Reconstruction of the historic sea level observations at Saint-Malo/Saint-Servan (French Brittany coast)

Changes of extreme coastal water levels since the 19th century

Alexa Latapy[1], Inge van den Beld[1], Romain Kermoal[1], Nathalie Giloy[1,2], Claire Fraboul[1], Yasser Hamdi[2], Antonin Migaud[2], Lise Bardet[2], Nicolas Pouvreau[1]

[1] French National Hydrographic Office (Shom)
[2] Institute for Radiological Protection and Nuclear Safety (IRSN)

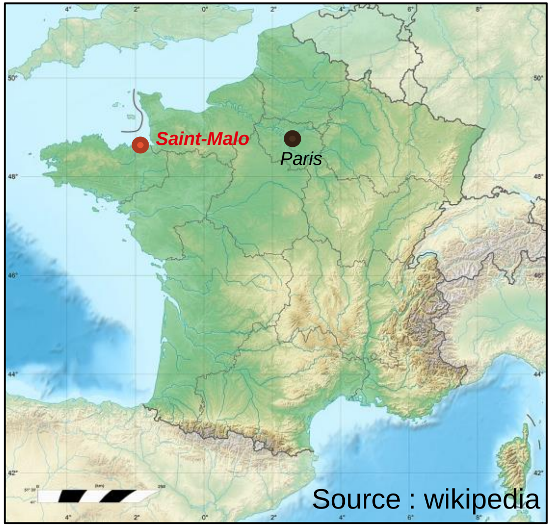
30/05/2022

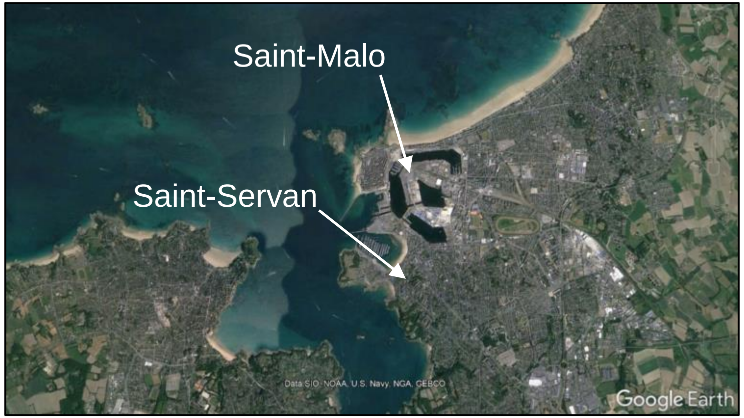
RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

SHOM
L'océan en référence

Context

- Saint-Malo is a historic **French port** in the Eastern part of Brittany on the **English Channel coast**



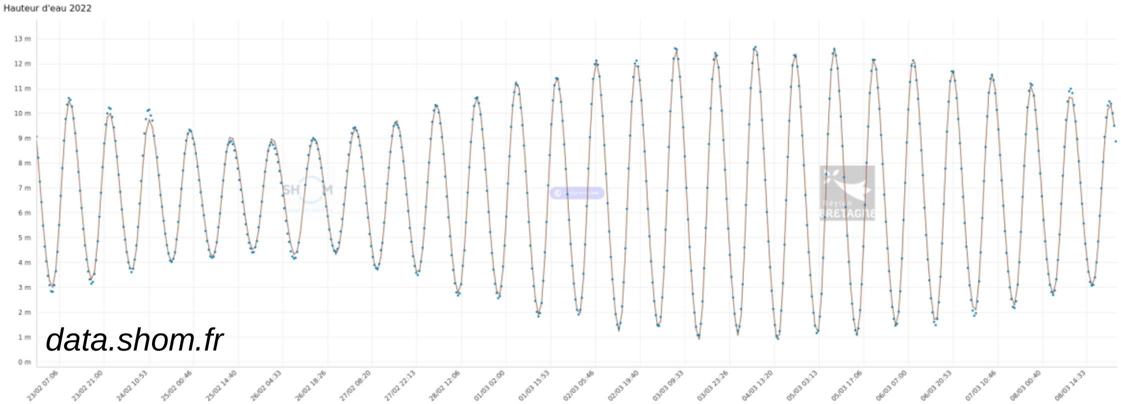


RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

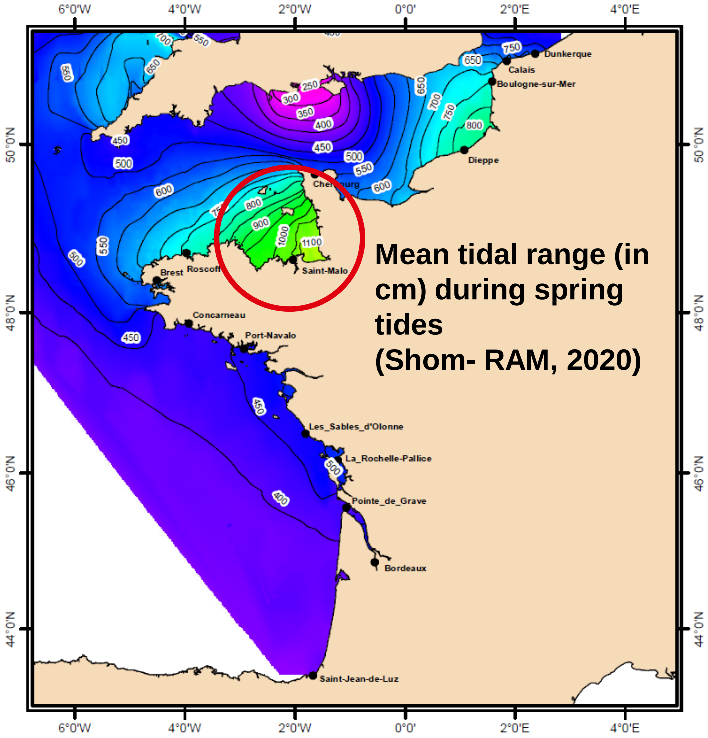
SHOM
L'océan en référence

Context

- Saint-Malo is a historic French port in the Eastern part of Brittany on the English Channel coast
- Characterized by **semi-diurnal tides** and **large tidal range** (max = 14 m)



