Multi-scale modelling of the water and sediment fluxes from the Nile Delta to the Suez Canal

Amaury Versaen[1], Essam Heggy[2,3], Jonathan Lambrechts[4] and Emmanuel Hanert[1,4]

[1] Earth and Life Institute (ELI), UCLouvain, Belgium, [2] Viterbi School of Engineering, University of Southern California, Los Angeles, CA, USA, [3] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [4] Materials and Civil Engineering (iMMC), UClouvain, Belgium

In recent decades, the construction of several (mega)dams along the Nile River has significantly reduced the amount of fluvial sediment reaching the **Nile Delta coast**. This sediment deficit has resulted in **accelerated coastal erosion**. The present study evaluates the potential **risk of sediment accumulation in the nearby Suez Canal (SC)**. As exemplified by the grounding of the Ever Given in 2021 (fig. 1), a blockage of the SC would represent a major disruption to global trade.
The first objective of this project is to investigate whether **coastal currents**—at both regional and local scales—can transport sediment **from** the eroding **Nile Delta** eastward **toward the SC**, potentially **entering it** through its northern mouth.
To address this question, we employ the **hydrodynamic model** SLIM3D and **validate** its outputs using observational data, comparisons with existing literature, and larger-scale oceanographic datasets such as those provided by CMEMS.

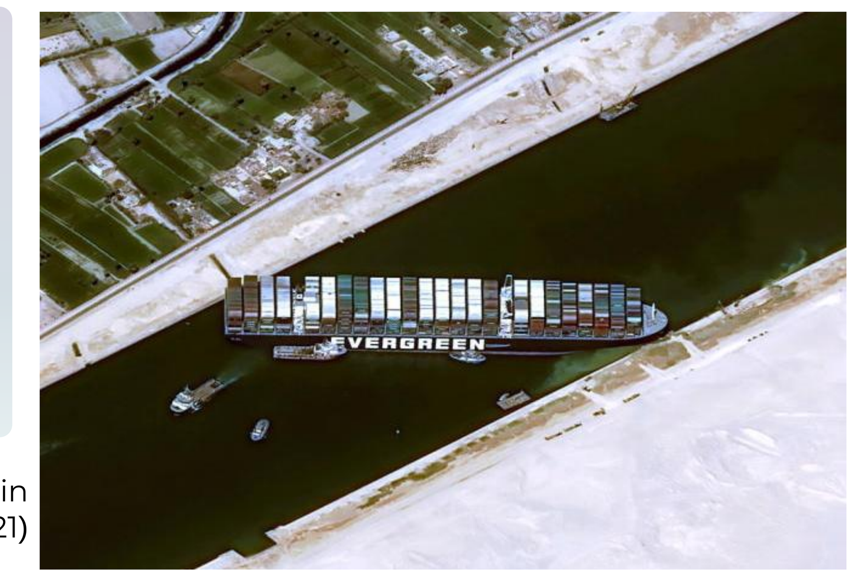

Fig. 1 – Grounding of the Ever Given in the Suez Canal (March 2021)

