Darkness monitoring in the Netherlands, 2009-2019

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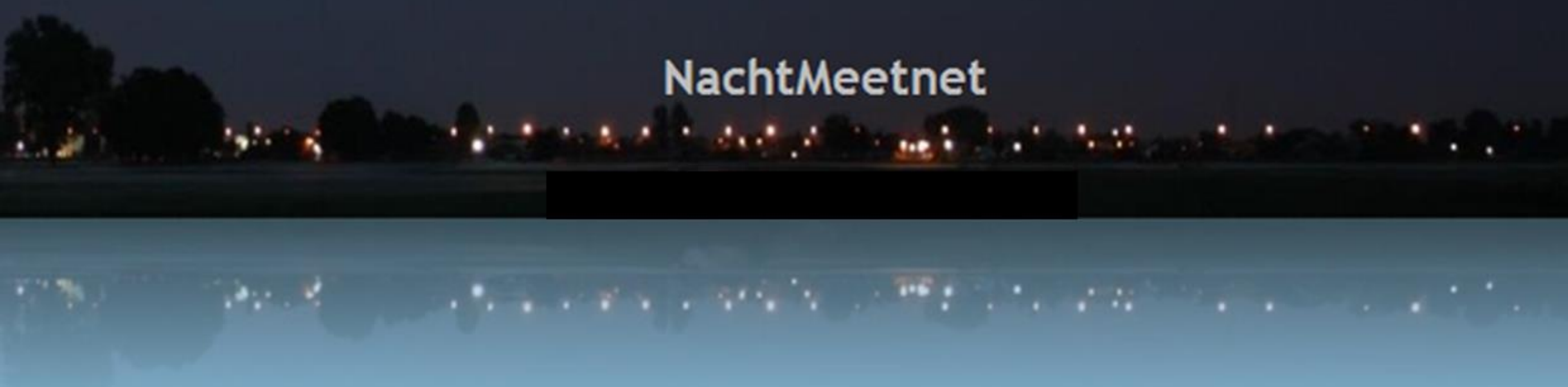

COLOPHON

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ABSTRACT

Between 2009 and 2019 a research program has been carried out on the development of the darkness in the Netherlands. During this period measuring devices, so-called SQM's, were installed at 15 locations, which measured the amount of light, coming from the sky at night.

Nearly every year an intercalibration has been conducted in which all SQM's were located at the same location and compared to an annually calibrated low light level meter (Digilum).

This intercalibration of the SQM's showed that most of the SQM's were getting less sensitive every year. We corrected all the 27 million measurements performed in the 10 year period for this decline of sensitivity.

To exclude light from natural light sources such as the moon and sun only measurements were used with the moon under the horizon and the sun more than 18 degrees under the horizon.

The main result of this research is the trend analysis of the darkness in the period between 2009 and 2019. We found a range between -3% per year to 16% per year. The mean of the all the trends at the individual measuring locations was a 0.6% increase of night sky brightness per year with a uncertainty of 0.8%.

The sky brightness is highest during the evening and during the night the sky brightness decreased with 30% to 50%, depending on the location.

In three locations the measurements was specifically made for a program to reduce the upward light. At those locations we see indeed an upward light reduction between 2 and 7%. So these programs were effective, but are not representative for the general development of the darkness in the Netherlands.

We compared the ground based SQM measurements also with the data from the Viirs-DNB-band of the Suomi-NPP satellite, which measures the upward light coming from the earth. The correlation between both results is very good. An increase of 1% per year for the whole of the Netherlands was calculated from the satellite data, although not statistically significant. Nevertheless this value is in line with the ground based measurements.

We show a map of the change of the upward light during the last 6 years, derived from the satellite data. The map shows big regional differences.

We conclude that the yearly increase in the Netherlands between 3% and 5% per year in the 20th century is not continued. In general we have a stabilization of the upward light when we compare it with the change in population or the Bruto National Product.

SAMENVATTING

Tussen 2009 en 2019 is onderzoek gedaan naar de ontwikkeling van de duisternis in Nederland. Gedurende deze periode is op 15 locaties meetapparatuur, zogenaamde SQM's, geïnstalleerd die de hoeveelheid licht meten die 's nachts van de hemel komt.

Bijna elk jaar is een interkalibratie uitgevoerd waarbij alle SQM's op dezelfde locatie stonden en vergeleken werden met een jaarlijks gekalibreerde low light meter (Digilum). Deze interkalibratie van de SQM's toonde aan dat de meeste SQM's elk jaar minder gevoelig werden.

We hebben alle 27 miljoen metingen, uitgevoerd in de periode van 10 jaar, gecorrigeerd voor deze afname van de gevoeligheid van de SQM's. Om licht van natuurlijke lichtbronnen zoals de maan en de zon uit te sluiten, werden alleen metingen gebruikt met de maan onder de horizon en de zon meer dan 18 graden onder de horizon.

Het belangrijkste resultaat van dit onderzoek is de trendanalyse van de duisternis in de periode tussen 2009 en 2019. We vonden een range tussen -3% per jaar en 16% per jaar. Het gemiddelde van de meest betrouwbare trends op de meetlocaties was een 0,6% toename van licht per jaar met een onzekerheid van 0,8%.

De hemelhelderheid is 's avonds het hoogst en' s nachts neemt de hemelhelderheid af met 30% tot 50%, afhankelijk van de locatie.

Op drie locaties zijn metingen uitgevoerd om het effect van maatregelen voor de reductie van opwaarts licht (ter voorkoming van lichtvervuiling) vast te stellen. Op deze drie locaties zien we inderdaad een reductie van 2% tot 7% van opwaarts licht. De maatregelen zijn dus effectief, maar zijn niet representatief voor de ontwikkeling van de duisternis in Nederland.

We vergeleken de metingen ook met de gegevens van de Viirs-DNB-band van de Suomi-NPP satelliet, die het opwaartse licht van de aarde meet. De correlatie tussen beide resultaten is erg goed.

Voor heel Nederland is uit de satelliet data een stijging van 1% per jaar berekend, alhoewel statistisch niet significant. Desondanks is deze waarde in lijn met de metingen vanaf de grond.

We laten een kaart zien van de verandering van het opwaartse licht in de afgelopen 6 jaar, afgeleid van de satellietgegevens. De kaart laat grote regionale verschillen zien.

We concluderen dat de jaarlijkse stijging tussen 3% en 5% per jaar in Nederland van de 20e eeuw niet doorzet. Over het algemeen hebben we een stabilisatie van het opwaartse licht als we het vergelijken met de verandering in de bevolking of het Bruto Nationaal Product.

1 Introduction

In this report the goal, progress and the results of the NachtMeetnet monitoring network in the Netherlands are described, which was operational from 2009 till 2020.

NachtMeetnet, translatable as Night Measurements Network, has the purpose to investigate the development of the darkness in the Netherlands.

Generally it is assumed, that there was in the twentieth century a yearly increase of around 5% per year of the night sky luminance in the developed western world. It has never been investigated what the increase was in the Netherlands. We may assume it was the same value in general. NachtMeetnet's purpose is to investigate this in the beginning of the twenty first century.

This report is the final result of all the measurements, conducted between 2009 and 2019 of the darkness in the Netherlands. Measurements at ground level will be discussed as well as satellite measurements in the same period with satellites.

At the end we present some other interesting results.

2 NachtMeetnet

NachtMeetnet started in 2014. Starting in 2011 measurements were already conducted in the same way by RIVM, the National Institute for Public Health and Environment. The two founders of NachtMeetnet privately started already in 2009. So we will evaluate the performed measurements from these three periods.

Phase 1: Initial Phase;2009-2011; The investigation started with a monitoring campaign in the Netherlands in 2009 with two private meters in Utrecht and Arnhem.

Phase 2: RIVM Phase; 2011-2014; The national organization for health and environment has operated seven meters between 2011 and 2014, next to the two original meters.

Phase 3: NachtMeetnet phase; 2014-2019. The RIVM ended the research, because the funding ended. Two different private companies, owned by the owners of the two original meters has taken over the meters, and started formally NachtMeetnet, but not all meters could be kept on the same RIVM locations. So new locations and cooperating parties were found. In these years six parties cooperated with providing facilities for the meters: three provinces, Tata Steel company, the National Forestry Commission and a private astro-observatory. In this third phase in total nine measuring stations were operational. The results were online presented on a website (www.NachtMeetnet.nl).

Starting 2011 every year an intercomparison campaign was performed where all meters operated at the same time in one location for 10 to 15 days. Apart from these national campaigns we participated also in international campaigns.

3 Zenital luminance, quantity and units

NachtMeetnet is monitoring the long term development of the darkness of the Dutch nights. The zenital brightness, or technically spoken the zenital luminance, is a good measure of the darkness of the night. By measuring it every night, under all cloud conditions, with and without moon, and during a period of 10 years the long term development can be established.

The (zenital) luminance of the night sky is measured during the time the sun is less than a few degrees above the horizon, during all weather conditions including snow, moon and twilight. The measuring device with a field of view of 21 degrees and is pointed to the zenith. So the measuring device “sees” a patch of the night sky in a cone with 21 degrees.

The quantity is luminance or usually called brightness. The unit is magnitude per square arc seconds ($mag/arcsec^2$). The natural sky luminance of a clear night sky without moon and without influence of artificial light is around 22 $mag/arcsec^2$. When the sky is brighter due to artificial light the value drops. When the night sky measures 20 $mag/arcsec^2$ the Milky way is hardly visible and a 17 $mag/arcsec^2$ means only a few stars are visible.
The quantity usually used for luminance in other sciences, is candela per square meter cd/m^2. As the values of the night sky are low the milicandela per square meter (mcd/m^2) is used. The conversion of $mag/arcsec^2$ to mcd/m^2 :

$$mcd/m^2 = 108 \times 10^6 \times 10^{(-0{,}4 \times mag/arcsec^2)}$$

In the report the results are given in both units.

4 Measuring locations and equipment

During all three phases measurements have taken place at 16 locations. Only one (Utrecht) was operational at the same location from 2009 till 2019. The change from phase 2 (RIVM period) to phase 3 (NachtMeetnet) caused a lot of meters to be relocated.

Measurements are done with Unihedron’s SQM-LU. The SQM’s are all housed in a container to prevent moisture entering the device. The housings are all different, due to lack of availability of standard housings in the past. Design of the housings are adapted to local requirements. A few are erected on long poles to prevent nearby lighting shining into the device.

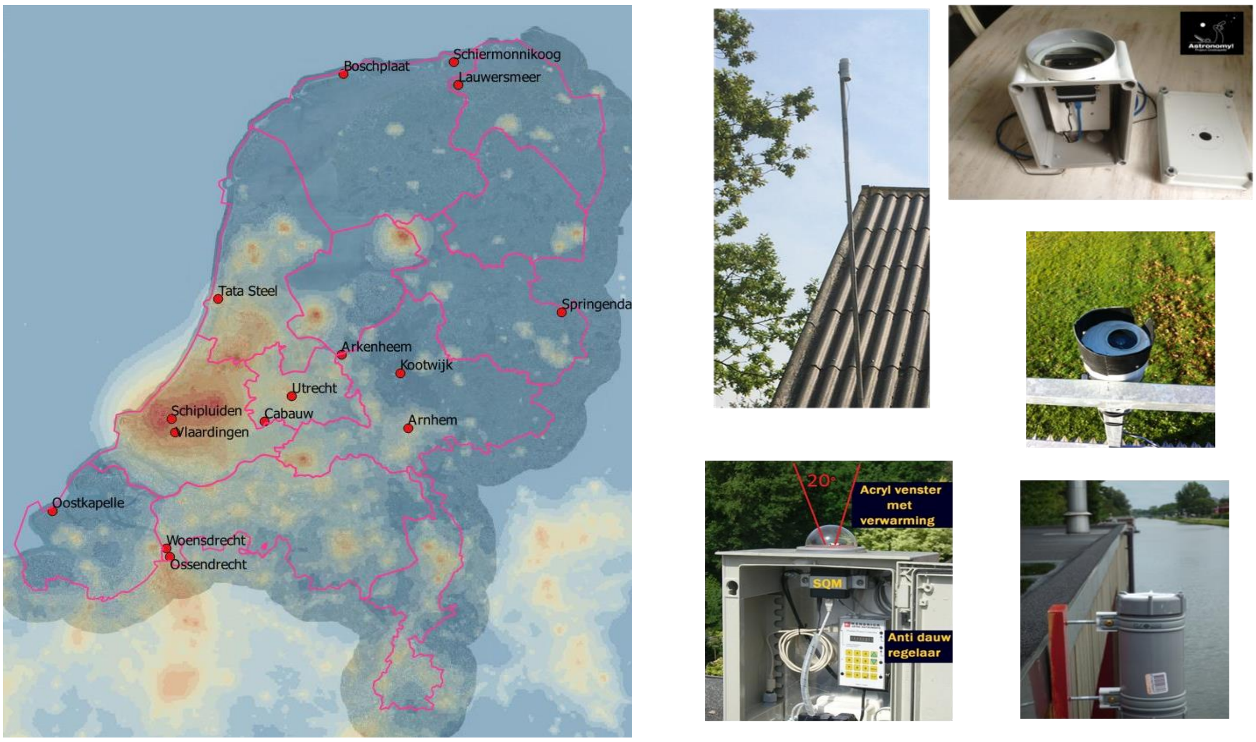


Figure 1 Locations of the meters and some meters at their location

In table 1 an overview is given of the type of location where the meters have been placed.

Table 1 Measuring location and classification

Measuring location	Type of location	Description
Arkemheen	R	Rural
Arnhem	C	At the edge of a city
Boschplaat	N	Remote natural location
Cabauw	R	Rural
Kootwijk	N	Remote natural location
Lauwersmeer	N	Remote natural location
Oostkapelle	R	Rural
Ossendrecht	C	At the edge of a small town
Schiermonnikoog	N	Remote natural location
Schipluiden	I	Near greenhouses
Springendal	N	Remote natural location
Tata Steel	I	At an industrial location
Utrecht	C	Inside a city
Vlaardingen	I	Near greenhouses
Woensdrecht	C	At the edge of a small town

One meter is a SQM-LU-DL, because there is no electricity at the chosen location. This SQM is in essence a data logger which can log 32.000 measurements. That is enough for more than 7 months of data. Every 4 months the data are read out and its batteries replaced.

The SQM-LU's 's are each connected to it's own industrial computer with local data storage. The computers are connected to the internet (through LAN, WIFI or a GSM-dongle). A reading is performed every 10 seconds. Once a day a graph of the measurements of the last day was uploaded to a central website, which is accessible to everyone: www.NachtMeetnet.nl. The locally stored data are downloaded every three weeks.

Figure 2 shows an example of a night with measurements. Left axis the units in mcd/m^2 and at the right the scale in mag/arcsec^2. The time in UT is on the horizontal axis.

Figure 2 Measurements in one location during one night

The green line shows the measurements, while the blue and red line indicates the

theoretical value without artificial lighting. The red line gives the value when the moon is above the horizon; the blue line under the horizon. This is an example in winter when the nights are long in the Netherlands. The measuring equipment is checked on site every 2 months for proper functioning.

4.1 OPERATIONALITY

The meters were in principle operational every night from dusk till dawn. During the annual intercalibration (2011-2019) no measurements were made. These calibration periods took about 10 to 20 days.

Besides the planned outage of measurements, we have had several kind of problems, from theft, SQM accidentally installed upside down, moisture ingress due to leakage of the glass window, to corrosion of the cable contacts. In a few cases the SQM had to be replaced with another one. In general in more than 80 % of the time measurements were conducted.

Every 10 seconds a measurement was made and stored locally. Not all measurements can be used. In order to determine the darkness no influence of the sun or moon should be present in the measurements. Therefore only measurements conducted with the altitude of the sun <-18 degrees and the altitude of the moon <0 degrees were used.

