Historical sea level data rescue to assess long-term sea level evolution

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Context

In coastal areas, the characterisation of sea-level rise and variations of sea level due to extreme weather events (e.g. storm surges) remains a strong societal concern.

→ **The analysis of long historical water level records proved to be an ideal way to provide relevant arguments regarding the observed long-term sea-level evolution.**

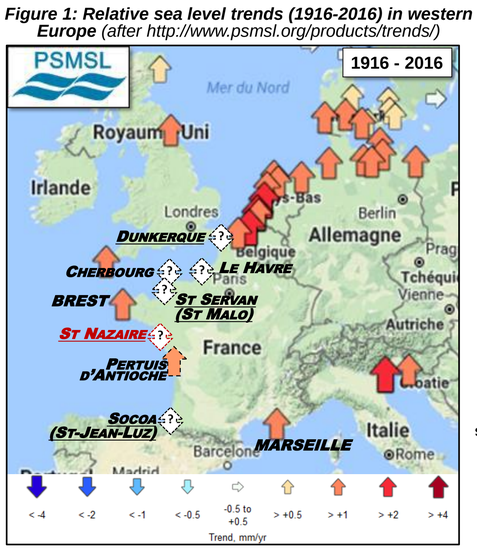
In France, many systematic sea level observations performed by mechanical tide gauge have taken place since the mid-1800s (Pouvreau, 2008)**. Despite this rich history, long water-level data sets digitally available are still scarce (Figure 1 & 2) !**

→ **Historical water level measurements need to be rescued !**

This time-demanding Work is undertaken at Shom for few years. It aims at recovering the French scientific and cultural heritage on sea level observations, and providing researcher community with new datasets to analyse (Figures 1 & 2). This Shom/SONEL initiative fulfills the recommendations of the Global Sea Level Observing System (GLOSS, developed under the auspices of the IOC/Unesco) on the recovery of forgotten sea level measurements (Bradshaw *et al.*, 2015).

An overview of the work conducted at Shom in data archeology is presented as well as a focus on the historical (1863 – today) sea level reconstruction for Saint-Nazaire (France).

Figure 1: Relative sea level trends (1916-2016) in western Europe (after http://www.psmsl.org/products/trends/)



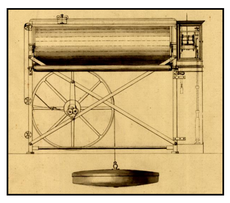
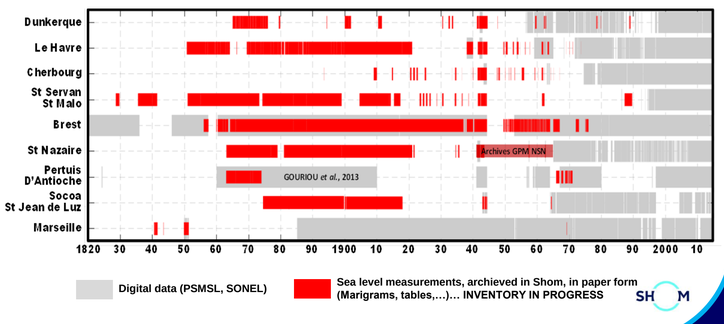


*Figure 2: picture on left. **Tide gauge used since the mid-1800s along the french coast** ("Chazallon's type")*

*On bottom : **Examples of sea level datasets digitally available for French historic tide gauges** (sources : SONEL, PSMSL) **and illustration of the potential of the Shom paper archives (not exhaustive, inventory still in progress)***



Steps involved in the Historical Data Rescue of Sea-level measurements

From paper documents … … To digital sea level data

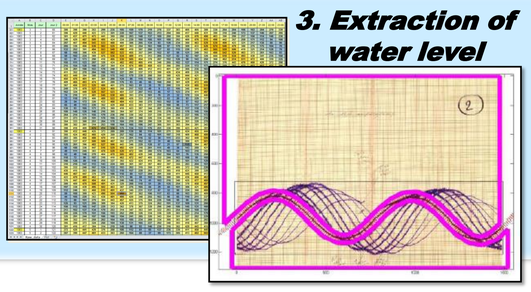
1. Inventory and recovery

→**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

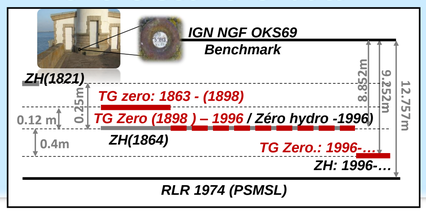
3. Extraction of water level



- **Handwritten ledgers** manually digitised into tables
- **Marigrams** « automatically » digitised with the use of the NUNIEAU software (Pons, 2008) based on color recognition

→ **DIGITAL RAW DATA**

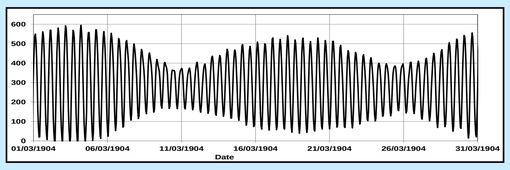
4. Vertical consistency of the sea level data



