SIMPLE TEMPERATURE SCENARIO FOR A GULF STREAM INDUCED CLIMATE CHANGE

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Abstract. Consequences of a Gulf Stream induced ocean surface cooling for the temperature climate of Western Europe were studied by means of a conditional perturbation of the observed daily temperature time series of the Netherlands. On days with advection of airmasses of maritime origin, the observed temperatures in the series were lowered with a fixed value, representing the influence of a cooler Atlantic Ocean. On the other days, the observed temperatures were left unchanged. The perturbation results in a decrease in the mean temperature that is almost constant over the year, and in a change in the standard deviation of the daily temperatures that is seasonally dependent. Due to preferential cooling of warm winter days, the standard deviation decreases in the winter, whereas in the other seasons the standard deviation increases as a result of preferential cooling of days with low temperatures. Although this ocean cooling scenario indicates an increase of the relative frequency of cold winters and cool summers, it is neither characterized by the occurrence of winters with unprecedented low temperatures nor by the disappearance of summer heatwaves.

1. Introduction

The Gulf Stream/North Atlantic Drift, which transports warm surface water from subtropical regions northwards, determines the mild climate at the west-side of the European Continent. An ocean cooling due to a sudden weakening of the northward water transport would have important consequences for the climate of Western Europe. To provide Dutch policy-makers with a temperature scenario for such a situation, a simple data perturbation study was performed. In this study, the observed time series of daily mean surface air temperature in the Netherlands for the period 1950–1994 was perturbed, conditional on the origin of airmasses (continental or maritime) as determined using the observed daily atmospheric circulation patterns. The temperatures on days with airflow from the Atlantic Ocean were lowered with a fixed value, whereas the temperatures on the other days were left unchanged. The cooling in the Netherlands introduced this way is considered to be representative of the cooling of the airmasses overlying the ocean, which in turn is proportional to the assumed change in the sea surface temperature resulting from a weakened northward component of the Gulf Stream. The methodology implicitly assumes that the temperatures of continental airmasses are not affected by an ocean cooling and that the atmospheric circulation remains unchanged. As such, the results are only first order estimates of possible regional climate changes. In fact, the scenario extrapolates the structure of the present climate, but by doing so it provides an insight in the nature of the temperature changes accompanying

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an ocean cooling with details that are not easily obtained from climate models or from reconstructions of the climates of the past.

2. Background

Various paleoclimatic indices (ice-cores, ocean sediments, etc.) reveal that, both during the transition from the last ice age into the present interglacial (Johnsen et al., 1992; Taylor et al., 1993; Bond et al., 1993) and during the last interglacial (GRIP members, 1993; Dansgaard et al., 1993; Keigwin et al., 1994; Field et al., 1994), the climate in the North Atlantic region showed large and rapid changes. It is widely believed that these changes, that took place even within decades (Grootes et al., 1993; Broecker, 1994), are related to changes in the ocean circulation. Similarly, the transitions in the 12th and 19th century, which mark the coming and going of the period with a relatively cold and variable climate known as the Little Ice Age, are brought in connection with changes in the ocean circulation (Meese et al., 1994).

The ocean component that is most important for the present climate of Western Europe is the Gulf Stream/North Atlantic Drift. It consists of surface currents that are driven by westerly trade winds and modified by the earth's rotation and the presence of the continents. Along the European continent they transport warm water northward. This transport is thought to be associated with the Conveyor Belt; the thermohaline circulation system that links the worlds oceans, driven by deep convection at specific regions in the North Atlantic (see e.g. Gordon, 1986). A temporary perturbation in this perhaps delicately balanced ocean-atmosphere system might result in a transition into another ocean circulation mode, with shifted convective regions and a Gulf Stream that is altered in strength and path (Broecker et al., 1985; Manabe and Stouffer, 1988; Held, 1993).

Given the observed changes in the past, natural variability in climate seems capable of inducing a transition between ocean circulation modes. According to ocean model studies (see e.g., Weaver and Hughes, 1994; Rahmstorf, 1994, 1995; Manabe and Stouffer, 1995), relatively small or temporary changes in the fresh water input into the North Atlantic Ocean (from ice-melt or increased rainfall) are sufficient to trigger the transition. Both in the observations and in the ocean models, transitions occur on a time-scale of a few decades, so rapid changes in the regional Western European climate might occur (Houghton et al., 1996).

