SPACE-TIME VARIABILITY FACTORS FROM AIR POLLUTION INSIDE PARIS BY CO MEASUREMENT

With 11 figures and 3 maps

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Zusammenfassung: Beobachtungen zu raum-zeitlichen Unterschieden der Luftverschmutzung in Paris durch CO-Messungen

Das Luft-Qualitäts-Netzwerk AIRPARIF informiert die Bevölkerung von Paris über die Luftqualität mithilfe des ATMO-Indexes, der Hinweise auf Basis der Gesamtagglomeration liefert. Ziel dieser Studie ist es, Beobachtungsmöglichkeiten für eine individuelle Skala[1)] zu entwickeln, um Daten, die auf regionaler Skala gesammelt wurden, mit Informationen der Umgebung zu vernetzen[2)].

Durch CO-Messungen konnten wir feststellen, dass die Schadstoffemissionen von Autos eine der wesentlichsten Ursachen für die schlechte Luftqualität von Paris und seinen Vororten sind. Die Einrichtung von variablen und festen Messpunkten, die an eine kleinräumliche Skala angepasst wurden, haben es möglich gemacht, die raumzeitliche CO-Variabilität zu beobachten. Die fest installierten Messinstrumente, die an sechs Messpunkten zwischen Oktober 2001 und Februar 2002 angebracht wurden, ergaben, dass das Muster der täglichen CO-Verteilung an allen Messpunkten ähnlich war. Ein erster Höhepunkt konnte am Morgen zwischen 8 und 9 Uhr, ein zweiter am frühen Abend zwischen 19 und 20 Uhr beobachtet werden. Allerdings variiert die CO-Konzentration sehr stark zwischen den einzelnen Messpunkten. Die variablen Messinstrumente, die im kleinräumlichen Bereich in kurzen Zeitintervallen (in Abständen von nur wenigen Metern und Sekunden) eingesetzt wurden, ergaben eine starke Variabilität der CO-Konzentration. In der Nähe von Ampeln stieg die CO-Konzentration auf das 25-fache während der Rot-Phasen der Ampeln. Der CO-Level zwischen einer Fußgängerzone und einer wichtigen Verkehrsstrasse kann durchschnittlich mit dem Faktor 10 multipliziert werden. Die Variabilität der Messungen ist abhängig von dem Verkehrsaufkommen, der Nähe zur Fahrbahn, der Stadtmorphologie und den Wetterbedingungen. Dieser Beitrag hilft nun einen Umgebungsindex zu definieren, der sowohl eine große Anzahl von Daten berücksichtigt (AIRPARIFs Netzwerk, Verkehrsdaten und Wetterdaten) als auch eine Analyse von kleinräumlichen Bereichen ermöglicht.

Summary: AIRPARIF (air quality network) informs the Parisian population about air quality through the ATMO index, which provides information on the agglomeration scale. The aim of this study is to develop the possibilities of observation, at individual scale[1)], in order to upgrade the data collected on a regional scale through information of proximity[2)]. We observed the air pollution caused by automobile traffic, which is a main contributor to bad air quality in Paris and its suburbs, through CO measurements. The installation of mobile and fixed measurements, adapted on fine space scales, made it possible to observe the spatio-temporal CO variability. Fixed measures carried out at six stations between October 2001 and February 2002 highlight that daily CO distribution presents a similar profile at all stations, having a first peak in the morning (between 8 and 9 a.m.) and then a second peak at the beginning of the evening (between 7 and 8 p.m.). But the CO concentration varies strongly between the stations. The itinerant measurements carried out at a small spatial and temporal scale (a few meters and a few seconds) highlight a strong variability of the CO concentration. Near a traffic light the CO concentration increases up to 25 times more between the phases where light is green and red. The CO level between a pedestrian street and a nearby street with important traffic can be multiplied by 10. Variability of this marker is conditioned by the characteristics of traffic, the proximity of traffic, urban morphology and weather conditions. This information contributes to the definition of a proximity index, taking into consideration the whole number of data (AIRPARIF network, traffic level and weather data) and an analysis on fine-scale districts.

1 Introduction

In Paris, information provided to the public about pollution characteristics (sort of pollutants, concentration and distribution) is produced by AIRPARIF with the ATMO index[3)]. This index presents information about the global level of pollution in the agglomeration of Paris (AIRPARIF 2000), broadcast on several local and national media (newspaper, television, radio, municipal board, Internet). The pollutants used in the calculation of the index are from various origins and natures. The measured concentrations depend on various emission sources and weather conditions (MESTAYER a. ANQUETIN 1995; PALMGREN et al. 1999; VARDOULAKIS et al. 2000).

The ATMO index characterizes global pollution on the agglomeration scale for one day. The ATMO index is calculated with the pollution level measured in the day by the urban (25 stations) and suburban stations (6) of Paris. Every day, an index of 1 (very good) to 10 (very bad) is announced to the Parisian population. Every day a sub-index is calculated for each pollutant (SO_2, NO_2, O_3 and PM10), based on the background station of the agglomeration. The worst sub-index determines the final ATMO index of the day – this characterising the global air quality of the agglomeration (AIRPARIF 2000).

The analysis of the annual data of the ATMO index shows that the bad quality of the air is frequently in relation to a high percentage of NO_x, mainly in NO_2 form. NO_x are also precursors in the formation of O_3 under the action of photochemical reactions and are mainly produced by the road traffic. The air pollution due to automobiles is a significant component of bad air quality. The transport sector is the largest source of pollutant emissions in the Paris region, an area in which there are 4 million passenger cars, more than one million of which run on diesel (AIRPARIF 2000).

The ATMO index does not seem to be representative of proximity pollution, because it gives global information, which is not significant at the individual scale.

Indeed, for HOYDYSH and DABBERDT (1988, 1994), the pollution produced at the street level contributes 50 times more to the measured pollution than ambient pollution. An approach on a finer scale would make it possible to approach the reality of the phenomenon at the individual level, carrying out an observation of proximity.

