RELAZIONE - REPORT
PROGRAMMA DI RICERCA STM - 2015

Fruitore: **Prof. BERND LEITL**

Istituto di afferenza:

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con qualifica **Professore** livello **Full professor**

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Dipartimento di afferenza

Dipartimento di Scienze del Sistema Terra e Tecnologie per l'Ambiente

Titolo del programma/Title of the program:

Feasibility study for a European urban-scale dispersion field experiment for models intercomparison in the emergency response framework

Relazione finale/Final Report

The main objectives of the STM program were:

(1) to evaluate the feasibility of carrying out a dispersion field experiment in a European city, specifically aimed at models validation and intercomparison in emergency response in built environment

(2) to design the possible field experiment and model intercomparison exercise

(3) to prepare a proposal describing the rationale of the project and outlining the experimental and modelling programs, to be submitted to the interested scientific community.

After an extensive exchange of project ideas, a critical review of the scientific and research potential of different project ideas and a detailed study of literature and profound analysis of the most critical issues related to meteorology and atmospheric dispersion of pollutants in built environments, Prof. Leitl and Dr. Trini Castelli have decided to focus their joint research efforts on one of the most crucial open issues in atmospheric flow and dispersion modeling at local scale. The most crucial situations regarding atmospheric transport, urban air pollution and ventilation and also with respect to a possible hazmat exposure of citizens occur at low wind conditions in urban terrain. Simultaneously the dynamics of low-wind conditions in complex urban structures, the corresponding decay in turbulence as well as resulting low-wind pollutant transport phenomena a far from being completely understood and properly implemented in today's modeling tools. Basic research on low wind conditions particularly in urban terrain is needed to drive the development of modelling tools for more applicative implementations in urban meteorology. A proposal for establishing a European research track for these open scientific issues was drafted jointly. The proposed project and the resulting gain in knowledge will substantially contribute to improvement in health and safety standards in the fields of urban air quality and emergency response by providing data and modelling tools for generating a substantially more reliable basis for risk assessments particular in critical environments and under critical environmental conditions.

During the STM, the following activities were fulfilled:

(1) the specific and distinctive scientific issues and characteristics of field experiments dedicated to model validation and model intercomparison for low-wind speed and tracer releases in built environments, with a particular attention to emergency response studies, were addressed and discussed

(2) a detailed analysis of the scientific literature focusing on low-wind speed and transient turbulent regime was conducted and open scientific issues have been identified and elaborated

(3) a survey of all relevant experimental studies performed in the field of urban meteorology, local-scale air pollution and ventilation as well as in the context of hazmat dispersion was carried out, identifying substantial shortcomings in existing experimental data

(4) the feasibility of carrying out dispersion field experiments in European cities, identifying possible candidates, was evaluated

(5) ideas for a comprehensive research campaign involving field experiments as well as modelling exercises were developed and elaborated, including also a discussion on the approach for particularized model validation and intercomparison protocols

(6) possible constraints regarding the feasibility of the project were outlined and potential participants in the scientific and stakeholder community were identified in order to improve chance for funding

(7) proper national and European platforms for fund raising to support the project were discussed and will be approached: the “Unità operativa di Bruxelles” of the “CNR _ Ufficio Relazioni Europee e Internazionali” was contacted and a first agreement has been taken for the possible presentation of the proposal; a similar action will be taken by Prof. Leitl contacting the corresponding German KOWI Office in Bruxelles in order to initiate the forming of a larger research consortium

(8) a comprehensive proposal addressing all former points and designing a hybrid experimental/modelling approach to the problem as well as a corresponding model intercomparison exercise was prepared and it is attached to the report.

The idea expressed in the proposal is not only original but will improve scientific knowledge and will reinforce the collaboration between the two Institutions, linking together different expertise.

Upon first approval of the project, it is intended to enlarge the group of experts and participating Institutions across Europe, also involving non-European expertise.

(ATTACHED: THE DRAFT PROPOSAL AS OF OCTOBER 2nd, 2015)

Torino, October 2nd, 2015

Il fruitore
Prof. Bernd LEITL

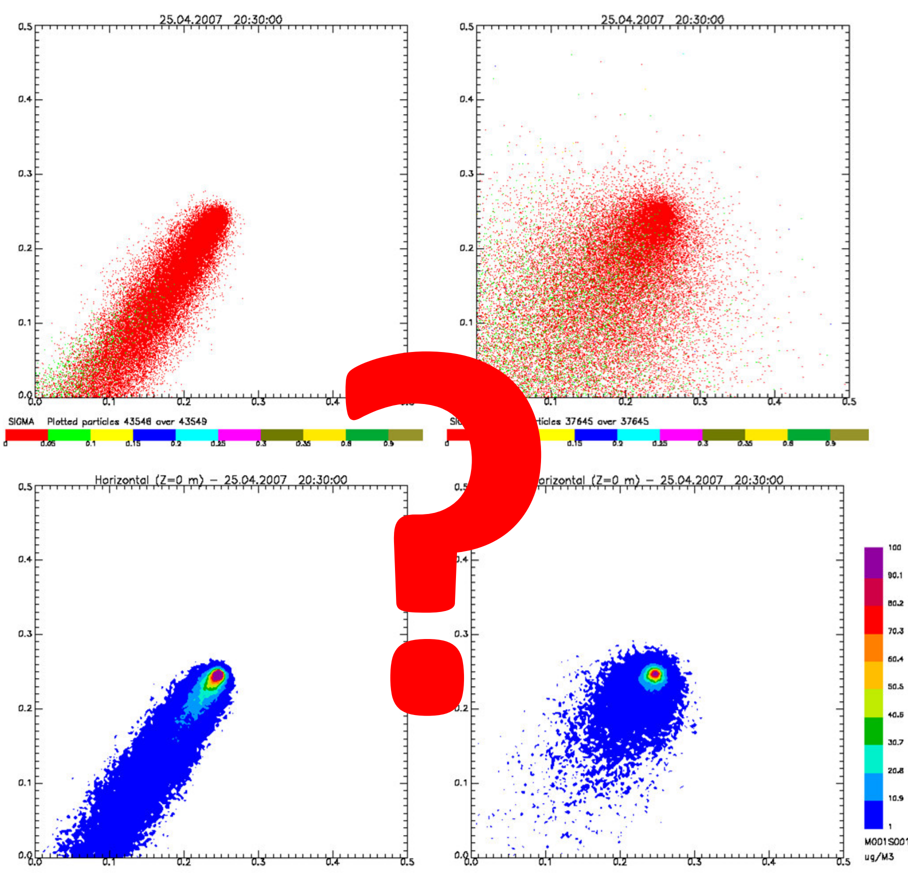
Il proponente
Dr. Silvia TRINI CASTELLI

Low Wind – High Risk: Improving the knowledge about dynamics of low winds and low wind dispersion phenomena in complex urban environments

Draft Project Outline   October 2, 2015

prepared within the scope of a CNR STSM by

Bernd Leitl & Silvia Trini Castelli



Pollutant dispersion simulation in low wind speed conditions:
left: standard turbulence parameterization, right: empirical low-wind formula, right.

