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Climate change and coastal zone: the importance of atmospheric pollutant transport

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Abstract

The importance of atmospheric circulation, particularly the typical phenomena associated with the discontinuity between sea and land, as well as the analysis of their contribution to air pollutant transport and dispersion is presented. The influence of climate on transport/deposition processes and the impact of climate change on coastal zones will be discussed, using a climate scenario induced by the increase of greenhouse gases. Additionally a case study have been included, based on work done about coastal zone vulnerability in Portugal, particularly the numerical simulation of air pollutants acidic deposition and ozone atmospheric concentrations resulting from pollutants dispersion over the littoral area.

1 Introduction

Coastal zones are very complex regions and very sensitive to stress caused by natural forces and human activities. On coastal zones live the most significant part of population and are located the most important cities and anthropogenic activities, such as industries and road traffic, with large emission rates to the atmosphere. For example, half of the humanity and 80% of Portuguese population lives on or near the coast and of the 25 largest cities of the world, 14 are located on a coast and support port facilities[1]. Figure 1 shows the location of the subset of coastal cities catalogued as polluted cities based on measured levels of sulphur dioxide[2]. This list is undoubtedly incomplete, since some polluted cities may be excluded simply because pollution monitoring in those

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cities has not been established or because other compounds related with pollution scenarios has not been considered.

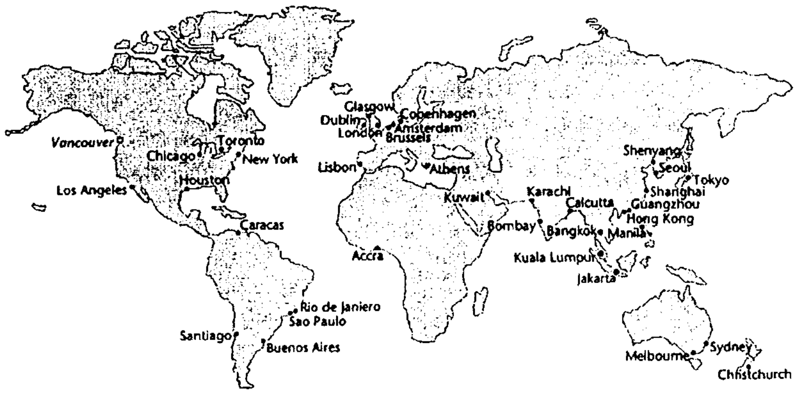

Figure 1: World map showing very polluted coastal cities[2].

Human activities (primarily the burning of fossil fuels and changes in land use and land cover) are increasing the atmospheric concentrations of greenhouse gases, which alter radiative balances and tend to warm atmosphere. However, in some regions, aerosols have an opposite effect on radiative balances and tend to cool atmosphere. The evidence of the human influence on the climate change is currently accepted, but most acknowledge uncertainties as to the speed and extent of this changing process, due to the complexity of involved phenomena.

If climate warming occurs, it will rise sea-level, heat shallow waters and modify precipitation, wind and water circulation patterns, especially in coastal zones and estuaries. Since the coastal zone is a major component in global budgets and global resources availability and utilisation, effective sustainable management strategies in such areas require a special ability to think beyond traditional sectoral divisions between different types of resources and human activities.

Other important atmospheric pollution phenomena influenced by anthropogenic activities are the photochemical pollution, the depletion of ozone on stratospheric layer, pollution due to particulate matter and aerosols. Photochemical pollution episodes, characterised by the increase of tropospheric levels of photochemical compound, particularly ozone, is directly related with emissions of nitrogen oxides and organic compounds principally due to the traffic and combustion processes. In spite of the preferential distribution of human activities on the littoral this

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photochemical pollution phenomena have significant importance on coastal urban areas.

2 Effect of climate change in coastal zones

Climate change is a reality on present days. In fact, it took an important role on the evolution process on the earth, during thousands of millions of years. Nevertheless, predicted changes on climate over the next century are larger than any since the appearance of civilisation and scientific community concerns due to the potential rapidity of the changes. For many scientists there are no doubts about the humanity contribution on this process.

