University of Texas Rio Grande Valley

ScholarWorks @ UTRGV

Earth, Environmental, and Marine Sciences
Faculty Publications and Presentations

College of Sciences

12-2004

Tracking the sea-level signature of the 8.2 ka cooling event: New constraints from the Mississippi Delta

Torbjörn E. Törnqvist

Scott J. Bick

Juan L. Gonzalez

Klaas van der Borg

Arie F. M. de Jong

Follow this and additional works at: https://scholarworks.utrgv.edu/eems_fac

Part of the Earth Sciences Commons, Environmental Sciences Commons, and the Marine Biology Commons

Tracking the sea-level signature of the 8.2 ka cooling event: New constraints from the Mississippi Delta

Torbjörn E. Törnqvist, Scott J. Bick, and Juan L. González
Department of Earth and Environmental Sciences, University of Illinois at Chicago, Chicago, Illinois, USA

Klaas van der Borg and Arie F. M. de Jong
Robert J. Van de Graaff Laboratory, Utrecht University, Utrecht, Netherlands

[1]   The ever increasing need for accurate predictions of global environmental change under greenhouse conditions has sparked immense interest in an abrupt, century-scale cooling around 8200 years ago, with a focal point in the North Atlantic and with hemispheric teleconnections. Despite considerable progress in the unraveling of this striking feature, including a conceivable driving mechanism (rapid drainage of proglacial Lake Agassiz/Ojibway and a resulting reduced strength of North Atlantic thermohaline circulation), several key questions remain unanswered. One salient aspect concerns the total amount of freshwater released during this catastrophic event, likely echoed by a near-instantaneous eustatic sea-level rise. So far, no attempts have been made to perform high-resolution sea-level studies that explicitly focus on this critical time interval. Here, we present new data from the Mississippi Delta suggestive of abrupt sea-level rise associated with the 8.2 ka event. However, the amount of sea-level rise was likely less than $\sim$1.2 m, corresponding to a meltwater volume of less than $\sim$4.3 10^{14} m^3; values lower than estimates used by several recent studies.   INDEX TERMS: 4556 Oceanography: Physical: Sea level variations; 1620 Global Change: Climate dynamics (3309); 4267 Oceanography: General: Paleoceanography; 3344 Meteorology and Atmospheric Dynamics: Paleoclimatology; 1827 Hydrology: Glaciology (1863). **Citation:** Törnqvist, T. E., S. J. Bick, J. L. González, K. van der Borg, and A. F. M. de Jong (2004), Tracking the sea-level signature of the 8.2 ka cooling event: New constraints from the Mississippi Delta, *Geophys. Res. Lett.*, *31*, L23309, doi:10.1029/2004GL021429.

1. Introduction

[2] The recognition and explicit definition of an abrupt, early Holocene, century-scale cooling in the North Atlantic region as inferred from the Greenland Summit ice-core records [*Alley et al.*, 1997] has triggered a virtual explosion of studies on this phenomenon. The significance of this so-called "8.2 ka event" lies in the fact that it is perhaps the best available analog from the paleoclimate record for possible abrupt, counterintuitive climate change that might take place in the future as a consequence of increased melting of ice sheets and/or increased precipitation rates over sensitive sections of the global oceans. For these reasons, the 8.2 ka event serves as a key example of natural,

interglacial climate instability in the most recent report of the Intergovernmental Panel on Climate Change [*Folland et al.*, 2001]. The 8.2 ka event has now been documented by a wide variety of studies, employing climate proxies as diverse as glacier equilibrium-line and tree-limit data [*Dahl and Nesje*, 1996], evidence from marine foraminifera as well as tree rings [*Klitgaard-Kristensen et al.*, 1998], lacustrine [*Von Grafenstein et al.*, 1998] and speleothem [*McDermott et al.*, 2001] δ^{18}O time series, lacustrine biogenic productivity records [*Willemse and Törnqvist*, 1999], ice-core CH$_4$ [*Blunier et al.*, 1995] and stomatal-frequency CO$_2$ [*Wagner et al.*, 2002] data, high-resolution pollen records [*Tinner and Lotter*, 2001], plus numerous others. The 8.2 ka event was characterized by abrupt cooling of up to $\sim$6°C in Greenland, along with increased dryness and windiness in considerable parts of the Northern Hemisphere (Figure 1a).