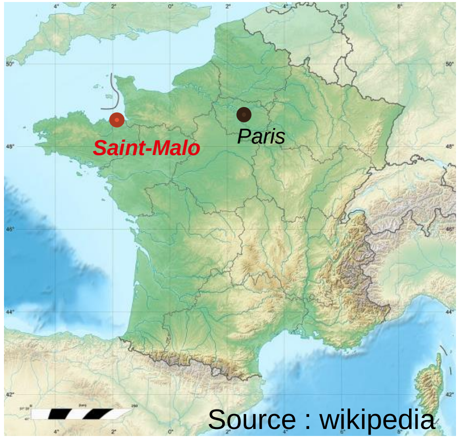
data.shom.fr

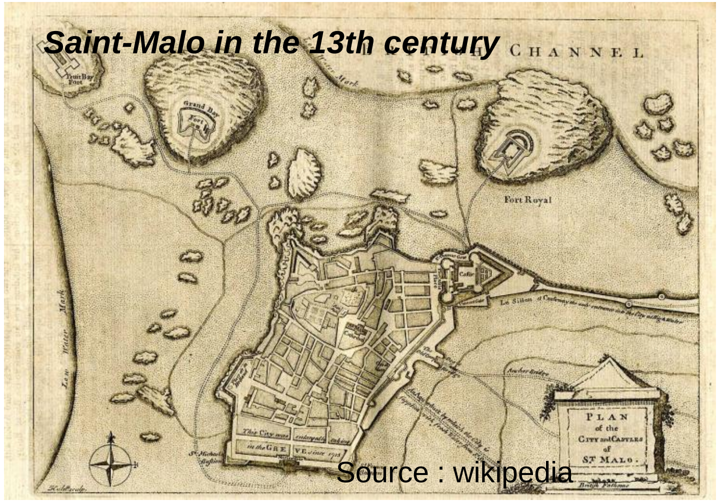


Mean tidal range (in cm) during spring tides (Shom- RAM, 2020)

Context

- Saint-Malo is a historic French port in the Eastern part of Brittany on the English Channel coast
- Characterized by semi-diurnal tides and large tidal range (max = 14 m)
- A part of the city (450 ha) was developed on a **maritime marsh** which was progressively **dyked and dried up since the 14th century**





Context

- Saint-Malo is a historic French port in the Eastern part of Brittany on the English Channel coast
- Characterized by semi-diurnal tides and large tidal range (max = 14 m)
- A part of the city (450 ha) was developed on a maritime marsh which was progressively dyked and dried up since the 14th century
- Floods induced by **tidal/meteorological events** are likely to impact this area
- Coastal floods are amongst the **most dangerous natural hazards**.
- Planning for coastal flooding estimate that more than **16,000 people might be impacted**

Credits : Gérard Cazade

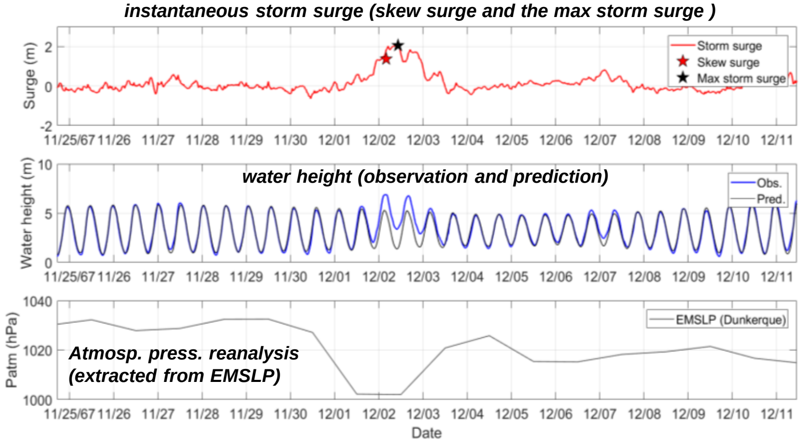
Credits: Michael Auvret

Context

- In order to improve the management of marine flooding hazard, a first Coastal Flood Prevention Plan for Saint-Malo has been initiated in 2017.
- In support of marine public policies, the Shom participates in two actions:
  - the **reconstruction of the historical tide gauge** series available for Saint-Malo since the 19th century, and
  - the improvement of the knowledge of meteorological phenomena (waves, currents, swells, surges) of Saint-Malo

Context

- In order to improve the management of marine flooding hazard, a first Coastal Flood Prevention Plan for Saint-Malo has been initiated in 2017.
- In support of marine public policies, the Shom participates in two actions:
  - the **reconstruction of the historical tide gauge** series available for Saint-Malo since the 19th century, and
  - the improvement of the knowledge of meteorological phenomena (waves, currents, swells, surges) of Saint-Malo



Storm surge, identified from the extended data series of Dunkirk, the 2nd of December 1867.

- Associated with modern observations, historical water level measurements allow to :
  - estimate the **long-term sea level evolution** ;
  - changes in **tidal components ;**
  - **rediscover historical storms**: the **estimates of extreme levels can be improved** by taking into account these forgotten extreme values (Bulteau et al., 2015, Hamdi et al., 2015).

Sea level data rescue process

FROM PAPER DOCUMENTS … … TO DIGITAL SEA LEVEL DATA

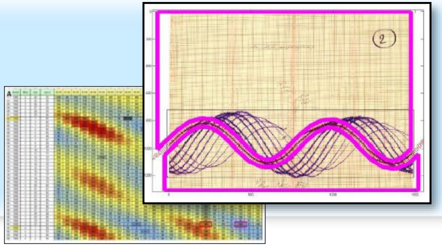
1. Inventory and recovery

→ **Several type of documents to process**
(tables, marigrams, metadata relative to measurements, …)

2. Scanning process

Potentially complicated depending on:
- Size of the document
- Preservation state

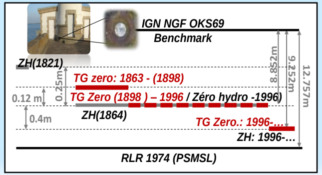
3. Extraction of water level



- **Handwritten ledgers** manually digitized
- **Marigrams** « automatically » digitized with the use of the NUNIEAU software (Ullman *et al.*, 2005) based on color recognition

