WORLD METEOROLOGICAL ORGANIZATION
GLOBAL ATMOSPHERE WATCH

WMO/IGAC

IMPACTS OF MEGACITIES ON AIR POLLUTION AND CLIMATE

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1.1 URBANIZATION

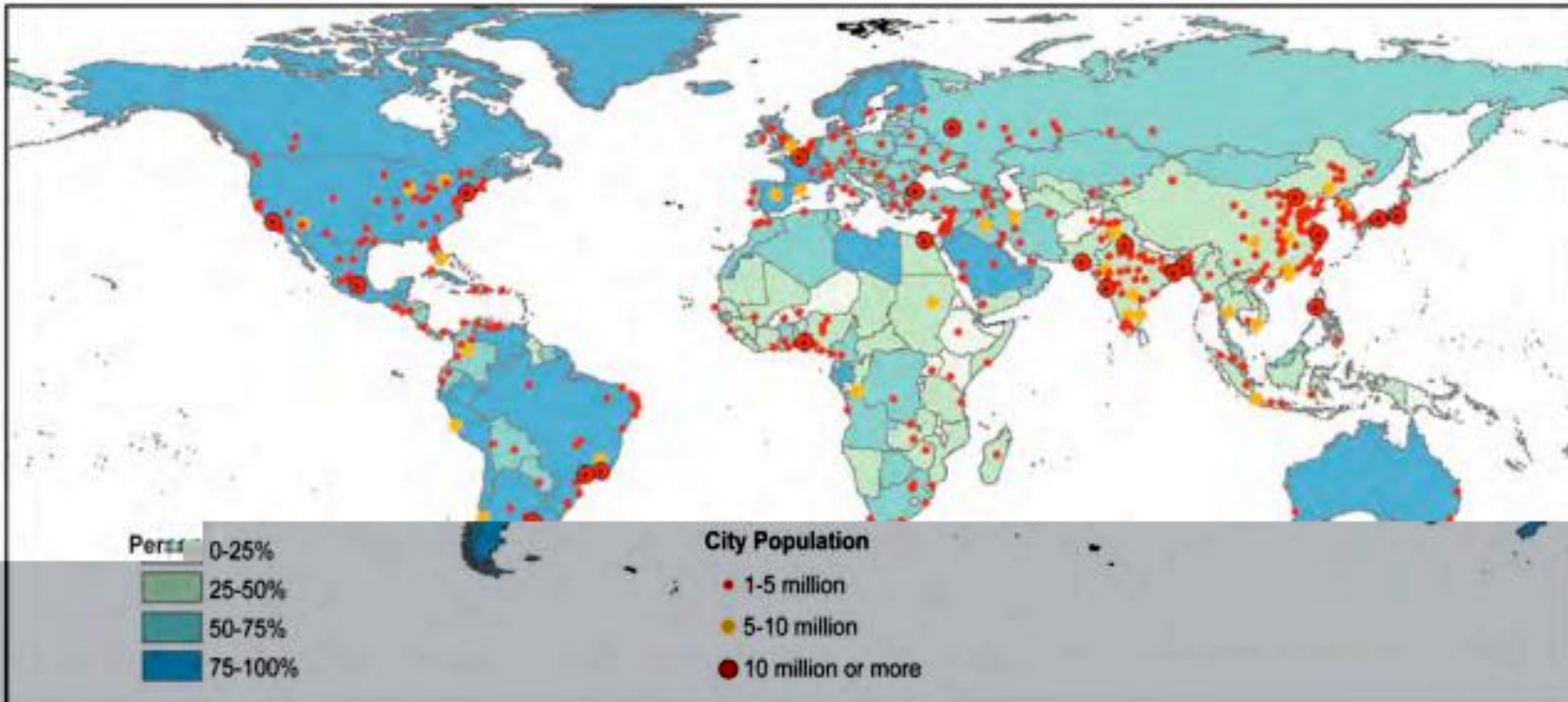

Figure 1 - Urban Agglomeration in 2009 (urban proportion of the world population: 50.1%)
Source: [*UN Department of Economic and Social Affairs*, 2010]

