The AQI applied to Chinese monitoring data

D2.3 Part III

Task 2.2 Air Quality Communication

Sef van den Elshout

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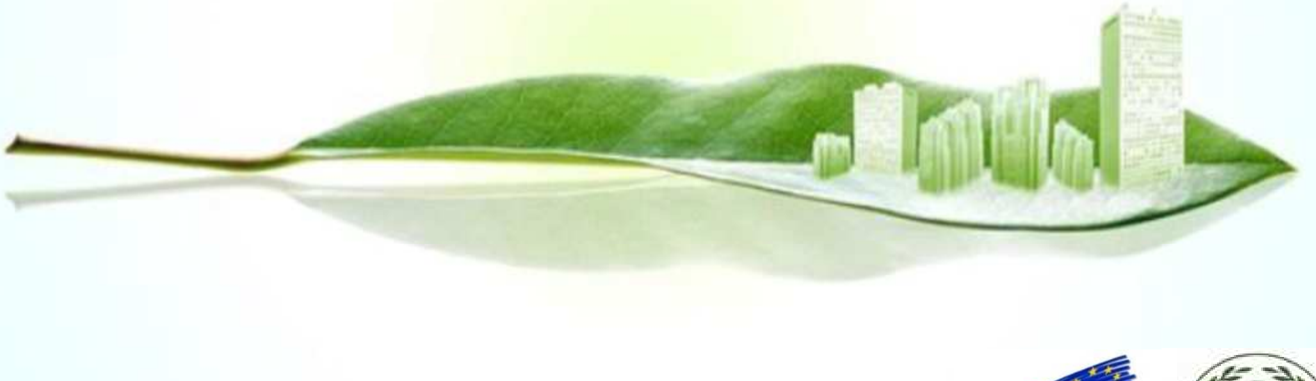

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Summary and conclusions

This document presents the results of data analysis of Chinese monitoring data used with the Chinese and some other AQI-s. In this report we test some of the issues raised in the previous two documents that are part of deliverable 2.3.

Based on the results we make recommendations about changes to the AQI grid. All recommendations are made from a **communication perspective** and deal with improving the consistency of the AQI calculation. **We do not comment on the AQI levels as such.** Our reference is the daily AQI calculation and the daily PM_{10} grid. All suggested changes are relative to this base case. This implies that the changes proposed in this document will not affected the average results of the official daily AQI report. In that sense they are simply optimisations.

Data

The data used were obtained from an online source that gets their data from the CNEMC[1] website. All data used are unvalidated data that only underwent basic data cleaning as part of this study. The data we obtained in this way over a year's time is far from complete. We are nevertheless confident that we managed to obtain a meaningful sample from all over the country.

PM_{10} and $PM_{2.5}$

The AQI breakpoint grid for $PM_{2.5}$ should be made consistent with the PM_{10} grid. This has two advantages:

- The iAQI-s for PM_{10} and $PM_{2.5}$ can provide additional information on the nature of the particulate pollution (e.g. predominantly coarse or fine pollutants (or evenly distributed) as the grids are no longer biased to either of the two pollutants (on average).
- If one of the two pollutants is missing, it is less likely that the resulting AQI will be strongly biased. Since PM_{10} is missing more often than $PM_{2.5}$ in the current situation either no AQI is available to inform the public or the AQI could be (downward) biased.

Making the iAQI grids for the PM species consistent does not affect (on average) the level of the AQI report (as was shown in section 3.3). The ratio $PM_{2.5}/PM_{10}$ to be used for the country is 0.56. This is in line with ratios found elsewhere in the world.

Daily and hourly AQI

The daily and hourly AQI reports currently produce different results. It is possible and desirable to improve the consistency between the hourly and daily AQI reports.

The current hourly index is dominated by PM (94%) of the time whilst in the daily index this is only 63%. This is mainly due to the fact that an inappropriate hourly PM iAQI-grid is used: the AQI grid from daily averaged PM measurements. **We strongly recommend to change this and make a proper hourly AQI grid for PM**.

The hourly grids for NO_2 and O_3 would also need to be redefined to make them more in line with the true behaviour of the data. This will increase their occurrence in the hourly AQI and make the hourly AQI more consistent with the daily AQI reports.

O_3 plays a role in the daily AQI during 24% of the time. In the hourly AQI this disappears completely and a major overhaul of the O_3 iAQI would be needed to overcome this. O_3 mainly dominates the AQI in the first two bands so from the Chinese perspective of warning the public this change is not very important.

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[1] China National Environmental Monitoring Centre.

International context

If different international indices are used to interpret the Chinese air quality one gets different results. European indices rate the Chinese air quality as quite bad/unhealthy. The Hongkong AQHI produces results similar to the EU indices. Though the US AQI rates the air quality as worse than the Chinese AQI, the two resemble each other and produce markedly better ratings than the other indices studied.

Given the current air quality, China needs an AQI with a breakpoint grid that covers the occasionally very high concentrations. Even the current Chinese AQI produces very high results too often (from a risk communication point of view) so all of the other indices would be less suitable. At the lower end of the scale, the Chinese AQI labels many hours as good/healthy. All other indices classify only a small number of hours in these categories. As there is some kind of epidemiological objectivity to the risk of health effects, these results suggest that the Chinese AQI labels too many hours as “good”.

1. Introduction

In documents D2.3 - part I and D2.3 - part II several aspects of the revised Chinese AQI as well as AQI characteristics in general are discussed. Since its revision in 2012 (HJ633-2012, on trial) the Chinese AQI has undergone another change in 2014: for the real-time hourly report one has switched from a 24-hour moving average PM concentration to hourly concentrations.

In this document we apply Chinese monitoring data to the original API (Air Pollution Index), the AQI and its revised version. In addition we compare the Chinese AQI to some other AQI-s using Chinese monitoring data. In the two previous reports some suggestions were made that could improve the AQI. In this document we test the suggestions using real Chinese monitoring data. Though there is data for CNEMC stations from over the whole country, our analysis mainly focusses on Beijing, Shanghai, and the three project cities Yangzhou, Taiyuan and Urumqi.

An AQI is a communication tool that simplifies and aggregates measurements of different pollutants into a single relative number, usually on an arbitrary scale. There are no right or wrong AQI grids and the many AQI-s used around the world are witness of the large variety of approaches. Having said this, one can still look at AQI properties both from a communication perspective (see D2.3 / part I. and part II) and from a perspective of consistency: do the grid breakpoints fit the behaviour of the data? In particular, if hourly and daily AQI reports are released (as in China) one can ask the question: do the averaging times convey, on average, the same results (AQI level, pollutant determining the AQI)?

In this document we will look at these consistency issues (chapters 3 and 4) and occasionally make recommendations on the existing Chinese calculation grid. If we recommend to make one thing more consistent with another the choice which one to adapt is of course arbitrary. In this document we generally depart from the grids for the 'oldest' pollutants (e.g. the **daily grids** for PM_{10}, NO_2 and SO_2 as these pollutants already occurred in the AQI's predecessor, the API) and suggest improvements relative to them. This doesn't mean that we think that this is the only, or the best option to improve consistency. Furthermore we don't make recommendations on the absolute breakpoint levels of the pollutants. Any changes proposed here are just examples of how to improve consistency.

Secondly we look at the current Chinese AQI and compare it to the previous API and to other AQI-s. (see chapter 5). The comparison of AQI-s is further supported by an AQI calculator described in Annex 3. For easy reference the annex includes the description of the AQI-s used in this report even though most of them have been described in parts I and II as well.

Please note: as we will discuss in the data acquisition (chapter 2), our access to Chinese monitoring data was indirect. Our recommendations are valid to the best of our knowledge but before any of them are considered **an analysis on validated data** is recommended. The work presented here can serve as an example.

2. Data used for this study

2.1. Data acquisition and cleaning

At the start of the AirINFORM project a request for time series of Chinese monitoring data was made. However, we were unable to obtain validated data so this study uses unvalidated data.

CNEMC publishes validated data in an aggregate way: an AQI value per city per day and the dominant pollutant at the time.[2] CNEMC's unvalidated monitoring data are shown online in real-time and various non-government apps/websites manage to capture these data to make their own air quality/AQI presentations. We managed to obtain unvalidated data through one of these sources. The website http://pm25.in/ publishes CNEMC data and several other websites and apps use them (see http://pm25.in/sharer).

When we started the data download we verified its correctness by comparing the download and what was published on the CNEMC website (one station, one day). The timing of the download appeared important. If the data arrived in time at the CNEMC website they appeared correct in our download. **Whatever is reported here is based on these *unvalidated* data obtained in this indirect way.** A sample of our data was compared to the official daily report of the CNEMC website and the results showed good agreement (see section 2.2.2).

The study period was from 9-July-2013 to 14- June 2014, covering almost a year and including a winter season when the air quality is often notoriously poor. The dataset we obtained comprised 5,806,817 hourly observations from up to 945 monitoring stations. Some 600.000 records were duplicates probably due to data transfer issues (repeated querying). Duplicates were deleted.

The study period had 8149 hours. We obtained data for 7134 hours (88%). What the problem was during the remaining hours is not known. Probably one of the other systems in the acquisition chain (from CNEMC monitoring site - via two websites - to our download) was temporarily unavailable. There were 679 cases where one or more successive hours were missing. In only a minority of cases (88) two or more consecutive hours were completely missing. This, together with the duplicate hours, suggests that the data capture in general was fairly complete (number of hours), yet there were problems for many monitoring sites as at several sites many successive hours were missing as we shall see.

The number of stations that were delivering monitoring data increased over time and almost doubled over a few months' time. A rapid expansion can lead to initial performance problems. In December this led to an hour where only data from 1 station was available. On the other hand if they were start-up problems they lasted quite long and from December onward also the existing monitoring sites showed poor coverage. We therefore assume that data transmission problems (the volume of data to be transmitted obviously also increased), either at the CNEMC side or in the public part of the data acquisition chain we had to use, was the cause. The deterioration of the performance standards also coincided with the onset of the winter season but continues into spring and summer so a seasonal effect doesn't seem to be the explanation neither.

The dataset contains both hourly observations and 24-hour moving averages as well as 8-hour moving averages for O_3. The CO values are recorded in mg/m^3 the others in µg/m^3. In this report CO was converted to µg/m^3 by multiplying all entries with 1000. Policies on the use of error codes in the database were unknown. We observed a substantial number of '9999' values as well as '0' and '-10'. There were no empty fields hence we assume that '0' is a missing value.

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[2] http://datacenter.mep.gov.cn/report/air_daily/air_dairy_en.jsp. Previously this website showed the API. Currently it shows AQI and (therefore?) no data before 1-1-2014 seemed to be available. (Last accessed 3-10-2014)

Table 1: data availability

Month	07*	8	9	10	11	12	1	2	3	4	5	06*
# hours with no data from any station	11	30	27	45	31	85	77	79	90	97	93	14
Available # monitoring stations	509	509	509	509 / 670	670	670	945	945	945	945	945	945
Average % stations delivering	100	100	100	100	99	99	99	98	99	98	94	79
Minimum % delivering	51	28	100	90	2	<1	<1	1	<1	<1	5	1

* Incomplete months.

The moving averages in the dataset were not used. CNEMC provides only hourly data on their website so the moving averages were calculated by the intermediate source that we used. All data in this study other than the hourly values were calculated from the hourly values obtained after data cleaning (as described in the next section). Note that calculating proper 24- or 8- hour moving averages was problematic due to many missing data.

Table 2: concentration data whole 'raw' dataset (5276584 records).

	CO (µg/m^3)	NO_2 (µg/m^3)	O_3 (µg/m^3)	PM_{10} (µg/m^3)	$PM_{2.5}$ (µg/m^3)	SO_2 (µg/m^3)
Average	1202	38.5	46.3	100.0	65.8	37.2
Min	-10000	-10	-10	-10	-10	-10
Max	90000	2108	1200	14294	86279	1598
St.deviation	1294	31.5	45.8	106.2	96.4	52.7

For the purpose of the study some data cleaning was undertaken to obtain a set of '**cleaned data'**:

- All concentrations below 0.01 were deleted, this way we avoid the confusion with missing values and 0 concentrations are unlikely;
- Concentrations >= 9999 (99999 for CO) were deleted as they are highly unlikely and we avoid the confusion with a potential specific coding of 9999;
- Days with more than 24 hourly entries were deleted (data transfer errors);

So far this is normal data cleaning. For the purpose of this study we applied two additional criteria to obtain a reduced set of '**complete day data'**:

- Hours where pollutants were missing were deleted (incomplete AQI calculation). Approximately 27% of the data was lost due to this criterion.
- For some analyses, days with less than 21 hours of 'cleaned' observations were deleted (sufficient data is needed to calculate daily values. Generally the minimum requirement would be 18 available hours for each individual pollutant for ordinary reporting but since we explicitly study the relation between hourly and daily observations this criteria was tightened. This causes an additional data loss of 48%.

After this procedure the so called 'complete day data' remain with 1,325,443 records of hourly observations. It covers 936 monitoring stations and the percentage of 'cleaned' hours per station varied from 0.3 to 58%. The dataset contains 59923 days satisfying the above completeness criteria.

This reduced set, meeting all criteria, is used in this study when reporting country averages, monthly averages, etc. When we zoom in on for example on a city and look at hourly values, some of these criteria are relaxed (set 'cleaned data') to assure the availability of sufficient hours to do meaningful calculations.

Applying cumulative completeness criteria as describe above rapidly reduces the number of available hours with a complete dataset. E.g. if each of the individual pollutants meets the 90% availability criterion, in the worst case one could still end up with only 53% (0.9^6) of the available hours. In this case the availability of all pollutants was 91 to 92%, except PM_{10} for which it was 82%. Why the PM_{10} availability is 10% less than all other pollutants is unclear. The effective availability of hours with complete data was 73% (of the hours where the download was successful!)

This implies that in principle the AQI cannot be calculated in 27% of the cases! Since PM_{10} appears to be a limiting factor, finding a grid where PM_{10} ***or*** $PM_{2.5}$ could be used for AQI calculation would greatly enhance the AQI availability.

2.2. Data characteristics

2.2.1. Subset characteristics

The overall characteristics of 'complete day data' are shown in table 3. Compared to the raw data (table 2.) the averages have gone slightly up due to the fact that "0-s" and "-10-s" were omitted. The maxima are somewhat lower but never attain the maximum of the filter used ('9999'). Apparently the very high values occurred on days that didn't meet the completeness criteria used. Note that even this cleaned dataset contains anomalies as at least in 1 one case the ratio $PM_{2.5}/PM_{10}$ >1.

