Atmos. Meas. Tech. Discuss., 7, 7793–7809, 2014
www.atmos-meas-tech-discuss.net/7/7793/2014/
doi:10.5194/amtd-7-7793-2014

Atmospheric Measurement Techniques
Discussions
Open Access

Improving HelioClim-3 estimates of surface solar using the McClear clear-sky model and recent advances on atmosphere composition

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Received: 8 June 2014 – Accepted: 23 July 2014 – Published: 29 July 2014

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Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

The HelioClim-3 database (HC3v3) provides records of surface solar irradiation every 15 min estimated by processing images from the geostationary meteorological Meteosat satellites using climatological data sets of atmospheric Linke turbidity factor. This technical note proposes a method to improve a posteriori HC3v3 by combining it with data records of the irradiation under clear sky from the new clear-sky model McClear whose inputs are the advanced global aerosol properties forecasts and physically consistent total column content in water vapour and ozone produced by the MACC projects. The method is validated by comparison with a series of ground measurements for 15 min and 1 h for 6 stations and for daily irradiation for 23 stations. The correlation coefficient is large, greater than respectively 0.92, 0.94, and 0.97, for 15 min, 1 h and daily irradiation. The bias ranges between −4 and 4 % of the mean observed irradiation for most sites. The relative root mean square difference (RMSD) varies between 14 and 38 % for 15 min, 12 and 33 % for 1 h irradiation, and 6 and 20 % for daily irradiation. As a rule of thumb, the farther from the nadir of the Meteosat satellite located at latitude 0° and longitude 0°, and the greater the occurrence of fragmented cloud cover, the greater the relative RMSD. The method improves HC3v3 in most cases and no degradation in the others. A systematic correction of HC3v3 with McClear is recommended.

1 Introduction

The downwelling solar irradiance observed at ground level on horizontal surfaces and integrated over the whole spectrum (total irradiance), is called surface solar irradiance (SSI). It is the sum of the direct irradiance, from the direction of the sun, and the diffuse, from the rest of the sky vault, and is also called the global irradiance. The SSI is an Essential Climate Variable (ECV) as established by the Global Climate Observing System in August 2010 (GCOS, 2010). Knowledge of the SSI and its geographical distribution is of prime importance for numerous domains where SSI plays a major role as e.g. weather, climate, biomass, and energy.

The HelioClim Project is an ambitious initiative of MINES ParisTech launched in 1997 to increase knowledge on the SSI and to offer SSI values for any site, any instant over a large geographical area and long period of time, to a wide audience (Blanc et al., 2011). The project comprises several databases that cover Europe, Africa and the Atlantic Ocean. The HelioClim-1 (HC1) database offers daily means of the global SSI for the period 1985–2005. The HelioClim-3 (HC3) database contains 15 min values of the global SSI. It has been created in 2004 and is updated daily from images taken by the Meteosat Second Generation satellites. Its recent improvements have taken place in the framework of the European MACC and MACC-II (Monitoring Atmosphere Composition and Climate) projects funded by the European Commission. The HelioClim-4 database is under creation in these MACC projects. It will contain 15 min values of the global, direct and diffuse components of the SSI with a daily update.

The HelioClim databases are available on the Internet through the SoDa Web site (www.soda-is.org) and support research and business by providing data of known quality on surface solar irradiance. More than 100 000 requests were made in 2012 to HC1 by users and more than 2 million to HC3, demonstrating the large use of HelioClim databases. Lefevre et al. (2014) perform a review of the scientific literature citing HelioClim and found many examples of usages in various domains: oceanography, climate, energy production, life cycle analysis, agriculture, ecology, human health, and air quality.

