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A study of the longest tide gauge sea-level record in Greenland (Nuuk/Godthab, 1958–2002)

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ABSTRACT

We study the longest tide gauge record available from Greenland, that is the Nuuk/Godthab site in southwest Greenland, for the time period 1958–2002. Standard regression methods and the application of the Ensemble Empirical Mode Decomposition technique reveal a rate of sea-level rise of ≈ 2 mm yr^{-1}, two complete cycles of the 18.6-years lunar nodal tide, and a negligible acceleration. Using previous assessments for the globally averaged sea-level rise during that period, glacial isostatic adjustment modeling and sea-level "fingerprinting" of the mass loss of continental ice sources, terrestrial water sources and oceanic steric effects, we evaluate the various contributions to local sea-level rise at the tide gauge location. The misfit between the observed and the modeled sea-level trend is unlikely to reflect tectonic deformations but, more intriguingly, may indicate that the mass balance of the Greenland ice sheets was, during the second half of the last century, somehow closer to balance than suggested by previous investigations.

1. Introduction

Since the seminal work of Gutenberg (1941), observations from tide gauges deployed along the world's shorelines have been recognized as a fundamental tool for the study of the global mean sea-level rise (for a review, see Spada and Galassi, 2012). The long term tide gauge records reflect various processes that change the total mass of the oceans (mass term) or their density in response to thermal expansion and salinity variations (steric component). The mass term includes effects from the melting of continental ice sheets, glaciers and ice caps, the alteration of land water reservoirs, and hydrological variations originating from human activity (see e.g., Milne et al., 2009; Cazenave and Remy, 2011).

Although the number and the quality of tide gauges observations have dramatically increased since the birth of the Permanent Service for Mean Sea Level (PSMSL) in 1933 (Woodworth and Player, 2003; Holgate et al., 2012), their geographical distribution remains largely non-uniform and biased toward the northern hemisphere. As of today, only a few tens of time series have a sufficient length for an assessment of secular sea-level variations (Douglas, 1991, 1997; Spada and Galassi, 2012) (only 73 PSMSL annual records have a length exceeding 100 years). In addition, they require suitable corrections for the effects of sediment compaction, water or hydrocarbon extraction, tectonics, and glacial isostatic adjustment (GIA). However, at the present time, global models useful for computing such corrections only exist for GIA (Spada and Galassi, 2012). Recent estimates of global mean sea-level rise point to values in the range between 1.5 and 2 mm yr^{-1}, although a significant scatter still exists, reflecting different approaches and averaging methods applied (Spada and Galassi, 2012).

In view of rapid changes affecting the polar ice sheets (see the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, hereinafter AR4, Bindoff et al., 2007), in situ sea-level observations from these regions would be potentially very important. In particular, it is expected that relative sea-level observations from tide gauges located in the vicinity of major ice sheets could help to constrain the recent time-history of their mass unbalance (before the year ~2000, this was only poorly determined because of the limited resolution of remote sensing techniques, see Bindoff et al., 2007). However, despite significant collaborative efforts, at the end of the nineties the state of polar tide gauges was generally unsatisfactory. The whole subject was reviewed by Plag (2000), who pointed out the degradation of the observing system and emphasized the relevance of Arctic tide gauge data for the geophysical community. Nonetheless, in some specific locations, such as southwest Greenland, the sparsity of instrumental observations can be partly alleviated using data from salt marshes (Woodroffe and Long, 2009), which are potentially valuable for reconstructing the relative sea-level variations during the last few centuries (Barlow et al., 2013).

As of the year 2000, a small number of tide gauges were in operation along the Arctic shores of Russia, Greenland, Iceland, Norway, Canada and USA (Plag, 2000). Among these, a few were characterized by record lengths exceeding a few decades, and thus are potentially suitable for estimating local long-term sea-level trends. For Norway and Russia,

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the state of the tide gauges has been recently reviewed by Henry et al. (2011), who have highlighted the importance of these observations for the assessment of the mass and steric components of recent sea-level rise. However, the situation was, and still remains, particularly problematic in Greenland, where the PSMSL database now collects records from only eight sites (Fig. 1), mostly located along the southwest margins of the Greenland ice sheet (GIS). The instrumental record from the Nuuk/Godthab tide gauge, hereafter referred to as NG, is remarkably long (>40 years) compared to other sites in Greenland (≤10 years), and covers a time span ~1958–2003 during which only a few assessments of the GIS mass balance are available (Hanna et al., 2005; Bindoff et al., 2007; Rignot et al., 2008; Slangen, 2012). The PSMSL tide gauge time series for Greenland are visualized in Fig. 2, which also shows the length (P, years) and completeness (c,%) of each record.

The context above encourages a new analysis of the NG record, which aims to test the consistency of the NG datum with the various contributions to sea-level rise in southwest Greenland and, in particular, to ascertain whether relative sea-level data from this site could be useful for constraining volume changes in the GIS during the second half of last century. We extend the previous analysis of Plag (2000), who recognized that trends shown by Arctic tide gauges are in broad agreement with an overall un-loading of the Arctic land-based cryosphere, and by Fleming et al. (2009) who focused on the present-day GIA contributions to sea-level change around Greenland. However, in comparison with previous studies, here we consider a longer time frame and we perform a more detailed study taking advantage of the AR4 assessments, of numerical modeling based on the solution of the "Sea Level Equation" (Farrell and Clark, 1976), and of the computation of sea-level "fingerprints" (Mitrovica et al., 2001; Tamisiea et al., 2011). Although we focus on an individual tide gauge record, our approach could be extended to other Arctic records with sufficient lengths.

