THE ROLE OF COASTAL URBANISATION IN ENHANCING TURBULENCE AND LAND-SEA BREEZE

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Abstract:
Recent increasing urbanisation phenomena it is expected will alter the morphology and texture of wide territories leading to a strong changes in the materials, from natural to man-made, at the surface. This land-use change can strongly affects the energy partition of the solar radiation substantially increasing the intensity of the sensible heat flux (along with the anthropogenic heat contribution). The sites which present local anemological circulation, such as the breeze regimes, can result more sensible to enhanced turbulence, and environmental impacts must be taking into account when considering managing plans for residential or touristic populations.

INTRODUCTION

As clearly stated in the old, but still fundamental, book of Hsu (1988): “Coastal meteorology is an integral part of the total-system approach to understanding coastal environments”. Nowadays explosive processes of coastal urbanisation, due to both increase in coastal urban residential population and touristic flows, lead to an effective impact in altering the surface energy balance at the sea-land discontinuity and consequently to the intensity of related a-biotic or biotic processes. In particular, the importance of physico-chemical behaviour of pollutants was markedly highlight during the ’80s-‘90s when several studies in coastal areas demonstrated the strict link between solar radiation and its partition at the surface, local atmospheric transport of chemical compounds and nocturnal continue fumigations episodes alongside the coastal areas (Giovanelli et al., 1985; Fortezza et al., 1993; Georgiadis et al., 1994; Millan Millan et al., 1991; 1992; 1996; 1997). These studies were strongly focussed on the problem of the ozone formation in land-sea breeze cells from transport off-shore of Nitrogen Oxides and other photochemical precursors.

BASIC INFORMATION ON OF BREEZE FORMATION

Sea- or Land-breeze components are generated by the differential heating of the surfaces which leads to density air changes that produce thermals and consequently horizontal transport of air masses respectively in-shore and off-shore (Fig.1). In the coastal zone when, under high stabilised pressure systems, the local breeze circulation forms, one of the most important changes close to the land-sea discontinuity is the development of an internal boundary layer over land when the breeze blows in-shore (Fig.2).

In Figure 3 is depicted a complex topographical environment in which are contemporary present a mountain range and a city at a coastal site where it is possible to note the extreme variability of both transport mechanisms and of ozone concentrations.

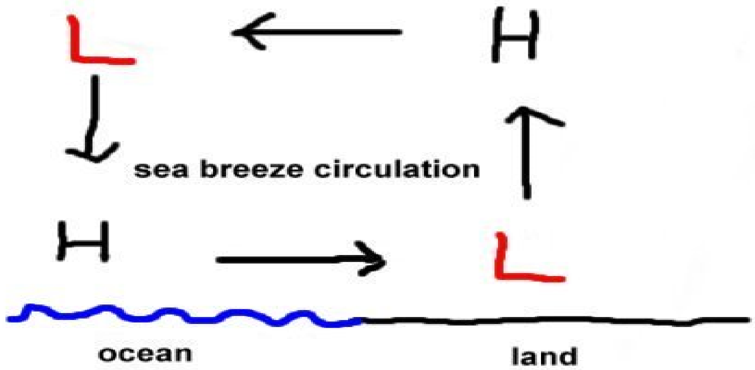

Fig.1 – Sea-breeze formation mechanism.

