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The likelihood of holding outdoor skating marathons in the Netherlands as a policy-relevant indicator of climate change

H. Visser · A. C. Petersen

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Abstract "When I was born – in 1956 – the chance of realizing a Frisian Eleven City Ice Skating Marathon in Netherlands was 1 in 4. When my daughter was born – in 1999 – this chance had diminished to 1 in 10. An enormous change in one generation!" This quote was taken from a speech by J. P. Balkenende, prime minister of the Netherlands. It illustrates how a seemingly odd indicator of climate change, the chance of organizing large-scale outdoor ice-skating marathons, can play a role in the public and political debate on climate change. Outdoor skating has a very strong public appeal in the Netherlands, and the diminishing chances of holding such events provide an additional Dutch motive for introducing climate-policy measures. Here, "ice skating marathons" are approached from three angles: (1) the societal/political angle as described above, (2) the more technical angle, of how to derive annual chances for holding large-scale marathons such as the Eleven City Marathon ('Elfstedentocht'), and (3) the role of (communicating) uncertainties. Since the statistical approach was developed in response to communicational needs, both statistical and communicative aspects are reported on in this article.

1 Introduction

> *Politics not only deals with what is 'now', but also with what comes 'later'. Creating conditions for people to have a good life, not only for the present generation, but also for the future generations. That's what politics is all about. These conditions are material (work, income, social security) and immaterial (freedom, security, health and a clean environment). I will talk today on the latter.*
>
> *A short newspaper article a few weeks ago reported that last year a part of the Amazonian rainforest was cut that was almost the size of the Netherlands. This*

H. Visser (✉) · A. C. Petersen
Netherlands Environmental Assessment Agency,
P.O. Box 303, 3720 AH, Bilthoven, The Netherlands
e-mail: Hans.Visser@pbl.nl

deforestation will continue for many years to come. We all know the pictures of melting glaciers on Greenland and satellite images of the hole in the ozone layer.

An example closer to home: when I was born – in 1956 – the chance of realizing a Frisian Eleven City Ice Skating Marathon taking place was 1 in 4. When my daughter was born – in 1999 – this chance had diminished to 1 in 10. An enormous change in one generation!

(.........)

(From a speech of J.P. Balkenende, prime minister of the Netherlands, June 6, 2005)

Climatic change is abound with uncertainty. Not only are uncertainties intrinsic in the science; societal actors also have different opinions on what aspects of climatic change constitute a problem and why. When analysts search for indicators to analyze and communicate information about climatic change, they therefore have to address both scientific and societal uncertainties. In this article, we report on the development and communication of a new indicator of climatic change for the Netherlands.

The indicator is innovative in two regards. First, the Dutch public was informed about a dimension of climatic change that directly appeals to them and that had not been clearly communicated before. Second, a new statistical approach was developed in order to be able to communicate robust messages about changes in this indicator. Since the statistical approach was developed in response to communicational needs, both statistical and communicative aspects of the new indicator are reported on in this article. Both aspects or 'storylines' meet in the Dutch prime minister's quote above.

Outdoor skating is an extremely popular sport in the Netherlands, with a large number of skating tours being organized throughout the country in the coldest winter periods. The 'tour of all tours' is the 'Elfstedentocht', the Eleven City Ice Skating Marathon, held in the province of Friesland. Here we will explore from several angles the likelihood (the annual chance) of an 'Elfstedentocht' being organized. This likelihood is considered to be a complex indicator of climate change, with many uncertainties attached to it, but with a very strong public appeal too, providing an additional Dutch motive for setting climate-policy measures.

Climate warming has influenced the conditions necessary for holding this outdoor skating marathon since the beginning of the twentieth century. In this article, the focus is on the evolution of the chance of holding an annual 'Elfstedentocht' in the period from 1901 to 2008.

For several reasons, estimating this chance indicator is more complex than evaluating other climate indicators such as annual averaged temperatures, annual total precipitation and drought frequencies. The chance of holding a marathon is dependent on:

- maximal ice thicknesses that are not measured routinely.
- the amount of open water due to drainage or flowing under bridges.
- organizational factors delaying the decision about whether to hold a marathon, e.g. creating "kluning" (walking on skates) facilities, and mobilizing competitive and non-competitive skaters.

Our approach here is to find an indicator calculated from standard meteorological data from the beginning of twentieth century, and related to maximal ice thickness in the province of Friesland. Clearly, this indicator should be homogeneous (i.e. corrected for changes in instruments, location of instruments, changes to the instrument by environment etc.). Finally, the annual chance for organizing the 'Elfstedentocht' is deduced from the chance of the ice-thickness indicator crossing a threshold.

Uncertainties play an important role in the evaluation of change in chances for a skating marathon. These uncertainties need to be assessed and communicated. To express uncertainty in statistical terms, we need to apply a trend model from the class of structural time-series models in combination with the Kalman filter. The rationale for choosing this particular model is not that it necessarily yields the "best" trend, but that it offers uncertainties for flexible trends and for any trend differences of interest (Visser 2004a, 2005).

The 'Elfstedentocht' indicator has appeared to be a good indicator for communicating climate change aspects in the Netherlands. The indicator, included by the Netherlands Environmental Assessment Agency in its *Environmental Balance* of May 2005, was subsequently taken up by the media and politicians (as can be seen, for instance, in the quote of the prime minister cited above). When MNP started its research on climate impact indicators the goal was to explain impacts of climate change to policy makers and the general public in the Netherlands, while searching for simple but convincing examples.

Our hypothesis was that such examples differ from country to country. For France, examples could relate to the annual number of elderly people dying during heat waves; for the Alps, it could be the melting of snow and glaciers, and the corresponding loss of ski tourism; for the USA it could be an increase in droughts, coupled with agricultural losses; changes in temperature (extremes) will affect tourist flows in many countries (Gössling and Hall 2006). For the Netherlands we chose, from amongst the indicators, the changing chances of holding large outdoor skating events.