Coastal zones are particularly at risk due to the potentially predicted effects of climate change and the ecological and socio-economic vulnerability of these areas. Coasts have been modified and intensively developed in recent decades and thus made even more vulnerable to higher sea levels, flooding and coastal erosion.

2.1 Greenhouse gases emissions and temperature increase

The increase on atmospheric levels of greenhouse gases (figure 2) as a direct result of human activity is changing the energy balance on the earth causing an "enhanced greenhouse effect". To keep the global "energy budged" in balance, the climate system must change somehow to adjust to rising greenhouse gas levels and the most probable result is a global warming of the earth's surface and lower atmosphere.

An analysis of temperature records shows that the Earth has warmed an average of 0.5°C over the past 100 years. Climate models predict that the global temperature will rise by about 1-3.5°C by the year 2100[3]. This projected change is larger than any climate change experienced over the past 10,000 years. It is based on current emissions trends and assumes that no efforts are made to limit greenhouses gas emissions.

Changes on global temperature have important effects. An example of the potential effect could be found from the *El-Niño* Southern Oscillation (ENSO) events and its consequences on inter-annual climate variability. ENSO is a short-term cycle in the ocean-atmosphere system with a mean recurrence interval of 3-8 years, characterised by an increase on ocean temperature, which produce a local atmospheric warming[4]. These atmospheric anomalies propagate horizontally such that the effects of the ENSO event are present in distant regions, with different types of

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affectation phenomena, characterised by extreme whether events (figure 3) like storms, floods and droughts.

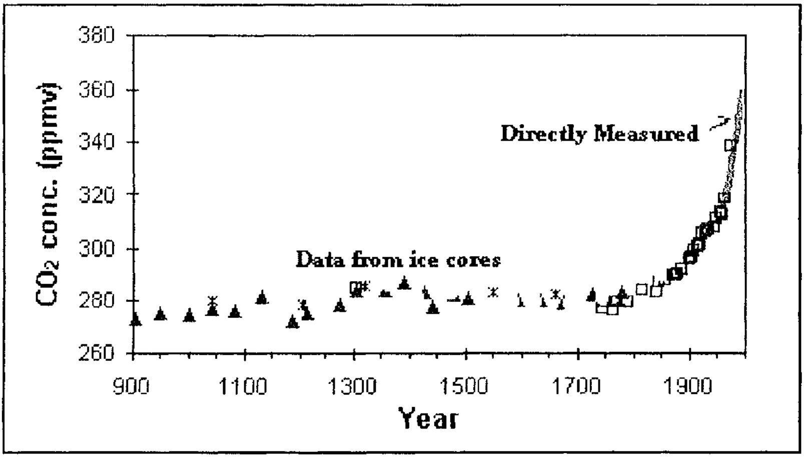

Figure 2: Trends in atmospheric concentrations of CO_2 on past 1000 years (Environment Canada's www site).

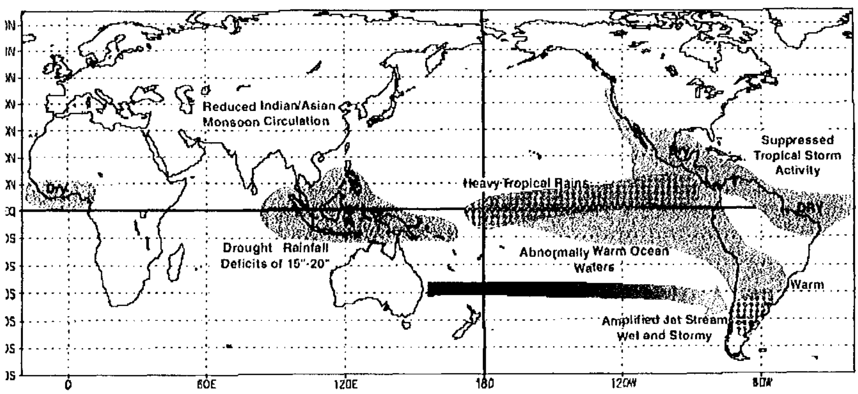

Figure 3: Sketch of the consequences of the 1997 *El-Niño* during the period of June-September 1997 (from Climate Prediction Centre, USA).