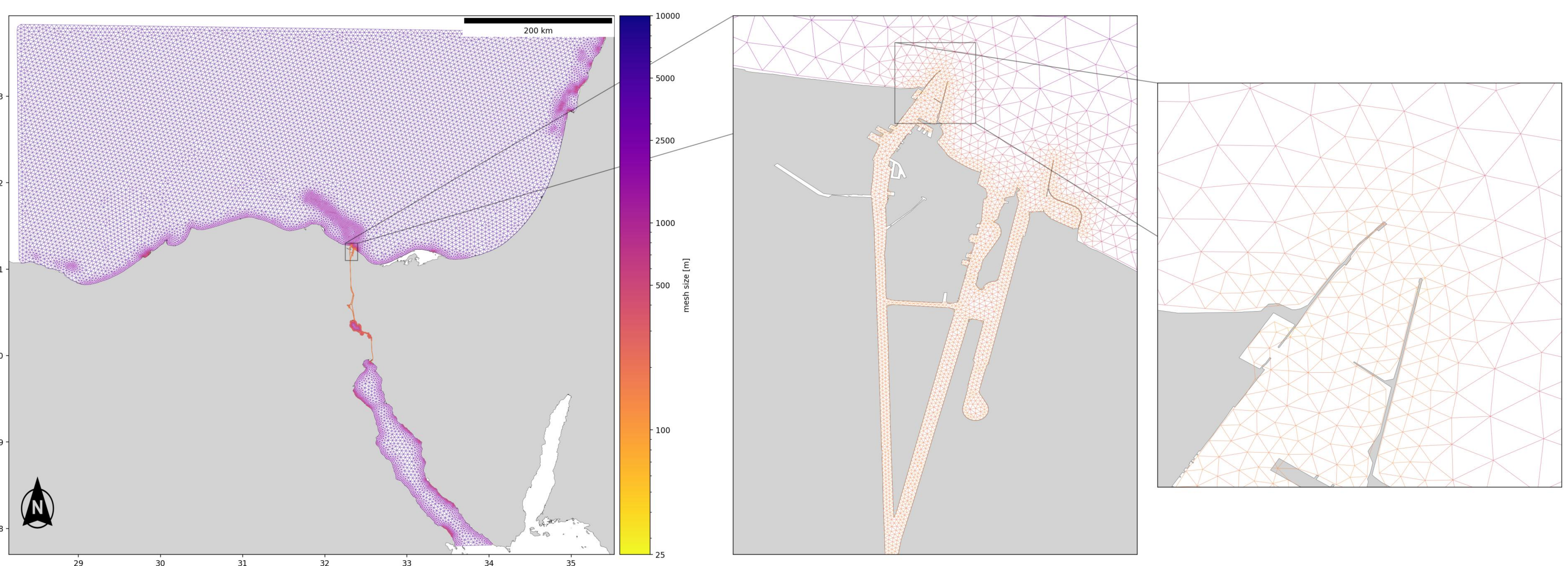

Fig. 2 – Unstructured mesh of the are of interest. The resolution changes depending on the distance to the coastline and the bathymetry.

The 3D baroclinic version of the multiscale coastal ocean model SLIM employs an **unstructured mesh** to seamlessly simulate flow through the SC, while also capturing the broader dynamics of the surrounding Mediterranean and northern Red Seas. The model features more than 170,000 horizontal elements and up to 85 vertical z-layers, achieving horizontal and vertical **adaptative resolutions** of resp. 25m and 1m (fig. 2, fig 6).
Model forcings include: tidal data from TPXO, wind forcing from the Copernicus European Regional Reanalysis (CERRA), sea surface temperature and salinity products from CMEMS, atmospheric variables such as precipitation, air temperature, and surface heat fluxes from ERA5 (ECMWF reanalysis) and several CMEMS Mediterranean Sea Physical Reanalysis datasets, e.g. 3D salinity and temperature fields, sea surface height, and 3D current velocity.

We compare the **large-scale surface currents** in the Eastern Mediterranean Sea between the literature (fig.3A), external large-scale hourly surface currents provided by CMEMS (not used in our model's forcings, fig.3B) and the outputs from SLIM3D (fig.3C). Our main interest are the **longshore current flowing eastward from the Nile Delta** (Libyo-Egyptian Current) and an inward current near the SC's mouth.

