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ANALYSIS OF LONG-TERM SEA LEVEL VARIATION IN THE NORTH ADRIATIC AND SEASONALITY

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Introduction

The STL (Seasonal Trend decomposition using Loess) method has been applied to investigate mean sea level variation in the North Adriatic. The STL is a statistical method widely used when attempting to decompose a signal in his components such as the periodic one and the long-term non periodic one. Finally, in order to achieve more information and explication of possible climate changes impact on sea level variation the seasonal analysis has been carried out.

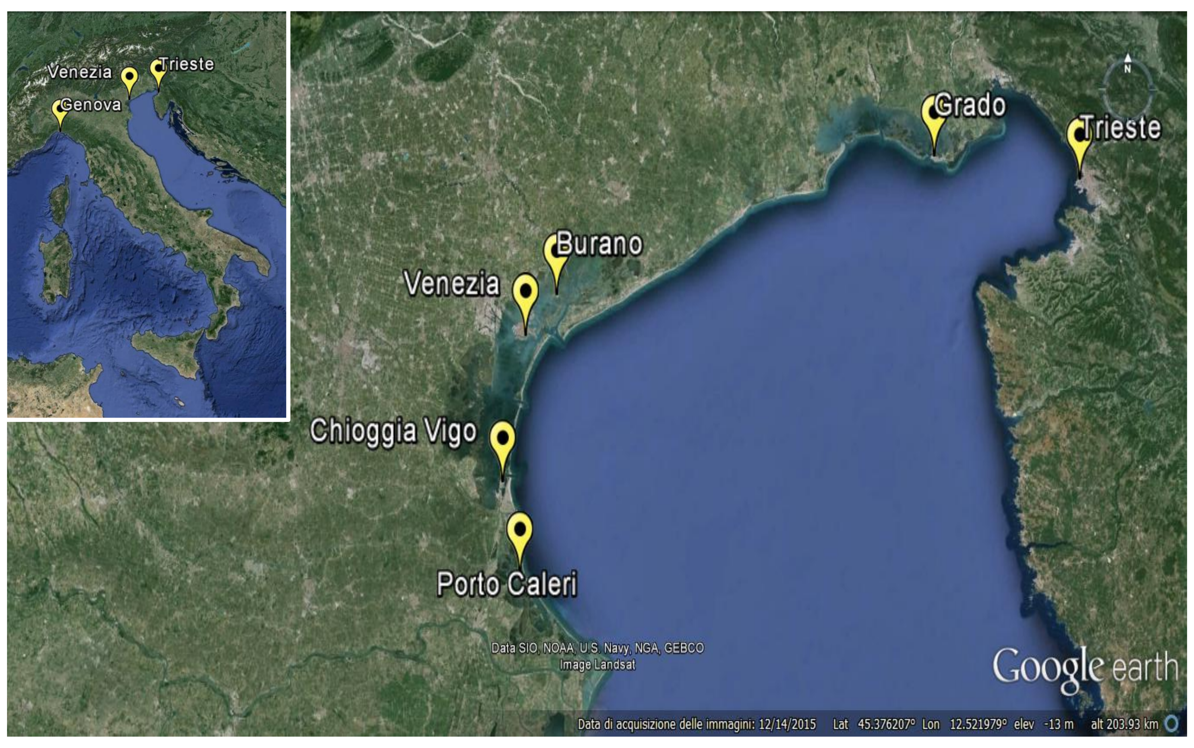

Figure 1: Tide gauges in the North Adriatic Sea and in the Venice Lagoon

Data and Method

The analysis here proposed, based on the Seasonal Trend decomposition using Loess (STL) method, has been applied to the long sea level time series recorded at Venice and Trieste. Data, provided by ISPRA Venice department and by Trieste CNR-ISMAR, represent almost secular time series; that is the best possible choice for any long-term statistical analysis in Italy. The selected statistical method has also been applied to sea level time series recorded at Chioggia, Burano, Porto Caleri and Grado tide gauges located in the transitional water bodies in the North Adriatic areas. Data are collected every 10 minutes, even if in this study the monthly means have been analysed. Decomposition methods may be used to break up a time series into the following components: trend, seasonal and irregular. The trend component consists of the underlying long-term aperiodic rises in the sea level over time. The seasonal component is a recurrent pattern over time. The irregular component is the remaining pattern in the series not attributed to trend or seasonality. Thus extracting the seasonal component will allow a clearer picture of the other features of the time series. A number of time series decomposition methods are available, but one of the most advanced is the STL (Seasonal-Trend decomposition procedure based on Loess) method, the locally weighted regression smoothing technique (Loess) developed by Cleveland (1979) (Cleveland et al.,1990).