Table 3: concentrations of the sample 'complete day data' (unvalidated hourly data after all cleaning procedures; 1325443 observations)

	CO (µg/m^3)	NO_2 (µg/m^3)	O_3 (µg/m^3)	PM_{10} (µg/m^3)	$PM_{2.5}$ (µg/m^3)	SO_2 (µg/m^3)	Ratio $PM_{2.5}/PM_{10}$
Average	1249	41.5	50.9	120.6	67.7	41.3	0.56
Min	1	1	1	1	1	1	0.00
Max	9998	1469	1200	7079	1371	1570	4.76
St. deviation	953	28.9	44.3	99.5	62.4	52.3	0.19

The standard deviations are somewhat lower but remained fairly identical. The completeness checks removed at least some absurdly high concentrations (note that in the previous table the $PM_{2.5}$ maximum was higher than the PM_{10} maximum).

A further selection of 41 stations was made to get a more manageable dataset to explore. This set comprises the CNEMC stations from Beijing, Shanghai and from the three project cities Taiyuan, Urumqi and Yangzhou. The average characteristics of this subset are quite similar to the country averages. NO_2 is slightly higher probably due to the fact that this is a uniquely urban environment with a substantial traffic contribution. PM_x and SO_2 levels are on average somewhat lower suggesting a less than average influence of industrial sources? See table 4.

Frequency distributions of the concentrations of all datasets are shown in Annex 1. The various selections have quite similar concentration distributions so the subsets are reasonably representative for the whole data set and can be used to illustrate the behaviour of the phenomena studied.

Table 4: five city sample (44932 hourly observations from set: complete day data)

	CO ($\mu g/m^3$)	NO_2 ($\mu g/m^3$)	O_3 ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	SO_2 ($\mu g/m^3$)	Ratio $PM_{2.5}/PM_{10}$
Average	1237	44.6	49.7	113.9	57.9	35.0	0.51
Min	2	1	1	4	1	1	0.01
Max	9400	360	644	1923	574	662	1.00
St.deviation	961	31.1	47.3	96.3	52.7	41.7	0.20

2.2.2. Comparing sample data to official data

As a check on data correctness we downloaded official data from the MEP website. These data cannot be compared directly. The official data is validated and all monitoring stations in a city are averaged for the day. We work with unvalidated hourly data averaged to daily data (or 8-hour maximum average for O_3) at individual monitoring stations. The MEP validated data contain almost complete city daily reports, whereas our dataset is far from complete. This is partly because we applied strict completeness criteria needed for this research. However it also confirms our assumption that the online data presentation that we used as a source is occasionally incomplete whereas the data are available, perhaps at a later time, for offline validation, analysis and reporting.

In this section we compare the official AQI for the 5 cities that we studied over the period January-until 6th of June 2014 to our data for the same period. See table 5. The results show a very good agreement between the two data sets. Considering that averaging reduces the extremes it is expected that the official data tend to be a little more frequently in the lower classes and this is the case (53 compared to 44%). Looking at the pollutant determining the AQI we also see a satisfactory agreement. Surprisingly for 6% of the official data no pollutant was identified despite the fact that the AQI was calculated.

Table 5: comparing official validated data and data acquired in this study (5 city sample, January - June 2014)

AQI determined by:	**Validated official data**	unvalidated sample acquired	AQI class		**Validated MEP website**	unvalidated sample acquired
NO_2	**6%**	11%	1	0-50	**4%**	4%
PM_{10}	**31%**	35%	2	50-100	**49%**	40%
$PM_{2.5}$	**47%**	43%	3	100-150	**29%**	33%
O_3	**9%**	8%	4	150-200	**11%**	12%
CO	**0%**	1%	5	200-300	**5%**	9%
SO_2	**0%**	2%	6	300-400	**1%**	1%
missing	**6%**		7	400-500	**1%**	1%

The results demonstrate that the data we obtained are quite plausible and that the data cleaning we undertook did not create a major bias. Note that in this sample we relied on daily maximum 8 hour average O_3.

2.2.3. Temporal patterns, spatial differences

Monthly averages were calculated to demonstrate the temporal variation. The curves show a typical pattern with all pollutants, except O_3, being high in winter when the dispersion conditions are generally less favourable and the demand for heating leads to additional emissions of all primary pollutants. On the contrary the daylight dependent secondary pollutant O_3, is lowest when the days are shorter.

The graphs for Shanghai and Beijing (Figure 3) show similar overall patterns. Shanghai being further south has higher average temperatures. The winter concentration increase coincides with the temperature drops and it is less extreme in Shanghai then in Beijing. (See figure 2.)

What caused the sharp drop in the 2013 November concentrations in Beijing is unknown. One would have expected an increase as the temperatures dropped below 0 for the first time that year. The somewhat erratic behaviour of the curves is probably also due to the fact that for some months relatively few data were available.

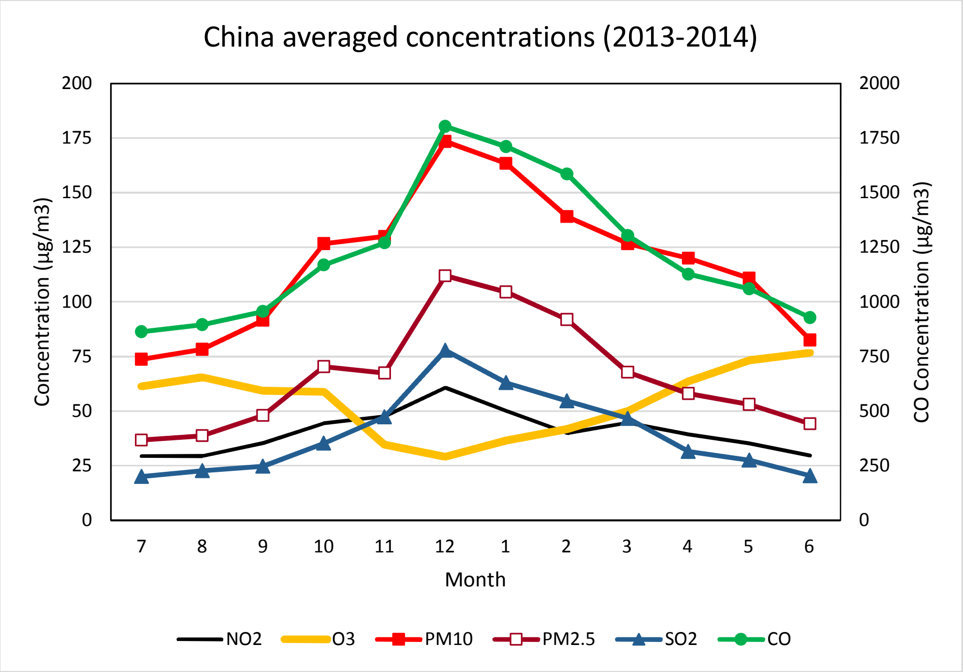


Figure 1: monthly averaged concentrations ('complete day data')

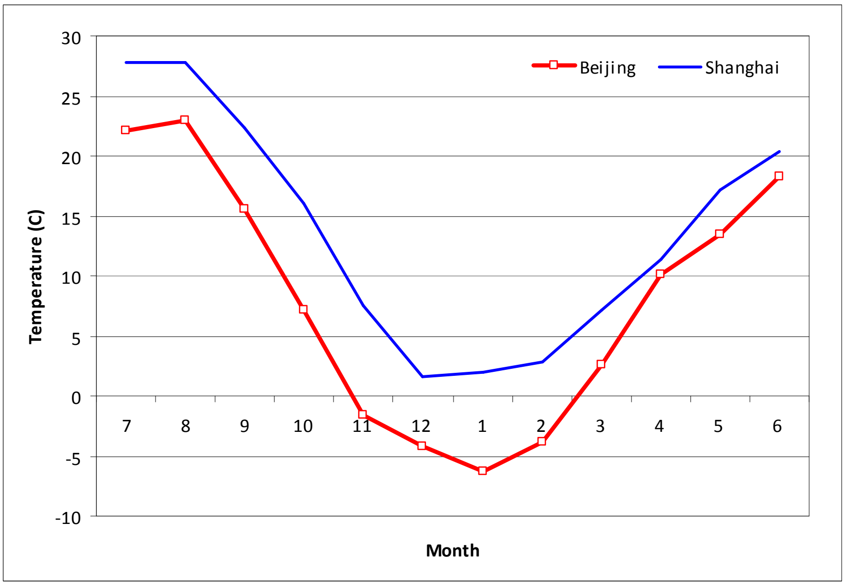
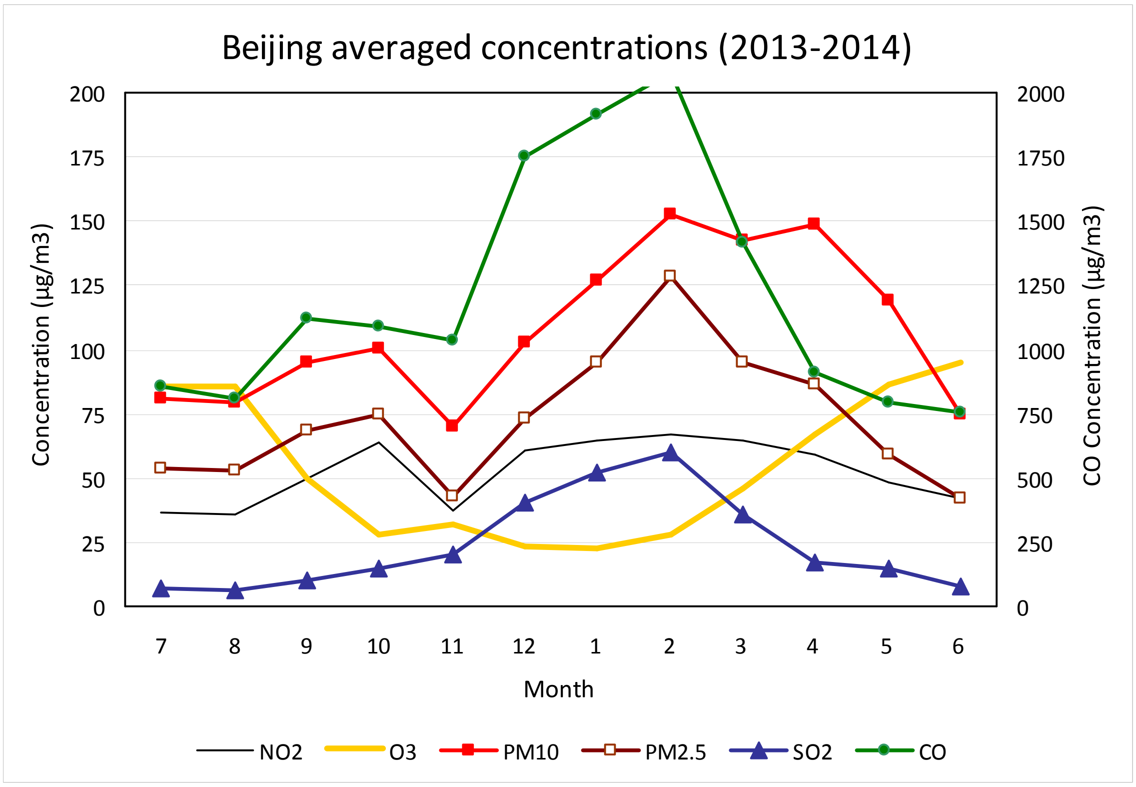


Figure 2: minimum temperatures 2013-2014 in Beijing and Shanghai (Source: www.ncdc.noaa.gov)



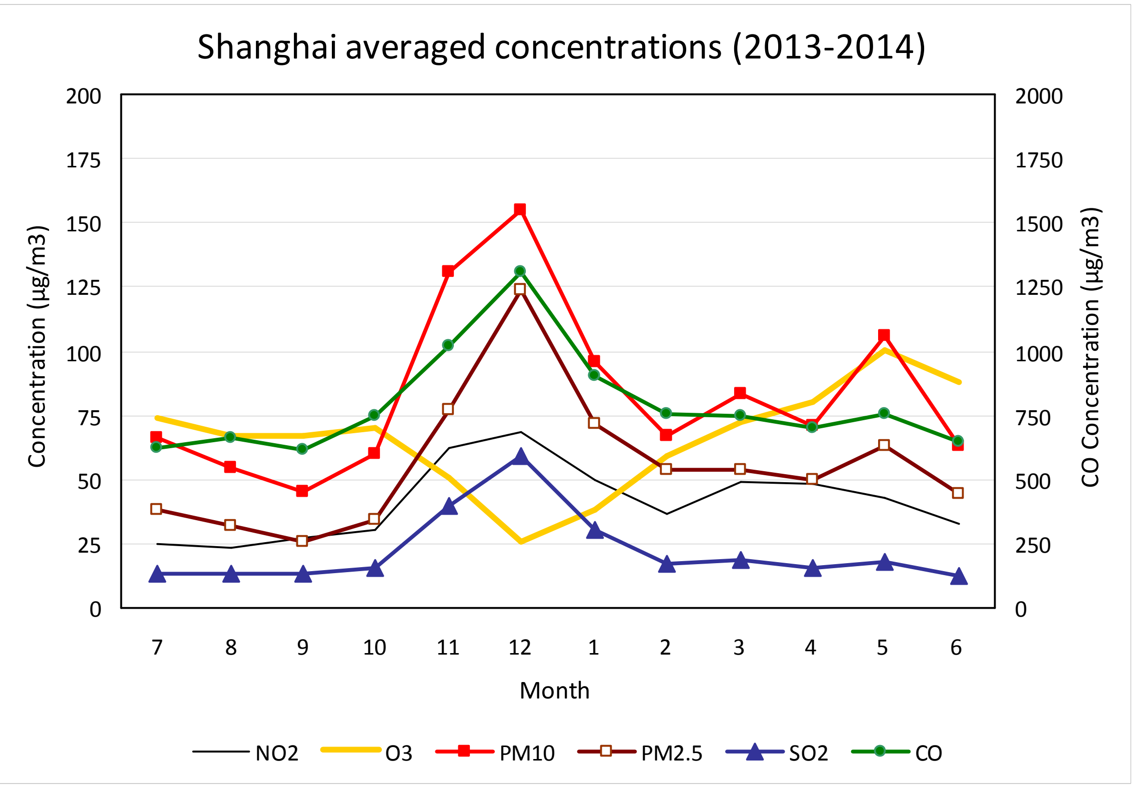


Figure 3: monthly averaged concentrations Beijing and Shanghai ('clean data')

3. $PM_{2.5}$ to PM_{10} ratios

3.1. Observed $PM_{2.5}$ to PM_{10} ratios

The ratio of $PM_{2.5}$ to PM_{10} is determined by the dominant sources of air pollution. In those areas where fugitive dust is an issue the ratio will be low. In places or times when secondary pollutants such as ammonium sulphate and nitrate are the main source of PM (pour dispersion conditions, imported polluted air masses from elsewhere) the ratio will be high (approaching 1).[3] The average for the whole of China is 0.56 (+/- 0.19). One might expect a higher ratio in winter and indeed the highest ratios occur in the month of February.

