Koninklijk Nederlands
Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu

Implementation of the Hinssen-Knap algorithm for the calculation of sunshine

Geert Groen, Rob Sluijter, Piet Stammes, Rudmer Jilderda

De Bilt, 2011 | Technical report; TR-319

Koninklijk Nederlands
Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu

Implementation of the Hinssen-Knap algorithm for the calculation of sunshine duration

Versie 1.0

Datum December 2011
Status Definitief

Abstract

The implementation of the Hinssen-Knap linear algorithm (HK-algorithm) for the calculation of sunshine duration is decided on by TOW on October 12th 2009. This implementation report proposes a three-step-plan. Start with creating a (seperate) series of hourly sunshine duration based on the global radiation (since 1992 or longer, more than 25 stations) with the HK-algorithm, secondly compare these series to the Bergman-Slob/Monna (BSM) series and to the conclusions of Hinssen (2006) and Hinssen and Knap (2007) and decide (when HK is acceptable) on replacing BSM by HK and in the end communicate details to users.

Contents

Chapter 1

Introduction

On October 12th 2009 the KNMI-group Tactisch Overleg Waarnemingen decided on the implementation of the improved algorithm on calculation of sunshine duration (called Hinssen-Knap-linear algorithm or HK-algorithm). The TOW-decision was based on the scientific report and article "Comparison of different methods for the determination of sunshine duration" [Hinssen, 2006] and "Comparison of Pyranometric and Pyrheliometric Methods for the Determination of Sunshine Duration"[Hinssen and Knap, 2007].

Relevant parts for the introduction of the different methods for the calculation of sunshine duration are quoted in this implementation report and internal and external operational and communicational aspects of the implementation are discussed.

The team responsible for the introduction of the improved algorithm started on April 15th, 2010 and consists of Wouter Knap, Rob Sluijter, Rudmer Jilderda and Geert Groen (projectleader). In due time the team changed, Knap was succeeded by Piet Stammes.

In our first meeting we discussed the main topics:

- Until October 1st 1992 sunshine duration was determined by subjective analysis of the cards of the Campbell-Stokes recorder.
- Since October 1st 1992 sunshine duration was calculated from global radiation measured by the pyranometer (Kipp & Zonen CM 11 solarimeter). This instrument is being used at all KNMI automatic weather stations in the Netherlands.
- Climatological series for sunshine duration (in climatological KIS-database) are based on global radiation measurements (via CIBIL) with the Slob/Monna algorithm, but ajusted by Bergman in order to get a better agreement with the Campbell-Stokes registration [Bergman, 1993]).
- Based on direct normal solar irradiance measured by a pyrheliometer at the Cabauw Baseline Surface Radiation Network site, Hinssen-Knap introduced in 2006 two methods to calculate sunshine duration from global radiation: a (preferred) direct "linear correlation algorithm" and an improved Slob/Monna algorithm. [Hinssen and Knap, 2007].
- Comparison of monthly and seasonal sunshine duration of the Bergman-Slob/Monna (BSM) to direct measurements (suntracker or pyrheliometric method) and to both HK-algorithms is shown in figure 1 (figure 6.10 in [Hinssen, 2006]).

