The impact of tidal predictions on historical extreme skew surges

Nathalie Giloy, Alexa Latapy, Gaël Andre, Nicolas Pouvreau, Lise Bardet, Antonin Migaud

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THE IMPACT OF TIDAL PREDICTIONS ON HISTORICAL EXTREME SKEW SURGES

Extreme sea and skew surge levels are variables commonly used in public policies and integrated coastal zone management. In France, this policy is mainly supported by the Ministry of Ecological Transition. More specifically in the framework of nuclear safety, the protective infrastructures are designed for a sea level corresponding to a combination of the highest astronomical tide, the upper bound of the 70% confidence interval corresponding to the 1000-year return skew surge and changes of mean sea level. So far, the extreme skew surges are estimated using systematic tide gauge data, but more and more historical information is considered to improve the estimates and to reduce the associated uncertainties due to the presence of an outlier in the sample.

Defined as the difference between the highest observed sea level and the highest astronomical level during a tidal cycle, the estimation of skew surges implicates the estimation of tidal predictions. While the process is well established for current tidal predictions, different approaches to estimate them for historic events have been used in several research projects and as parts of coastal flood prevention plans.

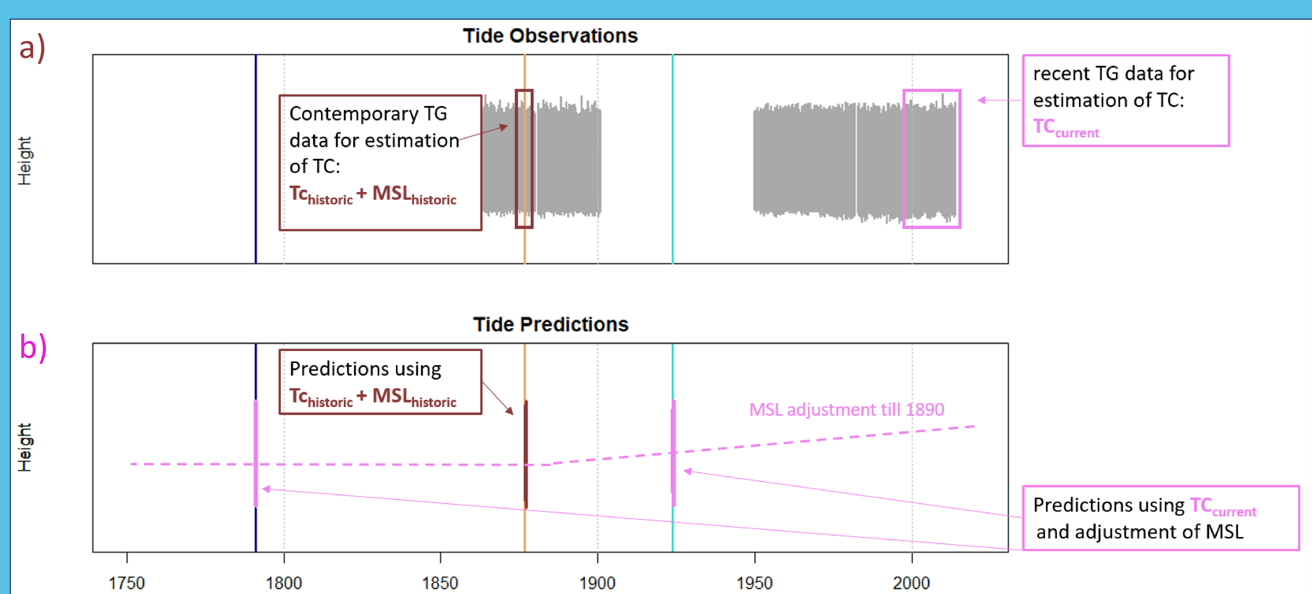
CONTEXT

The Working Group (WG) « Historic Storms and Floodings », founded in 2016, aims to identify, mutualize and qualify information on historic meteo-oceanic events. When reconstructing historic surge levels, the necessity of accurate tidal predictions is important.