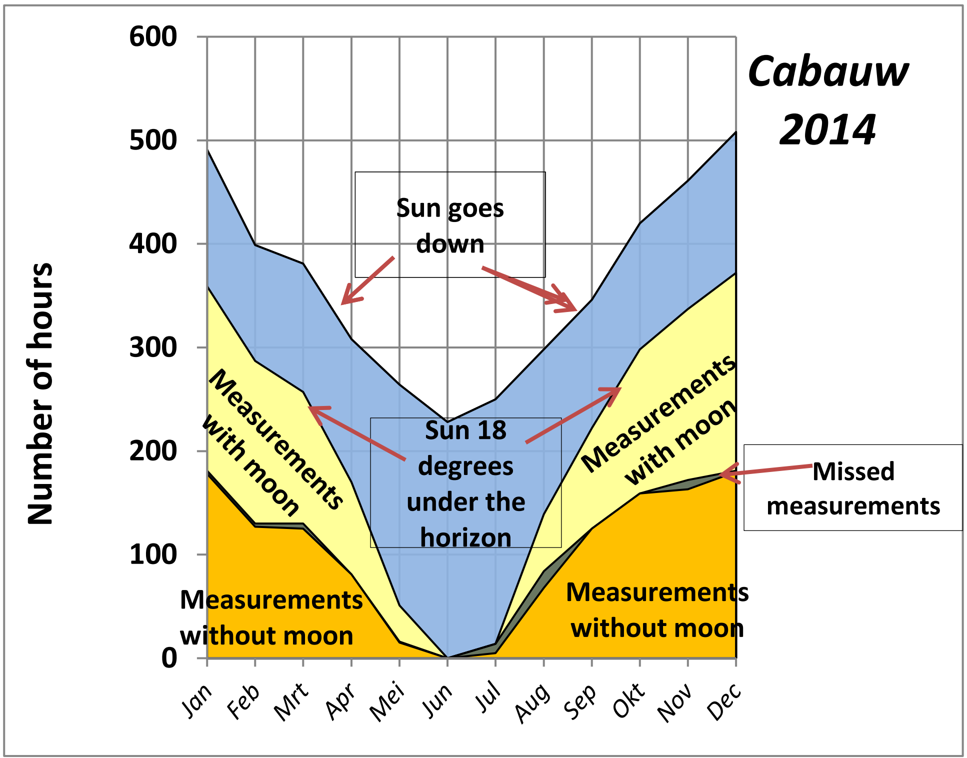


Figure 3 **Distribution of hours of measurements during the year**

In figure 3 this is graphically shown. In the blue region it is twilight, while in the light yellow regions the moon is above the horizon. Only the orange regions, with the sun more than 18 degrees under the horizon and the moon under the horizon, are used. Most used measurements are in the winter months.

In some cases two meters ran parallel at the same location for comparison reasons. A reading every 10 seconds, gives 360 measurements per hour at each location. Over the total measuring period 2009-2019 about 27 million measurements were done.

5 Calibration

5.1 INTERCOMPARISON SETUP

Starting from 2011 every year, except 2013, an annual intercomparison of the SQM's against a calibrated light meter (Digilum) was performed. All meters were setup at one and the same location measuring the night sky (the local zenithal luminance) during about ten to twenty days (see figure 4). The intercomparison periods are chosen about a week before new moon till about a week after new moon in order to gather measurements as much as possible during the darkiest skies.

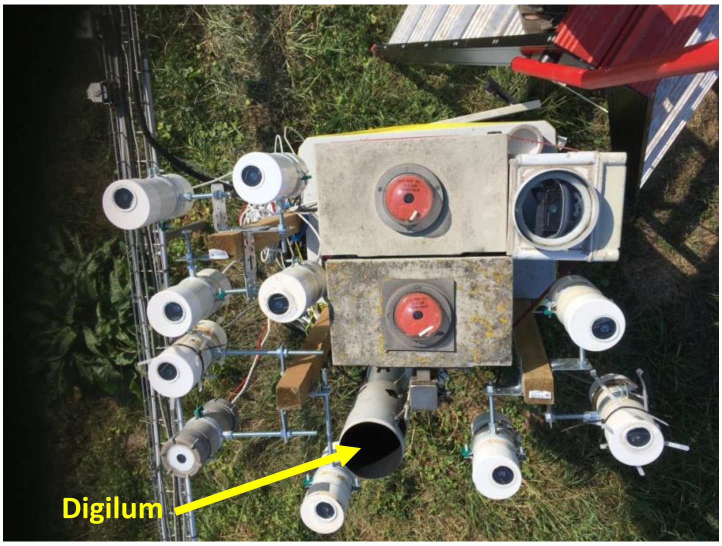


Figure 4 Setup of the Intercomparison with the SQM's at the same location

5.2 THE DIGILUM

The Digilum (see figure 5) is a for our purpose especially constructed luminance meter to measure in the low range of luminances.

The Digilum has the following technical specifications :

- Photometric sensitivity
- Temperature compensated
- Viewing angle 5°
- Linear between 0.05 and 10^7 mcd/m²
- Uncertainty 0.25 ± 0.05 mcd/m²

The Digilum was annually calibrated at the factory.

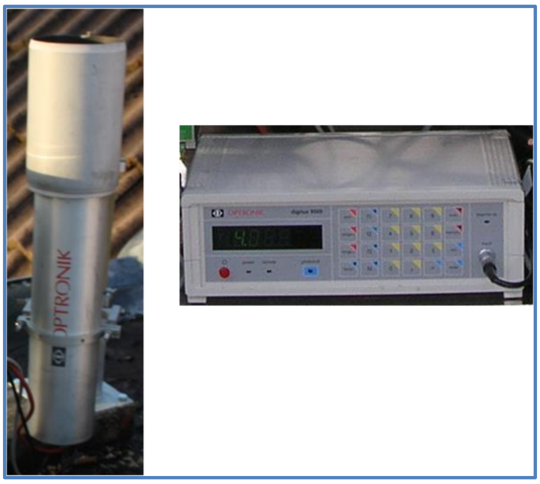


Figure 5 **The Digilum. Left: the measuring head. At the right the read out unit.**

5.3 CALIBRATION PRODCEDURE

In figure 6 (left) an example of the comparison of a SQM (blue dots) against the Digilum is shown during the intercomparison in 2018. The red line shows the 1:1 line. From left to right and from bottom to top is from dark to bright. The SQM and Digilum are more or less the same between 10 and 15 mag/arcsec^2 (in the middle of the graph), with the Digilum in general a little bit lower than the SQM. At the lower end (dark) and at the higher end (bright) the SQM measures darker than the Digilum. This non-linear response of the SQM is due to the difference in spectral response of the SQM with respect to the Digilum (photometric). At the upper right side are the measurements during dusk and dawn while, the “thick” blob at the lower end between 19.5 and 16 mags/arcsec^2 is due to measurements at clear and cloudy sky.

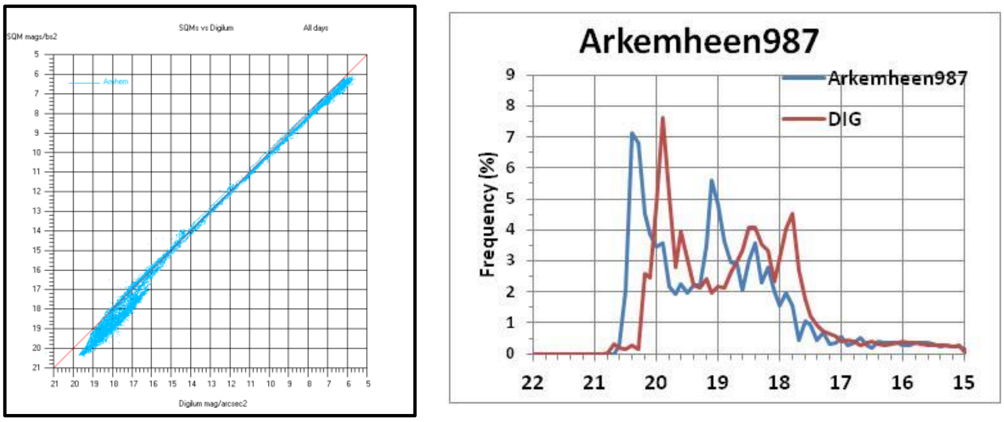


Figure 6 **Comparison measurements with Digilum and a SQM. Left: Measurements SQM versus Digilum. Right: Frequency graphs of the SQM (blue) and Digilum (red).**

At the right in figure 6 the frequency of measurements is shown of the two meters during an intercalibration. The frequency is shown in 0.2 mag/arcsec² bins. On the horizontal axis the luminance levels are shown (15 is bright and 22 is very dark) and on the vertical axis the frequency of the occurring luminance levels. The left peak is due to measurements under clear sky.

We see here also the SQM gives in general a higher value than the Digilum. We have interpretated this difference as the Digilum has been calibrated and the SQM has not and this difference grew during the years. We concluded that the SQM's are getting in the course of time less sensitive.

We have tried different methods to correct the measurements of the SQM with this difference. There are several methods possible. We chose to shift the SQM frequency data to coincide with the Digilum frequency data with the focus on the left peak (clear sky conditions).

The calibration of the SQM is done by subtracting a constant value (in mag/arcsec²) from the measured SQM values in such a way that the left SQM peak coincides with left Digilum peak. By this the SQM frequency graph shifts to the right. This constant value is then called the "calibration factor" of the SQM. The determination of the calibration factor is performed by means of a computer program by minimizing the differences in the frequency graphs of the SQM and Digilum with a resolution of 0.02 mag/arcsec² (0.02 mag/arcsec² frequency bins).

In general the coincidence of the left peak of the SQM and Digilum is very good. However towards the brighter values the match is less good. This is due to the difference in spectral sensitivity.

In the next graph the completed shift is illustrated.

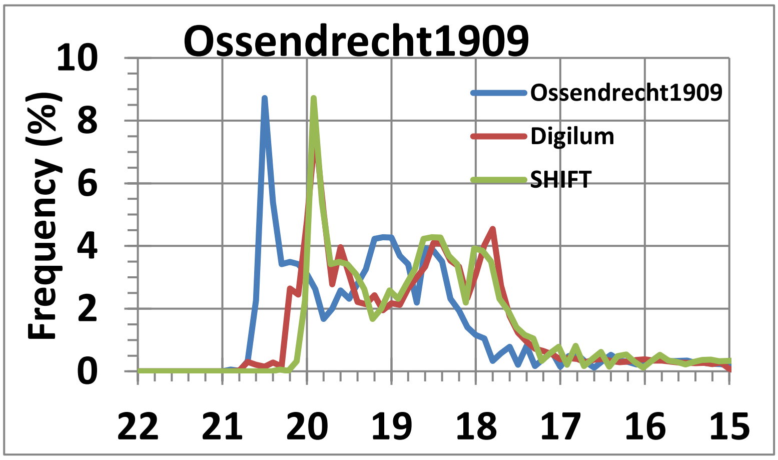


Figure 7 **Frequency graph with the Digilum (red), the SQM (blue) and the shifted (corrected) SQM (in green)**

The original SQM frequency data (in blue) has been shifted to the right by subtracting a constant value of 0.59 mag/arcsec² in such a way that the SQM frequency data coincide with the Digilum data (in red). The shifted SQM results are shown in green. The value of -0.59 mag/arcsec² means that the SQM measures darker than the Digilum. In the next figure the values for SQM 980 are shown during the period 2011-2019.

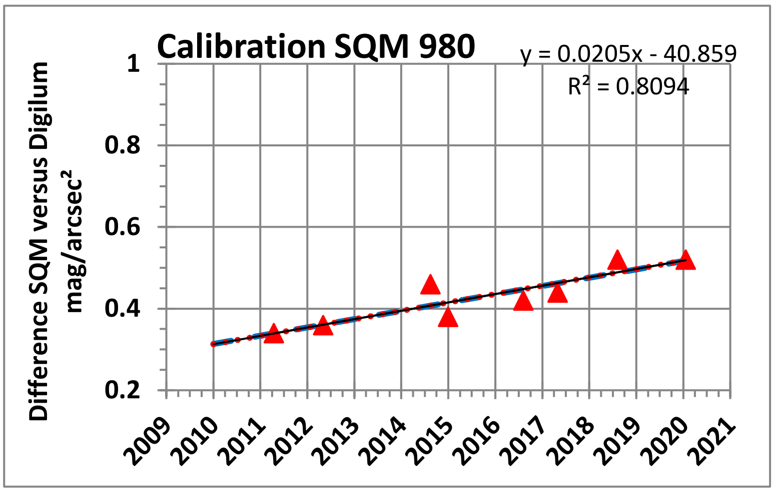


Figure 8 Deterioration of SQM 980 between 2011 and 2019

This SQM gets more insensitive during the years as most SQM's do. SQM 980 started at 0.3 mag/arcsec²and increased during the years to 0.5 mag/arcsec² in 2020.

This effect that the SQM is measuring lower (darker) than the Digilum we see in all the SQM's. The difference increased over the years and is probably caused by the deterioration of the SQM's. One of the cause for this deterioration is the darkening (browning) of the rectangular transparent cover on top of the SQM (see photo).

Figure 9 Browning of the tranparant cover of one of the SQM's

Also prolonged exposure to moisture could affect the lens. Maybe the light sensor becomes less sensitive.

As shown in figure 8 for SQM 980, we assumed since the start in 2009 a linear decline in sensitivity for all SQM's. The last years we discovered this is maybe changing. Here is an example in one of the oldest SQM's

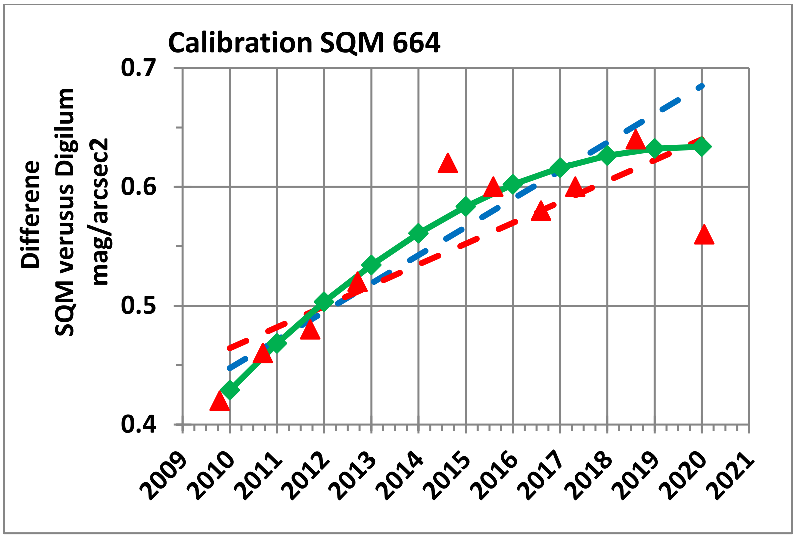


Figure 10 Sensitivity decrease of SQM 664 between 2011 and 2019

In this example we have tried different trendlines (blue and red) and a quadratic one (green) came out best. It looks as if this SQM after a certain number of years (ten) is not deteriorating anymore and stabilizing. The quadratic curve fits best for SQM 664.

We analysed all SQM's and we came for all at a different rate of decline, the most linear, one quadratic (SQM 664). For the SQM, which are short in service, we used not a linear decline, but a constant because we could not establish a linear decline yet. One meter SQM 2665 (Oostkapelle) is reacting different. We see no decline although we measured five years with this instrument. For this SQM also a constant is calculated.

In the next figure the sensitivity decline is shown for the years 2011 and 2019.