The HC1 and HC3 databases derive from images of the Meteosat series of satellites using the Heliosat-2 method (Rigollier et al., 2004). The Heliosat-2 method needs a so-called clear-sky model for predicting the SSI that should be observed under a clear sky. The ESRA clear-sky model (Rigollier et al., 2000) modified by Geiger et al. (2002) was selected with the climatology of the Linke turbidity factor from Remund et al. (2003) as inputs. The Linke turbidity factor is a convenient approximation to model the atmospheric absorption and scattering of the solar radiation under clear sky. The climatology of Remund et al. comprises 12 maps, one per month, covering the world by cells of 5′ of arc angle in size. The use of this climatology is one of the drawbacks of the HC1 and HC3, and especially HC3 whose high temporal resolution (15 min) is in principle well suited to monitor and reproduce rapid changes in SSI. Aerosols have different scattering and absorbing properties according to their type, and the spatial and temporal heterogeneity of their number, size, chemical composition, and shape (Elias and Roujean, 2008; Xu et al., 2011). These properties as well as total column content in water vapour and ozone may vary rapidly within a day or from day-to-day thus influencing the SSI under clear sky. Climatology cannot account for such changes and HC3 estimates are often underestimated in case of clear skies (Lefevre et al., 2013).

The MACC and MACC-II projects are preparing the operational provision of global aerosol property analyses and forecasts together with physically consistent total column content in water vapour and ozone available every 3 h (Benedetti et al., 2011; Kaiser et al., 2012; Peuch et al., 2009). Up to now a multi-annual reanalysis data set is provided and used here (Inness et al., 2013). Such information has not been available so far from any operational numerical weather prediction (NWP) centre. A new clear-sky model called McClear has been developed to exploit this new input data source for estimating the direct and global SSI (Lefevre et al., 2013). Validation of McClear outputs against beam and global irradiances measured at 1 min by BSRN stations in the world reveals satisfactory. Good correlation is attained, bias, standard-deviation and RMSE are small (Lefevre et al., 2013).

How such advanced data sets on aerosol properties, water vapour and ozone can be exploited to bring a significant improvement to the widely used HC3 without re-factoring the Heliosat-2 method and re-processing all Meteosat images since 2004? If this is possible, the dynamics of the aerosol properties, water vapour and ozone would be taken into account in the enhanced HC3 thus possibly yielding better estimates under clear sky conditions. This technical note investigates the changes brought to HC3 in an a posteriori manner, i.e. by applying a post-processing to the HC3 estimates, and assesses the benefit compared to the original HC3.

AMTD
7, 7793–7809, 2014

2 Data sets and method

The method is the following. A standard request to HC3v3 (version 3 of HC3) for a given site integrated over a given period, called summarization, e.g. 1 h or 1 d, yields several data, including the global SSI I_{HC3v3}, that under clear-sky condition I_{ESRA}, and I_0 the irradiance received on a horizontal surface at the top of atmosphere. The clear-sky index Kc is computed:

$$\mathrm{Kc} = I_{HC3v3}/I_{ESRA} \tag{1}$$

The McClear model yields the clear-sky value $I_{McClear}$ for the requested summarization and site, and the new version of the SSI $I_{HC3McClear}$ is obtained:

$$I_{HC3McClear} = \mathrm{Kc}\, I_{McClear} \tag{2}$$

A series of ground measurements of surface solar irradiation I_{ground} was assembled and serves as a reference in the comparison of I_{HC3v3} and $I_{HC3McClear}$. Comparison was performed for the period 2005–2009. Measurements were collected from 23 stations located in the field-of-view of the Meteosat satellite.

Measurements of 15 min, hourly, and daily irradiation were collected in 6 stations of the BSRN network (Baseline Surface Radiation Network). BSRN stations record global irradiation I_{ground} as well as its direct B and diffuse D components every min. Roesch et al. (2011) recommend keeping only I_{ground} measurements that obey the following constraints:

$$\begin{aligned} &\text{if } \theta_S \le 75°, 1.08 \ge (D+B)/I_{ground} \ge 0.92 \\ &\text{if } \theta_S > 75°, 1.15 \ge (D+B)/I_{ground} \ge 0.85 \end{aligned} \tag{3}$$

where θ_S is the solar zenith angle. Roesch et al. (2011) note a percentage of missing data of 4 % for global irradiance and 13 % for direct irradiance for all studied BSRN data. The original measurements passing Eq. (3) are summed up to yield 15 min, hourly and

AMTD
7, 7793–7809, 2014

daily irradiation provided a sum is made with at least 90 % of valid measurements, e.g. 54 valid 1 min data to yield 1 h irradiation.