This article will start with the history of the 'Elfstedentocht' (Section 2), followed in Section 3 by showing how the chance for organizing the marathon is derived in three steps formulated as questions:

- what is a simple annual indicator for maximal ice thickness, and how is this indicator coupled to the decision of organizing the marathon? (Section 3.1),
- how did the trend in ice-thickness indicator evolve over the 1901–2008 period and what are the corresponding uncertainties? (Section 3.2),
- what is the chance of an 'Elfstedentocht' being organized in the 1901–2008 period and what are the corresponding uncertainties? (Section 3.3).

Section 4 will wind up with a discussion on the role this rather odd 'Elfstedentocht' indicator has played in the public and political debate on climate change issues.

2 History

For a long time the Eleven city marathon, or 'Elfstedentocht' in Dutch, has been considered in the Netherlands as an attractive opportunity to skate along eleven Frisian cities on the ice-covered waterways in 1 day, covering a distance of almost 200 km (Fig. 1). The names of dozens of successful skaters from the last century

Fig. 1 The 'Elfstedentocht' covers a course of almost 200 km, proceeding from town to town, over lakes and ditches, between fields and under bridges. Hundreds of thousands of spectators cheer the skaters along the route. Leeuwarden, the capital of Friesland, has always been the start and finish. The marathon takes the participants from Leeuwarden (Ljouwert) to Sneek (Snits), IJlst (Drylts), Sloten (Sleat), Stavoren (Starum), Hindeloopen (Hynljippen), Workum (Warkum), Bolsward (Boalsert), Harlingen (Harns), Franeker (Frentsjer), Dokkum and back to Leeuwarden. At registration, every participant gets a card which has to be stamped in each town and at a number of checkpoints located in concealed places along the route. Source: http://www.elfstedentocht.nl

are still familiar, their stories being proudly passed on within their family circles from generation to generation. The 'Elfstedentocht' offers both competitive and non-competitive marathons for the same route on the same day. This event has taken place 15 times since 1909 (although tours were organized along the eleven cities long before this, the first description of a tour dates from 1749).

The marathon is highly dependent on specific weather conditions. For the marathon to actually take place, the ice needs to be at least 15 cm thick along virtually the whole route. During prolonged freezing, the regional organizing committee goes out every day at least once to measure the thickness of the ice. Sometimes ice is transplanted to places where the natural ice layer is thin. Once the marathon committee has given the green light, "klunen" (skate-walking) facilities are constructed along the vulnerable parts of the route. More information about the tour can be found at: http://www.elfstedentocht.nl (choose English).

A winner of the 'Elfstedentocht' becomes a hero whose name is remembered for generations. These winners are summarized by year and final time in Table 1 for all 15 tours organized since 1909. The extremely cold conditions in 1963 make that year's tour famous as national story of perseverance, solidarity and lonely fighting. Of the more than 10,000 starters only 136 skaters made it to the finish. Weather conditions during the tour were extremely grim, with a lot of snow falling during the tour. The 1963 tour has taken on almost mythical proportions in people's memories

Table 1 Winners of the 'Elfstedentocht' since 1909 in which final times were reduced from 13 h 50 min in 1909 to 6 h 47 min in 1985

Year	Name	Time
1909	M. Hoekstra	13 h 50 min
1912	C.C.J. de Koning	11 h 40 min
1917	C.C.J. de Koning	9 h 53 min
1929	K. Leemburg	11 h 9 min
1933	A. de Vries	9 h 53 min
	S. Castelein	
1940	P. Keizer	11 h 30 min
	A. Adema	
	C. Jongert	
	D. van der Duim	
	S. Westra	
1941	A. Adema	9 h 19 min
1942	S. de Groot	8 h 44 min
1947	J. van der Hoorn	10 h 51 min
1954	Jeen van den Berg	7 h 35 min
1956	No winner (five skaters finished simultaneously; this was not allowed anymore after 1940)	
1963	Reinier Paping	10 h 59 min
1985	Evert van Benthem	6 h 47 min
	Lenie van der Hoorn (first woman)	
1986	Evert van Benthem	6 h 55 min
	Tineke Dijkshoorn (first woman)	
1997	Henk Angenent	6 h 49 min
	Klasina Seinstra (first woman)	

(a contributing factor was the 22 year period between 1963 and the next marathon in 1985).

3 Derivation of the 'Elfstedentocht' indicator

3.1 Two-stage procedure

In principle, the marathon is organized if ice thicknesses ***exceed 15 cm***, as stipulated by an 'Elfstedentocht' committee. For this reason it would seem logical to derive an ice-thickness indicator and determine a threshold for maximal ice thicknesses so that conditions will be declared optimal for organizing the 'Elfstedentocht'. Finding this indicator and the corresponding threshold will be briefly described here. Other factors such as the amount of open water due to drainage or occurring under bridges are accounted for in our choice of a threshold.

Brandsma (2001) used averaged winter temperatures as an indicator for maximal ice thickness. He compared the winter temperatures with *calculated* maximal annual ice thicknesses for the province of Friesland over the 1901–2000 period, and found a reasonable linear relation. Maximal ice thicknesses were calculated by an ice-grow model developed at the Royal Netherlands Meteorological Institute (KNMI) (de Bruin and Wessels 1988, 1990).

Here, we followed the approach of Brandsma except that we correlated computed ice thicknesses with a number of simple meteorological indicators based on homogeneous temperature records at De Bilt. De Bilt is the location of the main observatory of KNMI and data can be downloaded from the Internet website http://eca.knmi.nl. For a discussion on the homogeneity of this series the reader is referred to Brandsma et al. (2002).

The indicator $I_t \equiv$ *"the average temperature of the coldest period of 15 consecutive days in winter (°C)"* was found to perform best (in terms of the highest correlation, namely 0.86). Here, winter is defined by the months DJF and the indicator value falls by definition in the year of JF.