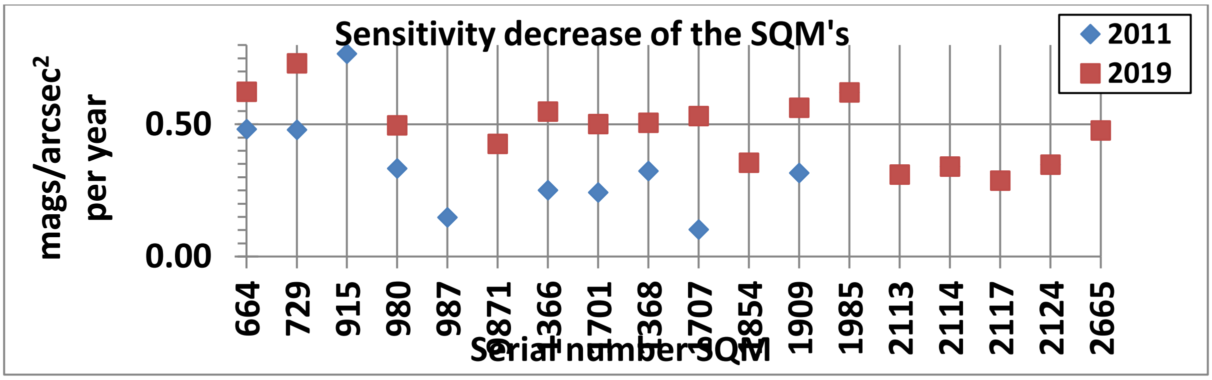


Figure 11 Sensitivity decrease of the SQM's between 2011 and 2019

The graph reads as follows: The decline in 2011 for SQM 729 is 0.48 mag/arcsec^2 and reached a value of 0.72 mag/arcsec^2 in 2019. For the SQM's 2113 and higher a constant values for all recent years are used.

The first four SQM's are calibrated more than 6 times.

All the 27 million measurements were corrected for the decline at that specific time of that specific SQM.

6 Results

The purpose of NachtMeetnet is to determine the sky brightness, caused by the artificial lighting in the environment and if possible detect an increase or decline in the night sky brightness. In order to determine this, there should be no influence of the sun or the moon. Therefore, only measurements, taken without moon and with the sun more than 18 degrees under the horizon are used. We present the results in two ways: in frequency diagrams and in numbers.

6.1 FREQUENCY DIAGRAMS

We have made frequency diagrams for all locations in each year (see Annex 1). As an example, Cabauw 2015, is shown in figure 12 (left). On the horizontal axis the night sky brightness (in two units) and vertical the relative frequency e.g. the (relative) number of times that a specific night sky brightness occurs.
Two peaks are evident: the left one represents clear sky. This is the situation in about 20% of the time.
The second peak at the right is due to the most common cloud situation in the Netherlands, with a completely covered sky, with the cloud base at about 1000-1500 meters.

At the right of figure 12, all locations in the year 2019 are shown. The relative frequencies are stacked in order to make the differences more visible. The highest peak in each (coloured) graph has a relative frequency of 1.
The lowest line is Lauwersmeer, the darkest location of NachtMeetnet. The top line is Utrecht.

What clearly can be seen is that the brighter the night sky at a location, the wider the graph. As an example: Lauwersmeer ranges from about 21.5 to 20 mags/arcsec^2. So a range of 1.5 mags/arcsec^2. And Utrecht ranges from about 19 to 14.5 mags/arcsec^2. Which is a range of 4.5 mags/ arcsec^2.

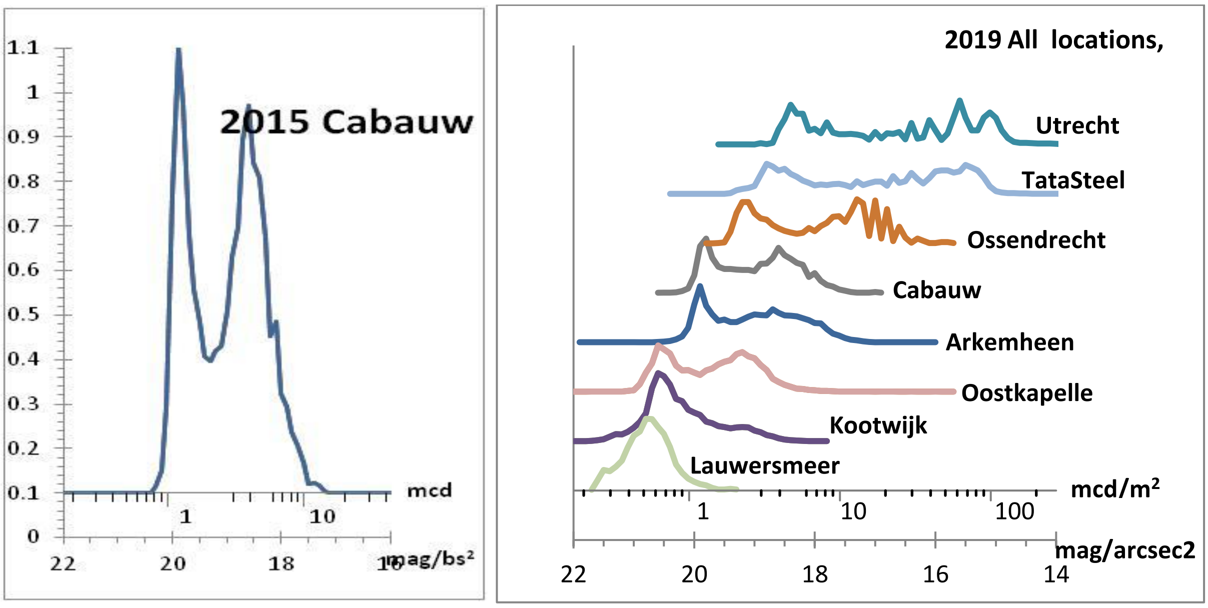


Figure 12 Frequency diagrams Left: Cabauw 2015. Right: all locations in 2019

The frequency diagrams at some locations such as Utrecht (see Annex I.2) show quite a number of peaks. This is not realistic. The frequency diagram should be more or less smooth. The peaks are due to a digital sampling effect in the SQM itself.

6.2 KEY NUMBERS AND TREND ANALYSIS

6.2.1 Key numbers

From Annex 1 with all the frequency diagrams it can be seen that the frequencies of clear skies and cloudy skies in a year fluctuates from year to year. As an example: at Cabauw in 2016 there were far more clear nights than cloudy nights. However in 2017 the number of cloudy nights was just a little more than the number of clear nights. Through this effect the median value fluctuates, so the median value is not a very reliable value to determine a change in night sky brightness over the years, as it contains also a certain amount of meteorological fluctuations (clear versus cloudy skies). So we chose not only the median (50-percentile) as a key value but chose two other key values also.

The key numbers we use are the 10-, the 50- and the 90-percentiles. In cities with a lot of light pollution, the 10- percentile is roughly the situation with a clear sky and the 90-percentile is the situation under a heavily cloudy sky. The 50-percentile is the median value.

As an example we present the results of Cabauw in figure 13.

	Uncertainty (%)		6.22
	Cabauw		
	mcd/m²		
year	10 - percentile	50 - percentile	90 - percentile
2010	1.12	2.65	6.37
2011	1.12	2.62	5.40
2012	1.15	2.75	5.49
2013	1.08	2.93	6.15
2014	1.13	2.65	5.63
2015	1.13	2.88	5.69
2016	1.07	2.17	5.30
2017	1.14	2.88	5.59
2018	1.13	2.51	6.02
2019	1.22	2.87	6.06

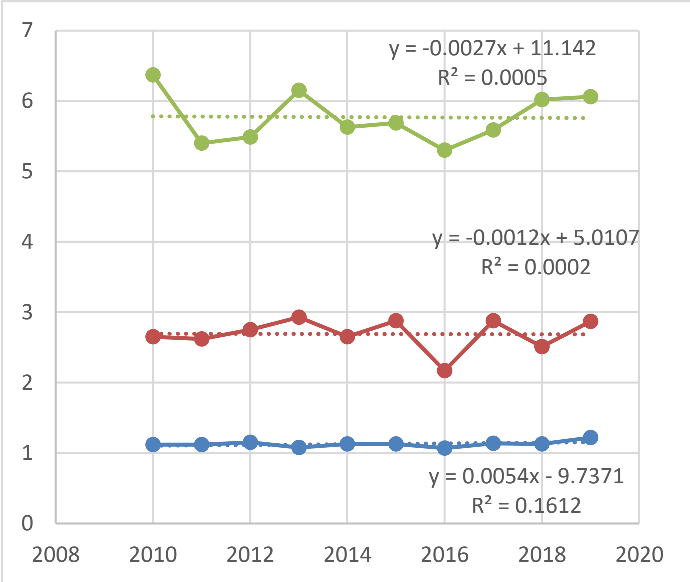


Figure 13 Results for Cabauw between 2011 and 2019

The results are not unambiguous. The 50 percentile (median, red) and 90 percentile (cloudy, green) give a small increase of the darkness and the 10 percentile (clear sky, blue) gives a small decrease. The uncertainty in the trend however is high, which is reflected in the very small R^2.

In Annex II the key number results for all locations are given.

From the key numbers we see that the level of the clear sky brightness ranges from about 0.3 mcd/m² (21.4 mags/arcsec²) at the darkest location to 4 mcd/m² (18.5 mags/arcsec²) in the bigger towns.

The night sky brightness under cloudy skies ranges from about 0.5 mcd/m² (20.85 mags/arcsec²) at the darkest location to about 92 mcd/m² (15.2 mags/arcsec²) in the bigger towns.

In the darkest locations, especially the locations in the north of the Netherlands, the darkness is always lower than the light of half moon (1 mcd/m²). So in these locations the effect of the moon cycle, important for different species of insects, is still apparent.

In the locations in the towns, like Arnhem and Utrecht the cycle of the moon is completely gone. The artificial light is always stronger than half moon and in around 50% to 70% of the time even more than the full moon (6.6 mcd/m²).

In the three rural locations we see a mixed situation. The two rural locations in the centre of the Netherlands, Arkemheen and Cabauw, the sky brightness caused by the artificial light is nearly always (around 95-99% of the time) brighter than the half moon. In about 10% of the time even brighter than the full moon.

In the third rural location, Oostkapelle 60% of the time the night sky is brighter than half moon, but never brighter than full moon. Here the cycle of the moon is partially visible.

We can't say anything about the Netherlands in total with this analysis but it is clear that a many parts in the Netherlands has such a high brightness, that the moon cycle is not anymore discernible and other parts of the Netherlands the influence of the moon cycle is disappearing.

6.2.2 Yearly trend

As we are searching for a trend in the night sky brightness we focus on the 10-percentile because we want to evaluate the clear night sky brightness. During the evaluation of the results we established a fixed relation between the 10-and the 90- percentile (see chapter 8). Through this relation we can convert the 90-percentile values to 10-percentiles and thus we can double the data points in an attempt to get a 10-percentile trend with less uncertainty.

In the next table we give the increase per year with and without the 90-percentile conversion to the 10-percentile, the probability of the increase and a qualification of it's significance:

Table 2 Results of the trend analysis with the following meaning of the significance:

- HS Highly Significant with a reliability, above 99%
- MS Maybe Significant with a reliability above 95%
- NS Not Significant.

Location	**Time frame**	**Data used**	**Trend (%/y)**	**Probability (%)**	**Significance**
Arkemheen	2011-2019	10-percentiles only	1.06	30.6	NS
		Combined 10- and 90 percentiles	1.14	59.7	NS
Arnhem	2010-2015	10-percentiles only	-1.45	84.6	NS
		Combined 10- and 90 percentiles	-2.73	99.0	HS
Cabauw	2010-2019	10-percentiles only	0.74	95.1	MS
		Combined 10- and 90 percentiles Year 2010 not included	0.62	98.7	MS
Cabauw combined with Digilum data	2010-2019	10-percentiles only	0.77	99.20	HS
		Combined 10- and 90 percentiles Year 2010 not included	0.54	97.57	MS
Kootwijk	2011-2019	10-percentiles only	0.74	30.7	NS
		Combined 10- and 90 percentiles	0.75	60.9	NS
Lauwersmeer	2015-2019	10-percentiles only	-7.07	98.3	MS
		Combined 10- and 90 percentiles	-3.68	97.2	MS

Oostkapelle	2015-2019	10-percentiles only	-2.61	96.9	MS
		Combined 10- and 90 percentiles	-1.21	91.3	NS
Ossendrecht/ Woensdrecht	2014-2019	10-percentiles only	0.12	11.2	NS
		Combined 10- and 90 percentiles	0.33	54.9	NS
Schiermonnikoog	2011-2014	10-percentiles only	16.28	85.4	NS
		Combined 10- and 90 percentiles	9.02	92.9	NS
Springendal	2011-2014	10-percentiles only	0.16	1.6	NS
		Combined 10- and 90 percentiles	0.85	21.7	NS
Tata	2015-2019	10-percentiles only	-2.77	79.4	NS
		Combined 10- and 90 percentiles	-1.88	91.0	NS
Utrecht	2009-2019	10-percentiles only	0.16	21.7	NS
		Combined 10- and 90 percentiles	0.15	32.8	NS

Note to the table:
At Cabauw the high 90-percentile result of 2010 was not included which was due to a snow cover in the winter of 2010. This high value at the beginning of the trend line has a very strong influence on the slope of the trend line.

We have looked at the overall trend and the significance of this trend. The development of the artificial light in a country is of course not a natural law, but the result of a number of different influences like technical innovation, introduction of laws and policy changes. So the development of the Dutch darkness is probably in reality not a straight line but is gradually changing with sudden jumps. (more about the artificial light production in the Netherlands in Annex III).

The results of two meters we don't mention: Boschplaat and Vlaardingen. In Vlaardingen measurements were performed only for a short time and the measurements were affected by direct light into the SQM which contaminated the results.
At the Boschplaat we had a meter more or less on the beach. We encountered there several problems. The wind caused often to cover the meter with sand and making the results unusable. Also we had to replace the meter with another one, due to theft. All this made the measurements very unreliable.

Arkemheen:

We see a small yearly increase of around 1%. It is not significant. It looks as if in the beginning there was a big increase of light but it dropped in the year 2016. The last years it is rising again.

Arnhem:

With an analysis solely on the 10-percentile no trend was determined. However together with the 90-percentile data a possible decrease in the night sky brightness could be present of 2.7%/year. In Arnhem in 2014/2015 a start was made with implementing LED public lighting, so this could explain the observed decrease.

Cabauw:

In the results in Cabauw we tried different techniques to get the most out of the data. We used not only the 10 and 90 percentile data, but also added the Digilum data. The Digilum had run parallel to the Cabauw SQM in the period 2010 to 2012.

From table 2 it shows that it is likely that at Cabauw an increase in the night sky brightness is present. Statistically it cannot be proved with a confidence above 99.9%, but the significance is above 95%. The average of the four calculated trends amounts 0.67%/year for Cabauw with a confidence between 95% and 99%.

Kootwijk:

The calculated increase is not significant, so we conclude that the night sky brightness has not changed in that area.

Lauwersmeer:

In this analysis a trend was determined of -3.7%/year. The probability of this trend is >95% but <99.9%, so statistically it cannot be stated that the trend is significant, but it also cannot be concluded that the trend is not significant. As measures in the surroundings have taken place, it could be stated that there is a decrease of the night sky brightness and thus an improvement of the darkness. In the nearby harbour all the fixtures were replaced by a type with no upward light and also the nearby military barracks have completely improved their lighting significantly. The barracks are now at night hardly visible anymore from the outside.

Oostkapelle:

The decrease ranges possibly from about 1.2%/year to 2.6%/year The probability in the 10-percentile is just above the 95% and the probability in the combined 10- and 90-percentile is 91%. So it is close to 95%. Very carefully we could state that there might be a decrease in night sky brightness. This is in line with a local light pollution reduction program.

TataSteel:

From this analysis no trend could be determined, however there are very clear results in the hourly charts which show a clear reduction in the night sky brightness, due to implementation of light pollution reduction measures (see TataSteel in paragraph 8.2

Darkness by the hour). One of the causes that no trend could be determined is that during the monitoring period the SQM had to be replaced with another one due to malfunctioning. This adds to uncertainty in the data.

Ossendrecht / Woensdrecht:

A small yearly increase of around 0.2% but not significant. So we conclude that there is almost no change in night sky brightness.

