Department of
Economics and Finance

US SEA LEVEL DATA: TIME TRENDS AND PERSISTENCE

Guglielmo Maria Caporale
Brunel University London, UK

Luis A. Gil-Alana
University of Navarra, Pamplona, Spain
Universidad Francisco de Vitoria, Spain

Laura Sauci
UNED, Madrid, Spain

March 2020

Abstract

This paper analyses US sea level data using long memory and fractional integration methods. All series appear to exhibit orders of integration in the range (0, 1), which implies long-range dependence; further, significant positive time trends are found in the case of 29 stations located on the East Coast and the Gulf of Mexico, and negative ones in the case 4 stations on the North West Coast, but none for the remaining 8 on the West Coast. The highest degree of persistence is found for the West Coast and the lowest for the East Coast.

Keywords: Sea level; time trends; fractional integration

Corresponding author: Professor Guglielmo Maria Caporale, Department of Economics and Finance, Brunel University London, UB8 3PH, UK. Tel.: +44 (0)1895 266713. Fax: +44 (0)1895 269770. Email: Guglielmo-Maria.Caporale@brunel.ac.uk

* Prof. Luis A. Gil-Alana gratefully acknowledges financial support from the MINEIC-AEI-FEDER ECO2017-85503-R

West coast the increase is around or below the GMSL rise of 1.7 mm year ^{1}. The highest regional sea levels increases have been observed in Louisiana, Eastern Texas and the stretch from Virginia to New Jersey, which can be explained by Gulf Stream variations, land subsidence and tectonic movements (Zervas, 2009; Sweet et al., 2017).

Future scenarios for the sea level rise are based on emissions and the associated risks. It is expected that GMSL will continue increasing during the 21st

methodology; Section 4 presents the empirical results; Section 5 offers some concluding remarks.

2. Literature Review

processes appear to be the most appropriate for geophysical/climate time series, since these tend to exhibit long-run dependence (LRD) or temporal correlations (Beran, 1994; Percival et al., 2001; Gil-Alana, 2006; Ercan et al., 2013; Graves et al., 2017). Such models range from those proposed by Hurst (1951) in hydrology, and later by Mandelbrot (1967) and Mandelbrot and Van Ness (1968) for self-similarity and the fractal dimension, to the AutoRegressive Fractionally Integrated Moving Average (ARFIMA) model of Granger and Joyeux (1980), and its subsequent extensions.

Long-memory models have been widely used for climate variables such as temperature (Bloomfield, 1992; Caballero et al., 2002; Franzke, 2012; Gil-Alana, 2005, 2008, 2018), but less for sea level data. In particular, there is very limited evidence concerning US tide gauge records. Jiang and Plotnick (1998) were the first to carry out fractal analysis using US coastline data with a continental dimension; applying the

In another recent study, Dangendorf et al. (2014) investigated sea level changes using 60 monthly average tide gauge records around the world. Their results from the Detrended Fluctuation Analysis -DFA2- (Kantelhardt et al., 2001) show, for all records, a LRD up to 35 years, which suggests the importance of the internal behaviour to understand sea level changes. By contrast, Becker et al. (2014) concluded that global and regional sea level changes are strongly driven by anthropogenic forces, in particular in the case of New York, Baltimore and San Diego. Finally, Royston et al. (2018) addressed the issue of residual noise when estimating linear trends, and showed that it is coloured but non-AR(1) in the majority of cases, the AR(1) model being more appropriate for shorter series (Bos et al., 2014). The inclusion of climate indices in the regression does not affect the choice of noise model: for San Francisco and Seattle, the preferred noise models are ARFIMA specifications, with a trend coefficient (including climate indices) of 2.37 and 2.71, respectively, while for Honolulu, the preferred model is the Generalized Gauss Markov (GGM) noise model, with an estimated trend coefficient of 1.29. The study by Royston et al. (2018) is the closest to ours, since we also consider long-range dependence models based on fractional integration and estimate the time trend coefficients allowing the errors to be fractionally integrated.

3. Data and Methodology

The data examined concern 41 US stations covering most of the US coast. Table 1 reports the names of the stations and the percentage of coverage; we only consider series with a maximum of 10% missing data, and compute them as a simple arithmetic mean of the previous and following monthly value in the series. The data are available at https://www.psmsl.org/data/obtaining/.