Measurements of daily irradiation were collected for another set of 17 stations of the meteorological networks archived in the WRDC (World Radiation Data Center) and available through the WRDC web site. Table 1 lists the 23 stations that have been selected in order to represent various climates in Europe, Africa and tropical South America.

The clearness index KT, also called global transmissivity of the atmosphere, or atmospheric transmittance, or atmospheric transmission, is defined as:

$$\mathrm{KT} = I_{\mathrm{ground}}/I_0 \tag{4}$$

For clear skies, KT is close to 0.8, and is close to 0 for overcast skies. This index has the advantages of removing most of the effects due to sun position and indicates the type of sky. While irradiation for clear sky conditions but a large solar zenith angle may be similar to that in cloudy conditions but with a low solar zenith angle, the clearness indices will be different. The clearness index is useful to analyse causes of discrepancies between the data sets. The clearness indices $\mathrm{KT}_{\mathrm{HC3v3}}$ and $\mathrm{KT}_{\mathrm{McClear}}$ are computed:

$$\mathrm{KT}_{\mathrm{HC3v3}} = I_{\mathrm{HC3v3}}/I_0 \tag{5}$$

$$\mathrm{KT}_{\mathrm{McClear}} = I_{\mathrm{HC3McClear}}/I_0 \tag{6}$$

The deviations ($I_{\mathrm{HC3v3}} - I_{\mathrm{ground}}$) and ($I_{\mathrm{HC3McClear}} - I_{\mathrm{ground}}$) are computed and synthesised by the bias, the standard-deviation, the root mean square difference (RMSD), and the correlation coefficient. Tables 2 to 5 report the results of the comparison for 15 min, hourly and daily irradiation respectively.

3 Results and discussion

The correlation coefficient for 15 min irradiation is reported in Table 2. For both I_{HC3v3} and $I_{\mathrm{HC3McClear}}$, the correlation coefficient is very large, greater than 0.95, except for

AMTD
7, 7793–7809, 2014

Toravere (0.91), indicating that the 15 min irradiation is well reproduced by both estimates. The correlation is slightly greater for $I_{\mathrm{HC3McClear}}$ than for I_{HC3v3}, showing that the combination of I_{HC3v3} with McClear brings a better reproduction of the observed changes in irradiation. This observation is supported by the fact that the correlation coefficient for clearness index $\mathrm{KT_{McClear}}$ is greater than that for $\mathrm{KT_{HC3v3}}$ (Table 2).

The bias for I_{HC3v3} ranges between −3.0 and 1.3 J cm^{-2} (Table 3). The bias for $I_{\mathrm{HC3McClear}}$ is similar to or smaller than that for I_{HC3v3} for all cases. An exception to the overall decrease in bias is Tamanrasset, where the bias is 1.3 J cm^{-2} (3 % of the mean irradiation) for I_{HC3v3} and 1.7 J cm^{-2} (4 %) for $I_{\mathrm{HC3McClear}}$. A closer examination of the data sets of irradiation and clearness index for Tamanrasset reveals that I_{HC3v3} exhibits negative bias for clear sky conditions and positive bias for cloudy situations. The balance between them yields an overall bias of 1.3 J cm^{-2}. The combination of I_{HC3v3} with McClear decreases the bias for clear sky conditions but this improvement does not counterbalance any longer the positive bias for cloudy situations, yielding a slightly greater bias of 1.7 J cm^{-2}.

