Flood Risk Assessment in a Changing Climate for Cities using EO (FRACCEO)

Combining satellite data & models to improve coastal flood prediction and risk assessment in a changing climate

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Project Objectives

Climate Space: Climate Change and Cities Activity – EXPRO

Overarching objective

Develop a consistent, globally applicable methodology that combined satellite altimetry with hydrodynamic models to improve coastal total water level estimation and, consequently, flood inundation modelling

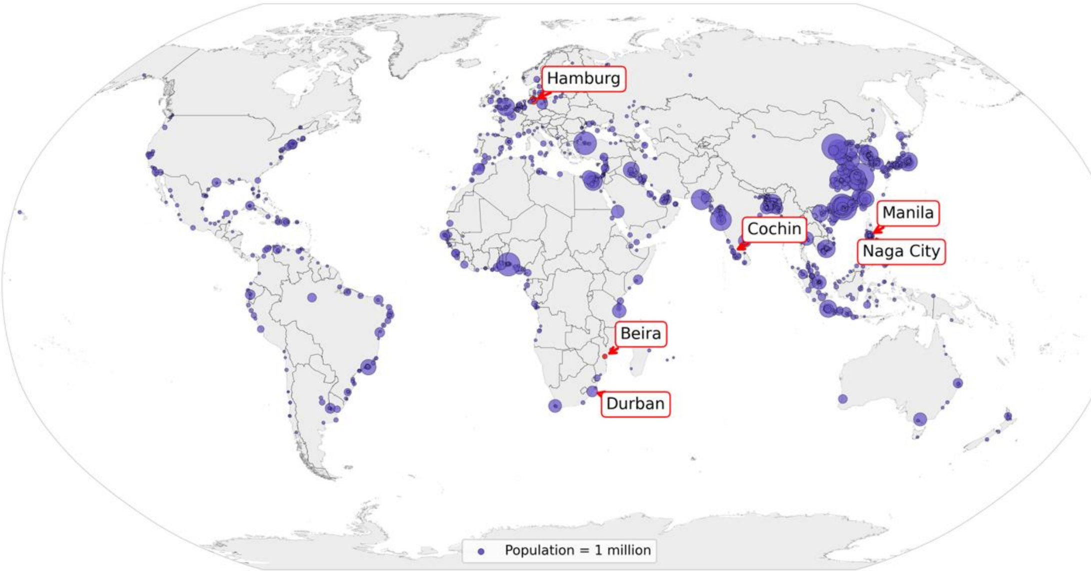
Connections with wider community and policy activities

- Contributing IPCC Special Report on Cities (Review and Scientific Roadmap)
- Builds on and contributes to multiple Horizon climate resilience projects (COMPASS, RECEIPT, REACHOUT, UP2030, Destination Earth)
- WCRP Safe Landing Climates – Sea Level Rise Theme
- EuroGOOS Scientific Advisory Group
- Copernicus Climate Service (C3S)
- World Bank EPIC Response
- Resilient Cities Network