Schiermonnikoog:

We see a big increase of the measured light. We doubt if this really is true. This is by far the darkest location with values around 21.4 mags/arcsec². Only the first years measurements were performed. Any deviation in the lighting situation around the location can have a big influence. Unfortunately we can’t find the cause anymore. So new measurements would be interesting.

Springendal:

Also here only during the first years measurements were performed. We calculated a small increase, but the significance is very low. So we regard these results as inconclusive.

Utrecht:

This is the only location with the same SQM at the same location for 10 years. In the year 2010 we see, due to a snow cover in the winter a hump, in the 90% percentile results, which had a big influence on the median values. If we only look at the 10 percentile results, the clear night situation, we see hardly a development. A small yearly increase of around 0.1 % but not significant. We conclude that the night sky brightness has not changed here.

Conclusion yearly trend

In order to have an idea of the general trend in the Netherlands, the mean of the trend of all NachtMeetnet locations, as presented in table 2, is a yearly increase of 0.4% per year.

When we look in more detail we can see three of the locations have a specific light reduction program in place: Oostkapelle, Tata Steel and Lauwersmeer and see a reduction between 2% and 7% by which the reduction programs are effective. These are not representative for the Dutch situation in general. In some locations we have measured only the first years and we have no measurements performed in the last years. So we omit these locations from the calculation of the trend.

We have five locations where we have good set of data and where we have measured a long time and which are more representative for the Netherlands as a whole. The yearly increase varies in those 5 locations from 0.12% to 1.14%, with a mean increase of the yearly night sky brightness of 0.6 % per year with an uncertainty of 0.8%.

We don’t have a representative measuring grid over the whole of the Netherlands of course and our result is based on not many locations. But we conclude that the night sky brightness has increased in the last 9 years in the Netherlands somewhere between -0.2% and 1.4 % per year. This is also in accordance with satellite data (see chapter 9).

7 Further analysis of the data

7.1 RELATION BETWEEN DARKNESS WITH CLEAR SKY AND CLOUDY SKY

There is a relation between the 10- and 90-percentiles. As already noticed in paragraph 6.1 the brighter the night sky is at a location, the wider the range of night sky brightness.

The 10-percentile represents the situation with clear sky and the 90-percentile is the situation with the sky completely overcast and the light from the ground is reflected to the cloud base.

In figure 14 the two percentiles of each year are plotted against each other.

In a formula (for mcd/m²) we found the following relation which fits the measuring point at best:

$CWB = 7 \cdot CSB^2$

Where:

- CWB Cloudy Weather Sky Brightness in mcd/m² (90-percentile)
- CSB Clear Sky Brightness in mcd/m² (10-percentile)

The uncertainty in the CWB is a factor of 2. In an earlier RIVM study a factor of 10 was found, however this was based on raw (uncalibrated) SQM-values.

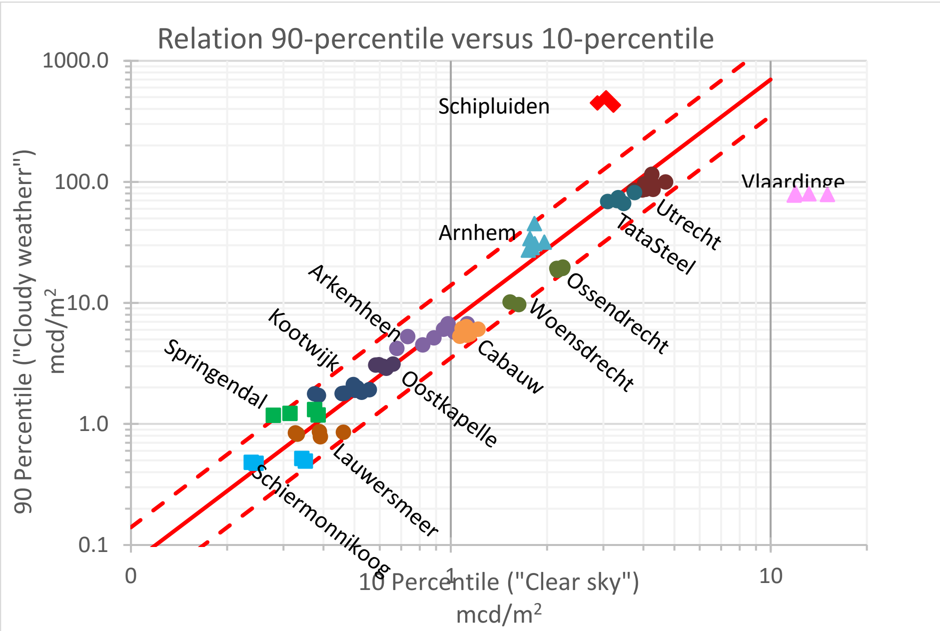


Figure 14 Relation between the 90-percentile ("Cloudy weather") and the 10-percentile ("Clear sky"). The individual points are the percentiles of each year.

7.2 DARKNESS BY THE HOUR

Another interesting feature is to look for the daily night time cycle of the night sky brightness. By using all data of all years and selecting the data at one specific time we can construct night time frequency plots. These plots are constructed with the sun below -18° and no moon. In the next figure we show the darkness during the night in the city of Utrecht (300.000 inhabitants).

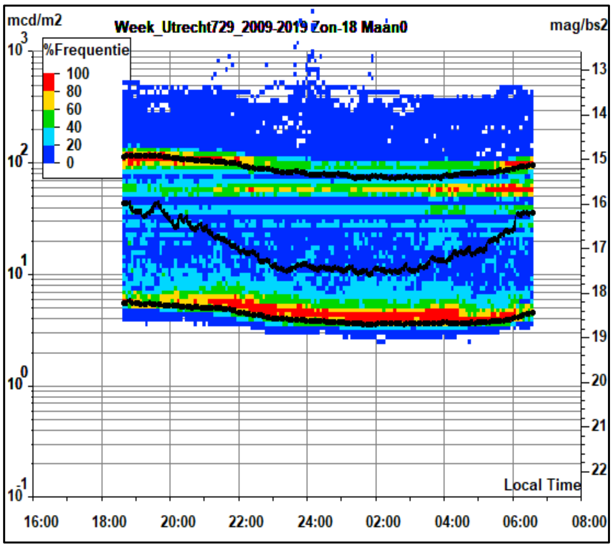


Figure 15 Darkness cycle in Utrecht.

In this graph we see a gradually decline in night sky brightness till about 1 am and after 4 am we see a incline. However if we zoom in on the 10-percentile and 90-percentile we see some more interesting features as shown in the next figure.

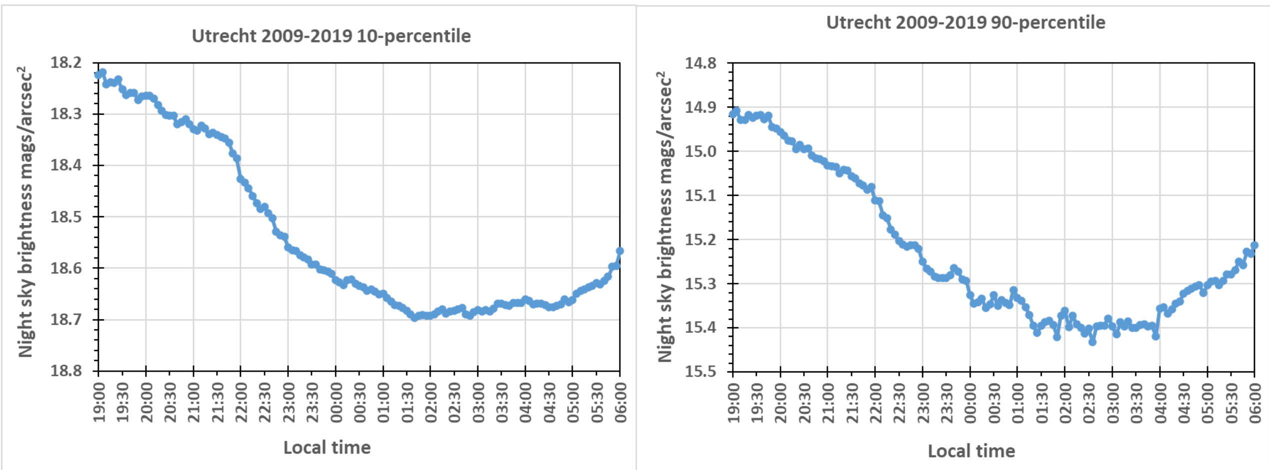


Figure 16 Darkness cycle in Utrecht with 10-percentile (left) and 90-percentile(right)

From this figure we see a short sharp decrease around 22:00 and the decrease continues till about 01:30, whereafter is stays more or less constant with an increase from 4:00 at the 90-percentile and around 5:00 an increase at the 10-percentile. The decrease from about 22:00 till 01:30 is obvious the switching off the lighting of shops, sporting activities and so on. After 4:00 the city slowly comes back to live again.

In the next figure we show the 10 and 90 percentiles of all locations in one graph.

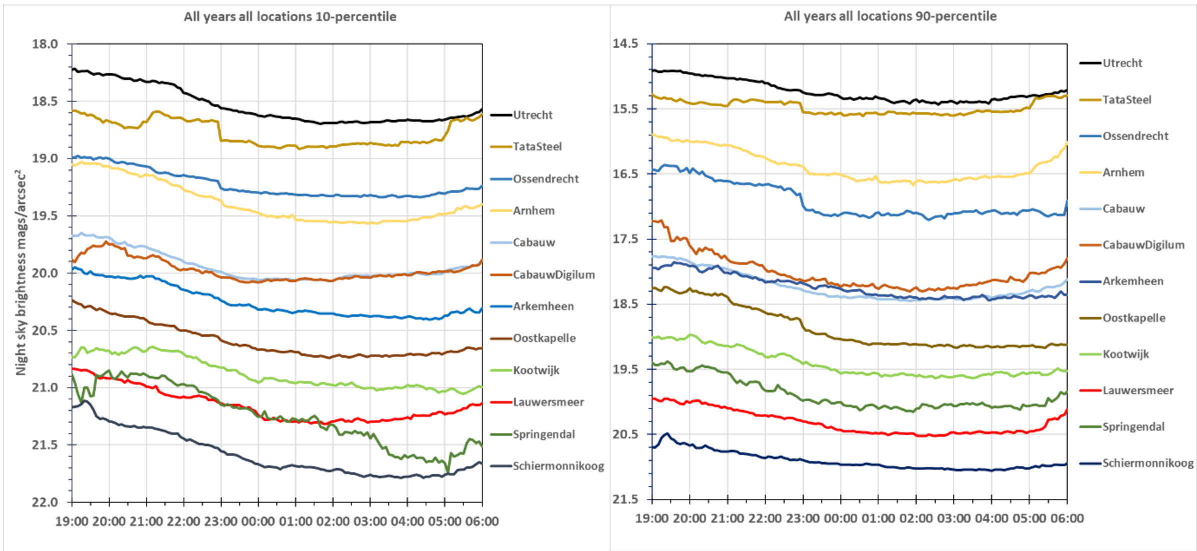


Figure 17 **Darkness cycles for all locations with 10-percentiles (left) and 90-percentiles (right)**

From the graphs we see sudden changes in the night sky brightness. A sudden decrease is clearly seen at TataSteel, Ossendrecht and Oostkapelle. A sudden increase is seen at TataSteel, Arnhem and Lauwersmeer.

We will now discuss the results of all locations.

Arkemheen:

At the night sky brightness decreases until 04:00 with a sharper decrease until about 00:00.

Arnhem:

At the night sky brightness decreases until 03:00 with a sharper decrease around 23:00. Which is due to switching off of certain public lighting and sports field lighting. At 05:00 (clear sky) and 06:00 (cloudy sky) we see a sharp increase. This is due to the switching on of greenhouses about 1 to 2 km away.

Cabauw:

At Cabauw we see a gradual decrease till 00:00. Then a constant night sky brightness till about 2:00 after which there is a slow increase and after 4:00 a steeper increase.

Kootwijk:

At Kootwijk the decrease in the clear sky brightness is steeper till 00:00, whereafter the decrease is less until 04:00. The cloudy sky brightness decreases till 00:00 whereafter it stays more or less the same.

Lauwersmeer:

The night sky brightness at Lauwersmeer decreases until 00:00 with a sharp decline around 00:00. Then stays the same till about 03:00 and then rises again

Oostkapelle:

At Oostkapelle we see a decrease until about 02:00, with a sharp decrease around 23:00 (clearly seen at the 90-percentile). After 02:00 we see that the sky brightness stays more or less the same.`

Ossendrecht:

At 23:00 a sharp increase (decrease of brightness) of about 0.1 mags/arcsec^2 occur, whereafter the decrease of brightness slowly continues till 02:00 and stays the same until 4:30, at which the 10-percentile brightness increases, while the 90-percentile stays the same. The 90-percentile increases in brightness at 6:00. Apparently the night sky brightness during clear sky increases due to light sources further away. While the cloudy sky brightness increase is due to more nearby light sources.

Schiermonnikoog:

At Schiermonnikoog the night sky brightness decreases until 00:00, then stays the same till about 02;00 and then decreases further till 04:00, whereafter it increases again.

Springendal:

At Springendal the clear sky brightness decreases almost continuously till 04:00. The cloudy sky brightness decreases till about 00:00 and then stays the same. After 05:00 this brightness increases again. Apparently here also further away light sources are being switched off during the night as this cannot be seen in the cloudy sky brightness.

TataSteel:

In the recent years TataSteel has been working to implement measures to prevent light pollution. This is done by changing the outdoor and road lighting to LED with far better fixtures. Also there is a “lighting” regime in which a substantial part of the lighting is switched on and off when a workers shift takes. Lighting is on at 21:00 till 23:00 and off from 23:00 till 05:00. These switching off and on are clearly seen in the 10- and 90-percentiles.

Utrecht:

As already mentioned a short sharp decrease around 22:00 and the decrease continues till about 01:30, whereafter is stays more or less constant with an increase from 4:00 at the 90-percentile and around 5:00 an increase at the 10-percentile.

General trend during the night.

In general we see a decrease in night sky brightness till about 00:00, then the night sky brightness stays the same or decreases more slowly till about 04:00. Apparently the lights sport fields, public lighting, shops and so on are being switched off until 00:00. After 00:00 it is most likely that meteorological effects play a role. As the height of the mixing layer becomes less, less aerosols and dust particles are present and thus light scattering occurs.

In general we see a decrease of the night sky brightness and thus a reduction of upward light of 0.3 to 0.4 mags/arcsec2, which is a reduction of 30% of the light.

In two remote locations Schiermonnikoog and Springendal we see a reduction of around 0.6 – 0.75 mags/arcsec2 which is a reduction of 42% - 50% in upward light.

8 Application of satellite data

The measurements of NachtMeetnet ended on December 31st 2019. We performed measurements over the last ten years but in the meantime also followed the use of satellite data to monitor the darkness in the Netherlands.

In 2011, an American satellite type, the Suomi-NPP, was launched to investigate various environmental aspects of the Earth. The satellite orbits the earth from pole to pole, at an altitude of approximately 800 km and crosses the Netherlands every day at around half past one in the morning.

On board are a number of instruments, suitable for measuring in different wavelengths. The Visible Infrared Imaging Radiometer Suite (VIIRS) is the main instrument and measures electromagnetic radiation (light) in 22 bands. One of the bands is the Day and Night Band (DNB), suitable for performing observations, both during the day and at night, in the part of the spectrum in which also humans eyes are sensitive.

This DNB is not specially designed for measuring the light from cities on Earth, but for example measuring ice formation at the North Pole during winter, when there is no sunlight. However, the measurements can be used to measure the upward light from the earth, such as cities, greenhouses, fires, and so on.