[3] While early studies remained speculative about the cause of the 8.2 ka event [e.g., *Alley et al.*, 1997], there is now wide consensus that it was triggered by the catastrophic release of meltwater from the North American proglacial Lake Agassiz/Ojibway through Hudson Strait into the Labrador Sea [*Barber et al.*, 1999] (Figure 1a). The sudden freshening of parts of the North Atlantic temporarily reduced the vigor of thermohaline circulation, resulting in a drastic reduction of heat transport to North Atlantic high latitudes. Most recently, it has been argued that this melt-water release likely took place as subglacial drainage underneath the collapsing Hudson Dome of the Laurentide Ice Sheet [*Clarke et al.*, 2003], and that the initial flood may have lasted 6 months or less [*Clarke et al.*, 2004]. In addition, these authors hypothesize that the drainage may have taken place in a series of catastrophic events, possibly occurring over several decades. Considering that the amount of water stored in the Lake Agassiz/Ojibway system was more than twice that of the present-day Caspian Sea [*Teller et al.*, 2002], this was a catastrophe of truly unparalleled dimensions and by far the largest of the past 100 kyr [*Clarke et al.*, 2003].

[4] Despite the rapid progress in our understanding of the 8.2 ka event and its cause, several important questions remain unanswered. In order to fully comprehend the effect of catastrophic freshwater release on the ocean-atmosphere-cryosphere system, recourse has been taken to climate modeling. Although model experiments can successfully reproduce reconstructed early Holocene climate change [*Renssen et al.*, 2001, 2002], the total meltwater volume is a critical, yet poorly constrained boundary condition.
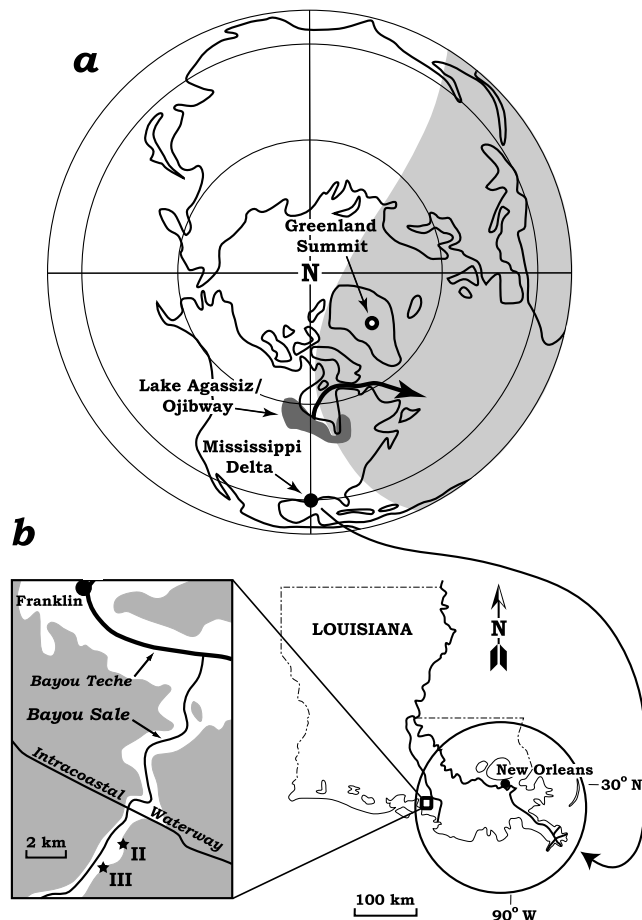
Figure 1. (a) Approximate geographic extent of abrupt climate change (cool, dry, and/or windy conditions) that has been related to the 8.2 ka event, indicated by light gray shading and based on *Alley et al.* [1997] plus other sources mentioned in the text. The strongest climate signal has been reported from the Greenland Summit ice cores. Also indicated is the presumed pathway of catastrophic Lake Agassiz/Ojibway drainage into the North Atlantic Ocean. Outline of Lake Agassiz/Ojibway according to *Leverington et al.* [2002]. (b) Location of study area and core sites Bayou Sale II and Bayou Sale III. Swamps and marshes are shaded.