→ **RAW DIGITAL DATA**

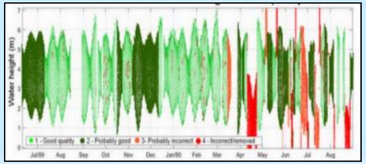
4. Vertical consistency of the sea level data



Based on the analysis of metadata linked to sea level observations: (levelling reports, technical notes, …)

→ The **knowledge of the history of the tide observatory over the time**

5. Quality check, data validation

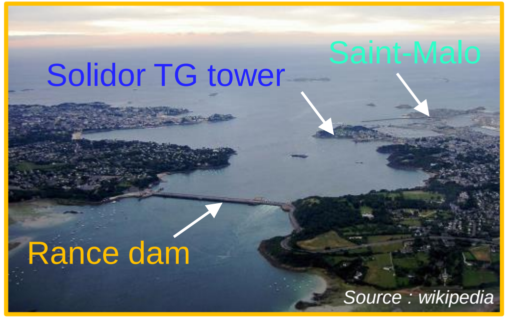


→ **Quality check** (spikes, consistency check, …)
→ **Buddy checking** (comparison with sea level time series of nearby stations)
→ **Data flagging** depending on the data quality

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

SHOM L'océan en référence

Saint-Malo/Saint-Servan reconstruction

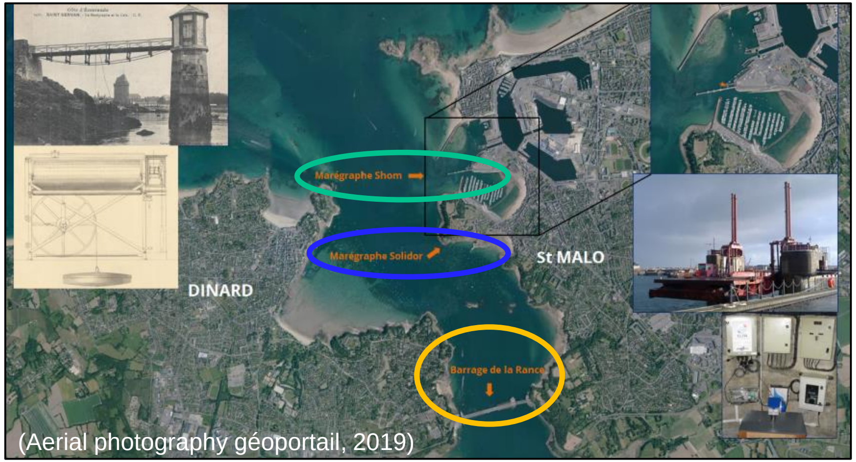


A reconstruction from 2 observation sites

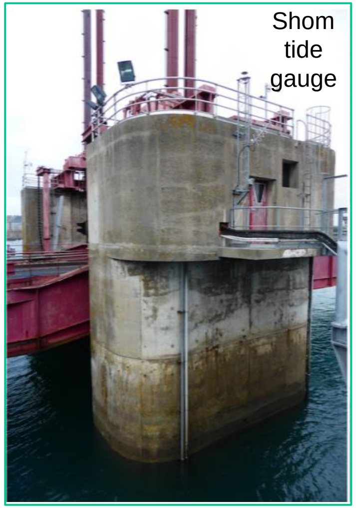
Two locations:

(1) In the Solidor Tower at Saint-Servan

(2) At the Naye terminal in the harbor of Saint-Malo



(Aerial photography géoportail, 2019)



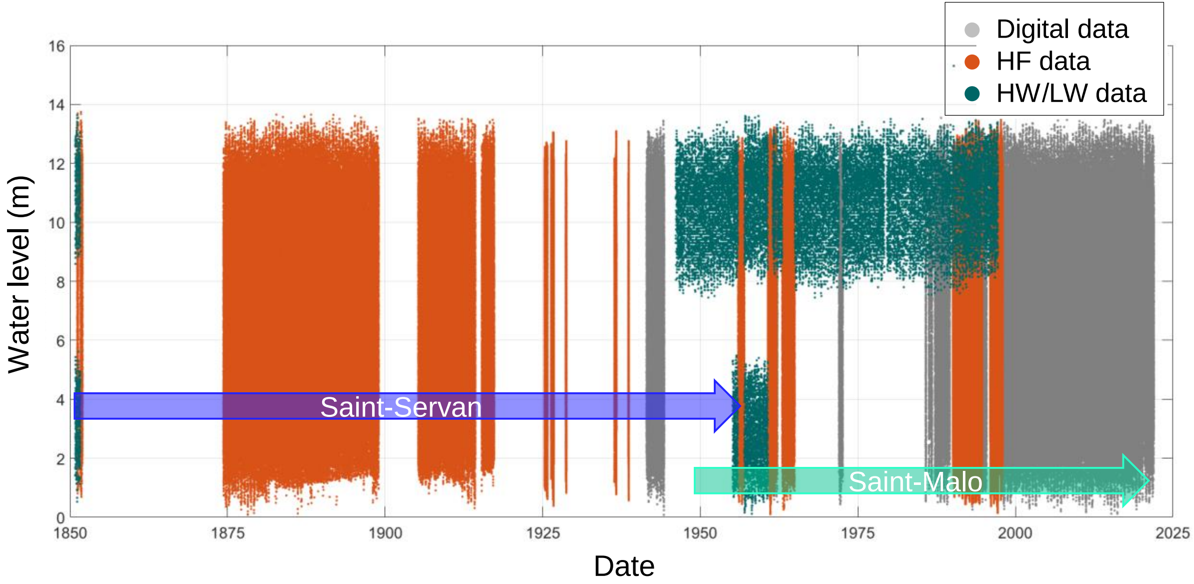
Construction of a tidal power plant at the mouth of the Rance river between 1961 and 1966

Saint-Malo/Saint-Servan reconstruction

A reconstruction from 2 observation sites

A total of 14,000 tidal ledgers and 2,000 marigrams were digitized, which represent about **300 GB of digital images** processed for this study.