The satellite makes a scan of 3000 km wide, which is registered by a CCD camera, whereby each pixel represents an area of approximately 740 by 740 meters. The DNB band can operate with different various gains and is able to properly measure the darkest and lightest parts of the earth without becoming saturated (overexposed). The unit of measurement is nW / (cm^2 -sr). This is an energy unit. This is due to the fact that the spectral sensitivity of the sensor differs slightly from the standard sensitivity of the human eyes. The sensor measures less in the blue part of the visible spectrum and more in red.

Calibration has been performed before the launch but calibration measurements are also carried out regularly during the flight. A systematic correction of the calibration method was carried out in January 2017.

The data are recorded every night, but most are not of interest due to clouds and so on. We used the monthly aggregate of the data, publicly published (since October 2019 at the Payne institute of mining).

8.1 CORRELATION BETWEEN VIIRS DATA AND NACHTMEETNET DATA

We have the impression that the improvements in calibration and resolution in the recent years are considerable and we presume monitoring of upward artificial light will be done in the future by satellite data.

To have a good transition to this new monitoring method we looked at the satellite data of the last 8 years and compared them with the ground based measurements of NachtMeetnet.

We drew four different circles around our measuring locations: 100 meter, 1 km, 5 km and one of 15 km. In the next picture we see the four circles around some of the locations. For each ring we calculated the total upward light and corrected for the distance to the measuring location. We chose 15km as maximum: light from farther has hardly any influence anymore in the Dutch skies.

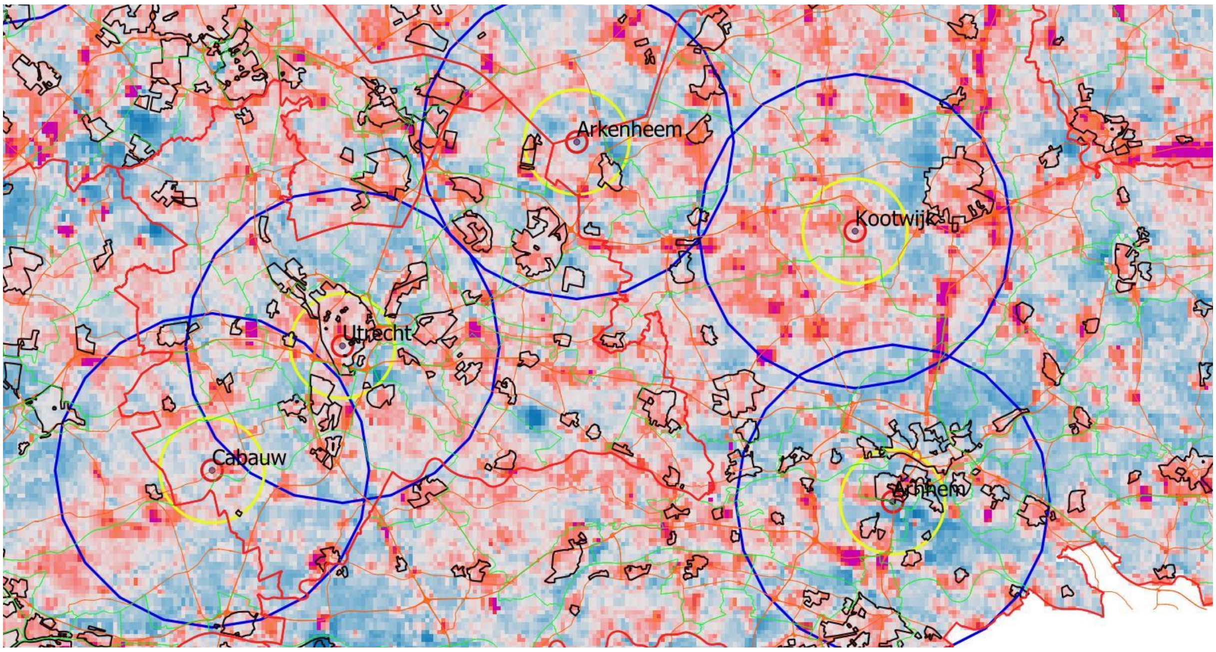


Figure 18 **Circles of 100m, 1 km, 5 km and 15km around some of the measuring locations; at the background the increase and decrease map.**

We correlated the results from our own NachtMeetnet measurements to the mean of measured values of the total light the satellite measured around our locations.

The results are shown in the next graph. There is a very obvious relation between the measured light from the ground by NachtMeetnet and the amount of upward light measured by satellite.

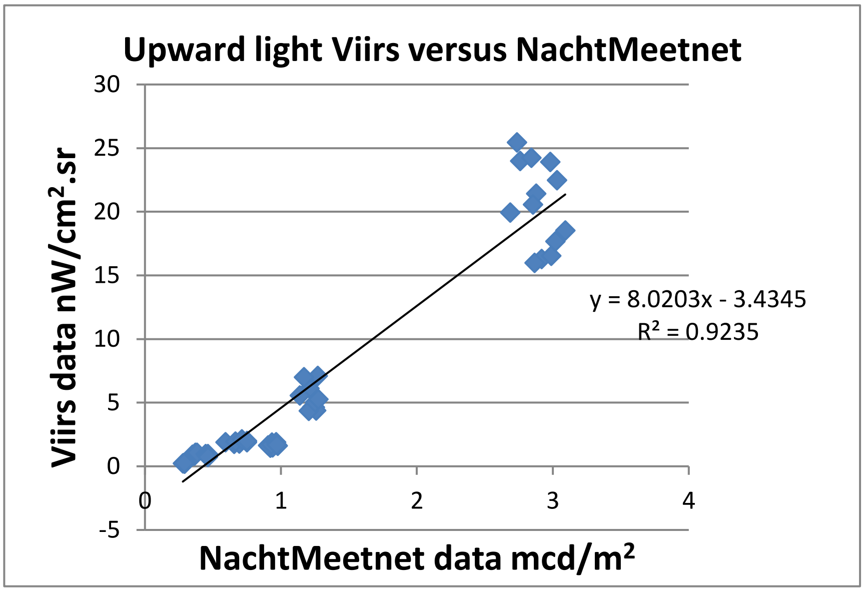


Figure 19 NachtMeetnet data (10-percentile) versus upward light measured with Viirs

We can conclude that the satellite data nicely matches with ground based measurements and are a good representation of the Dutch night sky brightness.

The use of satellite data has a lot of advantages over ground based measurements: no maintenance and no chance of failures, no theft and so on and applicable for the whole of the Netherlands and comparable with other parts of the world. So we recommend this will be the future of darkness monitoring in the Netherlands.

8.2 TREND ANALYSIS WITH VIIRS DATA

To give an impression of the results from the Viirs of the brightness trends in the Netherlands we present two results. A map with changes and a trend analysis.

Map:

The map in figure 20 shows the change in upward light between 2013 and 2019. The values correspond to a relative increase (red) or decrease (blue) of the measured light. The strong blue and red parts are all related to greenhouse locations. Closer inspection shows also new developments around highways. The highways between Deventer and Germany and between Apeldoorn and Arnhem are good examples.

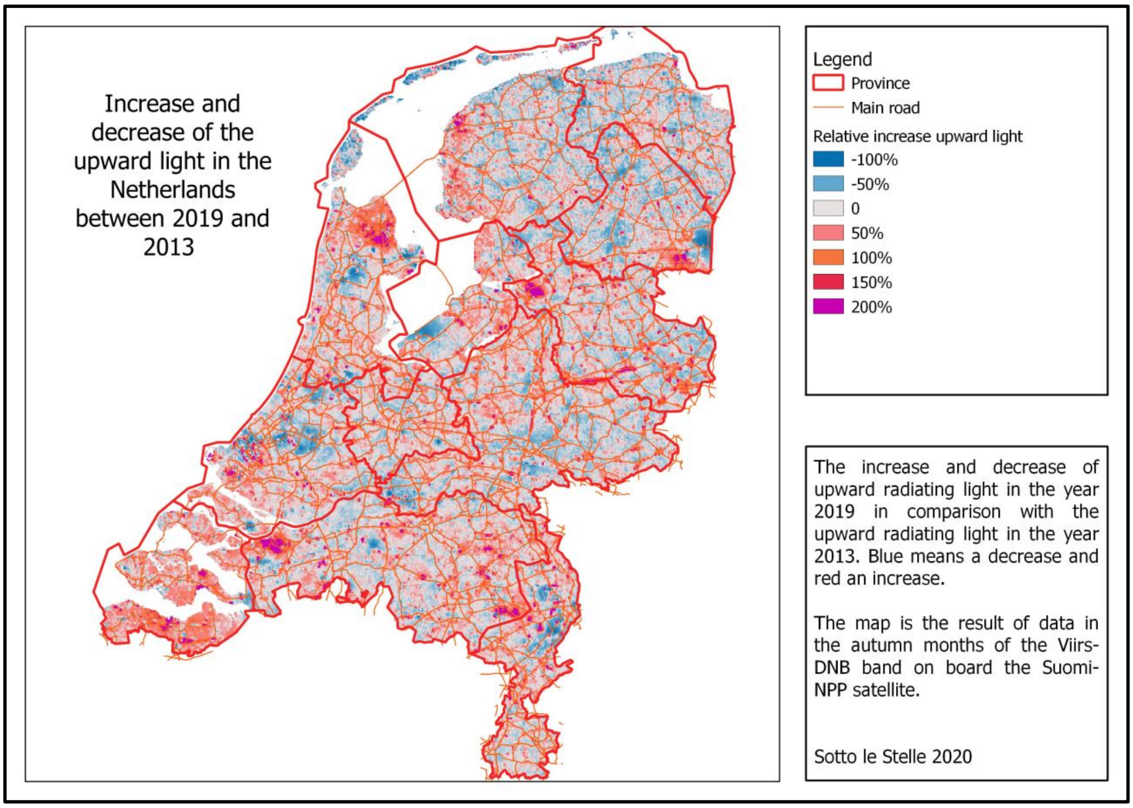


Figure 20 **Change of measured upward light by Viirs between 2019 and 2013**

Trend analysis:

In the next graph we present the total upward light measured by the satellite for the last 8 years for the whole of the Netherlands. From this graph a yearly increase of 1% per year is calculated. However this is statistically not significant.

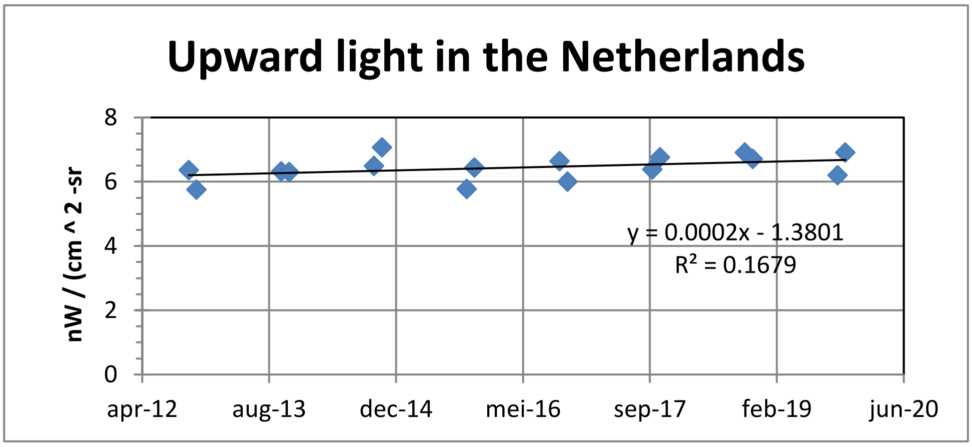


Figure 21 **Upward light trend in the Netherlands**

9 Discussion and conclusions

Over a period of nearly ten years we have determined the darkness at 11 locations in the Netherlands.

We find a wide range in results, from 0.3 mcd/m² to 4 mcd/m² for the clear sky situation. In cloudy situations the range is much higher, between 0.5 mcd/m² and about 92 mcd/m².

The moon cycle is in most locations not clearly discernible, which is important for many species.

In three locations the measurements was specifically made for a program to reduce the upward light. At those locations we see indeed an upward light reduction between 2 and 7%. So these programs were effective, but are not representative for the general development of the darkness in the Netherlands.

When we combine the measurements, where we performed at least 6 years of measurements, we find a yearly increase of 0.6% with an uncertainty of 0.8%. So we assume the yearly increase of the Dutch upward light is between -0.2% and 1.4%.

Our result of an increase of 0.6% per year is a very general statement. Of course the development of light is not a natural law which follows mathematical rules; it is a result of different factors, technical, psychology but also policy. We elaborate this in Annex III.

We compared our results also with satellite data and this showed a high correlation. In the satellite data we found a increase of the Dutch yearly upward light of 1% (although not statistical significant). So both results are well in accordance.

We can conclude that the trend of the twentieth century in the western world with a yearly increase of 3% to 5% per year is, at least in the Netherlands, not continued.

We combined these with other developments in the Netherlands. The mean increase of the Dutch population is around 0.5% per year from 16.5 million beginning of 2010 to 17.4 million at the beginning of 2020. (CBS, bevolkinkingsontwikkeling).

The Dutch BNP increased in the same decade with a mean of 1.4% per year, with only in 2012 a decrease and 2013 a stabilization. In the other years there was an increase of about two percent per year. (CBS, Bruto-Binnenlands-Product BBP).

The saying goes “rich people make light”; a yearly increase of the determined upward light of 0.6% and the increase of population and BBP are in the same range. This illustrates the idea that the amount of light in the Netherlands is stabilizing. There seems a stabilisation of the total amount of upward light per person or per euro.

Regional differences

We found in our measurements a yearly increase between a minimum of -7% and a maximum of 16%. This is a big difference. We see the same and even better in the map. There are regions which doubled in ten years their light output while in other regions it was only the half. The extremes are, we think, predominantly connected with greenhouse locations. But there other interesting signs in the map which need a more detailed inquiry.

10 Acknowledgement

We would like to thank the next parties for their contribution and cooperation providing data and access to measuring locations:

- RIVM
- Provinces of Groningen and Utrecht
- Omgevingsdienst Midden- en West-Brabant, OMVB
- Tata Steel
- Staatsbosbeheer
- KNMI
- Private person at the measuring location Oostkapelle and the municipality of Veere
- Earth Observation Group, Payne Institute for Public Policy

11 Literature

Sabrina Schnitt et al. 2013
Temperature Stability of the Sky Quality Meter

Christopher C. M. Kyba et al. 2010
Cloud Coverage Acts as an Amplifier for Ecological Light

Christopher D. Elvidge et al. 2011
National Trends in Satellite Observed Lighting: 1992–2009

Steve Mills et al. 2012
Calibration of the Viirs day/night band (DNB).

Miguel O. Román et al. 2018
Black Marble nighttime lights product suite.

Sirish Uprety et al. 2018
Improving the low light radiance calibration of SNNP Viirs day/night band in the NOAA operations.