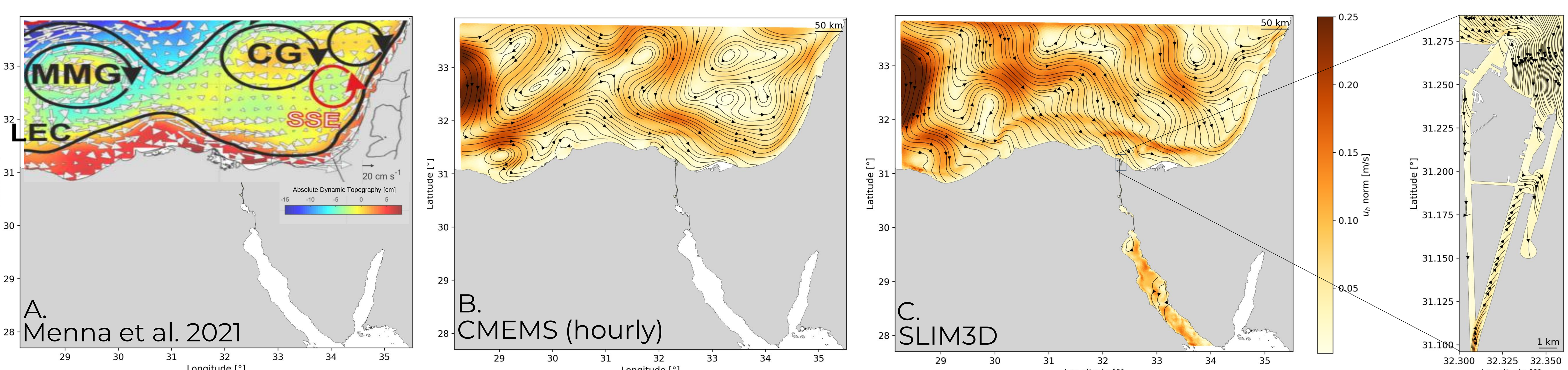

Fig. 3- A. Mean geostrophic currents (white arrows) superimposed on the mean ADT (colors) derived from altimetry and a schematic representation of the main currents and circulation structures, adapted from Menna et al. 2021. B. Sea surface velocity hourly currents from CMEMS' Mediterranean Sea Physical Reanalysis dataset, averaged over a year. C. SLIM3D's sea surface velocity currents, averaged over one year of simulation, with a zoomed inset of the SC's northern mouth

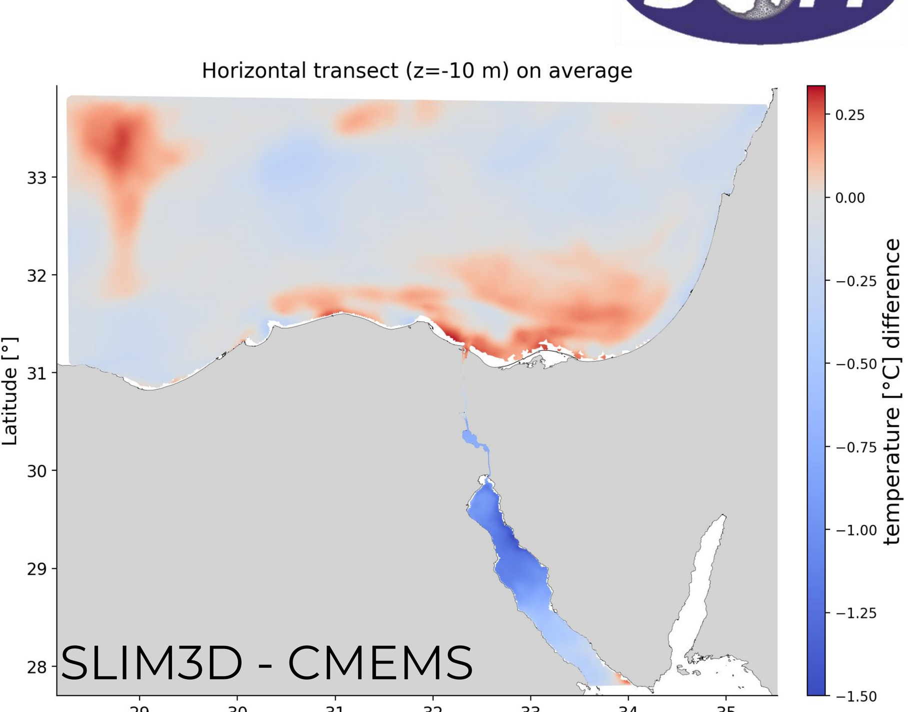

Fig. 4 – Average difference in water temperature : SLIM3D – CMEMS over 1 year

To **validate** our hydrodynamic model, we calculate the average difference in **sea temperature between SLIM3D and the CMEMS** 3D temperature at various depths (fig. 4). This comparison ensures that the model **does not generate unrealistic dynamics offshore**, where CMEMS data are considered reliable. Larger discrepancies near the coast are expected, as SLIM's adaptive resolution enables the model to capture smaller-scale processes that are often unresolved in coarser datasets.