Motivation/Background/Rationale

The areas of interest in atmospheric research are apparently splitting in two distinct pathways. One track is dedicated to large-scale/long-term observations and modelling for example in the context of climate research, climate mitigation and adaptation or traditional meteorological research and observations. The second path is dedicated to the implementation of meteorological knowledge and expertise at local scale as for example in the context of urban climate research or in air quality modelling. The impression is that present national and European funding schemes at local-scale predominantly cover applied research, not sufficiently considering the still existing fundamental gaps in knowledge particularly relevant at local scale in complex environments. Particularly in the field of urban meteorology and physics, basic research is found to be almost exclusively carried out at national level, often not reaching a 'critical mass' in expertise and funding to tackle the remaining fundamental questions adequately. On the other hand, substantial progress in both the application of models to local-scale atmospheric flow and dispersion problems and the application of advanced measurement techniques employed in observations trigger even new fundamental research questions in order to reveal the full potential of improved tools applied to local-scale problems in complex environments such urban agglomerations.

As an example of these developments, atmospheric dispersion modelling in the context of local-scale emergency response can be seen. Remarkable national and European research programs focus on improving the security of citizens in European countries and a substantial amount of money has been attributed to developing instrumentation for detecting and tracking hazardous materials if released in populated environments. However, instruments - no matter if they are permanently operated in the course of monitoring or temporarily applied in the course of emergency response - are of limited use in emergency management. Particularly in local-scale scenarios (a) they document, at best, a current situation at a given location or in a certain area and (b) they cannot provide much information on the future development of a scenario, which is mandatory for acting and not just reacting to a given threat. Atmospheric dispersion modelling is expected to be the only tool which can provide forecast information effectively supporting an efficient and reliable emergency response management. Nonetheless, dispersion models are not yet perfect. Typical challenges in the use of advanced dispersion models still range from the definition of appropriate model boundary conditions for an evolving situation such as the provision of short-term predictions of varying boundary conditions to more fundamental problems in scenarios approaching low wind speed conditions or in case of a gravity-driven dispersion of non-neutral releases. Other examples of still existing fundamental gaps in knowledge can be identified in urban micro-meteorology. When looking at established procedures for characterizing the urban micro-climate regarding wind flows and air pollution, for the sake of simplicity or because of a lack in basic understanding, approaches which are in a strict physical sense not appropriate to application in urban environments are still applied routinely. The assumption of local equilibrium conditions and the resulting use of the roughness length concept for characterizing an equivalent aerodynamic roughness are among the most prominent examples how the still existing lack of knowledge and understanding leads to simplified and rudimentary application of meteorological knowledge to local-scale problems.

Very challenging, yet not fully understood phenomena with a substantial impact on environment and population are the aforementioned low-wind scenarios. In particular in densely populated urban areas, low wind dispersion and ventilation events lead to the most critical conditions regarding air pollution, heat stress or exposure during accidental releases. Low wind conditions have been studied substantially from a classical meteorological perspective and commonly considered to relate to stable atmospheric conditions. However, the chances for low wind conditions are even higher in areas densely covered with buildings. With measurable mean winds above urban structures during near-neutral or convective conditions very low winds within the urban canopy can be observed, resulting in erratic and drastically reduced ventilation and high pollutant exposure. Whereas detection of low wind situations is readily possible with state-of-the-art measurement techniques, it remains a big challenge to analyse and quantify effects using measures applied under normal wind conditions. Statistical measures reach their limit because representativeness of data is decreasing with wind speed. Other methods such a wave-or meandering-based approaches are difficult to apply because the implied periodicity of phenomena often is difficult to be detected at relevant time scales. An improved understanding of processes and phenomena is desired to develop a physically consistent perception of wind, turbulence and diffusion as local winds in urban terrain approach calm conditions. Such an endeavour requires a reliable dedicated experimental database to build on, involving existing tools and expertise available in a larger research community across Europe. Concerted research activity in a dedicated community will deliver the link between the decay of turbulence and low wind dispersion in built environments, where most of us are living.

Although it is not explicitly a part of the draft proposal, at the very end the project and the resulting gain in knowledge will substantially contribute to improvement in health and safety standards in the fields of urban air quality and emergency response by providing data and modelling tools for generating a substantially more reliable basis for risk assessments particular in critical environments and under critical environmental conditions.

State of the Art

Theory of low-wind dynamics

Light and low winds are known to trigger distinctive flow dynamics and dispersion conditions in the atmospheric boundary layer. As incisively summarized by Luhar (2012), when the stratification is strongly stable, for instance during the night, intermittent turbulence in the vertical and low-frequency air motions in the horizontal can be generated (Mahrt, 1998). In this condition, the vertical diffusion of a tracer or contaminant released in the environment is reduced, while in the horizontal the tracer can be subjected to a large meandering. Lower diffusivity results in substantially larger instantaneous pollutant concentrations at even large distances from the emission source. When weak winds occur in unstable conditions, as in daytime, vertical diffusion can be instead enhanced because the convective velocity can become larger than the mean wind speed (Hanna and Paine, 1987). In this case, upwind diffusion can originate and its effect may have the same order of magnitude as the mean advection contribution.

Decaying turbulence, low wind speeds, turbulence anisotropy and meandering are processes are not yet not fully understood particularly at local scales. The outcome of this is the dynamics of the lower atmosphere still being generally unpredictable, and consequently diffusion under these conditions is found to be still indefinite (Sharan et al. 1995 and 1996a). Related atmospheric conditions become crucial issues for meteorology as well as understanding and modelling of dispersion. Consequently, they imply large uncertainties when employed in the context of air quality assessment or emergency response framework. This lack in knowledge becomes even more severe when considering the flow dynamics and the tracer diffusion in heterogeneous and complex terrain and built environments. Several theoretical, experimental and modelling studies have been conducted in homogenous and heterogeneous conditions, mostly in stable atmospheric stratification (Luhar et al. 2009, Mahrt 2010, Mahrt 2014…) and in a few cases in all atmospheric stabilities (Sharan et al. 2002, Moraes et al. 2005). It was found that generation of turbulence in low-wind stable conditions does not satisfy existing similarity theory but it is still poorly understood (see Mahrt et al. 2012 for a discussion). Also, low wind and meandering were proved to occur in all stability conditions, but scaling parameters that can clearly identify such regime are still not conclusively defined (Anfossi et al., 2005; Mortarini et al. 2013, Trini Castelli et al. 2014, Mortarini and Anfossi 2015).