TABLE 1 HERE

TABLE 4 AND FIGURE 1 HERE

All the estimated values of d are in the interval (0, 1) and range between 0.29 (Annapolis, Naval Academy) and 0.75 (La Jolla, Scripps Piers), which confirms that the series are fractionally integrated. The series can be divided into three categories according to their degree of persistence: those with values of d in the range (0, 0,5), that is, covariance-stationary series; those with values around 0.5, on the boundary between stationarity and non-stationarity; a third group with values in the interval [0.5, 1), which implies non-stationary mean-reverting behaviour (see Table 5 and Figure 2)

TABLE 5 AND FIGURE 2 HERE

of d

the West coast) there is evidence of non-stationary mean-reverting patterns

References

Barbosa, S.M., Silva, M.E., and Fernandes, M.J. (2008). Time series analysis of sea-level records: Characterising long-term variability. In: Donner R.V., Barbosa S.M. (eds) Nonlinear Time Series Analysis in the Geosciences. Lecture Notes in Earth Sciences, 112, 157-173.

Becker, M., Karpytchev, M., and Lennartz-Sassinek, S. (2014), Long-term sea level trends: Natural or anthropogenic? Geophysical Research Letters, 41, 5571 5580.

Beran, J. (1994). Statistics for long-memory processes. Chapman & Hall: New York, NY, USA, 1 315.

Bloomfield, P. (1992) Trends in global temperatures. Climatic Change, 21(1), 275 287.

Boon, J.D. and Mitchell, M., (2015). Nonlinear change in sea level observed at North American tide stations. Journal of Coastal Research, 31(6), 1295 1305.

Church, J.A., Gregory, J.M., Huybrechts, P., Kuhn, M., Lambeck, K., Nhuan, M.T., Qin, D., and Woodworth, P.L. (2001). Changes in Sea Level. In: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881pp.

Dangendorf , S., Rybski, D., Mudersbach, C., Müller, A., Kaufmann, E., Zorita, E., Jensen, J.(2014). Evidence for long-term memory in sea level, Geophysical Research Letters, 41, 5530 5537.

Dangendorf, S., Marcos, M., Muller, A., Zorita, E., Riva, R., Berk, K., Jensen, J. (2015) Detecting anthropogenic footprints in sea level rise. Nature Communications, Granger C.W.J., and Joyeux, R. (1980). An introduction to long memory time series models and fractional differencing, Journal of Time Series Analysis 1, 15 29.

Graves, T., Gramacy, R., Watkins, N., and Franzke, C. (2017). A brief history of long memory: Hurst, Mandelbrot and the road to ARFIMA, 1951-1980. Entropy, 19(9) 437, 1 21.

Houston, J. and Dean, R. (2011). Sea-level acceleration based on U.S. tide gauges and extensions of previous global-gauge analysis. Journal of Coastal Research 27 (3):409 417.

Hsui, A.T., Rust, K.A., and Klein, G.D. (1993). A fractal analysis of Quaternary, Cenozoic-Mesozoic, and Late Pennsylvanian sea level changes, Journal of Geophysical Research, 98(B12), 21963   21967.

Hurst, H.E. (1951) Long-term storage capacity of reservoirs. Transactions of the American Society of Civil Engineers, 116(1), 770-799.

Jevrejeva, S., Grinsted, A., and Moore, J.C. (2009), Anthropogenic forcing dominates sea level rise since 1850, Geophysical Research Letter,36, L20706, 1 5.

Jevrejeva, S., Moore, J.C., Grinsted, A., Matthews, A.P., and Spada, G. (2014). Trends and acceleration in global and regional sea levels since 1807. Global and Planetary Change, 113, 11 22.

Jiang, J., and Plotnick, R.E. (1998). Fractal analysis of the complexity of United States Coastlines. Mathematical Geology, 30(5), 535-546.

Kantelhardt, J. W., E. Kocielny-Bunde, H. A. Rego, S. Havlin, and A. Bunde (2001), Detecting long-range correlations with detrended fluctuation analysis, Phys. A, 295, 441 454.