Given the enormous size of Lake Agassiz/Ojibway, the meltwater release should have a sea-level imprint around the globe. While *Clarke et al.* [2004] contend that this rise of sea level was no more than ~40 cm, the sea-level signature of the 8.2 ka event from detailed empirical records is at present essentially unknown. In addition, the estimate by *Clarke et al.* [2004] does not include the unknown contribution of the rapidly disintegrating Laurentide Ice Sheet in the Hudson Bay area.

2. Approach

[5] A possible reason for the lack of early Holocene high-resolution sea-level data is the fact that along most submerging shorelines (i.e., those shorelines that stand the best chance to accumulate and preserve continuous records of sea-level change) sedimentary successions of this age tend to be located offshore. As a consequence, deltaic settings characterized by thick Holocene progradational successions hold particular promise in containing such records that can be accessed on land, thus providing a considerable logistical advantage. We have recently identified a study area in the western part of the Mississippi Delta (Figure 1b) that fulfills the requirements to elucidate the nature of sea-level rise around 8.2 ka.

[6] The Gulf of Mexico is an extremely favorable setting for obtaining high-resolution Holocene sea-level data because of its microtidal regime, with a present-day spring tidal range in coastal Louisiana <60 cm, and more typically ~40 cm. This reduces uncertainties inherent to most sea-level indicators that are usually related to tide levels. In addition, salt-marsh peat is common in the Mississippi Delta, providing sensitive sea-level indicators that formed within the <20 cm zone between mean high water and mean sea level.

[7] Our approach is based on the use of basal-peat samples as sea-level indicators, adhering to the rationale that the initial transgression of the highly consolidated Pleistocene basement transformed the area into a peat-forming wetland. Peat formation begins as soon as the (ground)water level rises above the land surface, and provided that this water level can be related unequivocally to sea level, it can yield extremely detailed records of sea-level change. Building on the pioneering work by *Chmura et al.* [1987] and a recent sea-level study elsewhere in the Mississippi Delta [*Törnqvist et al.*, 2004], we have used stable carbon isotope ratios of basal-peat plant remains as a proxy for paleosalinity. Brackish to saline marsh vegetation is dominated by C_4 taxa with distinctly heavier $\delta^{13}C$ values than freshwater C_3 plants. This provides us with a tool to verify whether peat accumulation was directly controlled by sea-level rise.

[8] Although tectonic subsidence and isostatic crustal movements (most notably glacial forebulge collapse related to the melting of the Laurentide Ice Sheet) are likely players in the Mississippi Delta, their effect is small given the short time frame of concern here, combined with the long distance of our study area from ice-covered regions.

3. Results and Discussion

[9] Figure 2 shows two cores, located about 2 km apart, which were obtained near Bayou Sale, an abandoned distributary of the Mississippi River (locations in Figure 1b). Only the lowermost portion of the cores is shown, featuring the Pleistocene basement that is capped by a weakly developed paleosol representing the initial transgression of the Pleistocene land surface and the gradual transformation of the area into a wetland, plus the transition into overlying Holocene deltaic strata. The paleosol is widespread in the Mississippi Delta [*Törnqvist et al.*, 2004], and in many cases the immediately overlying unit is a basal peat or organic-rich mud. The cores Bayou Sale II and Bayou Sale III both contain basal peat, but the striking difference is its thickness. In core Bayou Sale III, where the contact with the underlying paleosol is more than 14 m below present mean sea level, the basal peat is only 2 cm thick, and sharply (but not necessarily erosively) overlain by a muddy, lagoonal facies that contains the brackish bivalve *Rangia cuneata*. In contrast, core Bayou Sale II shows a ~60-cm-thick basal-peat bed at a higher
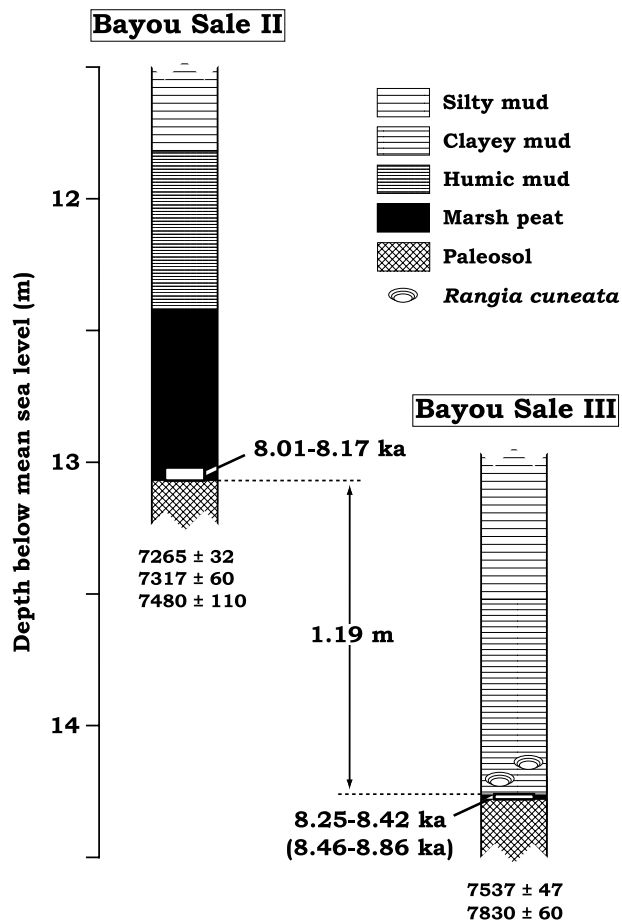
Bayou Sale II