A scatterplot between maximal ice thicknesses and I_t is shown in Fig. 2. Green bullets denote years in which a marathon was organized (15 times) or a year with a potential marathon (4 years). These "potential years" are years in which the marathon *could have been organized* (ice thicknesses of more than 30 cm). Potential years are 1939, 1979, 1987 and 1996.

The vertical orange line in Fig. 2 shows the optimal threshold, based on calculated ice thicknesses, for making a positive decision to organize a marathon. The optimal threshold appears to be ***20 cm***. The horizontal orange line shows the corresponding optimal threshold for I_t: ***−4.2°C***. We applied the latter threshold in the following decision criterion: I_t below the limit value −4.2°C implies a marathon, and I_t above the limit implies no marathon.

The performance of this simple criterion is as follows. In the 81 years in which no marathon was organized (black bullets in Fig. 2) only 4 years came out *below* the threshold of −4.2°C (thus yielding faulty predictions in 5% of the cases). In the 19 years with a (potential) marathon (green bullets in Fig. 2) only 3 years came out *above* the threshold (yielding faulty predictions in 16% of the cases). In fact, the indicator is almost as good as the model-based ice-thickness predictions: four faulty

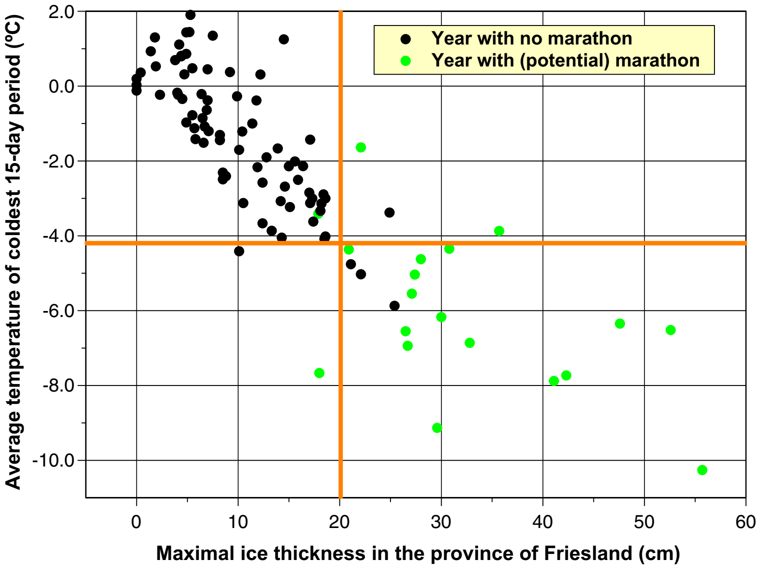

Fig. 2 Scatterplot between maximal ice thicknesses and the indicator selected. *Green dots* represent years for a (potential) marathon (19 for 1901–2000)

predictions for 81 years with no marathon (5%), and 2 faulty predictions for 19 years with (potential) marathons (11%). We note here that it is reasonable (from historical notes) to assume that plans for organizing the marathon started around the year 1901.

3.2 Time-series approach

To find the annual chance for organizing an 'Elfstedentocht' we should evaluate the trend evolution of I_t over the period of 1901 to 2008 along with uncertainties. There are a large number of methods to calculate a trend in a series of measurements. And generally speaking, there is no "best" trend model. The most appropriate model will depend on one's goals or "wishes". Here, we are looking for a trend model, μ_t, that is to a certain extent flexible. Furthermore, we want to have significance intervals for μ_t, with $1901 \leq t \leq 2008$, and the corresponding differences $\mu_{2008} - \mu_t$, with $t < 2008$. The latter difference is of importance because we want to make inferences on whether the 'Elfstedentocht' indicator is significantly increasing/decreasing over an arbitrary time interval [t, 2008], as we will point out in the next section.

The Integrated Random Walk (IRW) model (a submodel from the class of structural time series models) in combination with the Kalman filter appears to satisfy our wishes. The IRW model reads as

$$y_t = \mu_t + \xi_t \quad \text{and} \quad \mu_t = 2 * \mu_{t-1} - \mu_{t-2} + \varepsilon_t \tag{1}$$

with ξ_t and ε_t normally and independently distributed noise processes.

Statistical details are beyond the scope of this article. For the theoretical considerations, we refer to Harvey (1989) and Durbin and Koopman (2001), and for applications in the field of climatic change research to Visser and Molenaar (1995), Allen et al. (1999), Stern and Kaufmann (2000), Lenten and Moosa (2003), and

Visser (2004a). Applications of the IRW model are given by Kitagawa (1981), Young et al. (1991), van den Brakel and Visser (1996) and Visser (2005). Tests for choosing the proper time-series model are given by Visser (2004a, Appendix B therein). Trends have been estimated with the TrendSpotter software (Visser 2004b), a software package that allows one to estimate a variety of structural time-series models. TrendSpotter is available, without charge, from the first author.

An IRW trend model has been estimated for the indicator described in the preceding section. Because the residuals of the estimated trend model turn out to be skewed, the annual indicator values are transformed by taking logarithms:

$$y_t = ln\,(10.0 - I_t) = \mu_t + \xi_t \quad \text{and} \quad \mu_t = 2 * \mu_{t-1} - \mu_{t-2} + \varepsilon_t \tag{2}$$

with ξ_t and ε_t normally and independently distributed noise processes.[1] The constant 10.0 was found by "trial and error" and the threshold of −4.2°C transforms to 2.65.

Figure 3 shows the IRW estimation results for model (2).[2] The upper panel shows the estimated trend μ_t. The narrow bounds ($\mu_t \pm 2 * \sigma_{\varepsilon,t}$, green dashed lines) are 95% confidence limits for μ_t, while the wider bounds $\mu_t \pm 2^* \surd\left(\sigma^2_{\varepsilon,t} + \sigma^2_\xi\right)$, red dashed lines) are 95% confidence limits for a predicted value of y_t. The upper panel shows a slightly increasing indicator series up to 1950 and a decreasing trend thereafter. The lower panel shows that trend differences $\mu_{2008} - \mu_t$ are statistically significant for any year within the 1905–1997 period ($\alpha = 0.05$ and a two-sided test of significance).