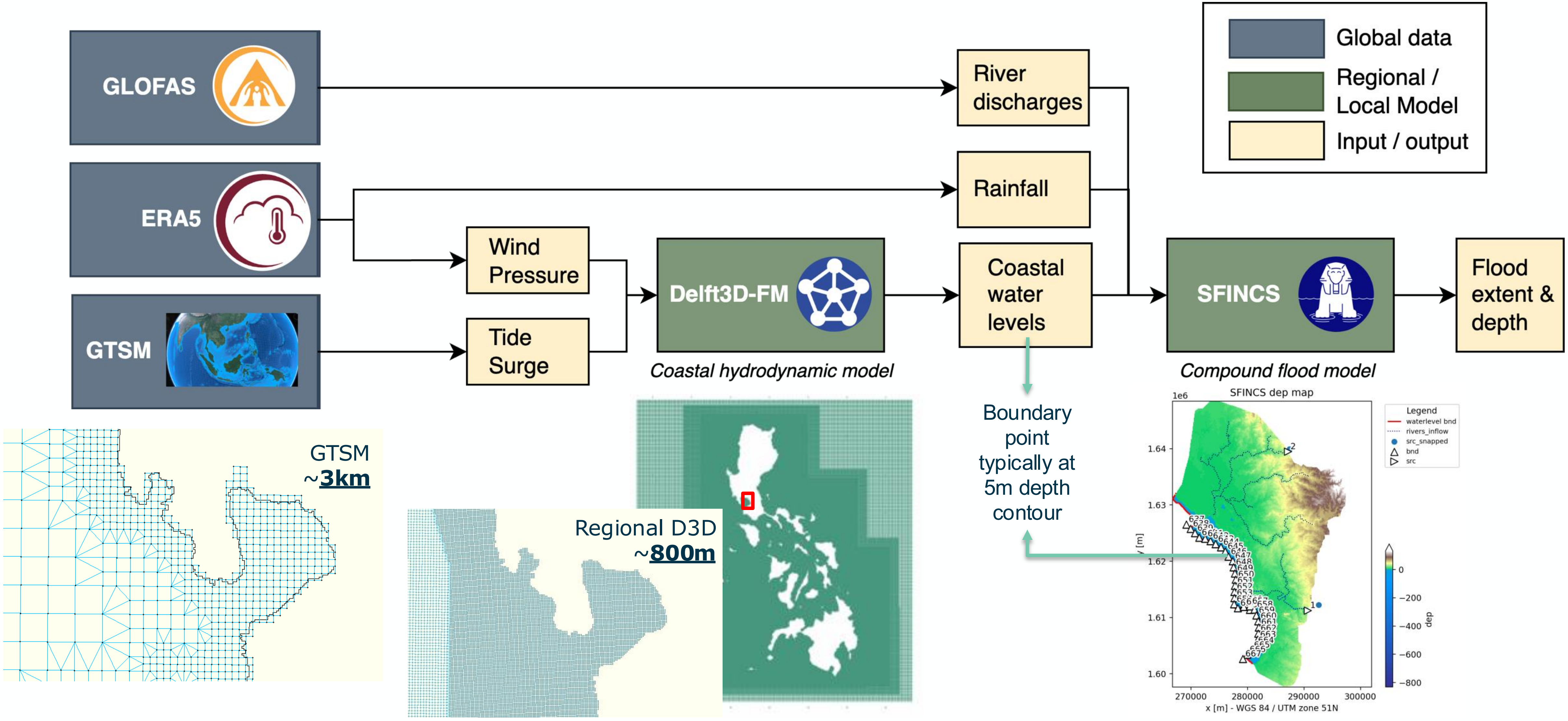
Project Objectives

Specific objectives

- **Extreme detection from EO:** Detect and characterise coastal sea-level and sea-state extremes from along-track altimetry with enhanced coastal QC/retracking and noise filtering.
- **EO-model fusion:** Combine EO-derived sea level and wave information with hydrodynamic models to enhance tides, surge, wave contributions affecting coastal flooding representation.
- **Vertical referencing:** Establish a globally consistent vertical-referencing workflow to align altimetry, hydrodynamic model outputs and DEMs for reliable flood risk assessment.
- **Uncertainty:** Quantify measurement, modelling and statistical (extreme-value) uncertainties, and assess representativeness / precision needed for decision-making.
- **Validate and demonstrate:** Validate the approach for Hamburg (DE) and Beira (MZ); and demonstrate global transferability and sensitivity across hydro-climate settings in Durban (ZA), Kochi (IN), and Manila & Naga City (PH).

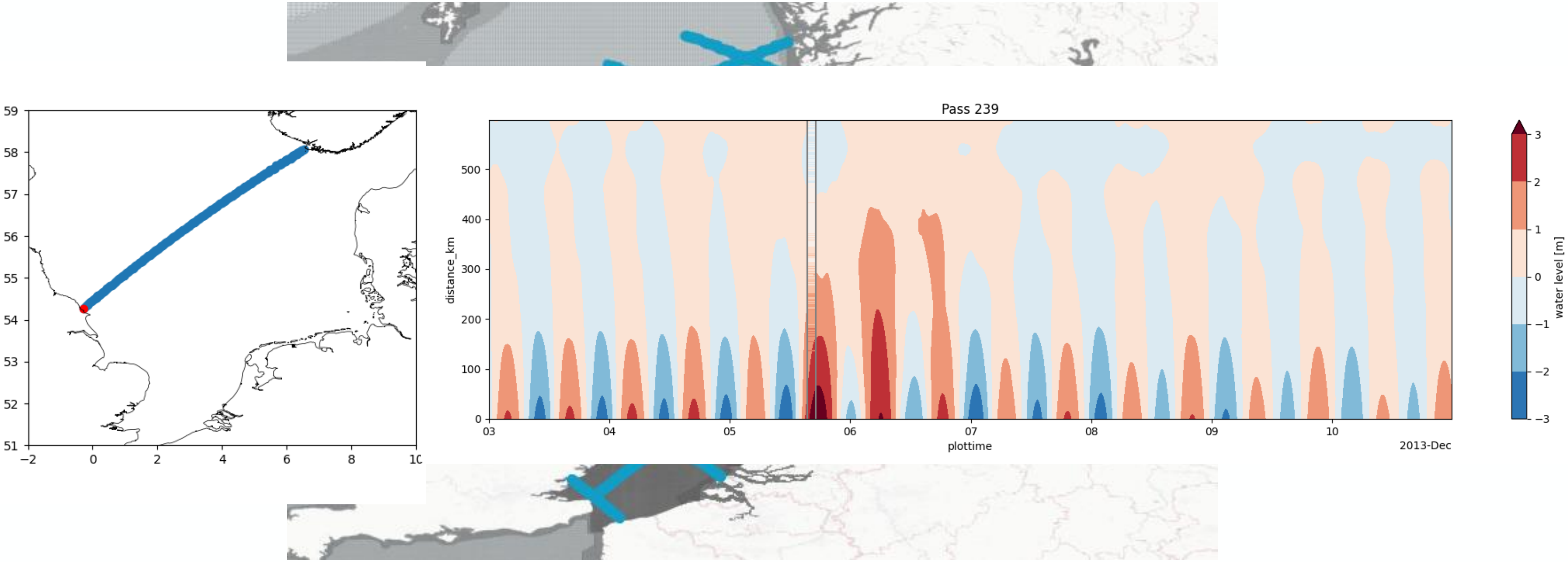


High-level modelling workflow



How best to leverage altimetry data?

Challenge #1: Spatio-temporal resolution of along-track altimetry data (and ESA CCI products)



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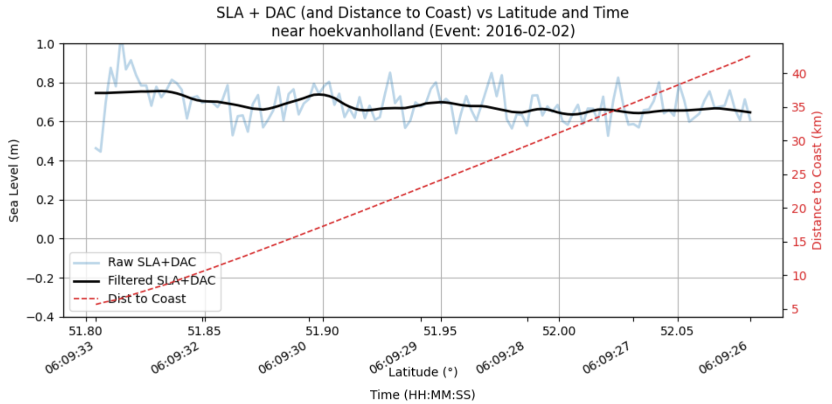
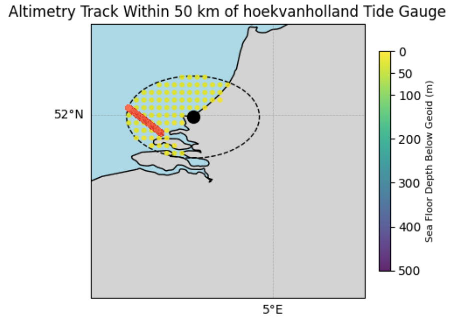
How best to leverage altimetry data?