Therefor, two methods for estimating these predictions are proposed, depending on the sea level data available:

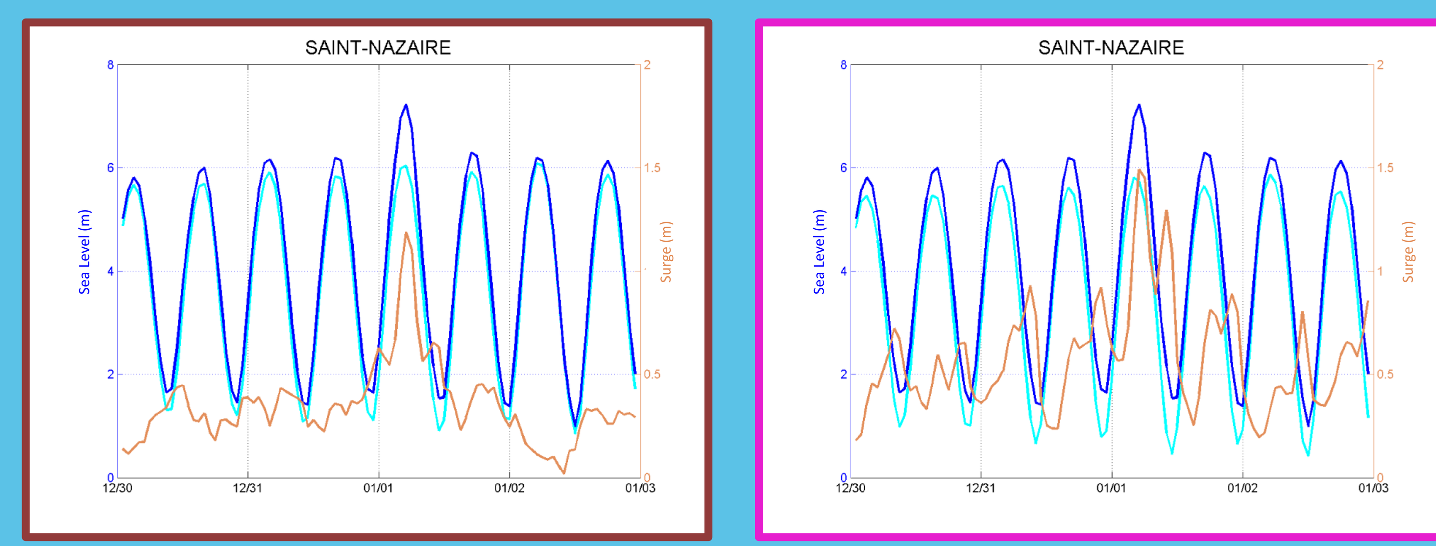
Depending on the existence of tide gauge measurements, different methods can be applied for the calculation of tidal predictions (TP) for historical events. By order of priority:

a) Use available historical Tide Gauge (TG) Data for the estimation of Tidal Constituents ($TC_{historic}$)
b) Use current Tidal Constituents ($TC_{current}$) and adjust the mean sea level (stable before 1890 and using a linear regression estimated on annual mean sea levels (MSL) after 1890 [1]



31st Décember 1876 – 1st January 1877 Saint Nazaire

a) Use of $TC_{historic}$ | b) Use of $TC_{Current}$ and correction of MSL



Observed High Water: 7.23 m CD

Predicted HW:	6.04 m CD	Predicted HW:	5.81 m CD
Skew Surge	1.19 m	Skew Surge	1.42 m

→ Difference > 0.2 m for one specific event.