3.3 Chance of organizing an 'Elfstedentocht'

Given the transformed indicator trend estimates μ_t, its standard deviation $\sigma_{\varepsilon,t}$ and the standard deviation of the residuals σ_ξ we can calculate for each year, t, the probability of an 'Elfstedentocht' being organized (the ln-transformed indicator y_t is normally distributed with mean μ_t and variance $\sigma^2_{\varepsilon,t} + \sigma^2_\xi$). More formally, if we denote the annual chance for organizing an 'Elfstedentocht' with E_t, we have:

$$E_t \cong P\,(I_t < -4.2°C) = P\,(ln\,(10.0 - I_t) > 2.65) = P\,(y_t > 2.65) \tag{3}$$

with $y_t \approx N\left(\mu_t, \sigma^2_{\varepsilon,t} + \sigma^2_\xi\right)$, and $1901 \leq t \leq 2008$.

[1] Because we are modeling a cold extreme, i.e. the coldest 15-day period, we might expect the residuals to follow a generalized extreme value (GEV) distribution. Please see http://www.isse.ucar.edu/extremevalues/extreme.html and references therein. To quote the statistician J. Tukey: "As I am sure almost every geophysicist knows, distributions of actual errors and fluctuations have much more straggling extreme values than would correspond to the magic bell-shaped distribution of Gauss and Laplace". However, our experience with many long-term climate series in the Netherlands is that residuals (or 'innovations' in Kalman filter terms) do follow that 'magic bell-shaped curve' (Visser 2004a, 2005). We only had to apply a logarithmic transformation of the form $y_t = \log$ (constant - I_t) to correct for skewed innovations. A probability plot of the innovation series showed that the data are in good approximation normally distributed.

[2] We have applied the filter equations of the discrete Kalman filter, using a diffuse prior for the state vector. For calculation of the maximum-likelihood estimate of the unknown noise variance σ^2_ε we have omitted the residuals over the period 1901–1920 (the 'start-up period' of the filter). Afterwards, trend estimates have been smoothed by the fixed-interval smoother. The rationale is that we can improve a trend estimate μ_t by using not only all the data before and up to time t, but also data *after* time t. As a consequence, the 'start up' behavior of the filtered estimates is not seen anymore in the smoothed estimates for the first 20 years. For a condensed formulation of the Kalman filter equations, we refer to Harvey (1984).

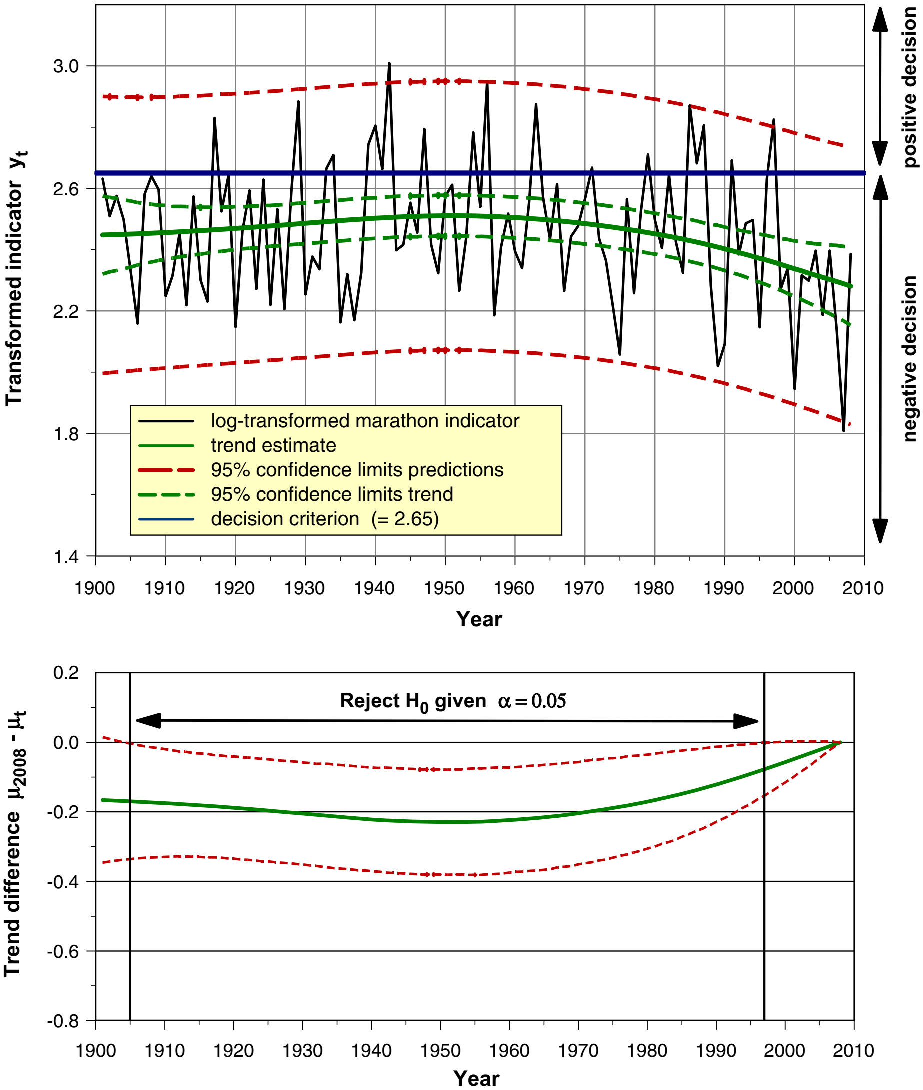

Fig. 3 Transformed 'Elfstedentocht' indicator y_t (*black line*), the estimated trend μ_t (*green line*) and the corresponding 95% confidence limits (*dashed green lines*). The *dashed red lines* represent 95% confidence limits for the y_t predictions. Note that the original indicator I_t has been transformed to $y_t = \ln(10.0–I_t)$ to account for the skewness of minimum temperature data. The lower panel shows the trend differences $\mu_{2008} - \mu_t$ with corresponding 95% confidence limits

We illustrate this by showing the probability density functions of I_{1901} (orange line), I_{1950} (green line) and I_{2008} (red line) in Fig. 4 (based on the estimates from Fig. 3). The densities follow a log-normal distribution with the long tail to the left due to the log transformation. The chances E_{1901}, E_{1950} and E_{2008} equal the surface of the density function's tail to the left of the vertical decision line at −4.2°C (yellow area's). For 1901 this is $E_{1901} = 0.19$, for 1950, $E_{1950} = 0.27$ and for 2008, $E_{2008} = 0.055$.

