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夜间废气排放加重中国雾霾污染*

Increase in Haze Pollutions in China due to Nocturnal Emissions

严少敏,吴 光**

YAN Shao-min,WU Guang

(广西科学院,广西生物科学与技术研究中心,广西南宁 530007)

(Guangxi Bioscience and Biotechnology Research Center,Guangxi Academy of Sciences,Nanning,Guangxi,530007,China)

摘要:工业和交通废气、农业和生活烟雾等污染物排放是城市雾霾的重要来源,其污染物特别是细颗粒物质对人体健康有损害。就区域而言,我国北方的污染物 PM2.5、PM10、CO、SO_2 的浓度较高,中西部、东南部和南部较低;中国大部分地区的季节性高污染通常出现在冬季。其原因主要是因为细颗粒物排放量大,且受不利气象条件的影响,停滞的气流不利于气溶胶扩散。夜间 PM2.5 的浓度通常高于白天,其原因:一是由于重型车辆通常在夜间作业,而且烧烤、非法秸秆焚烧等活动一般在夜间进行,导致夜间的污染物排放量增加;二是由于夜间地面温度低,空气湍流减少而导致垂直空气运动很少,故气流停滞现象夜间尤为明显。历史上喀麦隆尼奥斯湖和印度博帕尔灾难的加剧也是由于此类气象条件所致。本研究提出夜间废气排放加重了中国雾霾污染的设想,并通过分析北京地区 54511 气象观测站提供的 2014 年每天、每小时的地面气温数据,发现减少夜间污染排放可能是现阶段减少雾霾形成的低成本措施之一。

关键词:污染排放 雾霾 PM2.5 逆温 减排

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Abstract:Emissions from traffic,industrial combustion,heating and biomass burning are important sources for the formation of haze,of which fine particulate matter is particularly harmful to human health. Regionally,PM2.5,PM10,CO and SO_2 concentrations are generally higher in northern China than in western,southeast and southern China because of large PM emissions and unfavorable meteorological conditions for pollution dispersion. Seasonally high pollutions are often visible in winter in most parts of China. Daily,PM2.5 is frequently higher during nighttime than during daytime. The increase in PM2.5 in nighttime can be attributed to heavy vehicles such as diesel trucks,evening recreation activities such as barbecues,and illegal rubbish burning. Of various factors promoting the formation of haze, stagnant airflow is very important because it makes the dispersal of aerosols difficult. This is crucial for the nighttime because the ground temperature decreases during the nighttime and air turbulence decreases leading to very little vertical air motion. Such meteorological conditions had led to Lake Nyos and Bhopal disasters in history. In this study,we hypothesized that nocturnal emissions increase the haze pollutions in China,and analyzed the meteorological data on hourly surface temperature from Beijing 54511 Observation Station in 2014. The results show that the surface temperature

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作者简介:严少敏(1958－),女,研究员,主要从事计算变异学和生物信息学研究。

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**通讯作者:吴 光(1956－),男,研究员,主要从事计算变异学和模型研究,E-mail:hongguanglishibahao@yahoo.com。

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was lower at nighttime than at daytime. Therefore, reduction of emission at nighttime could be a cost-effective way to lessen haze pollution at the present stage.

Key words: pollution emissions, haze, PM2.5, inverse temperature, emission reduction