Table 6: monthly $PM_{2.5}/PM_{10}$ ratios (complete data days)

Month	Whole country Sample	Beijing	Shanghai	Taiyuan	Urumqi	Yangzhou
7	0.51	0.55	0.52	0.54	0.44	0.44
8	0.51	0.60	0.55	0.44	0.41	0.43
9	0.55	0.60	0.52	0.49	0.36	0.52
10	0.56	0.64	0.54	0.43	0.47	0.62
11	0.53	0.45	0.57	0.35	0.62	0.60
12	0.63	0.57	0.74	0.54	0.74	0.69
1	0.62	0.65	0.56	0.57	0.63	0.69
2	0.65	0.75	0.77	0.66	0.61	0.70
3	0.56	0.60	0.57	0.46	0.52	0.62
4	0.53	0.57	0.59	0.40	0.24	0.60
5	0.50	0.38	0.52	0.35	0.28	0.61
6	0.55		0.64	0.35	0.26	

In the whole sample 63% of the observations has a $PM_{2.5}$ to PM_{10} ratio above 0.50 suggesting that secondary aerosol plays a major role in the PM pollution. Figure 4. shows the two pollution phenomena in a scatterplot for the five city subsample. The graph seems to have two branches: one with high $PM_{2.5}$ to PM_{10} ratios (even approaching 1) and one with a ratio between 0.2 and 0.3. Note that a number of monitoring sites seem to have a PM_{10} maximum concentration of 1000 µg/m^3 implemented.

On average the $PM_{2.5}$ to PM_{10} ratio is quite stable over the concentration range. Table 7. shows the ratios observed for each PM_{10} index class. As table 6. already showed, the country averages vary from not only from time to time but also from place to place depending on the nature of the dominant air pollution. Looking at the five city subsample in table 8. one can see the differing behaviour of the PM fractions from place to place. In four of the cities, at higher PM_{10} concentrations, the $PM_{2.5}/PM_{10}$ ratio drops indicating that sandstorms or fugitive dust might play a role. This is particularly true for Urumqi and Beijing. In Yangzhou the finer secondary particulates appear to dominate at high concentration levels.

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[3] The mass of primary particles with a diameter < 2.5 µm is unlikely to have a major impact on the $PM_{2.5}/PM_{10}$ ratio.

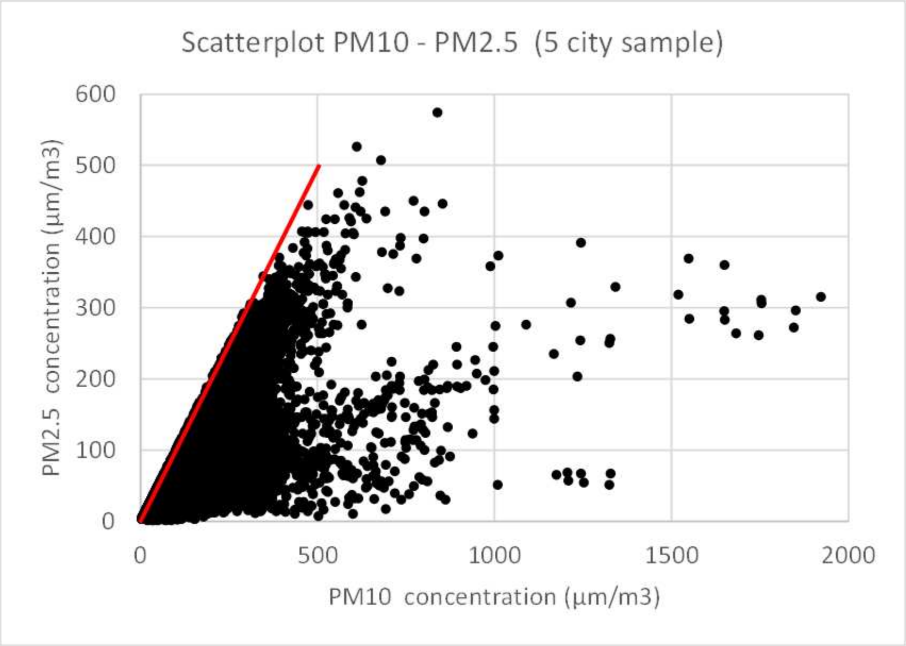

Figure 4: PM scatter plot (5 cities, complete day data)

Table 7: $PM_{2.5}/PM_{10}$ ratios depending on the PM_{10} iAQI class: observed ratios and ratios as defined by the Chinese AQI (complete day data).

PM_{10} iAQI class		$PM_{2.5}/PM_{10}$ ratio		Average concentrations in this iAQI class		# hours in sample
		Actually observed	**in use in the current AQI**	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)	
1	0-50	0.55	**0.70**	19	34	275293
2	50-100	0.56	**0.50**	51	92	701293
3	100-150	0.57	**0.46**	108	190	232927
4	150-200	0.57	**0.43**	166	290	74366
5	200-300	0.58	**0.60**	219	380	19782
6	300-400	0.58	**0.70**	265	454	10538
7	400-500	0.58	**0.83**	315	543	5928
>	>500	0.51		378	791	5316

Table 8: five city sample: $PM_{2.5}/PM_{10}$ ratios by iAQI class (complete day data)

iAQI PM_{10}	Beijing	Shanghai	Taiyuan	Urumqi	Yangzhou
0-50	0.50	0.54	0.50	0.55	0.48
50-100	0.58	0.57	0.46	0.45	0.51
100-150	0.66	0.64	0.49	0.44	0.62
150-200	0.71	0.52	0.53	0.43	0.63
200-300	0.67	0.34	0.51	0.39	0.74
300-400	0.60	0.33	0.49	0.36	0.73
400-500	0.47		0.42	0.32	0.81
>500	0.24		0.42	0.22	
Average	0.59	0.56	0.48	0.45	0.52

3.2. $PM_{2.5}$ to PM_{10} ratios in the revised AQI

Looking at the observed $PM_{2.5}$ to PM_{10} ratios and the ratio used in the current AQI that is currently in use (table 7) one can clearly see that – on average – the $PM_{2.5}/PM_{10}$ ratio in the AQI does not fit the ratio of the pollutants as they occur. The ratio in the AQI grid is too high both at the lower and the higher end of the AQI breakpoint scale. This means that in those cases the AQI is likely to favour PM_{10} over $PM_{2.5}$ as the dominant pollutant. In the middle pollution ranges, the ratio is too low. This implies that in these cases $PM_{2.5}$ is selected too often as the main culprit.

If one wants to align the $PM_{2.5}$ and PM_{10} AQI calculation grids one has to assume a ratio that works on average. Worldwide, WHO (2006) estimates that 50% of PM_{10} is $PM_{2.5}$ (hence the recommended threshold values of 50 and 25 µg/m^3 for daily mean values for PM_{10} and $PM_{2.5}$ respectively). For the urban areas in the EU Elshout et al (2013) used 0.6. De Leeuw and Horalek (2009) report ratios between 0.4 and 0.8 for monitoring stations across Europe. The values found in China are also in this range and the country average of 0.56 could be used to match both iAQI grid breakpoints. Currently the ratios between PM_{10} and $PM_{2.5}$ differ widely across the AQI grid.

If the grids were aligned, IAQI-s for PM_{10} and $PM_{2.5}$ could be used to further inform the public on the nature of the particle pollution. Secondly the overall AQI calculation would be less biased in case one of the pollutants is missing. The main shift will occur in the first band, alignment would result in more hours where $PM_{2.5}$ is the dominant pollutant. The other bands either occur less frequent, or the ratio used is much closer to the ratio observed.

Aligning the iAQI breakpoints could be done by either modifying the $PM_{2.5}$ or the PM_{10} AQI breakpoints. For the purpose of consistency it doesn't matter which one is changed. If it is decided to modify the $PM_{2.5}$ grid the monitoring data seem to suggest that the $PM_{2.5}$ breakpoints for bands 1, 6 and 7 could be slightly lowered without affecting – **on average** - the overall AQI outcome. This could be seen as a sign of responsible action as the breakpoints for $PM_{2.5}$ are considered rather high (in parts of) the public opinion. Similarly bands 2, 3 and 4 should ideally be slightly higher. This could be controversial in the public view, as this would also alter the overall AQI result, making it slightly lower.

Please note: aligning the grids will not affect the overall AQI outcome, averaged across the country. In different places the AQI could go slightly up or down. Table 8 shows that Shanghai has a ratio equal to the country average, in other cities the ratio differs so a revised calculation might lead to slightly different AQI results.

3.3. Applying an alternative $PM_{2.5}$ grid

In this section we demonstrate the use of an alternative $PM_{2.5}$ AQI grid. The grid is determined as:

$PM_{2.5}$ breakpoint = PM_{10} breakpoint * 0.56

The results for the five city sample are shown in table 9 and figure 5. The figure shows the cumulative frequency distribution of the AQI with the two $PM_{2.5}$ grids. The alternative $PM_{2.5}$ grid results in a more even behaviour of the two PM fractions throughout the range. At the lower end, the relative prominence of $PM_{2.5}$ increases and at the higher end it decreases. The graph shows that in this particular subsample (5 cities 2013-2014) the $PM_{2.5}$ line doesn't fully coincide with the PM_{10} line. The alternative $PM_{2.5}$ grid was derived from the national average ratio between the two and, as was discussed in the previous section, this differs slightly from place to place.

Looking at table 9 one can see that the impact on the overall AQI for the average of the five cities selected in this sample, is very minor indeed. One could easily harmonise the two grids and benefit from this advantage (less bias when one of the PM value is missing; more info on the nature of PM pollution at a given moment) without the AQI outcome being affected (on average). **This is highly recommended.**

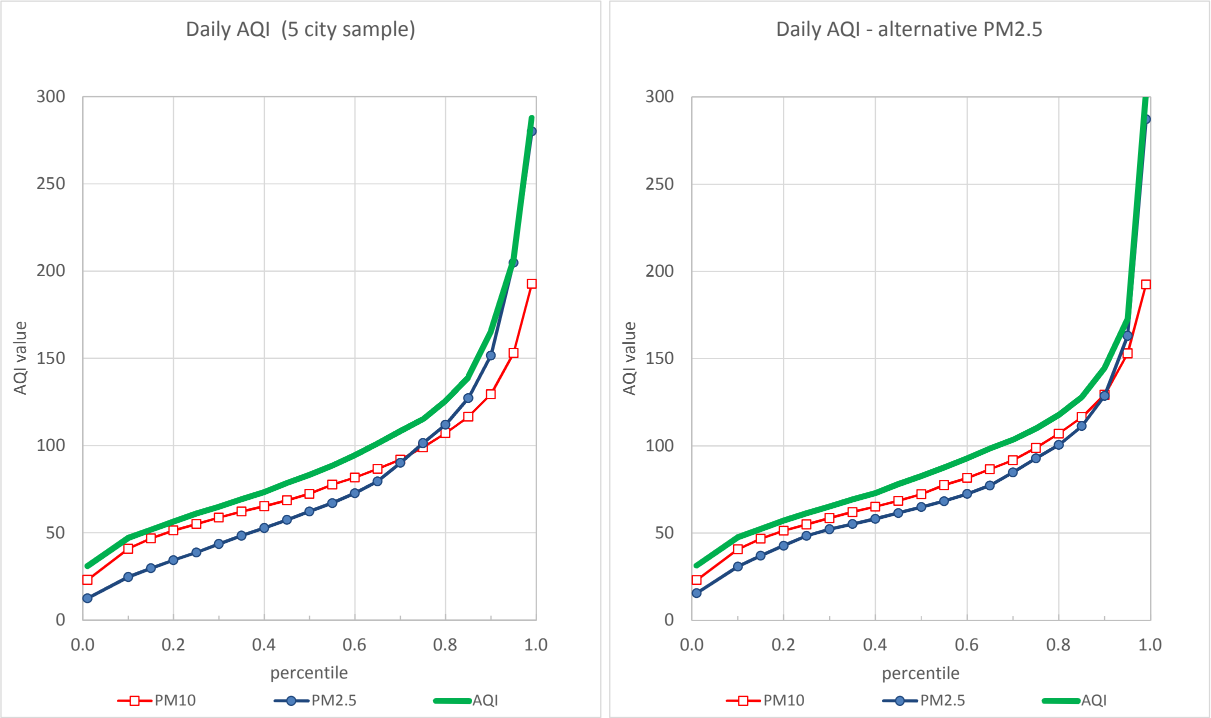

Figure 5: frequency distributions of the AQI and the AQI with an adapted $PM_{2.5}$ grid.

Table 9: frequency (%) of the existing AQI and AQI* with alternative $PM_{2.5}$ grid (5 city sample)

AQI class	**$PM_{2.5}$**	**AQI**	$PM_{2.5}$	AQI*	AQI determined by:	AQI	**AQI***
50	**36**	**12**	26	11	NO_2	11	11
100	**38**	**52**	54	55	PM_{10}	35	36
150	**15**	**24**	14	25	$PM_{2.5}$	27	26
200	**5**	**7**	4	6	O_3	24	24
300	**5**	**5**	2	2	CO	1	1
400	**0**	**0**	1	1	SO_2	1	1
500	**0**	**0**	0	0			
>=500	**0**	**0**	0	0			
Max	**354**	**1010**	442	1010			
Min	**8**	**20**	10	20			
Average	**78**	**103**	76	99			

3.4. Conclusion PM-ratio

The AQI breakpoint grid for $PM_{2.5}$ should be made consistent with the PM_{10} grid (or vice versa). This has two advantages:

- The iAQI-s for PM_{10} and $PM_{2.5}$ provide additional information on the nature of the particulate pollution (predominantly coarse or fine pollutants (or evenly distributed) as the grids are no longer biased to either of the two pollutants (on average).
- If one of the two pollutants is missing, it is less likely that the resulting AQI will be biased. Since PM_{10} is missing more often than $PM_{2.5}$ in the current situation either no AQI is available to inform the public or the AQI could be upward or downward biased (depending on where in the scale the concentrations are.

Making the iAQI grids for the PM species consistent does not affect (on average) the level of the AQI report (as was shown in section 3.3). The ratio $PM_{2.5}/PM_{10}$ to be used for the country is 0.56. This is in line with ratios found elsewhere in the world.

4. Daily and hourly AQI-s

4.1. Introduction

Currently the **Chinese AQI daily report** uses daily averaged concentrations for all pollutants except for O_3 (the maximum 8-hour average). For the **real-time hourly report**, hourly data are used and hourly AQI values are calculated using a specific hourly grid. However, for the two PM pollutants 24h moving average concentrations are used measured against the daily PM grids. Despite the fact that using 24h moving average concentrations are quite common in PM iAQI-s we argued that this is not the best solution. See for example report D2.3 part II, section 1.3.2.

Various (monitoring) organisations in China have argued the same case (a.o. Shanghai EMC), basically reporting that they got complaints that what people experienced was not what was being reported, in particular on days with rapid concentration changes.