Additional validation is carried out using **sea surface elevation data** recorded at a Joint Research Centre (JRC) station in Alexandria (fig. 5). These observations allow us to evaluate the performance of SLIM3D and CMEMS by comparing their outputs against measured sea levels. Benefiting from its higher resolution near the coast, **SLIM3D achieves greater accuracy** than CMEMS in this region.

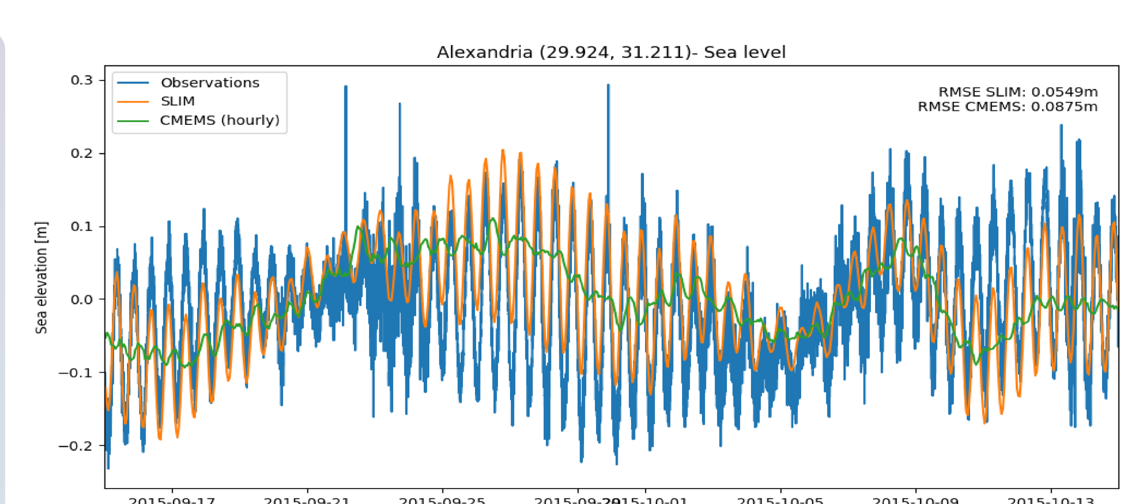

Fig. 5 – Difference in sea surface elevation between SLIM3D, CMEMS' Mediterranean Sea Physical Reanalysis dataset and observations from a Joint Research Center's station located in Alexandria, Egypt.

We extract SLIM3D's **northward velocity** along a vertical transect (Fig. 6, left) from the northern to the southern end of the SC. Fig. 6 (right, above) shows the annual average, with red indicating northward flow and blue southward flow.
Interestingly, negative values **near the northern entrance suggest a net inflow into the Canal**.