The emissions related to road traffic can be observed with the measurement of a marker like CO (PETERSEN a. ALLEN 1982; CHAN et al. 2002; WÅHLIN et al. 2001; KALTHOFF et al. 2002). Because of its strong volatility, this pollutant is measured on the street scale. CO is thus indicative of the car pollution and it is a dangerous pollutant for human health (cardiovascular effects) if the concentrations are strong (Health protection threshold according to the World Health Organization (criteria 1999): average over 8 hours <10 000 µg/m^3). We chose the CO because it is the only pollutant which can be measured with portable electrochemical sensors.

The work presented here concerns very fine spatial and temporal scales (distance: 1 to 10 meters, lapse time: 15 s), corresponding to a microclimatic scale defined by YOSHINO (1975). We work on this space-time scale to evaluate the pollution of proximity i.e. the pollution breathed by people. The variability of the air pollution concentration due to automobiles at the street level depends on the traffic characteristics (number, nature and speed of vehicles), on weather conditions (anticyclonic weather, perturbated weather, temperature inversion, cloudiness, wind speed[4]) and on areas characteristics (building morphology, street width) (OKE 1987, 1988; SALLÈS et al. 1996; MESTAYER 1998). COPPALLE et al. (2001) highlighted the impact of these various factors on the strong spatio-temporal variability of the automobile pollutants in the streets of Rouen. The observation on the street and the district scale allows us to highlight the variability of automobile pollution over distances of a few meters (FRANGI et al. 1996; BRIDIER a. QUÉNOL 2004).

After having determined the experimental sites and the measurement protocols, adapted to fine spatial scales, CO sensors were used in order to carry out proximity measurements, highlighting the strong spatio-temporal variability of automobile pollution. The use of a portable CO station enables us to improve the measurements and to obtain a higher precision on the localization of the pollution of proximity.

2 *Materials and methods*

2.1 CO measurement apparatus

The measurement apparatus is based on the use of an electrochemical CO sensor (Fluke Co–210, 1ppm resolution), whose signal is electronically amplified to get 0.1 ppm resolution, then recorded by a data-logger (Tinyvolt; range: 0–2500 mV).

The calibration is carried out in a bottle of 10 litres. The sensor is placed in the bottle which is first flushed with reconstituted air[5] to ensure an absence of CO.

[1] Individual scale: the scale of a pedestrian (Individuelle Skala: Beobachtungsebene eines Fußgängers).

[2] Project: "*Des paysages pour vivre la ville de demain*" directed by Mrs. Nathalie Blanc (LADYSS Laboratory) (Das Projekt „Des paysages pour vivre la ville de demain" wird von Frau Nathalie Blanc (LADYSS-Labor) geleitet).

[3] ATMO is an acronym which means "atmosphere" in French. It is a daily index calculated from the concentrations of SO_2, NO_2, O_3 and PM10 on the background station (far from proximity sources of pollutants) of the AIRPARIF pollution network.

[4] Most of the time, Paris, which is on a plain, benefits from a windswept, wet, oceanic climate that sweeps and cleans the atmosphere, thus encouraging the dispersal of air pollution. However, certain meteorological conditions (anticyclones and a lack of wind) can mean that the pollutants remain blocked in the atmosphere around the city, resulting, for the same levels of emissions, in significantly higher levels of pollution (AIRPARIF 2005).

Then volumes of gas[6] containing CO at a concentration of 1,000 ppm are successively introduced and mixed with the air in the bottle. An introduction of 1 ml leads to an increase of 0.1 ppm of the CO concentration in the bottle. A CO concentration of 1 ppm is equivalent to 1,164 µg/m³.

The data provided by the sensor are recorded continuously during the introduction and the mixture of gas containing CO. The protocol was reiterated to establish the sensor response curve as a function of CO concentration (Fig. 1). It is observed that the curve is fairly linear. Three calibrations have been done: the first one in September 2001 (before the beginning of the static measurement), the second one in December 2001 (during the experience), and the third one in March 2002 (at the beginning of the mobile measurement)

The sensor was then installed close to a station of the AIRPARIF network (Victor Basch, 14th administrative district of Paris), the two sensors were at the same elevation (2.5 m), in an open area on both sides of the street (8 m). Comparison with data of the AIRPARIF sensor, down loaded from the Internet, allowed us to check that our sensor provides reliable values of CO concentrations (Fig. 2). The experimental sensor takes instantaneous data at a lapse time of 15 min. The AIRPARIF data on the web have a one hour meaning. This could explain the main difference during the day (when the variations of CO concentration due to traffic evolution are very quick), the shortest lapse time of the experimental sensor taking into account more variation than the AIRPARIF's. During the night (when the traffic flows more evenly and is regular), the experimental sensor gives information very close to the AIRPARIF's.

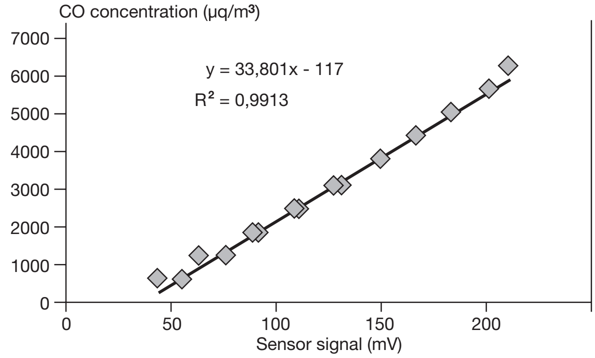


Fig. 1: Sensor no. 1 response curve and parameters of the linear regression

Messkurve und Parameter des Sensors Nr. 1 mit linearer Entwicklung

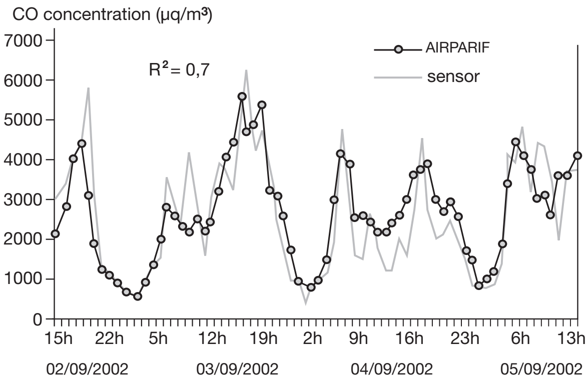


Fig. 2: Comparison between experimental CO sensor and AIRPARIF sensor

Vergleichsmessung zwischen Versuchssensor und AIRPARIF-Sensor

2.2 Technique and measurements protocols

Two types of CO measurements are carried out: measurements at fixed stations and mobile measurements according to a defined itinerary. During the experimentation period, the hourly diffused data by the AIRPARIF network is downloaded for the 5 proximity stations (Célestin Quay, Victor Basch Place, Champs Elysées Avenue, Bonaparte Street, Auteuil Ring Road). These data are used as reference for the daily and weekly CO cycle.