Figure 6 shows the average hourly variation in China in the 'complete day data' set. The variation is high for the daylight dependent O_3 (with a peak in the afternoon) and quite moderate for the other pollutants. CO and PM_{10} show a small morning peak (emissions rise as daily activities start when the mixing layer is still low). These pollutants are at their lowest in the afternoon when the atmosphere is generally well mixed. The other pollutants show a similar pattern but less pronounced.

Looking at this country average graph the need for an hourly AQI with a specific calculation grid for hourly concentrations is not very obvious. However this average hides the hour to hour variation in a city at a given day. For example, looking at a day in Urumqi (average of all CNEMC city monitoring sites) one can clearly see the magnitude of variation in the course of the day (on this particular day). See figure 7. The graph also shows why hourly PM data is needed. On this particular day there was a rapid decline of the PM concentrations (possibly due to a change in wind direction). An hourly AQI will immediately show the improvement, whilst an AQI based on a 24-hour moving average would have remained high for the larger part of the day.

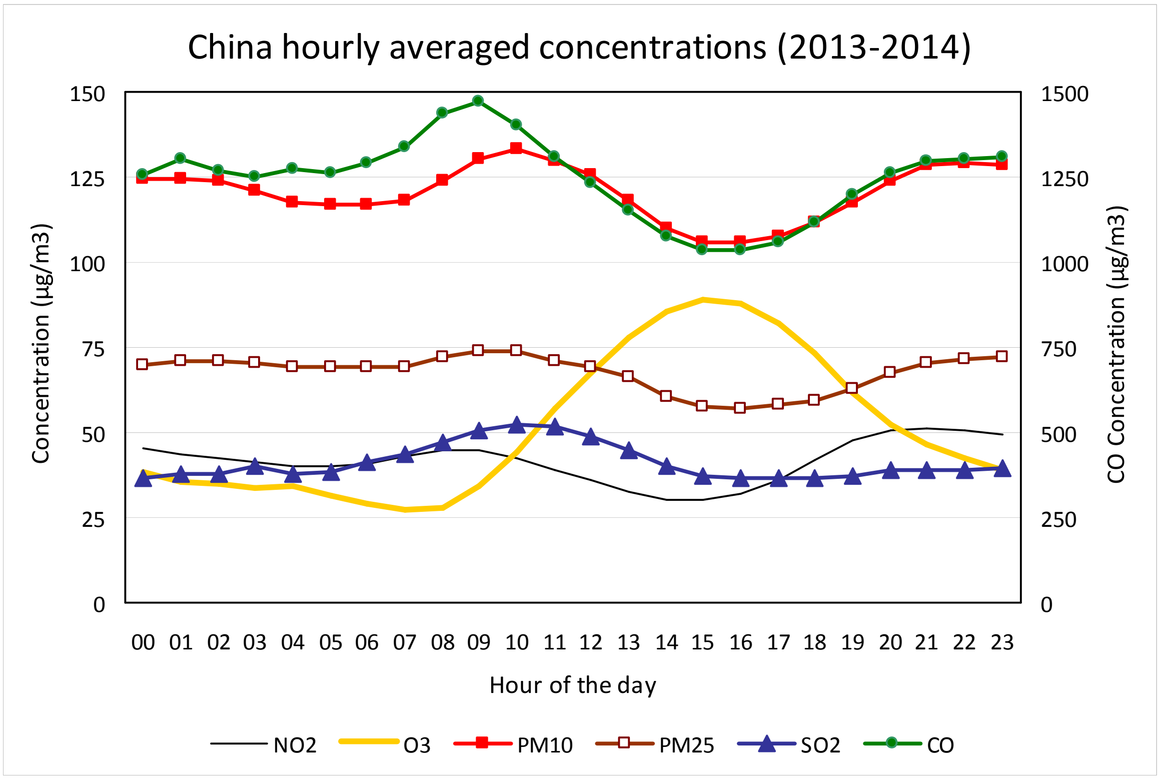

Figure 6: year average diurnal pattern of 6 pollutants (country average)

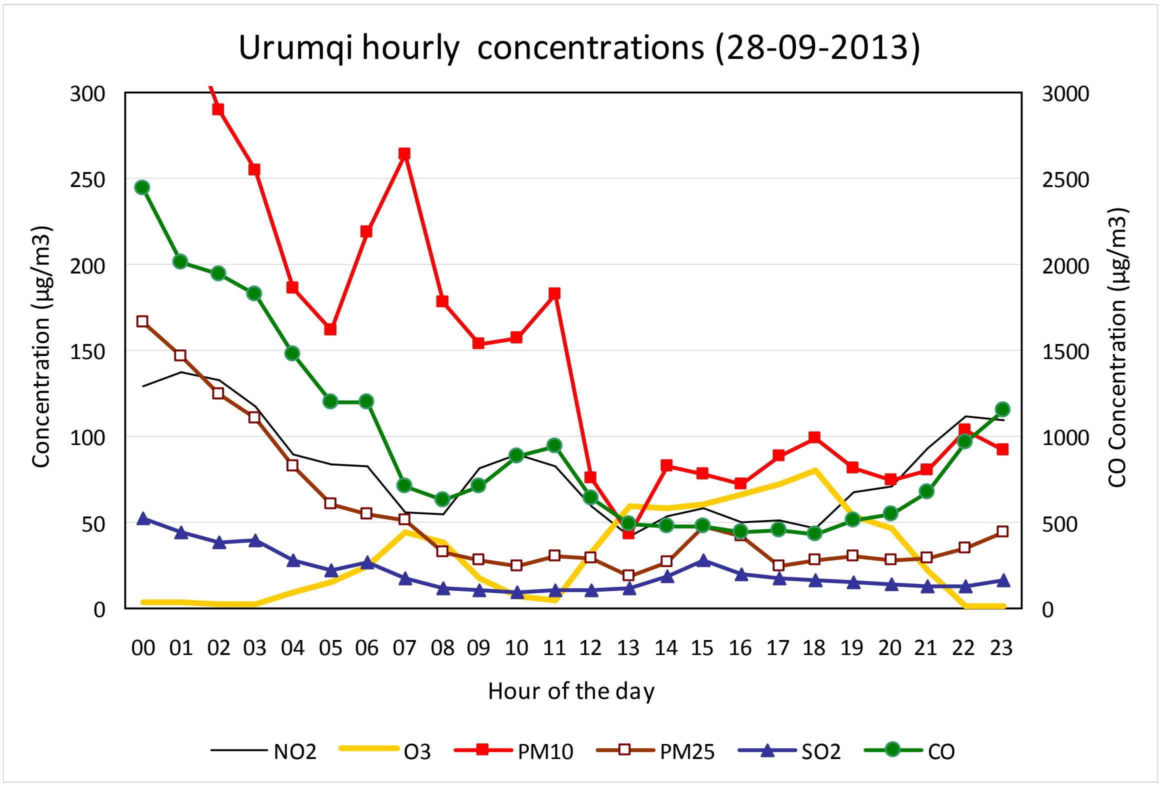

Figure 7: diurnal pattern of 6 pollutants during a single day in Urumqi

In this chapter we study the behaviour of the hourly and daily AQI-s is and recommendations are made for the hourly grids.

4.1.1. Issues using a daily grid for both daily and hourly values

Since April 2014 a few EMC-s for provincial capital cities are reporting hourly PM iAQI values, however, they are still derived from the daily calculation grid[4]. This is suboptimal. Hourly concentrations show more variation than the moving averages so iAQI-values based on hourly measurements judged against a daily calculation grid are:

- too high if they are above the average concentration and too low if they are below the average concentration;[5]
- the daily report will often not match with the hourly reports.

The latter could occur if someone watches the AQI evolution during the day and compares the outcome with the daily report. Though the two (real-time and daily report) can never be identical if the averaging times are different, their consistency can be improved by applying a daily AQI grid to the daily data and an accompanying hourly grid to the hourly data. This is done for some of the other pollutants in the AQI, **so why not for PM?** Currently the hourly PM iAQI-s are sometimes (erroneously!) very high and this won't be reflected in the daily report. Furthermore, people are unduly alarmed or the EMC might suspect that wrong measurements have occurred.

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[4] We expect many of the private made apps did and do the same. None of them explains in full detail how they handle the calculations.

[5] The latter is less important from a communication point of view.

As we shall see, the hourly and the daily AQI differ not only in level but also in the frequency of the pollutant that is too blame. The hourly AQI almost exclusively points to one of the PM fractions, whereas in the daily report NO_2 and O_3 occasionally play a role. Ideally the two AQI-reports should paint the same picture.

Daily and hourly iAQIs, a communication problem.

Ideally the real-time report of the air quality is consistent with the (often more official) daily air quality report. So, if someone looks at a website or an app and sees a high AQI, or iAQI for a certain pollutant at a given hour and day (let us say in band 4) one expects to see the same qualification in the daily report (also a band 4) issued for that day.

If the daily report gives a higher qualification, there is no problem: the person looking at the website/app could assume that he or she has missed the hour that caused the high classification. If however the daily report is lower, there is a problem! The person that has seen the high value could think that the official daily report is hiding information.

The CAQI index (Elshout et al. 2013, 2008) avoids this problem by using the highest hourly value of a day for the daily index. This way consistency is always assured.

4.1.2. Averaging and AQI grids

Air quality data have, approximately, a lognormal distribution (Larsen, 1969). See figure 8. for an imaginary example. Different degrees of averaging compress the original range and in case of a lognormal distribution this effect is higher at the top end of the concentrations. If an individual hourly concentration is judged by a standard (AQI class) that was developed for another averaging time the results are much too high at the top end of the distribution and a (bit) too low at the bottom (depending on the averaging time).

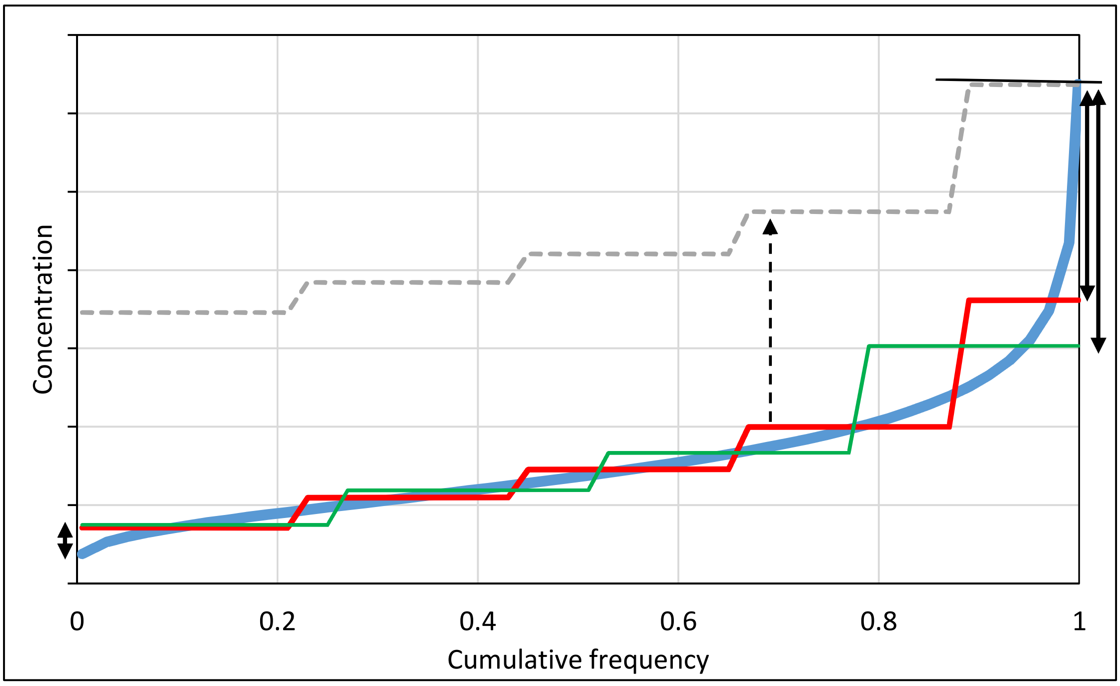

Figure 8: imaginary lognormal distribution and the effects of different averaging times.

In the middle range the differences are small and random over and under classification occurs. The true problems are at the top end! Adjusting the observed maximum concentration to the average over the whole range (dotted arrow) shifts the whole classifying scale upward. The top end concentrations are now classified in the correct way but all other concentrations are classified too low. The only correct way to do this is to adapt the whole classification grid for a larger averaging time to an hourly averaging time by expanding the classes at the top (and narrowing them at the bottom) to fit the true concentration distribution. The top class should reflect the relation between the average value of a series observations and the maximum value of this series.

4.2. Observed daily average and daily maximum hourly concentrations

4.2.1. Hourly-daily ratios

The observed ratios between hourly and daily average concentrations are a first indication of the variability of a pollutant during the day. Comparing the ratios to the ratios in use in the AQI tables provides a first indication of the need for separate hourly and daily grids and they can be used to check the consistency between the AQI grids and the actually observed data. Summary statistics are shown in table 10.

Table 10a: ratio daily average and daily maximum hourly concentration ('complete' dataset – 59923 days)

	CO	NO_2	O_3	PM_{10}	$PM_{2.5}$	SO_2
Average	0.66	0.59	0.53	0.62	0.62	0.52
Min	0.06	0.05	0.05	0.07	0.06	0.05
Max	1	1	1	1	1	1
St. deviation	0.17	0.13	0.16	0.13	0.14	0.18

Table 10b: ratio daily average and daily maximum hourly concentration ('complete' dataset five cities)

City	CO	NO_2	O_3	PM_{10}	$PM_{2.5}$	SO_2
Beijing	0.58	0.58	0.47	0.56	0.54	0.50
Shanghai	0.71	0.56	0.56	0.62	0.61	0.62
Taiyuan	0.72	0.59	0.48	0.60	0.59	0.55
Urumqi	0.57	0.59	0.46	0.52	0.55	0.44
Yangzhou	0.62	0.57	0.52	0.68	0.65	0.53

Table 10a. shows that the pollutants with a distinct daily pattern such as O_3 and to a lesser extent NO_2 have the lowest average ratio. The low number for SO_2 is somewhat surprising. For PM_{10} and $PM_{2.5}$ the differences in the course of the day are smaller. Seasonally the ratios are higher in winter. This is the period – at least in northern China - with episodic air pollution from secondary pollutants when the differences in the course of the day are small. For example in the city of Urumqi the ratio for PM_{10} varies from 0.4 in July to 0.7 in January. These ratios obviously vary a little from city to city depending on the nature of the dominant pollution problems. See table 10b.

The observed temporal and spatial variation implies that the relation between the hourly and the daily index report can never be fully consistent in all places in all times. Figure 9 shows that apart from a geographical variation there is also a temporal variation. The graph for Urumqi shows how the ratios vary from month to month.

The ratios are higher in winter than in summer suggesting the presence of substantial pollution levels that remain rather constant throughout the day. The unexpected dip in November could be due to the fact that relatively few data were available for that month.