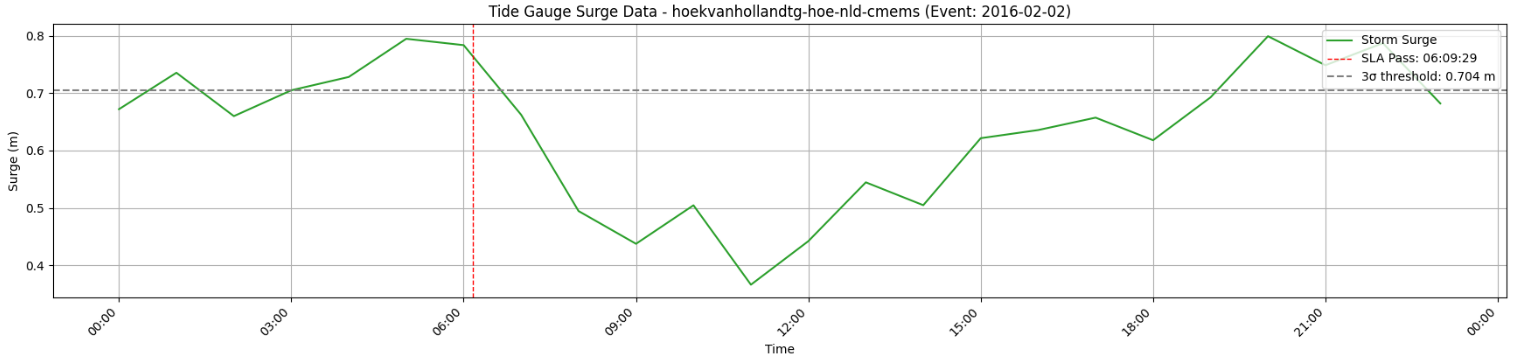
Challenge #2: Determining the surge from altimetry

- Compared several filtering methods (DBSCAN, Gaussian smoothing, LOWESS) and identified DBSCAN as the most effective for removing spurious coastal altimetry points.
- Tested multiple parameter sets, compared them against simultaneous tide-gauge data, and selected the combination that produced the lowest error.
- Applied filtering to FRACCEO case study locations and obtained clear improvements in surge estimation. E.g. North Sea

Data	Surge level
Tide gauge	0.784m
SLA + DAC raw	0.463m
SLA + DAC filtered	0.746m

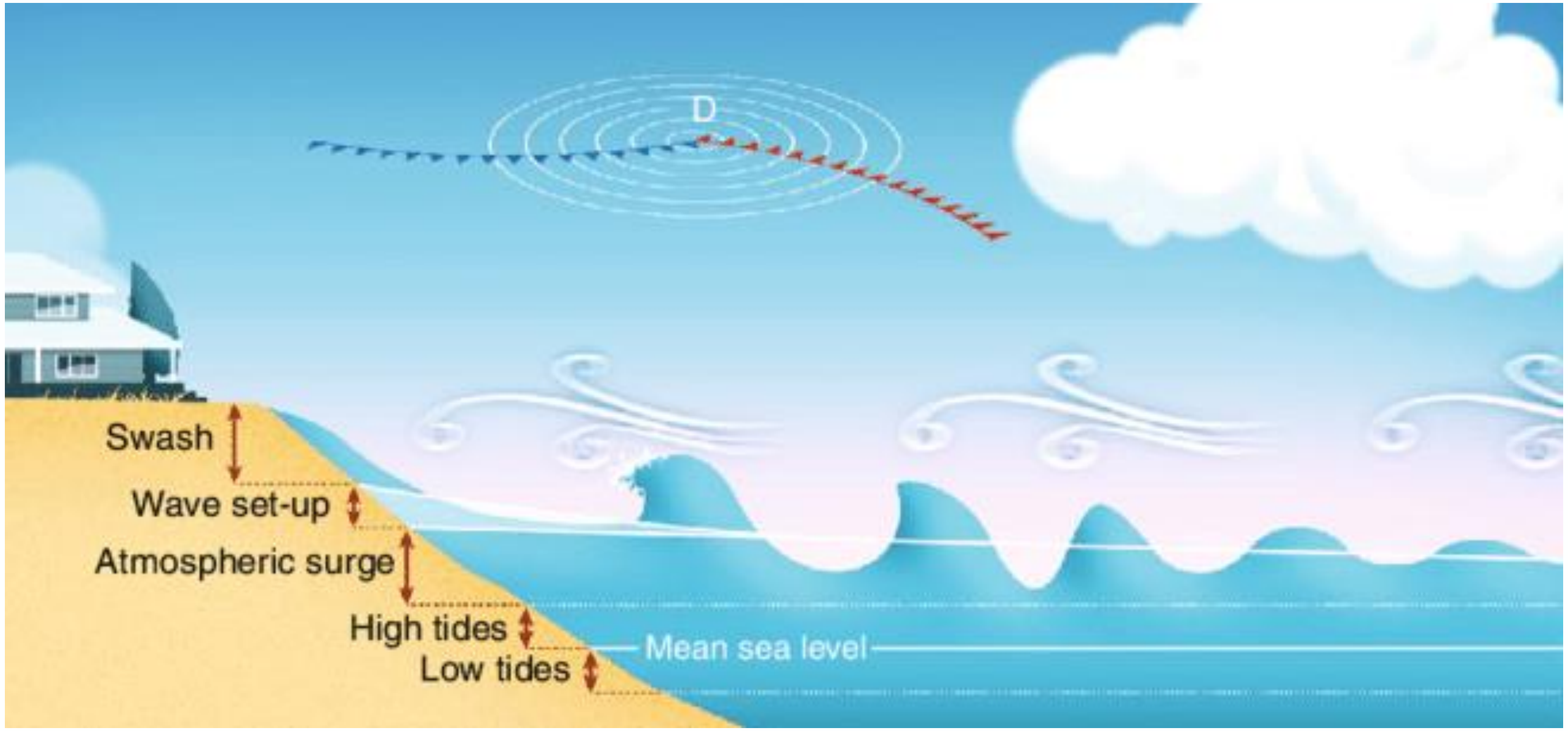






Modelling coastal total water levels

Challenge #3: Accurately resolving all processes contributing to total coastal water levels



Total Water Levels = MSL + Tides + Atmospheric storm surge + Wave Setup + Non-linear interactions (+ River discharge)

Baroclinic processes determine how these signals actually evolve and arrive at the coast.

Modelling coastal total water levels

Challenge #3: Accurately resolving all processes contributing to total coastal water levels

Baroclinic processes

- Density-driven gradients influence coastal sea level through steric height, thermal expansion, and salinity anomalies.
- Changes in stratification alter bottom friction, wave speed, and vertical structure of currents—affecting both timing and magnitude of extremes.