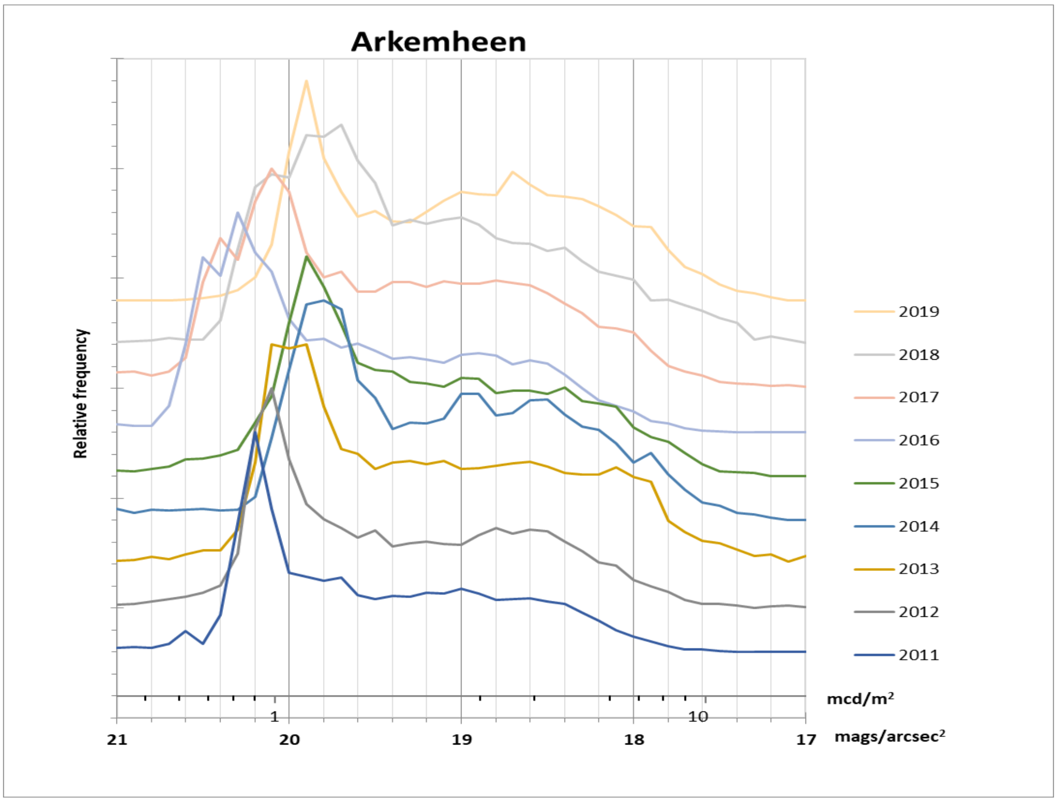
Kyba et al. 2017
Artificially lit surface of Earth at night increasing in radiance and extent

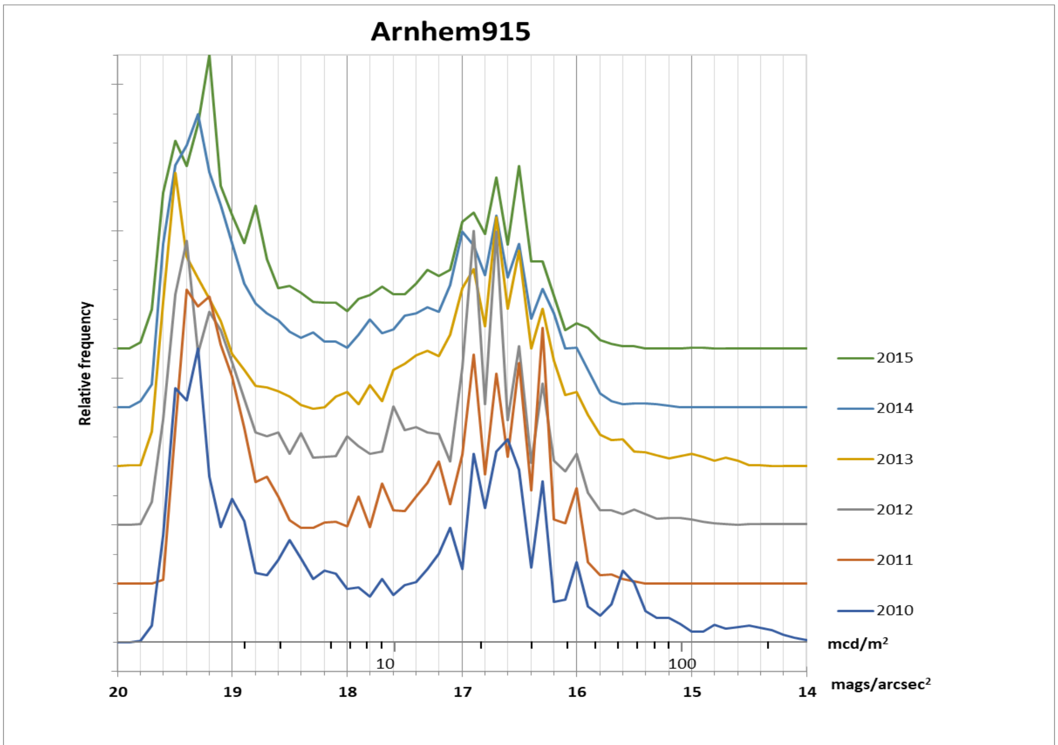
Jacqueline Coesfeld et al. 2018
Variation of Individual Location Radiance in VIIRS DNB Monthly Composite Images

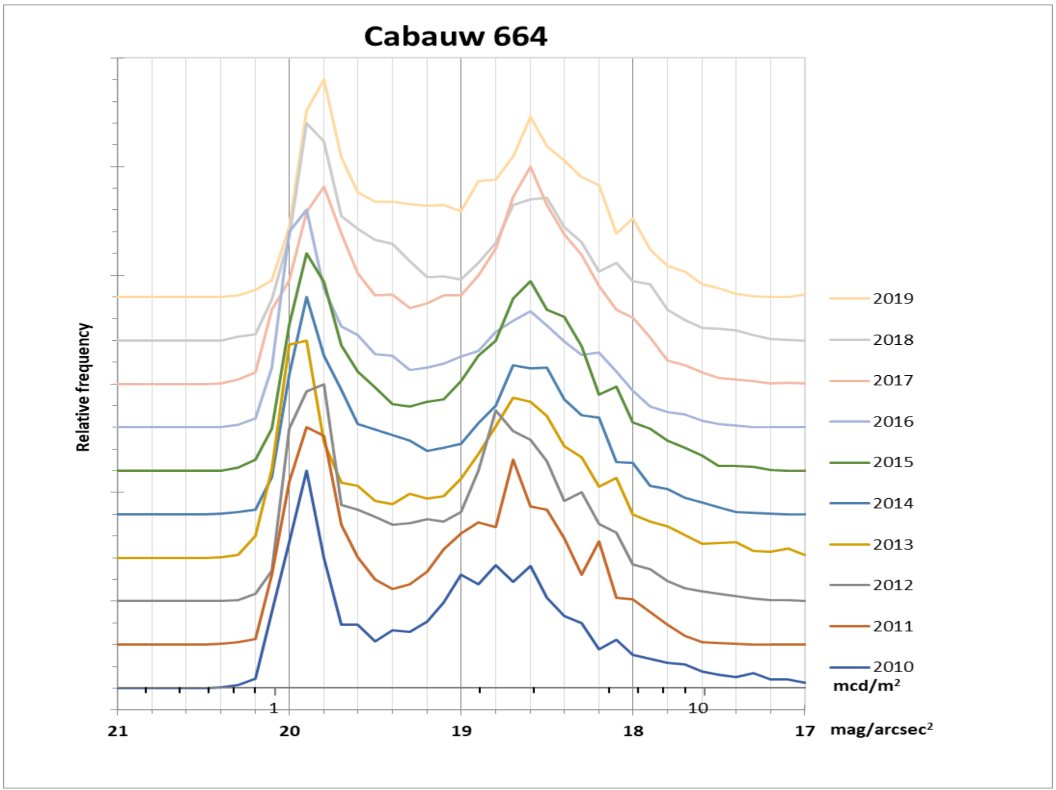
Alejandro Sanchez de Miguel et al. 2020
The nature of diffuse light near cities detected in nighttime satellite imagery.

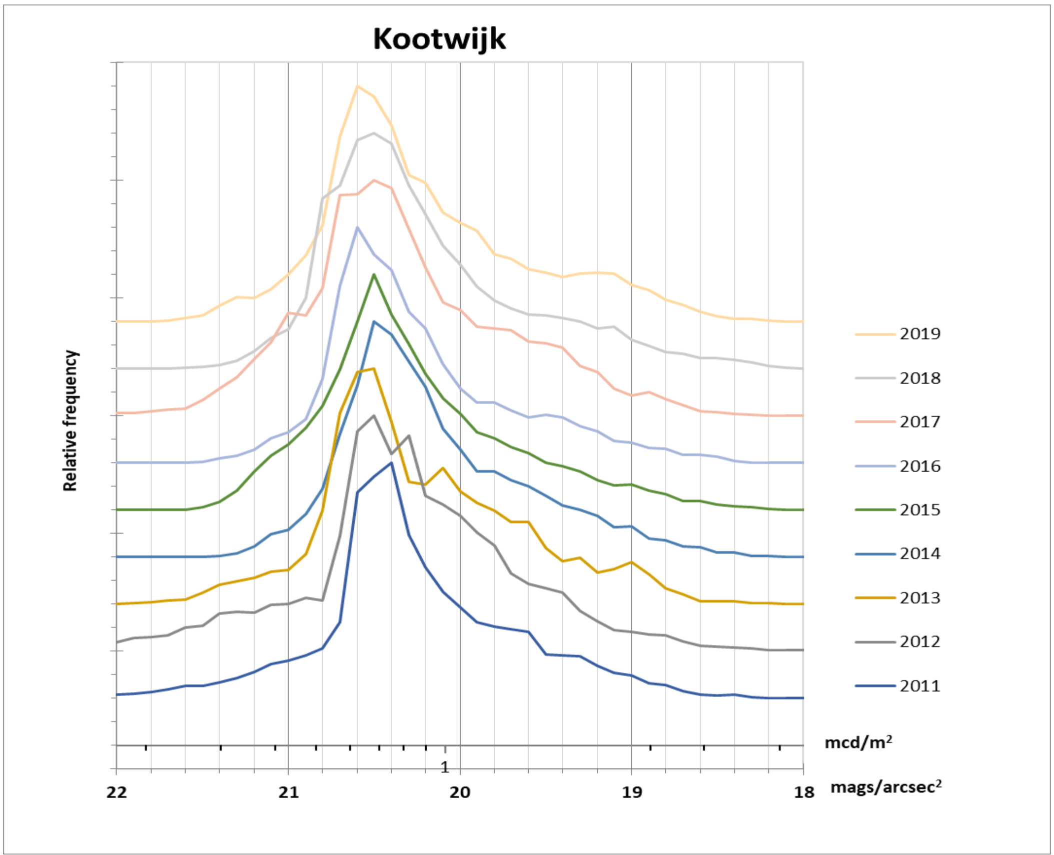
Jacqueline Coesfeld et al. 2020
Reducing variability and removing natural light from satellite Imagery: a case study using the VIIRS DNB

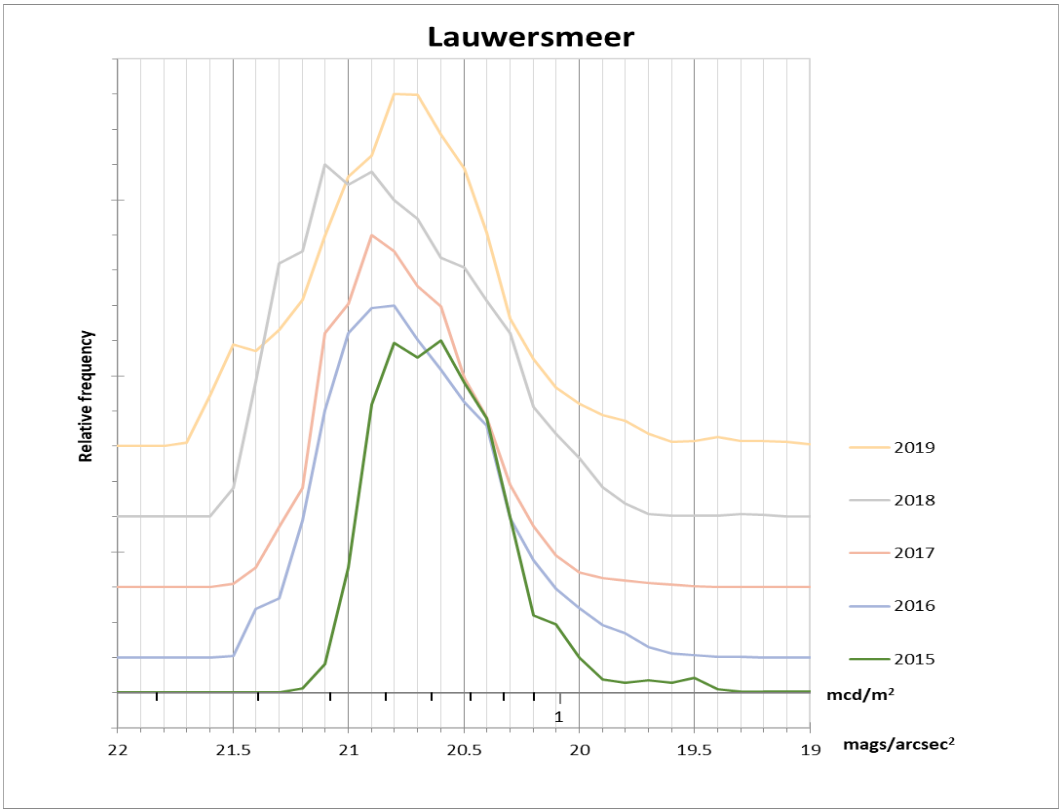
ANNEX I FREQUENCY DIAGRAMS (STACKED)



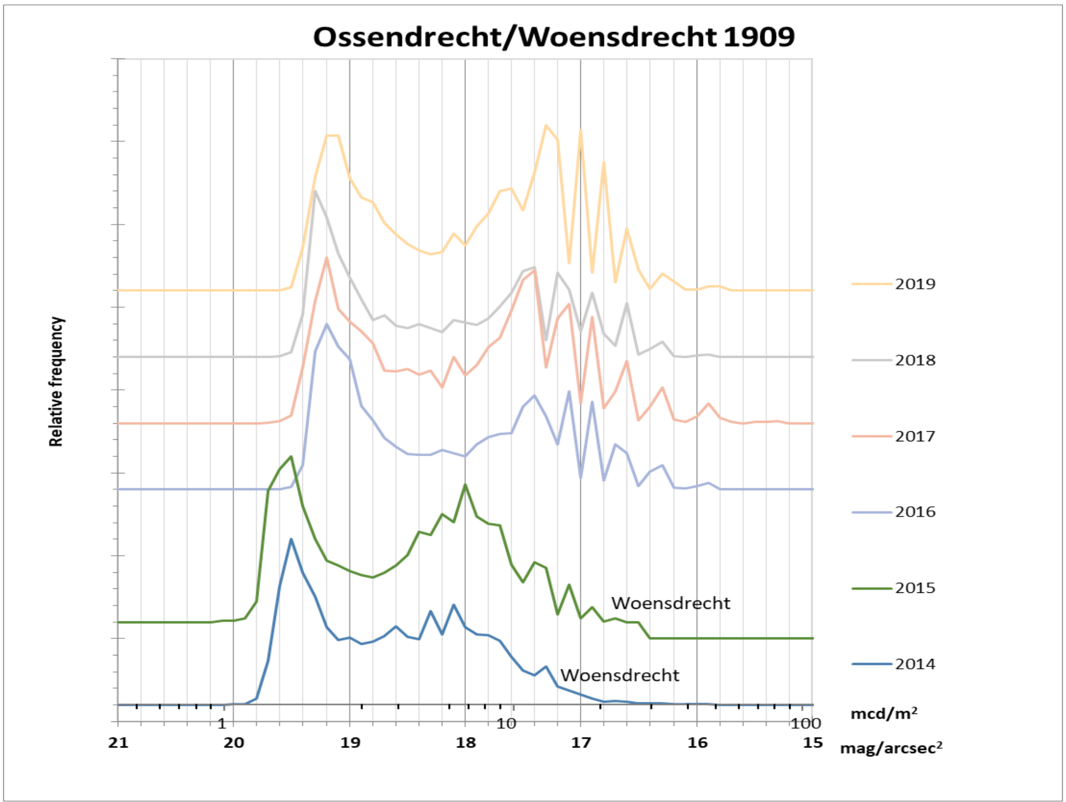



Cabauw 664
Relative frequency
2019
2018
2017
2016
2015
2014
2013
2012
2011
2010
mcd/m²
1
10
21
20
19
18
17
mag/arcsec²