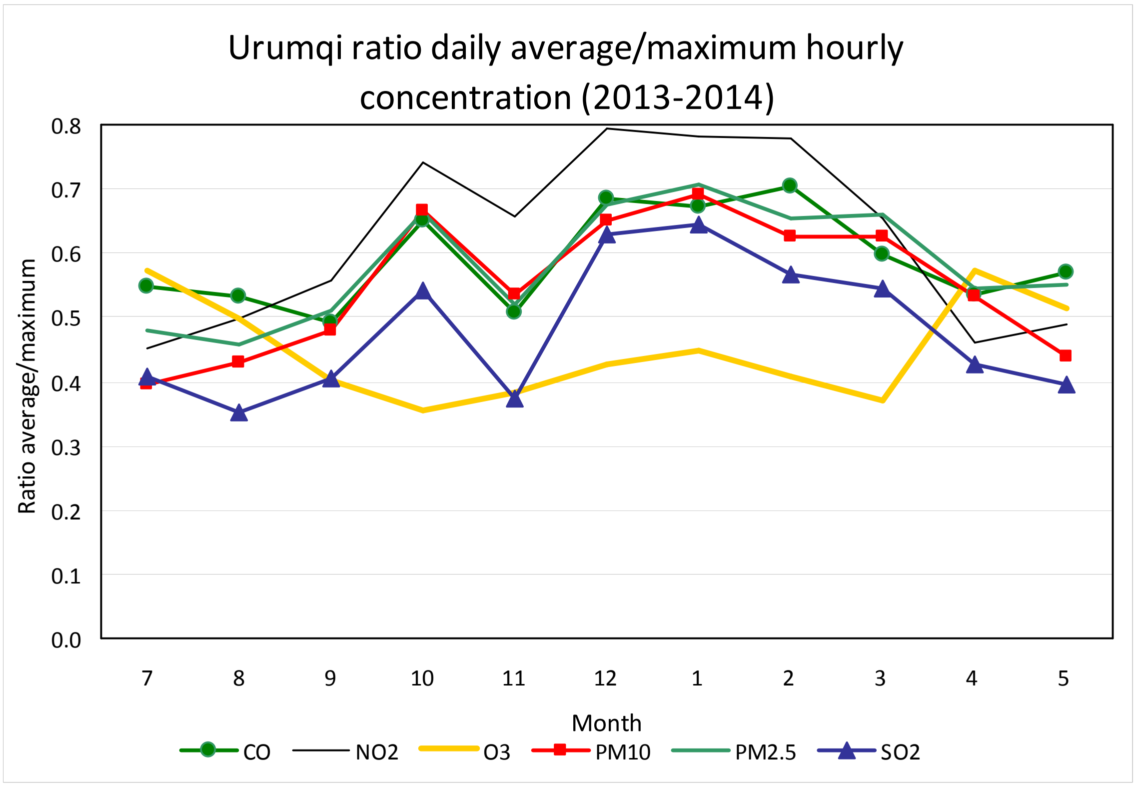

Figure 9: example of daily average and maximum ratio for 6 pollutants in the course of the year

As was mentioned in the previous section one cannot simply apply the relation between daily maximum and daily average concentration to transform a daily average grid into an hourly grid. Strictly speaking this relation only holds for the highest daily concentration so applying it across the board will result in an hourly index table that produces rather low AQI-s (compared to the daily report). Using the ratio between the daily average and the daily maximum concentration for an hourly grid will produce an AQI that is too low for 23 out of 24 hours.

Furthermore, the average ratios determined in this section are not constant over the concentration range. This can easily be seen: if the concentration approaches 0, the maximum and the average will be the same so by definition the ratio will be 1. In the next section we describe a way to transform the daily PM grid into an hourly grid.

4.2.2. **Proposed PM hourly grids**

To construct a proper hourly iAQI grid for the PM pollutants we look at the observed relation between the maximum hourly concentration during a day and the daily average concentration for the same day and we do this for the different AQI classes. See table 11.

The data show that there is an average ratio over most of the concentration range, but, there is also an intercept: one cannot extrapolate this ratio to 0-concentrations. The graph in figure 8 showed that except for the top end of the distribution the averaging will not have a major impact on the distribution of the pollutants over the different classes. Knowing that approximately 70% of the PM concentrations are in the first two AQI bands we:

- keep the first two bands the same in the hourly and daily iAQI (minor and random over and under estimates in each AQI band)
- for the other classes we apply the slopes as determined in table 11 (to avoid overestimating AQI-s in the highest part of the concentration distribution)

Table 11: PM maximum and average concentrations in each AQI band

AQI class	PM$_{10}$		PM$_{2.5}$	
	Average (µg/m^3)	Max. (µg/m^3)	Average (µg/m^3)	Max. (µg/m^3)
50	37	67	23	42
100	93	159	53	90
150	189	309	92	149
200	289	450	130	203
300	403	619	203	302
400	644	972	437	585
500				
Relation	Max =1.48 *Average +20		Max =1.30 *Average +25	

The results are shown in table 12. The table clearly shows that the use of daily iAQI grid breakpoints for hourly data result in PM iAQI values that are much too high. In the middle ranges the difference is one AQI class or more! To prevent this inconsistency between the daily and hourly AQI a true hourly grid should be implemented. Note that the first two classes cover the majority of the data. Nevertheless the change is important because the higher values attract most attention.

Table 12: alternative hourly PM AQI grid breakpoints derived from the daily PM grids and the observed average/maximum ratios (not rounded to 0 or 5)

AQI class		PM$_{10}$ (µg/m^3)			PM$_{2.5}$ (µg/m^3)		
		Daily grid	Related hourly grid	ratio	Daily grid	Related hourly grid	ratio
1	0-50	50	50	1	35	35	1
2	50-100	150	150	1	75	75	1
3	100-150	250	368	0.68	115	169	0.68
4	150-200	350	515	0.68	150	221	0.68
5	200-300	420	618	0.68	250	368	0.68
6	300-400	500	735	0.68	350	515	0.68
7	400-500	600	882	0.68	500	735	0.68

4.3. Relation daily and hourly AQI grid breakpoints other pollutants

For CO, NO$_2$ and SO$_2$ the Chinese AQI has both a daily and an hourly grid. Table 13. shows that while deciding on the hourly grids, apparently, a constant ratio was applied for CO. For NO$_2$ and SO$_2$ the ratios vary across the scale. NO$_2$ starts with the same constant factor but the higher end of the NO$_2$ scale strongly resembles the US-EPA scale, leading to lower ratios. The SO$_2$ scale also varies in its range.

On average the ratios as in use in the AQI are less than the average ratios observed in the monitoring data. This implies that for all three pollutants the chance that they are the dominant pollutant is different (lower!) in the hourly AQI calculation than in the daily calculation. For the consistency between hourly and daily AQI reports this is not desirable. We recommend:

- a fixed ratio across the calculation grid with the first class (or first two classes) being an exception
- the ratios should be closer to the values observed in table 10a. by modifying the hourly grids (in the way shown for PM).

For example, applying the methodology used for the PM grids to NO_2 would lead to 0.72 ratio (and 1 in the first class) between the daily and hourly grid. This is a huge difference from the grid actually in use. Adopting the hourly grid will make better real-time presentations without affecting the formal daily AQI report. For NO_2 it is worthwhile to make changes as it occasionally determines the AQI outcome. For CO and SO_2 it is less relevant as they are rarely decisive for the AQI.

Table 13: ratios between the daily and hourly grid breakpoints for SO_2, NO_2 and CO in the AQI.

AQI class		CO ($\mu g/m^3$)			NO_2 ($\mu g/m^3$)			SO_2 ($\mu g/m^3$)		
		daily	hourly	ratio	daily	hourly	ratio	daily	hourly	ratio
1	0-50	2000	5000	0.40	40	100	0.40	50	150	0.33
2	50-100	4000	10000	0.40	80	200	0.40	150	500	0.30
3	100-150	14000	35000	0.40	180	700	0.26	475	650	0.73
4	150-200	24000	60000	0.40	280	1200	0.23	800	800	
5	200-300	36000	90000	0.40	565	2340	0.24	1600		
6	300-400	48000	120000	0.40	750	3090	0.24	2100		
7	400-500	60000	150000	0.40	940	3840	0.24	2620		
Average ratio				0.40			0.29			0.45

4.3.1. **O_3 averaging times, a special case**

For O_3 the Chinese AQI relies on a daily maximum 8-hour average. This is quite common. However an hourly grid is presented as well. This has to be used for the highest values and the hourly presentations. A shorter averaging time for O_3 is recommended. E.g. in the UK they use hourly trigger concentrations since their last AQI revision (COMEAP, 2011) to be able to alert people that concentrations are rising even if the 8-hour moving average is still acceptable. In the EU CAQI O_3 is also handled with an hourly grid and in the daily report the highest hourly O_3 iAQI is used. This way consistency between daily and hourly AQI reports is assured even for this highly variable pollutant (Elshout et al 2013, 2008).

In this document we assume that the hourly O_3 concentration grid is the preferred grid, except for the daily AQI where the maximum 8-hour average is used. Table 14 shows the ratios between the hourly maximum and the maximum 8-hour average concentration for a given day and the way it is distributed over the AQI classes. The maximum 8-hour average and the daily O_3 AQI grid are used to classify the results. The table shows that, like all other pollutants, the hourly grid for O_3 is too lenient. This results in a very low relevance of O_3 to the hourly AQI as is visible from figure 10 and table 17.

Table 14: O_3 ratios in the AQI in use and observed in the monitoring data (5 city sample)

AQI class		O_3 AQI ($\mu g/m^3$)		ratio	O_3 observed ($\mu g/m^3$)		ratio
		hourly	8 hourly		hourly	8 hourly	
1	0-50	160	100	0.63	67	55	0.80
2	50-100	200	160	0.80	142	124	0.87
3	100-150	300	215	0.72	218	181	0.83
4	150-200	400	265	0.66	295	236	0.80
5	200-300	800	800		349	287	0.82
6	300-400	1000					
7	400-500	1200					
Average ratio				0.70			0.82

Devising an appropriate breakpoint grid for O_3 is complicated. Instead of comparing individual hourly concentrations to the average of these concentrations we compare them to the maximum 8-hour average. In other words the 16^t lowest values from the daily concentration contribution are already discarded. Looking at the example of figure 8 we discard the lowest part of the concentration distribution where averaging times didn't matter that much. Instead the whole operation takes place in the steep part of the curve. For O_3 one would need to make the lower class breakpoints of the 8-hour average table more restrictive otherwise O_3 will be a marginal pollutant in the hourly index (as shown in figure 10).

For O_3 it is recommended to keep the daily calculation grid for the hourly observations. This will not resolve the problem but it is a significant improvement. Further fine-tuning is possible (as shown in figure 11. right-hand side) but this would need a proper analysis on validated data.

4.4. Suggested modifications to the AQI calculation grid

In the previous parts of the reports several suggestions have been made to improve the consistency of the AQI. If one takes the daily AQI as a point of departure and starts from PM_{10} as it is the 'eldest' of the PM pollutants in the AQI, one can optimise the AQI **without** fundamental changes to the frequency distribution of the daily AQI results, in other words one will not get more good or bad days if these changes are implemented.

The proposed changes are twofold:

- Change the ratio between the PM_{10} and $PM_{2.5}$ grid breakpoints (see chapter 3); **subsequently** apply the daily-hourly PM conversion as discussed in section 4.2.2.
- Change the relation between the daily and the hourly grid for NO_2 and O_3 (and for O_3 this means applying the daily – 8-hour breakpoints to hourly data)

Applying all this, leads to an alternative AQI table. The current table is shown in table 15a and the new table in 15b. The breakpoints are not yet rounded to the nearest 5 or 10 to make a decent table. If the suggestion is applied this would be desirable. Given the fact that the PM pollutants are dominating the AQI **and** the fact that there is currently no PM hourly grid**, the PM updates suggested here are highly recommended.** The other changes are less important.

Table 15a: current Chinese AQI Table (all concentrations µg/m³)

AQI Classes and breakpoints		SO$_2$		NO$_2$		PM$_{10}$		CO		O$_3$		PM$_{2.5}$	
		daily	hourly	daily	hourly	daily	hourly	daily	hourly	8-hourly	hourly	daily	hourly
1	50	50	150	40	100	50		2000	5000	100	160	35	
2	100	150	500	80	200	150		4000	10000	160	200	75	
3	150	475	650	180	700	250		14000	35000	215	300	115	
4	200	800	800	280	1200	350		24000	60000	265	400	150	
5	300	1600		565	2340	420		36000	90000	800	800	250	
6	400	2100		750	3090	500		48000	120000		1000	350	
7	500	2620		940	3840	600		60000	150000		1200	500	

Table 15b: updated AQI table with improved consistency PM$_{2.5}$ to PM$_{10}$; true PM$_{2.5}$ and PM$_{10}$ hourly breakpoints; adjusted hourly breakpoints for NO$_2$ and O$_3$

AQI Classes and breakpoints		SO$_2$		NO$_2$		PM$_{10}$		CO		O$_3$		PM$_{2.5}$	
		daily	hourly	daily	hourly	daily	hourly	daily	hourly	8-hourly	hourly	daily	hourly
1	50	50	150	40	40	50	50	2000	5000	100	**100**	**28**	**28**
2	100	150	500	80	**111**	150	*221*	4000	10000	160	**160**	**84**	*109*
3	150	475	650	180	**250**	250	*368*	14000	35000	215	**215**	**140**	*182*
4	200	800	800	280	**389**	350	*515*	24000	60000	265	**265**	**196**	*255*
5	300	1600		565	**785**	420	*618*	36000	90000	800	800	**235**	*305*
6	400	2100		750	**1042**	500	*735*	48000	120000		1000	**280**	*364*
7	500	2620		940	**1306**	600	*882*	60000	150000		1200	**336**	*436*
Ratio PM$_{2.5}$/PM$_{10}$												0.56	
Ratio max.hour/daily avg.				0.74		0.68						0.77	

- Additions (the PM hourly grids) are marked in *italic light blue*; changes to the existing grid are marked in **bold dark blue**. Note that PM$_{2.5}$ has undergone changes to both the daily (consistency with PM$_{10}$) and the hourly grid (newly developed).
- Proposed changes are **not yet** rounded to nearest 5 or 10. This will be necessary to make a decent grid.

4.4.1. Daily and hourly AQI results compared

Tables 16a and 16b show the results for respectively the hourly and daily AQI. The tables show that on average the differences are minor. The daily report turns out to be slightly higher on average (in this sample). As classes are not linearly spaced over the concentration range this can be an effect of the averaging. The role of the daily averaging is evident from the maxima and minima: the maxima are lower in the daily AQI report, and the minima are higher.