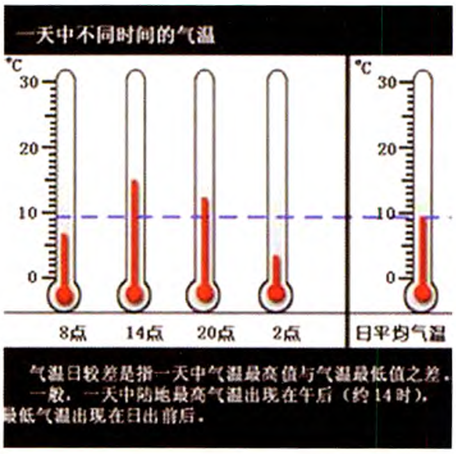
0 引言

雾霾对人类健康存在不利影响[1~3]，尤其是霾中直径等于或小于 2.5 μm 的细颗粒物(PM2.5)对健康的影响尤为明显[4~6]，因此 PM2.5 的污染及其防治备受重视。PM2.5 污染物可来自交通源的排放、道路扬尘、生物质燃烧、农业生产活动和区域运输气溶胶[7]。这意味着无论是城市，还是农村地区都受到雾霾的影响。已有研究发现农村的死亡率与烟雾事件高度关联[6]。针对北京市的调查发现，垃圾焚烧、化工制造、煤燃烧等产生的废气是 PM2.5 的主要来源[8,9]，关于这 3 方面的废气来源已有较多研究。娱乐活动排放的废气对雾霾的产生也不容忽视，例如烧烤产生的 PM10 和 PM2.5[10]，对人体健康均有影响[11~13]。就区域而言，PM2.5、PM10、CO、SO_2 浓度在我国北方较高，中西部、东南部较低[7]。就季节而言，文献[14]的结果显示 PM2.5 的浓度高低为冬季>春季 >秋季和夏季，文献[3]的结果显示 PM2.5 浓度高低为冬季>秋季>春季>夏季。事实上，雾霾的产生不能单独考虑区域性或季节性，应同时考虑这两个因素，例如，中国东南部的高雾霾污染事件频繁发生在秋季，而西部的高雾霾污染事件频繁发生在春季[7]。PM2.5 浓度也存在昼夜变化，研究发现 PM2.5 浓度最低的时段多数在下午，而最高的时段多数在晚上，总体上一年中的 PM2.5 浓度从 19:00 至24:00时段均处于高水平[15]。PM2.5 浓度存在季节性、昼夜性变化，其浓度在秋季、冬季的夜间高于白天，可能与秋冬季供暖增加废气排放和夜间大气边界层相对较低有关[15]。另外，由于重型车辆的排放因子比轻型车辆高 6 倍[16]，而大多数城市只允许大型柴油卡车在夜间进入市区，导致城市夜间的 PM2.5 浓度高。天气现象对雾霾的形成也有一定的影响，例如风速[14]、湿度[17]、降雨[18]、大气边界层高度[15]等均影响大气中细颗粒物的浓度。

减少废气排放量是控制雾霾的根本途径，因此需要对废气排放实行严格管控：控制交通源产生的挥发性有机化合物、氮氧化物以及区域工业源产生的二氧化硫[19]；应用末端管道的减排技术，使用更清洁的燃料；继续限制高排放密集型但低附加值的出口产业；减少施工活动；增加服务业在国民经济中所占的比例[20]。此外，植物叶片[21]、绿色灌木[22]等也有助于减少霾。再者，鉴于已有数据，夜间的 PM2.5 浓度高于白天，故本文认为减少夜间 PM2.5 的排放是控制 PM2.5 浓度的主要途径。通过分析北京地区 54511 气象观测站提供的 2014 年每天、每小时的地面气温数据，进一步确认夜间废气排放加重了中国雾霾污染。

1 昼夜气温变化与空气污染

目前，控制雾霾的可行方法和正在研究的方法都旨在将 PM2.5 污染物从大气中沉降到地面上。考虑到 PM2.5 浓度的时间变化大于空间变化[23]，即 PM2.5 污染程度每天的变化明显大于区域性变化。从该角度思考，也许利用大气中细颗粒物的时间变化来控制雾霾是一种可行的办法。燃烧产生的一氧化碳的分子量为 28，二氧化碳分子量为 44，而大气的平均分子量是 29，理论上污染气体和细颗粒物可以随地面的热空气上浮，减少雾霾的产生。而分析气象条件可知，地球表面的热量来自太阳辐射，30% 的太阳辐射受到地球表面的反射而返回外层空间。日落后地球表面的散热仍在进行，但由于此时没有太阳辐射，地表温度会下降，所以夜间的温度往往低于日间(图 1)。尤其是在晴朗的夜间，空气湍流被抑制，上层空气下沉，导致风速减小，被污染的空气滞留在地面。此时夜间的降水能更有效地清除空气中的污染物。但中国大多数地区晚上降雨次数有限，且人工降水也无法覆盖所有的污染区。