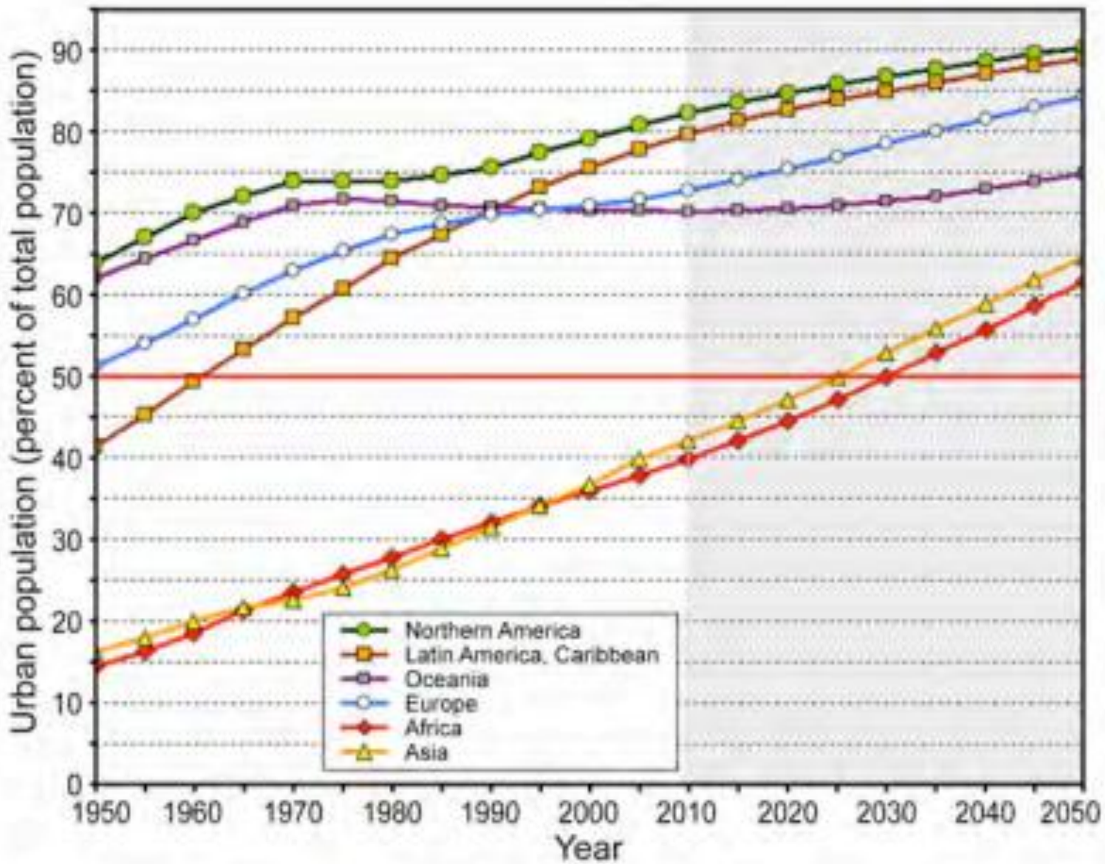

Figure 2 - Urban Population by major geographical area (in percent of total population)
[*UN Department of Economic and Social Affairs*, 2010]