For fixed measurements, the sensor is installed on a balcony, 3 m above the ground i.e. at the same elevation as the sensors of the AIRPARIF stations (Fig. 3). The system recorded the instantaneous CO concentration during 141 consecutive days (October 2001 to February 2002) with an interval of 15 min (96 times per day). During this period, the general climatology of Paris is characterized by an anticyclonic situation (from October to mid-January) with a long duration of winter sunshine (98 hours in December 2001, the highest value since 1958), with cold temperatures and a low north-easterly wind speed. Between January 15 and February, the conditions are cyclonic with regular precipitation, mild temperatures and a strong south-west wind (Météo France 2001, 2002). In general, during the measurements period, anticyclonic weather with a weak wind favoured air pollution.

[5] This first gas is an industrial reconstituted air (a product of Air Liquide) and contains only oxygen and nitrogen in atmospheric concentrations (O: 21% and N: 78%).

[6] This second gas is an industrial reconstituted air (a product of Air Liquide) and contains oxygen (21%) and nitrogen (78%) with a CO concentration of 1,000 ppm.

Other fixed measurements are punctually carried out on a much shorter temporal scale (from a few minutes to one hour, sampling with an interval of 15 s) at road level where traffic is variable (main avenues and secondary street). Simultaneous measurement at a station located near a street with heavy traffic and a station deployed on a pedestrian street aims to highlight the strong spatial variability of the CO concentration. The sensor is installed at the level of the respiratory tract and the data is recorded every 15 s.

Mobile measurements are taken (on foot) on a defined itinerary, with the CO sensor deployed on a backpack. A data logger connected to the CO sensor is programmed simultaneously with a GPS set at a 15 s interval. The itinerary time varies from 30 min to 2 hours. The comparison between the GPS and the sensor allows the geographical position at the time to be known, when the CO concentration is measured along the itinerary. During the experimental programme, each itinerary was followed on different schedules (several levels of traffic) and during different atmospheric situations (sunny, cloudy, strong wind).

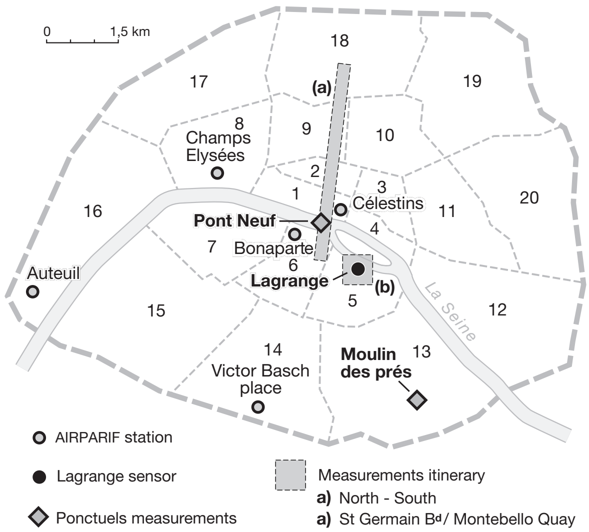


Fig. 3: Locations of CO measurement stations and measurement itineraries

Lage der CO-Messstationen und Messstrecken

2.3 Study site

The experiments were carried out inside Paris during 2001 and 2002. The measurement sites, presented on figure 3, were selected according to the traffic intensity and to the environment of the district (street morphology, parks …).

A fixed sensor was laid out on a balcony, 3 m above the surface in Lagrange Street (5^{th} administrative district). It is a one-way street distant from a crossroads with heavy traffic.

Punctual fixed measurements were taken in Pont Neuf (6^{th} administrative district) and between Peupliers Square and Moulin des Prés Street (13^{th} administrative district). Peupliers Square area is made up of a closed square one to two-storeyed adjoining with pedestrian streets. The square borders on Moulin des Prés Street, which is a double one-way lane, taken by commuters coming to Paris (traffic peak between 7:30 a.m. and 8:30 a.m.).

Mobile measurements were carried out on two itineraries, following a general idea of spatio-temporal variability of the CO concentration at the street level.

– A first transect North-South (A), from Sacré Coeur Basilica (18^{th} administrative district) to Saint Michel Place (5^{th} administrative district) takes successively smaller one-way light traffic streets (Orsel, Cadet, Croix des Petits Champs, …) and crosses wide roads with heavy traffic (Rochechouard Boulevard, Maubeuge Street, Lafayette Street, Poissonnière Boulevard, Réaumur Street, Rivoli Street, Grands Augustins Quay). This itinerary allows us to highlight the very fine localization of the pollution produced by intense traffic on an inter-district spatial scale.

– A second itinerary (b) allows us to observe pollution inside a mainly pedestrian-street district (Maubert impasse), in low speed zones (3 Portes, Lagrange, and Galande streets) and in several heavy traffic trunk roads (Montebello Quay, St Germain Boulevard, St Jacques Street). This itinerary makes it possible to show a strong spatial (between the various types of streets) and temporal variability (various hours of the day corresponding to a variable intensity of the traffic) of CO concentration on the intra-district scale.