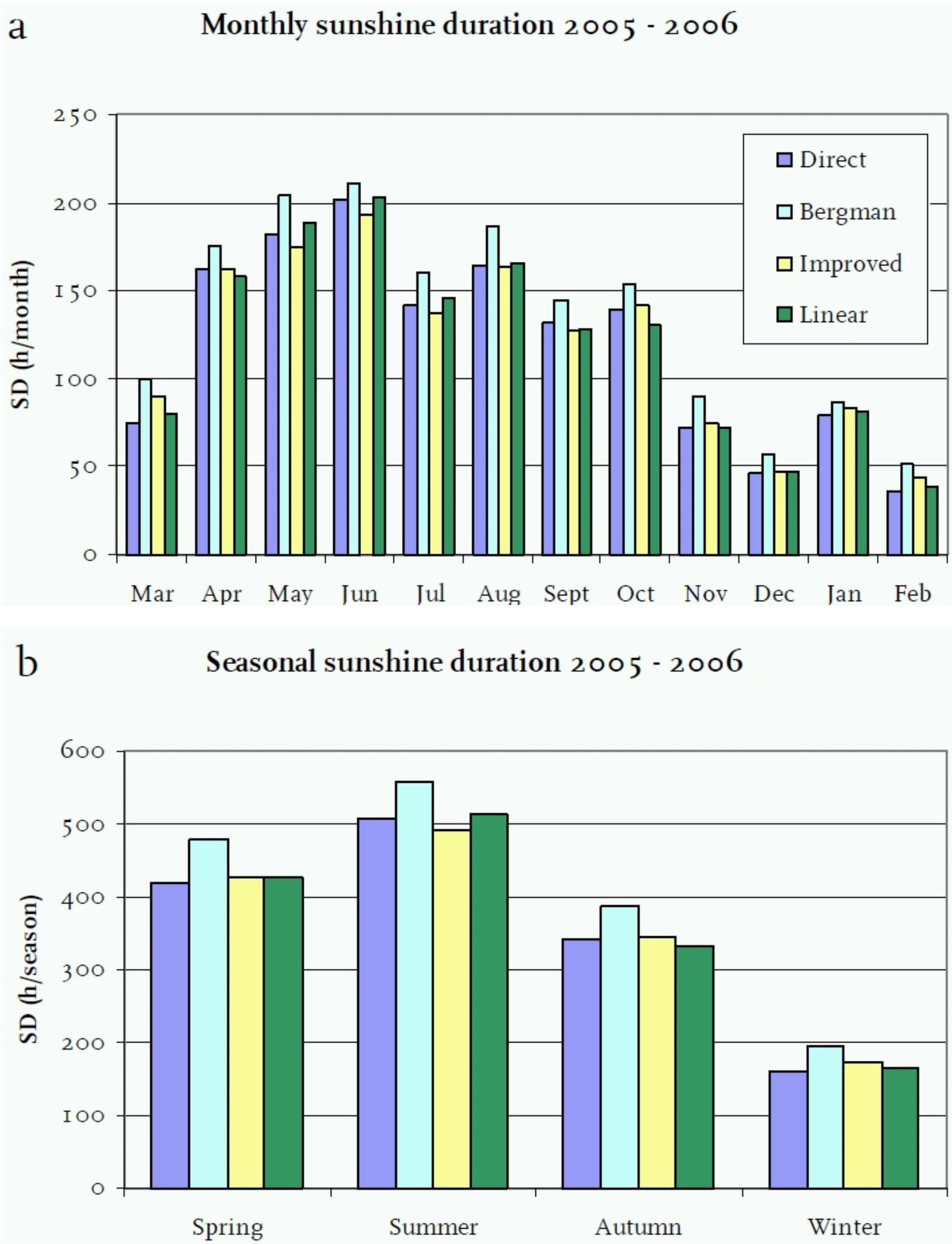


Figure 1. Comparison of sunshine duration from direct measurements and three algorithms for month (b) and seasomn (b), Bergman-Slob/Monna, Hinssen/Knap improved and Hinssen/Knap linear. Hinssen concludes that the linear algorithm is the best compared to direct measurements with the suntracker.

- In KIS, the climatological database, three tables are stored: global radiation (Q-table), sunshine duration Campbell-Stokes (SH-table, ended 1992) and sunshine duration based on Bergman-Slob/Monna (SQ-table). Details of these KIS-tables are mentioned in chapter 3.

- Some external users (providers like MeteoConsult) of sunshine duration receive receive sunshine duration based on global radiation measurements, using the original Slob-Monna algorithm (personal communication, van Oel) [Slob and Monna, 1991].

- Tactisch Overleg Waarnemingen (TOW) decided in 2009 on applying the Hinssen-Knap linear correlation algorithm. From their meeting regarding this aspect it has been noted: "Implementation new sunshine duration algorithm: The new algorithm is an improvement but may cause differences to present series up to 13%. KA should take care of the implementation, TOW requests preparation before decision on implementation."