The standard-deviation is fairly similar for I_{HC3v3} and $I_{\mathrm{HC3McClear}}$ for all stations. It ranges from 6.3 to 8.2 J cm^{-2} for I_{HC3v3}. It is smaller for $I_{\mathrm{HC3McClear}}$ and ranges from 6.1 to 7.8 J cm^{-2}. The smaller standard-deviation may be linked to the better correlation coefficient observed for $I_{\mathrm{HC3McClear}}$. Similarly, the RMSD is slightly less for $I_{\mathrm{HC3McClear}}$ than for I_{HC3v3}. Tables 2 and 3 show that the combination of HC3 and McClear brings a benefit for 15 min irradiation for the six studied stations.

Table 4 reports results for hourly irradiation. The correlation coefficient for $I_{\mathrm{HC3McClear}}$ is large, greater than 0.97, except Toravere (0.95), and is greater than that for I_{HC3v3}. The bias ranges between −11.1 and 4.9 J cm^{-2} for I_{HC3v3}, and between −6.8 and 6.5 J cm^{-2} for $I_{\mathrm{HC3McClear}}$. The bias for $I_{\mathrm{HC3McClear}}$ is similar to or smaller than that for I_{HC3v3} for all cases.

The standard-deviation ranges from 20.6 to 27.1 J cm^{-2} for I_{HC3v3}. In all cases, the standard-deviation is smaller for $I_{\mathrm{HC3McClear}}$ than that for I_{HC3v3}, and ranges from 19.7 to

25.2 J cm^{-2}. Like previously, the smaller standard-deviation may be linked to the better correlation coefficient observed for $I_{HC3McClear}$. The RMSD is less for $I_{HC3McClear}$ than for I_{HC3v3}. It ranges between 19.8 and 25.3 J cm^{-2}. Like for 15 min irradiation, Table 4 shows that the combination of HC3 and McClear brings a benefit for 1 h irradiation for the six studied stations.

Table 5 reports the results of the comparison for daily irradiation. The correlation coefficient for $I_{HC3McClear}$ is large, greater than 0.93, except for Aswan (0.92), Brasilia (0.86) and Bulawayo (0.85). For all stations except Asyut and Aswan, the correlation is greater for $I_{HC3McClear}$ than for I_{HC3v3}. The day-to-day changes in daily irradiation are well reproduced by I_{HC3v3} and slightly better by $I_{HC3McClear}$.

The bias ranges between −128 and 241 J cm^{-2} for I_{HC3v3}. The bias for $I_{HC3McClear}$ is similar or smaller for 16 stations out of 23, and ranges between −85 and 264 J cm^{-2}. Several stations exhibit spectacular decreases, such as Rucana: from 91 J cm^{-2} down to −11 J cm^{-2}, Thessaloniki: from −74 J cm^{-2} down to 3 J cm^{-2}, or Maputo: from 180 J cm^{-2} down to 65 J cm^{-2}. Seven stations exhibit greater bias for $I_{HC3McClear}$ than for I_{HC3v3}: Valentia, Camborne, Nice, Mersa Matruh, El Arish, Tamanrasset, Bulawayo.

The standard-deviation for $I_{HC3McClear}$ ranges from 102 (Uccle) to 292 J cm^{-2} (Bulawayo). It is similar or less than that for I_{HC3v3} except for Asyut and Aswan. The RMSD for $I_{HC3McClear}$ ranges from 102 to 394 J cm^{-2}, that is from 6 % to 20 % of the mean observed value. It is similar or less than that for I_{HC3v3}, with the exception of Asyut, Aswan and Bulawayo. Actually, the difference in standard-deviation or RMSD is small for these three sites and is less than 15 J cm^{-2}. This is less than the 66 per cent uncertainty required by the World Meteorological Organization for the measurement of the daily irradiation (WMO, 2008) which is 40 J cm^{-2} for $I_{ground} < 800$ J cm^{-2} and 5 % for $I_{ground} > 800$ J cm^{-2}. Taking this into account, it is found that $I_{HC3McClear}$ exhibits similar or better accuracy than I_{HC3v3} for daily irradiation.