Some evidences could be taken from the 1982-83 ENSO. Disastrous effects and meteorological changes took place around the world during this event, caused total damages estimated at over $8 billion: Australia - drought and bush fires; Indonesia, Philippines - crops fail, starvation follows; India, Sri Lanka - drought, freshwater shortages; Tahiti - 6 tropical cyclones; South America - fish industry devastated; Pacific ocean - coral reefs die; Colorado river basin - flooding, mud slides; Gulf States - downpours cause death, property damage; Peru, Ecuador - floods, landslides; Southern Africa - drought, disease, malnutrition. The 1997-1998 ENSO is expected to have an even more disastrous effect!

2.2 Sea-level rise

During the last hundred years the sea-level has risen by 10 to 25 cm. It is likely that much of this rise is related to an increase of 0.3-0.6°C in the lower atmosphere's global average temperature since 1860. Models project that sea levels will rise another 15 to 95 cm by the year 2100, due to the thermal expansion of ocean water and an influx of freshwater from melting glaciers and ice[3].

Sea-level rise will affect the coastal zones of some 180 nations and territories. Sea-level rise of one metre would cause estimated land losses of 0.05% in Uruguay, 1% in Egypt, 6% in the Netherlands and 17% in Bangladesh. Other consequences of sea-level rise are flooding, coastal erosion and salt-water intrusion which will reduce quality and quantity of freshwater supplies. Higher sea levels could also cause extreme events such as high tides, storm surges and seismic sea waves. As a result of those damages, important economical sectors will be affected directly fisheries, aquaculture and agriculture. Indirectly other human activities, such as tourism, human settlements and insurance could be at risk.

The displacement of flooded communities, particularly those with limited resources, would increase the risk of various infections, psychological and other illnesses. Insects and other transmitters of diseases could spread to new areas. The disruption of systems for sanitation, storm-water drainage and sewage disposal would also have health implication.

2.3 Precipitation and water circulation changes

Compared with predictions about rising sea-level or temperature, there is less certainty involved in prediction either changes in precipitation, water circulation or the ecological effects of such changes. Some potential impacts could be taken from the ENSO episodes (see fig. 3). Two types of changes on precipitation patterns could be expected: increase rainfall in some areas result on more floods and runoff; decline precipitation in other areas, which drier regional climate.

On coastal areas, changes on precipitation patterns combined with sea-level rise could result on shrink estuarine habitat or, on other hand, on salinity encroachment into the tidal freshwater. Changes on water circulations could have also secondary effects reducing soil infiltration and ground/surface water supplies. Arid and semi-arid areas could also become more sensitive and some typical habitats could be loss.

2.4 Wind circulation changes

Changes on wind speed and direction could have important effects on air pollution transport (thus on air quality). Coastal areas, with significant atmospheric emissions and where wind circulations took an important role on pollutants dispersion, are particularly at risk. Climate changes are also expected with more intense and frequent extreme weather events.

The topology of coastal zones is often very complex resulting from the presence of typical features, such as the sea/land interface, the irregularity of coastline, the presence of estuaries, the complex topography, with mountains, hills and valleys, etc.. This topology in conjugation with synoptic or mesoscale meteorological conditions, contributes to the development of a characteristic atmospheric circulation that plays an important role on the wind flow over coastal areas.

The most relevant coastal circulations are the sea and land breezes, due to the differential heating between sea and land. More complex flow patterns can be produced, when breezes are combined with orographic flows (for example, mountain and channel winds). Sea/land breezes are developed under slack synoptic gradients and moderated or stronger insolation. This conditions diurnal reversing produces a thermal driven circulation on the land/water interface[5] (figure 4).

The effects of coastal breezes on the dispersion patterns of the air pollutants are diversified, being their interaction with the flow on a synoptic scale very complex. However, it is possible to subdivide the impact of these mesoscale atmospheric circulations in two different effects: accrued mixture due to ventilation associated with the sea air intrusion and potential recirculation of air pollutants. The importance and combination of these aspects depend on the morphological characteristics of the region and on the meteorological conditions under consideration[6].