- Sunshine duration climatology in Klimaatatlas 1981-2010 is created from a mixed set, SH and SQ (Bergman and CampbellStokes) are used for climatological series of shunshine duration like in Klimaatatlas 1971-2000 (reference method in Handboek Waarnemingen) [Heijboer and Nellestijn (2002)] [Handboek waarnemingen].

- Klimaatatlas 1981-2010 explains in Dutch: "In principe publiceert het KNMI geen normalen indien er in de 30-jarige reeks een significante breuk aanwezig is, bijvoorbeeld als gevolg van een verandering in het gebruikte instrumentarium. Tot 1 oktober 1992 werd de duur van de zonneschijn geregistreerd met de zonneschijnautograaf van Campell-Stokes. Dit instrument kende een aantal tekortkomingen, en mede op basis van een advies van de WMO wordt het aantal uren zonneschijn sinds 1 oktober 1992 berekend uit gegevens van de globale straling volgens een op het KNMI ontwikkelde techniek. Omdat voor 1992 niet alle gegevens voor dit algoritme aanwezig zijn, kon de reeks met berekende zonneschijnduur niet naar het verleden worden uitgebreid. Dit betekent dat voor het tijdvak 1981-2010 samengestelde reeksen van de zonneschijnduur moeten worden gebruikt. Aangezien op het station De Bilt de registraties met het Campell-Stokes instrument nog een aantal jaren zijn voortgezet, kan voor dit station een indruk worden verkregen van de verschillen tussen beide methodes. In de wintermaanden blijkt dat de met het algoritme bepaalde waarden voor de zonneschijnduur ca. 15% hoger lagen dan die verkregen met de zonneschijnautograaf. In de zomermaanden geeft de zonneschijnautograaf ca. 7% hogere waarden. Over het hele jaar gezien is het verschil verwaarloosbaar. Bij het vergelijken van de nieuwe normaalperiode 1981-2010 met de oude periode 1971-2000 speelt de overgang naar de nieuwe meetmethodiek in 1992 ook een rol. De nieuwe periode bevat ca. 18 jaar metingen met de nieuwe methodiek, terwijl dat in de oude periode slechts 8 jaar zijn. Op basis van de overgang in methodiek alleen, zal de zonneschijnduur in De Bilt in de wintermaanden (DJF) in 1981-2010 periode ca. 4 uur/maand groter zijn dan die in de 1971-2000 periode. Voor de zomermaanden (JJA) geeft dat een zonneschijnduur in de 1981-2010 periode die 5 uur/maand kleiner is dan in de 1971-2000 periode".

Chapter 2

Scientific background

2.1 Definition

WMO defines sunshine duration as: "Sunshine duration during a given period is defined as the sum of that sub-period for which the direct solar irradiance exceeds 120 $\frac{W}{m^2}$" [WMO-guide, 1996].

Hours of sunshine should be measured with an uncertainty of ± 0.1 h and a resolution of 0.1 h.

2.2 Hinssen and Knap

Several methods for the determination of sunshine duration from solar radiation measurements have been studied and compared by Hinssen and Knap, like the pyrheliometric method, pyranometric method and CampbellStokes.

The pyrheliometric method is based on measurements of the direct solar irradiance, made with a pyrheliometer mounted on a sun tracker. The pyranometric method is based on measurements of global solar irradiance with a pyranometer and (parameterized) estimates of the direct and diffuse irradiance. The measured difference between the minimum and maximum value of the global irradiance during a 10-minute interval is used to determine whether or not there is a temporary eclipse of the sun by clouds. The method is referred to as pyranometric method.

The pyranometric method was originally designed by Slob and Monna [Slob and Monna, 1991]. According to these authors, the uncertainty is about 0.6 h for daily sums of sunshine duration. Two variations of the original Slob-Monna-algorithm were also considered. For historical reasons, Bergman [Bergman, 1993] adjusted the original algorithm to find more agreement with sunshine duration values derived from the traditional Campbell- Stokes sunshine recorder. This adjusted algorithm is operationally used by KNMI to estimate the sunshine duration for a network of 32 meteorological stations in the Netherlands. Schipper [Schipper, 2004] adjusted the original algorithm to find more agreement with the pyrheliometric sunshine duration.