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
(Good/probably good/probably bad/bad)

Shom & Sonel: Actions in data rescuing

State of the inventory of Shom archives

How many Documents in Shom archives

- More than **50.000 documents identified** and accurately inventoried
- **about 50 %** have already been **scanned**

→ **But … Still thousands of documents to carefully inventory/scan !**

Geographical extent

France (Fig. 3):

- about 1.000 years of cumulated sea level measurements, ~ 300 sites
- Total duration per site ranging for few days/weeks/months (observations for sounding reduction purpose) to several decades
- Longest time series correspond to historical tide gauge network (Fig. 2)

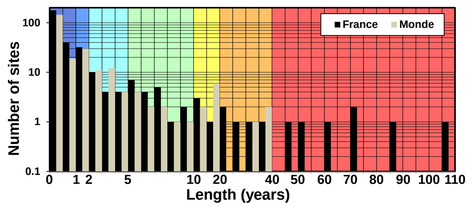
Around the world (Fig. 3 & 4):

- about 470 years of cumulated sea level measurements, ~ 240 sites
- Mainly short duration observations, but some « long » time series (fig. 4)

Applications in case of digitising these paper data

- Longest time series can be directly use to assess long term sea level evolution (necessity of visiting others archive centres to expand coverage)
- Shorter dataset could be use to **quantify historical storm surges** (if occured during measurements, **ex. Fig 5**) → Improvement of estimation and prediction of extreme coastal water levels (Bulteau *et al.*, 2015).

Figure 3: Number of locations with sea level observations according to the total duration of the measurements from Shom archives



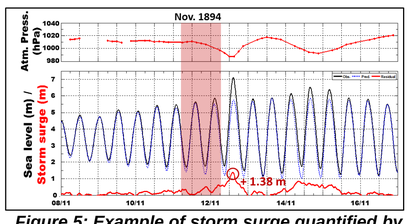


Figure 5: Example of storm surge quantified by digitizing paper sea level observation (Saint-Nazaire, 12th nov. 1894)

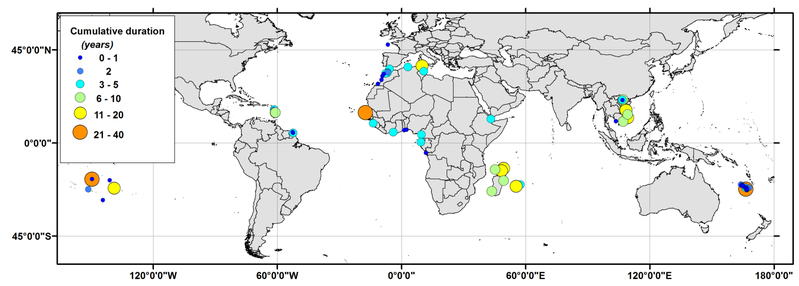


Figure 4: Partial view of the spatial distribution of the sea level data around the world, from Shom archives

Effort to improve the "automatic" digitization

Currently, NUNIEAU is the only tools allowing to digitise marigrams. With some complex marigrams **(Fig.6)** the process is not automatic and takes time. **Shom – Sonel initiative, in collaboration with CEREMA and L3I laboratory (La Rochelle university)** : work on the improvement on this step by using **signal processing approach**.

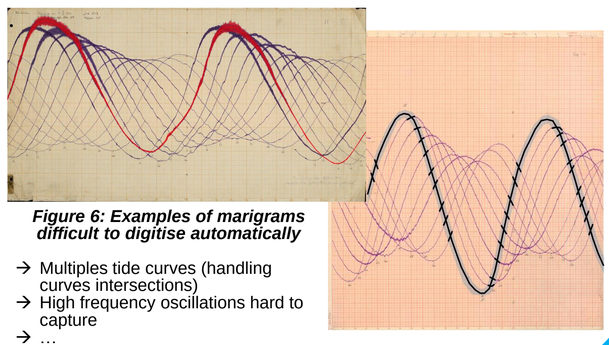


Figure 6: Examples of marigrams difficult to digitise automatically

→ Multiples tide curves (handling curves intersections)
→ High frequency oscillations hard to capture
→ …

Historical sea-level data at Saint-Nazaire : Example of outcomes

New dataset: long-term sea level evolution

Saint-Nazaire is located on the French Atlantic coast in the **mouth area** of the **macrotidal Loire estuary (Fig.1).** Sea level measurements automatically performed with the use of a mechanical float tide gauge **since 1863: more than 80 years of data have been retrieved, allowing to assess secular sea level rise (Fig. 7).**

