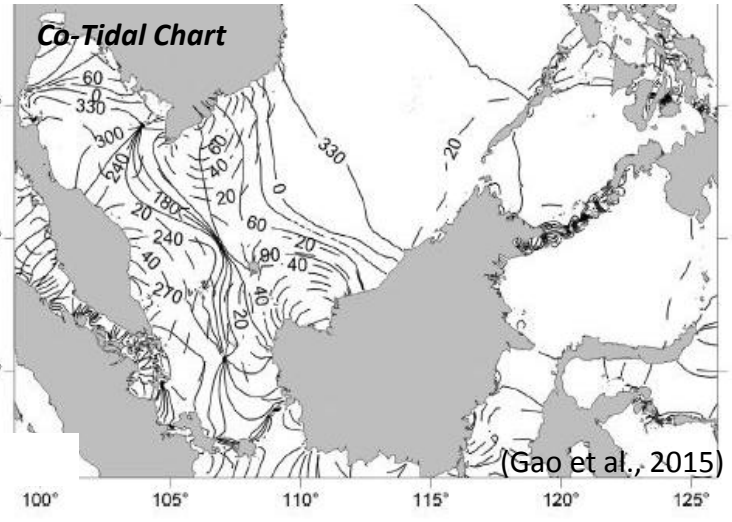



### Tidal Aliasing

| | $M_2$ | $S_2$ | $N_2$ | $K_2$ | $K_1$ | $O_1$ | $P_1$ | $Q_1$ | $M_f$ | $M_m$ | $S_{sa}$ | $S_a$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | TOPEX/Jason-1/-2 | | | | | | |
| $M_2$ | 62 | 1084 | 245 | 220 | 97 | 173 | 206 | 594 | 87 | 50 | 94 | 75 |
| $S_2$ | | 59 | 316 | 183 | 89 | 206 | 173 | 384 | 94 | 52 | 87 | 70 |
| $N_2$ | | | 50 | 116 | 69 | 594 | 112 | 173 | 134 | 62 | 68 | 57 |
| $K_2$ | | | | 87 | 173 | 97 | 3355 | 349 | 62 | 40 | 165 | 114 |
| $K_1$ | | | | | 173 | 62 | 183 | 116 | 46 | 33 | 3355 | 329 |
| $O_1$ | | | | | | 46 | 94 | 134 | 173 | 69 | 61 | 52 |
| $P_1$ | | | | | | | 89 | 316 | 61 | 40 | 173 | 118 |
| $Q_1$ | | | | | | | | 69 | 76 | 46 | 112 | 86 |
| $M_f$ | | | | | | | | | 36 | 116 | 45 | 40 |
| $M_m$ | | | | | | | | | | 28 | 33 | 30 |
| $S_{sa}$ | | | | | | | | | | | 183 | 365 |
| $S_a$ | | | | | | | | | | | | 365 |

(Smith, 1999)

### Co-Tidal Chart




(Gao et al., 2015)

# KL GeoHydro 2019

**Kuala Lumpur, Malaysia**
**18 – 19 November 2019**

KL GeoHydro 2019

UTM UNIVERSITI TEKNOLOGI MALAYSIA

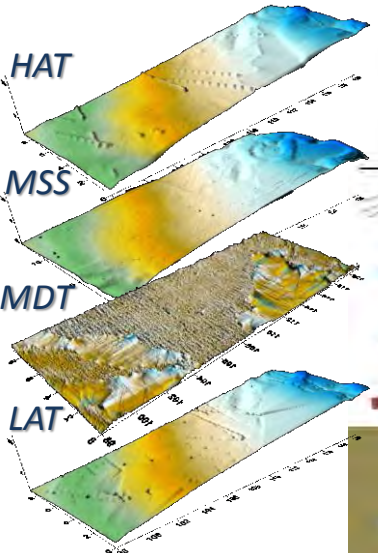
*"Empowering Marine Knowledge Through Hydrography"*