It is possible that the global climate change due to the enhanced greenhouse effect alters the probability of a transition between ocean circulation modes. Several transient warming simulations with coupled ocean-atmosphere models show a weakening of the thermohaline circulation of the oceans (Cubasch et al., 1992; Manabe and Stouffer, 1994). In this perspective, the concern about a regional climate cooling in Western Europe induced by a change in the Gulf Stream is part of the global warming issue.

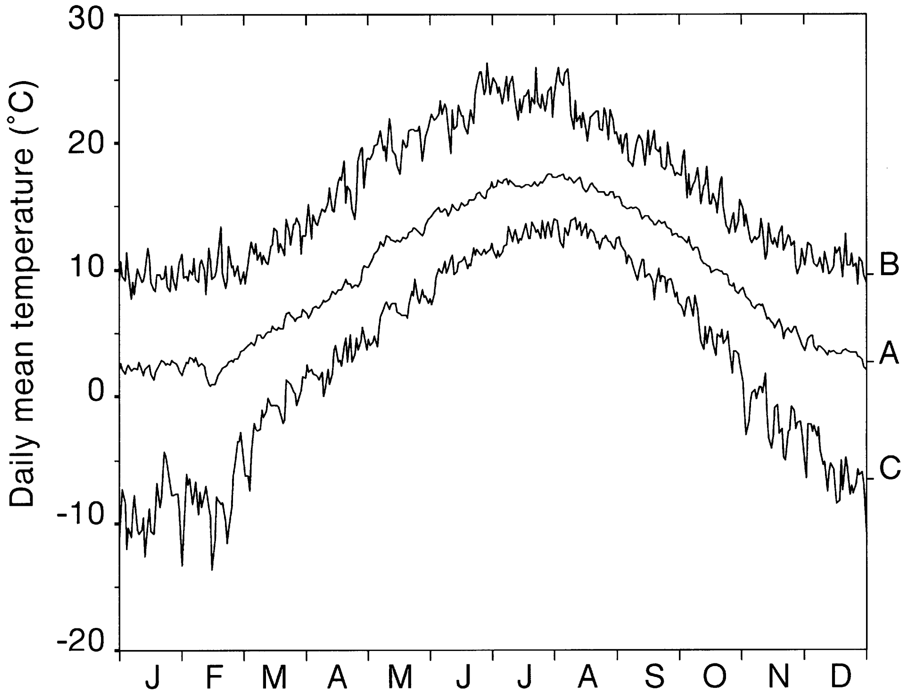

Figure 1. Annual cycle of the daily mean surface air temperatures in the Netherlands for the period 1950–1994. The middle (A) line represents the averages over the 45 observation years for each calendar (month–day) date. The top (B) and bottom (C) lines represent the highest and lowest temperatures observed for each calendar (month–day) date in the 45-year time series. J–D stands for January–December.

3. Temperature Scenario for an Ocean Cooling

In the present climate of Western Europe, airmass advection from the Atlantic Ocean results in mild days in the winter and cool days in the summer, whereas airmasses originating from the Eurasian continent give rise to the coldest winter days and the warmest summer days. Figure 1 presents the annual cycle of the daily mean surface air temperatures in the Netherlands. The top and bottom lines connect the highest and lowest recorded temperatures of each calendar (month–day) date in the 1950–1994 time series, whereas the middle line represents the temperature at each calendar date averaged over the 45-year period. The time series on which the figure is based consists of the spatial averages of the 15 principal meteorological stations in the Netherlands.

From Figure 1 it is seen that the extreme temperatures fluctuate more during the continental influenced cold winters and warm summers than during the maritime influenced mild winters and cool summers. The temperature of airmasses overlying the land shows higher variability than the temperature of airmasses overlying the ocean, because of the lower heat capacity of the soil. The steep increase in the lower line at the end of February can be attributed to the snow-albedo feedback over the continent, where a rapid decrease of the snow cover leads to an accelerated warming in early spring.

A cooling of the Atlantic Ocean would result in lower temperatures of airmasses advected to Western Europe with the prevailing western circulations. What happens with airmasses originating from the continent is not *a priori* clear. Model results (Manabe and Stouffer, 1988, Figure 22) indicate that the European continent would cool by about half the value of the ocean cooling. In the Gulf Stream induced ocean surface cooling scenario of the present paper, it is assumed that the temperature of the continental airmasses are to first approximation not affected by the ocean cooling. This means that the average cooling over Western Europe originates from maritime days only. As is shown below, the mean cooling in our scenario is about half the ocean cooling, like in Manabe and Stouffers (1988) model experiments. This agreement suggests that the assumption that the temperature of continental airmasses is little affected by an ocean cooling is indeed justified.