First of all we assume an additive decomposition in the time series, that means we are dealing with independent components:

(1) $Yt = Tt + St + Rt$

where Yt denotes the time series of interest, Tt denotes the trend component, St denotes the seasonal component and Rt represents the stochastic remainder (or irregular) component. The seasonally adjusted series, Y_t is simply computed by subtracting the estimated seasonal component from the original series, Y_t = Yt – St.

The STL technique consists in a series of consecutive applications of a Loess smoother with different moving windows. STL involves an iterative algorithm which progressively refine and improve the estimate of the trends and the seasonal components.

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Results

The results of the STL analysis, as shown in Figure 2, highlight a sea level rise during the last 92 years (1924-2015) and show the growth rate behavior, with a singular modulation in the 1986-1996 period in both Venice and Trieste stations. The same result was found in all the considered time series. Even though the reason is still an open matter of investigation, the findings are consistent with a global sea level rise associated with climate changes. The different locations show behavior strongly similar (Figures 2 and 3), confirming that the sea level rise is not only due to local physical effects, such as subsidence, but probably to climate changes effects. In order to deeply investigate these effects, seasonal analysis have been carried out. In this work it has been referred to the WMO classification of the 4 seasons. Hence an 'indicator' of seasonal variability has been defined. First of all the annual mean value of each season has been evaluated, hence a moving average (with an 11 years moving window) has been applied in order to smooth the seasonal trend. Finally this moving averages have been normalized as described in formula 2. This method has been applied to the two time series, and the results are here summarized in Figure 4 (the two panels represent, respectively, Venice and Trieste)

(2) $Tau = \mu au / \Sigma(\mu au + \mu wi + \mu sp + \mu su)$

where Tau is the trend indicator for autumn season, μau is the moving average on the autumn annual mean values and the denominator is the sum of each season moving average.