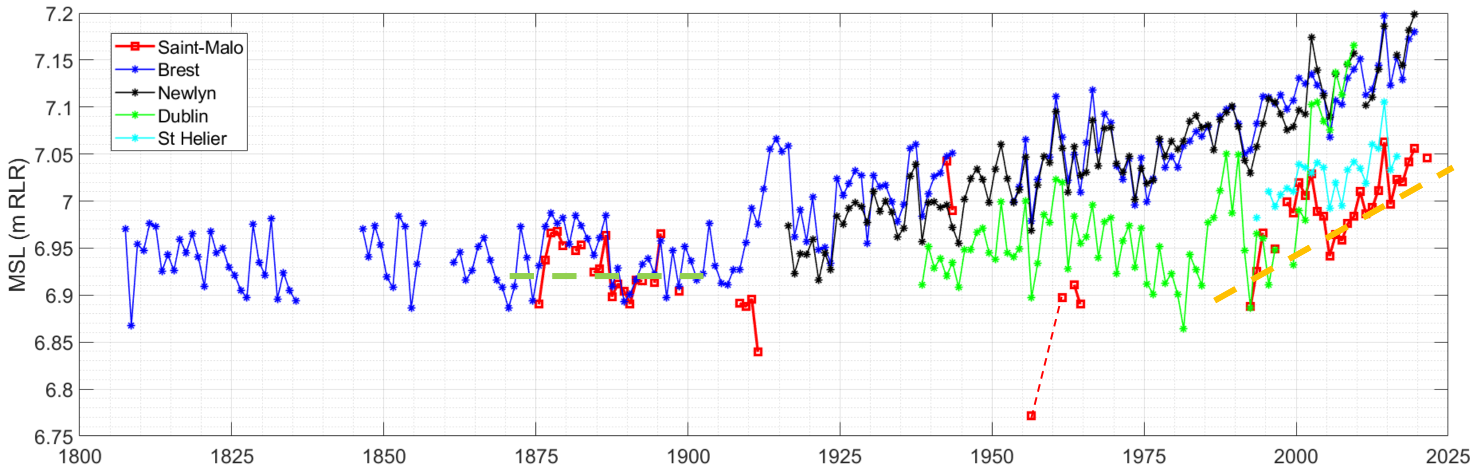
It represents **1.2 million** unpublished values digitized during the reconstruction of this Saint-Servan/Saint-Malo tidal time series.



Application and analysis

Mean sea level

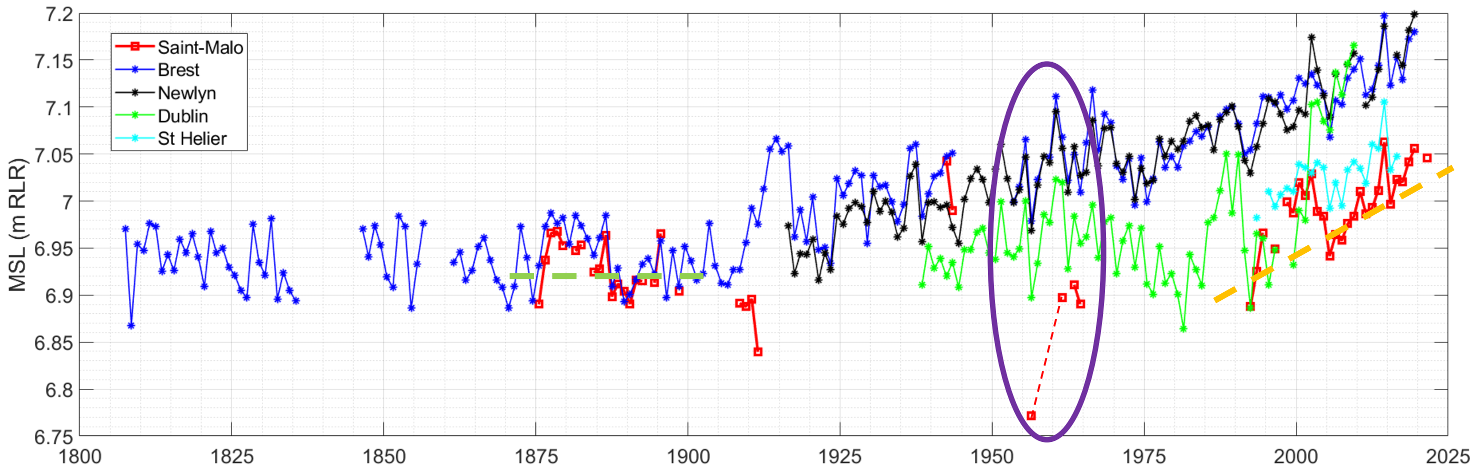
- Relative to a common datum RLR (Revised Local Reference) created by PSMSL
- Quite stable in the 19th century and correlated with Brest
- Significant rise since the 90s, variations correlated to those observed on nearby sites



Application and analysis

Mean sea level

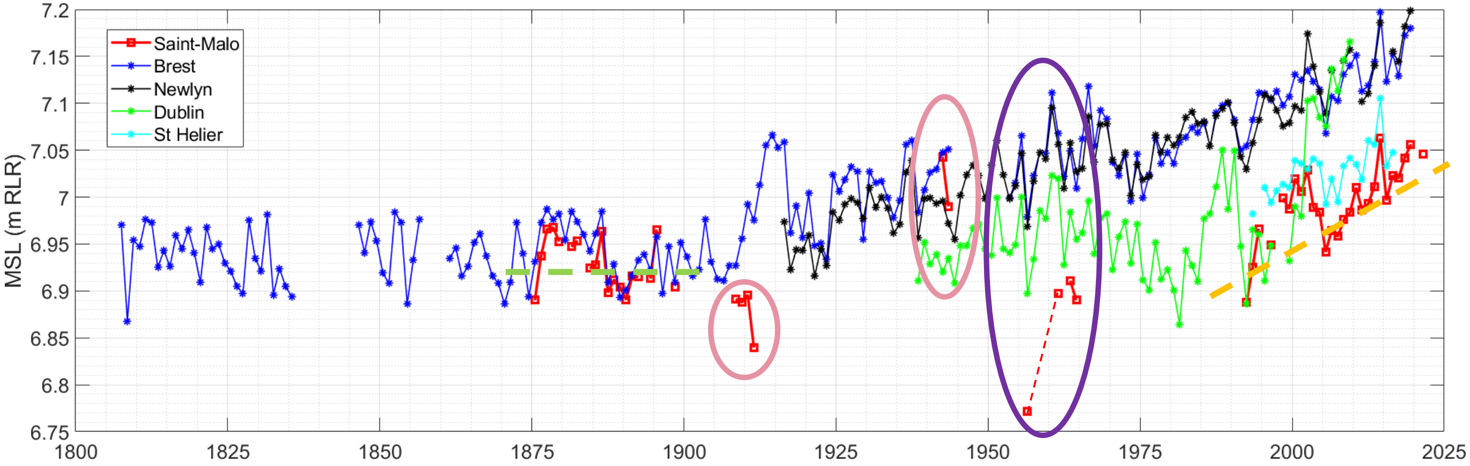
- Relative to a common datum RLR (Revised Local Reference) created by PSMSL
- Quite stable in the 19th century and correlated with Brest
- Significant rise since the 90s, variations correlated to those observed on nearby sites
- « Bump » in the 1960s : observed in a number of individual MSL records (drops in GMSL after some major volcanic eruption) (Grinsted et al., 2007)



