



*On the Job Training on
Tsunami Inundation Modelling and Mapping and Development of Tsunami Hazards Maps for
Implementation of UNESCO-IOC Tsunami Ready Pilot Sites in Madagascar, Maldives, Seychelles and Sri Lanka
Hyderabad – India, 16–21 March 2026*

Tsunami Inundation Modelling and Mapping

TIMM 1.7: DEM Development: Integrating Bathymetry & Topography

Dr. Vicki Ferrini

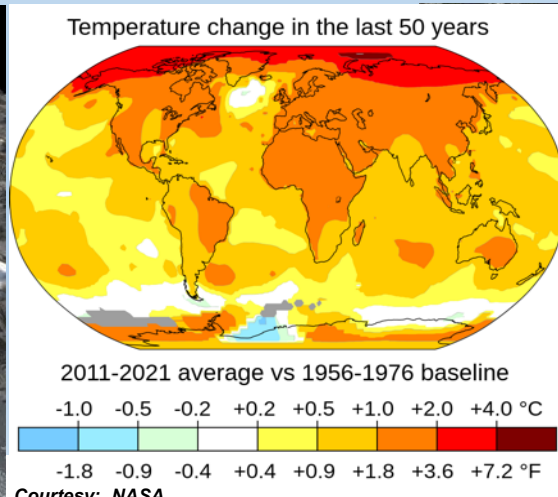
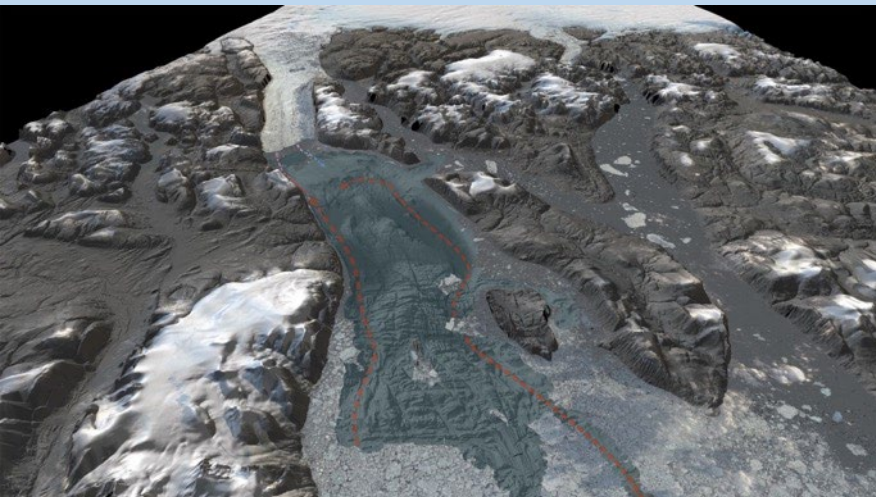
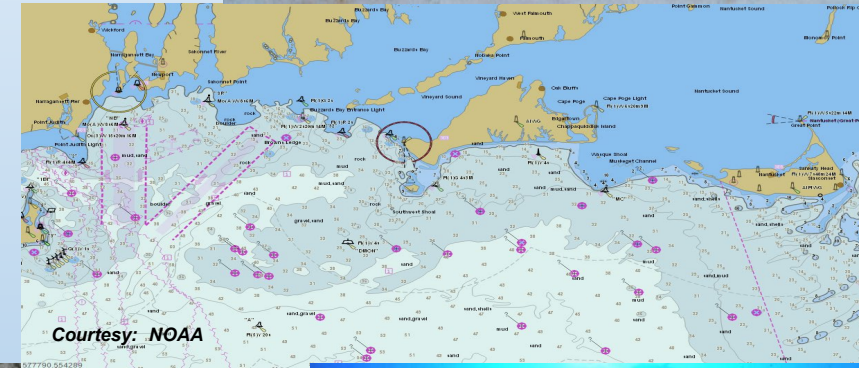
Lamont-Doherty Earth Observatory of Columbia University

Nippon Foundation – GEBCO Seabed 2030 Project

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Why is bathymetry data important?

- Nautical charts
- **Tsunami models**
- Safety & Emergency response
- Satellite verification models
- Offshore infrastructure
- Ecosystem management
- Ocean Models
- Coastal/Marine Spatial Planning
- Geohazard Assessment
- Oil and gas exploration
- Coastal Change Analysis
- Sea Level Rise Mitigation
- New Energy Siting
- Ocean Exploration
- Marine Heritage
- Blue Economy

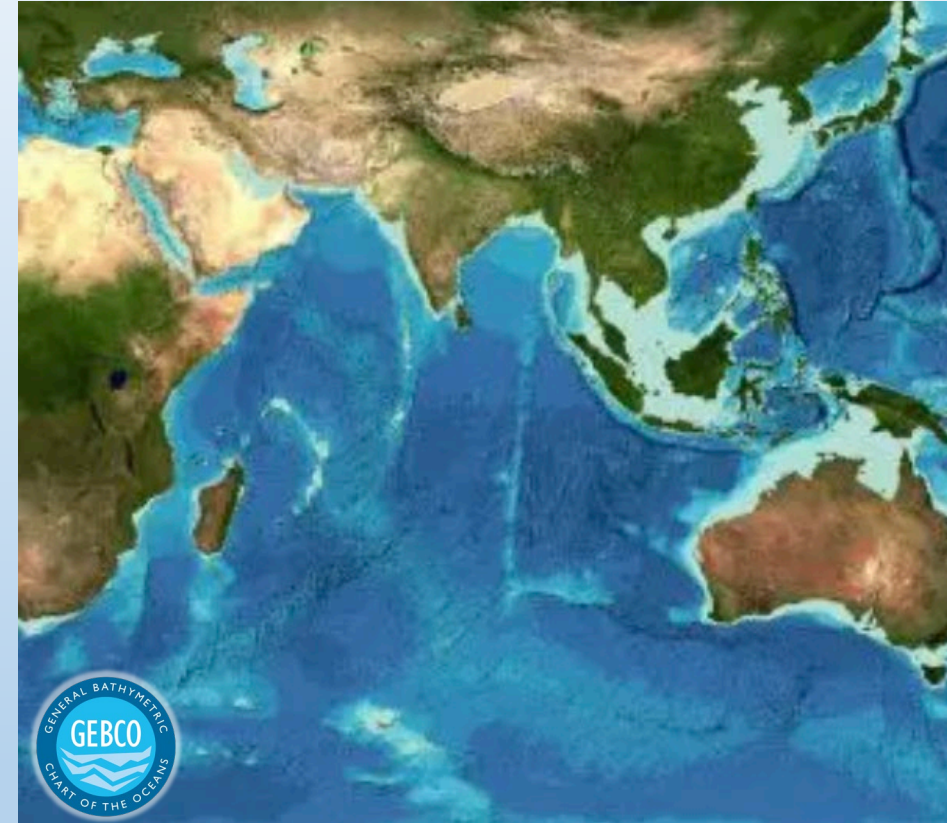


Courtesy: NOAA

Courtesy: NOAA

The GEBCO Grid: A Global Bathymetry Model

- **Overview:** Founded in 1903, the General Bathymetric Chart of the Oceans (GEBCO) provides authoritative, publicly available elevation data for the world's oceans.
- **Global Product:** The GEBCO grid is a global terrain model providing elevation data in meters on a 15 arc-second interval grid.
- **Challenges of Integration:** Creating this bathymetric product requires bringing together many different types of data in a *harmonious and seamless* way.
- **Data Composition:** The grid is a combination of both direct and indirect seafloor depth measurements contributed by organizations and individuals worldwide.



GEBCO Products

- Global gridded bathymetric data
 - 2014: 30 arc-second grid
 - 2019 - 2025: 15 arc-second grid
- Gazetteer of Undersea Feature Names
- Grid viewing software
- Printable maps
- Web Map Service (WMS)
- IHO-IOC GEBCO Cook Book

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IHO International Hydrographic Organization IOC Intergovernmental Oceanographic Commission

General Bathymetric Chart of the Oceans

GEBCO aims to provide the most authoritative, publicly available bathymetry data sets for the world's oceans.

Download GEBCO's global grid Download polar grids Contribute data

Gridded Bathymetry Data

GEBCO's gridded bathymetric data sets are global terrain models for ocean and land. The grids are available to download or access through Web Map Services.

Read more

Data & Products

GEBCO produces and makes available a range of bathymetric data sets and products. This includes a global bathymetric grid; gazetteer of undersea feature names, a Web Map Service and printable maps of ocean bathymetry.

Read more

Seabed 2030

Seabed 2030 is a collaborative project between the Nippon Foundation and GEBCO. It aims to bring together all available bathymetric data to produce the definitive map of the world ocean floor by 2030 and make it available to all.

Read more

Download the GEBCO grid from: gebco.net or seabed2030.org

Seabed 2030: A GEBCO Accelerator

The Nippon Foundation - GEBCO Seabed 2030 Project is a collaborative project to inspire the complete mapping of the world's ocean by 2030, and to compile all bathymetric data into the freely-available GEBCO Ocean Map.

Seabed 2030 aspires to empower the world to make policy decisions, use the ocean sustainably, and undertake scientific research that is informed by a detailed understanding of the global ocean floor.



Seabed 2030: A Regional Approach



Global Center

- Assemble global products
- Disseminate global products

Regional Centers

- Engage with stakeholders
- Build upon existing efforts
- Build capacity
- Assemble regional products
- Identify gaps