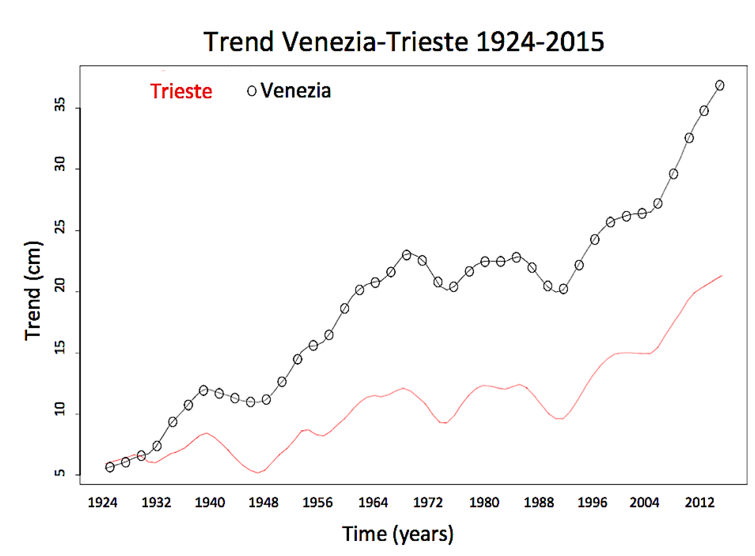

Figure 2: Mean Sea Level trend 1924-2015 in Venice and Trieste

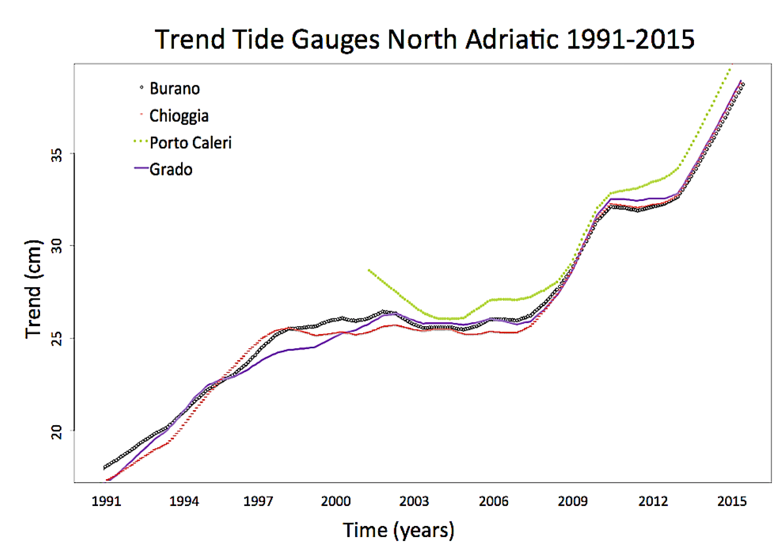

Figure 3: Mean Sea Level trend 1991-2015 in the North Adriatic and in the Venice Lagoon

Interesting results have been carried out in the seasonal analysis. Looking at Figure 4 it could be highlight that:

- "There are no more seasons", it means that seasonal components are moving towards a neutral value (25%) decreasing their gap and converging;
- Summer season is the neutral component, since it is rather stationary all over the time;
- Autumn and Winter are competitors, since they show an opposite behavior;
- Spring season is smoothly growing.

These are the interesting preliminary results related to possible climate changes impact on sea level seasonality.

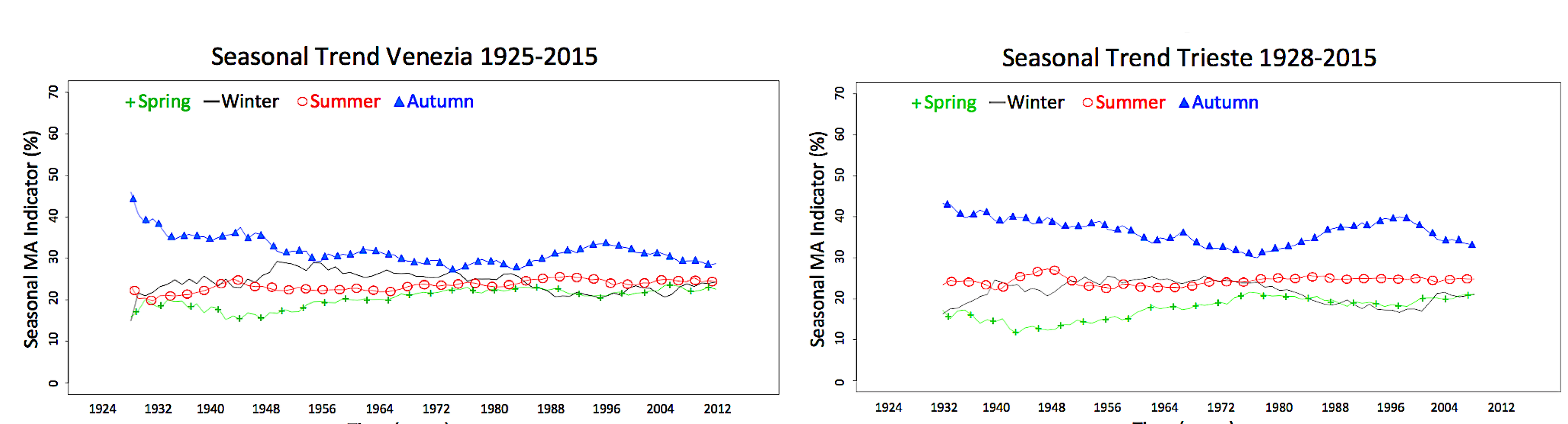

Figure 4: Moving average of seasonal components in Venice and Trieste

Conclusions

This paper develops a deep analysis of mean sea level time series in the North Adriatic and the Venice lagoon in order to highlight the mean sea level evolution as well as to compare the seasonal trend behaviours.

These important results show a strong mean sea level variation and a seasonality changing over the whole period of investigation, probably due to climate changes effects. These preliminary results lead to a further investigation, extending the analysis to other available locations such as Genoa, and concerning as the assessment and the management of flood risks required by the Directive 2007/60/EC as well as the management of Mose barriers (flap gates) at lagoon inlets and related port activities.