Application and analysis

Mean sea level

- Relative to a common datum RLR (Revised Local Reference) created by PSMSL
- Quite stable in the 19th century and correlated with Brest
- Significant rise since the 90s, variations correlated to those observed on nearby sites
- « Bump » in the 1960s : observed in a number of individual MSL records (drops in GMSL after some major volcanic eruption) (Grinsted et al., 2007)
- « Bump » in the 1910s/1940s : no clear explanation why MSL is lower/higher than before (and after)

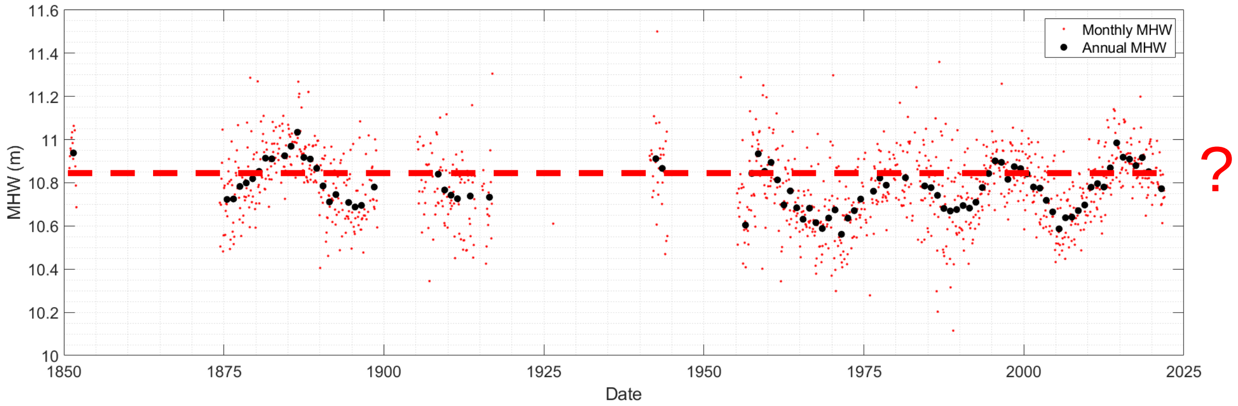


Application and analysis

What conclusions for the study of marine flooding ?

In the context of marine flooding hazard :

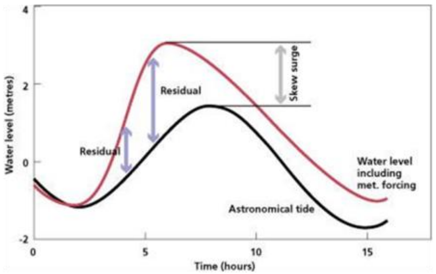
- Fast rising in the **MSL** since the 90s : +3.19 mm/yr ± 0.87
- Tidal characteristics : **MHW** levels could have influenced the marine flooding hazard**. But no clear trend**…



*And for **isolated events (storms)**, what about it?*

Application and analysis

Schematic of a skew surge – meteorological effects can have a notable effect on sea level and can alter the timing of high tide (Source : NOC)



Statistical sea level extreme events analysis

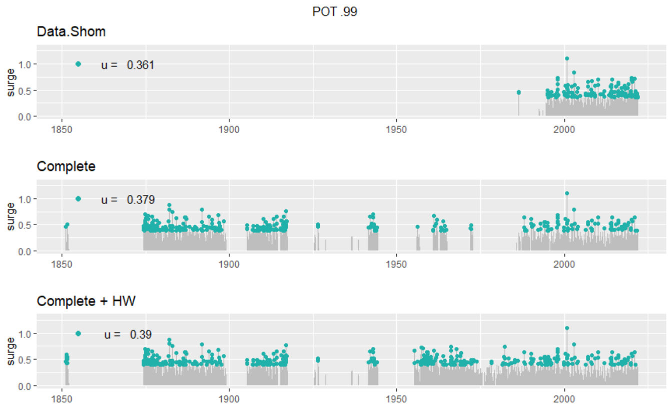
The use of historical information can significantly **improve the probabilistic and statistical modeling of extreme events.** Extreme sea and skew surge levels are variables commonly used in public policies and integrated coastal zone management.

Skew surges : difference between the **maximum observed sea level** and the **maximum predicted tide** regardless of their timing during the tidal cycle (see the poster "The impact of tidal predictions on historical extreme skew surges" of N. Giloy for more information in the calculation of historical skew surges).

Multi-sample analysis :

- *Data.shom* : initial dataset (1990s-now)
- ***Complete*** : new with HW extracted from the reconstructed systematic dataset (HF sea level records)
- *Complete+HW* : addition of punctual HW records (1850s and 1950-1990)

Method : **POT** (Peaks over threshold)
Threshold = 99 percentile



146 obs.

329 obs.

413 obs.