3 Results

3.1 Static measurements in Lagrange site and AIRPARIF stations

The data recorded every 15 minutes during 141 days from October 2001 to February 2002 by the fixed station at Lagrange Street, were averaged on an hourly basis and differentiated between weekdays and the weekend. The daily CO distribution concentration presents a similar profile to that which is described for the stations of AIRPARIF network, with a first peak in the morning (between 8 and 9 a.m.) and then a second peak at the beginning of the evening (between 7 and 8 p.m.) (Fig. 4 and 5).

station	ways number	direction	crossroads
Célestin	2 x 2	double	no
Ch. Elysées	2 x 4	double	yes
Auteuil	2 x 4	double	no
Basch	2 x 3	double	yes
Bonaparte	2	single	no
Lagrange	1	single	no

Fig. 4: Characteristics of CO stations
Kennzeichen der CO-Messstationen

The weekly CO distribution presents differences between the five days of the week and the 2 weekend days. Indeed, the strongest values for the entire AIRPARIF network are generally recorded on Saturday and Sunday evenings. At the weekend, the night-time leisure activities seem to generate traffic as heavy as that of economic activity during the day. However, the range of the CO concentration between the week and the weekend is larger for the morning peak than for the evening peak. This diurnal variation "workday and weekend" of the CO concentration is noted by many authors (KALTHOFF et al. 2002; WÅHLIN et al. 2001; QIN a. CHAN 1993; GRAM 1996). The highest CO concentrations were observed at the Victor Basch Place station (max = 4,152 µg/m^3; mean = 2,314 µg/m^3). This station is situated on a very busy lane (Général Leclerc Avenue) near a crossroad and near traffic lights. Général Leclerc Avenue is taken from the southern suburbs where motorists who leave the ring road to go into Paris (journey residence ↔ work). The environs of the sensor and the intensity of the traffic explain these high CO concentrations. The distribution of the CO concentration curves is characterised by a first peak in the morning (Monday to Friday) and then a second peak between 6 and 8 p.m. (week and weekend). A secondary peak, on Saturday evenings between 9 and 11 p.m., corresponds with night-time leisure (discotheque, pub). A similar distribution of the CO curves is observed at Célestins Quay (max = 3,092 µg/m^3; mean = 1,680 µg/m^3) and Porte d'Auteuil stations (max = 2,965 µg/m^3; mean = 1,741 µg/m^3), although the observed concentrations are a little lower than those of Victor Basch Place. These two stations are located on very busy traffic lanes (ring road, two-way street), but the environs of the sensor (neither crossroads nor traffic lights but very wide streets) seems to limit the CO concentration. The data recorded at the two stations of Champs Elysées Avenue (max = 2,179 µg/m^3; mean = 1,257 µg/m^3) and Bonaparte Street (max = 2,087 µg/m^3; mean = 1,105 µg/m^3) reveal smaller concentrations. Bonaparte Street is a one-way street. The most significant CO peak is observed during the week between 8 and 10 a.m. Contrary to other stations, the evening peak is not very high. As for the Champs Elysées Avenue, CO concentration is definitely higher during the week, except for Saturday evening to Sunday morning, from 9 p.m. to 5 a.m. (night-time leisure). The street's morphology (very wide) could explain the weak CO concentration in spite of the intense traffic (red street[7]).

CO concentrations measured by the Lagrange Street sensor (max = 2,188 µg/m^3; mean = 1,256 µg/m^3) are close to those observed at the Bonaparte Street station (station nearest to Lagrange). Two CO peaks are visible here but they are lower than at the other stations. The week and weekend values are homogeneous in the morning; however, the CO concentration between 7 and 11 p.m. is higher at the weekend. Lagrange Street is a one-way road leading tourists towards cathédrale Notre Dame. It is used less as an access street to work. Consequently, the week and weekend values are homogeneous at the time of the morning peak. On the other hand, in the evening, CO concentration is higher than at the weekend.

The analysis of the 6 stations allowed us to show the spatio-temporal variability of the proximity pollution, according to the environment sensor, the traffic level and the streets characteristics (one-way road, crossroads or a traffic light, width of the street …). For example, the Lagrange Street station shows the average concentration to be identical to the Champs Elysées station, for very different levels of traffic. Differences in morphology between the 2 sites (a narrow street lined with 6 storey buildings; wide open avenue) can explain these variations.

3.2 Static measurements at a short temporal scale

These observations were carried out with the equipment of mobile measurements on the street scale at an elevation of 1.5 m above the ground. The observations cover ten minute periods on that high level or average traffic intensity.

3.2.1 Measurements near a traffic light

The measurements carried out near a traffic light at the crossroads between Moulin des Prés Street (2 ways) and Tolbiac Street (2x2 ways) show that the CO concentration presents a cycle completely correlated with the traffic light cycle. The concentration increases

[7] Red street: classification of street with high circulation (excluding ring road which is higher).

when the vehicles are at a stop. It decreases after the vehicles move and when circulation is fluid. According to SALLÈS et al. (1996), the CO concentration strongly varies according to the vehicles' speed, knowing that it strongly increases when they stop. Moulin des Prés Street is a road which allows the commuters, coming from the southern suburbs by the ring road, to avoid the main roads, which are generally very congested. Traffic on this way is very heavy in the morning between 8:00 and 8:15 a.m., when people go to work. During this period of time (15 minutes), in 2002, on March 29th, the CO concentration was lower than 2,000 µg/m^3, when the traffic light was green. When the traffic light was red, the CO concentration suddenly increased, reaching in a few seconds values higher than 6,000 µg/m^3. CO concentration varies according to the number of standing cars at the traffic light, however, it also varies according to the type of vehicle. A CO concen-