# Applications of Satellite Altimetry

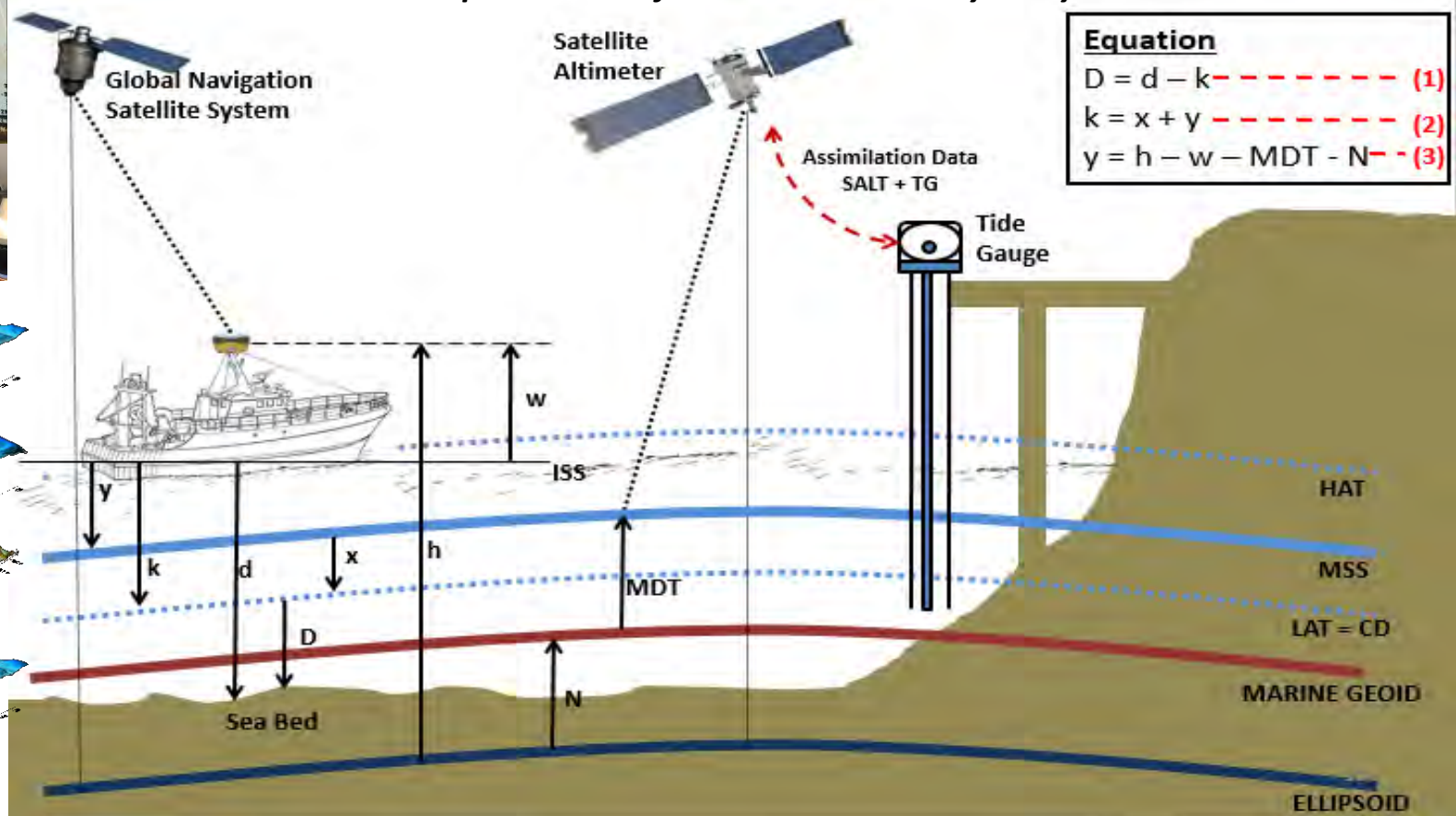
*Collaboration with*

Universiti Malaysia Terengganu UMT

## *"Ellipsoidal Reference Survey"*


***Conceptual Model for ERS-derived Bathymetry***



# KL GeoHydro 2019

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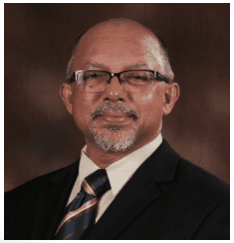
# Applications of Satellite Altimetry

## *"Ocean Renewable Energy"*

*Collaboration with*

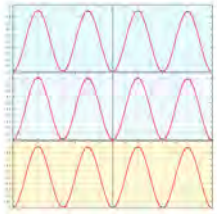
Universiti Malaysia Terengganu UMT



UTM Universiti Teknologi Malaysia — SCHOOL OF MECHANICAL ENGINEERING, Faculty of Engineering

***General flow of ocean renewable energy profiling***

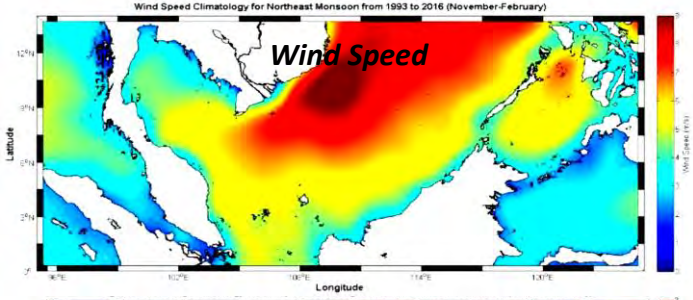
1. Resource Area Identification
2. Ocean parameter clustering
3. Ocean renewable energy density calculation
4. Ocean Renewable Energy Profiling