Studies in urban areas (e.g. Roth 2000, Rotach et al. 2004 and 2005) were seldom dedicated to tackle these particular conditions and, when this was done, the city scale was addressed (Mestayer et al. 2005) or only one or few observational stations were providing data (Oettl et al 2001, Ferrero et al. 2009, Fortuniak et al 2012). Thus, no details on the calm-regime dynamics within the obstacles in the urban fabric, at the neighbourhood and street scale, have been observed and investigated. The influence of the urban roughness sublayer on the turbulence and dispersion has been extensively studied (see for instance Rotach 1999). However, often low-wind data are just removed from the dataset because of the high sensitivity and uncertainty affecting their measurement (Christen et al. 2009) or associate dispersion experiments are not available. Monin-Obukhov similarity theory is proved to be inappropriate in urban boundary layer (see for instance Fisher et al 2006, Foken 2006), their scaling parameters were found to be possibly not appropriate in low wind (Mahrt et al. 2012, Trini Castelli et al., 2014). These limitations lead to inadequacies for related parameterizations in meteorological and atmospheric dispersion numerical models. Models cannot properly reproduce the flow dynamics and turbulence in low wind, not even tracer dispersion in such condition, unless they are specifically designed for it (Sharan et al. 1996b, Sharan et al. 2002, Goyal and Rama Krishna 2002, Hanna et al. 2003, Oettl et al. 2005, Anfossi et al. 2006, Essa and El-Otaify 2007, Trini Castelli et al. 2013, 2014). Theoretical knowledge and experimental basis to address these limitations and to establish adequate similarity functions are still lacking and it was largely recognized that more investigation of these critical processes is needed (Luhar 2009, Mahrt et al. 2012). In a recent paper, Mahrt et al. (2015) consider "(…) *formulation of similarity theory to be premature for the stratified weak wind regime because the governing physics is not yet sufficiently understood. (…) The turbulence behaviour needs further examination in terms of variations within the network and should also be extended to other field sites*". This becomes even truer when the flow interacts with obstacles.

From the previous discussion, it clearly follows that also dedicated experimental data for low-wind in all atmospheric stability conditions are needed, not only to deepen its understanding but also to support model developments, evaluation and improvements (Wannberg et al. 2010), especially for applications in urban studies. A particular attention to low-wind conditions has been paid in the framework of air pollution modelling and emergency response (see for instance Deaves and Lines 1998), since a wrong reproduction of the plume dispersion may compromise the actions made to protect the population and the environment. In these contexts, effective and successful release experiments cannot be planned if the physical processes behind are not understood.

Experimental Data – Field Campaigns

Only a few meteorological and tracer field experiments, aiming at urban boundary layer meteorology and dispersion and the evaluation of atmospheric dispersion model performance at smaller scales, were conducted in the last 20 year for example in the USA (e.g. MUST, Joint Urban 2003) and Europe (UBL-ESCOMPTE, BUBBLE, DAPPLE). The experiments published results on urban flow and dispersion under more or less regular wind conditions and no one was specifically designed to tackle the particular scientific issues in collecting and analysing measurements of flow and dispersion in critical low wind conditions, in decaying turbulence or explicitly considering the low wind interaction with urban structures. Contrary, low wind data are regularly excluded from field data sets because of the perceived erratic scatter in measured values complicating a consistent interpretation of the results. Hence, there is also hardly any reference data for validating urban flow and dispersion models specifically for low wind conditions. This gap in data and corresponding knowledge has noticeable consequences for the understanding, reproduction, description and quantification of the flow dynamics and dispersion in applied urban meteorology ranging from air quality management to local-scale emergency response.

The following paragraphs briefly illustrate some of the most comprehensive urban flow and dispersion studies carried out more recently. Although there were corresponding experimental campaigns even earlier, only the last 20 years are considered. For this period of time, sufficient availability of qualified field measurement techniques, able to capture low wind conditions properly, can be assumed.

Nantes 1999

The Nantes'99-Experiment was designed to investigate the effect of street-scale phenomena on local air pollution. Wind, turbulence and temperature patterns were captured by sensors installed in a cross-sectional plane of a street canyon with an aspect ratio of approximately H/W=1.4. Car pollution (CO) was chosen as tracer because of its low chemical reactivity at the scale of interest. A detailed description of the experimental setup can be found for example in Vachon et.al. (1999). The collected data was analysed in depth with regard to car induced turbulence and the effect of local temperature fields on street scale dispersion. Measured data was used in a number of cases to validate RANS-based micro-scale flow and dispersion models (e.g. Louka et. al. (2002)) and corresponding wind tunnel experiments (e.g. Kastner-Klein et.al. (2000)) extended the data base particularly with respect to the effect of car-induced turbulence. As expected, it could be shown that at lower wind speeds thermal effects as well as car-induced turbulence have an increasing impact on wind flow and dispersion patterns at street scale. However, no further detailed analysis regarding the dynamics of low wind turbulence and dispersion at neighborhood scale was carried out, most likely because of the limited extend of the experiment.

Urban 2000:

In October 2000 a comprehensive multiscale field study, funded by the US Department of Energy, was carried out in a typical US-type urban environment, Salt Lake City (see Allwine et. al. (2002)). The project intended to deliver validation data for atmospheric dispersion models as they are used in the course of terrorist attacks and emergency response generally. Further objectives were to concurrently resolving interacting scales of motion from building to regional scales and to analyse data to understand governing physical processes. Results of corresponding trace gas experiments document an extremely wide range of measured concentrations observed within a relatively small area of interest of a few square kilometres. Particularly during light wind conditions, released trace gas was found to be transported at measurement locations located 2km and 4km upwind of the release site. The peculiar behaviour was attributed to parts of tracer being retained in the area of interest while another release took place. A mesoscale recirculation pattern, visible at low wind conditions during several Intense Observation Periods was assumed to be responsible for specific pathways of transport particularly at low ambient wind speeds. The data has been used to evaluate emergency response modelling tools (e.g. Chang et.al., (2005)). However, further analysis of the effect of transitional low winds on flow dynamics and dispersion does not seem to be available, presumably due to limits of the database.

UBL/ESCOMPTE 2001

As a side-activity of the regional photochemistry campaign ESCOMPTE, the UBL/ESCOMPTE 2001 field campaign was carried out in the Berre-Marseille area (see Mestayer et.al. (2005) for details). The UBL-part explicitly focuses on the dynamics and thermodynamics of the whole urban boundary layer Marseilles on the Mediterranean coast of France. The objective of the project was to document the 4D urban boundary layer during periods of low wind using the ESCOMPTE setup in the Berre-Marseille area. Data analysis focused mainly on the validation several surface energy balance computational schemes, the search for urban canopy signatures suitable for estimation of urban albedos and aerodynamic surface temperature from satellite data, high-resolution mapping of urban land cover, land use and aerodynamic parameters used in models and finally to test the ability of high-resolution atmospheric models in replicating the structure of the urban boundary layer particularly during land and sea breezes. Considerable effort was spent in evaluating and comparing results from different measurement systems in search for a consistent characterization of urban parameterizations based on available instrumentation. Different mesoscale low-wind circulation patterns could be identified and documented from a classical meteorological perspective. However, the data does not seem to provide the potential for a systematic and fundamental in-depth analysis of low winds dynamics and dispersion because of the specifics of the site and the experiment.