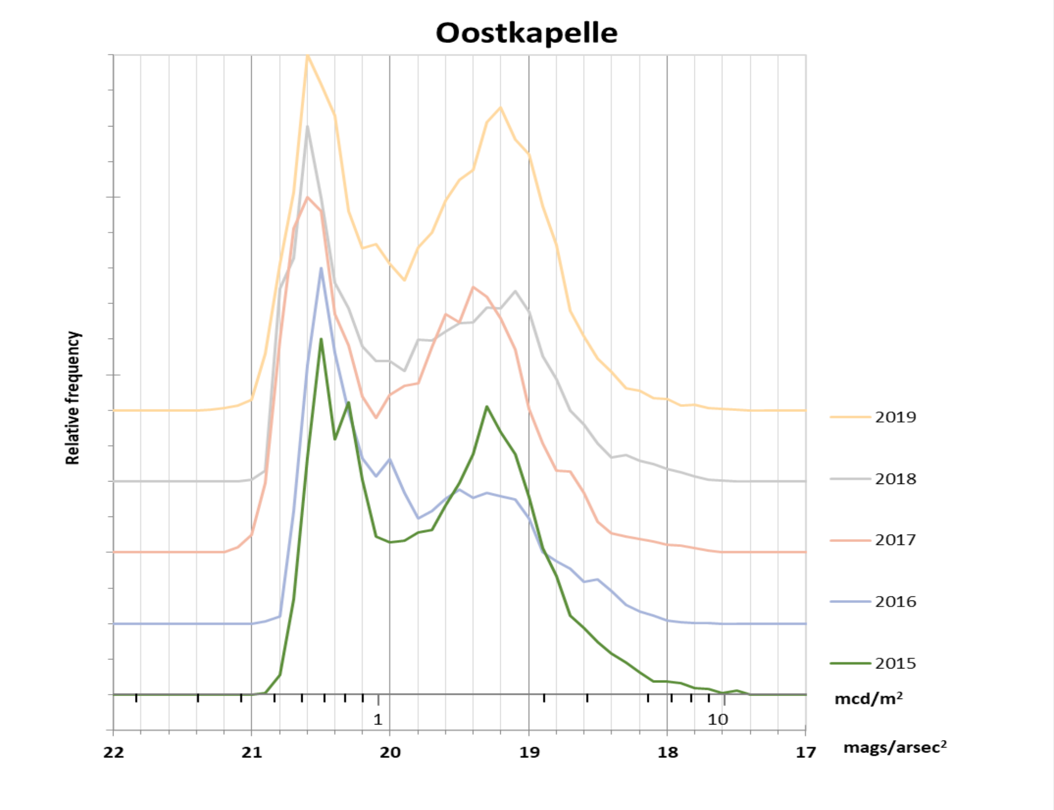

Kootwijk
Relative frequency
2019
2018
2017
2016
2015
2014
2013
2012
2011
mcd/m²
1
22
21
20
19
18
mags/arcsec²



Lauwersmeer
Relative frequency
2019
2018
2017
2016
2015
mcd/m²
1
22
21.5
21
20.5
20
19.5
19
mags/arcsec²



Ossendrecht/Woensdrecht 1909
Relative frequency
2019
2018
2017
2016
2015
2014
Woensdrecht
Woensdrecht
mcd/m²
1
10
100
21
20
19
18
17
16
15
mag/arcsec²


Oostkapelle
Relative frequency
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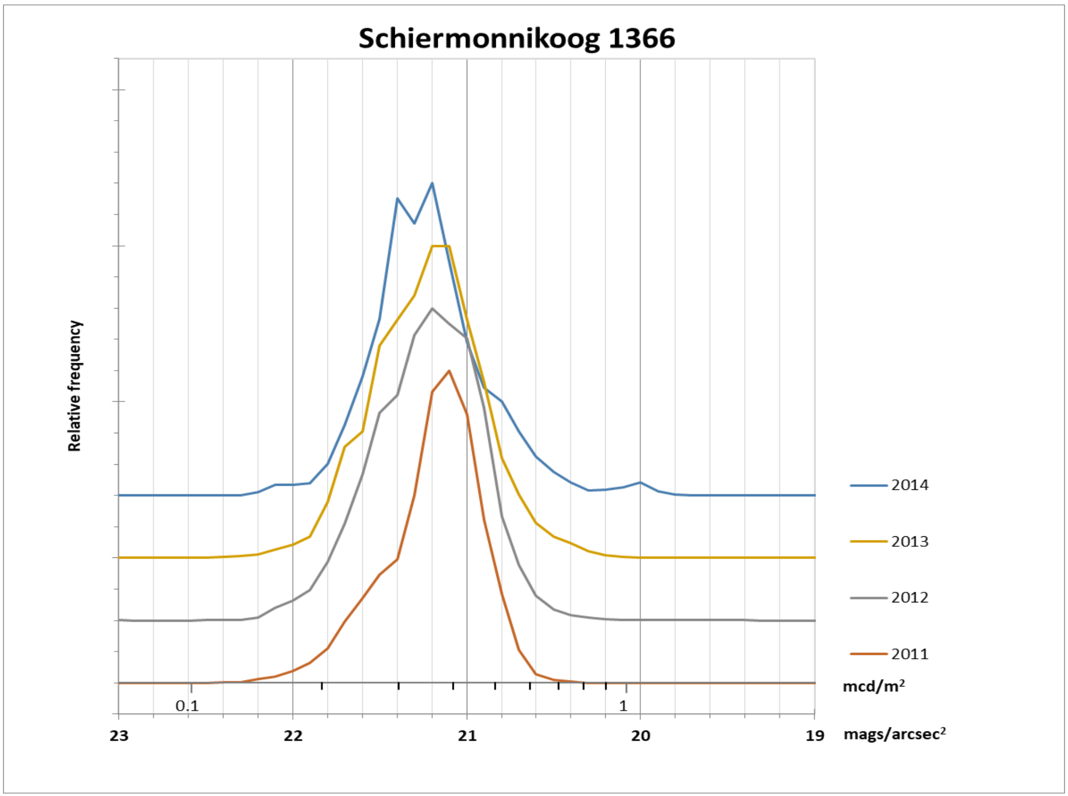
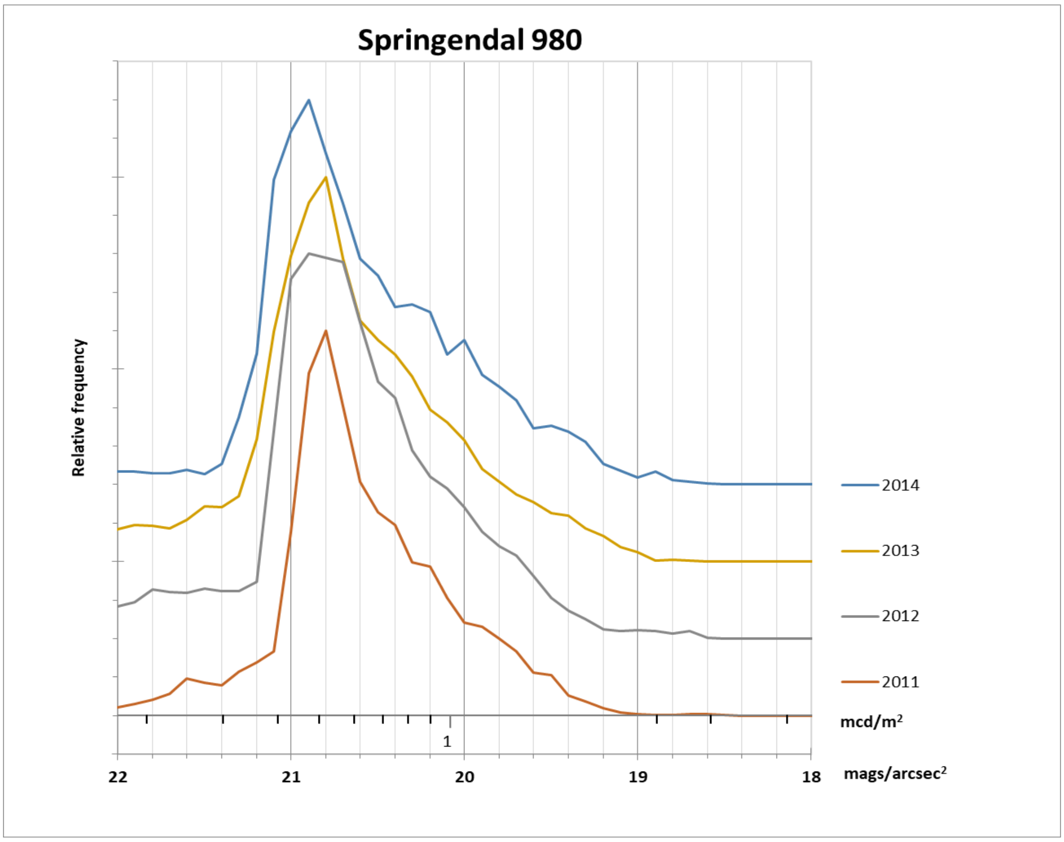
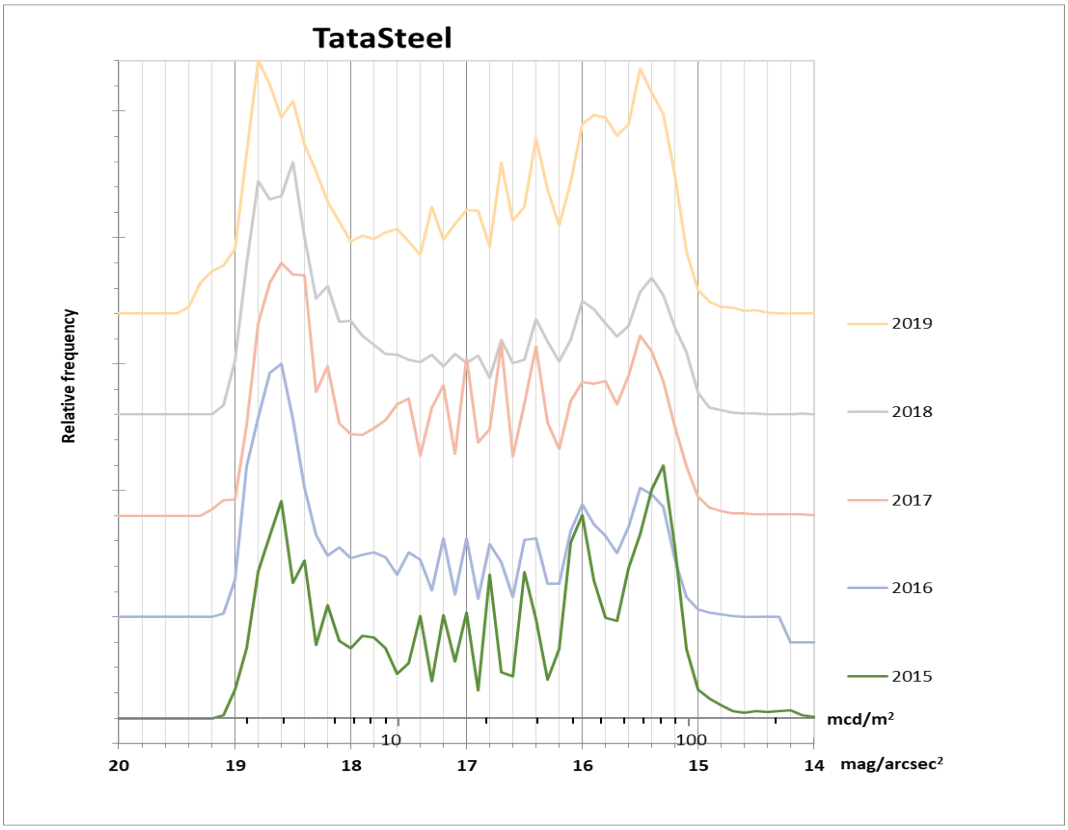
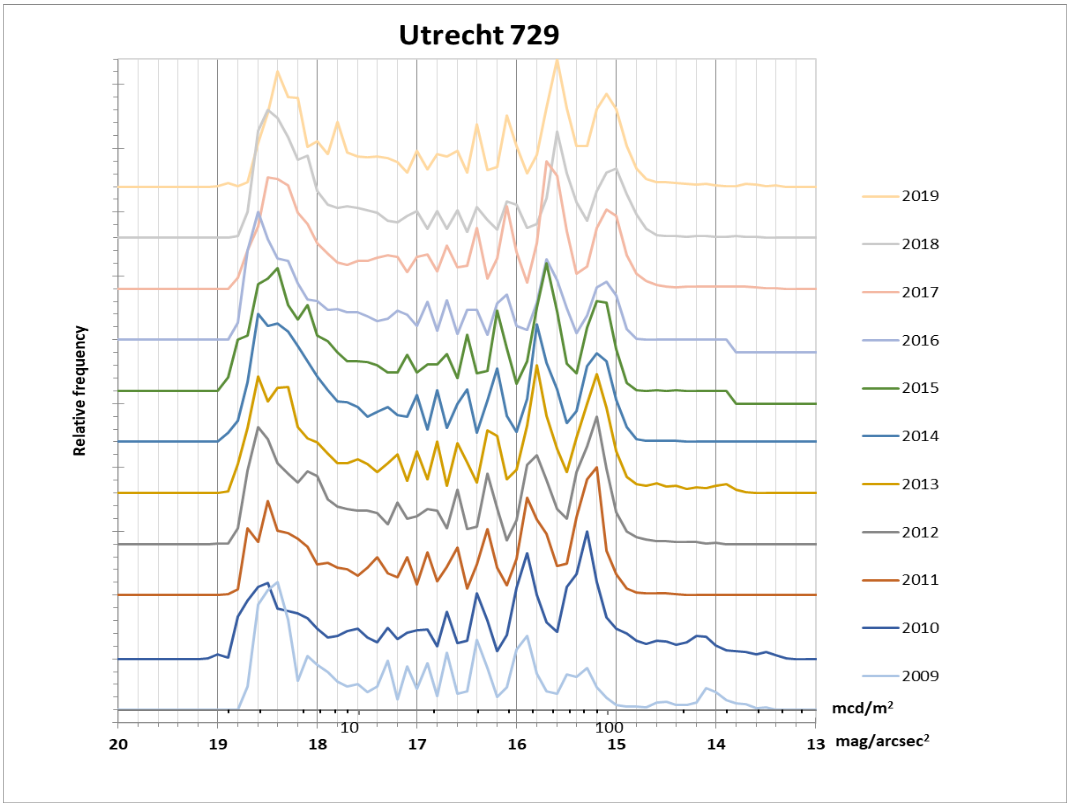
2018
2017
2016
2015
mcd/m²
1
10
22
21
20
19
18
17
mags/arsec²


Schiermonnikoog 1366
Relative frequency
2014
2013
2012
2011
mcd/m²
0.1
1
23
22
21
20
19
mags/arcsec²

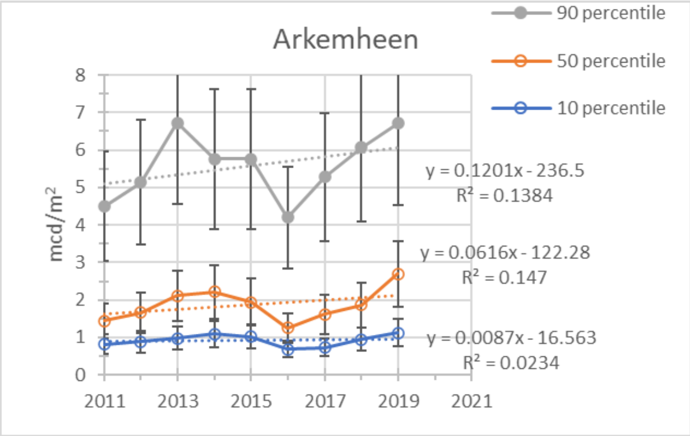

Springendal 980
Relative frequency
2014
2013
2012
2011
mcd/m²
1
22
21
20
19
18
mags/arcsec²


TataSteel
Relative frequency
2019
2018
2017
2016
2015
mcd/m²
10
100
20
19
18
17
16
15
14
mag/arcsec²