From one year of measurements at Cabauw (March 2005 to February 2006) the comparison between these two methods was done. The pyrheliometric method gives the cumulative sunshine duration of 1429 hours. This deviates from the yearly averaged sunshine duration over the Netherlands (1534 h for the period 1971-2000) because 41 days were omitted from the analysis, due to problems with the data acquisition system, power loss or sun-tracking problems on these days.

The three pyranometric methods give 1357 hours (Slob-Monna algorithm), 1620 hours (Bergman algorithm), and 1546 hours (Schipper algorithm). The differences between the pyranometric and pyrheliometric values are thus considerable: -72 h, +191 h, and +117 h, respectively, or, expressed as a percentage of the pyrheliometric sunshine duration, -5%, +13% and 8%. On a daily average basis, the differences amount to -0.22 +/- 0.05 h/d, +0.59 +/- 0.04 h/d, and +0.36 +/- 0.06 h/d. It thus appears that the original pyranometric method, designed by Slob and Monna, gives yearly cumulative and daily average values for the sunshine duration which are closest to trueh (WMO) sunshine duration.

The algorithm that is operationally used by KNMI (Bergman algorithm) significantly overestimates the true sunshine duration. This is not surprising because this algorithm has been tuned to the sunshine duration obtained by the Campbell-Stokes sunshine recorder. The Campbell-Stokes measurements are rather uncertain and tend to overestimate the sunshine duration, especially during broken-cloud conditions. The Schipper algorithm does not improve the original algorithm, in terms of yearly cumulative sunshine duration, but also in terms of daily totals, since the variations in the differences per day are found to be largest for the Schipper algorithm.

2.3 Improved operational method?

Given the large yearly difference in sunshine duration between the operational algorithm and the pyrheliometric method, improvement of the pyranometric method is desired. Hinssen and Knap investigated the possibility of improving the operational algorithm by means of a sensitivity analysis, in which the parameterizations as used in the algorithm are varied.

Solar radiation measurements are used as basis for the new parameterizations, after which the parameterized estimates of clear-sky direct and diffuse irradiance are tuned to the pyrheliometric sunshine duration. It appears that with adjustments of the atmospheric turbidity and parameterized diffuse irradiance closer agreement with the true sunshine duration can be obtained: with this improved algorithm the yearly cumulative sunshine duration becomes 1436 h. The difference between the pyranometric method using this improved algorithm and the pyrheliometric method reduces to only +7 h (0.5% of the pyrheliometric sunshine duration) for the whole period, and 0.02 +/- 0.04 h/d on daily average basis. At this point the improved algorithm thus performs much better than the operational algorithm. On daily basis, the improved algorithm is, however, still overestimating the sunshine duration for small solar elevation angles and underestimation is found for the larger solar elevation angles.

2.4 New algorithm!

Although the improved algorithm performs rather well, Hinssen and Knap also investigated the possibility of a completely different algorithm, in which the global radiation is directly related to sunshine duration. This algorithm consists of a lower limit for the global radiation below which periods are completely cloudy and an upper limit for the global radiation above which periods are completely sunny. For the global radiation between the lower and upper limit, the sunshine duration is linearly related to the global radiation, which is why we will call this the linear algorithm. The algorithm distinguishes between two different solar elevation angle intervals ($\mu_0 < 0.3$ and $\mu_0 \geq 0.3$), with different values for the lower and upper limits, since for smaller solar elevation angles better results are obtained if lower values are chosen for the lower and upper limits. The algorithm is optimized with respect to the pyrheliometric sunshine duration by variation of the upper and lower limits, resulting in a cumulative sunshine duration of 1437 h. This gives a cumulative difference of +8 h (0.6% of the pyrheliometric sunshine duration) between the pyranometric method using the linear algorithm and the pyrheliometric method, and a difference of 0.03 +/-0.03 h/d on daily average basis.