BUBBLE 2002

Similarly, the Basel Urban Boundary Layer Experiment (BUBBLE) focused on improving the knowledge about the urban boundary layer (see Rotach et.al. (2004)). The aim was to bridge the gap between typical field campaigns focusing on exchange processes near the ground and those who focus on flow and dispersion in the upper parts of the urban boundary layer. Within a COST Action based network, the BUBBLE project brought together research groups interested in the subject with expertise in working on both aspects. Amongst others, the data was used to develop and test energy balance schemes; to compare ground based radiation measurements with corresponding satellite data or for testing and improving urban surface exchange parameterizations. Measurements were lasting for about one year, including also periods of low winds. Since there was no focus on extreme conditions, the corresponding low wind data was excluded from analysis in the results published. Possible explanations might be, that in low wind situations the more routinely collected data do not have sufficient potential for a deeper analysis of turbulence or that conventional similarity concepts, most of the data analysis is based on, tend to reach their limits as wind speeds get lower.

Joint Urban 2003:

Joint Urban 2003 is perhaps the most extensive field tracer experiment in an urban environment typical for US cities. As one of several consecutive field campaigns it tried to overcome several of the limitations projects like Urban2000 or even earlier projects had. In a joint effort of the Department of Energy and the Department of Homeland Security, a high-resolution field data set for evaluation, testing and further improvement of hazmat dispersion models was generated. As described in Allwine and Leach (2007), the study integrated several scientific components including characterizing (a) the urban boundary layer; (b) flow within a street canyon including the effect of car-induced turbulence; (c) flow within and downwind of a tall building core typical for US cities; (d) the surface energy balance in an urban area; (e) the dispersion in, out and within buildings as well as (f) dispersion of trace gases throughout a typical US downtown core. Winds and meteorological quantities were measured at more nearly 100 locations in and around the downtown area and during tracer experiments more than 200 integrated samplers and 25 fast-response analysers were used. However, because the experiments were not dedicated to low wind conditions, the data contain a limited number of low wind cases only providing only limited potential for improving the understanding of low wind turbulence and dispersion phenomena.

DAPPLE-EPSRC & HO (2002-2009):

The 'Dispersion of Air Pollution and its Penetration in the Local Environment' - DAPPLE- was an experimental effort undertaken in the United Kingdom. The key aim of the DAPPLE project was to enhance understanding of pollutant dispersion processes, emissions and exposure in realistic urban environments and so make possible improvements in predictive ability that would enable better planning and management of urban air quality (http://www.dapple.org.uk/, Wood et. al. (2007)). For several years, a systematic series of field campaigns, dedicated numerical simulations and simplified wind tunnel experiments was carried out considering also the aspects of local-scale emergency response planning. As experimental results document, mean wind speed is substantially reduced by the presence of densely built-up urban structures, indicating that low wind phenomena should be of particular interest. However, with the DAPPLE field campaigns and data collection following a conventional multi-tracer experiment pattern, they were not specifically designed to capture low wind turbulence and dispersion. Hence, the extensive data provides potential for low-wind phenomena analysis in general while issues like representativeness of data acquired at particularly low winds or linkage of local low wind conditions with outer meteorological boundary conditions is not sufficiently captured.

Experimental Data – Modelling

As a second source of information on low wind turbulence and dispersion, sophisticated modelling can be used in principle. A basic requirement for the use of models as source of data is, however, that a model has been validated for a specific application before it is used as replacement for example for field trials. Because of the general lack of qualified systematic reference data for model validation particular for low wind scenarios in urban terrain, it remains an open question, if models can fulfil this requirement as necessary. More recently, there are attempts to build on simulation data only instead of involving complex field data. However, it should be kept in mind that particularly in the field atmospheric flow and dispersion, modelling is considered to be a second source of information still being more or less far from replacing full-scale experiments capturing reality. Both sources of information, field campaigns and modelling, suffer from severe limitations particularly if extreme scenarios like low wind turbulence and dispersion are of interest. By combining information from field and numerical experiments complementary results can provide a more comprehensive view of complex flow and dispersion phenomena in the atmosphere.

DIPLOS (2014-2017):

A project focussing on dispersion from localised releases in a street network is currently carried out in the UK, involving parts of the former DAPPLE group (see http://www.diplos.org for details). The project is aiming specifically at risks resulting from terrorist threats. Potential releases of air-borne chemical, biological, radiological or nuclear material as well as releases from industrial accidents in populated areas are intended to be studied in order to close gaps in fundamental knowledge and understanding of key dispersion processes, to enable those processes to be parameterized for use in operational models, and to implement them into an operational model, evaluate the improvement and apply the model to a case study in central London. The project is intended to generate a comprehensive reference data set not based on field measurements but using DNS and LES model simulation results for a neutrally stratified atmosphere instead. It is intended to implement the new parameterizations into the SIRANE model and run the model against reference data sets to be generated in dedicated wind tunnel experiments. The specifics of low wind turbulence and dispersion are not explicitly addressed and it remains an open question if the data base to be generated will be able to provide insight in such phenomena.

MODITIC project (2012-2015):

The MODITIC project is a joint research effort led by the Norwegian Defence Research Institute (FFI) with partners from the UK, France and Sweden. It focuses on dense gas dispersion in complex flows over hills and in urban areas. Six environments are modelled in a boundary layer wind tunnel facility, ranging from flat terrain and two-dimensional structures to idealised urban geometries. The experimental data is intended to be used as reference in order to assess the ability of different models to predict downwind dispersion and to reconstruct source locations from a limited set of given concentrations and wind conditions. Flow and dispersion fields are measured but results are not yet published, so it remains a question to what extend the project is dealing with low wind dispersion scenarios expected to be the most critical ones in dense gas dispersion. Physical modelling of low wind dispersion scenarios must be considered challenging and a careful evaluation of experimental data is required to judge the value of results with respect to low wind turbulence modelling.

Synopsis of remaining issues & questions

What is missing in theory

As discussed previously, decaying and anisotropic turbulence, low wind speeds and meandering are physical processes that need more investigation, particularly at local scales and when the atmospheric flow interacts with obstacles. A general consensus on the governing processes characterizing the flow dynamics and tracer diffusion in these conditions is still missing. Similarity theories to describe them are proven to be inappropriate and mostly empirical corrections have been proposed for low wind phenomena. Both meteorological and atmospheric dispersion models need specific physical theories to improve their representation and prediction of such phenomena. These will support the efforts already made by several researchers to adapt their models. Together with ad-hoc experimental data, they will provide the scientific basis for development, improvement, evaluation and validation of numerical models.

The main items that need to be addressed to overcome the lack in knowledge, focusing on phenomena occurring in built environment, are summarized hereafter. More scientific questions may certainly arise when studying these phenomena.