Requires 3D (full physics) models to

- Represent temperature-salinity structure
- Capture steric variability

Setting up and calibrating accurate 3D models is complex and resource intensive

Modelling coastal total water levels

Challenge #3: Accurately resolving all processes contributing to total coastal water levels

Pseudo-atmospheric-pressure forcing method

- Convert baroclinic water-level contribution (e.g. MDT) into a pseudo-atmospheric-pressure field
- Add this directly to the pressure forcing in the 2D tide-surge model

Baroclinic components are derived from

- DTU25 Mean Sea Surface (MSS)
- Regional geoid models
- Altimetry-derived long-term trends (ESA SL CCI)
- Annual & semi-annual baroclinic signals from EOT20

By-passes need for complex 3D modelling and can be applied globally using EO datasets

Common vertical reference surface

Challenge #4: Heterogeneity and inconsistency of vertical datums across all required datasets

Approach in FRACCEO

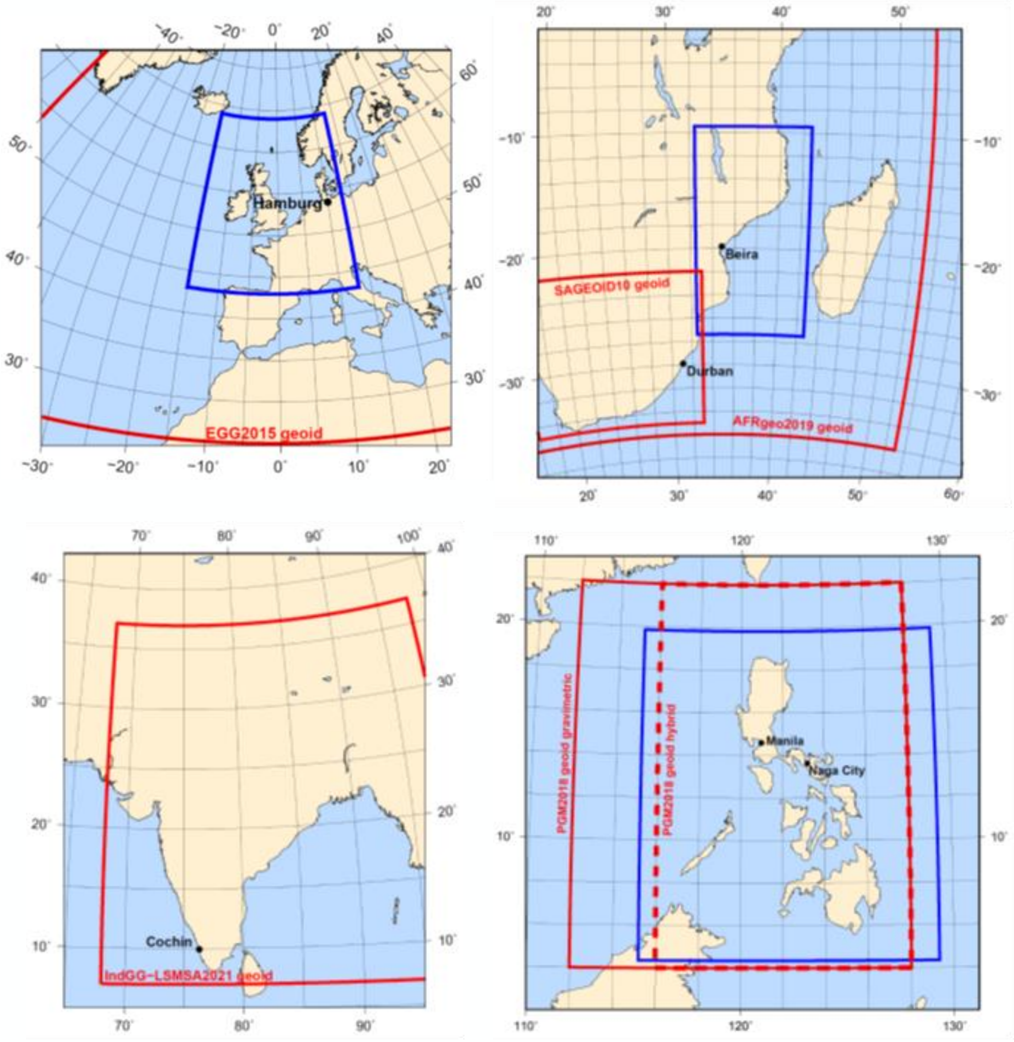
- Adopt a single, geoid-based vertical reference surface
- Use high resolution regional geoid models wherever possible, and global models offshore

High-resolution regional geoids for each case-study area:

- EGG2015 (Europe)
- AFRgeo2019 (Africa)
- IndGG models (India)
- PGM2018 (Philippines)