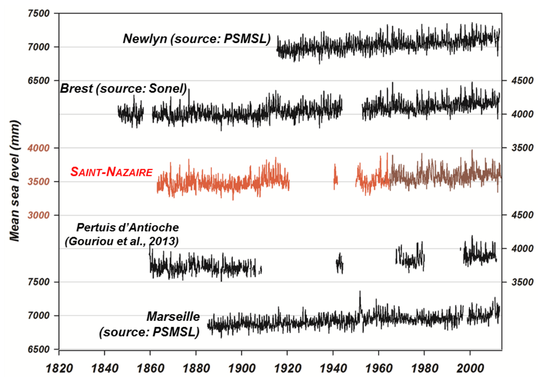


Figure 7: Monthly mean sea level time series in western Europe since mid-1800s. (Site locations on Fig.1)
The light red line: newly digitised data of Saint-Nazaire

Sea level trends at Saint-Nazaire :

- **[1863 – 2014] period: + 1.03 +/- 0.05 mm.yr^{-1}**
- **[1950 – 2014] period: + 1.59 +/- 0.22 mm.yr^{-1}**
- **[1993 – 2014] period: + 2.87 +/- 1 mm.yr^{-1}**

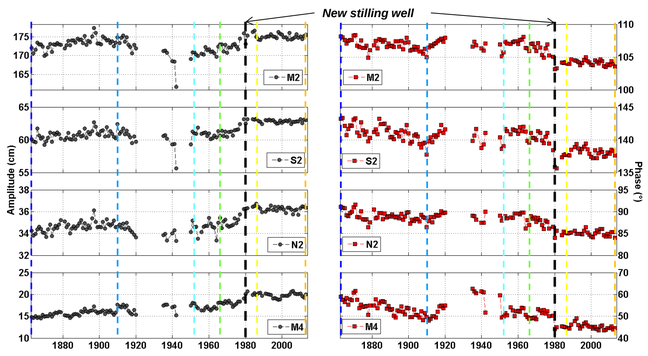
On the more recent period, calculated trends are consistent with values obtained from spatial altimetry and with those calculated from measurements at nearby stations.
Secular sea level trend tends to be lower at Saint-Nazaire than at Brest (+1.32 ± 0.07 mm.yr^{-1}) or deduced from the composite time series of le Pertuis d'Antioche (1.44 ± 0.13 mm.yr^{-1}).

⇩

- Periods with data which are "badly" referenced in vertical ?
- Influence of siltation occurring in the stilling well at Saint-Nazaire (overestimation of Low water levels) ?

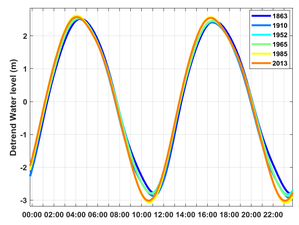
Stability of tidal constituents at Saint-Nazaire

Figure 8: Evolution of principal tidal constituents at Saint-Nazaire since 1863 (based on yearly Harmonic analysis)



Brutal behaviour change staring from 1980 (fig. 8):
Before: variations can be observed (especially for M4: amplitude rise ~5 cm associated with phase shift)
After: constituents are very stable
→ **It coincides with the installation of a new stilling well**

Figure 9: Standardised Tidal curves for the same spring tide (5-6 May 2000) predicted from different sets of tidal constituents



The shape of the tidal curves evolved over time (Fig. 9):
Tides in the past time show a strong temporal shift for low water associated with an increase of low water level
→ **Impact of siltation on old measurements ?**

Conclusion / Outlook

Although the recovery of forgotten sea level measurements is a time-demanding work, it is the only way to **assess long-term sea level evolution (at secular time scale) and to provide essential elements for the study of extreme sea levels.**
At Shom, an important effort has been initiated to rescue these data (detailed inventory – a reflection is conducted to make it available soon – scanning – digitizing – data qualifying). This effort has **to be extend to more archives center**s to get a more exhaustive inventory as possible.
Upcoming projects on historical sea level reconstruction in France: **Dunkirk, Saint-Servan and Socoa timeseries** (location Fig.1).
Need to continue to work on making this activity easier and faster in the future (tool/methodology development)

Acknowledgments

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References

Bulteau T., Idier D., Lambert J., Garcin M (2015) How historical information can improve estimation and prediction of extreme coastal water levels: application to the Xynthia event at La Rochelle (France), Nat. Hazards Earth Syst. Sci., Vol. 15, pp 1135-1147.
Bradshaw, E., Rickards, L. & Aarup,T., 2015. *Sea level data archaeology and the Global Sea Level Observing System (GLOSS)*. GeoResJ (6), pp. 9-16.
Gouriou T., Martin Miguez B., Wöppelmann G. (2013). *Reconstruction of a two-century long sea level record for the Pertuis d'Antioche (France).* Continental Shelf Research, Vol. 61-62, pp 31-40.
Pons F. (2008). Améliorations récentes apportées au logiciel NUNIEAU pour la numérisation des marégrammes papiers. Xèmes JNGCGC, octobre 2008, Sophia Antipolis.
Pouvreau N, 2008. *Trois cents ans de mesures marégraphiques en France : outils, méthodes et tendances des composantes du niveau de la mer au port de Brest.* Climatologie. Thèse, Université de La Rochelle, 468 pp.