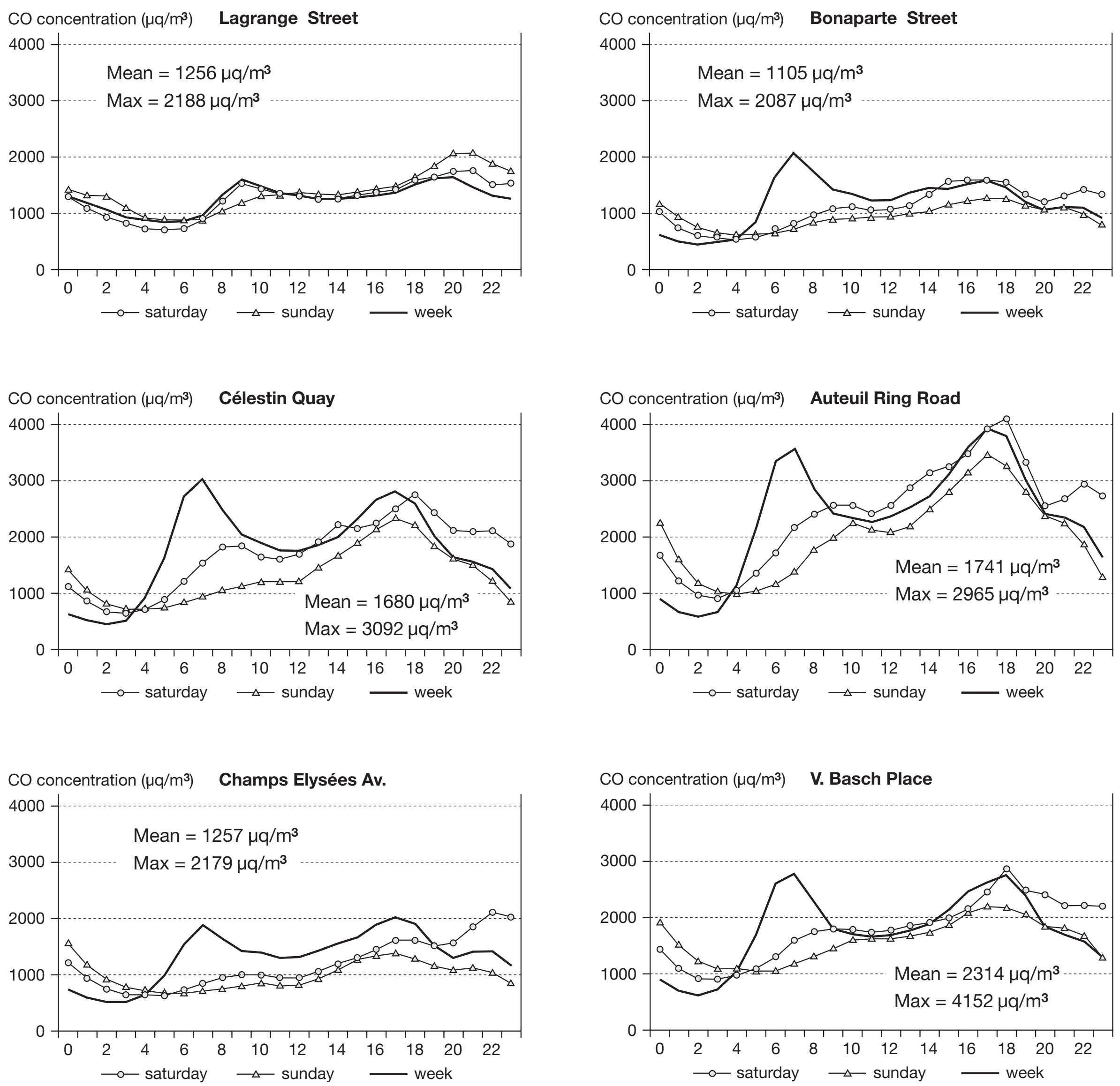


Fig. 5: Comparison of CO concentration between Lagrange site and neighbouring stations of AIRPARIF mean per hour by 141 days (October 2001 to February 2002)

CO-Variabilitäten an der Lagrange-Station und benachbarten AIRPARIF-Messpunkten (Stundenmittel aus 141 Tagen zwischen Oktober 2001 und Februar 2002) tration close to 12,000 µg/m³ was measured when a truck and a bus waited at the traffic light (Fig. 6).

3.2.2 Measurements during a short stop of the traffic

In the preceding examples, we saw that the CO concentration increases suddenly when the vehicles are waiting for the traffic light. On November 2nd 2001, the observation near the crossroad between the Pont Neuf and St Augustin Quay (4 lanes + 1 bus-lane) shows how the CO concentration sharply falls after a short halting of the traffic (5 min) due to the passage of a very large group of roller-skaters on the street. The CO concentration then changes from 9,000 µg/m³ which corresponds to a dense traffic, to 2,000 µg/m³ when there is no vehicle on the street for 5 min, then reaches to 7,000 µg/m³ after traffic picks up (Fig. 7).

3.2.3 Comparative measurements between a street with major traffic and a pedestrian district

During the measurements in Moulin des Prés Street in the morning of March 23rd, 2002, a second CO sensor was laid out in a lane of Peupliers Square (pedestrian area). The two sensors are approximately 50 m one from the other. In Peupliers Square, the CO concentration is homogeneous during the entire measurement period and it is definitely lower (always lower than 2,000 µg/m³) than that measured in Moulin des Prés Street (Fig. 6). This example shows that over a short distance, the level of the proximity pollution can vary strongly spatially and temporally. However, the measured concentration at the level of the pedestrian area is relatively high, showing that pollution level varies according to the areas' morphology (closed district).

3.3 Itinerant measurements along a north-south transect

Measurements carried out the night of November 2nd, 2001, from the connecting centre of Paris to the Sacré Coeur Basilica itinerary (northern Paris) highlight the variability of the CO concentration according to the traffic intensity (map 1). The lowest CO concentration was always measured in the streets where the traffic was weak or moderate, whereas the highest concentrations correspond to the avenue where the traffic is very heavy. Figure 8 shows that CO peaks, between 8,000 and 11,000 µg/m³, were recorded with the crossroads of Grand Boulevards or streets with heavy traffic. The spatial variability of the CO concentration is very high over a small distance. At 11:07 p.m., CO concentration on the Seine side was lower than 500 µg/m³, whereas at 11:10 p.m., at the Pompidou tunnel exit (with less than 50 m) it was higher than 6,900 µg/m³. The differences of CO concentrations measured varied between intense and weak traffic, having been reoccurred at various hours of the day, various days of the week, and for various weather types (calm and turbulent).