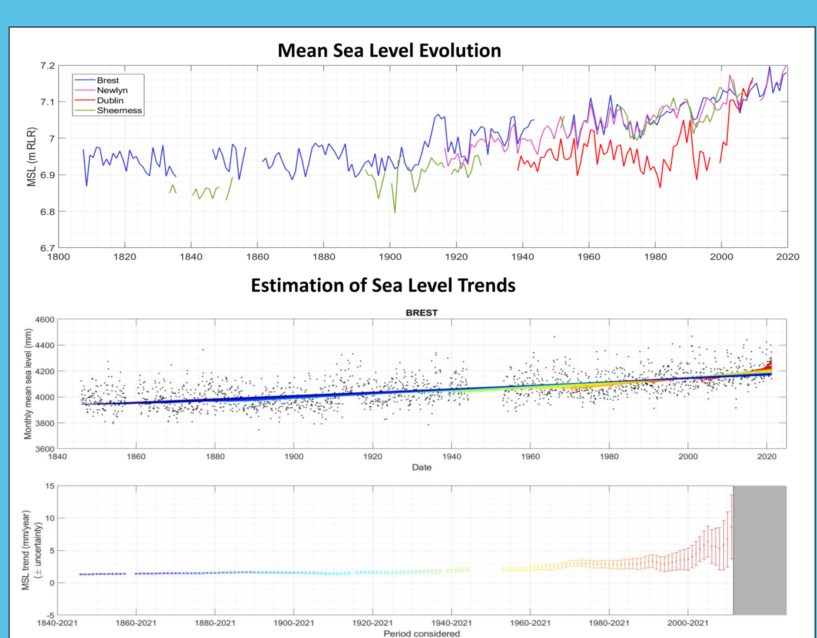
In this study we want to investigate what are the sources of uncertainties when estimating tidal predictions for the past.

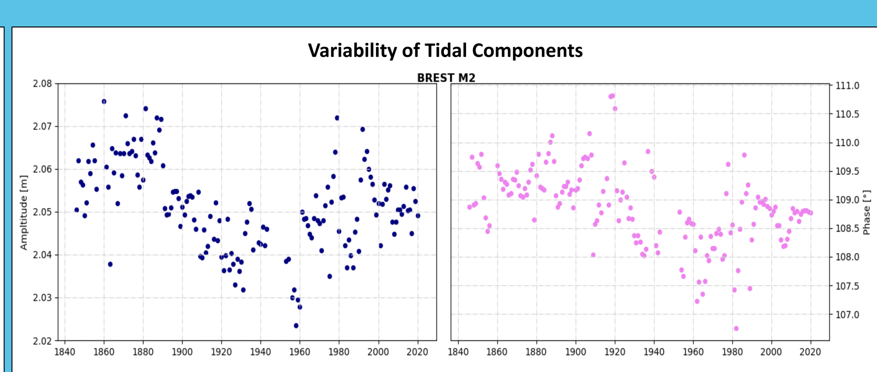
A LITTLE THEORY ON TIDES

The rise and fall of the sea is the ocean's response to astronomical (solar, lunar and terrestrial) gravitational forcing. These movements are periodic oscillations that can be described in terms of amplitudes (H_i) and periods (g_i) [2]. Mathematically via harmonic analysis, the sea level variation in function of time ($\zeta(t)$) can be represented in the following form:

$$\zeta(t) = \sum_i H_i \cos(\sigma_i t - g_i)$$

An important part of the oscillation can be captured by the principal lunar wave M2 and approximately 99% is captured by 14 terms [3]. To estimate all constituents affected by the nodal cycle, 18.6 years of data would be necessary. While these nodal modulations can be adjusted by nodal factors (amplitude factor and phase factor) tidal components vary, depending on the length of period analyzed.