A recent work[7] assessed the impact of ENSO in the atmospheric physical properties over Portugal, by means of a downscale approach, ranging from global scale to regional scale. Simulation results shows that large-scale atmospheric circulation induced by ENSO generates some changes, both in wind direction and in potential temperature field over the studied region. However, more developments are needed in order to

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study the relation between possible storm and drought condition in Portugal related to ENSO events.

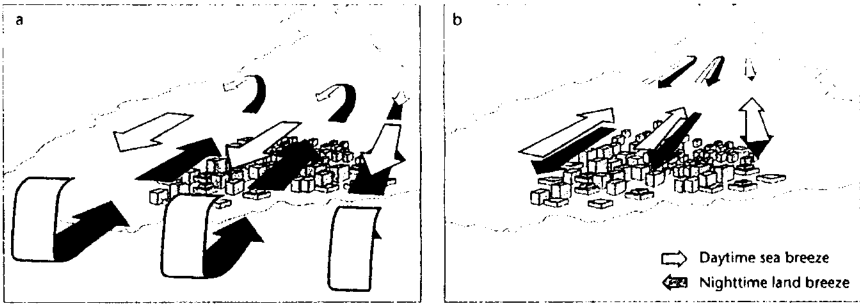

Figure 4: a) Vertical recirculation in sea breezes and upper return flow, b) horizontal recirculation in daytime sea breezes and night-time land breeze[2].

3 Study case: Portuguese coastal zone

Portugal has a quite extensive coastline (850 km) associated to significant terrain features and sea-land breezes circulation, which result in complex wind field with strong implications on the production and transport patterns of atmospheric pollutants, particularly photochemical species such as ozone. Like in other countries, Portuguese littoral is the region with higher population density and economic development. On a narrow band of 50 km from the coastline (figure 5) live about 80% of the population and are settled almost all the main industries and power plants. The resulting pollutant emissions carry out a high pressure on the Portuguese coastal areas environment and the natural resources[8].

3.1 Atmospheric emissions on Portuguese littoral

A significant part of the Portuguese anthropogenic emissions - 85% of total NO_x and 95% of NMVOC - are emitted on the narrow band of 50 km nearby the coastline. Table 1 shows that "per capita emissions" and "emissions per km^2" for Portugal mainland are significantly smaller than EU similar parameters. On other hand, considering “emissions per GDP” the figures are larger than the EU, what might be means that the industrial production in Portugal mainland is still less efficient than the average industrial production on EU. All parameters for the coastal areas are

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closer to the ones of EU, particularly the "emissions per km^2" parameter, which is the same order of magnitude[7].

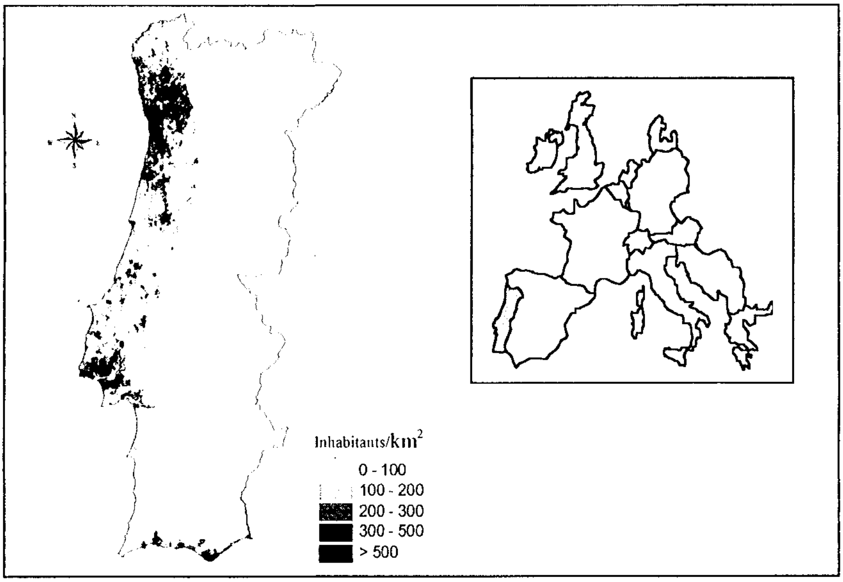

Figure 5: Population density of Portuguese littoral (50 km).