Figure 2. Sedimentary logs of cores Bayou Sale II and Bayou Sale III, with position of basal-peat samples. [14]C ages of macrofossil subsamples are listed underneath the logs. Calibrated weighted mean age ranges are provided by means of 95% confidence intervals, expressed in ka before AD 1950. Further explanation provided in the text and in auxiliary Table A.

altitude, gradually giving way to fine-grained clastic facies that lack *Rangia cuneata*. Clearly, peat formation at this site was able to keep pace with the rate of sea-level rise for a prolonged period of time. In contrast, at Bayou Sale III the peat-forming ecosystem was rapidly transgressed and converted into an open-water, brackish environment.

[10] We obtained five ^{14}C ages from the two basal-peat samples (Figure 2), based on measurements of botanical macrofossils by accelerator mass spectrometry (see auxiliary Table A[1]). We found $\delta^{13}C$ values for herbaceous charcoal extracted from the Bayou Sale II and III basal-peat beds of −18.3‰ and −13.0‰, respectively, clearly demonstrating an environment within the narrow zone between mean sea level and mean high water. The ^{14}C data for the three subsamples from the Bayou Sale II core are relatively consistent and allow us to calculate a weighted mean ^{14}C age of 7290 ± 38 yr BP, corresponding to a calibrated age range (95% confidence interval, expressed in ka before AD 1950) of 8.01−8.17 ka. The two subsamples from the

Bayou Sale III core (7537 ± 47 yr BP, calibrated age range 8.25–8.42 ka; and 7830 ± 60 yr BP, calibrated age range 8.46–8.86 ka) show an offset that could be a random effect, or, perhaps more likely, could be due to problems with one of the subsamples. Since it is difficult to envisage a conceivable mechanism for ages in this rapidly aggrading environment which are too young, we entertain the possibility that the older subsample contains reworked plant material. Either way, the age populations derived from the two cores are distinctly different, and the ^{14}C ages bracket the 8.2 ka event as recognized and dated in the variety of high-resolution paleoclimate records discussed above.

[11] Based on the combination of the sedimentology and stratigraphy (suggestive of a rapid transgressive interval between the two sampled levels) and the ^{14}C data, we find that our two samples predate and postdate the 8.2 ka event, respectively, and enable us to constrain the amount of associated abrupt sea-level rise. The altitudinal difference between the top of the lower dated level (Bayou Sale III) and the base of the upper dated level (Bayou Sale II) is 1.19 m (Figure 2). Given the vertical indicative range of our samples of ∼20 cm, inclusion of this uncertainty yields an amount of sea-level rise of 0.99 to 1.39 m. However, it should be kept in mind that the end-members in this range represent combinations where one sample formed exactly at mean high water and the other exactly at mean sea level. Hence, in terms of probability, the 1.19 m outcome is considerably more likely than the end-member estimates. Finally, it is important to note that any tectonic subsidence or glacio-hydro-isostatic effects, with the latter dominated by glacial forebulge collapse [e.g., *Mitrovica and Milne*, 2002], would result in a lesser amount of eustatic sea-level rise.