- Investigation of the dynamics in transitional range going from turbulence, to intermittent turbulence, to non-turbulent sub-mesoscale motions; identification of the scaling parameters and elaboration of its theoretical basis
- Study of the interaction of the low-speed flow with structures, identification of the related scaling parameters, elaboration of analytical formulations
- Assessment of the effect of urban structures on the incoming wind meandering
- Study of the effect of the isolated buildings and of the urban structure on the flow dynamics and turbulence in calm regime, particularly in the skimming zones, wakes, roof recirculation zones
- Study of the possible distinctive characteristics of the dynamics and turbulence in case of (1) an incoming low-speed flow and (2) an incoming 'windy' flow going towards calm conditions due to the interactions with topography and obstacles
- Assessment of the limits of the classical similarity theory (Monin-Obhukov) when applied to decaying turbulence, low wind, urban boundary layer
- Elaboration of a proper theoretical description for diffusion under extreme low wind conditions and in different atmospheric stratification, in urban canopy
- Addressing the question whether the Reynolds number is still the only representative similarity number for characterizing the dynamics in a calm flow regime?

What is missing in field data?

With reference to existing experimental data, the following open issues must be approached in a comprehensive manner for better understanding low-wind flow dynamics and diffusion:

- There is not yet a completely elaborated experimental strategy for capturing low wind flow and dispersion phenomena as precise as possible in reality. Common experimental concepts must be critically revised with respect to specific challenges of collecting field data under varying low wind conditions. A concept for appropriate linking of locally measured data with adequately captured outer boundary conditions (sub-mesoscale variability) must be developed and implemented specifically for field campaigns in complex urban environments. Available instrumentation must be carefully evaluated in order to use measurement technology appropriate for data collection in light winds. A comprehensive standard for local low-wind flow and dispersion measurements and data collection in urban structures must be established, ensuring a sufficient data quality as well as compatibility of data measured at different sites in different campaigns.

- Limitations in collecting statistically representative data particularly for low frequency phenomena, as they are typical for light wind situations in urban structures, require combining information from all possible sources of data/information. Strategies for designing efficient field campaigns for example with support from physical and numerical modelling must be developed and verified. Also, a physically motivated methodology for seamlessly combining data from field experiments with corresponding results from physical and possibly numerical modelling must be developed, verified and implemented for future experimental campaigns. Enhancing field data sets with complementary data from modelling is more crucial yet more challenging particularly in urban low-wind scenarios than in more regular flow and dispersion studies.

- Assuming a qualified experimental approach to be successfully arranged still reliable and commonly accepted methods for data quality assessment and data quality assurance must be established. Similarly, physically sound methodologies for identifying, characterizing and quantifying low wind turbulence and low wind diffusion phenomena in corresponding experimental data need to be implemented. Extending existing approaches, special attention must be given to the often limited statistical representativeness of data as well as to the transient and intermittent nature of the phenomena in focus.

What is missing in modelling?

The scientific community recognizes that there is a lack of experimental data for low-wind conditions apt at making model development, improvement and evaluation. This is particularly true for experiments in urban cases and complex terrain. Calm regime and urban complexity are among the most critical conditions for which flow and dispersion models experience their limitations. Models need to be modified and/or adapted, appropriate parameterisations and similarity functions need to be established and implemented in both the simplest models and in the most advanced ones. Methods for translating the theoretical and experimental understanding to operational atmospheric flow and dispersion models need to be developed. The reliability of models application in air quality and emergency response frameworks needs to be investigated. The main aspects that are to be addressed are summarized hereafter.

- Identifying and addressing the specific limits of the different existing models, Gaussian, Lagrangian, Eulerian RANS and LES, with respect to simulating low wind conditions in complex terrain and urban sites
- Verification of the theoretical basic assumptions and simplifications made in models when they are applied in calm regime and urban sites
- Implementation and verification of theoretical formulations specific for turbulent parameters in low-wind conditions on the basis of the experimental investigation
- Evaluation of the optimum strategies to be applied in existing models to enable their seamless use in low wind conditions in complex terrain and urban sites

Relevant Expertise of the Consortium

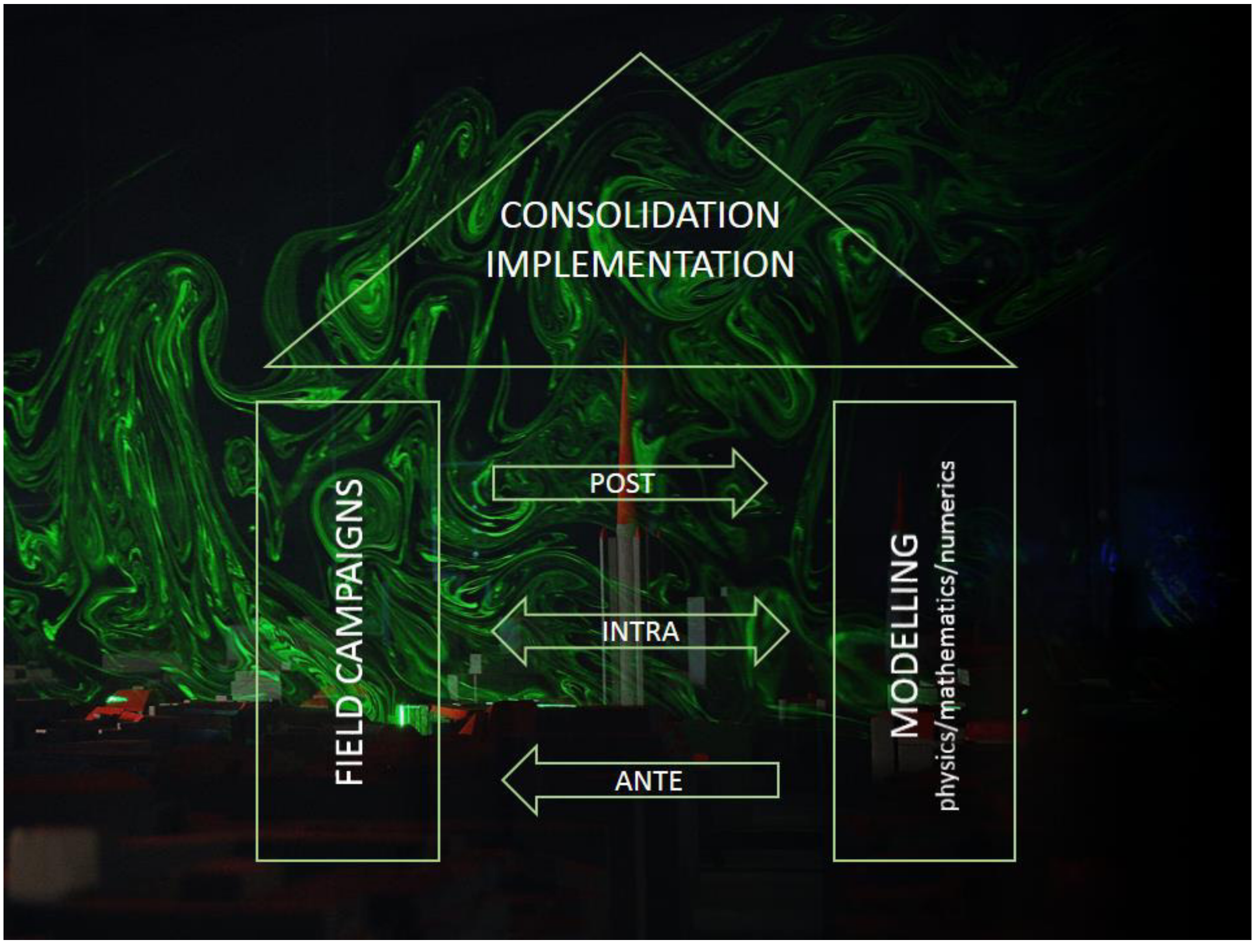
The project outline is based on expertise, the authors developed while carrying out and coordinating research in the field of atmospheric physics, meteorology and scientific and applied atmospheric flow and dispersion modelling at relevant scales. In particular, long-term experiences gained during COST Actions 732 (Quality Assurance and Improvement of Micro-Scale Meteorological Models, 2005-2009) and ES1006 (Evaluation, improvement and guidance for the use of local-scale emergency prediction and response tools for airborne hazards in built environments, 2011-2015), triggered the initiative for a comprehensive European experimental and modelling program focusing on extreme low winds in complex urban structures. Working on air quality modelling and dispersion modelling in the context of emergency response in urban areas, repeatedly it became obvious, that processes such as low-wind conditions, decaying turbulence or gravity-driven dispersion in calm conditions (a) trigger the most critical conditions in urban environments with respect to air pollution, ventilation or dispersion of hazardous materials; (b) are not sufficiently described by the physics implemented in most of the existing models and (c) are not sufficiently understood for substantially improving the quality of modelling.