A changed temperature contrast between the ocean and the continent will certainly affect the atmospheric circulation. However, there are no unambiguous indications from coupled ocean-atmosphere models (see e.g., Schiller et al., 1996) of how atmospheric circulation will change and how, for instance, an ocean cooling will affect the frequency of blockings.

Figure 2 and Table I show the results of the simplest scenario for an ocean cooling. Here 4 °C was subtracted from the observed temperatures at days in the 1950–1994 time series with advection of airmasses of maritime origin and the temperatures on days with advection of continental airmasses were left unchanged. This scenario implicitly assumes an unchanged atmospheric circulation. The adopted value, 4 °C, of the cooling at maritime days is within the range of ocean surface cooling observed in model experiments by Manabe and Stouffer (1988) or Rahmstorf (1995) and corresponds with the current temperature difference between the North-Atlantic and the North-Pacific, where no equivalent of the Gulf Stream is found (Levitus, 1994). The maritime days in the time series were selected with the use of Kruizinga's (1979) objective P30-classification of the daily atmospheric circulation at 500 hPa, assigning his classes 1–17, 19, 20 and 22 as maritime. We note that the results are very similar if the daily Grosswetterlagen (Gerstengarbe and Werner, 1993) or even a classification based on the direction of the surface winds in the Netherlands is used for the selection of maritime days.

According to Table I, a 4 °C ocean cooling would lead on average to a 2.7 °C lower surface air temperature in the Netherlands. This decrease in the mean is almost independent of season, as can be seen from the hardly varying width of Figure 2's middle band. In contrast, the widths of the lower and the upper band do show a strong variation throughout the year. The annual courses of the widths of these bands are almost reversed, implying seasonal dependent changes in the standard deviation and in the extremes of the daily temperatures. In the winter, the lower band is smaller than the upper band. Accordingly, the lower 5% quantile (the

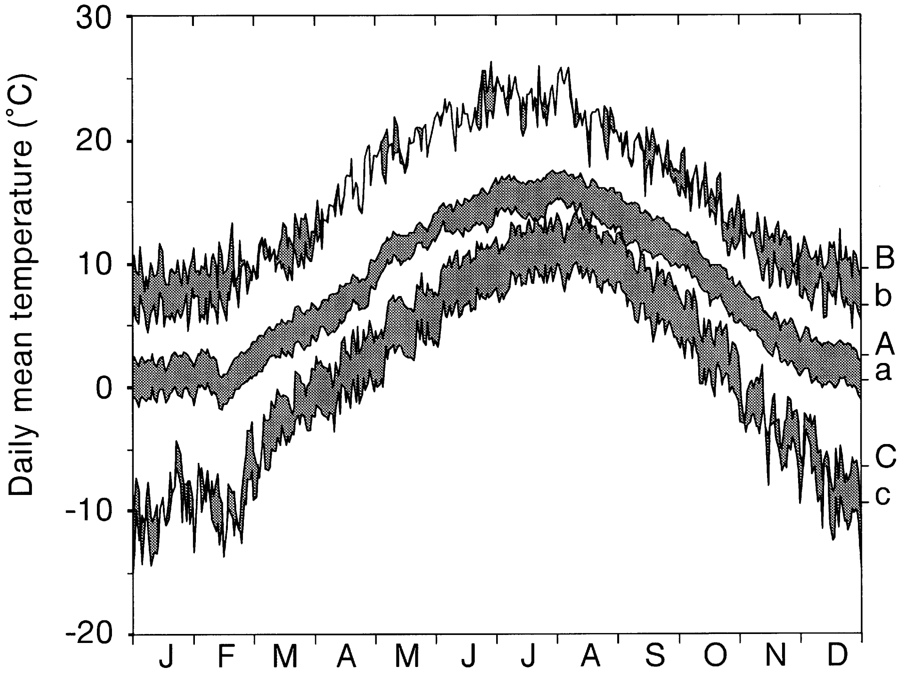

Figure 2. As Figure 1, but now the temperature decrease (shaded) resulting from the 4 °C ocean cooling scenario is added. Lines A, B and C are identical to Figure 1. The lines a, b and c have the same meaning as A, B and C, but are obtained from the perturbed time series, in which 4 °C was subtracted from the observed temperatures at days with advection of airmasses from the Atlantic Ocean. The middle band defined by the lines (A,a) represents the decrease in the 45-year averages introduced by the perturbation; the upper (B,b) and lower (C,c) bands represent the decrease in the 45-year extremes.