IHO DCDB

- Long-term archive



LAMONT-DOHERTY EARTH OBSERVATORY
COLUMBIA CLIMATE SCHOOL



Land Information
New Zealand
Toitū te whenua

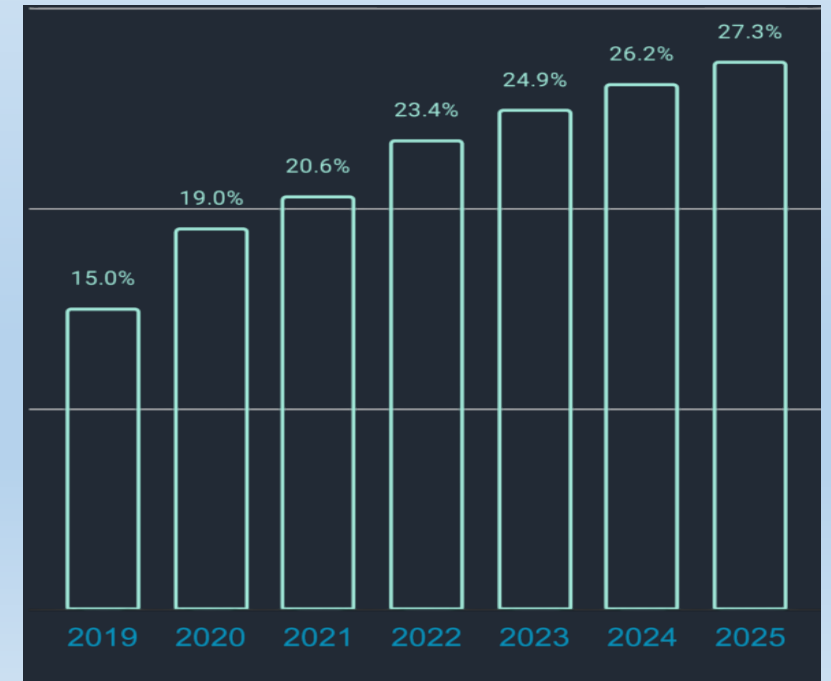
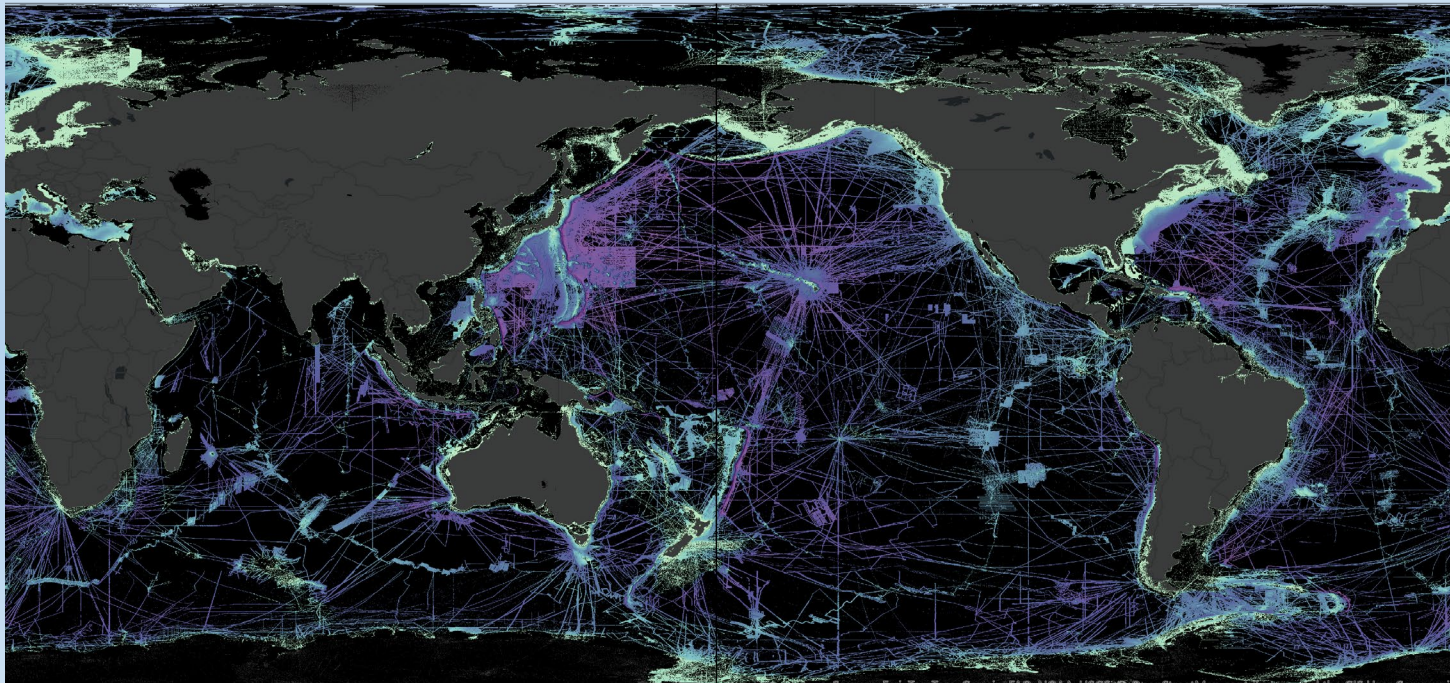


Why is Seabed 2030 Important?

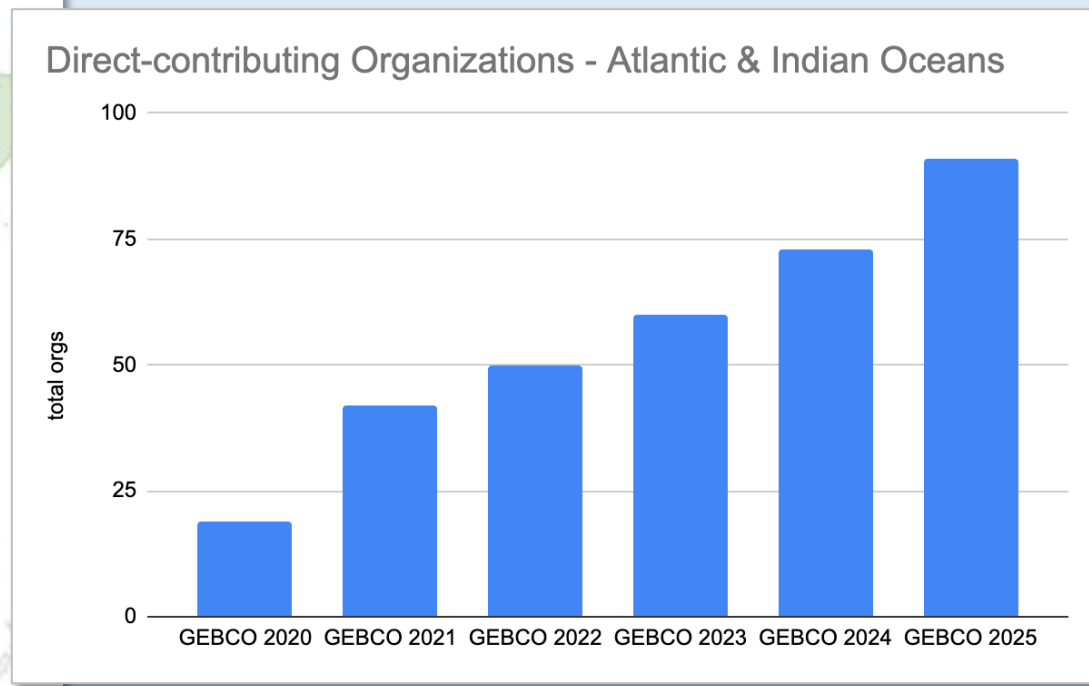
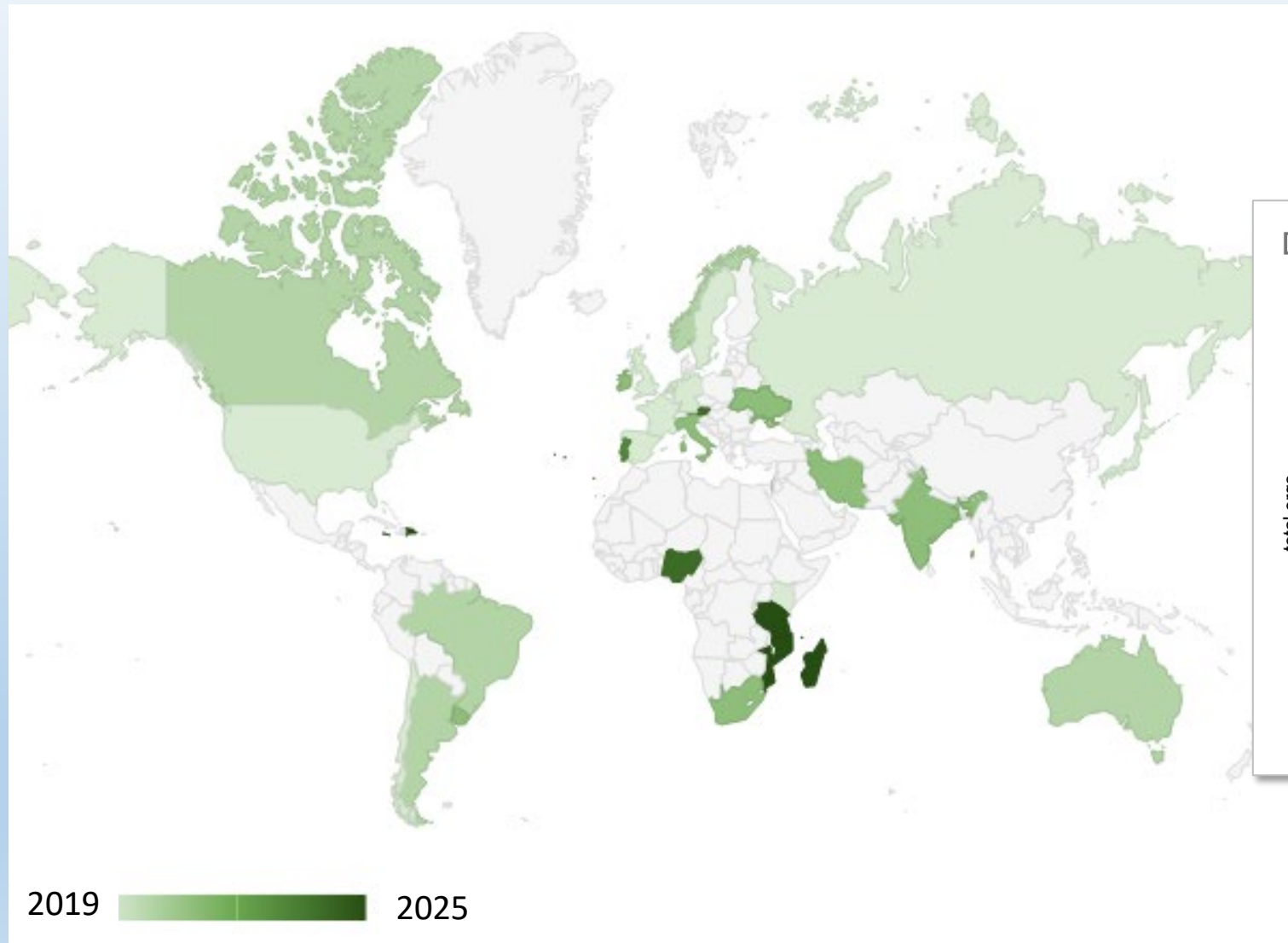
- Bathymetry data is an essential ocean observation
- Seabed mapping data has broad use and value
- **Ocean processes extend beyond territorial waters**
- Can only be achieved through **cooperation & coordination**
- Only 27.3% of the ocean has been mapped with direct observation (GEBCO 2025)

Only 6% of the ocean floor was mapped to an adequate resolution when the initiative first started...

Seabed 2030 was launched at the first ever UN Ocean Conference in New York in 2017. Today, we've seen the figure grow to a quarter of the seabed mapped.