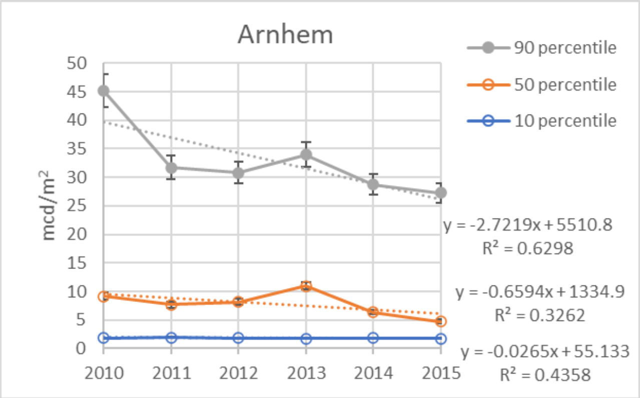

Utrecht 729
Relative frequency
2019
2018
2017
2016
2015
2014
2013
2012
2011
2010
2009
mcd/m²
10
100
20
19
18
17
16
15
14
13
mag/arcsec²

ANNEX II KEYNUMBERS

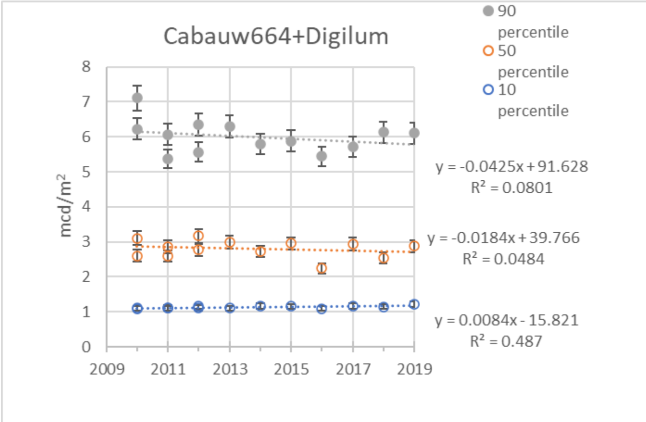
		Uncertainty (%)	32.33
	Arkemheen		
	mcd/m2		
year	10 percentile	50 percentile	90 percentile
2011	0.82	1.44	4.49
2012	0.88	1.67	5.14
2013	0.98	2.11	6.73
2014	1.09	2.21	5.76
2015	1.02	1.94	5.76
2016	0.68	1.25	4.21
2017	0.73	1.62	5.28
2018	0.95	1.86	6.07
2019	1.13	2.70	6.71



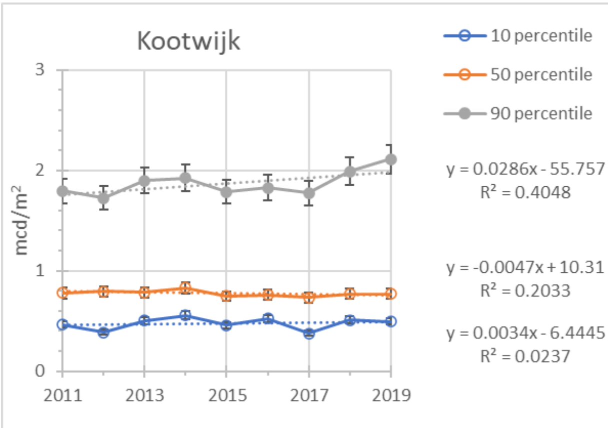
	Uncertainty (%)		6.39
	Arnhem		
	mcd/m2		
year	10 percentile	50 percentile	90 percentile
2010	1.82	9.17	45.15
2011	1.96	7.68	31.73
2012	1.83	8.15	30.83
2013	1.77	10.98	33.96
2014	1.80	6.38	28.75
2015	1.75	4.77	27.25



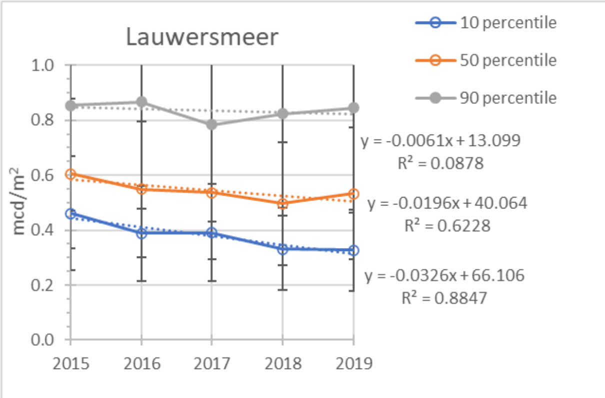
		Uncertainty (%)		6.22
		Cabauw		
		mcd/m2		
	year	10 percentile	50 percentile	90 percentile
	2010	1.10	2.61	6.23
	2011	1.11	2.59	5.37
	2012	1.16	2.77	5.56
	2013	1.11	2.99	6.29
	2014	1.16	2.73	5.80
	2015	1.15	2.95	5.89
	2016	1.10	2.24	5.44
	2017	1.16	2.94	5.72
	2018	1.15	2.55	6.13
	2019	1.22	2.87	6.11
DIG	2010	1.11	3.11	7.11
DIG	2011	1.11	2.86	6.07
DIG	2012	1.11	3.17	6.34



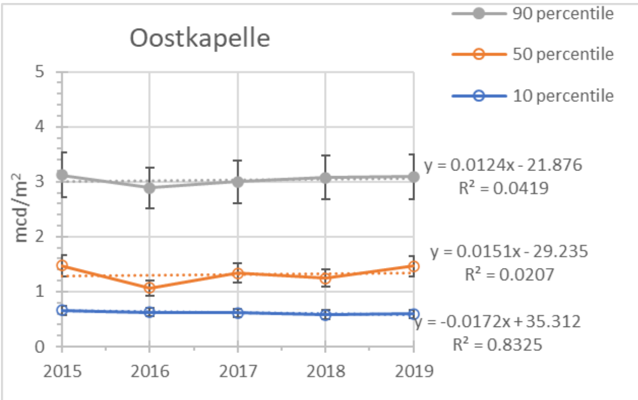
	Uncertainty (%)		6.8
	Kootwijk		
	mcd/m2		
year	10 percentile	50 percentile	90 percentile
2011	0.46	0.78	1.80
2012	0.39	0.79	1.73
2013	0.50	0.78	1.90
2014	0.56	0.83	1.92
2015	0.46	0.75	1.79
2016	0.53	0.76	1.83
2017	0.37	0.73	1.78
2018	0.51	0.77	1.99
2019	0.50	0.77	2.11



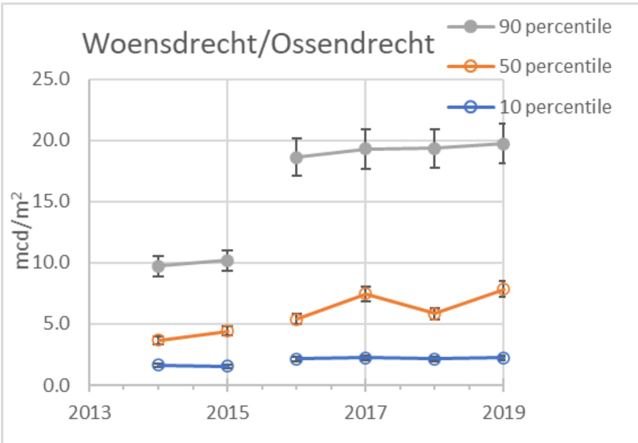
	Uncertainty (%)		45.88
	Lauwersmeer		
	mcd/m2		
year	10 percentile	50 percentile	90 percentile
2015	0.46	0.61	0.85
2016	0.39	0.55	0.87
2017	0.39	0.54	0.78
2018	0.33	0.50	0.82
2019	0.33	0.53	0.84



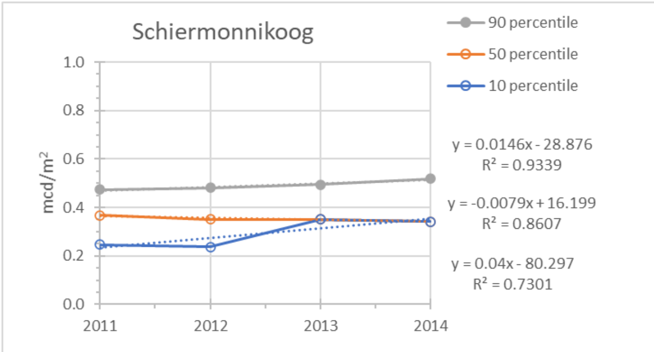
	Uncertainty (%)		12.89
	Oostkapelle		
	mcd/m2		
year	10 percentile	50 percentile	90 percentile
2015	0.66	1.47	3.12
2016	0.63	1.07	2.89
2017	0.61	1.33	3.00
2018	0.58	1.25	3.08
2019	0.60	1.46	3.09



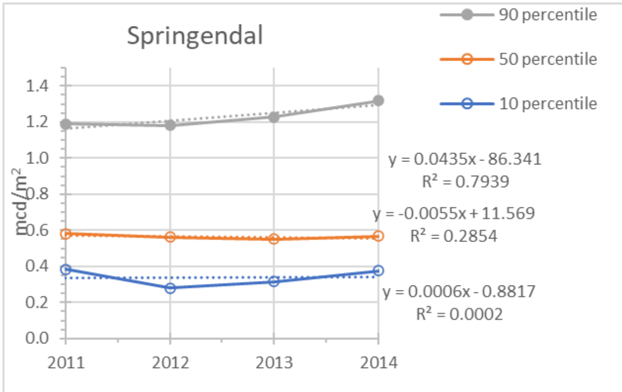
	Uncertainty (%)		8.26
	Woensdrecht/Ossendrecht		
	mcd/m2		
year	10 percentile	50 percentile	90 percentile
2014	1.63	3.67	9.71
2015	1.53	4.40	10.18
2016	2.15	5.39	18.60
2017	2.24	7.46	19.29
2018	2.14	5.83	19.33
2019	2.24	7.85	19.73



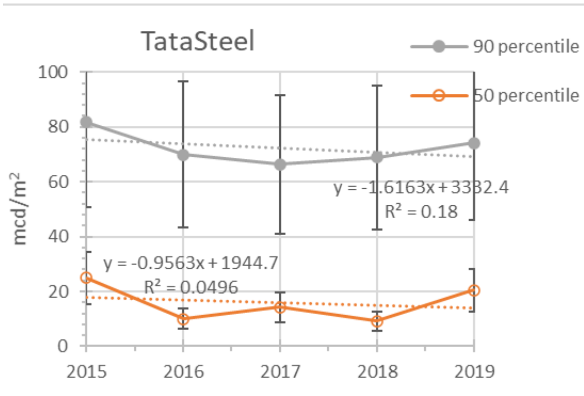
	Uncertainty (%)		no data
	Schiermonnikoog		
	mcd/m2		
year	10 percentile	50 percentile	90 percentile
2011	0.25	0.37	0.47
2012	0.24	0.35	0.48
2013	0.35	0.35	0.49
2014	0.34	0.34	0.52

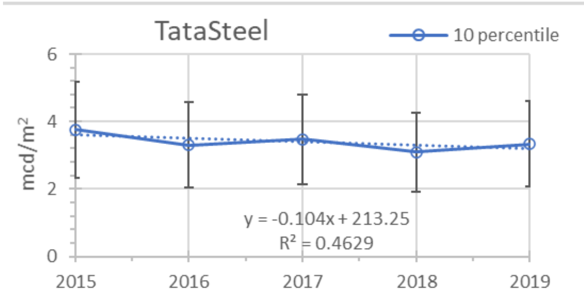


	Uncertainty (%)		6.1
	Springendal 980		
	mcd/m2		
year	10 percentile	50 percentile	90 percentile
2011	0.38	0.58	1.19
2012	0.28	0.56	1.18
2013	0.31	0.55	1.23
2014	0.37	0.57	1.32

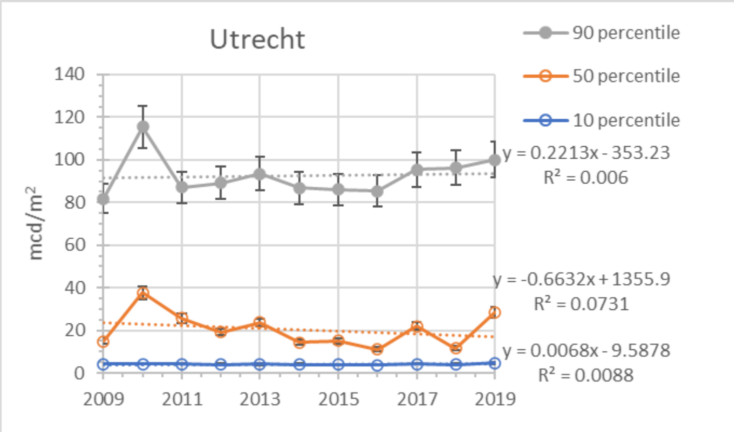


	Uncertainty (%)		38
	TataSteel		
	mcd/m2		
year	10 percentile	50 percentile	90 percentile
2015	3.75	24.88	81.78
2016	3.31	9.96	69.99
2017	3.47	14.30	66.41
2018	3.09	9.18	68.90
2019	3.34	20.48	74.24





		Uncertainty (%)	8.47
	Utrecht		
	mcd/m2		
year	10 percentile	50 percentile	90 percentile
2009	4.20	14.94	81.83
2010	4.24	37.55	115.51
2011	4.28	25.76	87.06
2012	4.06	19.21	89.25
2013	4.08	23.61	93.55
2014	4.05	14.29	86.74
2015	3.96	15.16	86.02
2016	3.73	11.11	85.31
2017	4.26	21.93	95.46
2018	4.03	11.48	96.26
2019	4.69	28.43	100.14



ANNEX III LIGHTING IN THE NETHERLANDS

Public lighting

The development of led lighting has a big impact on the Dutch nights. No new conventional lighting for public lighting is sold anymore. The same happens at sport fields where led lighting is replacing the traditional lighting.

This transformation has both good and bad effects. Some new lighting installations hardly send directly light into the atmosphere and thus is improving the darkness in the Netherlands. Also with this transformation to led, lights are dimmed after rush hours. We see this in our hourly graphs.

But at the same time we see, with the transformation to led, an increase of the total light output, because with the new lampposts the municipality is changing to the regulations which asks for more light than before. Also the change from warm light to the more cold light of led's is deteriorating the night sky.

In some regions especially in the north and east of the Netherlands darkness is appreciated and is actively supported. There are municipalities with a program, to reduce the amount of lampposts in the countryside, in accordance with the people living there.

The Dutch national governmental body for the Dutch highways (RijksWaterStaat) decided around 2010 lighting was not necessary and switched off a substantial part of the highway lighting during the night. If this will be, the coming years, continued, is unsure.

Sport field lighting

At sport fields we see in general a worsening of the situations. The necessary high energy led's are in general bad designed; the old conventional fixtures were superior to most of the modern led lights. So the upward light output rises steeply from those sport fields.

Greenhouse lighting

Greenhouse lighting is typical for the Dutch nights. They are producing a huge amount of light. The amount of light emitted by the greenhouse is regulated by Dutch law. Unfortunately in this law a municipality can depart now from these regulations when a greenhouse asks for it and this is allowed in some parts of the Netherlands.

Commercial lighting

There is little knowledge about the amount of light used as façade lighting of a building or for advertising. A high percentage of the produced light goes directly into the sky (we presume in the order of 50% or more). We have the impression the amount of light for this purpose is still rising., The Netherlands are a so called distribution country and we see a strong increase in big storage facilities along our highways with the corresponding light. At the other hand although there are initiatives to reduce this kind of lighting, such as energy reduction programs or by public pressure on websites where people can point where there is too much light.

Advertisement near highways is maybe more regulated or shut off during the night. The future will tell us what the total net result is of all those developments will be

Upward light in the Netherlands is the result of a lot of different factors and continuation of the monitoring is important to monitor this development.