3.4 Itinerant measurements in the Lagrange district

The itinerary of the Lagrange district follows heavily-used roads (4 lanes), streets (1 lane), small roads, and pedestrian streets. The same itinerary was carried out at various hours of the day, corresponding to levels of variable traffic, and different weather types. Maps 2 and 3 show that CO concentration presents significant variations, corresponding to traffic intensity on the various lanes. However, the measured CO concentration

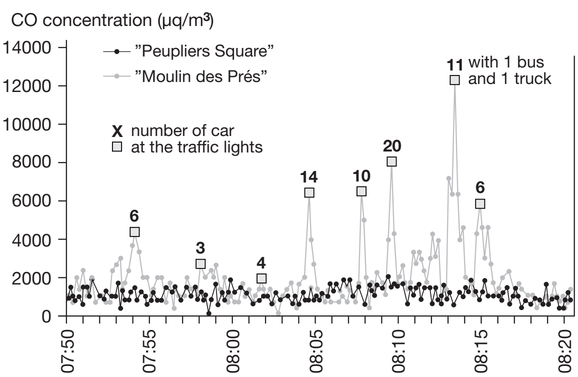


Fig. 6: Simultaneous measurements of CO concentration between pedestrian area and high traffic street (29/03/02, 07:50 to 08:20 a.m.)

Gleichzeitige CO-Messung an einer Hauptverkehrsstraße und in einer Fußgängerzone (29.3.02, 07.50 – 08.20 Uhr)

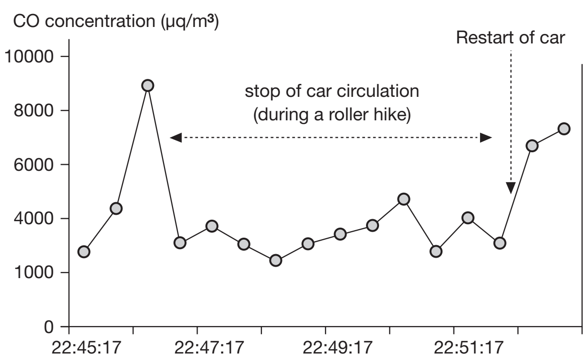


Fig. 7: Static measurements of CO concentration at the Pont-Neuf (02/11/01, 10:45 to 10:53 p.m.)

CO-Messung an der Pont Neuf-Messstation (2.11.01, 22.45 – 22.53 Uhr) also depends on the proximity to the traffic. The recorded values at the level of Viviani Square were much lower than those measured at the level of Montebello Quay, whose distance was less than 40 meters. In the same manner, the recorded concentration in the small roads (less than 50 m from the heavy traffic) was weaker than that of Lagrange Street or Montebello Quay. Figure 9 shows comparative itinerant measurements with two CO sensors produced on March 29th, 2002 in the morning. Between 10:00 and 10:06 a.m., the first operator was on the Montebello Quay, whereas the second one was in Viviani Square. On average, CO concentration is twice as high for the first sensor. On the other hand, between 10:07 and 10:10 a.m., when the second operator was leaving Montebello Quay and the first one was leaving small adjacent streets, the curves were reversed and the strongest data was obtained by the second sensor. At 10:11 a.m., the two operators met up and the CO concentrations recorded were nearly identical.

This measurement itinerary was carried out during varied weather conditions (calm, turbulent). The CO concentration varies according to the atmospheric conditions, even though its spatial distribution is always identical whatever the weather. The spatial CO variability thus depends mainly on the proximity of the traffic. Figures 10 and 11 show the variation of the CO

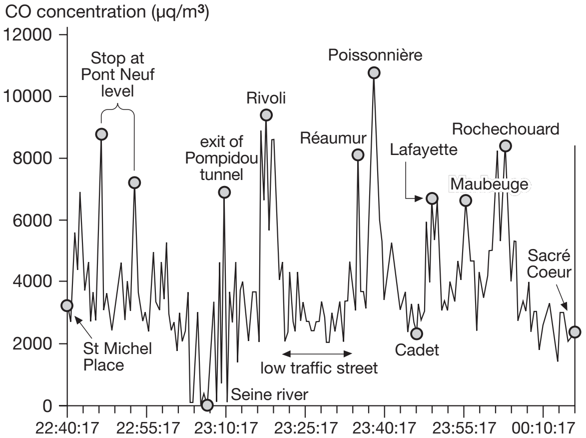


Fig. 8: CO concentration between St Michel Place (1) and Sacré Coeur Basilica (2), (night of 02/11/2001)

CO-Messung zwischen Place St Michel (1) und Sacré Coeur (2), (Nacht v. 2.11.01)

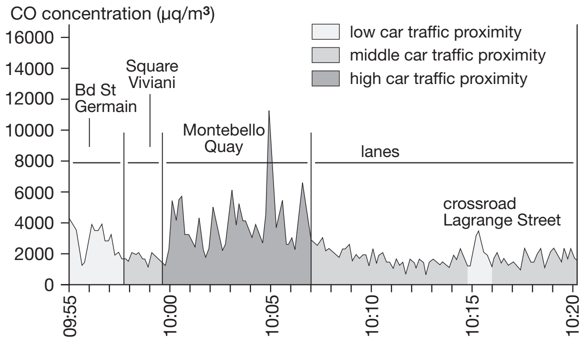


Fig. 10: Itinerary measurements of CO concentration between St Germain Boulevard (09:55 a.m.) and St Jacques Street (10:20 a.m.) the 29/03/02 during anticyclonic weather conditions (clear sky and low wind)

CO-Streckenmessung zwischen Boulevard St Germain (9.55 Uhr) und Rue St Jaques (10.20 Uhr) am 29.3.02 während antizyklischer Wetterbedingungen (klarer Himmel, schwacher Wind)