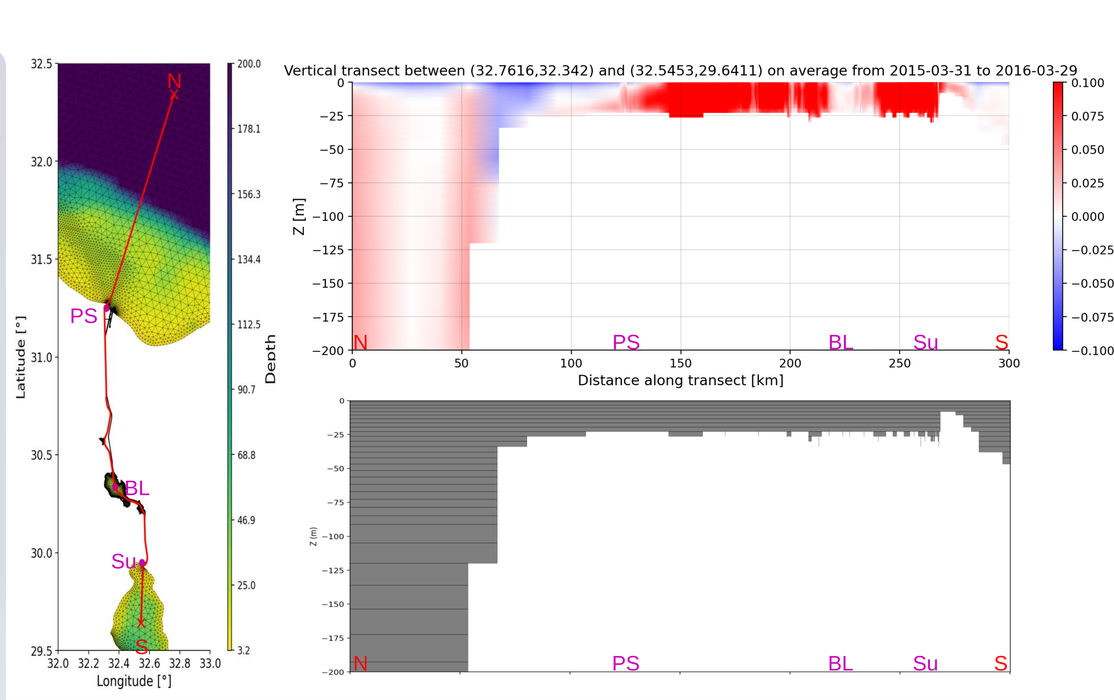

Fig. 6 – Left : location of the vertical transect (N = North, PS = Port Saïd, BL = Bitter Lake, Su = Port Suez, S = South) and bathymetry. Right : Above : vertical (longitudinal) transect of the yearly-averaged northward velocity. Below : vertical extrusion of the mesh over the Suez Canal, highlighting the z-layers.

We also compute **sea surface elevation differences** (south-north) between key locations: Port Said (PS), the Bitter Lake (BL), and Port Suez (Su) (fig. 7). While the difference is always positive, it **decreases during summer**.

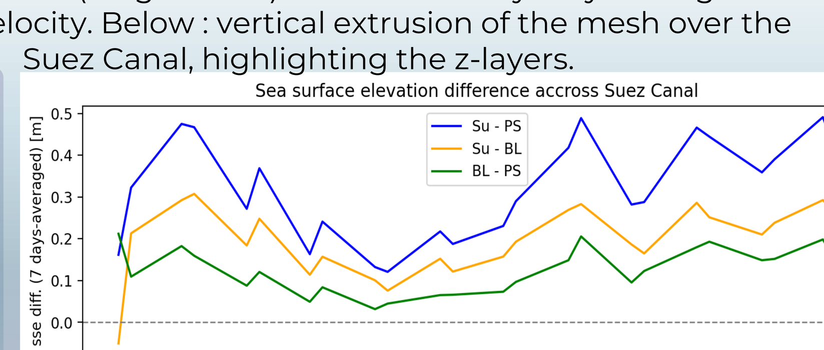

Fig. 7 – Weekly-averaged sea surface elevation difference between several key points (PS, BL, Su) from the Suez Canal (see Fig. 6 for locations).