Koop, R.E. (2013). Does the mid-Atlantic United States sea level acceleration hot spot reflect ocean dynamic variability?. Geophysical Research Letters, 40(15), 3981-3985.

Lennartz, S. and Bunde, A. (2012). On the Estimation of Natural and Anthropogenic Trends in Climate Records. Washington DC American Geophysical Union Geophysical Monograph Series. 196. 177 189.

Mandelbrot, B. (1967). How long is the coast of Britain? Statistical self-similarity and fractional dimension," Science 155, 636-638.

Mandelbrot, B. (1982). The Fractal Geometry of Nature. W. H. Freeman and Company.

Mandelbrot, B.B., van Ness, J.W. (1968). Fractional Brownian motions, fractional noises and applications. SIAM Review 10, 422 437.

Marcos, M., Marzeion, B., Dangendorf, S., Slangen, A.B.A., Palanisamy, H., and Fenoglio-Marc, L. (2016). Internal variability versus anthropogenic forcing on sea level and its components. Surveys in Geophysics, 38(1), 329 348.

Mudelsee, M. (2010). Climate time series analysis. Classical statistical and bootstrap methods. 2nd ed., Springer, Dordrecht.

Oppenheimer, M., Glavovic, B.C., Hinkel, J., van de Wal, R., Magnan, A.K., Abd-Elgawad, A., Cai, R., Cifuentes-Jara, M., DeConto, R.M., Ghosh, T., Hay, J., Isla, F., Marzeion, B., Meyssignac, B., and Sebesvari, Z. (2019). Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate, 321 446.

Parris, A., Bromirski, P., Burkett, V., Cayan, D., Culver, M., Hall, J., Horton, R., Knuuti, K., Moss, R., Obeysekera, J., Sallenger, A., and Weiss, J. (2012). Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1. 37 pp.

Percival, D.B., Overland, J.E. and Mofjeld, H.O. (2001) Interpretation of North Pacific variability as a short- and long-memory process. Journal of Climate, 14(24), 4545 4559.

Robinson, P.M. (1994). Efficient Tests of Nonstationary Hypotheses, Journal of the American Statistical Association 89, 1420 1437.

Royston, S., Watson, C.S., Legrésy, B., King, M.A., Church, J.A., & Bos, M.S. (2018). Sea-level trend uncertainty with Pacific climatic variability and temporally-correlated noise. Journal of Geophysical Research: Oceans, 123, 1978 1993.

Slangen, A.B.A., Church, J.A., Agosta, C., Fettweis, X., Marzeion, B., and Richter, K. (2016). Anthropogenic forcing dominates global mean sea-level rise since 1970. Nature Climate Change 6, 701 705.

Sweet, W.V., Kopp, R.E., Weaver, C.P., Obeyskera, J., Horton, R.M., Thieler, E.R., and Zervas, C. (2017). Global and regional sea level rise scenarios for the United States, NOAA Technical Report NOS CO-OPS083.

Visser, H., Dangendorf, S. and Petersen, A.C. (2015). A review of trend models applied
-
of Geophysical Research: Oceans, 120,

Visser, H., Dangendorf, S., and Petersen, A.C. (2015). A review of trend models applied

of Geophysical Research: Oceans, 3873 3895.

Warrick, R. A., and Oerlemans, J. (1990). Sea level rise. In: Climate Change: The IPCC Scientific Assessment [Houghton, J.T., Jenkins, G.J., and Ephraum, J.J. (eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 260 281.

Watson, P.J., 2016. Acceleration in U.S. mean sea level? A new insight using improved tools. Journal of Coastal Research, 32(6), 1247 1261.

WCRP Global Sea Level Budget Group, 2018: Global sea level budget 1993

Table 1: Time series examined and abbreviations

Series	Name	% of observed data

Table 4: Classification based on the time trend coefficient

Significant negative

Table 5: Classification based on persistence

$0 < d < 0.5$ **Stationarity**	$0 < d < 1$	$0.5 \leq d < 1$ **Non-stationarity**

Figure 1: Time trend coefficients. Summary of data extracted from Table 4.

Figure 2: Degree of persistence. Summary of data extracted from Table 5.