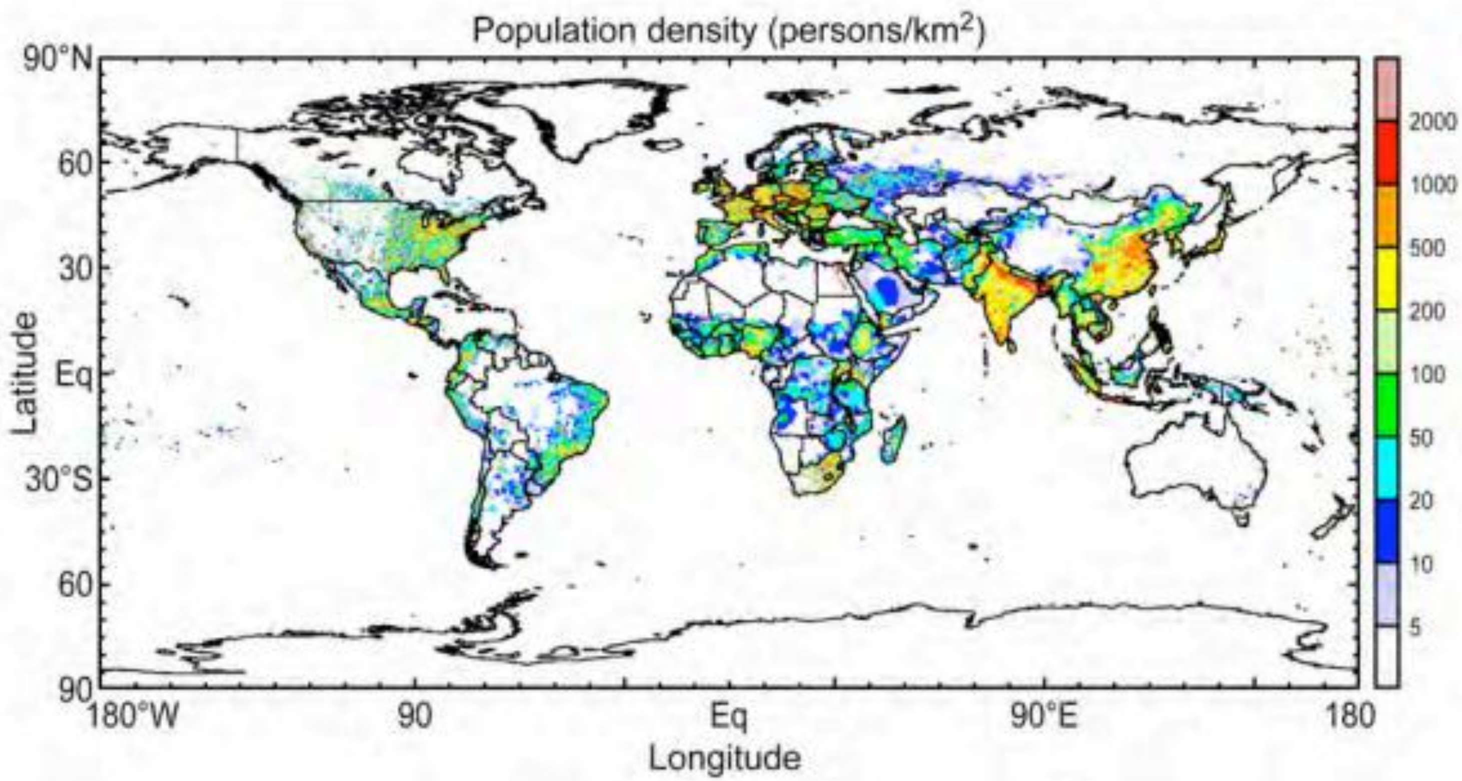

Figure 3 - Map of the world population density (persons per km²), based on 0.25° gridded data for 2000 from the Center for International Earth Science Information Network (CIESIN) at Columbia University [*http://sedac.ciesin.columbia.edu/gpw/*]