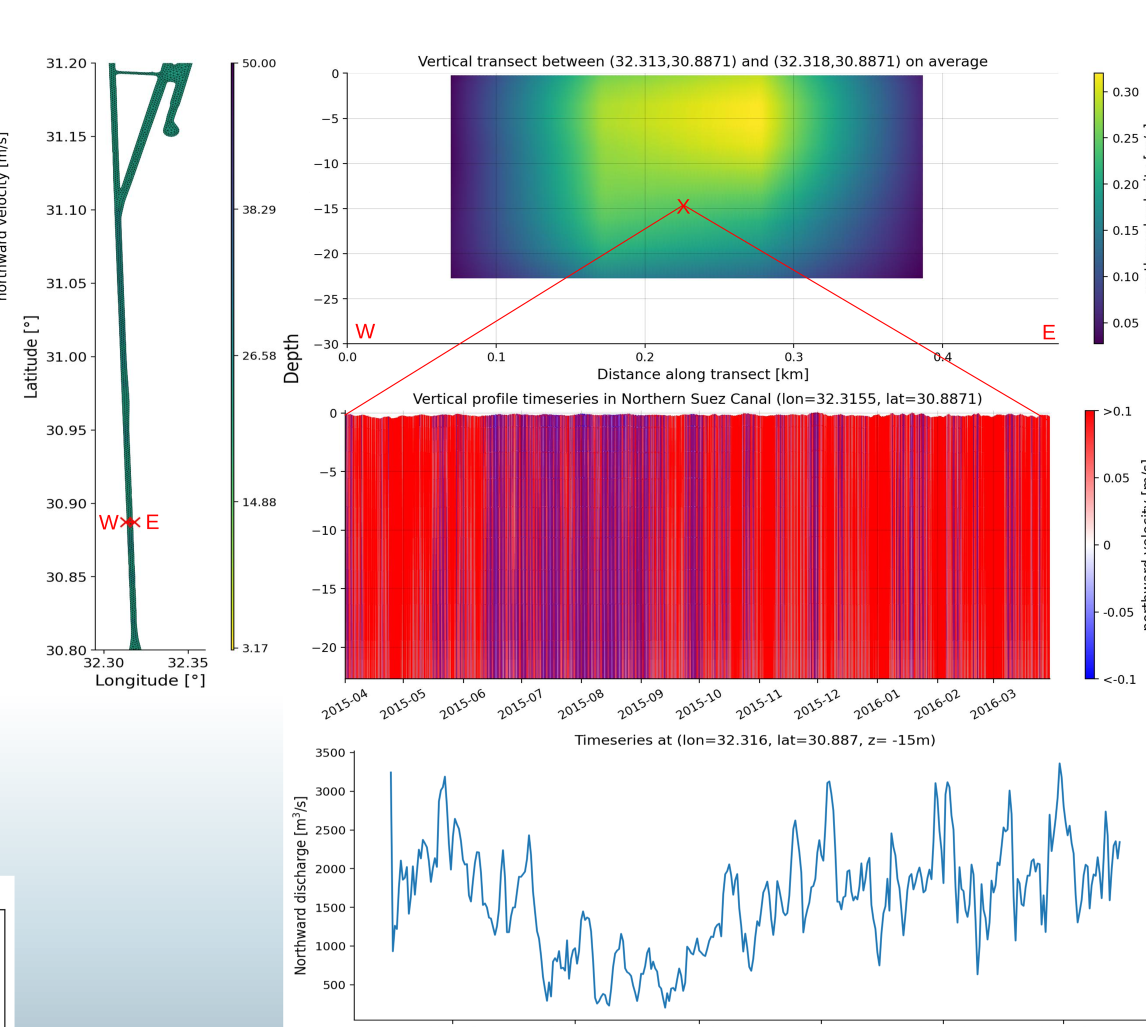

Fig. 8 – Left : location of the vertical transect and bathymetry. Right : Above : vertical (cross) transect of the yearly-averaged northward velocity in a random section of the Northern SC. Middle : timeseries of the vertical profile of the northward current velocity in the center of the cross section. Below : Daily-averaged discharge simulated in the center of the cross section.

We focus on a section near the northern mouth of the Suez Canal (fig. 8, left), where the yearly-average northward velocity is positive (fig. 8 right, above). However, time series at the section's center reveal a **southward flow in summer** (fig. 8, right, middle), despite a positive daily-averaged discharge (fig. 8, right, below). This seasonal change aligns with the drop in sea level difference and is consistent with findings from Ibrahim et al. (2023) and Biton et al. (2020), who observed current reversals in the Canal.

This seasonal inflow, together with the eastward longshore current, likely **facilitates sediment transport toward the Suez Canal** — an essential dynamic explored further in the next steps of this study.

References
Biton, E. (2020). *Possible implications of sea level changes for species migration through the Suez Canal*. **Scientific Reports, 10, 21195.**
Ibrahim, O. et al. (2023). *Impacts of recent development processes on the temporal and spatial sea-level variations along the Suez Canal*. **Regional Studies in Marine Science**, **66**
Menna, M. et al. (2021). *On the circulation and thermohaline properties of the Eastern Mediterranean Sea*. **Frontiers in Marine Science**, **8**.

Spring 2025