The paper is organized as follows: in Section 2 we analyze the NG time series, in Section 3 we examine various contributions to sea-level change at NG, and we discuss the results in Section 4, with the conclusions presented in Section 5.

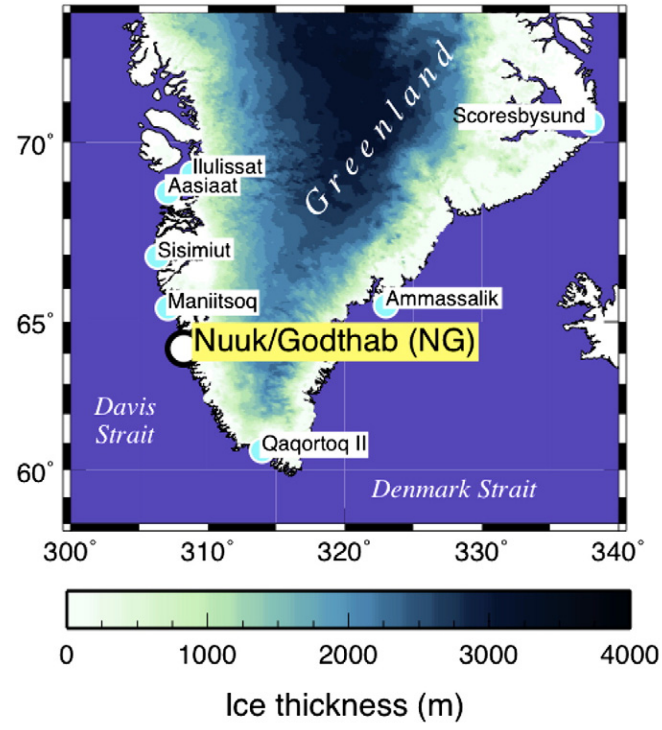

Fig. 1. Map of southern Greenland, showing the location of the Nuuk/Godthab (NG) tide gauge (longitude = 51.73°W, latitude = 64.17°N) and of other PSMSL sites in Greenland: Ilulissat, Aasiaat, Sisimiut, Maniitsoq, Qaqortoq II, Ammassalik and Scoresbysund. The time series for these tide gauges are displayed in Fig. 2. The figure also shows the present-day ice thickness of the GIS (in meters); ice thickness data are from Bamber et al. (2013).

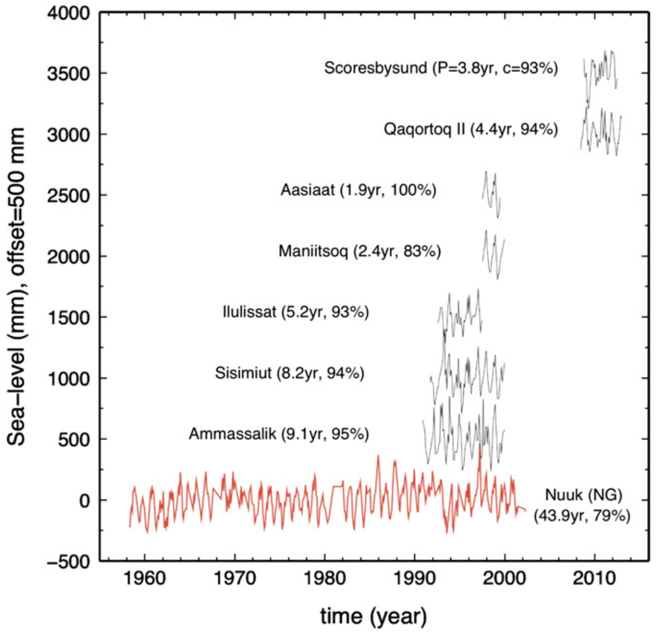

Fig. 2. Overview of the PSMSL metric monthly time series available from the Greenland sites in Fig. 1. For visualization purposes, the time series have been shifted by 500 mm and the average has been subtracted. The record length P (in years) and the completeness c (%) are also shown.

2. Sealevel trend at the NG tide gauge

The NG tide gauge record, obtained from the database of the PSMSL (http://www.psmsl.org/[1]), contains monthly mean sea-level values between 1958.4 and 2002.3. The total time span of the record is thus $P = 43.9$ years and its completeness is $c = 79\%$ (the minimum completeness requested by Douglas (1997) and Spada and Galassi (2012) in their studies on secular sea-level rise was $c = 80\%$ and 70%, respectively). The time series does not belong to the RLR ("Revised Local Reference") PSMSL dataset; rather, the data is from the "metric" dataset, hence the benchmark is arbitrary and jumps are undetected (unfortunately, only metric observations are available from Greenland). Nevertheless, the NG observations can be used in this context, since we are mostly interested in the average rate of relative sea-level rise over several decades, which is unaffected by the choice of the benchmark. In 2002, the NG instrument was damaged and is no longer maintained by the DMI (Danish Meteorological Institute). Coincidentally, the time period of the NG tide gauge almost exactly overlaps the one adopted in the AR4 assessments of the total budget of global mean sea-level change during the second part of the 20th century (namely, 1961–2003). In her recent study, Slangen (2012) also payed specific attention to this time period. This will greatly facilitate, in Section 3, comparisons between the observed rate at the NG site and existing assessments for the various components of sea-level change.

The NG time series is reproduced in Fig. 3a. A few interruptions are visible, which, however, do not affect seriously its completeness. Although a small change of coordinates is reported in 1969 in the PSMSL station documentation, a visual inspection does not reveal anomalies or discontinuities in the record at that epoch. Since Nuuk is located along the western coast of Greenland (see Fig. 1), distant from collisional boundaries, tectonic deformations are not expected to significantly contaminate the observations. The NG time series suggests the

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[1] Extracted from Database 26 June 2013.