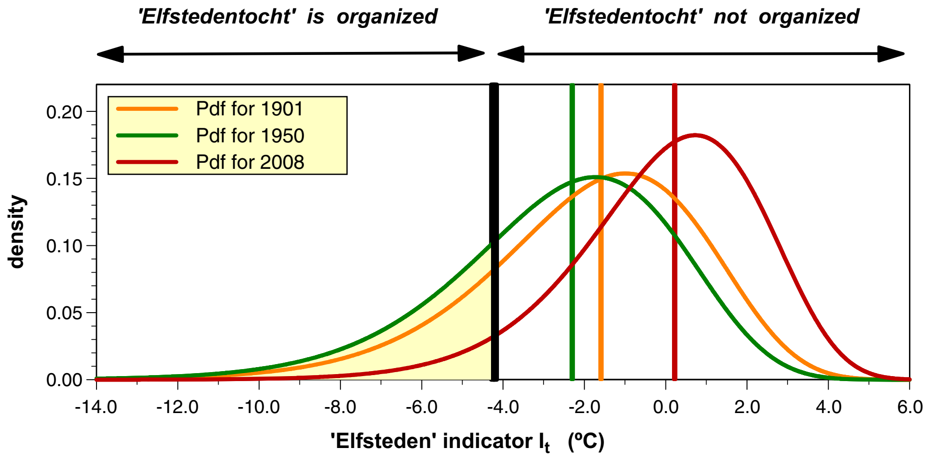

Fig. 4 Probability density functions (Pdfs) for the 'Elfstedentocht' indicator I_{1901} (*orange line*), I_{1950} (*green line*) and I_{2008} (*red line*). *Vertical lines* are the geometric mean values: −1.6°C in 1901, −2.3°C in 1950 and +0.22°C in 2008. The probability functions are shifted log-normal with long tails to the left (due to the transformation $y_t = \ln(10.0 - I_t)$). The surface of the *yellow* area for each curve equals the chance for holding a marathon

The chances, E_t, are shown in Fig. 5 for all years in the 1901–2008 period. Since y_t is normally distributed and its variance $\sigma^2_{\varepsilon,t} + \sigma^2_{\xi}$ is almost constant $\left(\sigma^2_{\xi} \gg \sigma^2_{\varepsilon,t}\right)$, we can state that:

$$E_t = P\,(y_t > 2.65) = f\,(\mu_t) \approx \frac{1}{\sigma\sqrt{2\pi}} \int_{2.65}^{\infty} e^{\frac{-1}{2}\left(\frac{x-\mu_t}{\sigma}\right)^2} dx \tag{4}$$

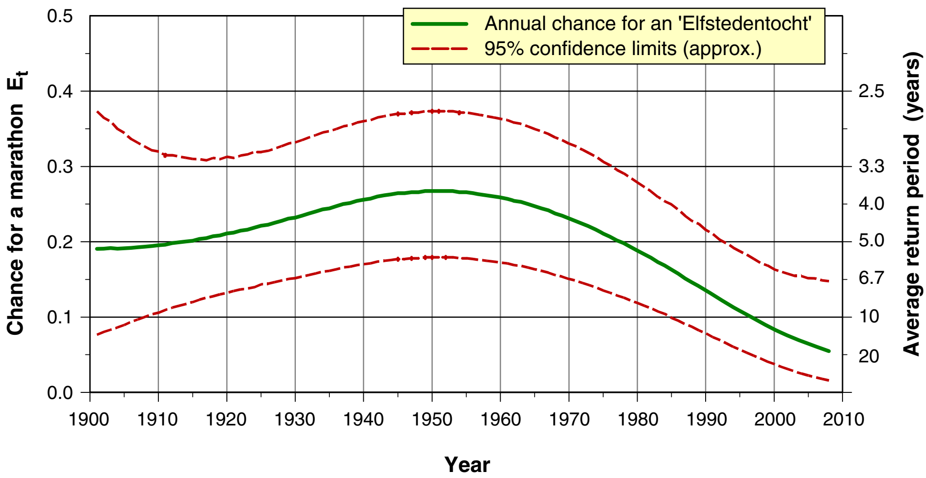

Fig. 5 Annual chance of organizing an 'Elfstedentocht' E_t. The right y-axis shows the corresponding return periods R_t, which are simply the inverse of the annual chances

with $\sigma = \sqrt{\left(\sigma^2_{\varepsilon,t} + \sigma^2_{\xi}\right)} \approx 0.22$ (cf. red dashed lines in upper panel of Fig. 3). Now, the 95% confidence limits for E_t follow in good approximation from:

$$\left[f\left(\mu_t - 2*\sigma\right), \quad f\left(\mu_t + 2*\sigma\right)\right] \tag{5}$$

with f defined in (4). These confidence limits from are also shown in Fig. 5.