Application and analysis

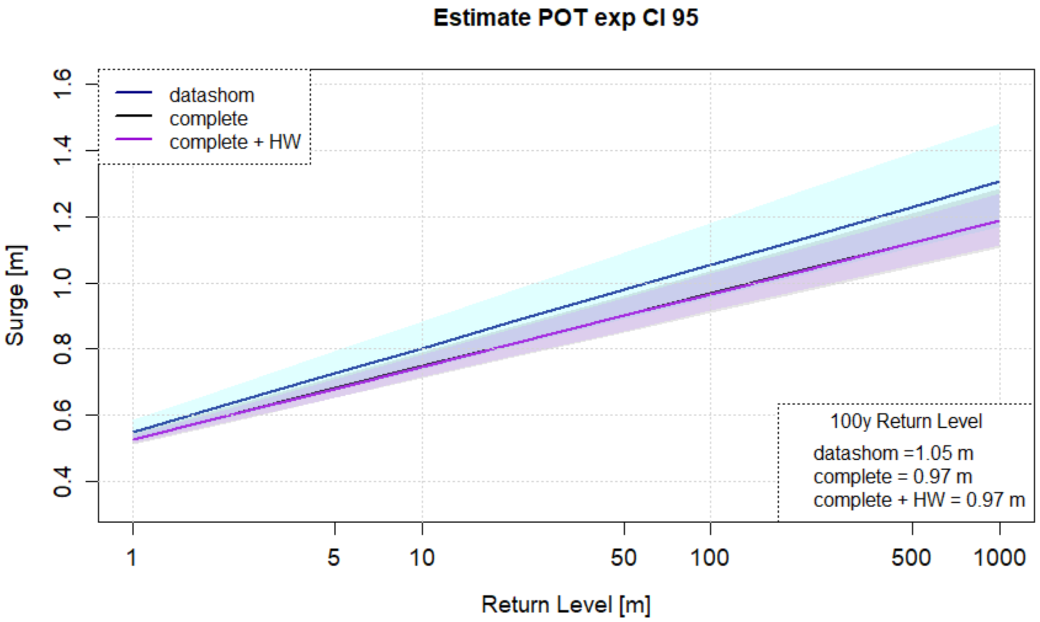
Statistical sea level extreme events analysis

We improve the results in terms of return period and in the uncertainty. The **100-year surge** was estimated at 1.05 m with the initial data set and is now lowered to **0.97 m**.

Maximum skew surge was recorded in 2000 : we didn't find **any events highest than this one.**

The *Complete* and *Complete+HW* samples give the same results → validate the SL reconstruction and the use of datasets from 2 different observatories.

First statistical analysis that could be improved → but already gives interesting results



RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

SHOM
L'océan en référence

Conclusions and perspectives

- We digitized about **125 years of cumulative sea level measurements** (with some gaps). Observations are essential for management of the ocean (UN Decade for Ocean Science) (Workshop on Sea Level Data Archaeology, UNESCO, 2020)

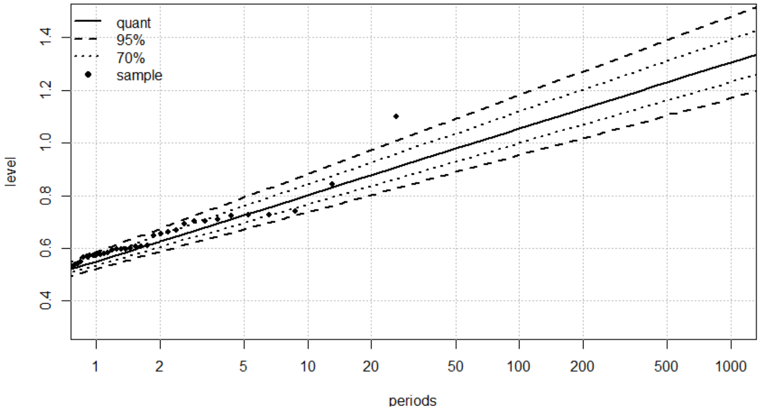
- MSL evolution : **some anomalies**, why ?

Construction of a tidal power plant at the mouth of the Rance river during the 1960s ?
Megatidal behavior ?
Geomorphological effect on hydrodynamics ?

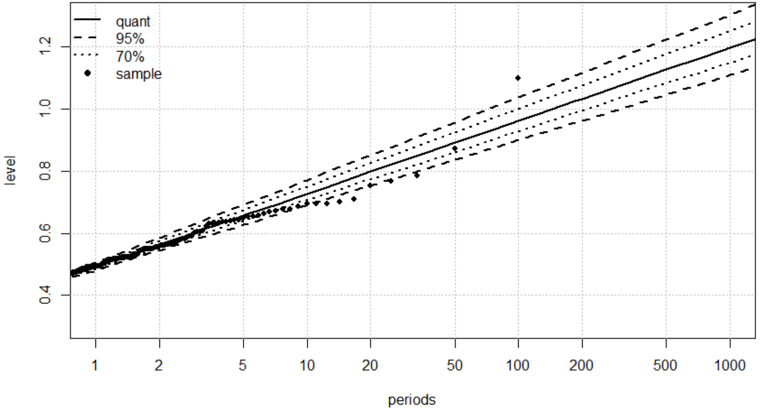
- Extreme events : the **100-year surge is now at 97 cm**

No skew surges higher than 1 m in the historical datasets. Explanation : no such events in the past OR the tide gauge didn't work during a storm and didn't record the surge.
The unpublished records added "classic" surges to the analyzed dataset. They highlighted the exceptional character of the 1.1 m surge of October 2000.

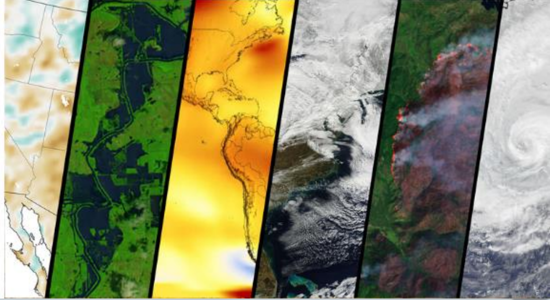
Sample : *data.shom*
Threshold : u = 0.361



Sample : *complete+HW*
Threshold : u = 0.39



EVAN 2022
ADVANCES IN EXTREME VALUE ANALYSIS AND APPLICATION TO NATURAL HAZARDS



Thank you for your attention

Saint-Malo/Saint-Servan reconstruction

Flag	Description
1	Good quality
2	Probably good quality
3	Probably bad quality
4	False : deleted data