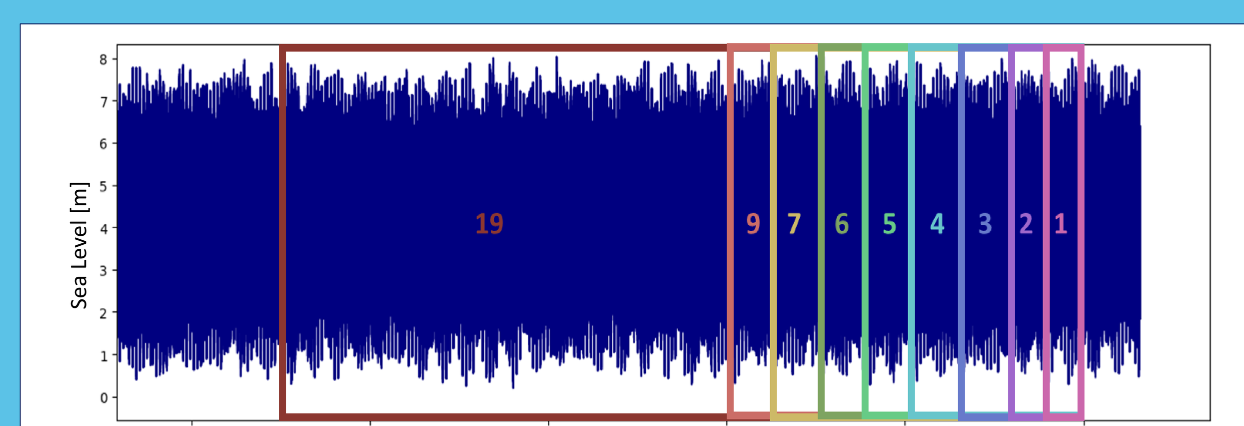


These tidal variations are then added to a mean sea level, which is also subject to interannual, annual and long-term climatic variations. Linear regressions are applied on mean sea level values, but the estimation of reliable trends with small uncertainties need long-term series [4].

METHODOLOGY

1) Choose the use of number of years necessary for Tidal Analysis

The ideal case would be to use 19 years of observations for tidal analysis. Unfortunately, the more we go back into the past, the less data is available. In order to see the differences for HW (High Water) and LW (Low Water) predictions, we produced 9 different tidal component datasets, using different length of tide gauge observations: 1, 2, 3, 4, 5, 6, 7, 9 and 19 years. Using these datasets we estimated tidal predictions for the entire tide gauge series. HW and LW were compared, the reference tidal component (TC) dataset was TC19, estimated using 19 years of observations. We used recent tide gauge data (2002-2020) and older tide gauge data (1871-1889).



2) Comparison of skew surges estimated using 2 different methods

We worked with the series of Brest and Saint-Nazaire and estimated 10 major skew surges per year:

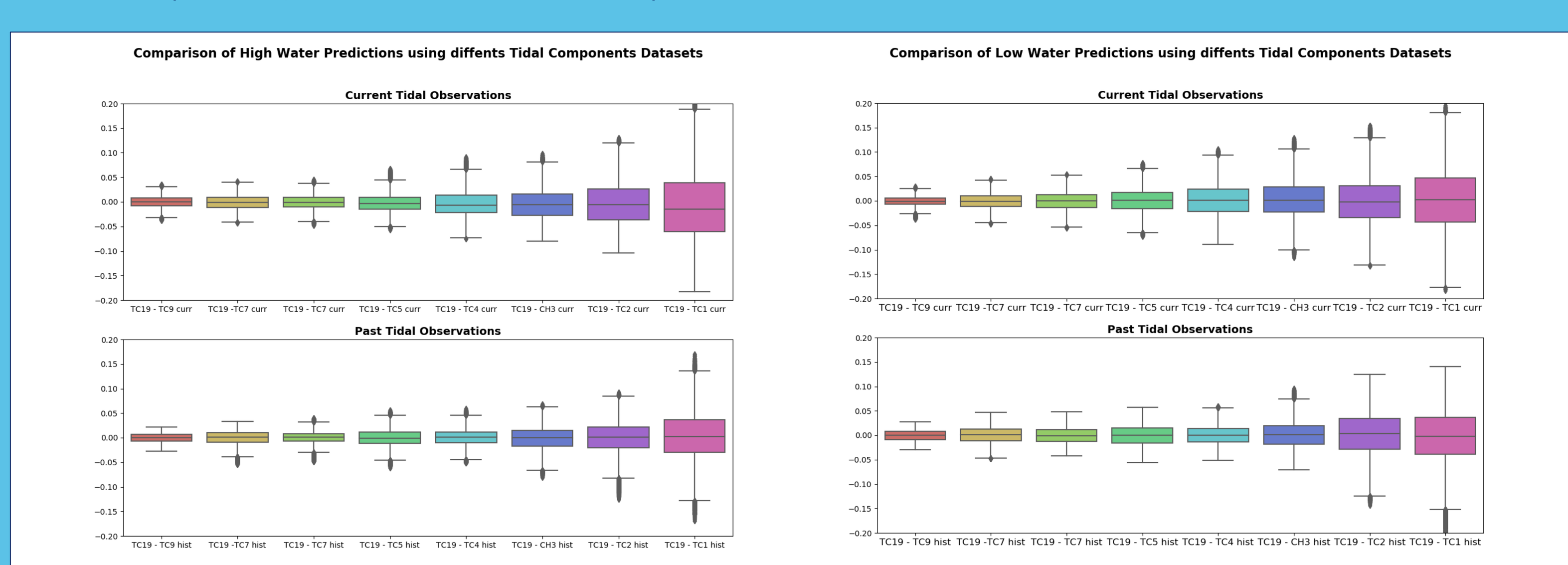
- Estimating surges using 5years of observation around the event $TC_{historic5}$
- Using current TC and applying a correction of mean sea level $TC_{current+msl,}$ mean Sea Level Corrections applied using a trend estimated for three different periods

RESULTS

1) Choose the use of number of years necessary for Tidal Analysis

The figures below represent in boxplots the difference between HW (left) LW (right) levels estimated using tidal predictions made with different length of tide gauge series, relative to TC19. The upper panels are estimated on recent TG data (2002-2020), the lower panel on historic TG data (1871-1889).

→ The longer the tide gauge observations, the smaller the differences
→ As a compromise, we chose to work with 5 years of TG data.