Table 16a: frequency (%) of the AQI and iAQI-s using hourly monitoring data (5 city subsample); data current AQI and previous AQI (using PM moving averages) presentations

AQI class	NO_2	PM_{10}	$PM_{2.5}$	O_3	CO	SO_2	**AQI**	With PM moving average PM_{10}	$PM_{2.5}$	**AQI**
50	94	23	42	97	99	98	**22**	15	34	**15**
100	6	53	33	2	1	2	**46**	61	42	**53**
150	0	17	13	1	0	0	**18**	19	14	**20**
200	0	5	5	0	0	0	**7**	4	5	**7**
300	0	1	5	0	0	0	**6**	0	4	**4**
400	0	0	1	0	0	0	**1**	0	0	**0**
500	0	0	0	0	0	0	**0**	0	0	**0**
>=500	0	0	0	0	0	0	**0**	0	0	**0**
Max	116	1823	549	261	94	154	**1823**	941	354	**941**
Min	1	4	1	0	0	0	**6**	9	7	**13**
Average	22	82	77	16	12	11	**95**	82	78	**93**

Table 16b: frequency (%) of AQI using daily average monitoring data (5 city subsample)

AQI class	NO_2	PM_{10}	$PM_{2.5}$	O_3 (max. 8-hour)	CO	SO_2	**AQI**
50	49	17	36	63	85	78	**10**
100	42	59	38	24	13	21	**50**
150	9	19	15	6	2	1	**26**
200	0	5	5	2	0	0	**9**
300	0	0	5	0	0	0	**5**
400	0	0	0	0	0	0	**0**
500	0	0	0	0	0	0	**0**
>=500	0	0	0	0	0	0	**0**
Max	194	1010	354	204	112	124	**1010**
Min	2	10	8	1	2	1	**20**
Average	55	82	78	49	30	30	**103**

The communication issue concerning high values by inappropriate hourly breakpoints that is particularly relevant to PM becomes apparent by looking at the highest AQI classes and the maxima. One can see that the hourly PM approach, while using a daily grid, leads to higher iAIQ-s and hence to higher AQI-s, in the hours with the highest concentrations (top few %). Looking at the minor frequency of the inconsistency this seems to be a non-issue. On the other hand, these are the moments when everyone is watching the AQI because the pollution is high![6] And what will the public think if they see an iAQI of, say 1000 during the day whilst in the daily report only an AQI of 500 or so is reported?

The right-hand part of table 16a shows the AQI as it was originally published, with PM based on moving averages. For the PM pollutants this distribution should be almost identical to that in the daily report in table 16b. The minor differences are caused by the considerable amounts of missing data that hamper the calculation of correct and complete moving average series.

Table 17 provides another indication that the inappropriate grid for hourly PM concentrations causes inconsistent results between the hourly and daily AQI. In the hourly grid almost all hours are determined by PM with NO_2 and O_3 completely dropping away. Secondly the nature of the PM problems at stake (mainly coarse or mainly fine) appear to be different in the two reports. With well aligned hourly and daily grids, the hourly and daily report should, over a longer period such as used here, depict a similar situation. The fact that NO_2 and O_3 are less prominent is also due to their awkward hourly grids that are not at all in line with the observed ratios between hourly and daily data (see section 4.3). This is also visible from the frequency distributions in figure 10.

Table 17: Frequency (%) of pollutant determining the daily AQI and the hourly AQI-s (5 city subsample)

AQI determined by:	AQI - daily	AQI - hourly	AQI - hourly 'old' (with m.a. PM)
NO_2	11	1	1
PM_{10}	36	59	62
$PM_{2.5}$	27	35	34
O_3	24	5	3
CO	1	0	0
SO_2	1	0	0

Figure 10. shows that in the hourly AQI calculation NO_2 and O_3 carry much less weight than in the daily AQI calculation, resulting in a dramatic drop in their relevance for the AQI as was shown in table 17.

Table 17 shows another interesting result: $PM_{2.5}$ determines the AQI only approximately 1/3rd percent of the time. This implies that those websites and apps showing only the $PM_{2.5}$ iAQI as if it is the AQI underestimate the true level of air pollution.

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[6] Besides a few % of hours is still a sizeable number: 87 hours per station per year for each 1%.

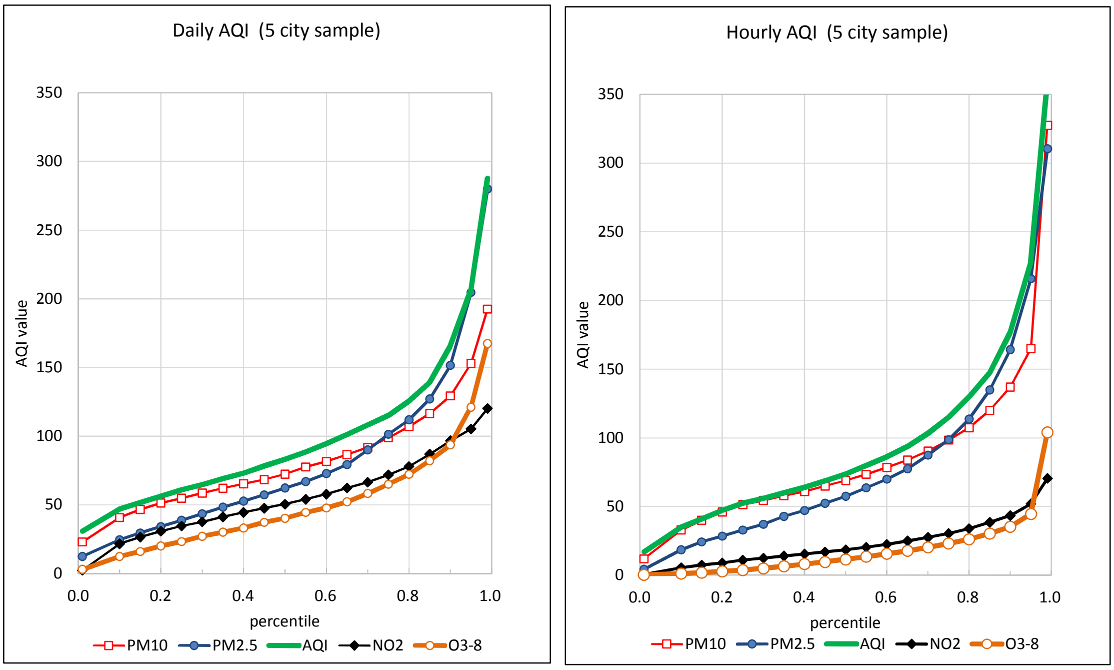

Figure 10: cumulative frequency distribution of the AQI and some iAQI-s: comparing daily and hourly calculation grids (5 city sample).

4.4.1. AQI results using improved hourly grids

If we apply the proposed changes (table 15b) for the breakpoint grids to the PM fractions and to NO_2 the results improve and approach the daily AQI much better. See figure 11. left hand side. O_3 is still lagging behind even if the 8-hour maximum grid is used with hourly data. To improve this a completely different set of O_3 hourly breakpoints was empirically developed to more or less align the hourly grid in such a way that O_3 cumulative frequency distribution is similar for the hourly and daily indices. The result is shown in figure 11. right hand side. Serious changes in particular to the lowest category were needed.

The frequency of each pollutant determining the AQI is shown in table 18. The results of the hourly AQI are now much closer to those of the daily AQI. The table 15b changes do improve the O_3 results but, as mentioned, for consistency for O_3 more work would be needed.

Table 18: Frequency (%) of pollutant determining the AQI daily and hourly AQI-s (5 city subsample) improved hourly grid, PM hourly grid and improved PM_{10}/$PM_{2.5}$ grid

AQI determined by:	AQI - daily	AQI - hourly
NO_2	11	12
PM_{10}	36	43
$PM_{2.5}$	27	32
O_3	24	13
CO	1	0
SO_2	1	0

Table 19: Frequency (%) of AQI using hourly monitoring data (5 city subsample): true PM hourly grid, NO_2 improved hourly grid, O_3 daily grid

AQI class	NO_2	PM_{10}	$PM_{2.5}$	O_3	CO	SO_2	**AQI**
50	53	23	32	86	99	98	**15**
100	44	53	47	11	1	2	**53**
150	3	22	17	3	0	0	**26**
200	0	1	3	1	0	0	**4**
300	0	0	1	0	0	0	**1**
400	0	0	0	0	0	0	**0**
500	0	0	0	0	0	0	**0**
>=500	0	0	0	0	0	0	**0**
Max	188	1208	689	271	94	154	**1208**
Min	1	4	2	1	0	0	**9**
Average	47	75	70	27	12	11	**87**

Table 19 shows the frequencies of the AQI and the iAQI-s for PM and NO_2 the hourly distribution is now much closer to the daily distribution. It resembles table 16b much better than table 16a (based on the current daily breakpoints) both for the AQI as well as the iAQI-s for PM_{10}, $PM_{2.5}$ and NO_2. Simply using the daily grid for O_3 is only a minor improvement and its relative importance for the AQI is still underestimated (table 18 and figure 11-left). O_3 appears to be important for the AQI when other concentrations are low. That is why in particular the lowest breakpoints should be modified.

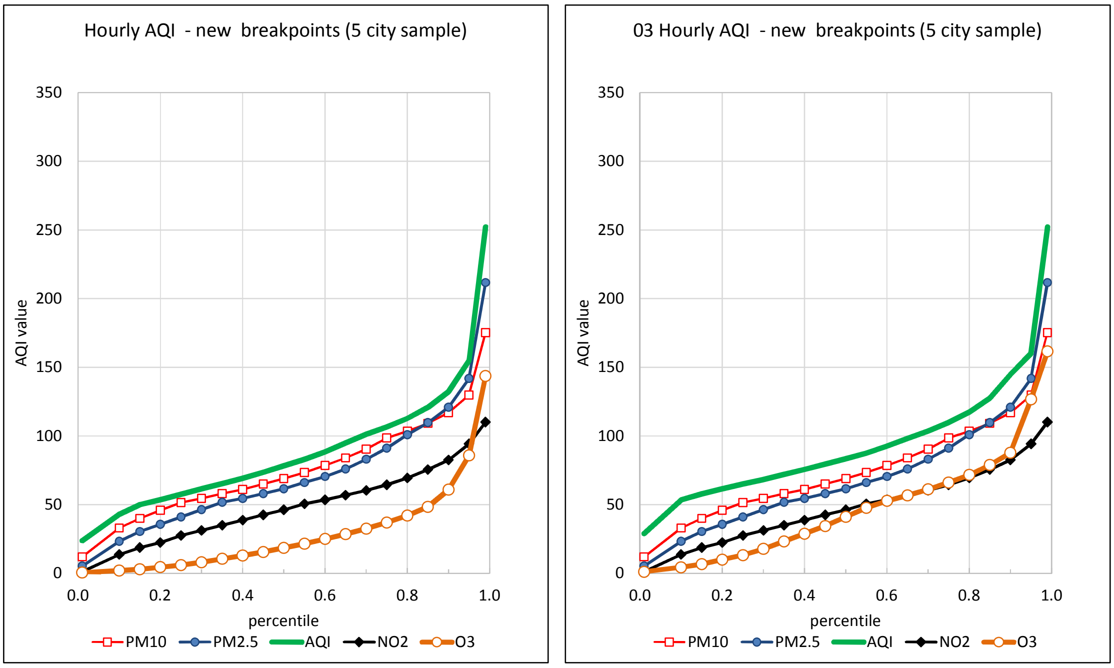

Figure 11: Cumulative frequency distribution of the AQI and some iAQI-s: using a proper PM hourly grid + an improved NO_2 grid (left) and in addition an experimental O_3 grid (right). (5 city sample).

4.5. Hourly breakpoint grid – conclusion

The results in this chapter show that it is very well possible to improve the consistency between the hourly and daily AQI reports. This increased consistency is welcome from a communication perspective and, if the daily indices are taken as a starting point, this improvement will not affect the official daily report.

The current hourly index is dominated by PM (94%) of the time whilst in the daily index this is only 63%. This is mainly due to the fact that an inappropriate hourly AQI-grid is used for PM: the AQI grid from daily averaged PM measurements. We strongly recommend to change this.

The hourly grids for NO_2 and O_3 would also need to be redefined to make them more inline with the true behaviour of the data. This will increase their occurrence in the hourly AQI and make it more consistent with the daily AQI reports.

O_3 plays a role in the daily AQI during 24% of the time. In the hourly AQI this disappears completely and a major overhaul of the O_3 iAQI would be needed to overcome this. O_3 mainly dominates the AQI in the first two bands so from a perspective of warning the public this is not very important.

Several apps and websites only show $PM_{2.5}$ iAQI data claiming that this is the AQI, or the most relevant information. From our analysis it turns out that $PM_{2.5}$ only determines the AQI in 27% or 35% of the time for the daily and hourly AQI reports respectively (5 city sample). This implies that they underestimate the true level of air pollution and potentially misinform the public.

5. Chinese data applied to the API, AQI and other AQI-s

5.1. The index update: API and AQI

With the introduction of the AQI a number of pollutants were added to the index calculation and the grid for NO_2 was updated. AQI bands 1 and 2 were lowered, raising the AQI if the concentrations were in this range. In general all the changes mainly affected the lower concentrations and as a result the number of days with good air quality (according to the AQI) was reduced (See D2.3/part I, section 4.1). Using monitoring data from the 5 city sample we demonstrate the results of the index update. See table 20.

Table 20: frequency (%) of AQI (left) and API (right) classes using daily average monitoring data (5 city subsample)

AQI class	NO_2	PM_{10}	$PM_{2.5}$	O_3 (max. 8-hour)	CO	SO_2	**AQI**	NO_2	PM_{10}	SO_2	**API**
50	49	17	36	63	85	78	**10**	91	17	78	**17**
100	42	59	38	24	13	21	**50**	8	59	21	**59**
150	9	19	15	6	2	1	**26**	1	19	1	**19**
200	0	5	5	2	0	0	**9**	0	5	0	**5**
300	0	0	5	0	0	0	**5**	0	0	0	**0**
400	0	0	0	0	0	0	**0**	0	0	0	**0**
500	0	0	0	0	0	0	**0**	0	0	0	**0**
>=500	0	0	0	0	0	0	**0**	0	0	0	**0**
Max	194	1010	354	204	112	124	**1010**	193	1010	124	**1010**
Min	2	10	8	1	2	1	**20**	0.8	10	1.	**12**
Average	55	82	78	49	30	30	**103**	29	82	30	**83**

The table shows that indeed the percentage of days with ‘good’ (first two index bands) air quality was reduced from 76% with the API to 64% with the AQI. The IAQI-s for PM_{10} and SO_2 are the same in both indices as their calculation grid remained unchanged. NO_2 according to the API, used to have an iAPI above 100 in only 1% of the days. This has gone up to 9% in the AQI.

In the API PM_{10} used to be the dominant pollutant 95% of the sample. In the AQI this has changed to 36 and 27% respectively for PM_{10} and $PM_{2.5}$. O_3, the other newly introduced pollutant determines the AQI in 24% of the cases. So both are relevant additions. NO_2, due to its improved grid, now determines the AQI for 11% of the cases in this sample. Figure 12 shows the cumulative frequency distribution of the API and the AQI. It can be seen that the API and the PM_{10} iAPI are almost identical, it also shows that the AQI is indeed higher than the API.