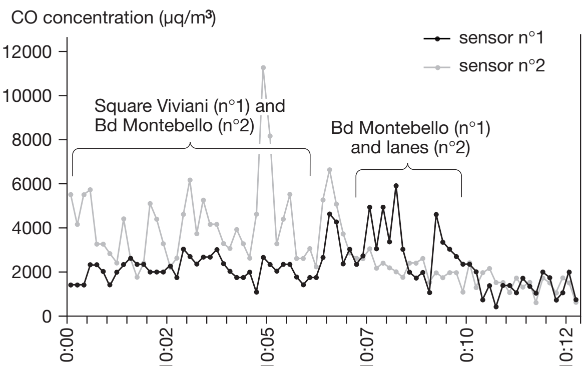


Fig. 9: Simultaneous measurements of CO concentration during anticyclonic weather (29/03/02, clear sky and low wind)

Gleichzeitige CO-Messung während antizyklischer Wetterbedingungen (29.03.02, klarer Himmel, schwacher Wind)

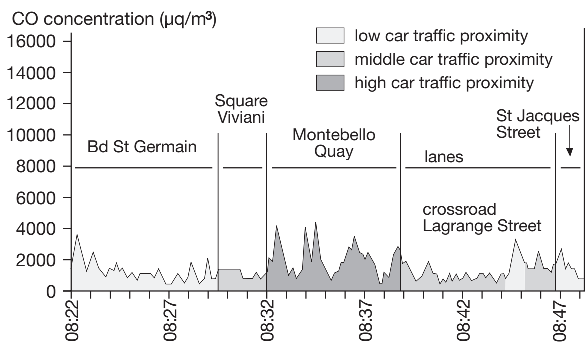


Fig. 11: Itinerary measurements of CO concentration between St Germain Boulevard (08:20 a.m.) and St Jacques Street (08:50 a.m.), the 22/03/02 during perturbated weather conditions (north-west wind >5 m/s)

CO-Streckenmessung zwischen Boulevard St Germain (08.20 Uhr) und Rue St Jaques (08.50 Uhr) bei starkem NW-Wind (>5 m/s) concentration on the itinerary in calm and sunny weather (morning of March 29th, 2002) and in turbulent and windswept weather (north-west wind direction, up to 5m/s wind speed) (morning of March 23rd, 2002)[8]. The highest CO concentrations were recorded during calm weather. Indeed, the anticyclonic conditions were favourable to the CO concentration, due to the absence of strong wind, limiting the air mixing and the CO dispersion (CHANG et al. 1980; ALARY et al. 1994; COPPALLE et al. 2001; KUKKONEN et al. 2001; CHAN 2002). The profile of the two CO curves is similar and the strongest concentrations are obtained in the streets where the traffic is higher (Montebello Quay). However, the CO peaks are less intense during disturbed weather.

4 Discussion and conclusion

The aim of this study was to show that the level of pollution can vary strongly from one street to another and that a single index for all the agglomeration is insufficient. Consequently, results show that people exposure depends on spatio-temporal variability. The analysis of CO does not permit one to evaluate the influence of the pollution of proximity on human health and to improve the alert system (in Paris, there is no concentration level of CO). CO is dangerous for health when a long high concentration level period occurs. In the context of a development of an alert system adapted to the pollution of proximity, it is necessary to observe other pollutants such as NO_2 and SO_2.

The measurements (fixed and mobile) carried out on a microclimatic scale show a strong spatio-temporal variability of CO concentration in relation to the traffic's density and proximity, and the morphology of the district as well as the weather type. To estimate traffic characteristics, information such as the lanes' characteristics, their use according to the day and hour, the district economic activities (offices, trade, industry, leisure …) which generate traffic would allow the building of a traffic data base on a local scale. The traffic level can be estimated starting from the information distributed by the "Direction Départemental de l'Equipement" (SYTADIN websystem) on the steady flow of traffic. The maps materialize the steady flow traffic level of the busiest traffic streets on the agglomeration scale, and therefore the most frequently used. The traffic level is updated every three minutes. This information allows us to estimate the CO production according to the traffic density and the steady flow of traffic.

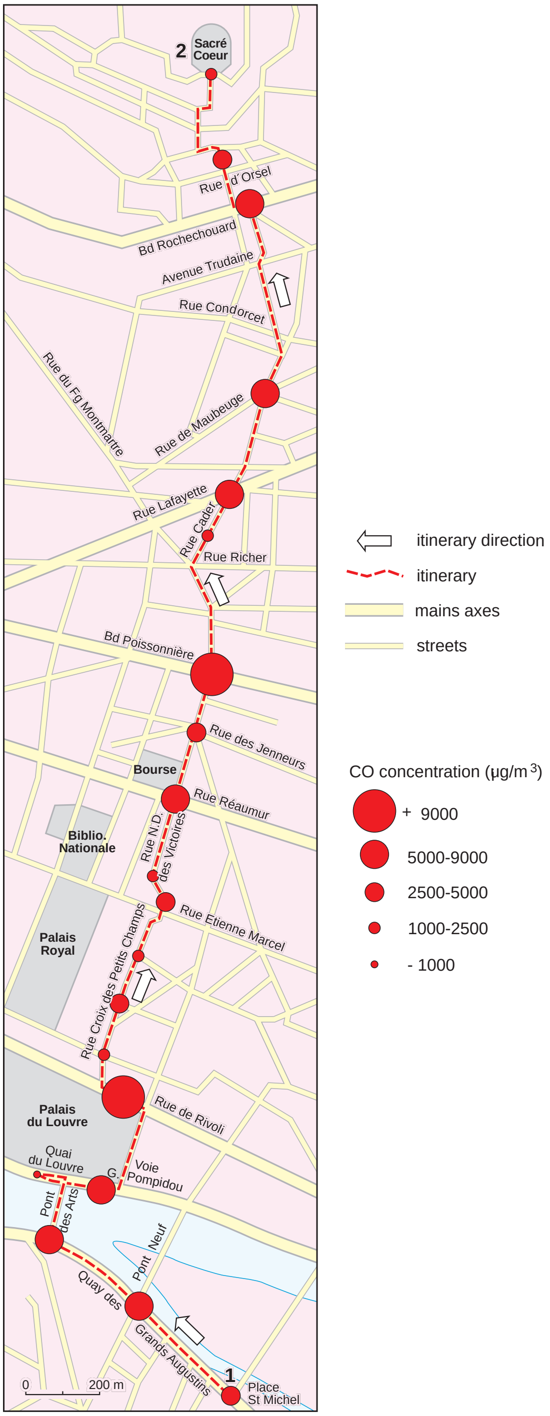
To understand the impact of the urban environment on the CO concentrations, a good knowledge of urban morphology can be established from a data base on the streets (width) and the buildings (height). These data will make it possible to characterize the urban canyon, to differentiate the sheltered sectors from the open sectors, in order to make a cartography of the area where pollution is supposed to concentrate or to be dispersed, as the Lagrange and Champs Elysées stations data made clear (cf. chapter 3.1).