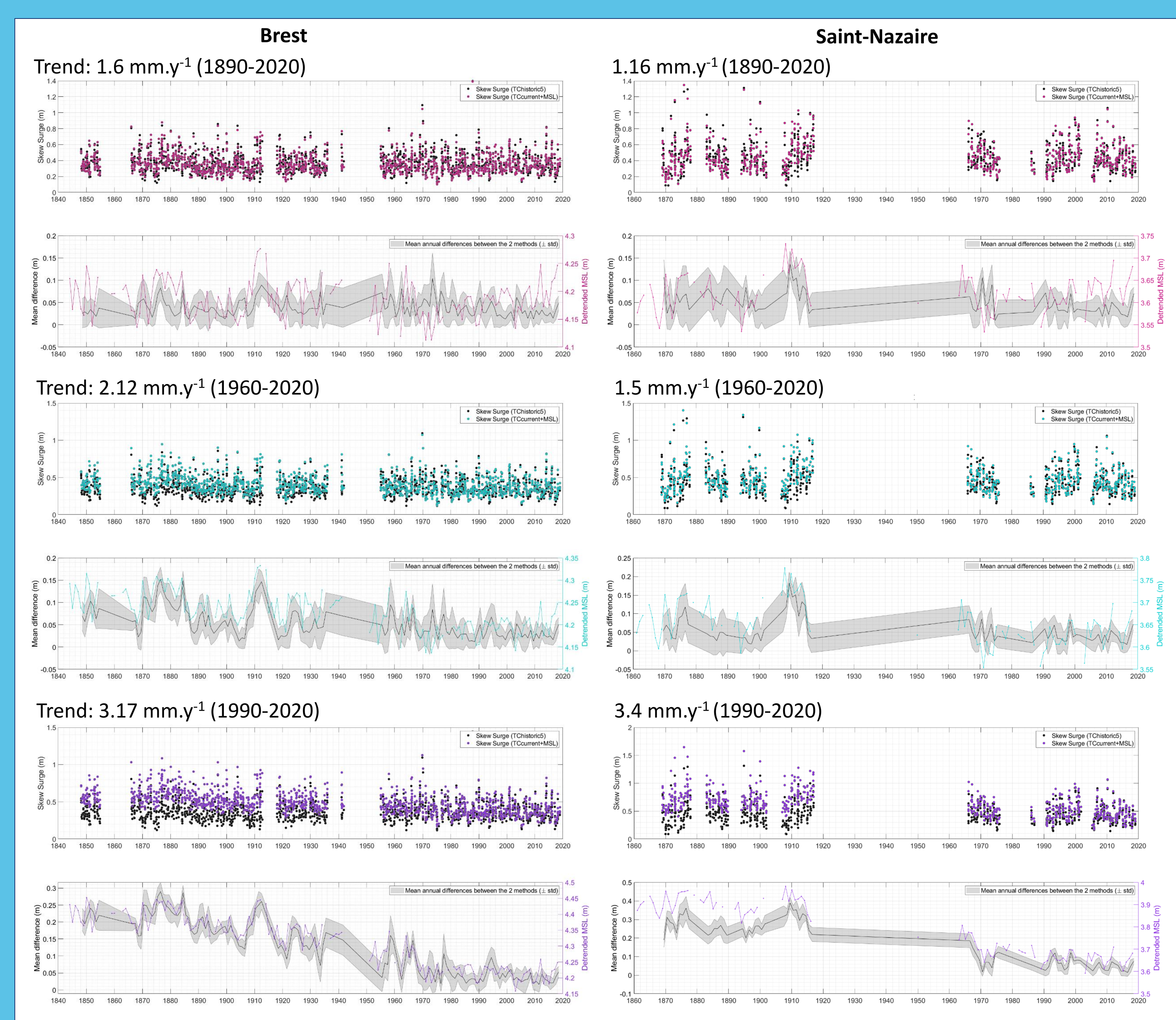
2) Comparison of skew surges estimated using 2 different methods

Looking at the presented figures on the right, it becomes clear that the main variability of the skew surges results from the trend applied on the mean sea level when using $Tc_{current+msl}$ in comparison of $TC_{historic5}$:

- Using 130 years for a trend estimations reduces differences to around 15 cm
- Using 60 years for trend estimations elevates mean differences up to 20 cm
- Using 30 years increased up to 30 cm (Brest) to 50 cm (Saint-Nazaire) the mean differences

→ These differences are higher than the variability of separate tidal constituents.

→ The variations of differences seem related to mean sea level variations.



CONCLUSIONS AND PERSPECTIVES

The aim of this work is to better understand uncertainties when estimating tidal predictions for past extreme events, when no tide gauge observations are available for harmonic analysis. Thus using current tidal constituents and adjusting mean sea level, while being a good alternative, show variabilities are rather related to the MSL trend applied then to variations of tidal constituents.

When no or too short tide gauge series for estimating trends are available, the use of regional trends could be an alternative [5]. Further investigations on applying a correction of mean sea level variations to a local or regional trend are projected.

References

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Nathalie GILOY [1,2], Alexa LATAPY[1], Gaël ANDRE[1], Nicolas POUVREAU[1], Lise BARDET[2], Antonin MIGAUD[2]

[1] Shom, 13 rue du Chatellier, CS 92803 - 29228 Brest CEDEX 2, France
[2] IRSN, BP 17, 92262 Fontenay-aux-Roses cedex, France

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