This means that, on yearly basis, the linear algorithm performs equally well and are both improvements compared to the original and the operational algorithm. However, the linear algorithm does not overestimate the sunshine duration for small solar elevation angles or overestimate the sunshine duration for larger solar elevation angles, meaning that the diurnal variations in sunshine duration are better represented by the linear algorithm, so that on daily basis it performs better than the improved algorithm. Compared to the improved algorithm, the linear algorithm is more transparent. The linear algorithm can therefore be adjusted more systematically, making tuning to the true sunshine duration easier.

2.5 Further research

The study of Hinssen and Knap makes it possible to obtain more accurate sunshine duration estimates on the basis of global radiation measurements. By using either the linear algorithm instead of the operational (KNMI) algorithm, the overestimation of the sunshine duration by the pyranometric, compared to the pyrheliometric method, can be reduced from 13% to only 0.6%, on yearly basis. The current analysis of sunshine duration determination is based on a one-year dataset. A recommendation for future research is therefore to apply the linear algorithm to a multi-year dataset, to study whether the linear algorithm is still the best algorithm to use in the pyranometric method to estimate the sunshine duration from global radiation measurements.

Hinssen and Knap recommend to process and archive at KNMI two sunshine duration products:

- a product that is generated only for the purpose of continuation of the Campbell-Stokes record of sunshine duration. For this product, the currently operational algorithm should be used.
- a product that gives best agreement with the WMO definition of sunshine duration. It is suggested that only this product is used for external purposes, such as seasonal or annual overviews of the sunshine duration and tourism. For this product the linear algorithm can be used, giving better estimates of the sunshine duration. However, it is desirable to evaluate the algorithm with additional measurements made at e.g. the Cabauw BSRN site.

2.6 Summary of the Hinssen-Knap linear algorithm

From the article (in which the linear algorithm is referred to as the correlation algorithm) of Hinssen and Knap [Hinssen and Knap, 2007] (symbols and acronyms in the hext section):

In the Earth's atmosphere, radiation is partly absorbed and scattered by air molecules, clouds and other particles in the atmosphere. The radiation that reaches the surface consists of a direct normal component (I) from the direction of the sun and a diffuse component (D) from all other directions. The global radiation (G) on a horizontal surface is partitioned into a direct and diffuse component: $G = \mu_0 I + D$, where $\mu_0 = cos(\theta_0) = sin(\gamma_0)$, in which θ_0 is the solar zenith angle and γ_0 the solar elevation angle (figure 2).

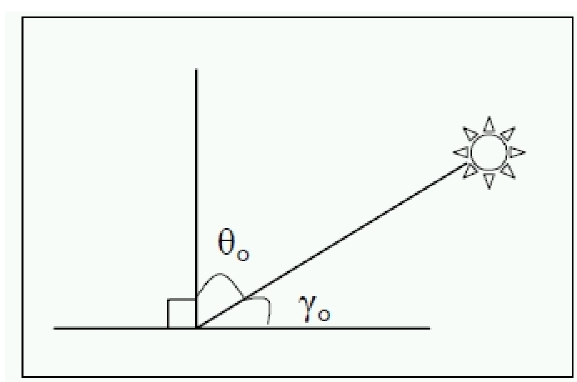


Figure 2. θ_0 is the solar zenith angle and γ_0 is the solar elevation angle.

The correlation algorithm is based on a direct correlation between pyrheliometric values of f (derived from summation of sunshine seconds) and 10-min mean values of the normalized global irradiance G/G_0. The algorithm consists of a lower limit (l) for G/G_0 below which there is no sunshine ($f = 0$) and an upper limit (u) above which 10-min intervals are labeled as completely sunny ($f = 1$). Between the limits, the sunshine duration is linearly related to the normalized global irradiance (figure 3).

The algorithm distinguishes between two different μ_0 intervals ($0 \leq \mu_0$ <*0.3 and* $\mu_0 \geq$ *0.3*), because measurements showed that l and u are lower for smaller solar elevation angles. For the measurements considered, the best results are obtained for a separation at μ_0 =*0.3*.