Global geoid model

- XGM2019e



Validation

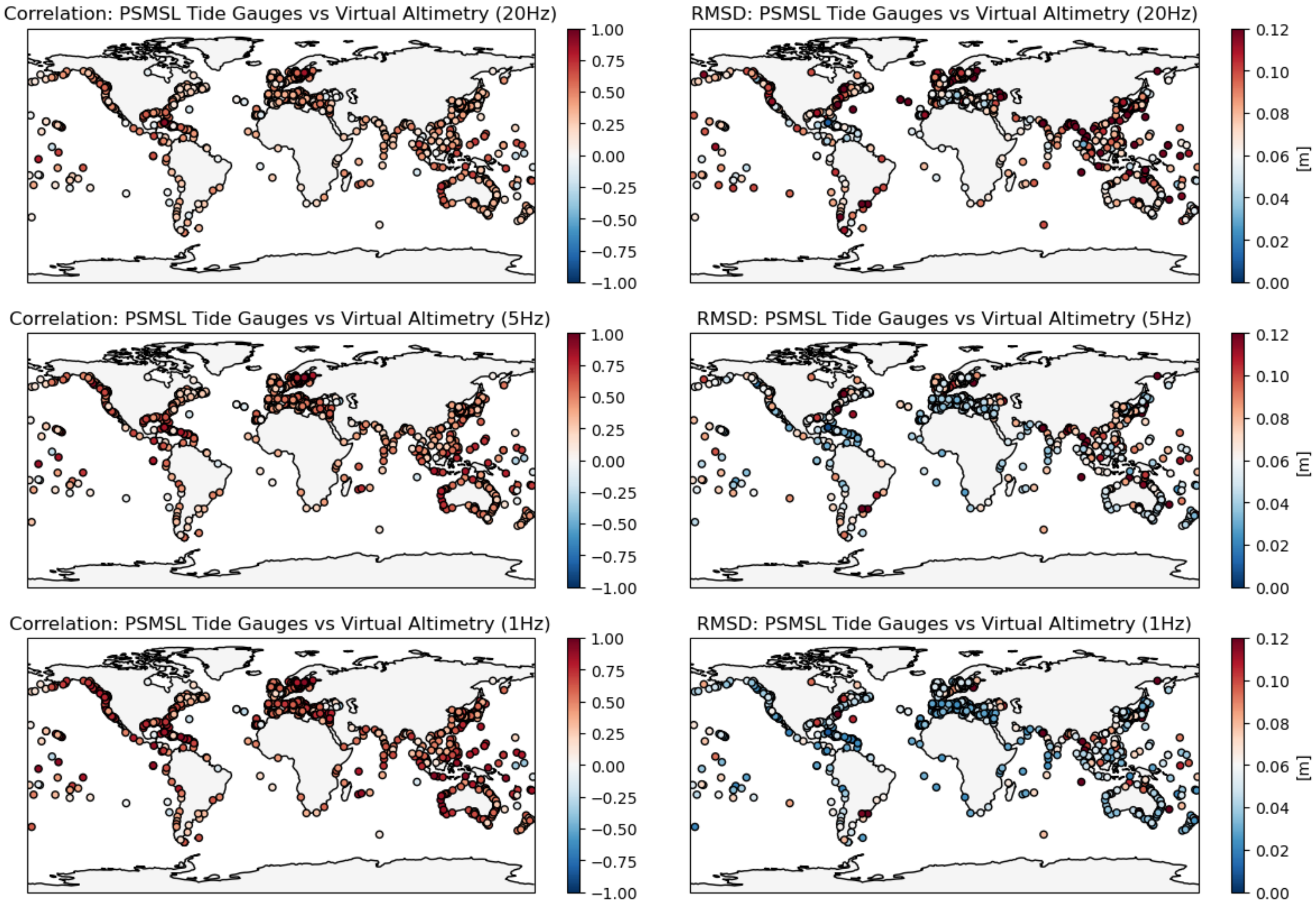
Challenge #5: Validating outputs in data scarce areas and quantifying uncertainty

Approach:

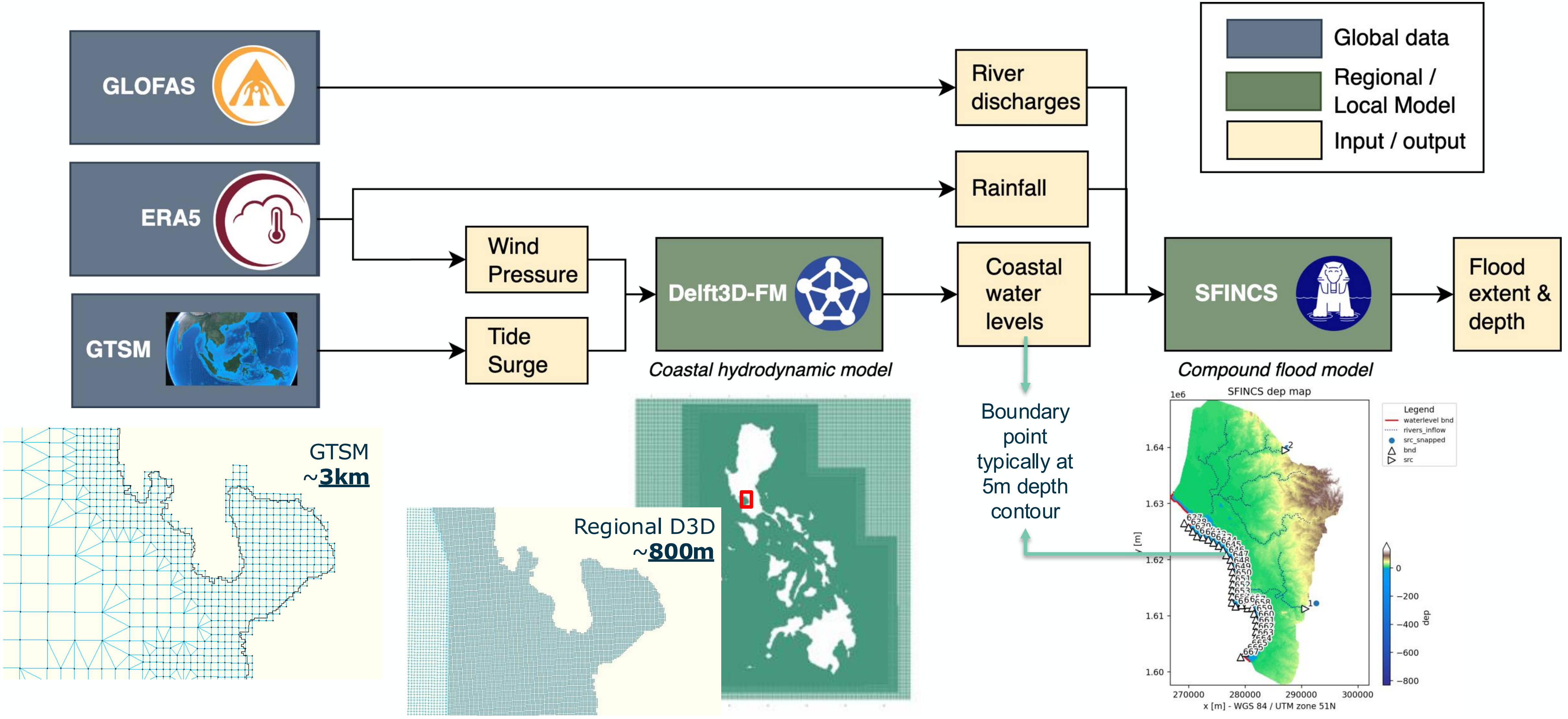
- Assess if Sea Level ESA CCI virtual altimetry stations can serve as validation data in the absense of in situ tide gauges
- Quantify uncertainty of data by comparing to tide gauges