Has the chance of organizing an 'Elfstedentocht' E_{2008} been significantly reduced since 1999, 1956 or any other year? To answer this question, we have to make an approximation explained in Appendix. The difference $\Delta_t \equiv E_{2008} - E_t$ can be shown to be approximated by (first-order Taylor expansion):

$$\Delta_t \approx \left(\mu_{2008} - \mu_t\right) * \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-1}{2}\left(\frac{2.65-\mu_t}{\sigma}\right)^2} \tag{6}$$

Now, Δ_t will simply be statistically significant if the same holds for the difference $\mu_{2008} - \mu_t$ (the exponential term on the right-hand side is always positive). Therefore, the significance periods of marathon chances follow in first approximation from the significance of $\mu_{2008} - \mu_t$, as shown in the lower panel of Fig. 3. Thus, if we choose $\alpha = 0.05$ and a two-sided test on significance,[3] we find that the chance of an 'Elfstedentocht' taking place in 2008 is (statistically) significantly smaller than all the chances within the 1905–1997 period.

The chances E_t can also be expressed in terms of *average return periods* R_t (right axis of Fig. 5). A return period is simply the inverse of the annual chance E_t: $R_t = 1/E_t$, so that $R_{1901} = 5.3$ [2.7–13.0] years, $R_{1950} = 3.7$ [2.7–5.6] years and $R_{2008} = 18.2$ [6.8–64] years. The results found here are consistent with the prime minister's quote at the beginning of this article ("a chance of 1 to 4 in 1956" and "1 to 10 in 1999"): $R_{1956} = 3.8$ [2.7–5.7] years and $R_{1999} = 11.3$ [5.9–24] years.

4 Communication of uncertain but policy-relevant indicators

An initial question in communicating chances or uncertainties to policy makers and/or the public is: do they understand what the chance expression means? Gigerenzer et al. (2005) used a survey to find out if the statement *"there is a 30% chance of rain tomorrow"* would invoke contradictory interpretations. According to their findings, if the class of events that the chance expression is referring to is not specified, the chance will be multi-interpretable. Most European respondents thought that chance meant *"it will rain 30% of the time"*, followed by *"it will rain in 30% of the area"*. Only respondents in the city of New York supplied in majority the standard meteorological interpretation, namely that *"when the weather conditions are like today, in 3 out of 10 cases there will be (at least a trace of) rain the next day."* Wardekker et al. (2008) discuss problems concerning verbal probability expressions. The use of such expressions – as is done for instance by the IPCC – is problematic, since differences in interpretation are large and context-dependent.

[3] Without giving details we note here that tests on significance have not gone unquestioned in literature. For discussion, please refer to Sterne and Smith (2001) and references included in the article.

In our case 'the class of events' is unambiguous. The location of the Eleven City marathon is known to everybody and the specific day is of no importance. The only factor that counts is the "go–no-go" decision of the 'Elfsteden' committee.

How was the 'Elfstedentocht' indicator communicated? In the report "the significance of climate change in the Netherlands" (Visser 2005), the conclusion concerning the 'Elfstedentocht' indicator was presented as follows:

Over the course of the twentieth century the chance of an 'Elfstedentocht' has decreased from once every 5 years (in 1901) to once every 10 years (in 2004). Even though this change is not yet statistically significant, it resides 'on the edge' of significance: within a few years more evidence may become available to firmly establish the diminishing likelihood of outdoor skating in the Netherlands.

Three months later, the *Environmental Balance* (MNP 2005) displayed a graph to illustrate this indicator (Fig. 5 in this article, without confidence limits and the period 1901–2004) accompanied by the following conclusion:

It is likely that the chance of an 'Elfstedentocht' has decreased from once every 4 years in 1950 to once every 10 years in 2004.

This statement about the second half of the twentieth century was alluded to by the prime minister of the Netherlands in his speech (see quote cited above). The term "likely" is used in the same way as in WG I of the Intergovernmental Panel on Climate Change, i.e. as a 66–90% chance.

The great amount of attention that we have paid to determine and communicate the uncertainties in the 'Elfstedentocht' indicator have not prevented this indicator from being taken up rapidly as an icon of climate change in the Netherlands. We were careful about making overly strong claims, since we feel responsible for being just as rigorous and transparent in our treatment of uncertainty as in assessing climate change and communicating the risks to a wider audience.

There is an historical reason for being extra careful. In 1999, the environmental assessment division (later: Netherlands Environmental Assessment Agency, MNP and since May 2008: PBL) of the Dutch National Institute for Public Health and the Environment (RIVM) made news in the Netherlands for having failed to communicate properly about uncertainties (van Asselt 2000; van der Sluijs 2002; Petersen 2006). This led to the development of the *RIVM/MNP Guidance for Uncertainty Assessment and Communication* (MNP/UU 2003), designed to help environmental assessors to deal with uncertainty and the framing of policy problems in a more appropriate and systematic way. It was produced by RIVM/MNP, together with Utrecht University and an international team of uncertainty experts (see Janssen et al. 2005; Refsgaard et al. 2007; van der Sluijs et al. 2008 – see also http://www.nusap.net/guidance).

The Guidance documents offer assistance to PBL employees in mapping and communicating uncertainties in environmental assessments and have been evaluated as good means for facilitating scientists in dealing with uncertainties throughout the whole environmental assessment process. It was not to be limited to applying ready-made tools for uncertainty analysis and communication, since in all aspects of environmental assessments choices are made which influence the way uncertainties are dealt with. Especially the way perspectives of other scientists and stakeholders are treated is crucial in assessing policy problems that are relatively unstructured (see also Petersen 2006; van der Sluijs 2007).

The Guidance identifies six parts of environmental assessments which have an impact on the way uncertainties are dealt with:

1. problem framing;
2. involvement of stakeholders (that is, all those involved in or affected by a policy problem);
3. selection of indicators representing the policy problem;
4. appraisal of the knowledge base;
5. mapping and assessing relevant uncertainties and
6. reporting the uncertainty information.

Parts 5 and 6 usually reveal a focused effort to analyze and communicate uncertainty. However, the choices and assessments made in the other four parts are also of great importance in dealing with uncertainty.