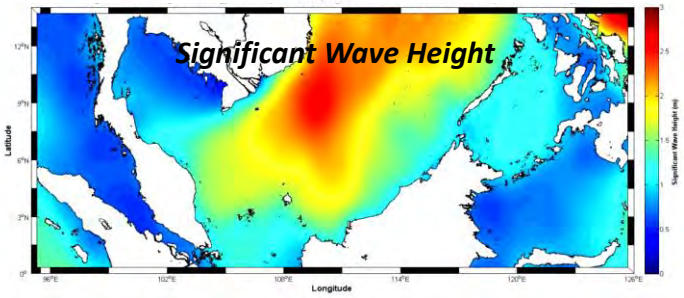


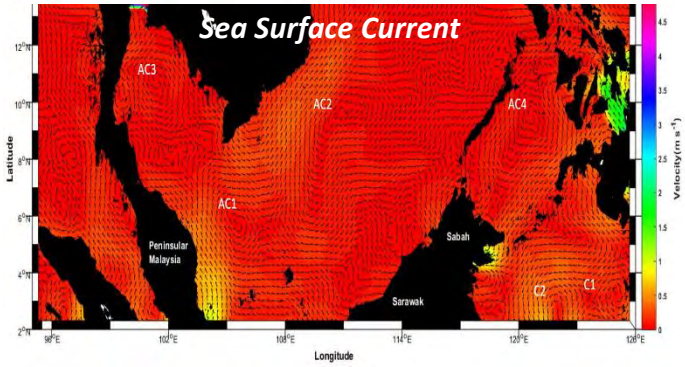
Wind energy profiling

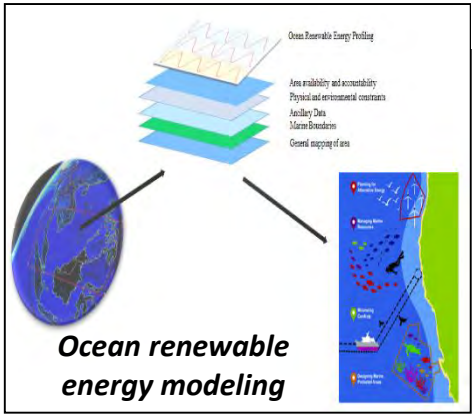
Wave energy profiling

Ocean current energy



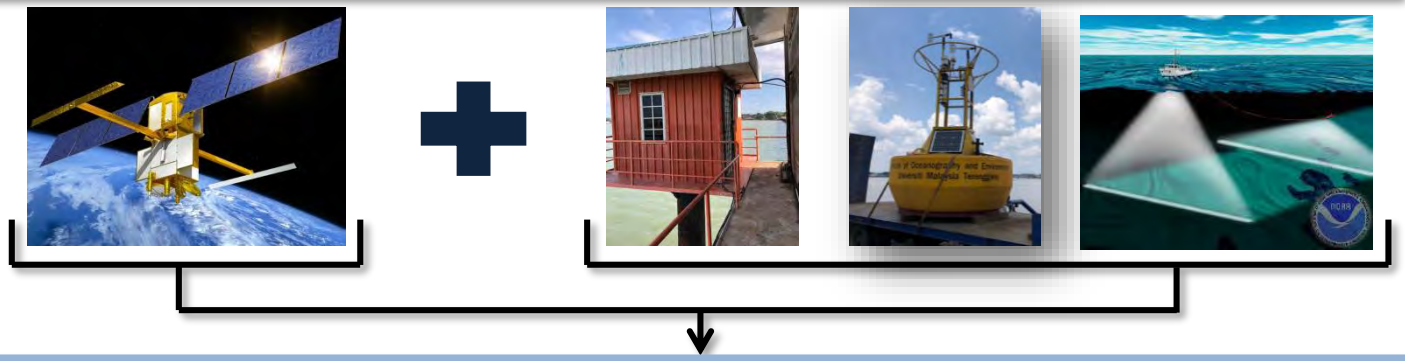




***Ocean renewable energy modeling***

***UMT Buoy installation in South China Sea***

# Concluding Remarks



## Advantages

- Measure parameters that are not observable in situ (**global coverage**)
- Represent the **spatial and temporal** which is difficult to be represented with only sparse in situ instruments
- Can be densified by **merging multiple missions**
- Provide a unique **long term observational dataset** to characterize how sea level variability evolves from the open ocean to coastal zone

As the state-of-the-art technology, satellite altimetry opens up new possibilities in **deep ocean exploration** providing much more information than surface observations.

# Thank you