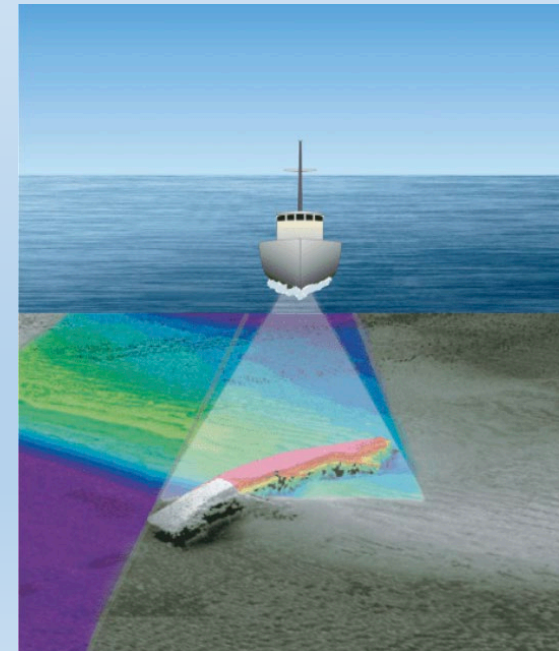
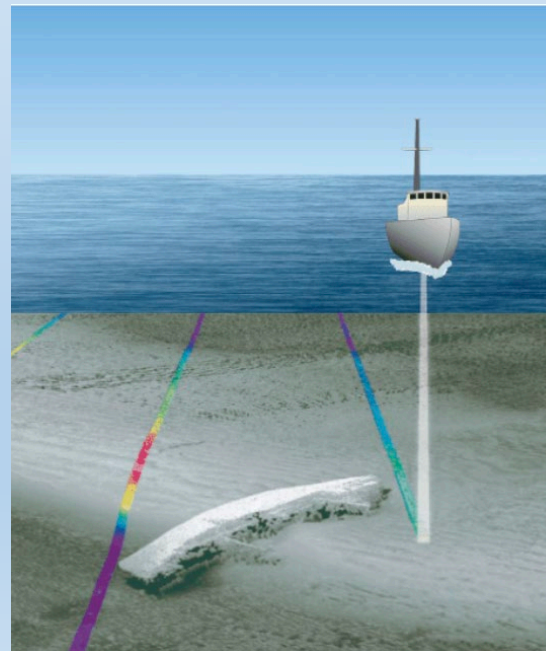
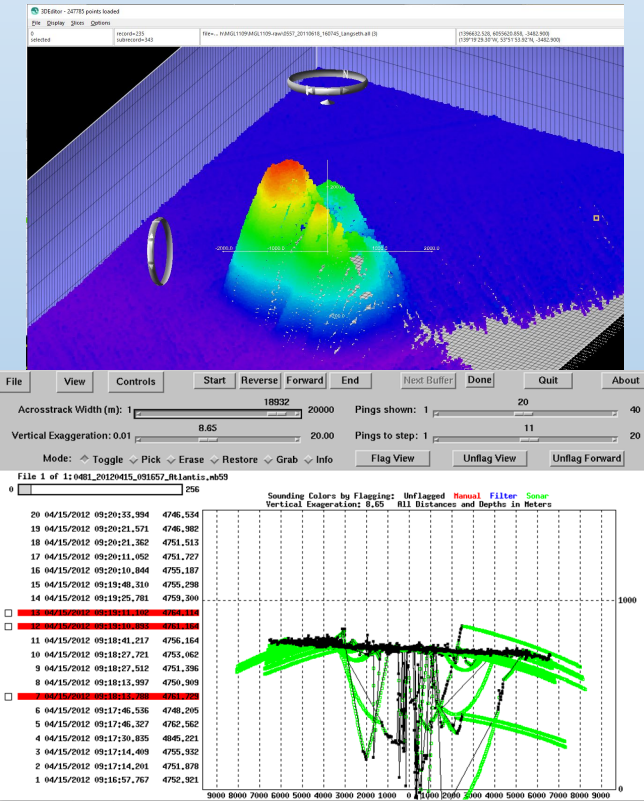
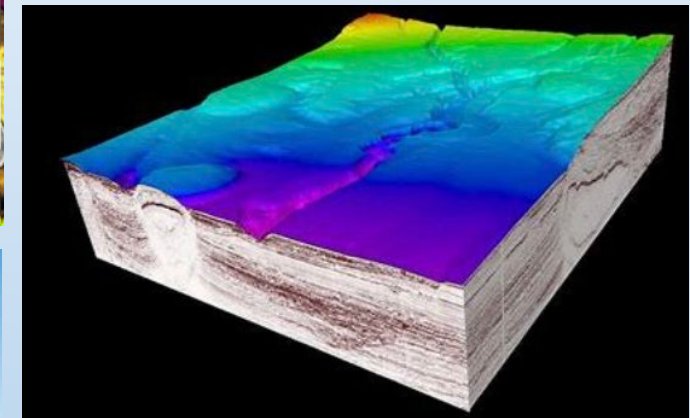
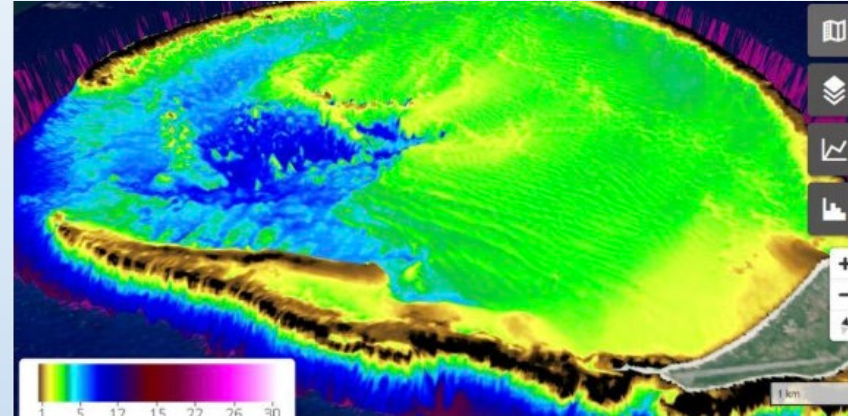
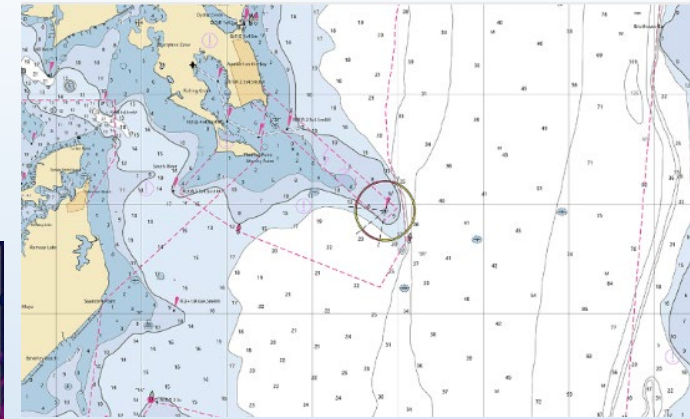


Data Contributors – Atlantic and Indian Oceans

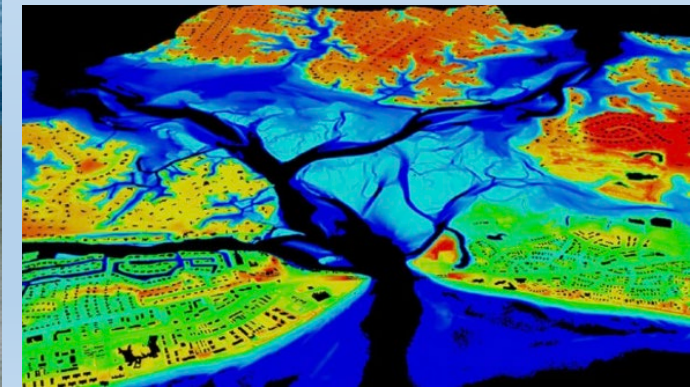


Harmonizing Data Sources

- Capabilities of Sensor
- Product Resolution
- Vertical/Horizontal Datum
- Uncertainty
- Multiple tools and approaches



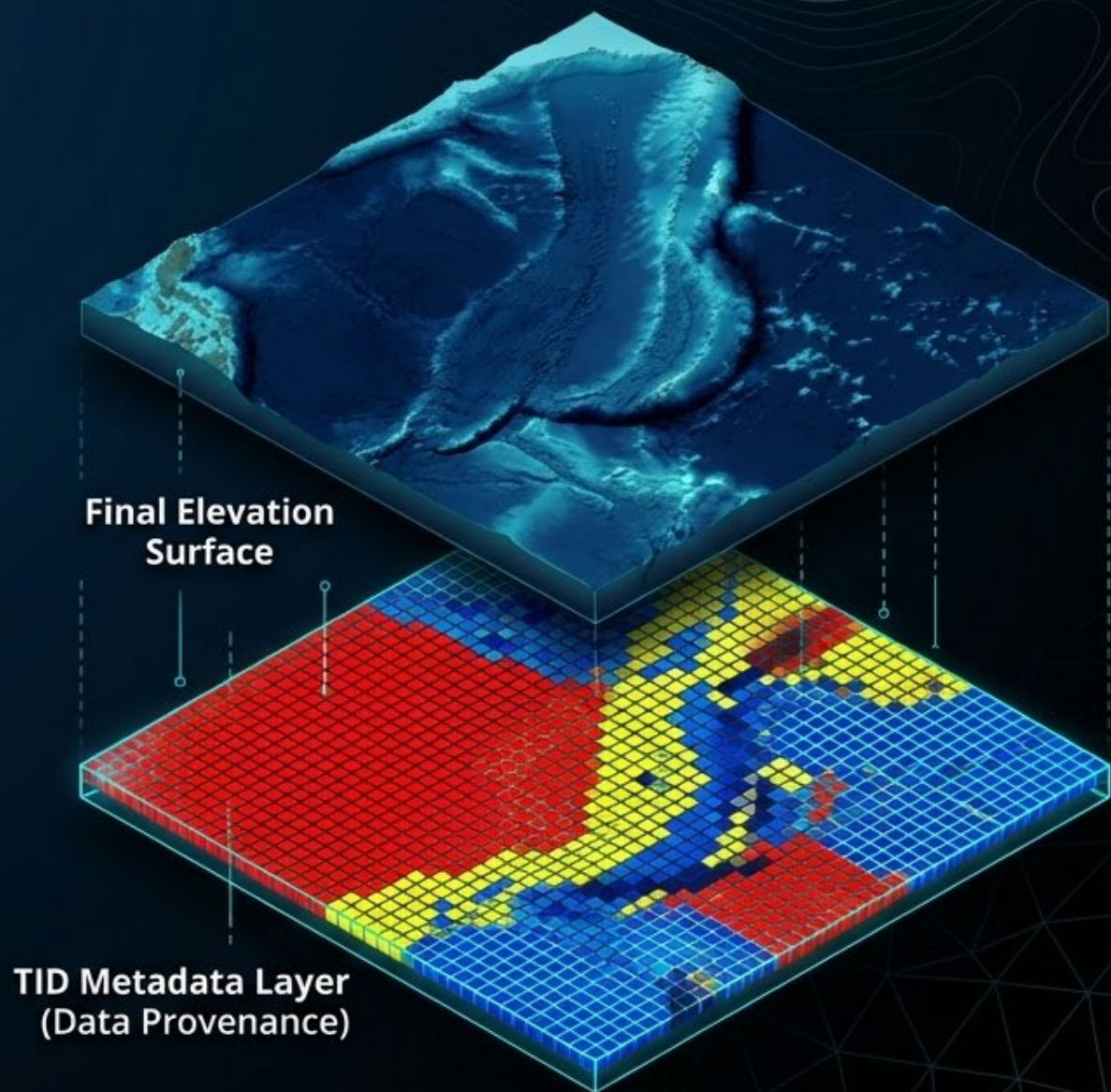
Tsunami Inundation Modelling and Mapping, INCOIS, Hyderabad, 16-21 March 2026



