Megacities in the Coastal Zone

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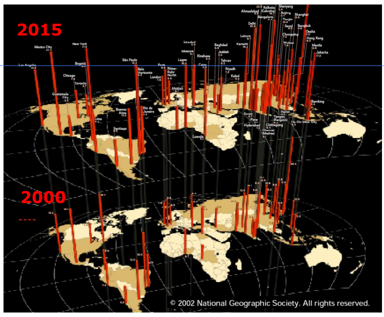
Abstract

Megacities are important drivers for socioeconomic development but also sources of environmental challenges. A large number of megacities are located in the coastal zone where land, atmosphere and ocean meet, posing multiple environmental challenges which we consider here. The atmospheric flow is complicated by urban heat island effects and topographic flows and sea breezes leading to profound changes in clouds and precipitation. Inflow of oceanic air (rich in sea salt) into the polluted city's atmosphere and outflow of polluted air onto a much cleaner ocean lead to unique but poorly understood biogeochemical processes. Contaminant input to coastal waters can damage their ecosystem function and resources such as fisheries and aquaculture, induce harmful algal blooms and feedbacks to the atmosphere via marine emissions. The scale of influence of megacities in the coastal zone is hundreds to thousands of kilometres in the atmosphere and tens to hundreds of kilometres in the ocean.

Introduction



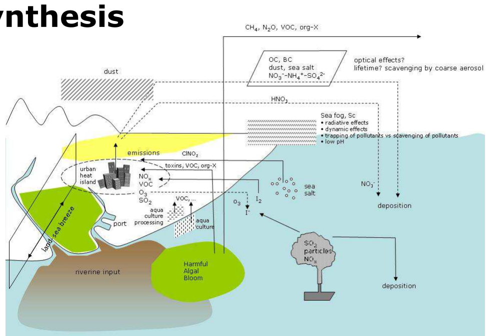
World's megacities. A Megacity is defined as having a population of 10 million or more.

- Almost 10% of the world's population live in megacities, and this proportion is growing (UN, 2010)
- Megacities in the Coastal Zone (MCCZ):
  - Data: UN 2010, "*World Urbanization Prospects: The 2009 revision*"
  - 2009: 14 of 21 megacities are MCCZ, 221 M people in MCCZ
  - 2025: 18 of 29 megacities are MCCZ, 302 M people in MCCZ
- Interactions between the coastal waters and the land in these regions are profoundly affected by the megacity…
- …and the environmental conditions in the megacity are profoundly affected by the coastal seas.
- IGBP/SCOR Fast-Track-Initiative workshop held in Norwich, UK, April 2010; co-organised by SOLAS/IGAC/LOICZ

Table 1 Population of urban agglomerations with 10 million inhabitants or more, 2009 and 2025 in millions. Coastal agglomerations are in bold, those with coastal influence in italics. Data from UN (2010).

Rank	2009 Urban agglomeration	Population	Rank	2025 Urban agglomeration	Population
1	**Tokyo, Japan**	36.5	1	**Tokyo, Japan**	37.1
2	Delhi, India	21.7	2	Delhi, India	28.6
3	**São Paulo, Brazil**	20.0	3	**Mumbai (Bombay), India**	25.8
4	**Mumbai (Bombay), India**	19.7	4	**São Paulo, Brazil**	21.7
5	Ciudad de México (Mexico City), Mexico	19.3	5	*Dhaka, Bangladesh*	20.9
6	**New York-Newark, United States**	19.3	6	Ciudad de México (Mexico City), Mexico	20.7
7	**Shanghai, China**	16.3	7	**New York-Newark, United States**	20.6
8	**Kolkata (Calcutta), India**	15.3	8	**Kolkata (Calcutta), India**	20.1
9	*Dhaka, Bangladesh*	14.3	9	**Shanghai, China**	20.0
10	**Buenos Aires, Argentina**	13.0	10	**Karachi, Pakistan**	18.7
11	**Karachi, Pakistan**	12.8	11	**Lagos, Nigeria**	15.8
12	**Los Angeles-Long Beach-Santa Ana, United States**	12.7	12	Kinshasa, Democratic Republic of the Congo	15.0
13	*Beijing, China*	12.2	13	*Beijing, China*	15.0
14	**Rio de Janeiro, Brazil**	11.8	14	**Manila, Philippines**	14.9
15	**Manila, Philippines**	11.4	15	**Buenos Aires, Argentina**	13.7
16	**Osaka-Kobe, Japan**	11.3	16	**Los Angeles-Long Beach-Santa Ana, United States**	13.7
17	*Al-Qahirah (Cairo), Egypt*	10.9	17	*Al-Qahirah (Cairo), Egypt*	13.5
18	Moskva (Moscow), Russian Federation	10.5	18	**Rio de Janeiro, Brazil**	12.7
19	Paris, France	10.4	19	**Istanbul, Turkey**	12.1
20	**Istanbul, Turkey**	10.4	20	**Osaka-Kobe, Japan**	11.4
21	**Lagos, Nigeria**	10.2	21	**Shenzhen, China**	11.1
			22	Chongqing, China	11.1
			23	**Guangzhou, Guangdong, China**	11.0
			24	Paris, France	10.9
			25	**Jakarta, Indonesia**	10.8
			26	Moskva (Moscow), Russian Federation	10.7
			27	Bogotá, Colombia	10.5
			28	**Lima, Peru**	10.5
			29	Lahore, Pakistan	10.3

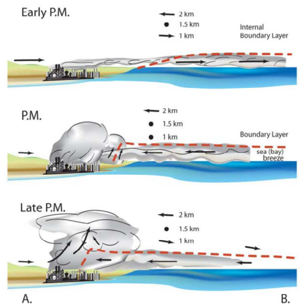
Synthesis



Schematic depiction of the main processes and feedbacks in MCCZ. OC – organic carbon, BC – black carbon, VOC – volatile organic compounds, org-X – organic halogens compounds.