[12] A number of studies have estimated the amount of meltwater that was released during the catastrophic drainage of Lake Agassiz/Ojibway [*De Vernal et al.*, 1997; *Von*
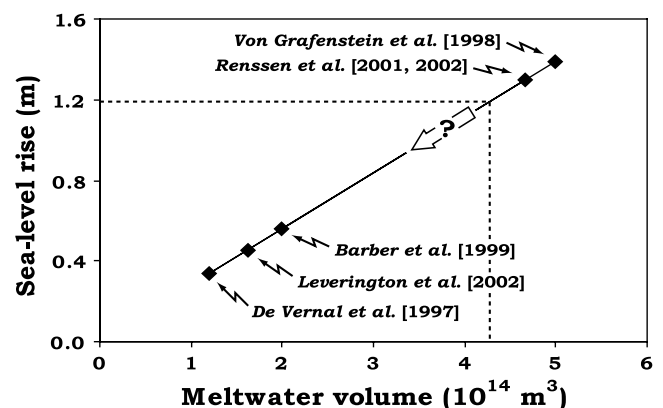

Figure 3. Relationship between estimated meltwater-volume release due to catastrophic Lake Agassiz/Ojibway drainage and the associated sea-level rise. Calculations are based on an Earth radius of 6400 km and a proportion occupied by oceans of 0.7. Data points indicate estimates of meltwater volumes according to a variety of studies. Stippled line shows maximum amount of sea-level rise in our study area (based on the most probable amount of sea-level rise between the two dated levels) that can be attributed to the 8.2 ka event, along with the corresponding meltwater release.

[1]Auxiliary material is available at ftp://ftp.agu.org/apend/gl/2004GL021429.

Grafenstein et al., 1998; *Barber et al.*, 1999; *Leverington et al.*, 2002]. Figure 3 shows the equivalent sea-level rise calculated from these meltwater volumes. Also included is the estimate that was used by *Renssen et al.* [2001, 2002] in their climate model experiments. The maximum amount of 8.2 ka sea-level rise as inferred from our new data is also plotted, showing that the highest estimates of meltwater volumes used previously have likely been too high and did not exceed ~4.3 10^{14} m^3. Obviously, with our present data it remains an open question how much less the 8.2 ka-equivalent sea-level rise may have been. Although recent studies (notably *Leverington et al.* [2002]) have provided exceptionally detailed data on water volumes in Lake Agassiz/Ojibway prior to its final drainage, a potentially significant, but as of yet largely unknown contribution was derived from the rapidly disintegrating Laurentide Ice Sheet during the meltwater release(s). In addition, the position of the margin of the Laurentide Ice Sheet in reconstructions that form the basis for water-volume calculations is not always accurately known [*Teller and Leverington*, 2004]. Hence, it may well prove extremely difficult to quantify the freshwater release at any level of detail from studies in the Hudson Bay area alone. We therefore expect that high-resolution sea-level records from the most favorable settings worldwide will help elucidate this critical problem.

References

Alley, R. B., P. A. Mayewski, T. Sowers, M. Stuiver, K. C. Taylor, and P. U. Clark (1997), Holocene climatic instability: A prominent, widespread event 8200 yr ago, *Geology*, 25, 483–486.

Barber, D. C., et al. (1999), Forcing of the cold event of 8,200 years ago by catastrophic drainage of Laurentide lakes, *Nature*, 400, 344–348.

Blunier, T., J. Chappellaz, J. Schwander, B. Stauffer, and D. Raynaud (1995), Variations in atmospheric methane concentration during the Holocene epoch, *Nature*, 374, 46–49.

Chmura, G. L., P. Aharon, R. A. Socki, and R. Abernethy (1987), An inventory of ^{13}C abundances in coastal wetlands of Louisiana, USA: Vegetation and sediments, *Oecologia*, 74, 264–271.

Clarke, G., D. Leverington, J. Teller, and A. Dyke (2003), Superlakes, megafloods, and abrupt climate change, *Science*, 301, 922–923.

Clarke, G. K. C., D. W. Leverington, J. T. Teller, and A. S. Dyke (2004), Paleohydraulics of the last outburst flood from glacial Lake Agassiz and the 8200 BP cold event, *Quat. Sci. Rev.*, 23, 389–407.