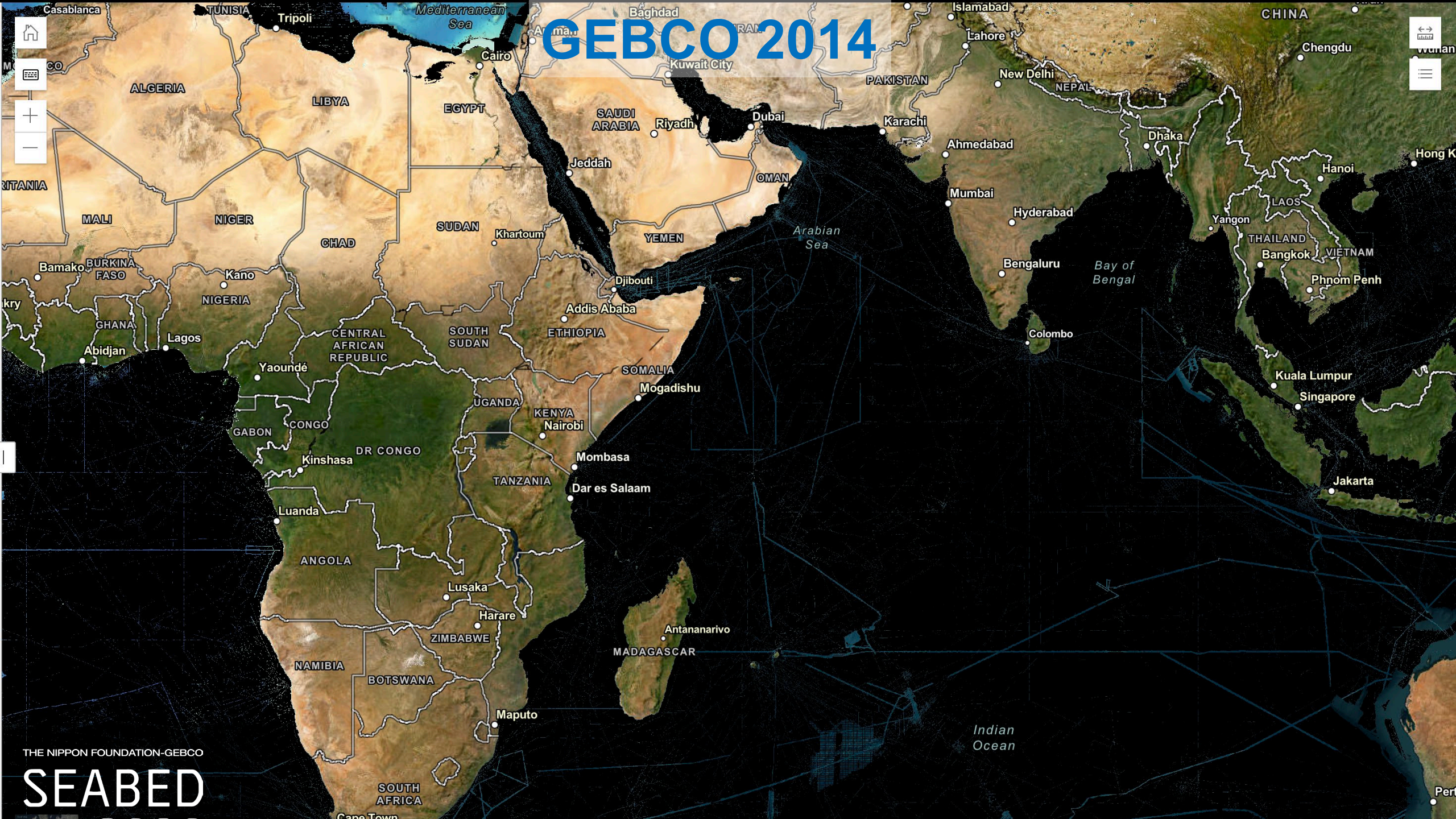
The DNA of the DEM: Type Identifiers (TID)

A modern DEM is a mathematical amalgamation. To maintain data integrity, the GEBCO grid utilizes a Type Identifier (TID) layer. TID logs the precise provenance of every single grid cell.

Without this genetic code, scientists cannot differentiate a hard sonar measurement from a mathematical prediction.



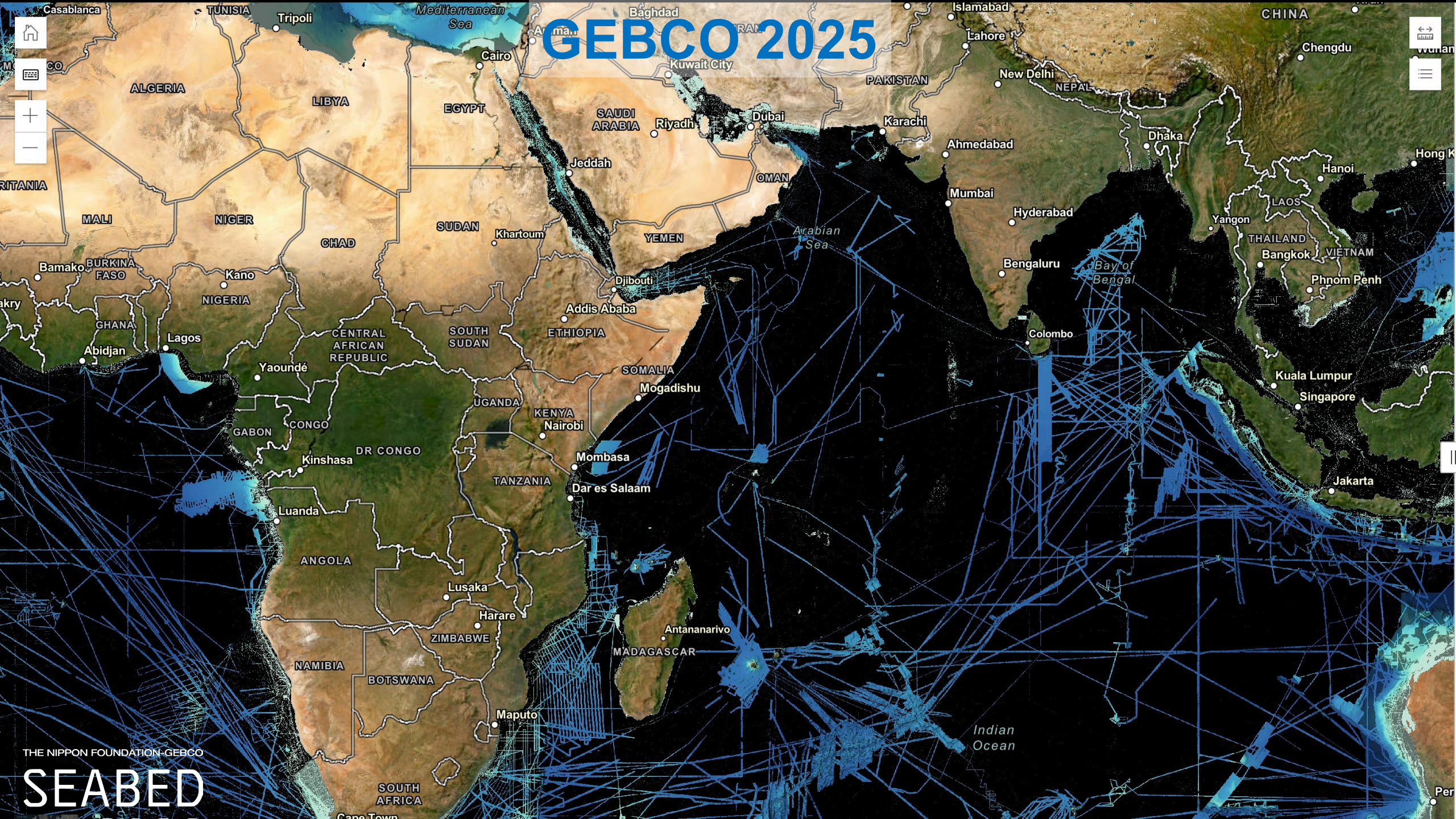
GEBCO 2014



THE NIPPON FOUNDATION-GEBCO

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GEBCO 2025



THE NIPPON FOUNDATION - GEBCO

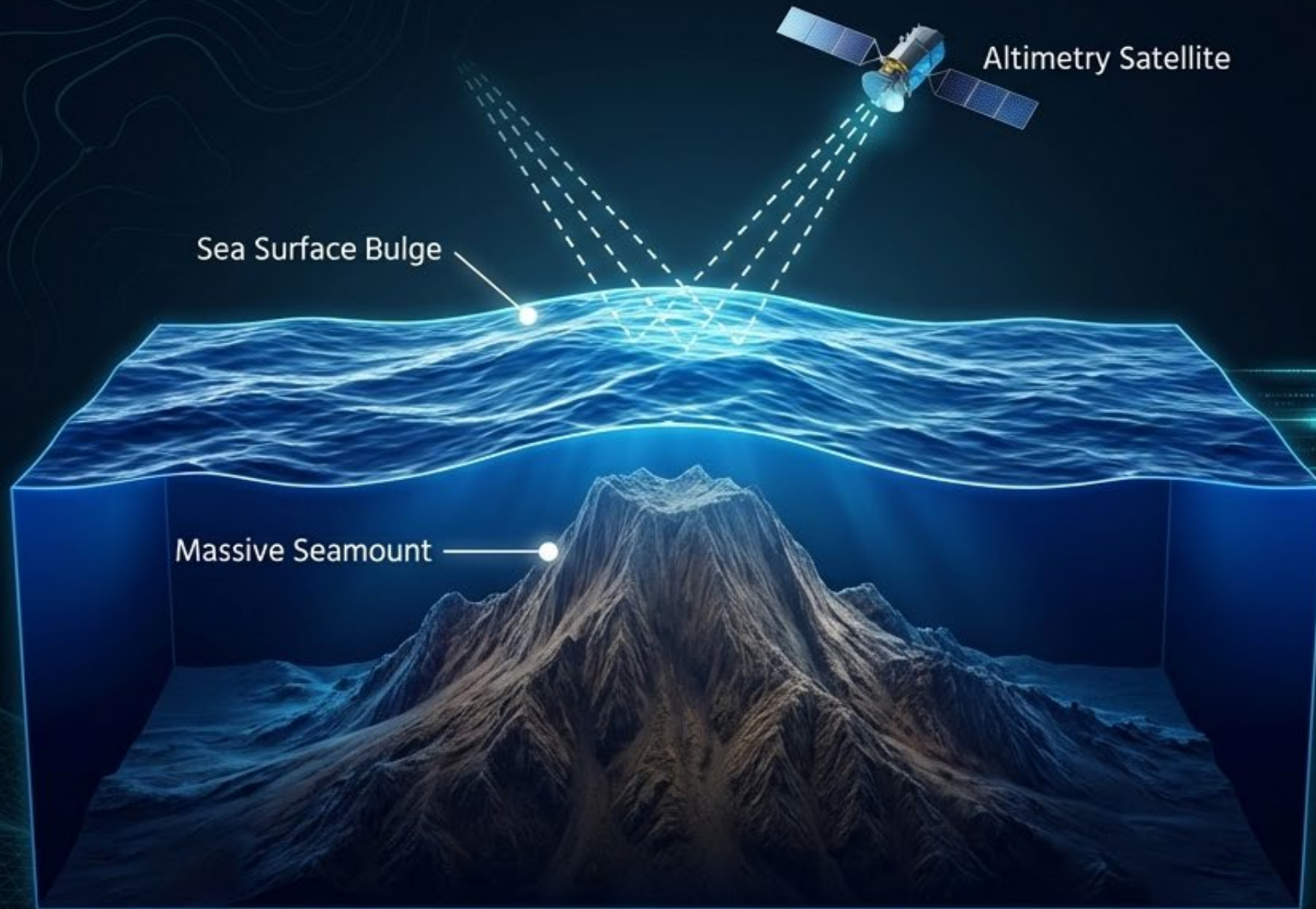
SEABED

Indian Ocean

Charting the Seafloor: Direct vs. Predicted Bathymetry

	Direct Measurement (Sonar/LiDAR)	Indirect Prediction (Satellite Altimetry)
Methodology	Acoustic pings & laser pulses	Sea-surface gravity fluctuations
Spatial Resolution	Ultra-High (meters/centimeters)	Low/Limited (kilometers)
Global Coverage	Tracklines & specific swaths (26%)	Full global perspective (100%)
The Trade-off	Provides ground-truth accuracy but leaves massive spatial data gaps.	Efficiently fills the global map but suffers from variable vertical accuracy.