Physical/climatic links

- Circulation/mixing
  - Urban heat island (UHI)
  - Changes to Land-sea breeze
  - Special topography surrounding the megacity
  - Examples: Tokio (mountain), Lima (mountain, sea fog), Los Angeles (mountain)
- Hydrological cycle
  - Changes in precipitation due to UHI
- Aerosol effects on hydrological cycle and radiative forcing



Megacity heat island strengthening effect of sea breeze. Schematic based on observations during the TexAQS campaign, August 2000 (Banta et al., 2005)

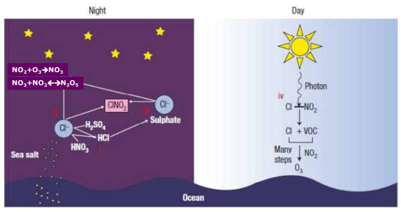
Atmospheric chemistry links

Input from marine atmosphere to megacity

- When pollution and sea salt meet… (see figure)
  - Input of large amounts of sea salt aerosol (depending on location and prevailing wind speed/direction) into urban environment
  - Release of chlorine from aerosol leads to additional O_3 production
  - Impact on megacity air quality
- Deposition of salt on urban surfaces might have chemical effects and corrosion effects

Input from megacities into marine atmosphere

- Ozone:
  - Short range: transformation of O_3 sink to O_3 source regions (NO_x, VOC)
  - Long range: possibly increase of O_3 sink due to halogen release
  - Overall effect on O_3 is uncertain
- Long lifetime of pollution induced changes due to multiphase cycling of halogens
- Uptake of HNO_3 to sea salt and rapid deposition
- Input of HNO_3, NH_3 etc to ocean



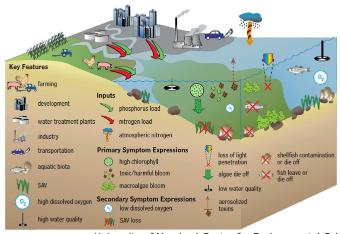
Formation of nitryl chloride ($ClNO_2$) in regions with high NO_x and high salt loadings, e.g. MCCZ (Osthoff et al., 2008). This leads to formation of a NO_x-reservoir species and leads to the formation of peroxy radicals after sunset due to the reaction of Cl atoms with volatile organic compounds (VOC). In the presence of NO_x this leads to the formation of ozone (O_3). (Figure: von Glasow, 2008)

Marine Ecosystem Responses

Input of nutrients and pollutants via the atmosphere and from runoff

- Alter primary and secondary production
- Potentially contributing to local and regional hypoxia and dead zones
- Creating ecosystem changes and loss of key habitats including coral reefs, sea grasses and mangroves
- Alter emissions of marine trace gases
- Potentially induce Harmful Algal Blooms (HABs, see schematic and photos)

There are feedbacks to the urban populations directly via marine gas and possibly bacterial fluxes and indirectly via impacts on food supply and aquaculture, habitat loss, environmental detoxifying capacity and loss of recreation and cultural services



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Enteromorpha bloom, Qingtao 2008

Scales

- Atmosphere
  - Outflow on the ocean: effects are discernible for several hundred or even thousand kilometres
  - Long-lived greenhouse gases: global influence
- Ocean
  - 100s km and governed by local hydrographic patterns
- Economic reach
  - Food, water and energy have to be provided and this often involves long range transport into the megacity
  - Example: Los Angeles - Water and energy is sourced from the Sierra Mountains and the Colorado River, hundreds of kilometres away from Los Angeles
- Recovery timescale
  - Atmosphere: days to weeks for the removal of aerosol particles and reactive gases, but on the order of months for less reactive gases; greenhouse gases 100s and 1000s years
  - Ocean: ecosystems is on the order of 10s – 100s years

Change

- MCCZ are impacted by a changing climate and are also contributing to this change
- Rising sea levels globally and due to local subsidence plus changes in river flows and coastal habitat will increase flooding pressures
- Shifts in the physical environment including:
  - Atmospheric circulation; precipitation patterns
  - Coastal circulation; river flows and urban runoff
- Benefits of MCCZ:
  - Frontline of change – especially in positive sense: air pollution regulation and environmental management in general, energy use, transportation, education, innovation etc.
  - Changes (in the direction of improving quality of living etc) can be implemented more easily than elsewhere.
  - Greenhouse gas emissions per capita are often lower for megacities compared to the national average due to more efficient use of resources even though there are a few noteworthy exceptions (Hoornweg et al., 2011)

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