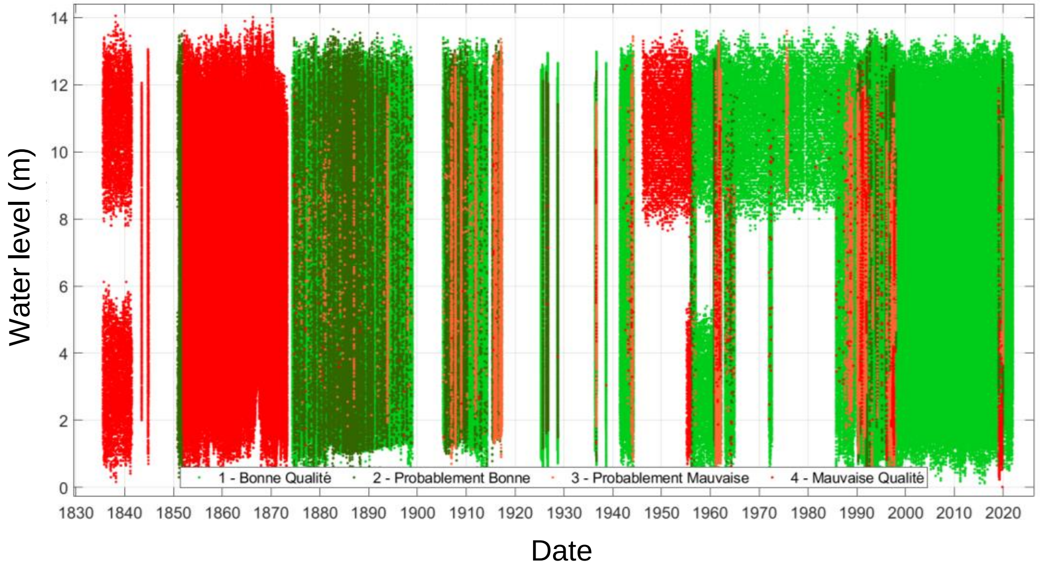
A reconstruction from 2 observation sites

The control and validation phase highlights 4 major time periods for which the digitized data had to be deleted, as they are considered false:

- [1734-1735] (not shown on the graph)
- [1835-1841]
- [1851-1873]
- [1946-1954]

Quality flags are assigned to the data
→ **87.5% of the measurements are of (probably) good quality**

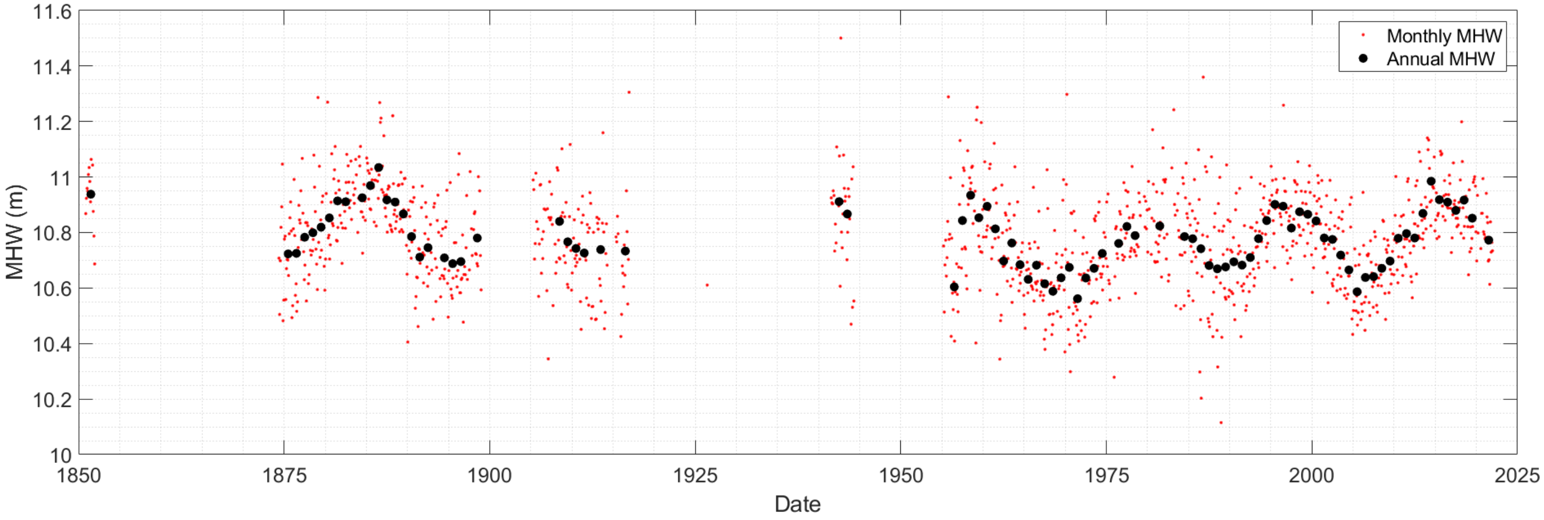
Quality flags on raw data



Application and analysis

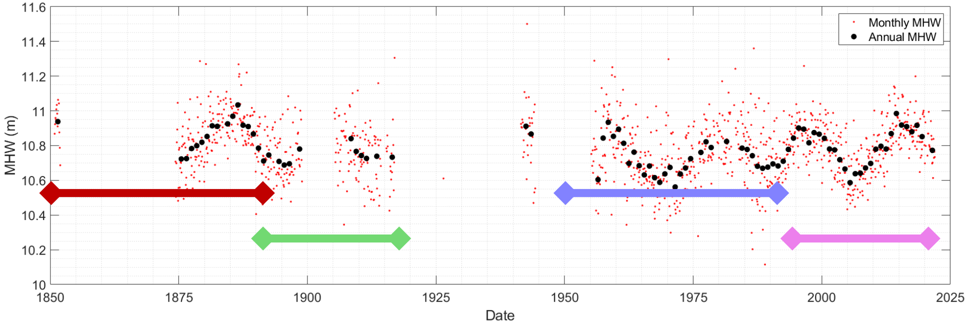
Mean high water levels – monthly and annual changes

- Addition of HW levels (1960-1990) to complete the dataset
- Nodal cycle (18.6 yrs) is well observed in the tidal signal
- But **not significant trend** appears from these levels (even when the nodal cycle is removed)