Preliminary results

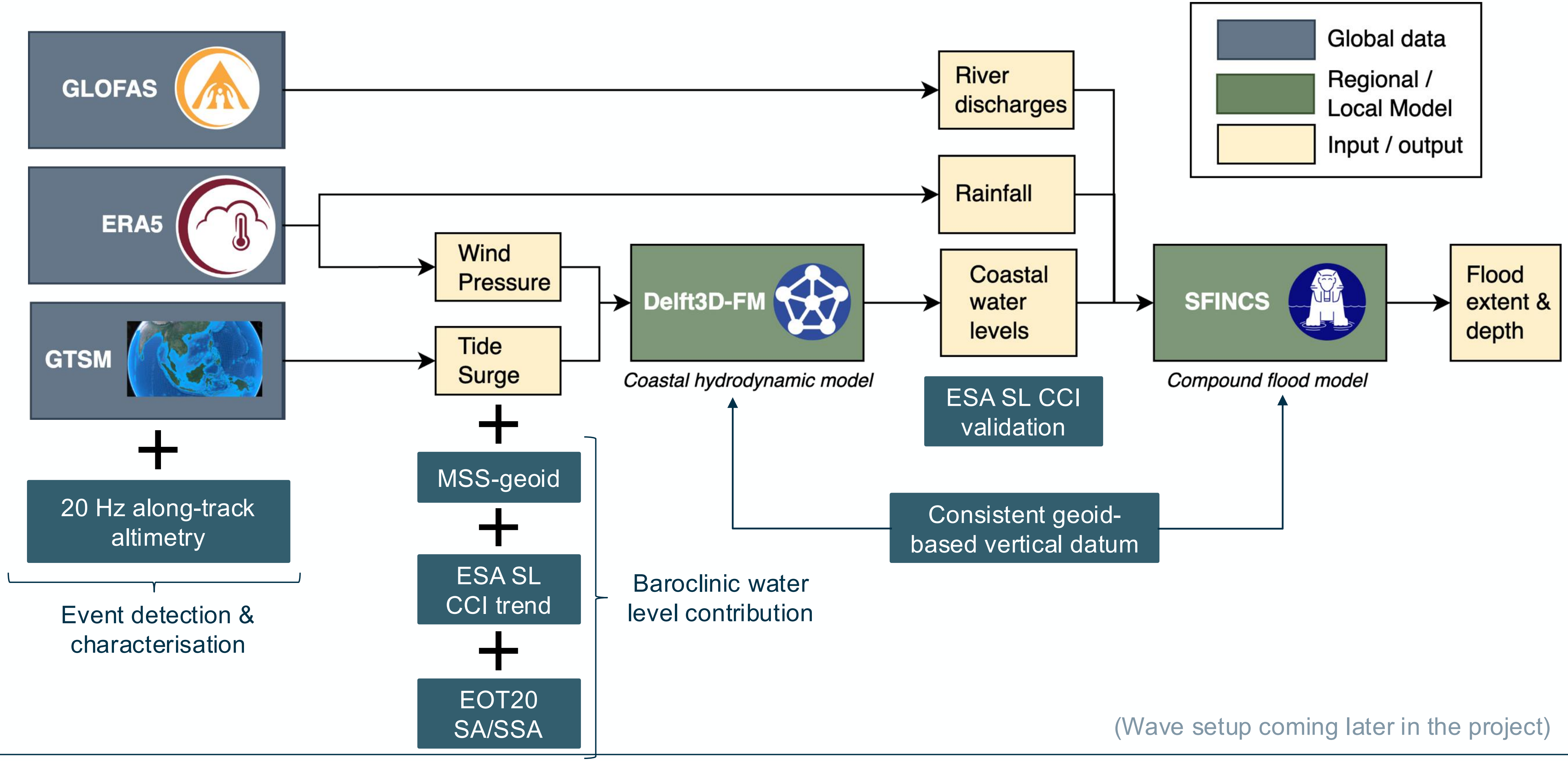
- Qualitatively good agreement
- Agreement improves with along-track averaging: 20Hz → 5Hz → 1Hz



High-level modelling workflow



Current approach to EO-model fusion



(Wave setup coming later in the project)

ECVs being used

ECV	Chosen because…	Strengths & Weaknesses	Wishlist
Sea Level incl. raw data from which derived			
Sea State			

Early insights & relevance to the CCI community

- **Coastal altimetry** (20 Hz + enhanced QC/filtering) shows potential for indicating surge signals where tide-gauge coverage is sparse, though temporal sampling remains a limiting factor.
- Using **EO-derived baroclinic fields** (MSS–geoid, trends, SA/SSA) is a potentially low-cost pathway to approximate 3D effects in 2D surge models, pending further validation.
- A **geoid-based vertical reference workflow** is being assembled; it may help harmonise EO, models, and DEMs, though coastal inconsistencies persist.

Implications for CCI:

- Sea Level CCI and Sea State CCI could add value (event indication, model comparison, baroclinic fields) but coastal usability needs improvement (sampling, corrections, coastal MSS–geoid consistency).
- Future coastal-focused SL-CCI and SS-CCI products would benefit from
  - higher-frequency coastal data,
  - improved coastal corrections and MSS–geoid consistency,
  - enhanced retrievals for storm conditions, and
  - expanded wave parameters