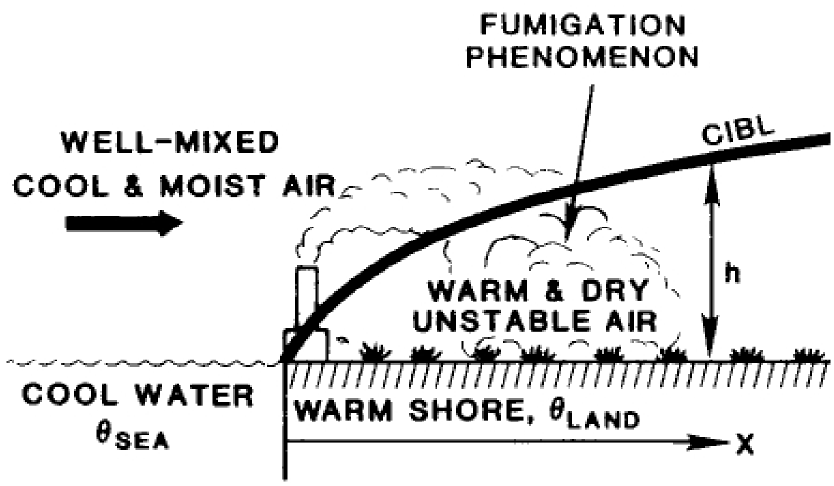

Fig. 2 – Fumigation production within the convective internal boundary layer (CIBL) *(from Hsu, 1988)*

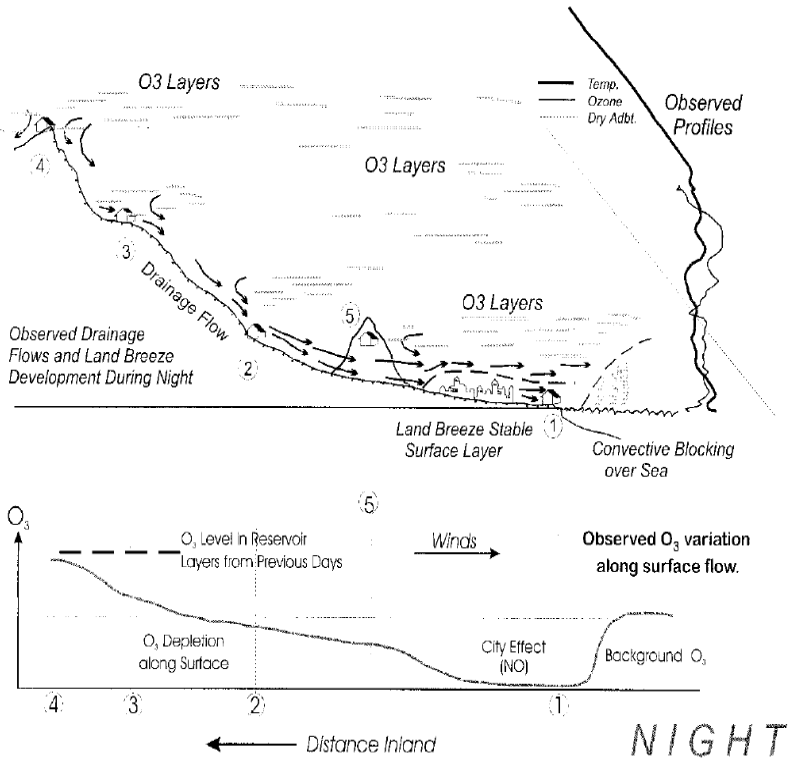

Fig.3 – Cycle of ozone in a complex coastal site (*From Millan Millan et al. 2000).*

IMPORTANCE OF URBANISATION PHENOMENA

All the Italian Adriatic coastline is well known all over the world to be one of the pleasure touristic site characterised by great services and hospitality. In particular, the coastal strip between Ravenna and Rimini was subject during the last part of the former century to a strong urbanisation phenomenon.

Tourism is one of the main economic income of the Italian gross domestic product: historical cities, mountain and coastal touristic activities account for the greatest economic value of this sector. From the '50s up today the touristic offer was characterised by an increase in number and quality of services, permanently differentiated and renewed. The touristic coastal areas have been undergone to the major changes in terms of territory, population and built environment (Fig. 5a-b).

Albeit this issue had surely increased the economic capabilities of these touristic coastal areas the impacts in terms of environmental sustainability have been deep and wide. In particular, the surface optical and emissive properties of building materials, their urban arrangement in both surface texture and sky view factor value very often lead to a strong increase in the solar radiation absorption by walls and pavements within that new architectural product that is know as 'urban canyon'. The final result of this interaction between the incoming radiation and the buildings is an increase of the thermal regime of the city as a whole (urban heat island, UHI).