1.2 ATMOSPHERIC CHEMISTRY OF AIR POLLUTION

1.2.1 Acid rain formation

1.2.2 Tropospheric ozone

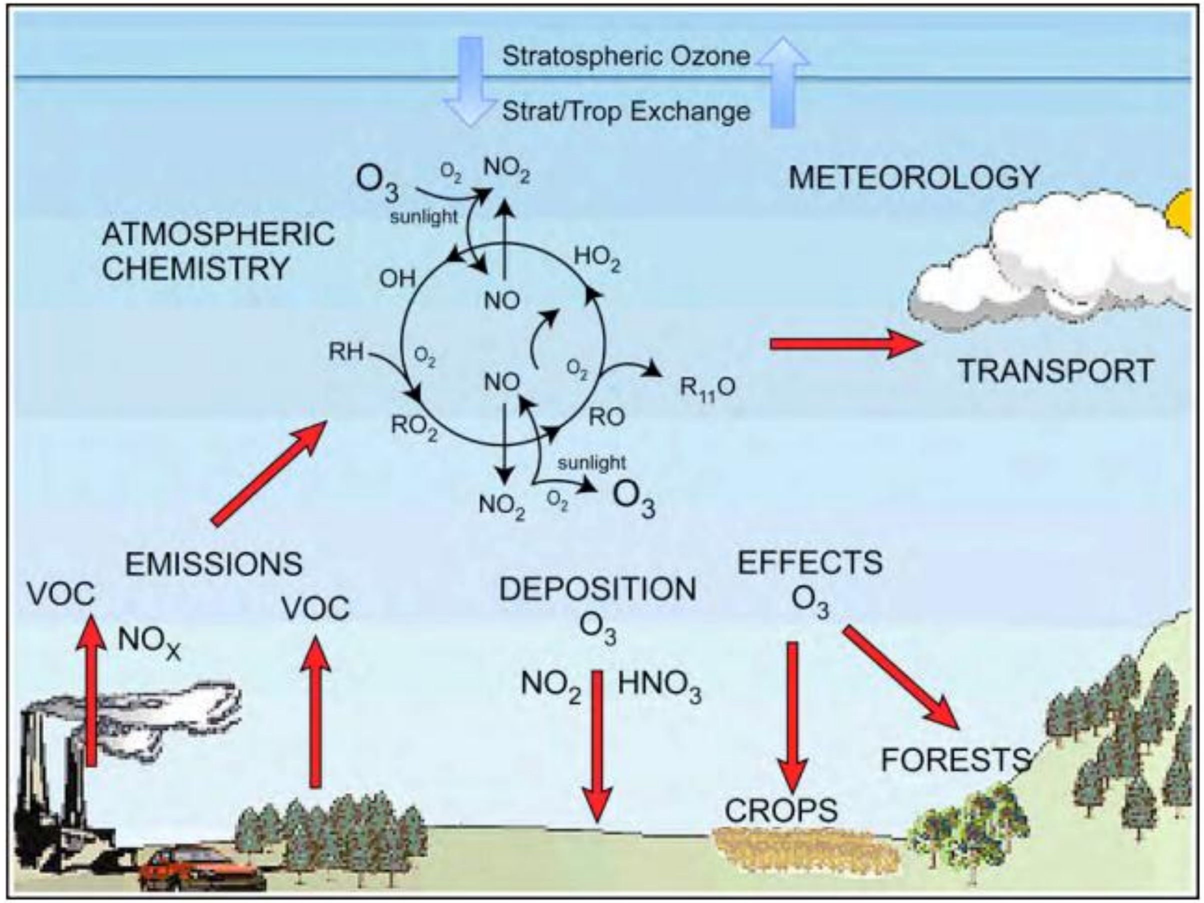

Figure 4 - Physical and chemical processes affecting tropospheric ozone
[*http://www.globalchange.umich.edu/gctext/Inquiries/Inquiries_by_Unit/Unit_9.htm*]

1.2.3 *Particulate matter*

Table 1 - Terminology Related to Atmospheric Particles
Source: *Seinfeld and Pandis*, 1998 (pg. 97)

Aerosols, aerocolloids, Aerodisperse systems	Tiny particles dispersed in gases
Dust	Suspension of solid particles produced by mechanical disintegration of material such as crunching, grinding, and blasting.
Fog	A loose term applied to visible aerosols in which the dispersed phase is liquid. Usually a dispersion of water or ice close to the ground.
Fume	The solid particles generated by condensation from the vapour state, generally after volatilization from melted substances, and often accompanied by a chemical reaction such as oxidation.
Haze	An aerosol that impedes vision and may consist of a combination of water droplets, pollutants, and dust.
Mist	Liquid, usually water in the form of particles suspended in the atmosphere at or near the surface of the Earth; small water droplets floating or falling, approaching the form of rain, and sometimes distinguished from fog as being more transparent or as having particles perceptibility moving downward.
Particle	An aerosol particle may consist of a single continuous unit of solid or liquid containing many molecules held together by intermolecular forces. A particle may also be considered to consist of two or more such unit structures held together by interparticle adhesive forces such that it behaves as a single unit in suspension or upon deposit.
Smog	A term derived from smoke and fog, applied to extensive contamination by aerosols. Now sometimes used loosely for any contamination of the air.
Smoke	Small gas-borne particles resulting from incomplete combustion, consisting predominately of carbon and other combustible material, and present in sufficient quantity to be observable independently of the presence of other solids.
Soot	Agglomerations of particles of carbon impregnated with "tar", formed in the incomplete combustion of carbonaceous material.