此图源自中国气象数据网[24]

This figure is publically available in the Chinese Meteorological Data Network[24]

图 1 昼夜气温变化示意图

Fig. 1 Schematic diagram of daily temperature change

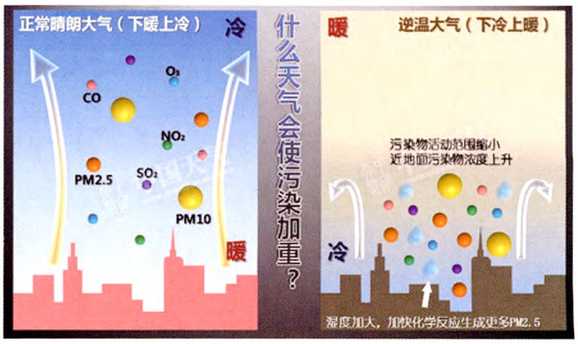
近年来，夜间废气排放越来越密集，例如重型卡车行驶、建筑施工、烧烤、非法的垃圾焚烧等都发生在

夜间，因此雾霾往往在清晨被发现。事实上，夜间不是废气排放的最佳时间，因为夜间地面表面温度降低使得向上的空气运动减少，被污染的空气很难自动上浮到大气上层。现实中，中国一般禁止重型车辆在白天进入市区，建筑工地白天也停止施工，导致中国城市的雾霾污染似乎越来越严重，但这些举措是否与雾霾存在相关性尚未有报道。而从气流变化看，一天中10:00 至 15:00 空气向上流动最强。假如污染的排放活动集中在晴天，日间气温较高的时段进行，将有利于污染的空气上浮、消散，从而减轻地面的空气污染。

2 逆温现象与空气污染

逆温现象指地面上空的大气温度随高度增加而升高的反常现象，这种现象在冬天尤为明显。逆温在北京地区的冬季已被确认存在[25]，这也有助于理解北京地区严重的空气污染。由于上层大气比下层大气的温度高，不利于地表污染气体和细颗粒物在热气流作用下的上浮，故未能在大气上层被风吹散(图 2)。

持续数天的逆温现象曾发生于 1952 年 12 月 5 日到 9 日的英国首都伦敦，造成了重大污染。1984 年印度博帕尔发生的异氰酸甲酯泄露事件造成 3787 人死亡[26]。1986 年喀麦隆尼奥斯湖发生的二氧化碳泄露事件造成 1700 余人死亡[27]。后两次事件都发生在夜晚，上层大气与下层大气之间的温差减小，不利于异氰酸甲酯或二氧化碳扩散，是造成这两次灾难的原因之一[29]。



此图源自中国气象[28]

This figure is publically available in the Chinese Weather[28]

图 2 正常大气和逆温大气对污染物活动范围的影响示意图

Fig. 2 Schematic diagram of influence of normal atmosphere and inversion on pollutant activities

3 北京地区的昼夜气温变化

根据 2014 年北京 54511 气象观测站每天、每小时地面气温纪录[30]得到北京市每 1 小时、每 2 小时、每 3 小时和每 4 小时的地面气温变化情况(图 3～图 6)。结果显示，北京市的地面气温在凌晨和上午较高(图 6 的红线和绿线)、在傍晚和前半夜较低(图 6 的蓝线和粉红线)。这表明北京地区气温昼夜变化较复杂(与图 1 显示的一般气温昼夜变化不同)。可想，在这种地面气温模式下，大规模的夜间排放势必加剧雾霾的形成。