Table I

Changes in the mean, in the standard deviation (s.d.), in the lower 5% quantile and in the upper 5% quantile of the daily temperatures (°C) resulting from the 4 °C ocean cooling scenario

	Winter (DJF)	Spring (MAM)	Summer (JJA)	Autumn (SON)	Year
Δ mean	–2.9	–2.3	–2.6	–3.0	–2.7
Δ s.d.	–0.3	+ 0.6	+ 1.0	+ 0.4	+ 0.4
Δ lower 5% quantile	–2.2	–3.3	–3.9	–3.2	–3.1
Δ upper 5% quantile	–3.3	–1.2	–0.8	–1.9	–1.8

temperature below which 5% of the days fall) in Table I decreases less than the upper 5% quantile (the temperature above which 5% of the days fall). Hence, the standard deviation decreases in the winter. These results mean that an ocean cooling would lead to an increase of the relative frequency of winters with temperatures below the present normals, while at the same time the coldest winters will not be more severe than those of the present climate.

For the other seasons, Table I indicates that the lower 5% quantiles decrease with almost the full value of the assumed ocean cooling, whereas the upper 5% quantiles change little. Hence, the temperature in these seasons becomes more variable and cold days become colder, but at the same time warm days comparable to those in the present climate continue to occur.

The values presented in Table I and Figure 2 should be viewed in the perspective of the adopted ocean cooling, whose real magnitude is unknown. But taken together, the results indicate distinct changes in the distribution of the daily temperatures, and the nature of these changes is the same for any adopted cooling.

4. Discussion

Our data perturbation study for a weakened northward component of the Gulf Stream indicates that a seasonally independent change in ocean temperature would result in seasonally dependent changes in the temperature climate of Western Europe. An analogue of the climate resulting from a weakened northward component of the Gulf Stream can be the Little Ice Age, which also showed an increased frequency of winters in the Netherlands with temperatures below the present normals. The occurrence of winters with unprecedented low temperatures was not characteristic of that period, neither is it seen in the scenario.

The temperature decrease on the coldest summer days in the scenario is probably not very realistic, because of the assumption of an equal cooling of airmasses over the Atlantic Ocean during the cold and warm part of the year. In fact, in the warm season the ocean is covered by a stable surface layer, hampering the cooling of the overlying atmosphere. Hence, the Gulf Stream determines the sea-surface temperature and thus the air temperature mainly during the cold season.

It should be emphasised that the present scenario represents only a first guess. Two assumptions are made, namely that of an unchanged temperature of continental airmasses and that of an unchanged atmospheric circulation. While the comparison with model results indicates that the former assumption is probably not too bad after all, such a justification lacks for the second assumption. Rather, it seems likely that a transition into a different mode of the Gulf Stream will be accompanied by a significant change in atmospheric circulation. However, simulations with coupled ocean-atmosphere models give no unambiguous indication as to what atmospheric circulation changes will occur in Western Europe in the situation of a weakened Gulf Stream, nor how such changes would affect the ratio maritime/continental days. This uncertainty clearly limits the predictive value of this kind of a scenario.

The consequences of the ocean cooling scenario can be compared with that of a transient greenhouse warming, in which the ocean warming lags behind the warming of the continent. A scenario with analogue assumptions as before (unchanged atmospheric circulation and temperature changes of continental airmasses only) results in changes in the standard deviation of the daily temperatures which are similar to those in the ocean cooling scenario, but now the changes arise from cold winters and warm summers instead.

Contrary to the expected warming resulting from the enhanced greenhouse effect, of which the time dependence is predictable, it is impossible to determine whether or not a rapid change in ocean circulation will occur in the near future and whether such a sudden change can actually be realised in response to global warming (Houghton et al., 1996). Little is known about the stability of the present ocean circulation mode and about the conditions favorable for triggering a transition into another mode. Nevertheless, the first-guess scenario presented in this study is answering some of the questions about the nature of a perhaps never occurring rapid temperature change caused by an Atlantic Ocean cooling, and in some sense the simple scenario has a surprising level of detail.

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