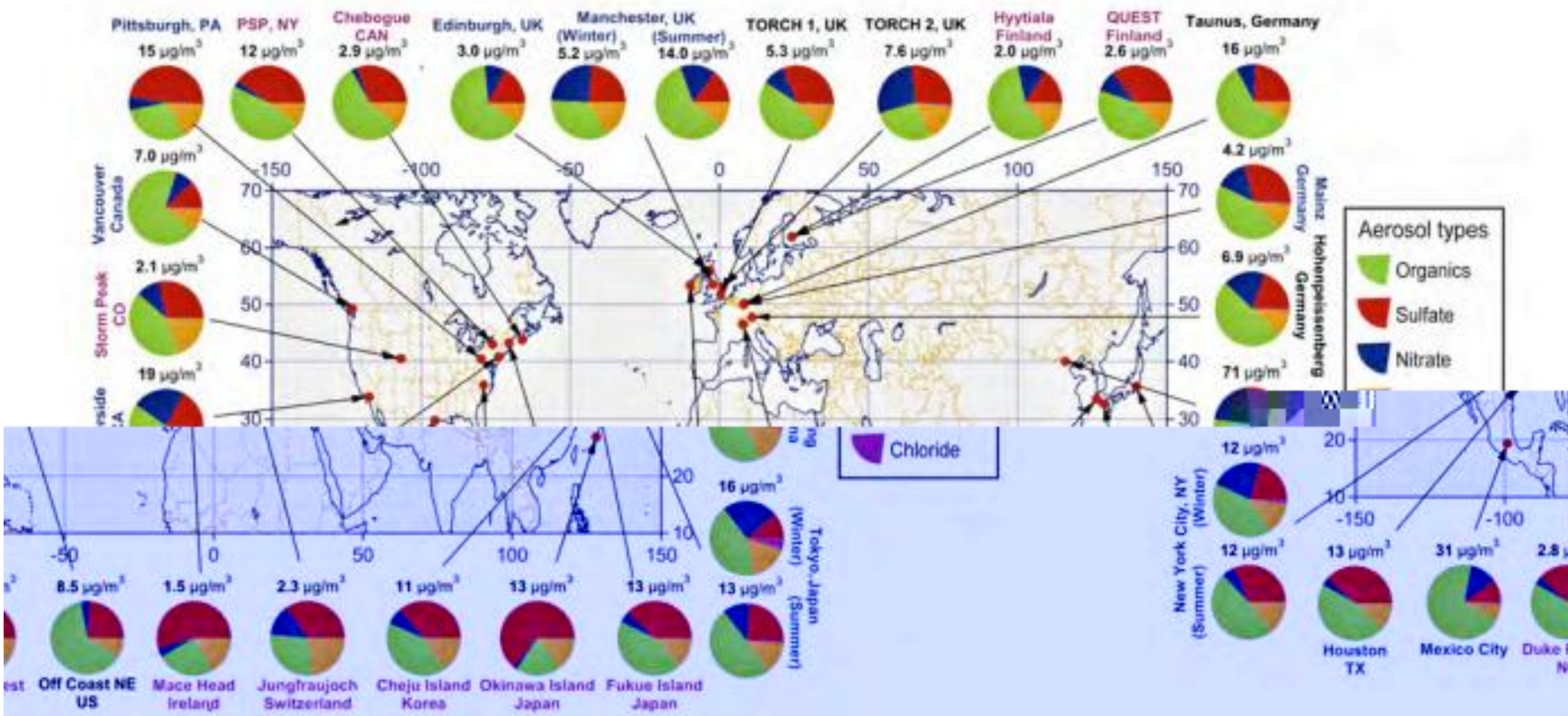

Figure 6. Average aerosol mass concentration and chemical composition measured with AMS at multiple locations in the Northern Hemisphere. [Zhang et al., 2007]