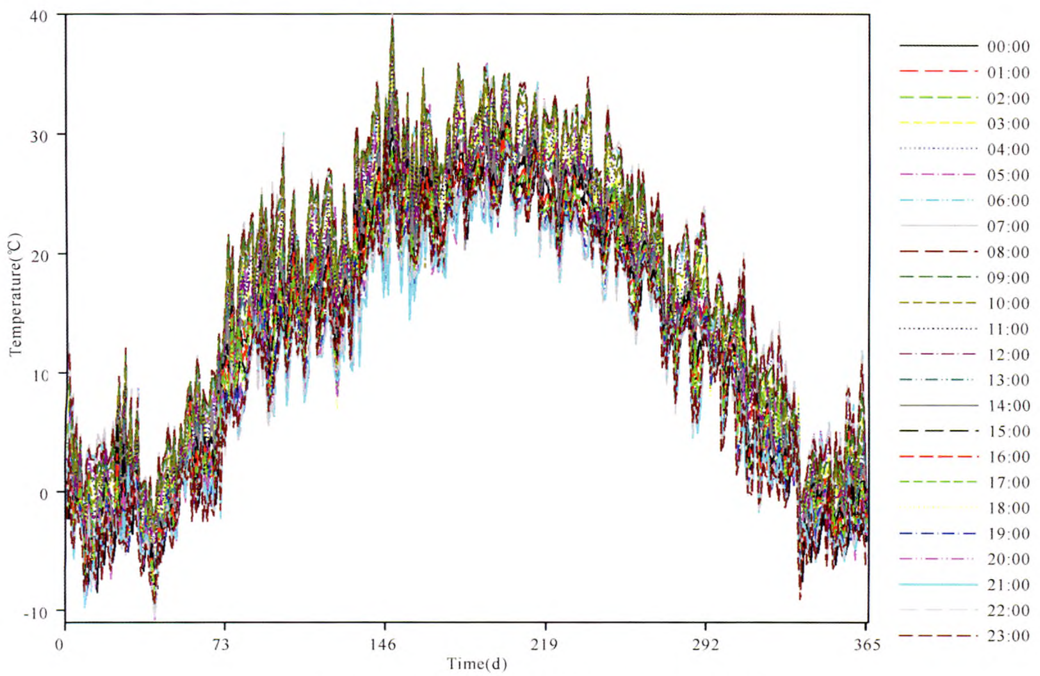


图 3 北京市 2014 年每小时的地面气温变化

Fig. 3 Hourly surface air temperature in Beijing in 2014

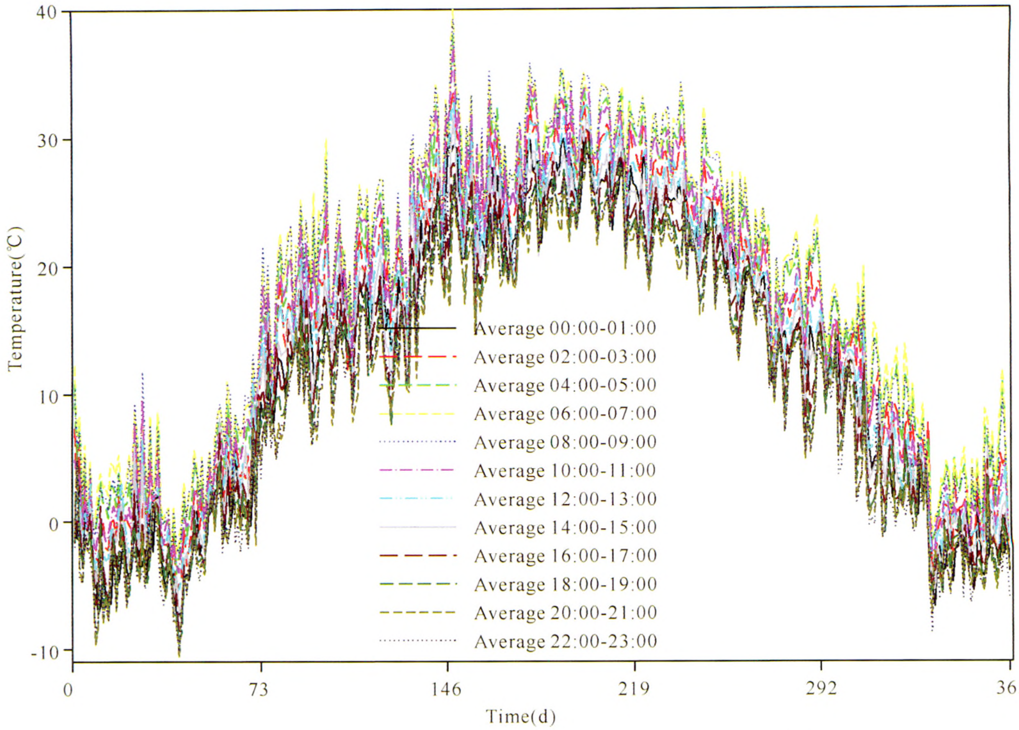


图 4　北京市 2014 年每 2 小时的地面气温变化

Fig. 4　2-hour surface air temperature in Beijing in 2014