Predicting the Deep: Mapping by Gravity



1. Mass Accumulation

Massive underwater topographic features (like seamounts) exert an excess gravitational pull.

2. Surface Topography

This localized gravity actually draws water toward the mass, creating a physical "bulge" on the sea surface.

3. Altimetry Detection

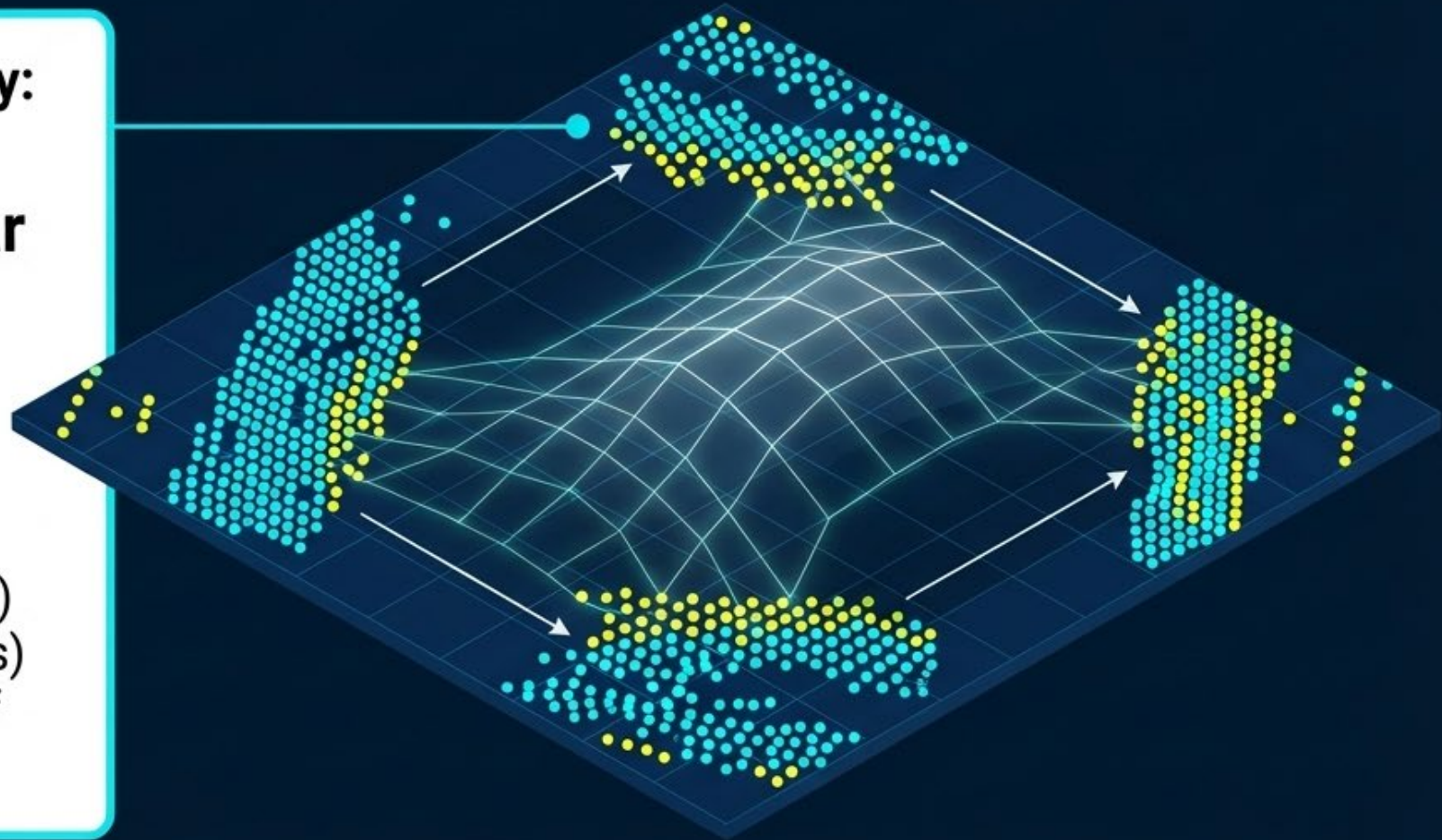
Satellites emit radio waves to measure minute fluctuations in sea surface height, allowing scientists to reverse-engineer the shape of the seafloor below.

Mathematical Interpolation

**Tobler's 1st Law of Geography:
Everything is related to
everything else, but near
things are more related
than distant things.**

The Method:

Applying deterministic (math-only) or geostatistical (math + statistics) algorithms to predict the shape of the **unmeasured seafloor**.



Assembling the Global Mosaic

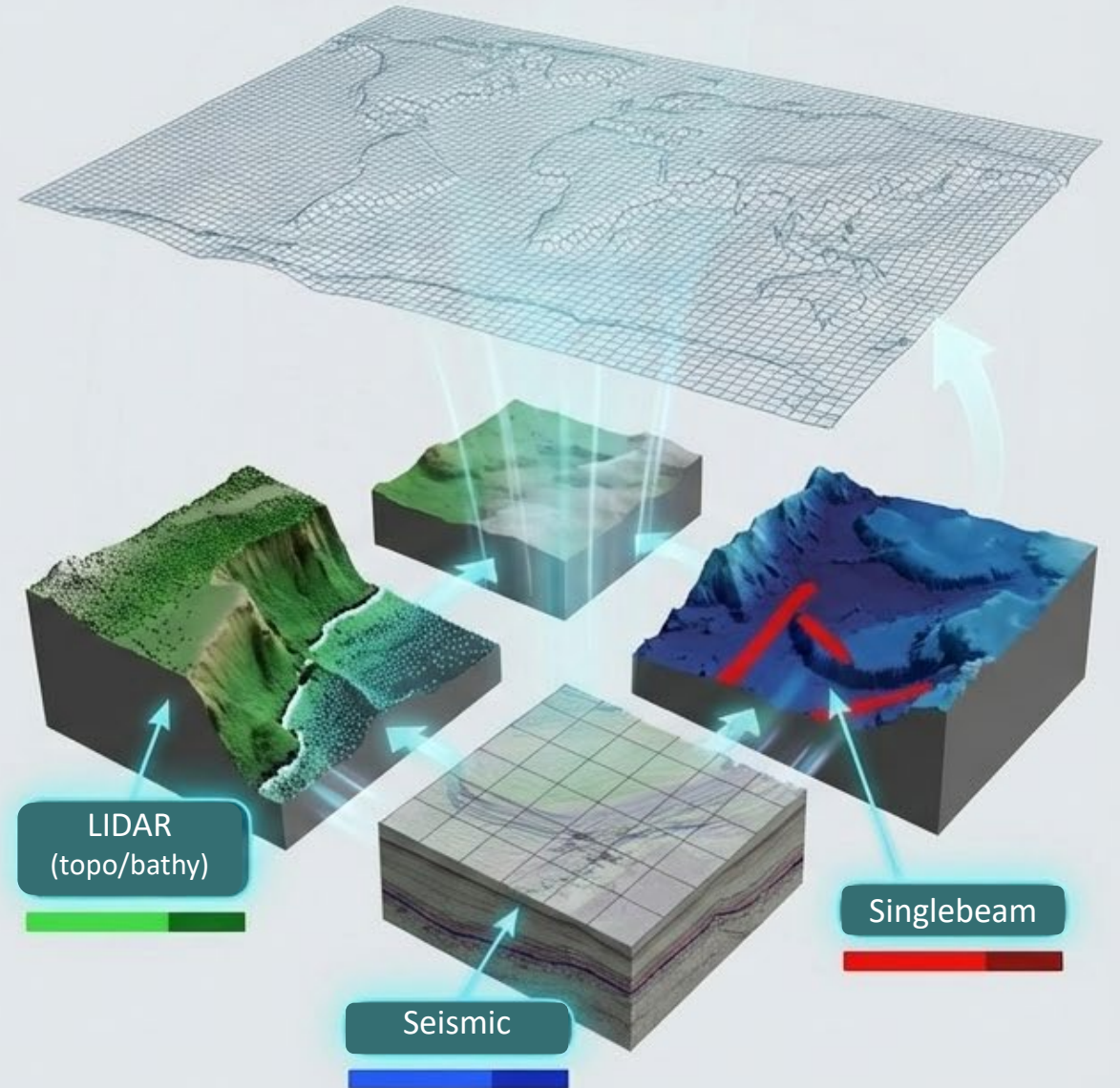
Integrating data from global contributors requires precise TID tracking to avoid compounding errors across borders and data sets.