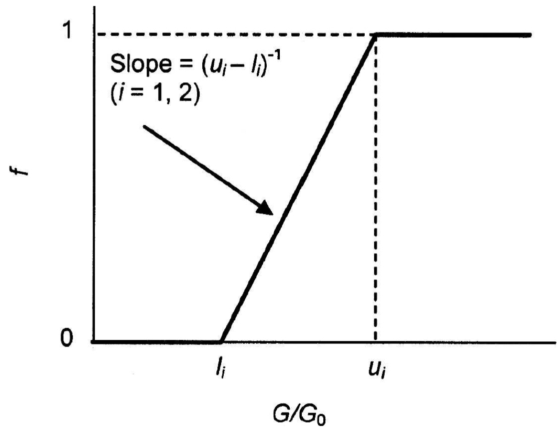


Figure 3. Schematic representation of the linear algorithm for the estimation of sunshine duration from global irradiance measurements. On the vertical axis the fractional sunshine duration (f) is given; on the horizontal axis the normalized global irradiance is given (G/G_0). The lower limit for G/G_0 below which $f = 0$ is indicated by l_i; the upper limit for G/G_0above which $f = 1$ is indicated by u_i. The index i indicates a separation for 0 in two intervals: < 0.3 *and* ≥ 0.3.

The functional form of the correlation algorithm is is given by the following equation [Hinssen and Knap, 2007], equation 4:

For $0 \leq \mu_0 < 0.3$*:*	*For* $\mu \geq 0.3$*:*
$G/G_o < l_1 \rightarrow= 0$	$G/G_o < l_2 \rightarrow f = 0$
$l_1 \leq G/G_o < u_1 \rightarrow f = (G/G_0 - l_1)(u_1 - l_1)^{-1}$	$l_2 \leq G/G_o < u_2 \rightarrow f = (G/G_0 - l_2)(u_2 - l_{12})^{-1}$
$G/G_o \geq u_1 \rightarrow f = 1$	$G/G_o \geq u_2 \rightarrow f = 1$
Advice HK: $l_1 = 0.4$, $u_1 = 0.5$	Advice HK: $l_2 = 0.45$, $u_2 = 0.6$.

The algorithm was applied to every 10-min interval, but now only the mean measured global irradiance is needed. The sunshine duration (in minutes per 10- min interval) was again obtained by multiplying the fractional sunshine duration (f) by 10.

After optimization of the algorithm by variation of the lower and upper limits Hinssen advises for the parameters $l_1 = 0.4$, $u_1 = 0.5$, $l_2 = 0.45$, $u_2 = 0.6$. [Hinssen and Knap, 2007]

Chapter 3

KIS-tables

In the climatological database KIS tables (like table 1) with hour-data are available for several stations with the elements global radiation (Q), sunshine-duration based on Campbell-Stokes (SH) and sunshine-duration based on Bergman-Slob/Monna (SQ). Main stations (with station numder) are shown in figure 4.