In the case presented in this article, the ‘Elfstedentocht’ indicator, we have addressed all six parts. First, by focusing on the example of the ice-skating marathon, climate change is framed at the level of collective cultural experience. The ‘Elfstedentocht’ is largely a cultural phenomenon, deeply rooted in Dutch culture. Second, although we did not invite stakeholders to sit at the table while developing the indicator, we decided to take the viewpoints of the Dutch population into account in the development of a set of climate change impact indicators. Third, we have provided adequate scientific backing for these indicators and discussed their limitations. Fourth, we have determined the bottlenecks in the available knowledge and methods, and their impact on the results, and fifth, we have done a statistical uncertainty analysis for indicator I_t.[4] Our final effort was to ensure that all relevant uncertainty information would be published with the indicator.

The ‘Elfstedentocht’ indicator was one of many other interesting indicators published by Visser (2005). Examples of other changes over the twentieth century were the number of extremely wet days (increased from 19 ± 3 to 26 ± 3 days) and the length of the growing season (increased by nearly a month). Globally averaged temperatures are obviously much less appealing to the public than indicators more related to local conditions. Apparently, the peculiar ice-skating marathon indicator hit a nerve in Dutch society and has therefore received wide publicity. We reckon that more such peculiar measures of climate-change impacts can be found for many countries and urge scientists to look for the indicators that really appeal to a larger audience.

The statistical approach in this article only offers the possibility to detect changes in climate change impact indicators, but does not provide for the possibility to attribute these changes to, e.g., anthropogenic influences. A separate argument is needed – and can be given – to make the results policy-relevant. As van Oldenborgh and van Ulden (2003) have shown, the seasonally averaged temperature in De Bilt over the twentieth century is described well by (1) a warming, independent of wind direction, proportional to the globally averaged temperature; (2) an increase in

[4]The uncertainty analysis holds for the second stage of the analysis, the trend analyses. The uncertainty in the ‘−4.2°C criterion’, the first stage of our analysis, is difficult to give. It is based on 19 (potential) marathons in the period 1901–2000. However, since the criterion is directly coupled to ice-thickness calculations, shown in Fig. 2, yielding faulty predictions in only 5% and 16% of the cases, we judge the criterion to be reasonably robust.

southwesterly circulation in February–April after 1950; and (3) almost white noise due to other variations in wind directions and other effects. Since the first term explains most of the observed trend over the twentieth century, we can say that the changes observed in the 'Elfstedentocht' indicator are consistent with what we would expect from anthropogenic climate change. Visser (2005) also shows extrapolations of this indicator to 2020, on the basis of both statistical extrapolation and GCM results (which give consistent values).

Scientists bear a responsibility for addressing the concerns of their societies, but also need to remain diligent and communicate uncertainties in a consistent and transparent fashion. We endeavored in this article to provide an example of a policy-relevant indicator for climate-change impacts with large uncertainties associated with it. Communicating these uncertainties as part of the message to policy makers will not prevent them from getting the message that the climate is changing, as is illustrated by the quote of the Dutch prime minister at the beginning of the introduction. Still, policy makers and politicians also have a responsibility to make uncertainties explicit and defend their decisions in the context of uncertainty.

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Appendix

From Eq. 4 we have:

$$E_s = f(\mu_s) \approx \frac{1}{\sigma\sqrt{2\pi}} \int_{2.65}^{\infty} e^{\frac{-1}{2}\left(\frac{x-\mu_s}{\sigma}\right)^2} dx \tag{A.1}$$

Now, if two trend values μ_t and μ_s are near, or in other words the difference $(\mu_t - \mu_s)$ is small, we may apply the following Taylor series expansion:

$$E_t = E_s + (\mu_t - \mu_s) * f'(\mu_s) + 0.5 * (\mu_t - \mu_s)^2 * f''(\mu_s) + \ ..... \tag{A.2}$$

Now, if we combine (A.1) and (A.2) we find in first approximation:

$$\begin{aligned}
E_t - E_s &= (\mu_t - \mu_s) * \frac{d}{d\mu_s} E(\mu_s) + \textit{higher order terms} \quad \approx \\
&\approx (\mu_t - \mu_s) * \frac{1}{\sigma\sqrt{2\pi}} \int_{2.65}^{\infty} e^{\frac{-1}{2}\left(\frac{x-\mu_s}{\sigma}\right)^2} \frac{d}{d\mu_s}\left[\frac{-1}{2}\left(\frac{x-\mu_s}{\sigma}\right)^2\right] dx \\
&= (\mu_t - \mu_s) * \frac{1}{\sigma\sqrt{2\pi}} \int_{2.65}^{\infty} e^{\frac{-1}{2}\left(\frac{x-\mu_s}{\sigma}\right)^2} \frac{-d}{dx}\left[\frac{-1}{2}\left(\frac{x-\mu_s}{\sigma}\right)^2\right] dx \\
&= (\mu_t - \mu_s) * \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-1}{2}\left(\frac{2.65-\mu_s}{\sigma}\right)^2}
\end{aligned} \tag{A.3}$$

The last expression in (A.3) equals Eq. 6 if we set year t to 2008.

References

Allen K, Francey R, Michael K, Nunez M (1999) A structural time series approach to the reconstruction of Tasmanian maximum temperatures. Environ Model Softw 14:261–274

Brandsma T (2001) How many 11 city ice-skate marathons in the 21st century? Zenit 28:194–197 (in Dutch)

Brandsma T, Können GP, Wessels HRA (2002) Empirical estimation of the effect of urban heat advection on temperature series of De Bilt. Int J Climatol 23:829–845

de Bruin HAR, Wessels HRA (1988) A model for the formation and melting of ice on surface waters. J Appl Meteorol 27:164–173

de Bruin HAR, Wessels HRA (1990) Ice in the low lands. Zenit 17:437–444 (in Dutch)

Durbin J, Koopman SJ (2001) Time series analysis by state space methods. Oxford Statistical Science Series, Oxford

Gigerenzer G, Hertwig R, Broek E, van den Fasolo B, Katsikopoulos KV (2005) A 30% chance of rain tomorrow: how does the public understand probabilistic weather forecasts? Risk Anal 25(3):623–629