Spare slides

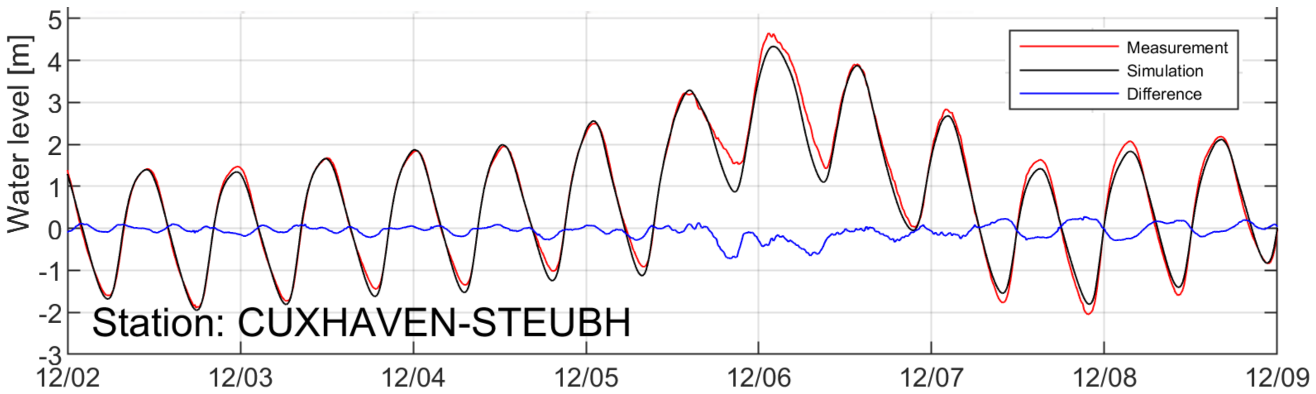
Hamburg use case

- Storm Xaver (December 2013)
  - severe flood warnings in most North Sea countries
  - Significant coastal flooding in Hamburg and parts of the UK due to high storm surge
  - Storm surge coincided with high tide, causing highest water levels at the Dutch coast since the 1953 flood disaster
- Data and models
  - Ample in-situ water level measurements available
  - Dutch Continental Shelf Model (DCSM-FM) provides accurate hindcast
  - Altimetry data can be compared and integrated with reliable data sources to find synergies

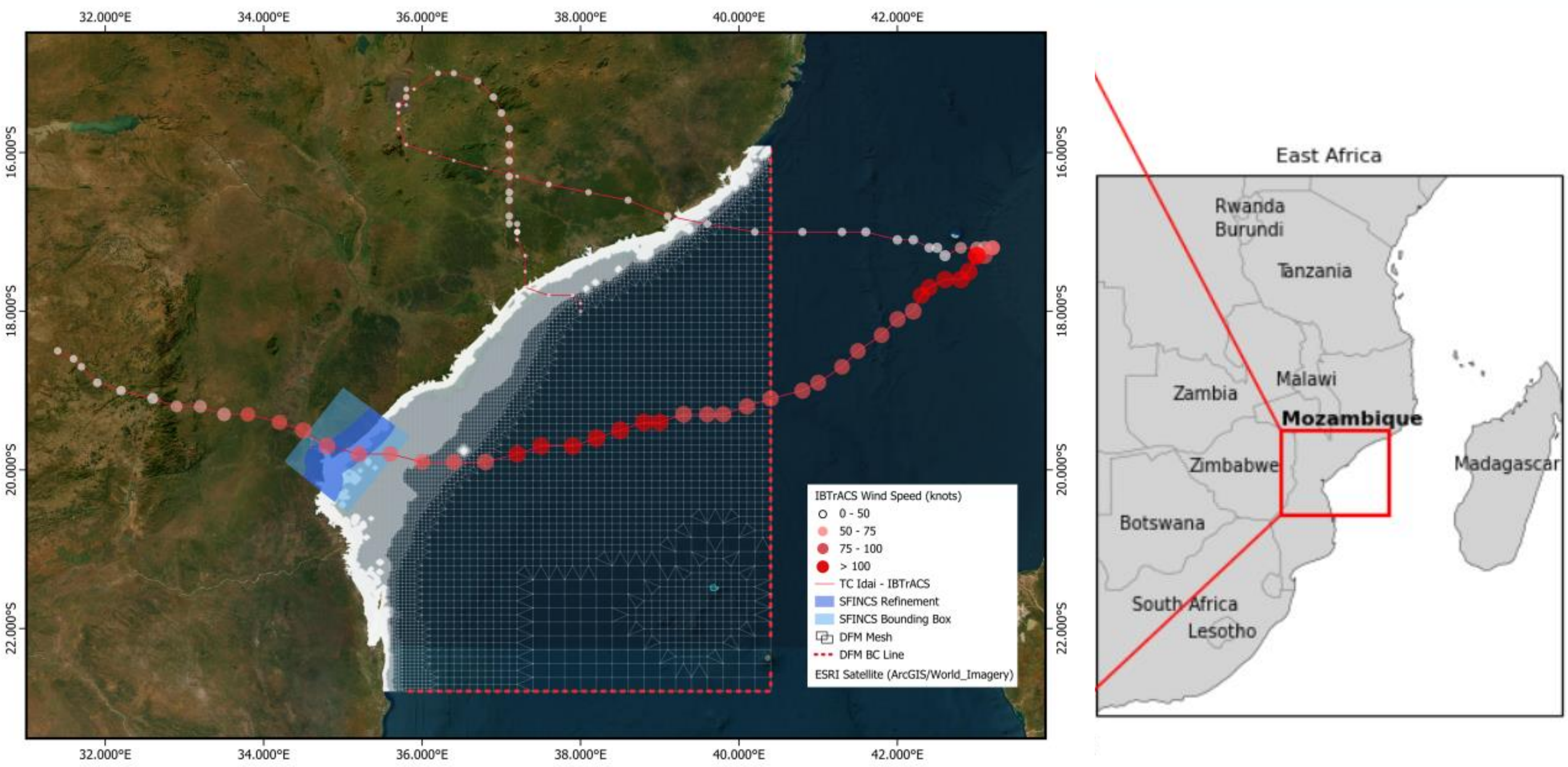
Flooding near the Hamburg Fish Market.
Credit: @Timna_Angermair/Twitter.