Figure 4. Main observing stations in the Netherlands

Station	Element	Startdate	Stopdate	Station	Element	Startdate	Stopdate	Station	Element	Startdate	Stopdate
17	Q	19810611	19891231	8	SH	19801001	19811231	17	SQ	19820401	19920930
210	Q	19870325	99999999	17	SH	19820401	19920930	210	SQ	19510901	99999999
235	Q	19641101	99999999	33	SH	19810101	19901231	235	SQ	19080901	99999999
240	Q	19870911	99999999	41	SH	19820501	19900410	240	SQ	19630101	99999999
244	Q	19910212	19960801	128	SH	19810630	19911231	244	SQ	19910227	19960801
247	Q	19941228	20010601	135	SH	19801002	19920930	247	SQ	19941228	20010601
249	Q	19990315	99999999	153	SH	19801003	19911231	249	SQ	19990315	99999999
251	Q	19940526	99999999	166	SH	19801001	19911231	251	SQ	19940526	99999999
257	Q	20010430	99999999	210	SH	19510901	19911231	257	SQ	20010430	99999999
260	Q	19570701	99999999	235	SH	19080901	19911231	260	SQ	19010101	99999999
263	Q	20010417	20020515	240	SH	19630101	19930409	263	SQ	20010417	20020515
265	Q	19931007	20081118	244	SH	19910227	19930410	265	SQ	19931007	20081118
267	Q	19930819	99999999	250	SH	19710101	19911231	267	SQ	19930819	99999999
269	Q	19900117	99999999	260	SH	19010101	99999999	269	SQ	19910227	99999999
270	Q	19870422	99999999	263	SH	20010417	20020515	270	SQ	19550901	99999999
273	Q	19930922	99999999	269	SH	19910227	19930410	273	SQ	19930922	99999999
275	Q	19870410	99999999	270	SH	19550901	19921031	275	SQ	19630101	99999999
277	Q	19910318	99999999	275	SH	19630101	19930410	277	SQ	19910318	99999999
278	Q	19930716	99999999	277	SH	19910318	19930410	278	SQ	19930716	99999999
279	Q	19891013	99999999	279	SH	19910227	19930409	279	SQ	19910227	99999999
280	Q	19650101	99999999	280	SH	19060101	19911231	280	SQ	19060101	99999999
283	Q	19891017	99999999	283	SH	19910227	19930409	283	SQ	19910227	99999999
286	Q	19900117	99999999	286	SH	19910227	19930409	286	SQ	19910227	99999999
290	Q	19870416	99999999	290	SH	19710101	19921031	290	SQ	19710101	99999999
310	Q	19630701	99999999	310	SH	19070101	19911231	310	SQ	19940713	99999999
319	Q	19910625	99999999	319	SH	19910625	19930409	310	SQ	19070101	19940131
323	Q	19891105	99999999	323	SH	19910227	19930409	319	SQ	19910625	99999999
330	Q	19950801	99999999	325	SH	19710101	19880430	323	SQ	19910227	99999999
344	Q	19870911	99999999	344	SH	19780101	19930409	330	SQ	19950801	99999999
348	Q	19860810	99999999	350	SH	19511101	19921031	344	SQ	19780101	99999999
350	Q	19870403	99999999	356	SH	19910227	19930409	348	SQ	19970227	99999999
356	Q	19900305	99999999	370	SH	19780101	19930409	350	SQ	19511101	99999999
				375	SH	19930101	19930409				
				380	SH	19060101	19911231				

Table 1: Climatological stations with global radiation measuremenets

and calculated sunshine duration from two methods, Campbell-Stokes and Bergman-Slob/Monna.

Chapter 4

Actions

1. Retrieve code HK-algorithm and test the code for a limited set of Hinssen-Knap (2007) (incl. comparison to the WMO-pyrheliometric method), action Piet Stammes (TBD= to be decided)

2. Create a seperate KIS-table with hourly sunshine duration from HK-algorithm for all stations and periods for which global radiation is stored, action Rob Sluijter (TBD).

3. Compare these series with Bergman-Slob/Monna (>25 stations, about 20 years or more) for comparison in order to communicate on the changes to other series of sunshine duration. action Dirk Wolters (TBD).

4. Decision (by TOW) whether both series (BSM and HK) have to be maintained, action Theo Brandsma (TBD).

5. Complete this report with the comparison conclusions and clear figures to inform providers and external and internal users about reason, background and consequenses of the changes in the calculation of sunshine duration, action Geert Groen or Dirk Wolters (TBD).

6. create KD-brochure, NaderVerklaard, meta-information in KIS, adjust chapter 8 in Handboek-Waarnemingen, Meteorologica and Weerspiegel, action Rob Sluijter (TBD).

Bibliography

[Bergman, 1993] Bergman, U.: Het programma voor berekening van zonneschijnduur uit globale straling.
Technische Rapporten; TR – 158. KNMI, De Bilt (1993).

[Handboek waarnemingen] Handboek waarnemingen, KNMI.
Internet: http://www.knmi.nl/samenw/hawa/download.html

[Heijboer and Nellestijn (2002)] Heijboer, D., and J. Nellestijn (ed): Klimaatatlas van Nederland (Climate Atlas of the Netherlands). KNMI, 2002.