Gössling S, Hall CM (2006) Uncertainties in predicting tourist flows under scenarios of climate change. Clim Change 79(3–4):181–183

Harvey AC (1984) A unified view of statistical forecasting procedures. J Forecast 3:245–275

Harvey AC (1989) Forecasting, structural time series models and the Kalman filter. Cambridge University Press, UK

Janssen PHM, Petersen AC, van der Sluijs JP, Risbey JS, Ravetz JR (2005) A guidance for assessing and communicating uncertainties. Water Sci Technol 52:125–131

Kitagawa G (1981) A nonstationary time series model and its fitting by a recursive filter. Journal Time Series Analysis 2:103–116

Lenten LJA, Moosa IA (2003) An empirical investigation into long-term climate change in Australia. Environ Model Softw 18:59–70

MNP (2005) Environmental balance 2005, the Dutch environment explained. Netherlands Environmental Assessment Agency (MNP), Bilthoven, RIVM/MNP report (in Dutch)

MNP/UU (2003) RIVM/MNP guidance for uncertainty assessment and communication. MNP/UU report. Netherlands Environmental Assessment Agency (MNP), Bilthoven, and Utrecht University, Utrecht. Download from http://www.mnp.nl/guidance or http://www.nusap.net/guidance

Petersen AC (2006) Simulating nature: a philosophical study of computer-simulation uncertainties and their role in climate science and policy advice. Het Spinhuis Publishers, Apeldoorn and Antwerp. Download from http://hdl.handle.net/1871/11385

Refsgaard JC, van der Sluijs JP, Højberg AL, Vanrolleghem PA (2007) Uncertainty in the environmental modelling process: a review. Environ Model Softw 22:1543–1556

Stern DI, Kaufmann RK (2000) Detecting a global warming signal in hemispheric temperature series: a structural time series analysis. Clim Change 47:411–438

Sterne JAC, Smith GD (2001) Sifting the evidence–what's wrong with significance tests? BMJ 322:226–231

van Asselt MBA (2000) Perspectives on uncertainty and risk: the PRIMA approach to decision support. Kluwer Academic Publishers, Dordrecht

van den Brakel J, Visser H (1996) The influence of environmental conditions on tree-ring series of Norway spruce for different canopy and vitality classes. For Sci 42(2):206–219

van der Sluijs JP (2002) A way out of the credibility crisis of models used in integrated environmental assessment. Futures 34:133–146

van der Sluijs JP (2007) Uncertainty and precaution in environmental management: insights from the UPEM conference. Environ Model Softw 22:590–598

van der Sluijs JP, Petersen AC, Janssen PHM, Risbey JS, Ravetz JR (2008) Exploring the quality of evidence for complex and contested policy decisions. Env Res Lett 3:024008(9 pp)

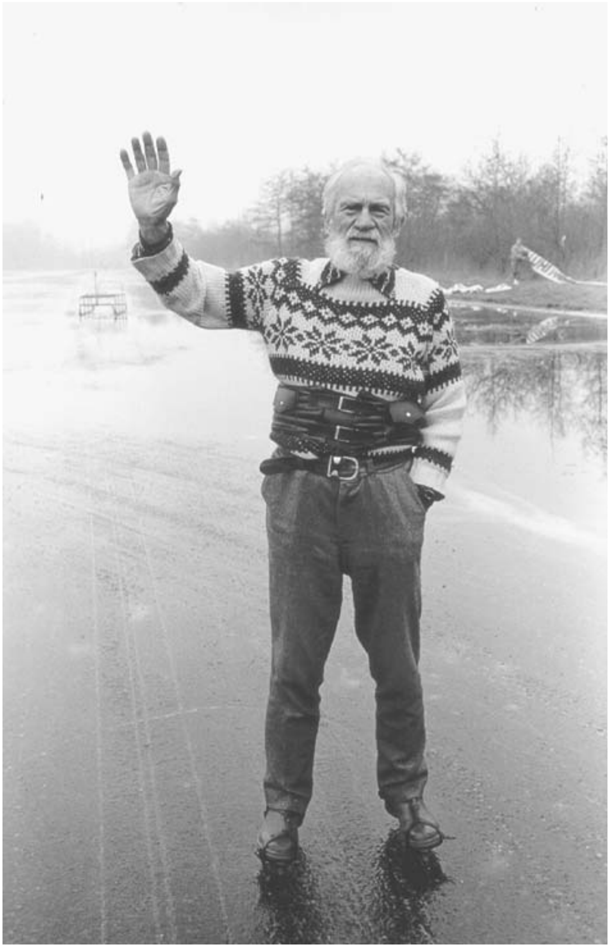
van Oldenborgh GJ, van Ulden A (2003) On the relationship between global warming, local warming in the Netherlands and changes in circulation in the 20th century. Int J Climatol 23:1711–1724

Visser H (2004a) Estimation and detection of flexible trends. Atmos Environ 38:4135–4145

Visser H (2004b) Description of the TrendSpotter software. RIVM Memo 007/2004 IMP

Visser H (2005) The significance of climate change in the Netherlands. An analysis of historical and future trends (1901–2020). RIVM/MNP report 550002007. Download from http://www.rivm.nl/bibliotheek/rapporten/550002007.pdf

Visser H, Molenaar J (1995) Trend estimation and regression analysis in climatological time series: an application of structural time series models and the Kalman filter. J Climate 8(5):969–979
Wardekker JA, van der Sluijs JP, Janssen PHM, Kloprogge P, Petersen AC: (2008) Uncertainty communication in environmental assessments: views from the Dutch science-policy interface. Env Sci Pol 11(7):627–641
Young PC, Lane K, Ng CN, Palmer D (1991) Recursive forecasting, smoothing and seasonal adjustment of non-stationary environmental data. J Forecast 10:57–89



The chance of holding a large outdoor skating marathon such as the 'Elfstedentocht', has decreased from once every five years in 1901 to once every 18 years in 2008. Photo: H. Visser