The authors have been working on the assessment and the quantification of uncertainties of meteorological and air quality measurements in built environments and were leading or actively participated in related research on the evaluation of limits and uncertainties in atmospheric flow and dispersion modelling (References?).

Draft Project Ideas

The main objective of the initiative is to understand the underlying physics of atmospheric processes driving low-wind dynamics and diffusion in urban environments, which eventually (a) create critical conditions for pollutant dispersion and ventilation in cities and (b) are not correctly described and captured by the physics presently implemented in urban flow and dispersion models.

In the following paragraphs, the main research lines are illustrated briefly. The implementation of the initiative will be particularized during a preparatory workshop eventually fixing the research content and assigning the main coordinators responsible for organizing and structuring research along the major tracks. The figure below sketches the conceptual structure of the proposed activities.



The experimental program:

The experimental program aims for closing the gaps in the existing data base on low wind dynamics and diffusion as described above. Core activities in the program will be:

- the planning and implementation of large field campaigns truly reaching a critical mass regarding multidisciplinary expertise and the instrumentation being involved in individual field trials;

- to approach in a comprehensive way critical problems related to assessment and quantification of representativeness of both meteorological and dispersion measurements in real field measurements specifically for data collected under local low wind conditions in built environments, representativeness of measured data becomes an increasing problem as the frequency of variations decreases whereas typical time frames for consistent data collection remain more or less the same;

- the development and implementation of methods for homogenizing and consolidating data from independent field campaigns in a truly physically motivated and mathematically adequate manner, forming a comprehensive and likewise consistent data base for further developing and improving theory and modelling of low-wind conditions in urban terrain;
- the establishment of a generally accepted standards for data collection as well as quality control and assurance specifically for low-wind flow and dispersion measurements in complex urban environments

The modelling program:

The fundamental aims of the modelling program are:

- to carefully evaluate and possibly revise and finally extend the limitations of the standard fluid dynamics assumptions and formulations currently applied in atmospheric models (both physical and numerical) when simulating flow in complex urban terrain in decaying turbulence at low-wind conditions;
- to evaluate the limitations and applicability of existing concepts for dispersion models in built environments at low-wind conditions, both for air quality and emergency response;
- to address the sensitivity of models with respect to low-wind input data, providing feedback on the suitability and applicability of standard meteorological measurements in extreme low wind conditions;
- to develop and improve similarity functions and turbulence parameterizations in urban flow and dispersion numerical models and to test them against qualified experimental data as they are generated in the experimental program;
- to critically review and substantially improve the standard statistical model evaluation protocols with respect to model application in urban environments at low-wind conditions

The consolidation and implementation program:

A third major activity will be the consolidation and implementation program. The "3 x 3" consolidation program merges expertise and results available from field measurements with corresponding skills from physical, mathematical and numerical modelling at all three phases of a field campaign, eventually implementing project results in research, education and practical applications:

1. EX ANTE: planning phase

   Jointly applying appropriate physical modelling and numerical modelling, simulations will be performed in support of an efficient planning of the field campaigns, (i) to optimize feasibility and to maximize the output of the experimental program, depending on the model predictions capability; (ii) to provide guidance and feedback for designing dedicated low-wind field experiments in general and (iii) to identify and specify theoretical issues to be approached in different types of models in order to define dedicated measurement tasks in the field campaigns.

2. INTRA: run-time phase

   Simulating the field campaigns also during the intense observation periods will
   (i) allow for improving the efficiency of field experiments 'on-the-fly' because larger domain that can be investigated, data collection longer than the real experiments can be considered and acute changes in the experimental boundary conditions can be better accounted for;
   (ii) enable a direct quantitative model validation to evaluate representativeness of simulation results with respect to wind flow, turbulence and dispersion data measured;
   (ii) facilitate testing different types of models also at an operational level.

3. POST: elaboration phase

   In the third phase of consolidation and implementation, the completed field campaigns will be reconstructed with models having access to the experimental database in order to:
   (i) evaluate models against the observed data, with and without improved low-wind functions or corrections;
   (ii) deepen the understanding of the observed processes and phenomena, through an analysis and comprehensive interpretation of measured and simulated data, improving conceptual, theoretical and mathematical models of low wind dynamics and diffusion;
   (iii) testing and evaluating new theoretical formulations and similarity functions elaborated to account for specific atmospheric conditions linked to the calm regimes within the urban canopy and facilitating their implementation in applied modeling.

The outputs from concerted observational and modelling work will be collected in comprehensive dedicated datasets as they do not yet exist. The data will constitute qualified, case-specific benchmarks, not only for boundary-layer meteorology studies in low wind, but also for air quality modelling and management and local-scale emergency response applications in densely populated urban environments.

A specific deliverable with an immediate impact on improving the quality of life and the security of citizens will be advanced low-wind theoretical formulations and parameterisations to be elaborated during the project. Already within the scope of the proposed activities, improved mathematical descriptions and parameterizations will be implemented and tested in existing models. Models designed to represent well urban low-wind meteorological and dispersion conditions will be used in the frame of air quality assessment and emergency response with a much larger degree of confidence. Model outputs (meteorological fields, concentration and deposition fields, value and location of extrema, affected areas etc.) are expected to be closer to the real conditions than models can do at present state.