The weather type, and in particular the wind, must be taken into account to estimate the capacities of mixing and evacuation of the air mass inside the "urban canopy". The wind seems to be an important weather factor that limits the CO concentration. According to the street morphology (narrow, wide, sheltered, …), the wind's action on the CO dispersion is variable. By carrying out CO measurements in various ways, CHAN et al. (2002) show that the CO concentration is stronger in closed sectors with a weak aerology such as a tunnel or a sheltered district. That confirms the observations made on the level of Peupliers Square (chapt. 3.2.3, Fig. 7). VARDOULAKIS et al. (2002) explain the peak CO concentration in July 1999 in the Rennes Street (Paris 6th administrative district) observed on a Saturday when the traffic was lighter than during week days, but when regional wind speed was lower than 3 m/s. To highlight this influence on the pollutants' concentrations, the weather conditions can be taken into account with "Météo France" data (regional scale) and measurements on a fine scale (district, street).

Pollution, traffic and weather type data processing enable us to consider the creation of a proximity index. The Global Information System (KOUSA et al. 2002; MENSINK et al. 2000) is adapted to the combination of these data and an analysis on fine scales can lead to more precise information on the vehicle-generated proximity pollution at the street and public space scale.

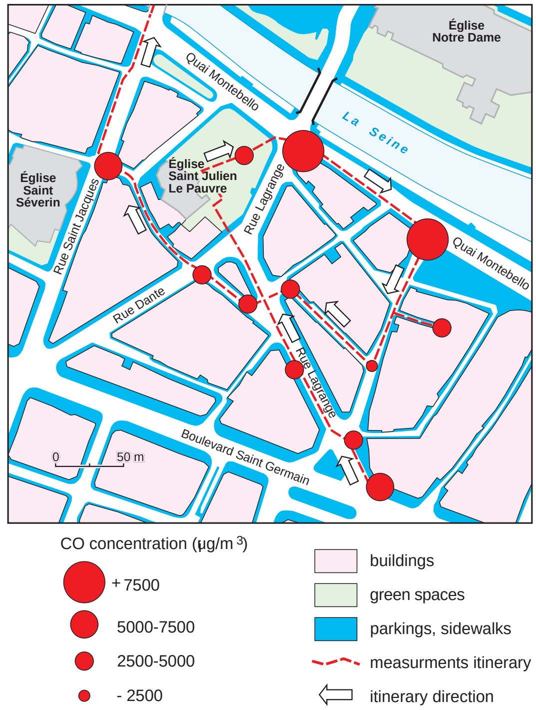
The air quality observation on the district scale shows a strong spatio-temporal variability of the CO concentration, related to local parameters such as the proximity and the intensity of traffic, street morphology and atmospheric situation. The current grid of AIRPARIF network is too widely spaced to provide satisfactory information on proximity. Establishment of secondary sensors networks of pollution (with SO_2, NO_2, O_3 et PM10) according to a street typology, taking

[8] For the figures 10, 11 and the map 3, the traffic intensity estimated with the standards used by the "Direction Départementale de l'Equipement" and AIRPARIF". "High traffic" = between 1,500 and 3,000 vehicles per hour; "middle traffic" = between 500 and 1,500 vehicles per hour; "low traffic" corresponds to less than 500 vehicles per hour.



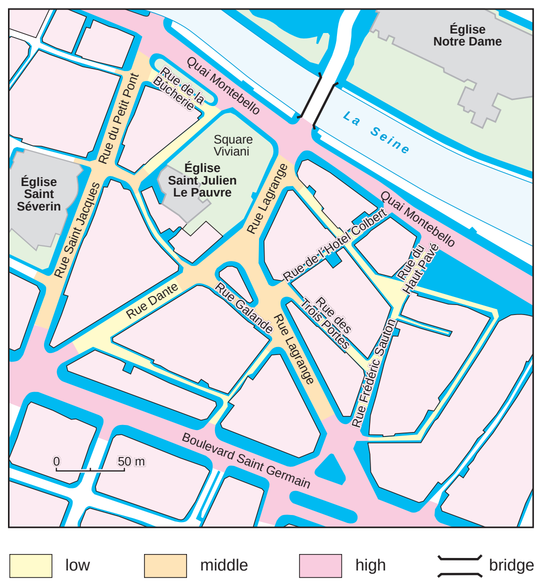
Map 1: Spatial representative of CO concentration between St Michel Place (1) and Sacré Coeur Basilica (2), night of 02/11/01 (10:40 p.m. to 00:15 a.m.)

Räumliche Verteilung von CO-Konzentrationen zwischen Place St Michel (1) und Sacré Coeur (2) am 2. u. 3.11.01 (22.40 – 00.15 Uhr)



Map 2: CO concentration between St Germain Boulevard and Montebello Quay the 16/03/02 (05:30 to 06:30 p.m.)

CO-Konzentration zwischen Boulevard St Germain und Quay Montebello am 16.3.02 (17.30–18.30 Uhr)



Map 3: Traffic density the 16/03/02 at about 06:00 p.m. (estimated from D.D.E. data and local observation)

Verkehrsdichte zwischen Boulevard St Germain und Quay Montebello am 16.03.02 um etwa 18 Uhr (geschätzt nach Daten des D.D.E. und eigener Beobachtung) into account their characteristics (orientation and width of the streets, morphology of the building, …) and traffic density, should allow the definition of a proximity index as well as a weather type spatial modelisation by class.

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