Table 1: Current emissions situation in Portugal mainland, Portuguese coastal areas and EU (12).

	Portugal Mainland		Coastal Area		European Union (12)	
	NOx	NMVOC	NOx	NMVOC	NOx	NMVOC
Total emissions (kton/year)*	220.8	201.8	183.4	180.6	12145.0	12455.0
Per capita (kg)	23.5	21.5	24.1	23.7	34.8	35.7
Per GDP (kg)	3.1	2.8	na	na	2.2	2.3
Per km2 (ton)	2.5	2.3	4.8	4.7	5.1	5.3

source : Eurostat and Portuguese Institute of Statistic
* : excluding biogenic emissions; na : not available; GPD: Gross Domestic Product

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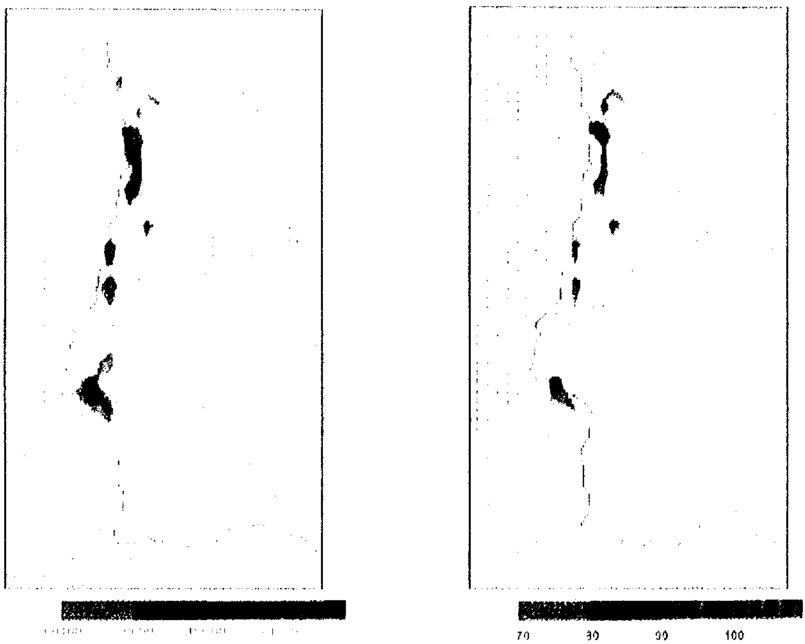
3.2 Simulation of pollutants transport, deposition and transformation

In order to evaluate the vulnerability of the Portuguese coastal zones, an extended study have been carried out, focused on different environmental parameters, including the atmospheric system[9]. To analyse critical load capacity of the coastal ecosystems, numeric simulations (MAR system) have been made to calculate the spatial distribution pattern associated to air pollution at a national level. A specific episode (typical summer day) has been considered and simulation domain includes all Portuguese continental territory.

Globally, the obtained hourly atmospheric levels, both in ozone concentrations and in NO_x deposition levels (figure 6), are below the critical loads almost over the entire domain. However, the maps shows also that higher pollution levels are located on a twin band near the littoral.



(I) (II)

Figure 6 - Hourly wind field and distribution pattern of atmospheric pollutants levels over Portugal for a typical summer conditions: (I) acidic deposition of NOx (keq H^+/ha) at sunrise; (II) ozone concentration ($\mu g/m^3$).

If local meteorological conditions contribute to stagnation or recirculation processes, pollutants transport and dispersion could be strongly affected, and thus air pollutants concentration and deposition levels could be higher than those predicted. Taken into account the spatial distribution of Portuguese population along the coast, probably an important fraction could be occasionally exposed to a significant air pollution level.

4 Conclusions

The difficulties of predicting the direction and scale of change in the climate, whether globally or regionally, are mirrored by the difficulties in predicting the responses of ecosystems and atmospheric patterns. The limited data allow some general predictions, but the complexity of biological systems and climate behaviour prevents more detailed forecastings at present. It would seem prudent to scale correctly the release of greenhouse gases, to begin practicing sustainable economic approaches to resource use and to develop the data base needed to mitigate challenges to the coastal zone without damaging the diversity of ecosystems and allowing the real quality of human life.

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