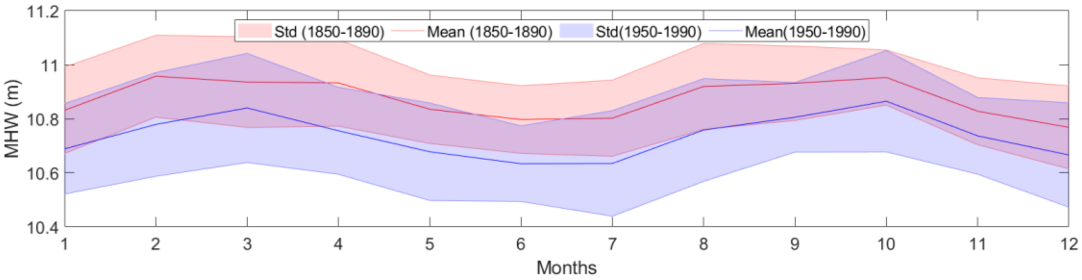
Application and analysis

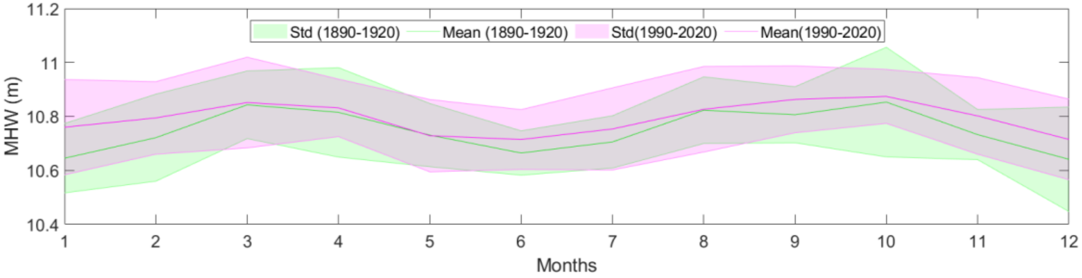
Mean high water levels – seasonal evolution



- Clear seasonality in MHW levels (winter's MHW are higher than summer's)
- But depending on the period considered, we don't observe the same evolution

→ **Difficult to conclude on any evolution**





RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

SHOM
L'océan en référence

Application and analysis

Mean tidal range changes

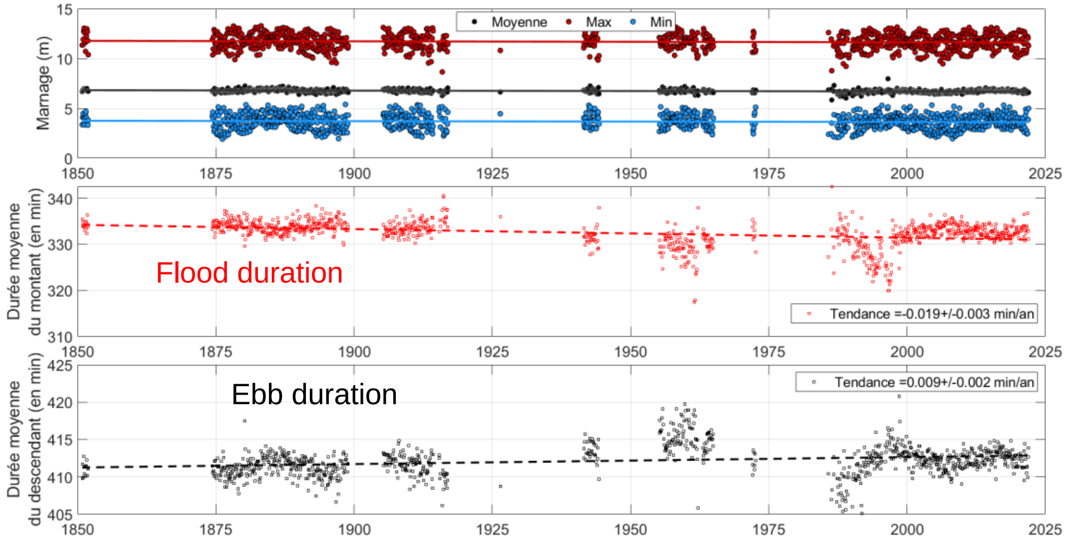
Monthly tidal range	*Trend [1850-2022]*
Mean	**-0,79 mm.yr^{-1} ± 0,18**
Max	**-1,00 mm.yr^{-1} ± 0,92**
Min	**-0,74 mm.yr^{-1} ± 0,88**

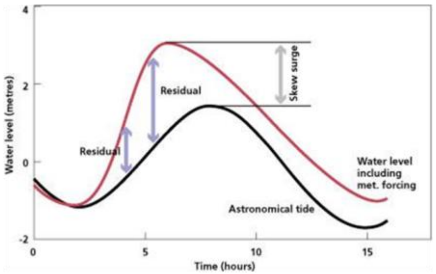
Mean tidal range decrease since the 19th century

Previous work has shown that on the British Isles, the evolution of the **tidal range was correlated with the long-term evolution of the M2 harmonic component** (Woodworth et al., 1991).

The amplitude and phase of the M2 wave have tended to decrease at St. Malo since 1850.
It is possible that for St. Malo, the evolution of the **M2 wave** has an **influence on the tidal range**, hence the observed decrease over more than a century.

Ebb and flood duration : similar to what is observed in Haigh et al. (2010) for Brest





Schematic of a skew surge – meteorological effects can have a notable effect on sea level and can alter the timing of high tide (Source : NOC)

Application and analysis

Statistical sea level extreme events analysis

Skew surges : difference between the **maximum observed sea level** and the **maximum predicted tide** regardless of their timing during the tidal cycle (see the poster "The impact of tidal predictions on historical extreme skew surges" of N. Giloy for more information in the calculation of historical skew surges)

SL observations : from **reconstructed datasets**
SL Predictions : calculated on **different periods** to be as free as possible from sea level variations and changes in tidal characteristics :

- [1850-1875]
- [1876-1900]
- [1901-1914]
- [1915-1938]
- [1939-1970]
- [1971-2000]
- [2001-2022]

HW levels observed and predicted are then extracted to calculate skew surges.