1.2.4 Climate change

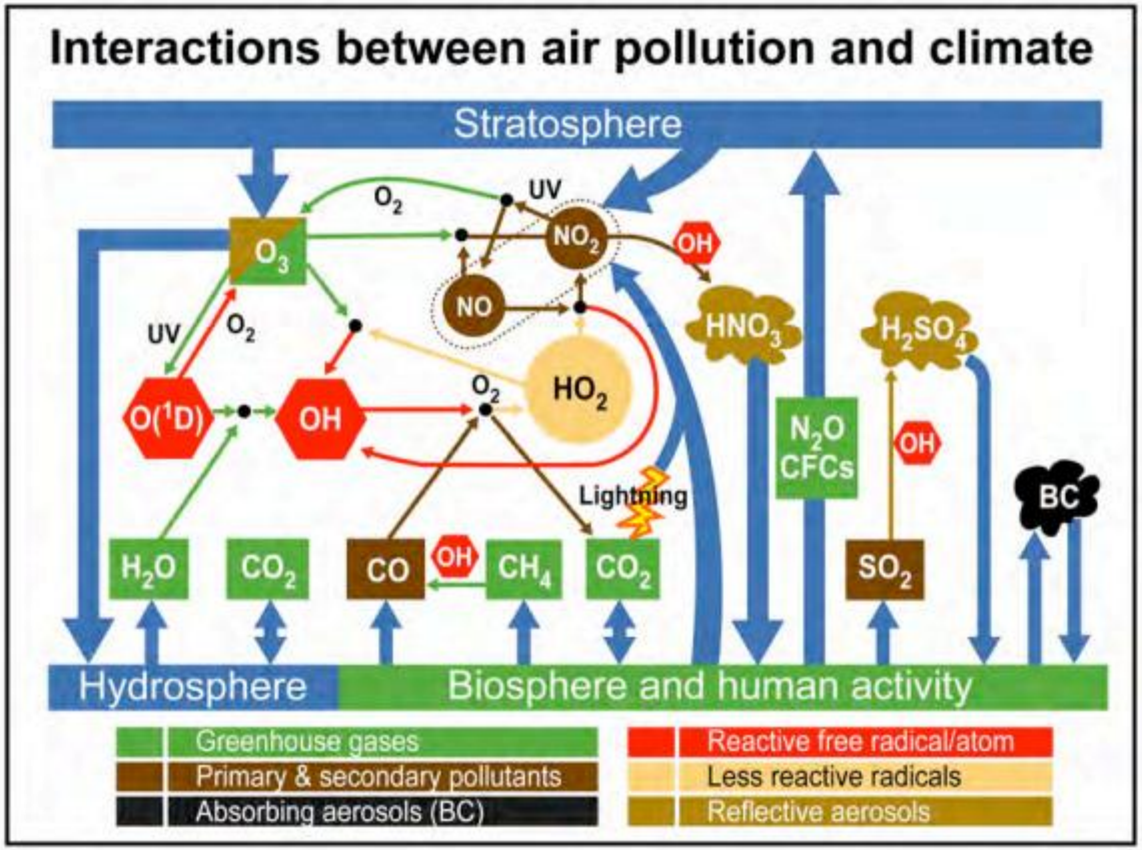

Figure 7 - Air pollution and climate are inexorably linked
[*http://www.ocw.cn/OcwWeb/Chemical-Engineering/10-571JSpring-2006/CourseHome/index.htm*]

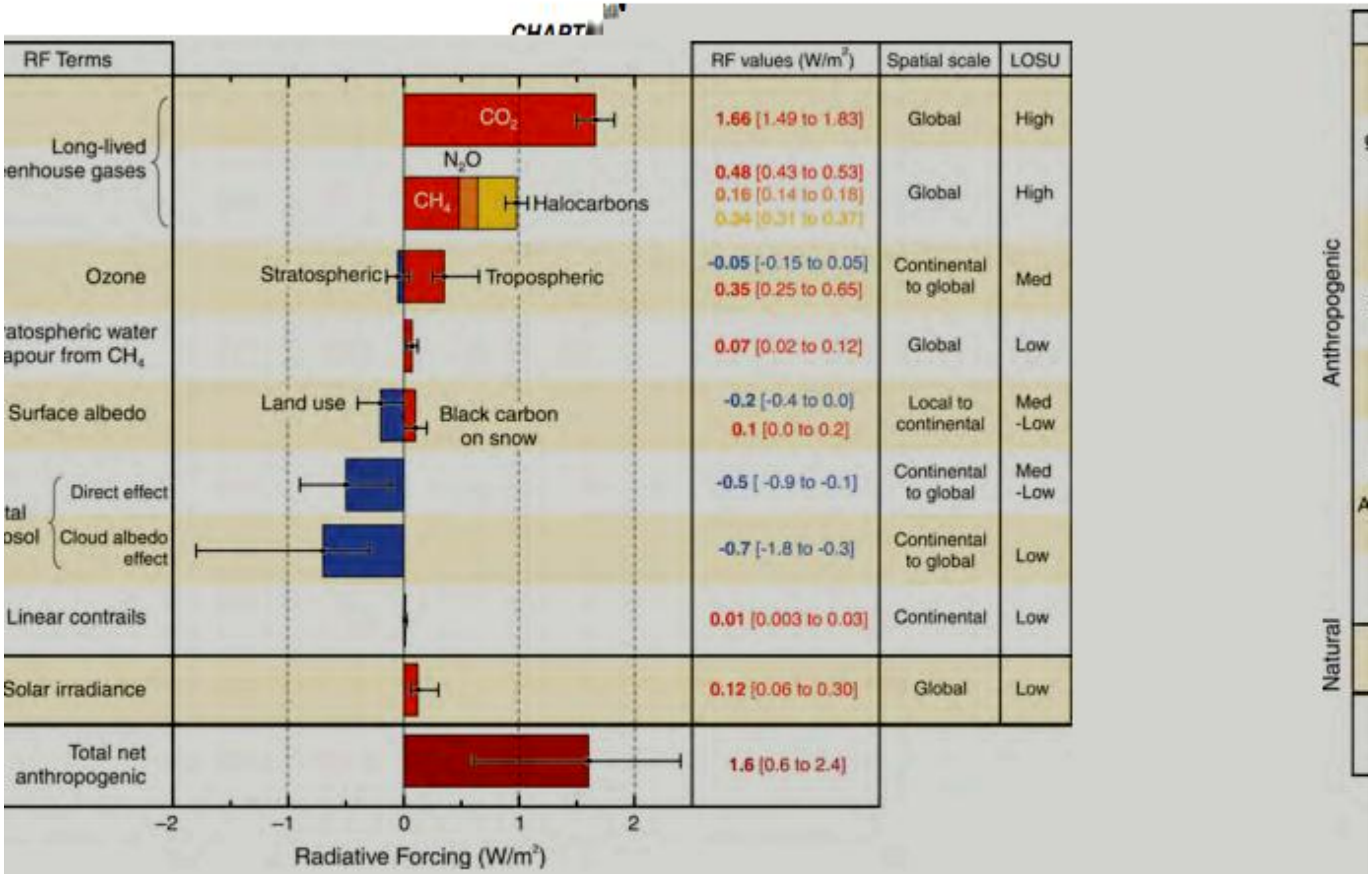

Figure 8 - Global average radiative forcing estimates and ranges in 2005 [*IPCC, 2007*]