Dimensions of a Concerted Action at European Scale

As highlighted in the motivation, basic research is still missing in order to improve understanding of low wind dynamics and dispersion in complex urban environments, which is triggering some of the most critical conditions regarding air quality and human health in urban environments. A better knowledge will drive development and adequate improvement of simulation tools also at application level as far as urban ventilation; air quality assessment as well as urban-scale emergency response or risk assessment is concerned. Past studies were successfully starting from transnational concerted basic research to improve the knowledge and then produced concrete outputs, like reference publications, new methodologies, new modelling guidelines. This was the case, for instance, of CASES-99 field experiment (Poulos et al., 2002), carried out in USA flat open terrain and intensely investigating the characteristics and processes in the stable nocturnal boundary layer. A similar concerted approach has never been undertaken for urban low-wind scenarios and the proposed activity will be the first one, specifically addressing very critical, yet still not fully understood processes in urban meteorology.

Potential Contributors to a Joint Effort

A European scale is mandatory for adequately approaching the research questions. With respect to field experiments, an extensive set of measurement devices will be required to capture both, the outer meteorological boundary conditions as well as flow and transient dispersion patterns within urban environments. Since there is essentially no prevailing wind direction, dispersion experiments in low wind scenarios require a more or less homogenous and sufficiently dense grid of measurement stations around release locations to capture all possible pathways of tracer transport. Joining resources at a European scale will give a chance to reach the 'critical mass' for such a big effort to be reached. With a firmly planned logistics of the intended intense observational periods it will be possible to successfully manage approximately one experimental campaign per year, concentrating as much as possible measurement technology at one site.

The intended project will involve at least two densely built European cities with substantially different boundary conditions triggering low-wind conditions. Preferably, sites of larger urban low-wind measurement campaigns should already provide a qualified record of meteorological data and/or well-instrumented relevant measurement sites which may act as reference stations. Examples of potential hosts for intense observation periods are the city of

- Torino (Italy), which frequently encounters low-wind conditions generated by the weather patterns formed at synoptic scale (topography);
- Paris (France), which is perhaps covering the largest densely built area in Europe, forming an almost purely urban wind pattern;
- Hamburg (Germany), which develops low-wind scenarios in an otherwise moderate to strong wind environment and provides a super-site for urban boundary layer measurements

Contributors to the joint effort will be called from well-established networks collecting experts in the fields of atmospheric physics, experimental meteorology, physical and numerical modelling as well as from the applied operational side of air quality management and local-scale emergency response. The multidisciplinary approach referring to past and present collaborations carried on in experimental, numerical and theoretical research will ensure a successful project. More specifically, the project consortium will include:

- European partners with experience in low-wind flow and diffusion research at sub-mesoscale
- Experimental meteorologists with state-of-the-art instrumentation able to capture either the driving boundary conditions (inflow/outflow) or local low wind and diffusion.
- Urban climate experimentalists with instrumentation for and experience in time-resolved trace gas measurements
- Model developers working on/with obstacle-resolving models (numerical/physical)
- Theoreticians (boundary-layer meteorologists / turbulence and diffusion experts / mathematicians) with experience in developing similarity concepts and methodologies for comprehensive data post-processing and analysis

The initiative is intended to be open to scientific contributions from outside Europe, working on their own funds, as long as unrestricted access to measured data and scientific results is agreed upon. In addition, a board of external experts from outside Europe successfully working and publishing in the relevant fields of research is intended to be established. Members of the board are expected to act as critical reviewers during all the project phases. This will ensure possible developing weaknesses to be tracked and compensated immediately as progress is made.

Potential Timescale of the Joint Effort

ACTIVITY	YEAR											
	1		2		3		4		5		6	
observations / field campaigns	■	■	■	■	■	■	■	■	■	■	■	■
establishing teams and particularizing tasks	■											
preparatory field trials / comparative measurements		■	■									
preparation / IOP City A / post processing				■	■							
preparation / IOP City B / post processing						■	■					
preparation / IOP City C / post processing								■	■			
data consolidation and publishing			■	■	■	■	■	■	■	■	■	■
preparing and publishing best practise guidance		■	■		■		■				■	■
modelling	■	■	■	■	■	■	■	■	■	■	■	■
establishing teams and particularizing tasks	■											
evaluating/identifying limits of models	■	■										
modelling in support of field trials		■	■	■	■	■	■	■	■			
modelling in the context of enhancing field data sets				■	■	■	■	■	■	■		
modelling in the context of improving simulation tools			■	■	■	■	■	■	■	■	■	■
development and test of improved mathematical/theoretical models		■	■	■	■	■	■	■	■	■	■	■
consolidation and implementation	■	■	■	■	■	■	■	■	■	■	■	■
establishing teams and particularizing tasks	■											
development and testing of methods for data consolidation		■	■	■	■							
development and implementation of post-processing standards			■	■	■	■						
combination of observation and simulation data					■	■	■	■	■	■	■	■
joint activities	■	■	■	■	■	■	■	■	■	■	■	■
open workshop series on low-wind in urban terrain					■		■		■			■

Bibliography

Allwine J, Shinn JH, G. E. Streit GE, Clawson KL, Brown M (2002). Overview of URBAN 2000. A Multiscale Field Study of Dispersion through an Urban Environment. Bulletin of the American Meteorological Society , 83(4):521-536

Allwine J, Leach M (2007). EDITORIAL. J Appl Meteor Climatol, 46:2017–2018

Anfossi D, Oettl D, Degrazia G, Goulart A (2005) An analysis of sonic anemometer observations in low-wind speed conditions. Boundary-Layer Meteorol 114:179-203

Anfossi D, Alessandrini S, Trini Castelli S, Ferrero E, Oettl D, Degrazia G (2006) Tracer dispersion simulation in low wind speed conditions with a new 2-D Langevin equation system. Atmos Environ 40:7234-7245

Chang JC, Hanna SR, Boybeyi Z, Franzese P (2005). Use of Salt Lake City URBAN 2000 Field Data to Evaluate the Urban Hazard Prediction Assessment Capability (HPAC) Dispersion Model. J Appl Meteorol 44:485-501

Christen A, Rotach MW, Vogt R (2009) The Budget of Turbulent Kinetic Energy in the Urban Roughness Sublayer. Boundary-Layer Meteorol 131:193–222

Deaves DM, Lines IG (1998) The nature and frequency of low wind speed conditions. J Wind Eng Ind Aerodyn 73:1-29

Essa KSM, El-Otaify MS (2007) Mathematical model for hermitized atmospheric dispersion in low winds with eddy diffusivities as linear functions of down wind distance. Meteorol Atmos Phys 96:265–275

Ferrero E, Anfossi D, Richiardone R, Trini Castelli S, Mortarini L, Carretto E, Muraro M, Bande S, Bertoni D (2009) Urban Turbulence Project – The Field Experimental Campaign. Internal Report ISAC-TO/02-2009, p 37, October 2009, Torino, Italy

Fisher B, Kukkonen J, Piringer M, Rotach M, Schatzmann M (2006). Meteorology applied to urban air pollution problems: concepts from COST 715. Atmos Chem Phys 6 : 555 – 564

Foken, T. (2006) 50 years of the Monin–Obukhov similarity theory. Boundary-Layer Meteorology 119(3):431-447

Fortuniak K, Pawlak W, Siedlecki M (2013) Integral Turbulence Statistics Over a Central European City Centre. Boundary-Layer Meteorol 146:257-276

Goyal P, Rama Krishna TVBPS. (2002) Dispersion of pollutants in convective low wind: a case study of Delhi. Atmos Environ 36:2071–2079

Hanna SR, Paine RJ (1987) Convective scaling applied to diffusion of buoyant plumes from tall stacks. Atmos Environ 21:2153-2162

Hanna SR, Britter R, Franzese P (2003). A baseline urban dispersion model evaluated with Salt Lake City and Los Angeles tracer data. Atmos Environ 37:5069–5082.