Direct Measurements

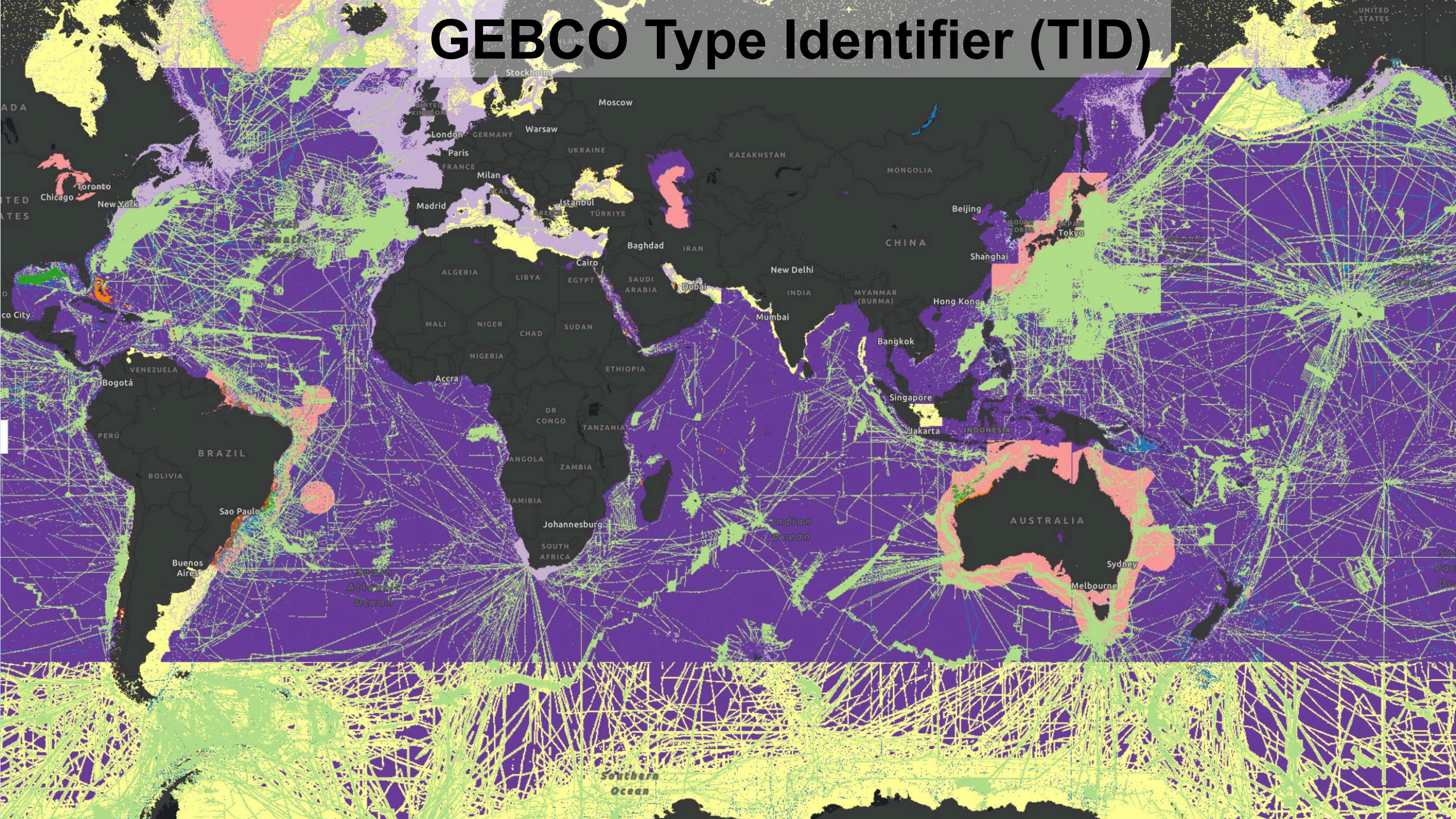
- Sonar: Multibeam, Single-beam
- Seismic
- Electronic Nautical Chart (ENC)
- LiDAR
- Satellite Derived Bathymetry (SDB)

Indirect Measurements

- Predicted Bathymetry
- Mathematical Interpolation



GEBCO Type Identifier (TID)



Real-World Stakes: Tsunami Inundation Modeling

Why does a seamless, reconciled DEM matter? Because tsunamis are ocean-spanning events. When a wave impacts the coast, its physics, speed, and inundation path are dictated entirely by the shape of the shallow bathymetry and bare-earth topography.

A null depth value, a poor interpolation, or an uncorrected coastal “step” will crash the simulation or provide fatal inaccuracies.



The Coastal Collision Creates a Technological Blind Spot

Merging topography (land) and bathymetry (sea) is inherently **difficult** because they require entirely different measurement environments and instruments.

Air (Topography)

Instrument: Airborne LiDAR.
Limitation: Pulses often cannot penetrate turbid or murky coastal waters.



Water (Bathymetry)

Instrument: Ship-borne Multibeam Swath Sonar.
Limitation: Survey vessels cannot safely navigate or ping efficiently in ultra-shallow, rocky surf zones.

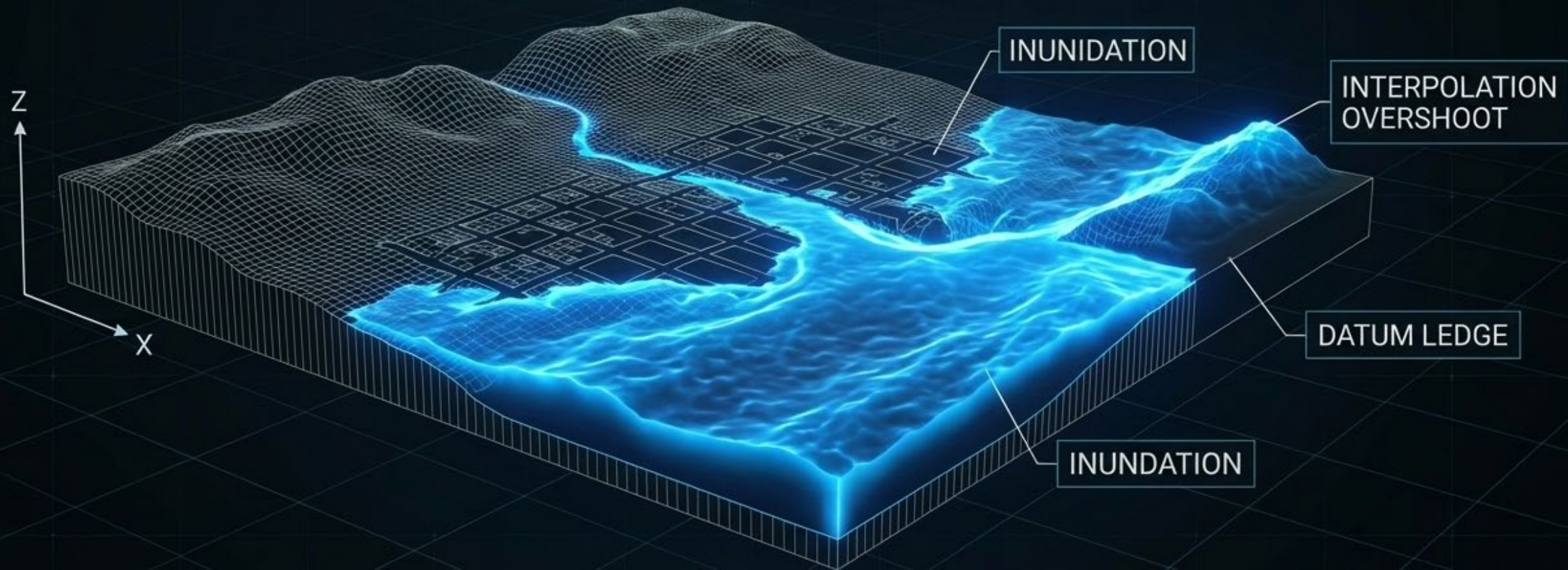


The Coastal Gap:
A persistent,
dangerous data gap.

Why Precision Matters: Tsunami Inundation Modeling

Seamless Topo-Bathy DEMs are the foundational inputs for advanced tsunami forecasting software.

If a DEM contains an artificial datum ledge or an interpolation overshoot, it will cause the numerical model to become unstable, resulting in unphysical wave behaviors and inaccurate flood predictions for coastal communities.



The Datum Problem: Artificial Ledges

Topography and bathymetry utilize completely different baselines for 'zero.' Merging these datasets directly without mathematical reconciliation creates artificial vertical cliffs at the coastline.

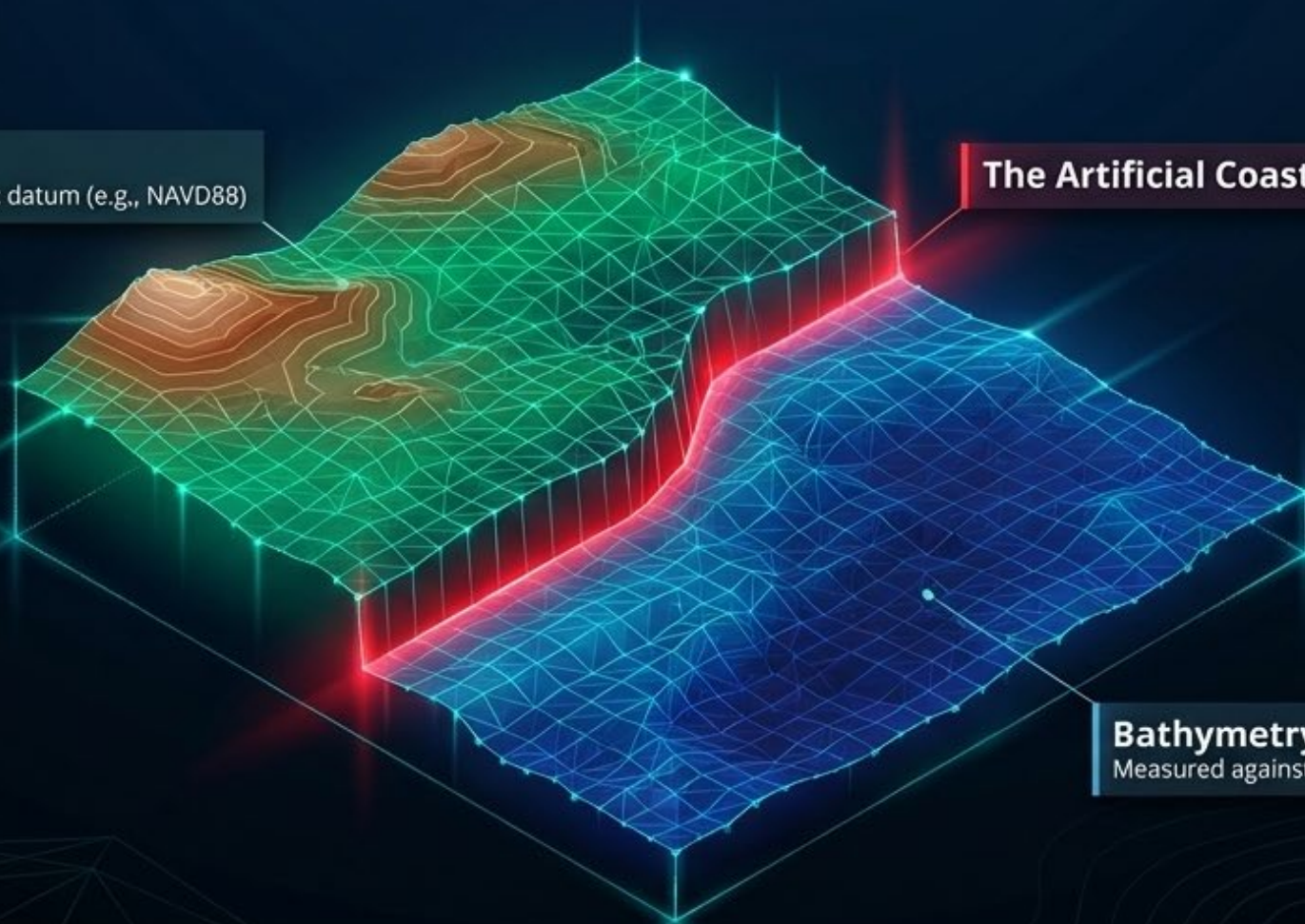
Topography

Measured against a geodetic datum (e.g., NAVD88)