Dutch Continental Shelf Model

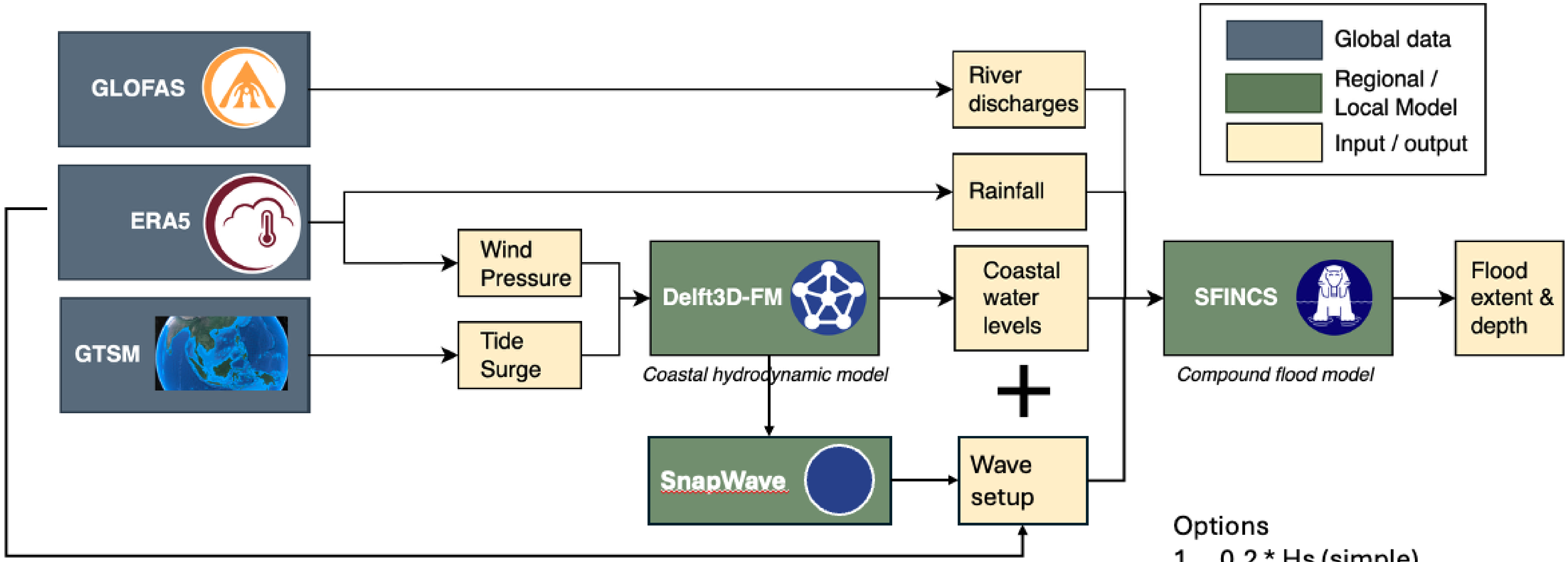
- Used for both operational forecasting and in-depth scenario studies
- In FRACCEO we will use the depth-averaged version (DCSM-FM 2D 100m or 0.5m)
- In the German Bight, spatial resolution is ~400m
- Xaver (2013) surge is well-represented, with some underestimation of the surge peak
- River discharges not included, limited grid refinement in the Elbe estuary



Example Beira model setup

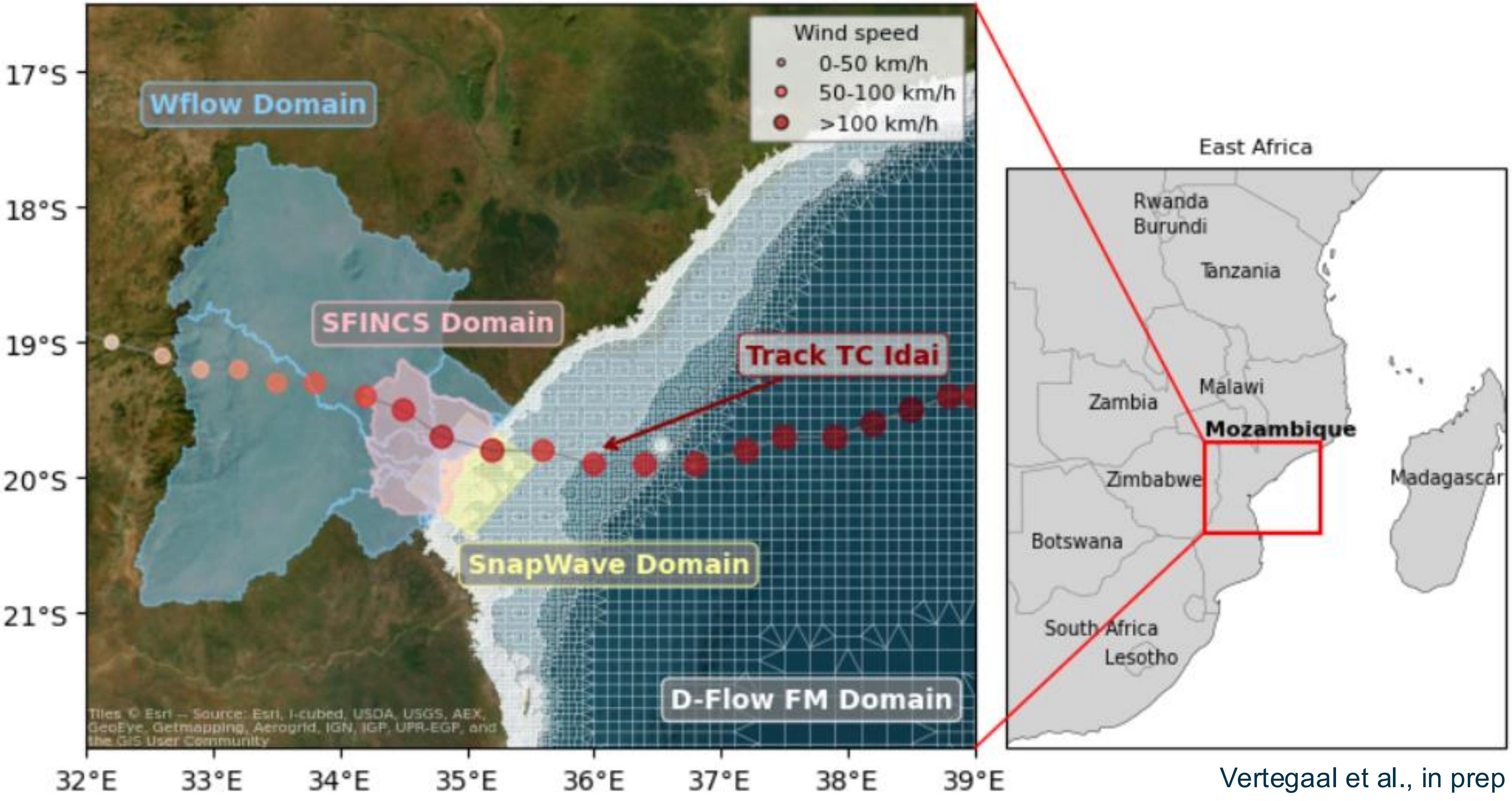


High level modelling workflow including wave setup



Options
1. 0.2 * Hs (simple)
2. Empirical wave setup (van Ormondt et al., 2021)
3. Coupled D3D to Snapwave

Example Beira setup for compound flooding



Vertegaal et al., in prep

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