[Hinssen, 2006] Hinssen, Y.B.L.: Comparison of different methods for the determination of sunshine duration, WR2006-06, KNMI (Internet: http://www.knmi.nl/bibliotheek/knmipubWR/WR2006-06.pdf)

[Hinssen and Knap, 2007] Hinssen, Y.B.L., Knap, W.H.: Comparison of Pyranometric and Pyrheliometric Methods for the Determination of Sunshine Duration. Journmal of atmospheric and oceanic technology, vol. 24, 835-846, 2007.

[Schipper, 2004] Schipper, J.: Vergelijking van diverse methodes voor de berekening van zonneschijnduur uit globale straling.
Technisch Rapport; TR – 258. KNMI, De Bilt (2004).

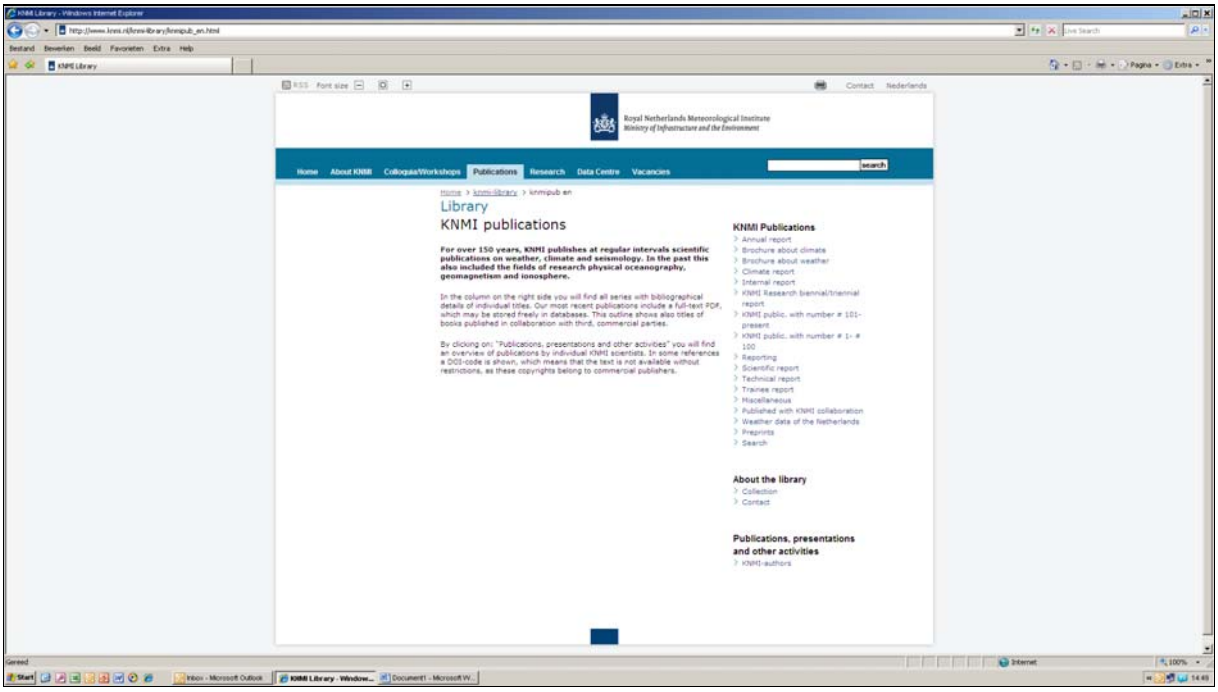
[Slob and Monna, 1991] Slob, W.H. and W.A.A. Monna.: Bepaling van directe en diffuse straling en van zonneschijnduur uit 10-minuutwaarden van de globale straling.
Technische Rapporten; TR – 136. KNMI, De Bilt (1991).

[Velds, 1996] Velds, C.A.: Zonnestraling in Nederland.
Thieme/KNMI, Baarn/De Bilt (1992).

[WMO-guide, 1996] WMO Guide to Meteorological Instruments and Methods of Observation.
Sixth Edition (Chapter 7 and 8) (1996).

A complete list of all KNMI-publications (1854 – present) can be found on our website

www.knmi.nl/knmi-library/knmipub_en.html



The most recent reports are available as a PDF on this site.