The Artificial Coastal Step

Bathymetry

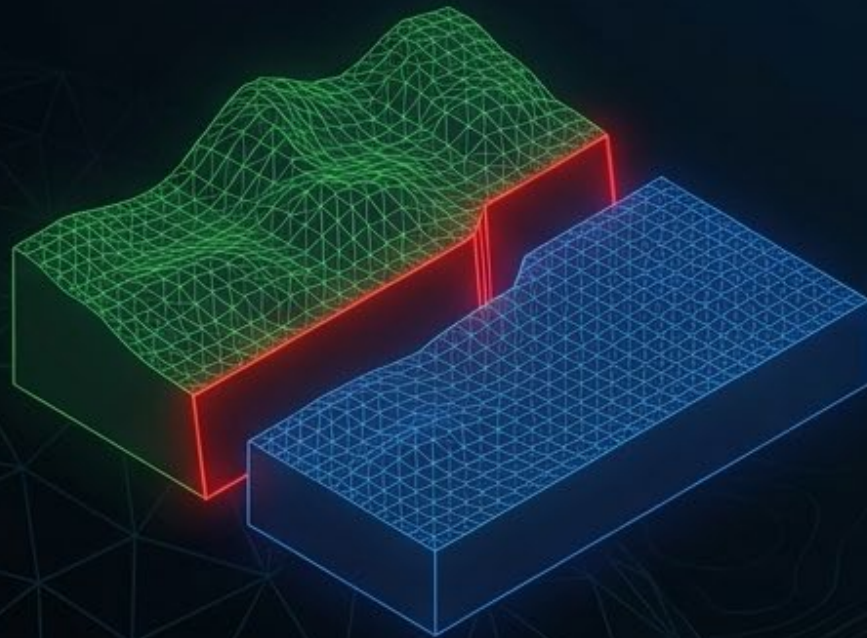
Measured against tidal datums (e.g., Mean Lower Low Water, MLLW)



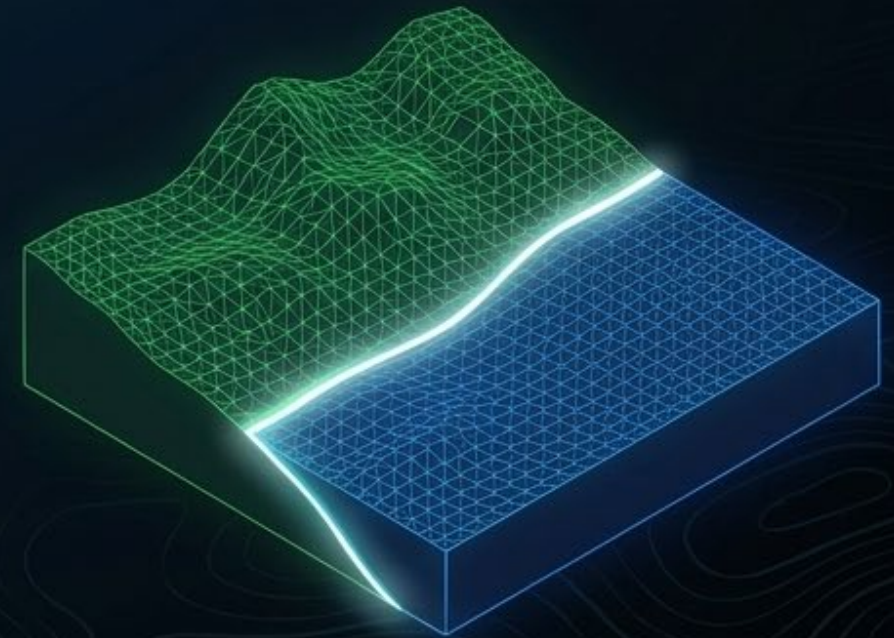
VDatum: Ironing out the Seam

To eliminate the coastal step, tools like NOAA's VDatum act as the mathematical translator. VDatum systematically transforms geospatial point data among varying tidal, orthometric, and ellipsoidal vertical datums. This localized mathematical adjustment is what finally allows the mountains to seamlessly connect to the abyss.

Before: The Datum Mismatch



After: Seamless Reconciliation



Point-Cloud Integration: Reconciling Sensor Density

Airborne LiDAR (Topography & Shallow Bathymetry)

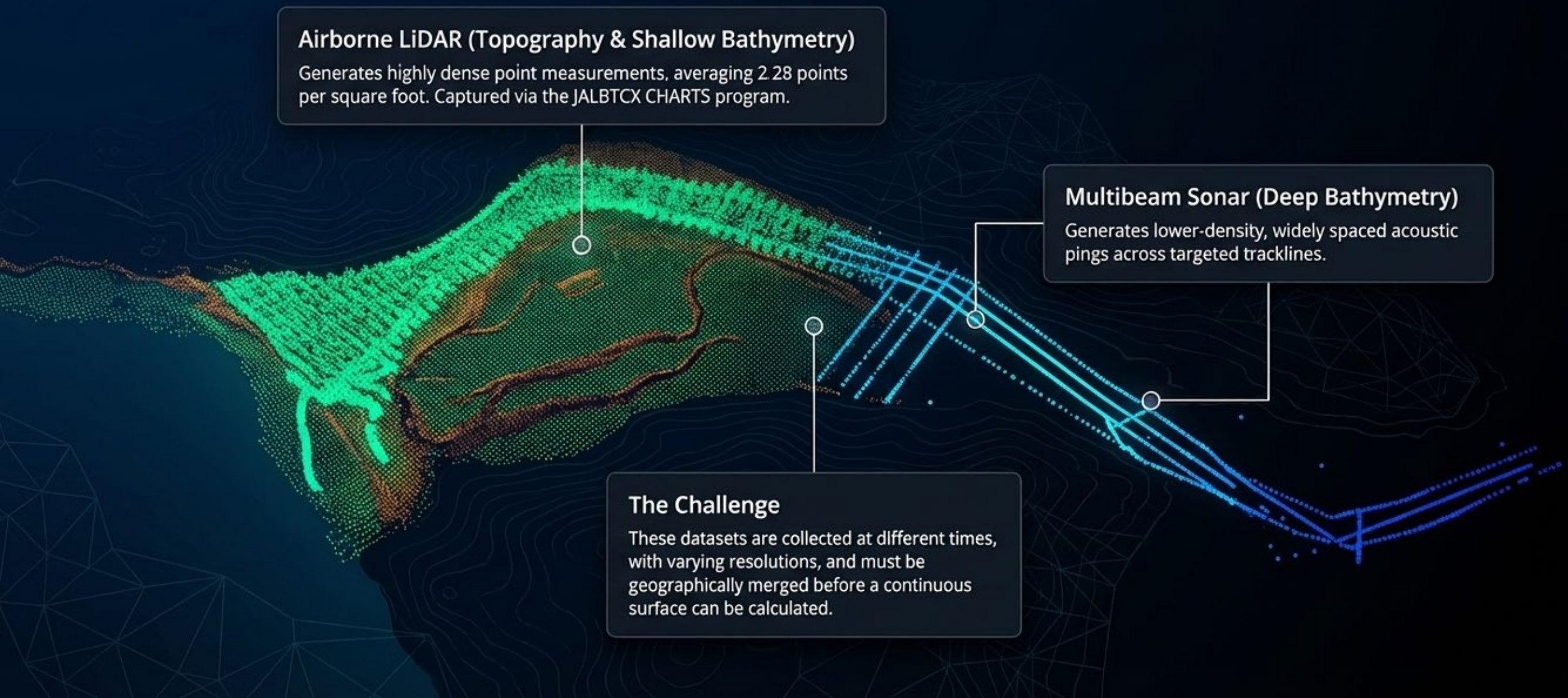
Generates highly dense point measurements, averaging 2.28 points per square foot. Captured via the JALBTCX CHARTS program.

Multibeam Sonar (Deep Bathymetry)

Generates lower-density, widely spaced acoustic pings across targeted tracklines.

The Challenge

These datasets are collected at different times, with varying resolutions, and must be geographically merged before a continuous surface can be calculated.



Bridging the Void: Mathematical Interpolation

When measurements are sparse, algorithms must estimate the unknown based on spatial autocorrelation. Research demonstrates that accuracy naturally decreases as distance, slope, and curvature increase.

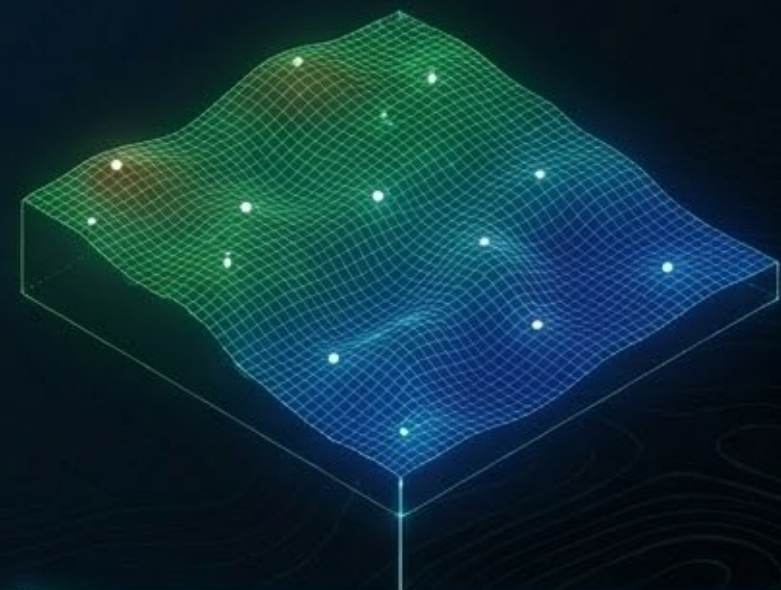
IDW (Inverse Distance Weighting)



Triangulation / Kriging



Spline



The Optimal Constraint:
Frequently the most accurate technique for heterogeneous coastal bathymetry, preventing extreme, unnatural depth spikes.