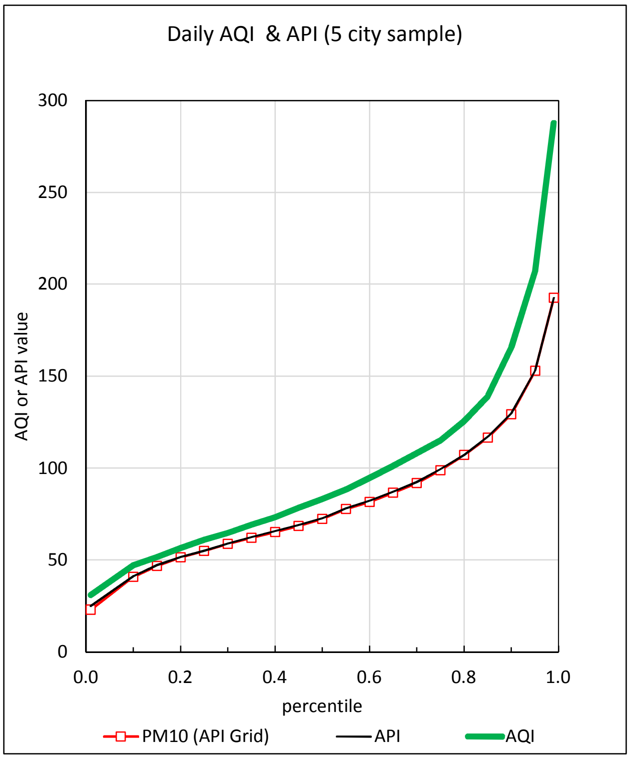

Figure 12: Cumulative frequency distribution of the AQI and the API (daily data, 5 city sample)

5.2. Chinese data used with Chinese, US, HongKong and two EU AQI-s

Comparing indices is quite difficult as all indices use different concepts (see D2.3 part II for more explanations). Nevertheless it is useful to do this, if only to demonstrate that different concepts do exist. As a basis for comparison we look at the concentration of the first AQI class in which health recommendations occur, and at the highest class (e.g. what the index makers considered to be the worst conditions). By aligning the different AQI-s in this way we can compare the frequencies in each of these three AQI classes (no recommendations; health effects (start to) occur, severest pollution). For the different AQI-s one can also calculate the average AQI occurring and compare it to the maximum AQI. This is also an indicator of where the average pollution occurs on the total AQI scale.

A calculator comparing Chinese, US, UK, EU and HongKong indices were developed to further illustrate this point. It is available at the project website or from the author.

www.airinform.com/airinform_web/airinform_en/AQI_calcualtor/AQI_calcualtor.htm

Table 21: Frequency (%) of the Chinese (hourly/daily) and US AQI-s and the UK AQI (data: 5 city sample)

AQI class (China, US)	**Chinese AQI**		US AQI	Classes UK AQI	AQI	classes AQHI Hongkong	AQHI*	classes CAQI (EU)	CAQI	Pollutant determining AQI:	**China**		US	UK AQI	CAQI
50	**22**	**10**	2	1-3	13	1-3	21	25	3	NO_2	**1**	**11**	0	0	1
100	**46**	**50**	31	4-6	20	4-6	50	50	17	PM_{10}	**62**	**35**	3	95	61
150	**18**	**26**	26	7-9	18	7	9	75	28	$PM_{2.5}$	**34**	**27**	95	2	30
200	**7**	**9**	36	10	49	8-10	16	100	32	O_3	**3**	**24**	2	3	8
300	**6**	**5**	4			10+	9	>100	21	CO	**0**	**1**	0	0	0
400	**1**	**0**	0							SO_2	**0**	**1**	0	0	0
500 or >	**0**	**0**	0												
Max	**1823/ 1010**		937		10		43.7		584						
Min	**6/20**		5		1		3.2		8						
Average	**95/103**		130		9		14.1		78						

*The Hongkong AQHI provides a continuous risk scale that is linked to classes for communication with the public.
Scale 10 is associated with an ER of 19.37%. This is used as the maximum value of the index.
The AQHI combines the effects expressed as Relative Risks of the different pollutants so there is no single pollutant determining the index (as with the other AQI-s). Looking at the five city sample and the whole period the average ER of 14.1is mainly due to PM (66%) and NO_2 (22%).

The Chinese and US indices resemble each other though the way they handle moving averages for PM and O_3 is (somewhat) different. The grid is the same (0-500) but the concentration breakpoints, in particular at the lower end of the scale, are different. The UK AQI uses a 1 to 10 scale and much lower concentration breakpoints. The concentration range spanned by European AQI-s is often much lower than in the US and China. This can also be seen from the CAQI. It has a scale from 1 to 100 and, like the UK index, a substantial number of Chinese observations would be off the scale (21%). The Hongkong AQHI index uses an entirely different approach as explained below table 21.

Concerning the pollutants to blame, the US AQI seems to single out $PM_{2.5}$ as the only relevant pollutant whereas the Chinese hourly AQI-report it is a combination of the two PM fractions (with PM_{10} being more important). According to the UK AQI PM_{10} seems to be the only relevant pollutant. The CAQI resembles the Chinese hourly index report quite closely. The Hongkong AQHI doesn't use the concept of a pollutant determining the index but if we study the weight that each pollutant carries in the outcome it is clear that PM_{10} is the most important pollutant. Note that the AQHI adds the impacts of different pollutants so using both PM_{10} and $PM_{2.5}$ in the calculation would overestimate the health effect of the air pollution. Only one of the two PM species could be used and since PM_{10} was monitored more often this pollutant was chosen.

Looking at the distribution of the AQI classes in table 21, the US AQI puts the air quality generally one class higher than the Chinese with 40% of the observations above 200 compared to 14% according to the Chinese AQI. This is the result of the different breakpoints at the lower end of the scale used by the two AQI-s. So though the US AQI produces higher AQI results (almost twice the time a health warning) the highest class almost never occurs in both the Chinese and US AQI-s. For the two European AQI-s and the Hongkong AQI the situation is very different. Though the concepts cannot be compared, all three are somehow linked to, or inspired by the WHO guidelines. Depending on the AQI 10 - 49% of the observations are in the top AQI band and the average AQI of the sample is close to the maximum (ratio varies between 0.73 and 0.9). For the Chinese and the US AQI-s the average AQI of this sample is around 20-25% of the maximum.

Table 22: Comparing different AQI-s frequency (%) of different situations occurring

Criteria	China hourly	China Daily	US	UK	Hongkong	CAQI
No health warning	68	60	33	13	21	n.a.*
Some health warnings	32	40	67	38	75	n.a.*
Maximum grid class or above	0	0	0	49	9	21
Ratio Average AQI/Grid max.	0.19	0.21	0.26	0.90	0.73	0.78

* Note that the CAQI doesn't provide health advice

The results show that the EU index scales are way too short to be relevant to China. The **expectations** about the level of (acceptable) air pollution are much lower in Europe. Looking at the first band where health advice (to the most sensitive subgroups of the population) is to be given, the four AQI-s differ as well. What is judged as safe (or in the Hongkong AQHI words, an acceptable risk) is lowest in the UK, next comes Hongkong, the US and finally China.

The Hongkong AQHI would rate the Chinese air quality as rather bad. Though this is a correct assessment from an epidemiological point of view, it implies that the AQHI would not be a useful index for China given the current pollution levels. For air quality communication it would be awkward to have a message of 'serious' air pollution and the advice to 'restrict the time of stay outdoors' for 9% of the time. It is simply not a practical, and hence relevant, behavioural advice.

5.3. Discussion and conclusion

If different international indices are used to interpret the Chinese air quality one gets different results. European indices rate the Chinese air quality as quite bad/unhealthy. The Hongkong AQHI produces results similar to the EU indices. Though the US AQI rates the air quality as worse than the Chinese AQI, the two resemble each other and produce markedly better ratings than the other indices studied.

Given the current air quality China needs an AQI with a breakpoint grid that covers the occasionally very concentrations. Even the current Chinese AQI produces very high results too often (from a risk communication point of view) so all of the other indices would be less suitable. At the lower end of the scale, the Chinese AQI labels many hours as good/healthy. All other indices classify only a small number of hours in these categories. As there is some kind of epidemiological 'objectivity' to the risk of health effects, these results suggest that the Chinese AQI labels too many hours as "good".

China is right in saying that their air quality standards reflect the development stage of the country but then the wording of the first bands should have been something like "meets current standards" and not a health wording stating that the air quality is "good".

A switch to an AQHI style index (as in Canada or Hongkong) as suggested by Chen et al (2013) would produce a conceptually better index but this is not recommended unless the bands are carefully tweaked to avoid that the AQI is quasi permanently in the unhealthy part of the scale.

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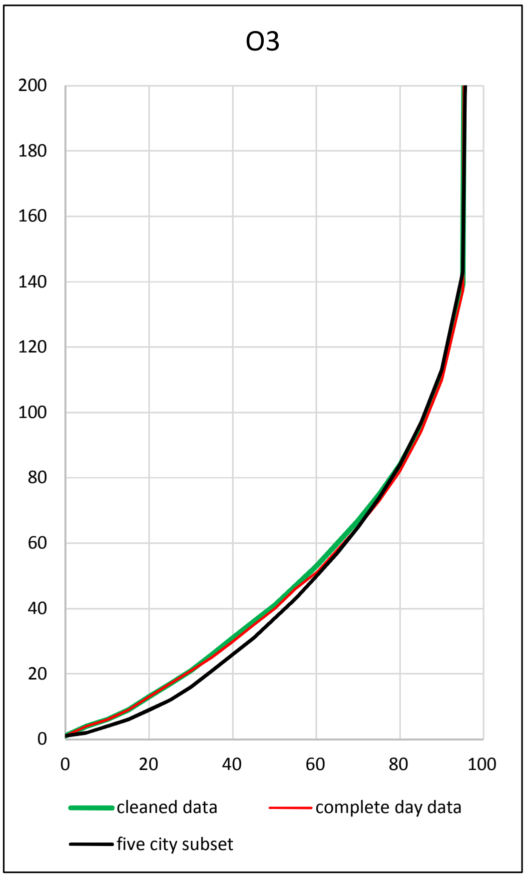
Annexes

Annex 1. Frequency distributions data samples

Table A1: cumulative frequency distribution of pollutant concentrations (μg/m³) and the ratio $PM_{2.5}/PM_{10}$ for subsets of acquired hourly data.

	Cleaned data (3857292 hours)							Complete day data (1325443 hours)						
Percentile	CO	NO2	O3	PM10	PM2.5	SO2	Ratio	CO	NO2	O3	PM10	PM2.5	SO2	Ratio
0	1	1	1	1	1	1	0	1	1	1	1	1	1	0
5	317	7	4	25	11	4	0.24	320	8	4	26	11	4	0.24
10	431	11	6	34	16	6	0.31	426	11	6	35	15	6	0.30
15	516	14	9	42	20	8	0.36	506	15	9	42.6	20	8	0.35
20	592	17	13	49	25	10	0.40	577	17	13	49	24	10	0.39
25	662	20	17	56	29	11	0.44	645	20	17	56	27	12	0.43
30	731	23	21	63	33	14	0.47	711	23	21	63	31	14	0.46
35	800	26	26	70	37	16	0.5	778	26	25	70	36	17	0.49
40	870	29	31	78	42	18	0.53	847	29	30	78	40	19	0.51
45	942	32	36	86	46	21	0.56	918	32	35	85	45	22	0.54
50	1019	35	41	94	51	24	0.59	993	35	40	94	50	25	0.56
55	1103	39	47	103	57	27	0.62	1074	38	46	103	55	28	0.59
60	1197	43	53	113	63	31	0.64	1166	42	51	113	61	32	0.61
65	1302	47	60	125	70	36	0.67	1270	46	58	125	68	37	0.64
70	1425	52	67	138	79	41	0.70	1392	51	65	138	77	43	0.67
75	1576	57	75	153	88	49	0.73	1539	56	73	154	87	49	0.70
80	1769	64	84	172	100	58	0.76	1727	63	82	174	99	59	0.73
85	2030	72	96	197	117	71	0.80	1981	70	94	200	116	72	0.76
90	2411	82	112	233	141	93	0.85	2356	80	110	237	140	93	0.80
95	3145	99	139	298	186	135	0.91	3080	97	137	303	186	134	0.86
100	9998	2108	1200	7894	2112	1597	388	9998	1469	1200	7079	1371	1570	4.76

The results are also shown in figure A1. The figure also includes the 5 city subset from the complete day data. The frequency distributions are virtually identical for the cleaned data and the complete day data. This shows that this selection applying strict criteria of completeness is still representative of the whole data set. The five city subsample of the complete day data is also quite similar to the whole set. For NO_2 and $PM_{2.5}$ there are small differences, probably due to very 'urban' nature of this subset.