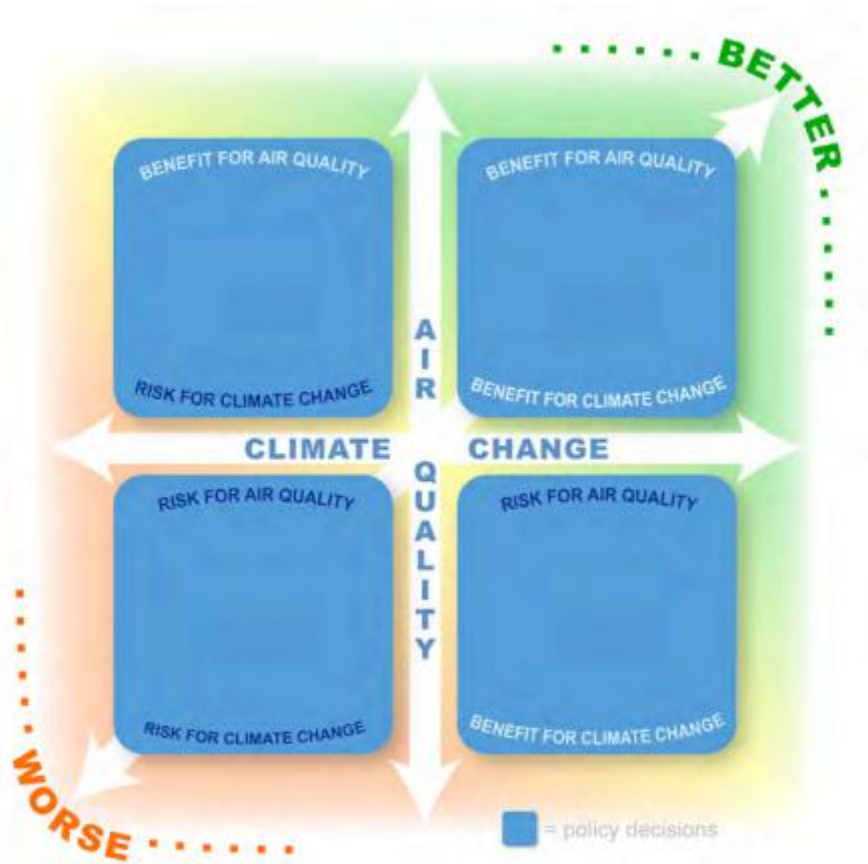

Figure 9 - Schematic of the trade-offs between the [illegible]

1.3 HEALTH IMPACTS OF AIR POLLUTION

1.4 AIR QUALITY REGULATION

Table 2 - US National Ambient Air Quality Standards

Pollutant	Concentration	Averaging Period
Particulate Matter ($PM_{2.5}$)	15 µg/m3 35 µg/m3	1 year 24 hour
Particulate Matter (PM_{10})	150 µg/m3	24 hour
Ozone	0.075 ppm	8 hour
Nitrogen Dioxide	100 ppb 53 ppb	1 hour 1 year
Sulphur Dioxide	75 ppb 0.5 ppm	1 hour 3 hour

Table 3 - European Commission Air Quality Standards

Pollutant	Concentration	Averaging Period
Particulate Matter ($PM_{2.5}$)	25 µg/m3	1 year
Particulate Matter (PM_{10})	50 µg/m3	24 hours
Ozone	120 µg/m3	8 hr
Nitrogen Dioxide	40 µg/m3 200 µg/m3	1 year 24 hour
Sulphur Dioxide	125 µg/m3 350 µg/m3	24 hours 1 hour

[redacted]

Table 4 - World Health Organization Air Quality Guidelines

Pollutant	Concentration	Averaging Period
Particulate Matter ($PM_{2.5}$)	10 µg/m³ 25 µg/m³	1 year 24 hour
Particulate Matter (PM_{10})	20 µg/m³ 50 µg/m³	1 year 24 hour
Nit[illegible] Di[illegible]xid[illegible]	4[illegible] 2[illegible]	[illegible]y[illegible]a[illegible] [illegible]h[illegible]
Sulphu[illegible] Di[illegible]xide	2[illegible] 5[illegible]	24 h[illegible] 1[illegible]inute

[redacted]

1.5 SCIENTIFIC TOOLS FOR STUDYING AIR POLLUTION IN MEGACITIES

1.5.1 Ground-based, ship, and aircraft observations

1.5.2 Satellite observations

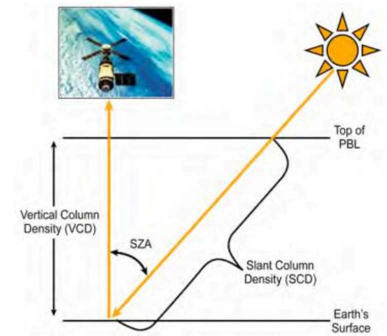

Figure 11 - Simplified schematic of solar backscattering measu

The **nadir** (from Arabic: نظير / ALA-LC: *naẓīr*; meaning "opposite") is the direction pointing directly *below* a particular location; that is, it is one of two vertical directions at a specified location, orthogonal to a horizontal flat surface there.