One may observe that the relative RMSD for $I_{HC3McClear}$ is less than 12 % in most cases. Exceptions are Toravere (15 %), Rucana (16 %), Camborne (14 %), Valentia

AMTD
7, 7793–7809, 2014

(18 %), Rochambeau (13 %), Brasilia (14 %), and Bulawayo (20 %). These stations are seen with a large viewing angle by the Meteosat satellite. Marie-Joseph et al. (2013) argue that such angles induce shift in actual location of clouds and in conjunction with the large size of the pixel over these stations may contribute to increasing the standard-deviation and RMSD in case of fragmented cloud cover. As a rule of thumb, the farther from the nadir of the Meteosat satellite located at latitude 0° and longitude 0°, and the greater the occurrence of fragmented cloud cover, the greater the relative standard-deviation and RMSD.

4 Conclusions

This technical note proposes a very simple method to improve HC3v3 records by combining it with data records of the irradiation under clear sky from the new clear-sky model McClear. Inputs to McClear are the advanced global aerosol properties forecasts and physically consistent total column content in water vapour and ozone produced by the MACC projects. All irradiation data sets may be retrieved on the SoDa Web site (www.soda-pro.com), and therefore the method is easily applicable. The method can be applied at any scale; it is not necessary to correct HC3v3 at 15 min resolution and then summing up to obtain hourly or daily irradiation. Hourly and daily irradiation can be corrected using corresponding irradiation from McClear.

The method has been validated against ground measurements made at several summarizations: 15 min, 1 h, and 1 day. The correlation coefficient is large, greater than respectively 0.92, 0.94, and 0.97, for 15 min, 1 h and daily irradiation. The bias ranges between −4 and 4 % of the mean observed irradiation for most sites. The relative root mean square difference (RMSD) varies between 14 % and 38 % for 15 min, 12 % and 33 % for 1 h irradiation, and 6 % and 20 % for daily irradiation.

For all studied scales: 15 min, 1 h and 1 day, and almost all stations, the corrected irradiations $I_{HC3McClear}$ are closer to the ground-based measurements than those of I_{HC3v3} obtained with a climatology of the Linke turbidity factor. There are few stations for

AMTD
7, 7793–7809, 2014

which $I_{\mathrm{HC3McClear}}$ does not show better performances than I_{HC3v3}, and in these cases, the difference is not large and less than the 66 per cent uncertainty required for daily irradiation by the World Meteorological Organization (WMO, 2008). It is believed that the main cause of the benefit of this combination of HC3 and McClear is due to the fact that the inputs to McClear: aerosol properties and total column content in water vapour and ozone, are estimated every 3 h. The main advantage of combining HC3v3 and McClear is that the large irradiations are better reproduced. The method brings an improvement in most cases and no degradation in the others and a systematic correction of HC3v3 with McClear is recommended.

Acknowledgements. The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007–2013) under grant agreements no. 283576 (MACC-II project) and no. 262892 (ENDORSE project). The authors thank all ground station operators of the BSRN network for their valuable measurements and the Alfred Wegener Institute for hosting the BSRN website, and acknowledge the help of the Baseline Surface Radiation Network (BSRN), the World Radiation Data Center (WRDC) and the meteorological networks supplying measurements of irradiation to the WRDC.

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AMTD

7, 7793–7809, 2014

Table 1. List of stations, ordered from North to South. Data from 2005 to 2009, except stated otherwise.