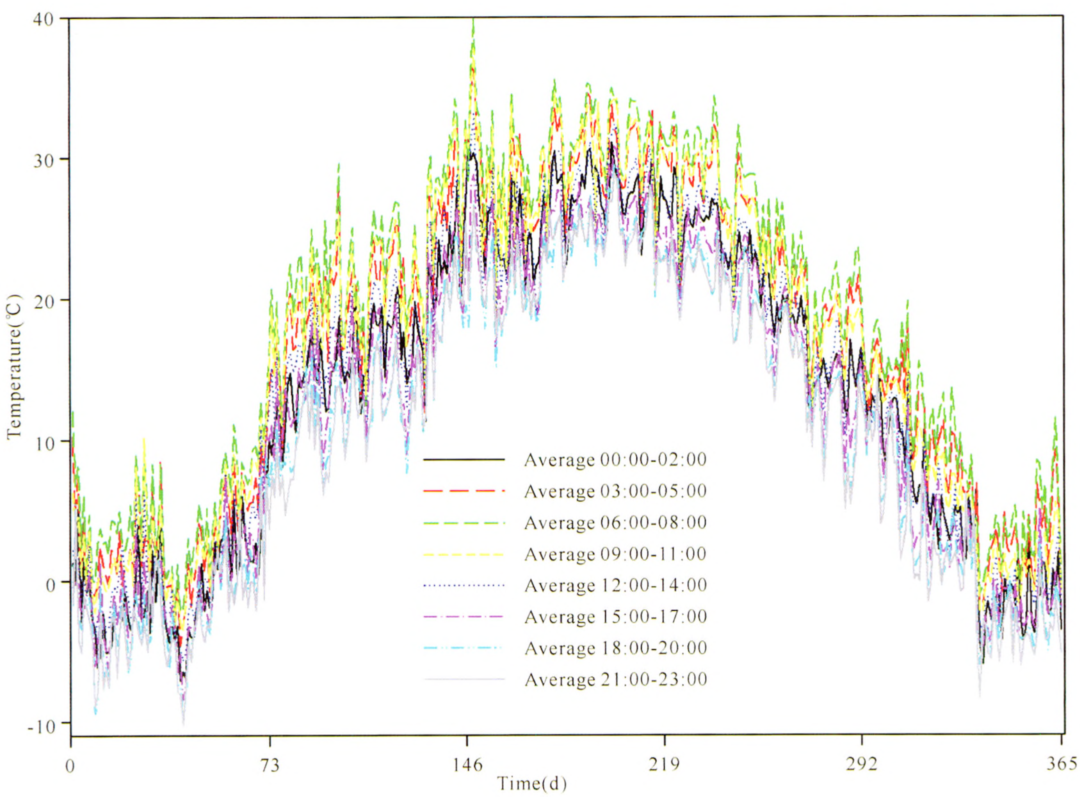


图 5　北京市 2014 年每 3 小时的地面气温变化

Fig. 5　3-hour surface air temperature in Beijing in 2014

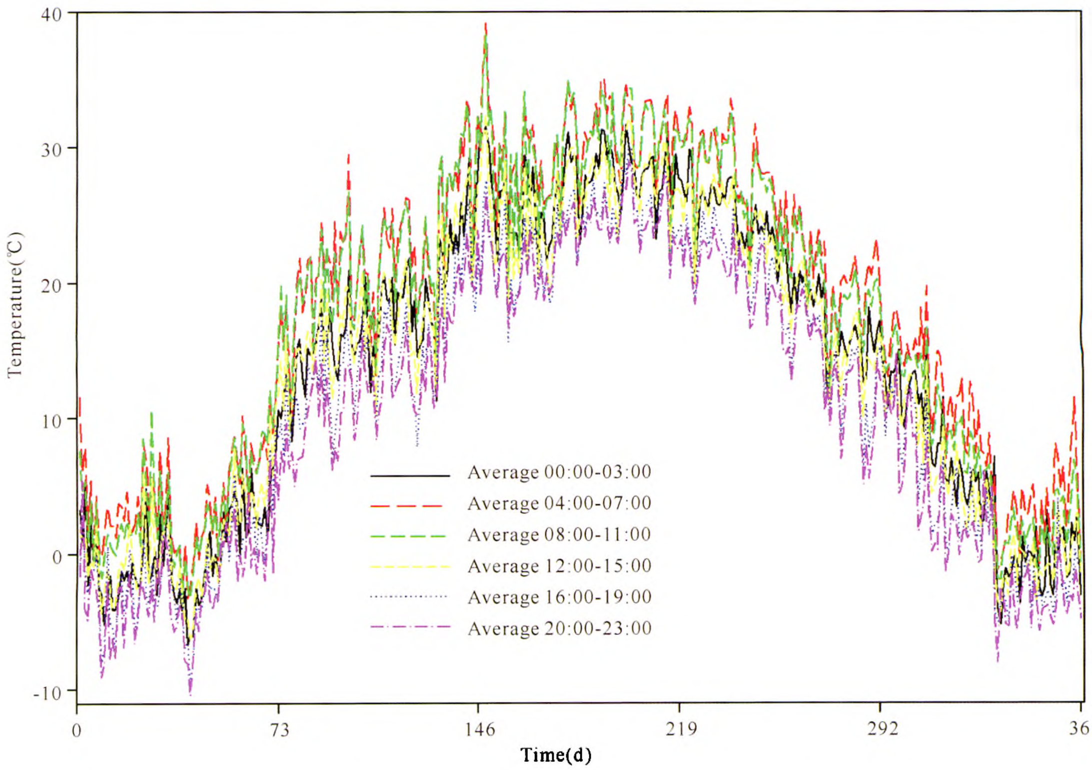


图 6 北京市 2014 年每 4 小时的地面气温变化

Fig. 6 4-hour surface air temperature in Beijing in 2014

4 结论

北京-天津-河北的气象特点是风速较低、边界层高度较低，故易形成空气停滞，为气溶胶的积累、形成和发展提供了适宜的条件[31]。而漫长的冬季人们为了取暖需求，大量燃烧化石和生物质燃料，导致废气的排放量增加，加之不利的气象条件，如频发的寒流带来的停滞天气和逆温，都阻碍污染物扩散。因此，充分利用气温昼夜变化的自然条件、减少夜间废气排放可能是现阶段减少雾霾污染比较符合成本效益的办法。

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