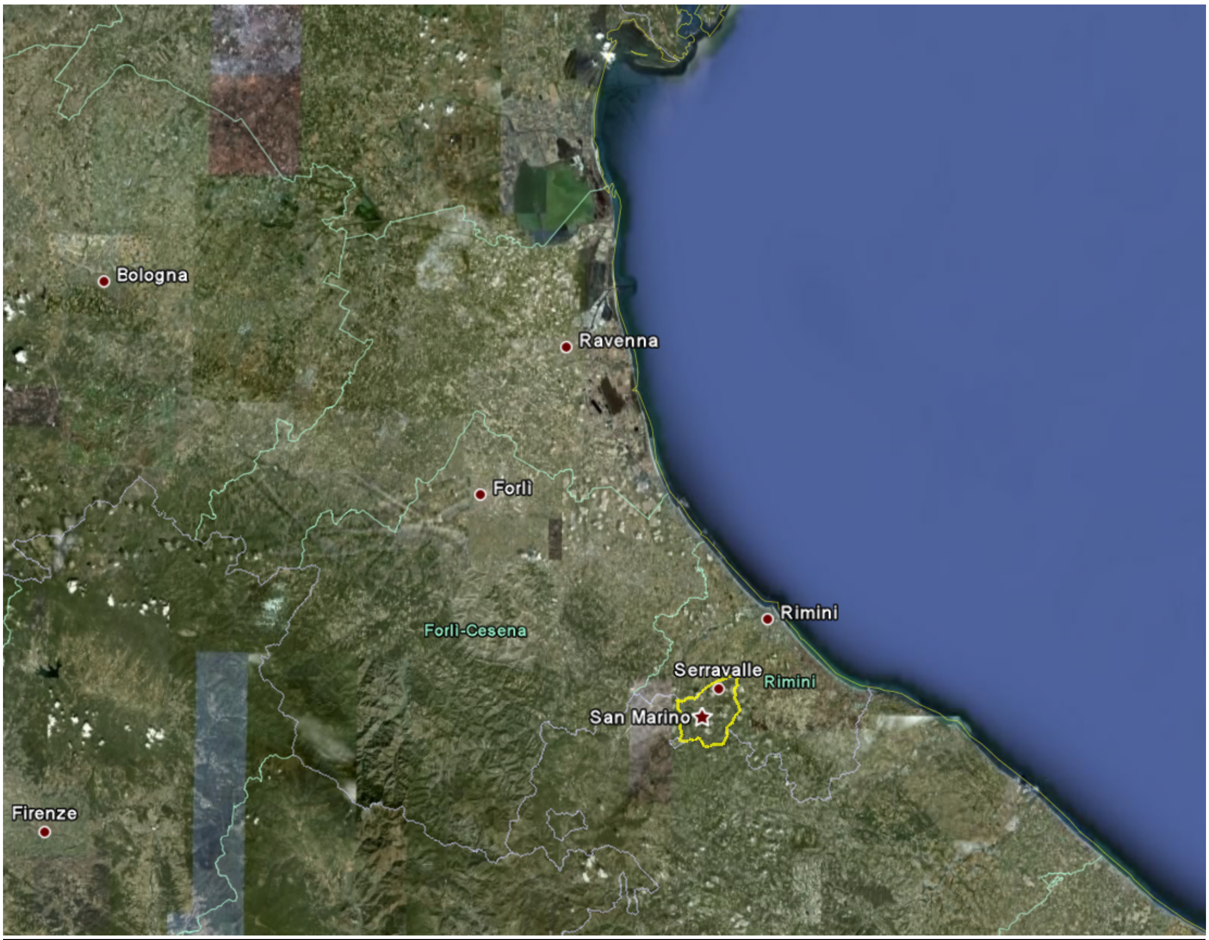

Fig 4 – The Emilia-Romagna coastal strip

To an increase in the thermal regime of the built environment will correspond an increase to the secondary circulation within the urban environment caused by the formation of the thermals.

At the same time this effect will lead to an increase to the horizontal transport caused by the enforcement of the sea-land component of the breeze system. Consequently, to better asses the impact of possible changes in the anemological regime of coastal environments is necessary to characterise how and where air masses transported in stable stability layers start to fumigate thus creating impacts to the environment or to the population.