Station	Country	Latitude	Longitude	Elevation (m)	Available summarization
Toravere	Estonia	58.250	26.467	70	15 min, 1 h, 1 d
Rucana	Latvia	56.150	21.167	18	1 d
Hamburg	Germany	53.633	10.000	16	1 d
Valentia	Ireland	51.933	−10.250	9	1 d
Uccle	Belgium	50.800	4.350	100	1 d
Camborne	UK (2004–2007)	50.217	−5.317	88	15 min, 1 h, 1 d
Wien	Austria	48.250	16.367	203	1 d
Kishinev	Moldova (2005–2007)	47.000	28.817	205	1 d
Payerne	Switzerland	46.815	6.944	491	15 min, 1 h, 1 d
Carpentras	France	44.083	5.059	100	15 min, 1 h, 1 d
Nice	France	43.650	7.200	4	1 d
Thessaloniki	Greece (2005–2006)	40.633	22.967	60	1 d
Casablanca	Morocco (2005)	33.567	−7.667	62	1 d
Mersa Matruh	Egypt	31.333	27.217	25	1 d
El Arish	Egypt	31.083	33.750	31	1 d
Sede Boqer	Israel	30.905	34.782	500	15 min, 1 h, 1 d
Asyut	Egypt (2005–2007)	27.200	31.167	52	1 d
Aswan	Egypt	23.967	32.783	192	1 d
Tamanrasset	Algeria (2005–2007)	22.783	5.517	1378	15 min, 1 h, 1 d
Rochambeau	French Guiana	4.822	−52.365	4	1 d
Brasilia	Brazil (2006–2007)	−15.601	−47.713	1023	1 d
Bulawayo	Zimbabwe (2005)	−20.150	28.620	1343	1 d
Maputo	Mozambique	−25.967	32.600	70	1 d

AMTD
7, 7793–7809, 2014

Improving HelioClim-3 estimates of surface solar irradiance

Z. Qu et al.

Table 2. Comparison of correlation coefficient for 15 min irradiation and clearness index. Best values are in bold.

Station	I_{HC3v3}	$I_{HC3McClear}$	KT_{HC3v3}	$KT_{McClear}$
Toravere	0.921	**0.924**	0.765	**0.773**
Camborne	0.950	**0.952**	0.829	**0.830**
Payerne	0.958	**0.959**	0.846	**0.853**
Carpentras	0.970	**0.972**	0.842	**0.845**
Sede Boqer	0.973	**0.975**	0.829	**0.846**
Tamanrasset	0.965	**0.970**	0.824	**0.830**

AMTD
7, 7793–7809, 2014

Table 3. Comparison of differences for 15 min irradiation, in J cm^{-2}. The mean value is obtained from the measurements. First value is I_{HC3v3}, second is $I_{HC3McClear}$, with best value in bold. Bias and RMSD of $I_{HC3McClear}$ relative to the mean irradiation are given in brackets.

Station	Mean 15 min irradiation	Bias	Standard-deviation	RMSD
Toravere	20.5	0.3/**−0.1** (0 %)	7.9/**7.8**	7.9/**7.8** (38 %)
Camborne	23.2	**0.4**/0.5 (2 %)	6.8/6.8	6.8/6.8 (29 %)
Payerne	25.5	−1.6/**−0.3** (−1 %)	6.8/6.8	7.0/**6.8** (27 %)
Carpentras	31.9	0.6/0.6 (2 %)	6.3/**6.1**	6.4/**6.2** (19 %)
Sede Boqer	47.6	−3.0/**−1.8** (−4 %)	6.5/**6.4**	7.1/**6.6** (14 %)
Tamanrasset	47.6	**1.3**/1.7 (4 %)	8.2/**7.7**	8.3/**7.8** (16 %)

AMTD
7, 7793–7809, 2014

Table 4. Comparison of differences for hourly irradiation, in $J\,cm^{-2}$. The mean value is obtained from the measurements. First value is I_{HC3v3}, second is $I_{HC3McClear}$, with best value in bold. Bias and RMSD of $I_{HC3McClear}$ relative to the mean irradiation are given in brackets.