Dahl, S. O., and A. Nesje (1996), A new approach to calculating Holocene winter precipitation by combining glacier equilibrium-line altitudes and pine-tree limits: A case study from Hardangerjøkulen, central southern Norway, *Holocene*, 6, 381–398.

De Vernal, A., C. Hillaire-Marcel, U. von Grafenstein, and D. Barber (1997), Researchers look for links among paleoclimate events, *Eos Trans. AGU*, 78, 247, 249.

Folland, C. K., T. R. Karl, J. R. Christy, R. A. Clarke, G. V. Gruza, J. Jouzel, M. E. Mann, J. Oerlemans, M. J. Salinger, and S.-W. Wang (2001), Observed climate variability and change, in *Climate Change 2001. The Scientific Basis*, edited by J. T. Houghton et al., pp. 99–181, Cambridge Univ. Press, New York.

Klitgaard-Kristensen, D., H. P. Sejrup, H. Haflidason, S. Johnsen, and M. Spurk (1998), A regional 8200 cal. yr BP cooling event in northwest Europe, induced by final stages of the Laurentide ice-sheet deglaciation?, *J. Quat. Sci.*, 13, 165–169.

Leverington, D. W., J. D. Mann, and J. T. Teller (2002), Changes in the bathymetry and volume of glacial Lake Agassiz between 9200 and 7700 ^{14}C yr B.P., *Quat. Res.*, 57, 244–252.

McDermott, F., D. P. Mattey, and C. Hawkesworth (2001), Centennial-scale Holocene climate variability revealed by a high-resolution speleothem δ^{18}O record from SW Ireland, *Science*, 294, 1328–1331.

Mitrovica, J. X., and G. A. Milne (2002), On the origin of late Holocene sea-level highstands within equatorial ocean basins, *Quat. Sci. Rev.*, 21, 2179–2190.

Renssen, H., H. Goosse, T. Fichefet, and J.-M. Campin (2001), The 8.2 kyr BP event simulated by a global atmosphere–sea-ice–ocean model, *Geophys. Res. Lett.*, 28, 1567–1570.

Renssen, H., H. Goosse, and T. Fichefet (2002), Modeling the effect of freshwater pulses on the early Holocene climate: The influence of high-frequency climate variability, *Paleoceanography*, 17(2), 1020, doi:10.1029/2001PA000649.

Teller, J. T., and D. W. Leverington (2004), Glacial Lake Agassiz: A 5000 yr history of change and its relationship to the δ^{18}O record of Greenland, *Geol. Soc. Am. Bull.*, 116, 729–742.

Teller, J. T., D. W. Leverington, and J. D. Mann (2002), Freshwater outbursts to the oceans from glacial Lake Agassiz and their role in climate change during the last deglaciation, *Quat. Sci. Rev.*, 21, 879–887.

Tinner, W., and A. F. Lotter (2001), Central European vegetation response to abrupt climate change at 8.2 ka, *Geology*, 29, 551–554.

Törnqvist, T. E., J. L. González, L. A. Newsom, K. van der Borg, A. F. M. de Jong, and C. W. Kurnik (2004), Deciphering Holocene sea-level history on the U.S. Gulf Coast: A high-resolution record from the Mississippi Delta, *Geol. Soc. Am. Bull.*, 116, 1026–1039.

Von Grafenstein, U., H. Erlenkeuser, J. Müller, J. Jouzel, and S. Johnsen (1998), The cold event 8200 years ago documented in oxygen isotope records of precipitation in Europe and Greenland, *Clim. Dyn.*, 14, 73–81.

Wagner, F., B. Aaby, and H. Visscher (2002), Rapid atmospheric CO_2 changes associated with the 8,200-years-B.P. cooling event, *Proc. Nat. Acad. Sci. USA*, 99, 12,011–12,014.

Willemse, N. W., and T. E. Törnqvist (1999), Holocene century-scale temperature variability from West Greenland lake records, *Geology*, 27, 580–584.

————————————
S. J. Bick, J. L. González, and T. E. Törnqvist, Department of Earth and Environmental Sciences, University of Illinois at Chicago, 845 West Taylor Street, Chicago, IL 60607-7059, USA. (tor@uic.edu)

A. F. M. de Jong and K. van der Borg, Robert J. Van de Graaff Laboratory, Utrecht University, PO Box 80000, NL-3508 TA Utrecht, Netherlands.