O3
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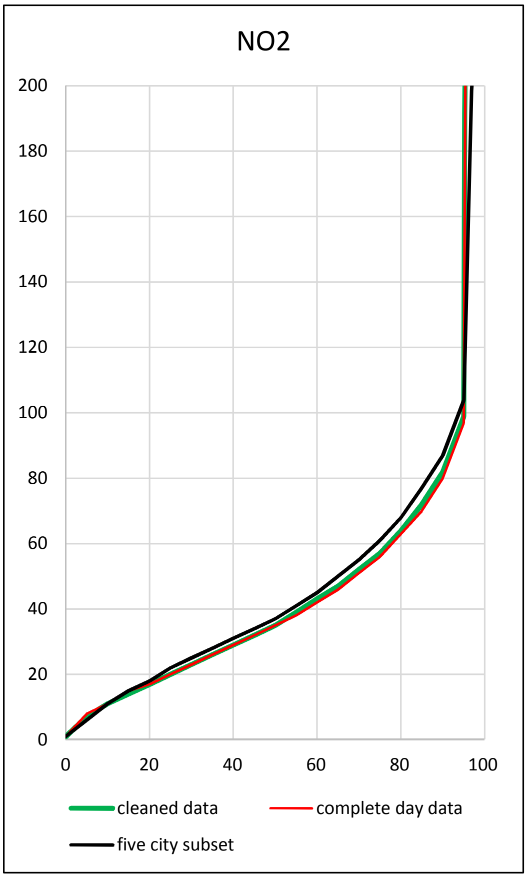
cleaned data
complete day data
five city subset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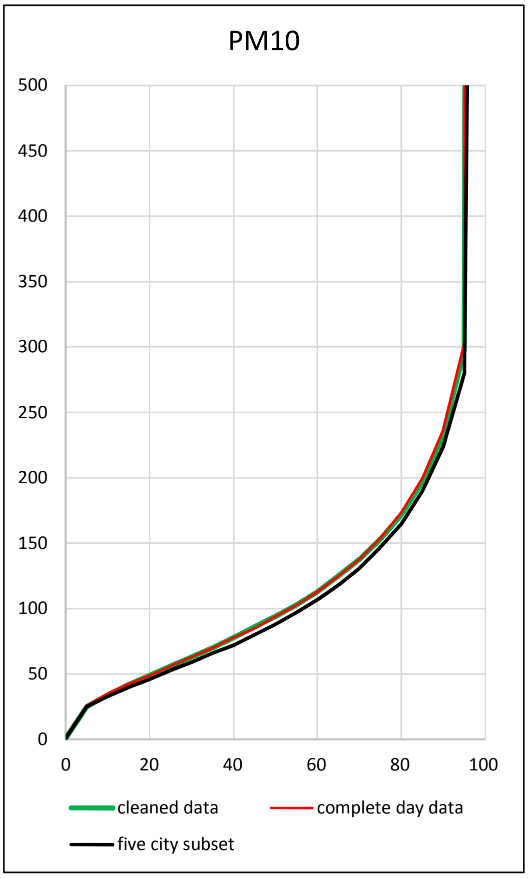
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cleaned data
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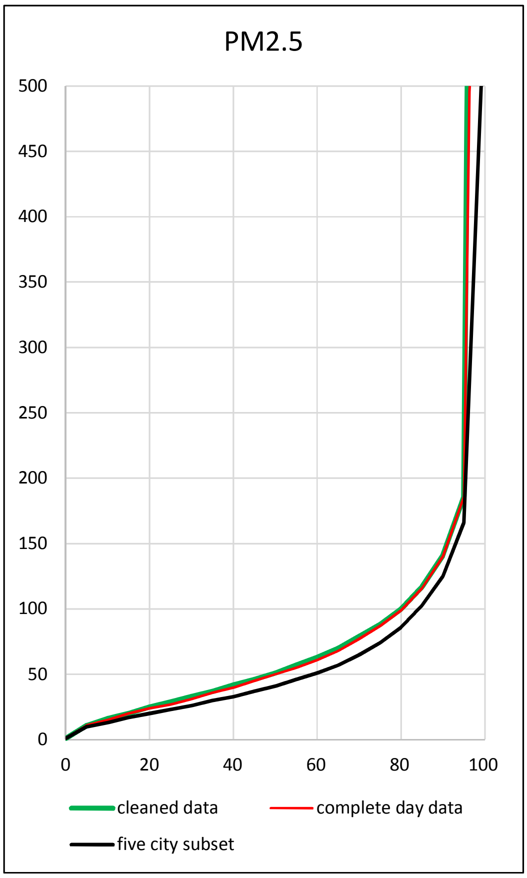
five city subset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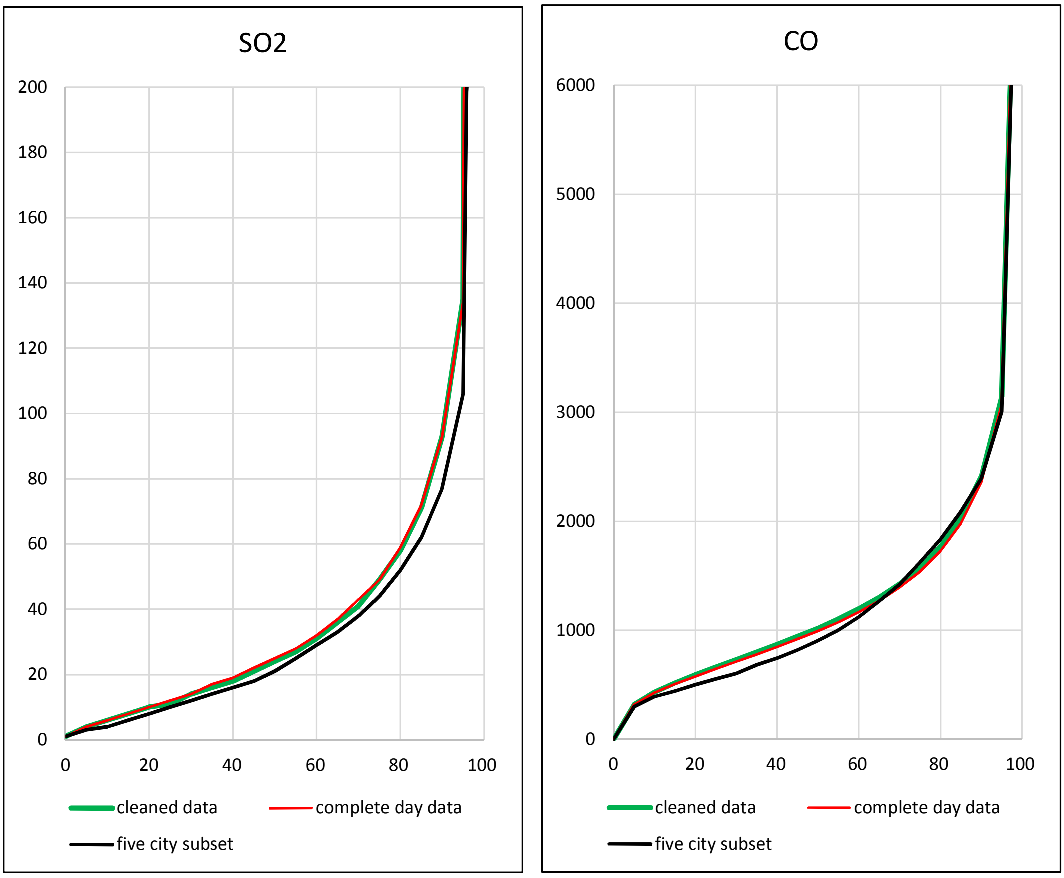

Figure A1: Cumulative frequency distribution of the 6 pollutants in 3 subsets of the acquired data

Annex 2. Index tables of non-Chinese AQI-s used in this report

Table A2: US-AQI breakpoints[7]for AQI bands (µg/m^3)

US-AQI**		SO_2 1h	NO_2 1h	PM_{10} daily	$PM_{2.5}$ daily	CO 8h (mg/m^3)	O_3** 1h	O_3** 8h
1	50	90	100	54	12	5.1		120
2	100	200	190	154	35	10.8	250	150
3	150	480	680	254	54	14.3	320	190
4	200	800*	1220	354	150	17.7	400	230
5	300	1580*	2350	424	250	35.0	790	730
6	400	2110*	3100	504	350	46.5	990	Use hourly O3
	500	2630*	3850	604	500	58.0	1180	Use hourly O3

*Daily averaged concentrations are used
** The highest of the two parameters is used. For the first two bands only 8-hour averages are used.
Source: www.epa.gov/airnow/aqi-technical-assistance-document-sep2012.pdf. The three lower bands for $PM_{2.5}$ are based on www.epa.gov/pm/2012/decfsstandards.pdf (Accessed June 3, 2013).

Table A3: UK AQI breakpoints (µg/m^3) (COMEAP, 2011)

Index Band	1	2	3	4	5	6	7	8	9	10
		Low			Moderate			High		Very High
O3 8h	33	66	100	120	140	160	187	213	240	241 or more
NO2 1h	67	134	200	267	334	400	467	534	600	601 or more
SO2 15 min.	88	177	266	354	443	532	710	887	1064	1065 or more
PM2.5 24h	11	23	35	41	47	53	58	64	70	71 or more
PM10 24h	16	33	50	58	66	75	83	91	100	101 or more

Table A4: Hongkong AQHI (Wong et al, 2013)

Index Band	1	2	3	4	5	6	7	8	9	10	10+
Health Risk category		Low			Moderate		High		Very High		Serious
% Extra risk	0-1.88	>1.88-3.76	>3.76-5.64	>5.64-7.52	>7.52-9.41	>9.41-11.29	>11.29-12.91	>12.91-15.07	>15.07-17.22	>17.22-19.37	>19.37

The AQI includes NO_2, O_3, PM_{10} and SO_2. Using epidemiological studies based on Hongkong air pollution and hospital admissions each pollutant is given a relative risk per 10 µg/m^3. These RR-s apply to Hongkong and can be different elsewhere. They are 1.0045, 1.0051, 1.0028 and 1.0014 per 10 µg/m^3 for the four pollutants respectively.

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[7] Note that US breakpoints are given in PPM for the gasses. Here they were converted to µg/m^3.

Table A5: pollutants and calculation grid for the CAQI hourly and daily grid (Elshout, 2013)

Index class	Grid	Traffic						City Background							
		core pollutants			pollutants			core pollutants				pollutants			
		NO_2	PM_{10}		$PM_{2.5}$		CO	NO_2	PM_{10}		O_3	$PM_{2.5}$		CO	SO_2
			1-h.	24-h.	1-h.	24-h.			1-h.	24-h.		1-h.	24-h.		
Very low	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	25	50	25	15	15	10	5000	50	25	15	60	15	10	5000	50
Low	25	50	25	15	15	10	5000	50	26	15	60	15	10	5000	50
	50	100	50	30	30	20	7500	100	50	30	120	30	20	7500	100
Medium	50	100	50	30	30	20	7500	100	50	30	120	30	20	7500	100
	75	200	90	50	55	30	10000	200	90	50	180	55	30	10000	350
High	75	200	90	50	55	30	10000	200	90	50	180	55	30	10000	350
	100	400	180	100	110	60	20000	400	180	100	240	110	60	20000	500
Very High*	> 100	> 400	>180	>100	> 110	>60	>20000	> 400	>180	>100	>240	> 110	> 60	> 20000	>500

NO_2, O_3, SO_2: hourly value / maximum hourly value in µg/m^3

CO 8 hours moving average / maximum 8 hours moving average in µg/m^3

PM_{10}, $PM_{2.5}$ hourly value / daily value in µg/m^3

* An index value above 100 is not calculated but reported as “ > 100”

Annex 3. Description AQI Calculator

An online calculator was developed to do the same calculations as those in chapter 5. The calculator demonstrates that there are different indices. They all use different concepts and all give a (sometimes very) different appreciation of air quality. Often this is linked to the air quality in the area/country for which the AQI was made. This even applies to indices that seem similar. One Index is not necessarily better than the other. This calculator will simply highlight the differences.

Pollutant concentrations have to be entered in the grey column on the calculator sheet. Each index requires different a different combination of pollutants and **pollutant averaging times**. The latter is very important and it is awkward. Usually someone has only one type of information and entering a daily average concentration in a field for hourly concentrations produces wrong results (see chapter 4). Therefor another calculator will be made that only uses hourly values. In that case the results will be only indicative.

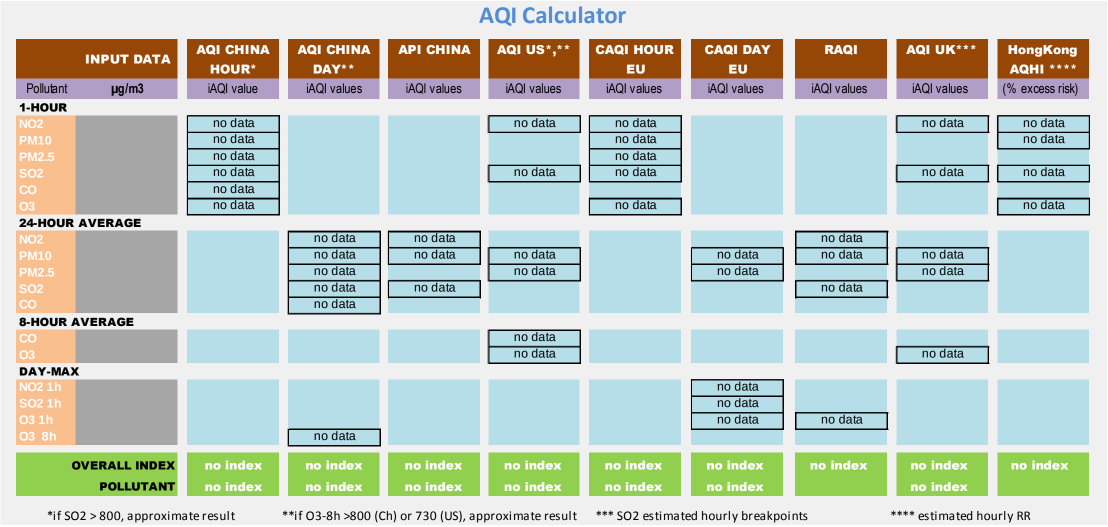
The information required to calculate a specific index is indicated by the boxes under the specific index. Go to the grey column on the right and supply the correct information.

Summary explanations of the index grids can be found an annex 2. More information about these indices can be found in D2.3 part II (and to a lesser extent part I). In these documents references to the original indices are also available. **This is important as indices change over time. Always check the latest description.**

This calculator uses the Chinese AQI definition in use since 2012, with the update in 2014 whereby hourly PM concentrations are used instead of 24-hour moving averages. This calculator also uses a few approximations for very high concentrations that rarely occur and for a few odd averaging times in the UK and Hongkong AQI-s:

> *If SO2 > 800 the Chinese index indicates the use of daily averaging time. This is not implemented;
> **If O3-8h >800 (China) or 730 (US) the AQI description indicates the use of hourly values;
> *** For the UK the SO2 hourly breakpoints are estimated as the UK AQI originally uses 15 minute average concentrations;
> **** The AQHI uses RR based on 3-hour averaged concentrations so these results are not exact.

The figure shows an impression of the calculator interface. The calculator is available on the project website or from the corresponding author of this report.
www.airinform.com/airinform_web/airinform_en/AQI_calcualtor/AQI_calcualtor.htm



AQI Calculator

INPUT DATA		**AQI CHINA HOUR***	**AQI CHINA DAY****	**API CHINA**	**AQI US*,****	**CAQI HOUR EU**	**CAQI DAY EU**	**RAQI**	**AQI UK*****	**HongKong AQHI *******
Pollutant	µg/m3	iAQI value	iAQI values	iAQI values	iAQI values	iAQI values	iAQI values	iAQI values	iAQI values	(% excess risk)
1-HOUR										
NO2		no data			no data	no data			no data	no data
PM10		no data				no data				no data
PM2.5		no data				no data				
SO2		no data			no data	no data			no data	no data
CO		no data								
O3		no data				no data				no data
24-HOUR AVERAGE										
NO2			no data	no data				no data		
PM10			no data	no data	no data		no data	no data	no data	
PM2.5			no data		no data		no data		no data	
SO2			no data	no data				no data		
CO			no data							
8-HOUR AVERAGE										
CO					no data					
O3					no data				no data	
DAY-MAX										
NO2 1h							no data			
SO2 1h							no data			
O3 1h							no data	no data		
O3 8h			no data							
OVERALL INDEX		no index	no index	no index	no index	no index	no index	no index	no index	no index
POLLUTANT		no index	no index	no index	no index	no index	no index		no index	

*if SO2 > 800, approximate result **if O3-8h >800 (Ch) or 730 (US), approximate result *** SO2 estimated hourly breakpoints **** estimated hourly RR