Fig. 5a - Rimini: Marina centro promenade during the ‘50s

Fig. 5b - Rimini: Marina centro nowadays

(Courtesy of the Rimini Municipality)

It is important to note that from an economic point of view a clear assessment of various impacts, in terms of positive and negative externalities, should be made. In fact, some reinforcement of the local wind regime can promote the development of new services and activities. Tourisms can improve some sectors such as coastal sports (as the one magnificently captured in Figure 6), and wind energy can be more attractive considering off-shore plants.

Fig. 6 – Riding the sea breeze (photo by courtesy of David Daggar)

As usual, the role of science is to define the frame in which changes will operate and to render possible a realistic approach to options. In the present case it is possible to applied a peculiar modelling of the interactions in order to furnish to local administration and city planners useful indications for further developments of the territories.

MODELLING THE IMPACTS

The development of mathematical models able to parameterise the mixed height evolution as a function of meteorological and micrometeorological parameters collected at the surface, can furnish a powerful tools to overcome the highlighted problems. The main question arising in their utilisation is to establish their degree of reliability in presence of changing surface texture and different atmospheric stability conditions.

The continuity solution at the surface represented by the presence of changing roughness, such as the presence of a coastline, strongly limits the utilisation of models that considers an ideal, convective and homogeneous PBL, as the widely utilised by Batchvarova and Gryning (1991).

The most dramatic change in the PBL occurs when stable stratified flows encounter warmer surface as happens in the case of coastal discontinuities.

The development of the convective- or thermal- internal boundary layer (CIBL or TIBL), starting from the coastline and evolving trough the inland, can be represented by the Arya (1988) parameterisation:

$$\delta_t(x) = a \cdot \left[\frac{H_0 x}{\rho C_p \gamma U} \right] \quad (1)$$

where the constant a is equal to 1.5, ρ is the air density, C_p is the specific heat at constant pressure, U is the wind speed, H_0 is the sensible heat flux, x is the distance from the coastline and γ is the potential thermal gradient. This last parameter, representing the thermodynamic profile of the atmosphere outside the TIBL, can be considered nearly-constant and assumed equal to 0.005 K m^{-1}.

The Arya parameterisation requires the determination of the surface sensible heat flux. At present this is a measure of moderate complexity giving the fact that sonic anemometers are capable to provide a direct computation of this quantity, but, one major problem is strictly related to its direct utilisation foe city planners: the usage of sonic anemometers in the past, as well as in the present, was very rare. Thus, the comparison in function of space-time evolution of urban texture in general it is not possible.

Venkatram (1988) developed a parameterisation in which the sensible heat flux is substituted with the temperature difference between the sea temperature and the land temperature:

$$\delta_t(x) = 1.7\frac{u_*}{U}\cdot\left[\frac{(\Theta_l - \Theta_w)x}{\gamma}\right]^{1/2} \quad (2)$$

where u_* is the friction velocity, Θ_w the surface sea temperature and Θ_l the land surface temperature.

This new parameterisation provide the great advantage that the physical quantities needed to obtain the behaviour of the TIBL (or CIBL for daytime conditions) are normally available at every coastal site by means of common meteorological stations recorded over tens of years.

Nardino et al. (2004) reported of the application of a simple model, based on (1) and (2) parameterisations, in measuring the development of the PBL for application on small islands. This model is a friendly user interface and easy-to-use. Utilising more evolved computational systems Lu et al. (2010) demonstrated how the analysed effects promoted strong changes in the breeze system in the Pearl River Delta region in China. The study allowed the authors to draw the conclusion that not only the magnitude of the urbanisation has a strong role in modifying the breeze patterns in intensity but also the position of the new urban settlements can modify the patterns on the spatial occurrence and shape. This last effect can be of paramount importance especially in delta regions where the modification of local atmospheric flows can has strong through-backs on biotic systems.

CONCLUSIONS

Recent studies confirmed the existence of relevant impacts, caused by the urbanisation of coastal strips, on the local regime of winds. Accurate design of type and distribution of urban centres are consequently necessary in look of a sustainable development of territories capable to assure the lower possible impacts to biotic and a-biotic coastal systems.

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