Station	Mean hourly irradiation	Bias	Standard-deviation	RMSD	Correlation coefficient
Toravere	76.8	1.1/-**0.4** (−1 %)	25.9/**25.2**	25.9/**25.2** (33 %)	0.945/**0.949**
Camborne	87.4	**1.6**/2.0 (2 %)	21.5/**21.2**	21.5/**21.3** (24 %)	0.968/**0.970**
Payerne	95.0	−5.9/**−1.2** (−1 %)	20.9/**20.8**	21.8/**20.8** (22 %)	0.974/**0.976**
Carpentras	120.4	2.3/**2.2** (2 %)	20.6/**19.7**	20.7/**19.8** (16 %)	0.980/**0.982**
Sede Boqer	184.3	−11.1/**−6.8** (−4 %)	20.8/**20.1**	23.5/**21.2** (12 %)	0.984/**0.985**
Tamanrasset	179.8	**4.9**/6.5 (4 %)	27.1/**24.4**	27.5/**25.3** (14 %)	0.977/**0.982**

AMTD
7, 7793–7809, 2014

Table 5. Comparison of differences for daily irradiation, in $J\,cm^{-2}$. The mean value is obtained from the measurements. First value is I_{HC3v3}, second is $I_{HC3McClear}$, with best value in bold. Bias and RMSD of $I_{HC3McClear}$ relative to the mean irradiation are given in brackets.

Station	Mean daily irradiation	Bias	Standard-deviation	RMSD	Correlation coefficient
Toravere	1237	30/**8** (1 %)	204/**184**	206/**184** (15 %)	0.969/**0.974**
Rucana	1336	91/**−11** (−1 %)	237/**211**	254/**211** (16 %)	0.966/**0.971**
Hamburg	1112	−26/**6** (1 %)	114/**110**	117/**111** (10 %)	0.989/**0.991**
Valentia	1065	**42**/49 (5 %)	200/**188**	205/**194** (18 %)	0.968/**0.972**
Uccle	1113	−23/**20** (2 %)	**108**/110	**111**/112 (10 %)	0.990/**0.991**
Camborne	1150	**24**/38 (3 %)	169/**156**	171/**160** (14 %)	0.978/**0.982**
Wien	1237	−36/**0** (0 %)	119/**124**	124/124 (10 %)	0.989/0.989
Kishinev	1348	37/**21** (2 %)	171/**154**	175/**156** (12 %)	0.980/**0.984**
Payerne	1275	−79/**5** (0 %)	145/**138**	165/**138** (11 %)	0.985/**0.987**
Carpentras	1552	28/**27** (2 %)	162/**126**	164/**129** (8 %)	0.982/**0.989**
Nice	1589	**48**/60 (4 %)	152/**130**	160/**143** (9 %)	0.984/**0.988**
Thessaloniki	1646	−74/**3** (0 %)	128/**102**	148/**102** (6 %)	0.988/**0.992**
Casablanca	1954	−45/**−44** (−2 %)	176/**172**	181/**178** (9 %)	0.972/**0.974**
Mersa Matruh	1853	**−36**/52 (3 %)	185/**165**	189/**173** (9 %)	0.962/**0.972**
El Arish	1754	**−16**/53 (3 %)	205/**177**	206/**185** (11 %)	0.956/**0.964**
Sede Boqer	2087	−128/**−85** (−4 %)	151/**134**	198/**159** (8 %)	0.978/**0.984**
Asyut	2092	94/**84** (4 %)	**168**/185	**193**/204 (10 %)	**0.962**/0.951
Aswan	2230	−26/**15** (1 %)	**175**/190	**177**/191 (9 %)	**0.933**/0.920
Tamanrasset	2319	**58**/76 (3 %)	236/**186**	229/**170** (7 %)	0.903/**0.951**
Rochambeau	1750	157/**123** (7 %)	221/**200**	271/**234** (13 %)	0.927/**0.934**
Brasilia	1964	205/**162** (8 %)	257/**228**	328/**280** (14 %)	0.815/**0.857**
Bulawayo	1948	**241**/264 (14 %)	300/**292**	**385**/394 (20 %)	0.842/**0.852**
Maputo	1801	180/**65** (4 %)	215/**201**	281/**211** (12 %)	0.944/**0.951**

AMTD
7, 7793–7809, 2014