The Terrain Penalty: Slope and Curvature Degrade Accuracy

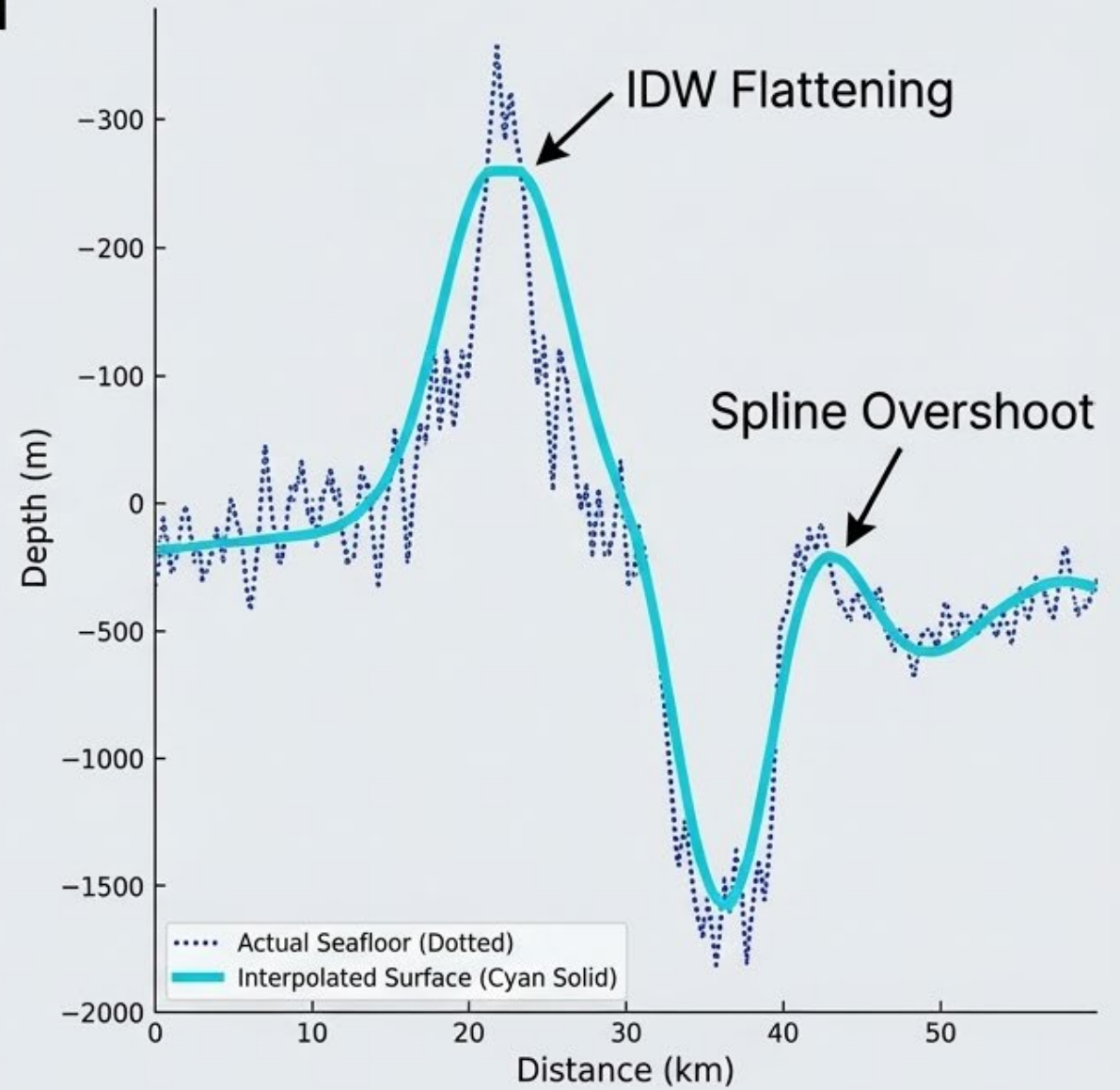
Interpolation accuracy drops significantly as the distance to the nearest physical measurement increases. This error compounds drastically in rugged environments.

1 The Flattening Effect:

Algorithms like IDW literally cut the corners off the sharpest seamounts and fill in the deepest oceanic trenches.

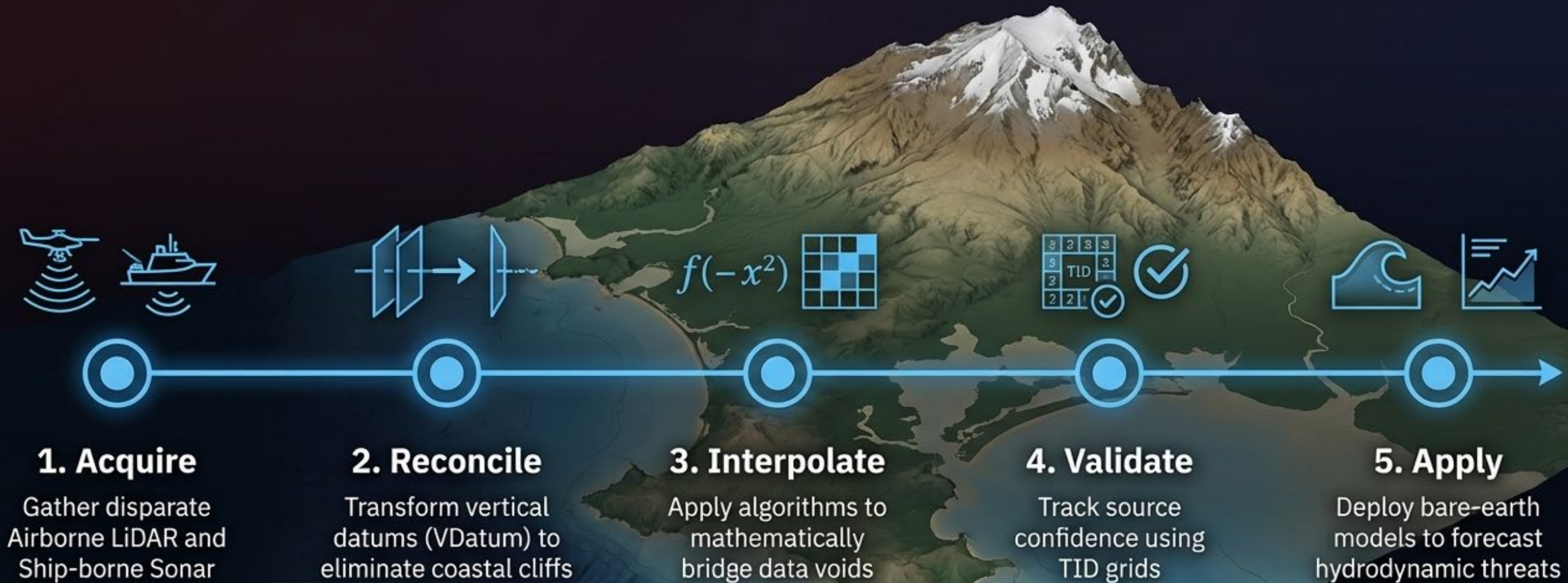
2 The Overshoot Effect:

Spline algorithms accurately track slopes but can mathematically overshoot when the terrain curves too sharply, creating false ridges.



The Anatomy of a Seamless Surface

Bridging the divide between land and sea requires a rigorous, multi-step data pipeline.



Telescopic Resolution for Coastal Safety

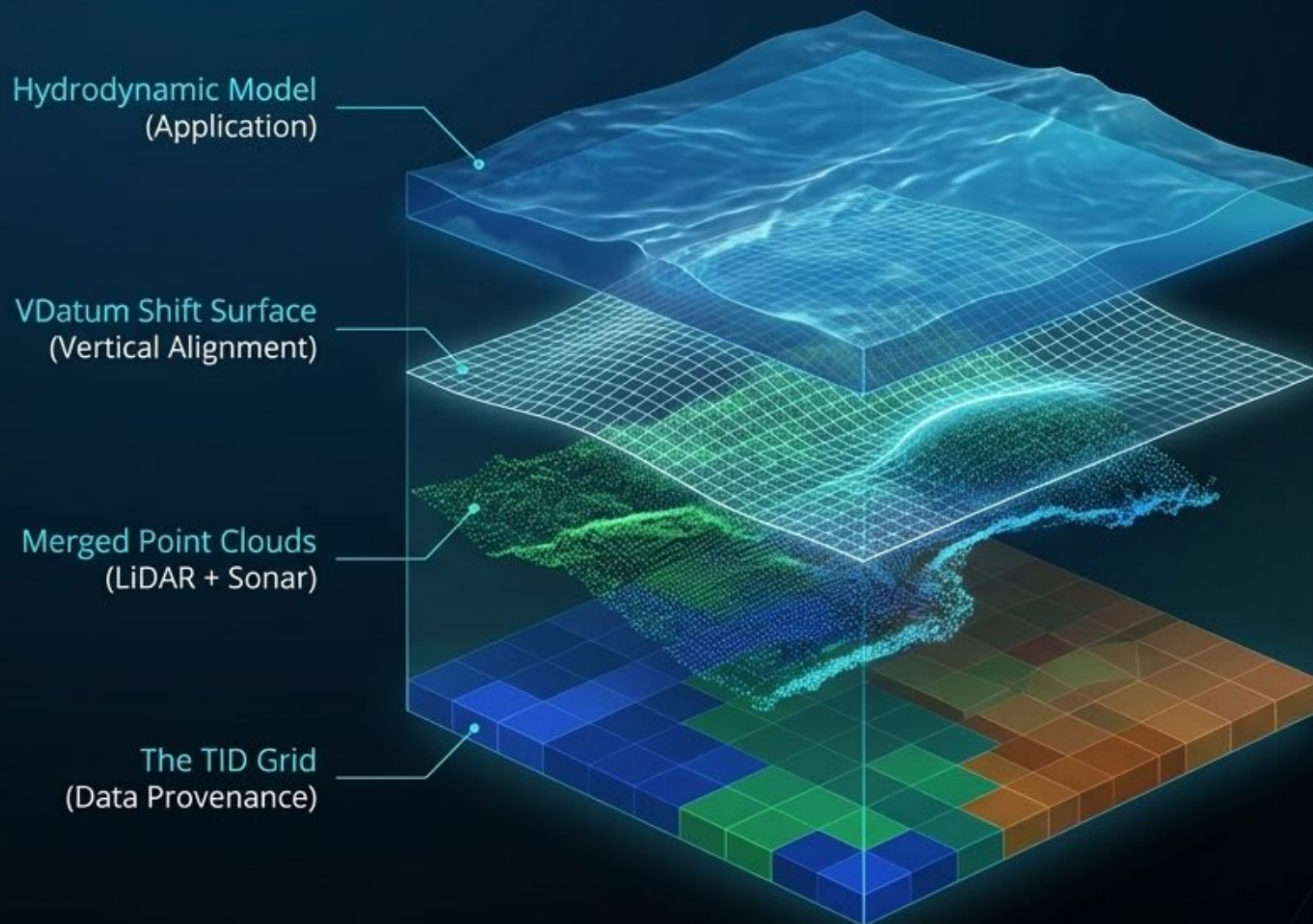
Tsunamis propagate across massive, open ocean basins but inundate at the highly localized scale of single city streets and harbors.

To manage computational load, simulations utilize nested, telescopic grids:

- **Outer Grid:** Low resolution for deep-ocean propagation.
- **Intermediate Grid:** Medium resolution capturing islands and regional coastlines.
- **Inner Grid:** Ultra-high resolution hugging specific rugged shorelines and harbor basins.



The Mathematical Tapestry



A modern DEM is not a static picture; it is a meticulously reconciled mathematical surface. By combining Data Provenance, Spatial Estimation, and Vertical Alignment, we create the seamless models required for resilient coastal survival.

Mapping the unseen 70% of our planet by 2030 is not just an act of exploration—it is the foundation of our future.

Seabed 2030 Indo-Pacific Ocean Mapping Meeting & Data Sprint

9th – 11th June 2026 | Kuala Lumpur, Malaysia

Hosted by the National Hydrographic Centre, Malaysia

Program Schedule

- June 9 – 10: Plenary Sessions (Hybrid): Knowledge exchange and showcase of regional ocean mapping activities
- June 10 – 11: Regional Data Sprint (In-person): Hands-on collaborative session to accelerate the preparation and integration of bathymetric data into the global GEBCO grid

Registration & Attendance

- **Cost:** Registration is FREE
- **Deadline:** In-person registration closes Friday, April 17
- **Travel Support:** Limited financial support is available for eligible participants (decisions announced April 28)



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Thank you