Kastner-Klein P, Rotach MW, Fedorovich E (2000) Experimental study on mean flow and turbulence characteristics in an urban roughness sublayer. *Proceedings of the* 14th AMS Symposium on Boundary Layer and Turbulence, Aspen (CO, USA), 7-11 August 2000, 306-309

Louka P, Vachon G, Sini JF, Mestayer PG, Rosant JM (2002) Thermal Effects on the Airflow in a Street Canyon – Nantes '99 Experimental Results and Model Simulation. *Proceedings* of the 3rd international conference on Urban Air Quality – Loutraki 19-23 March 2001, 4pp

Luhar AK, Hurley PJ, Rayner KN (200) Modelling Near-Surface Low Winds over Land under Stable Conditions: Sensitivity Tests, Flux-Gradient Relationships, and Stability Parameters. Boundary-Layer Meteorol 130:249-274

Luhar A (2012) Lagrangian particle modelling of dispersion in light winds. In "Lagrangian Modeling of the Atmosphere", AGU Geophysical Monograph, vol 200, American Geophysical Union, pp 37-51

Mahrt L (1998) Stratified Atmospheric Boundary Layers and Breakdonw of Models. Theoret Comput Fluid Dynamics 11:263-279

Mahrt L (2010) Variability and Maintenance of Turbulence in the Very Stable Boundary Layer. Boundary-Layer Meteorol 135:1-18

Mahrt L, Richardson S, Seaman N, Stauffer D (2012) Turbulence in the nocturnal boundary layer with light and variable winds. Q J R Meteorol Soc 138:1430-1439

Mahrt L (2014) Stably stratified atmospheric boundary layers. Annu Rev Fluid Mech 46:23-45

Mahrt L, Sun J, Stauffer D (2015) Dependence of turbulent velocities on wind speed and stratification. Boundary-Layer Meteorol 155:55-71

Mestayer PG et al. (2005) The Urban Boundary-Layer Field Campaign in Marseille (UBL/CLU-ESCOMPTE): Set-Up And First Results. Boundary-Layer Meteorol 114: 315–365

Moraes OLL, Acevedo OC, Degrazia GA, Anfossi D, Da Silva R, Anabor V (2005) Surface layer turbulence parameters over a complex terrain. Atmos Environ 39:3103–3112

Mortarini L, Ferrero E, Falabino S, Trini Castelli S, Richiardone R, Anfossi D (2013) Low-frequency processes and turbulence structure in a perturbed boundary layer. Q J R Meteorol Soc 139:1059–1072

Mortarini L, Anfossi D (2015) Proposal of an empirical velocity spectrum formula in low-wind speed conditions. QJR Meteorol Soc 141:85-97

Öttl, D., Almbauer, R. A., and Sturm, P. J. (2001) A New Method to Estimate Diffusion in Stable, Low Wind Conditions, J. Appl. Meteorol. 40: 259–268.

Öttl D., A. Goulart , G. Degrazia, D. Anfossi (2005) A new hypothesis on meandering atmospheric flows in low wind speed conditions. Atmos Environ 39:1739–1748

Roth M (2000) Review of Atmospheric Turbulence over Cities. Quart J Roy Meteorol Soc 126:1941–1990

Rotach MW (1999) On the influence of the urban roughness sublayer on turbulence and dispersion. Atmos Environ 33:4001-4008

Rotach MW, Gryning SE, Batchvarova E, Christen A, Vogt R (2004) Pollutant dispersion close to an urban surface - the BUBBLE tracer experiment. Meteorol Atm Phys 87:39-56

Rotach MW, Vogt R, Bernhofer C, Batchvarova E, Christen A, Clappier A, Feddersen B, Gryning SE, Martucci G, Mayer H, Mitev V, Oke TR, Parlow E, Richner H, Roth M, Roulet YA, Ruffieux D, Salmond J, Schatzmann M, Vogt J (2005) BUBBLE - an Urban Boundary Layer Meteorology Project. Theor Appl Climatol 81: 231-261

Sharan M, Yadav AK, Singh MP (1995) Comparison of various sigma schemes for estimating dispersion of air pollutants in low winds. Atmos Environ 29:2051-2059

Sharan M, Singh MP, Yadav AK (1996a). A mathematical model for the atmospheric dispersion in low winds with eddy diffusivities as linear functions of downwind distance. Atmos Environ 30:1137–1145

Sharan M, Singh MP, Yadav AK, Agarwal P, Nigam S (1996b). A mathematical model for dispersion of air pollutants in low wind conditions. Atmos Environ 30: 1209–1220.

Sharan M, Yadav AK, Modani M (2002) Simulation of short-range diffusion experiment in low-wind convective conditions. Atmos Environ 36:1901-1906

Trini Castelli S, Falabino S (2013) Parameterization of the wind velocity fluctuation standard deviations in the surface layer in low-wind conditions. Meteorol Atmos Phys 119:91-107

Trini Castelli S, Falabino S, Anfossi D (2013). Effect of the turbulence parameterizations on the simulation of pollutant dispersion with the RMS modelling system. Air Pollution Modeling and its Application XXII, D.G. Steyn and P. Builtjes Eds., Springer Publishers, 529-534. ISBN 978-94-007-5576-5

Trini Castelli S, Falabino S, Mortarini L, Ferrero E, Richiardone R, Anfossi D (2014) Experimental investigation of the surface layer parameters in low wind conditions in a suburban area. Q J R Meteorol Soc 140:2023-2036

Vachon G, Rosant JM, Mestayer PG, Sini J (1999) Measurements of Dynamic and Thermal Field in a Street Canyon, URBCAP Nantes '99. *Proceedings of the* 6th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Rouen, France, 11–14 October 1999, CD-ROM proceed, paper 124.

Wannberg VE, Williams G, Sawyer P, Venedam R (2010) An Experimental Field Dataset with Buoyan, Neutral, and Dense Gas Atmospheric releases and Model Comparisons in Low-Wind Speed (Diffusion) Conditions. J Appl Meteorol 49:1805-1817

Wood CR et al. (2009) Dispersion Experiments in Central London The 2007 Dapple Project. Bulletin of the American Meteorological Society, 90(7):955-970