The **limb** of the Earth is simply the horizon, or the edge of the Earth at the horizon, especially if you see it from a spacecraft.

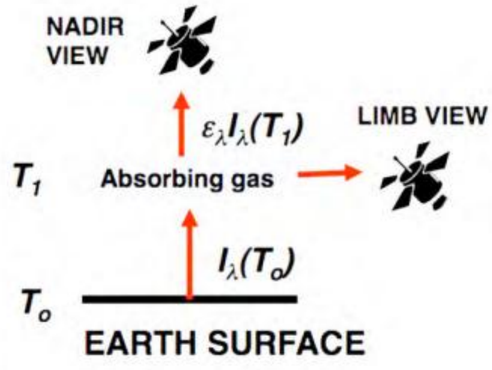

Figure 13 - Schematic of thermal emission measurements

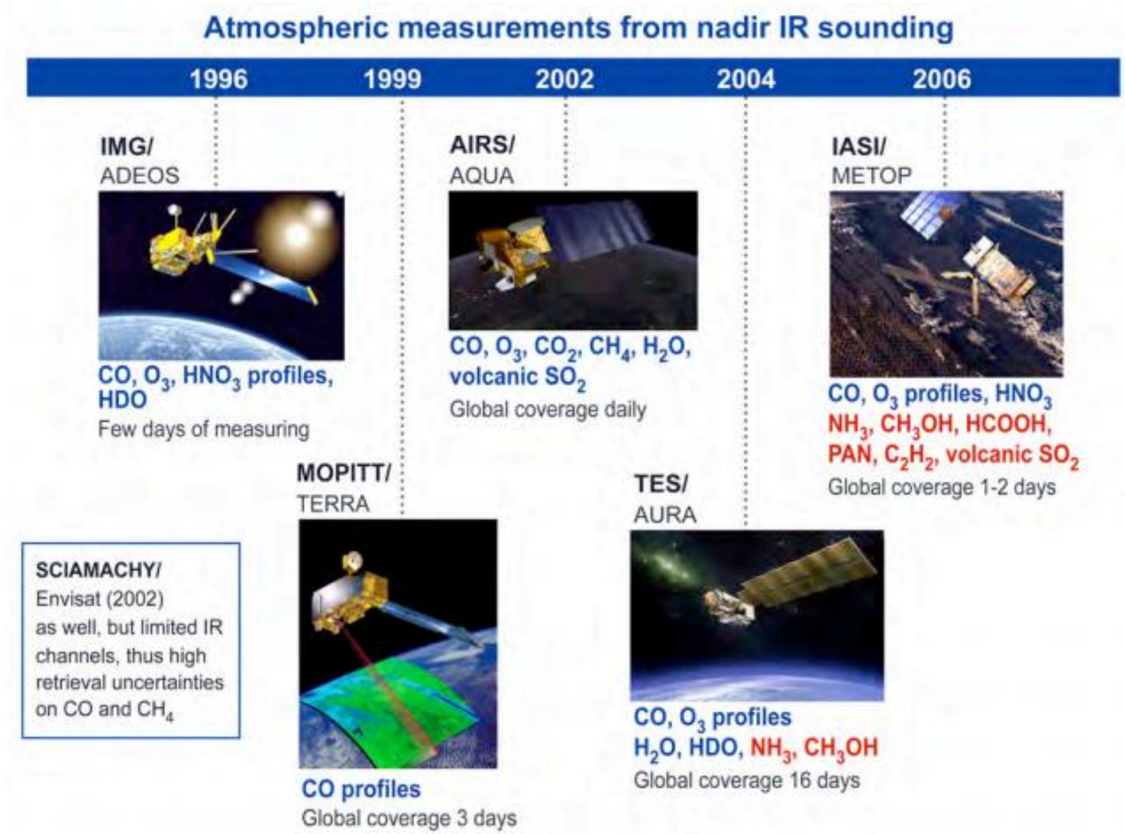

Figure 14 - Atmospheric composition measurements from thermal emission instruments

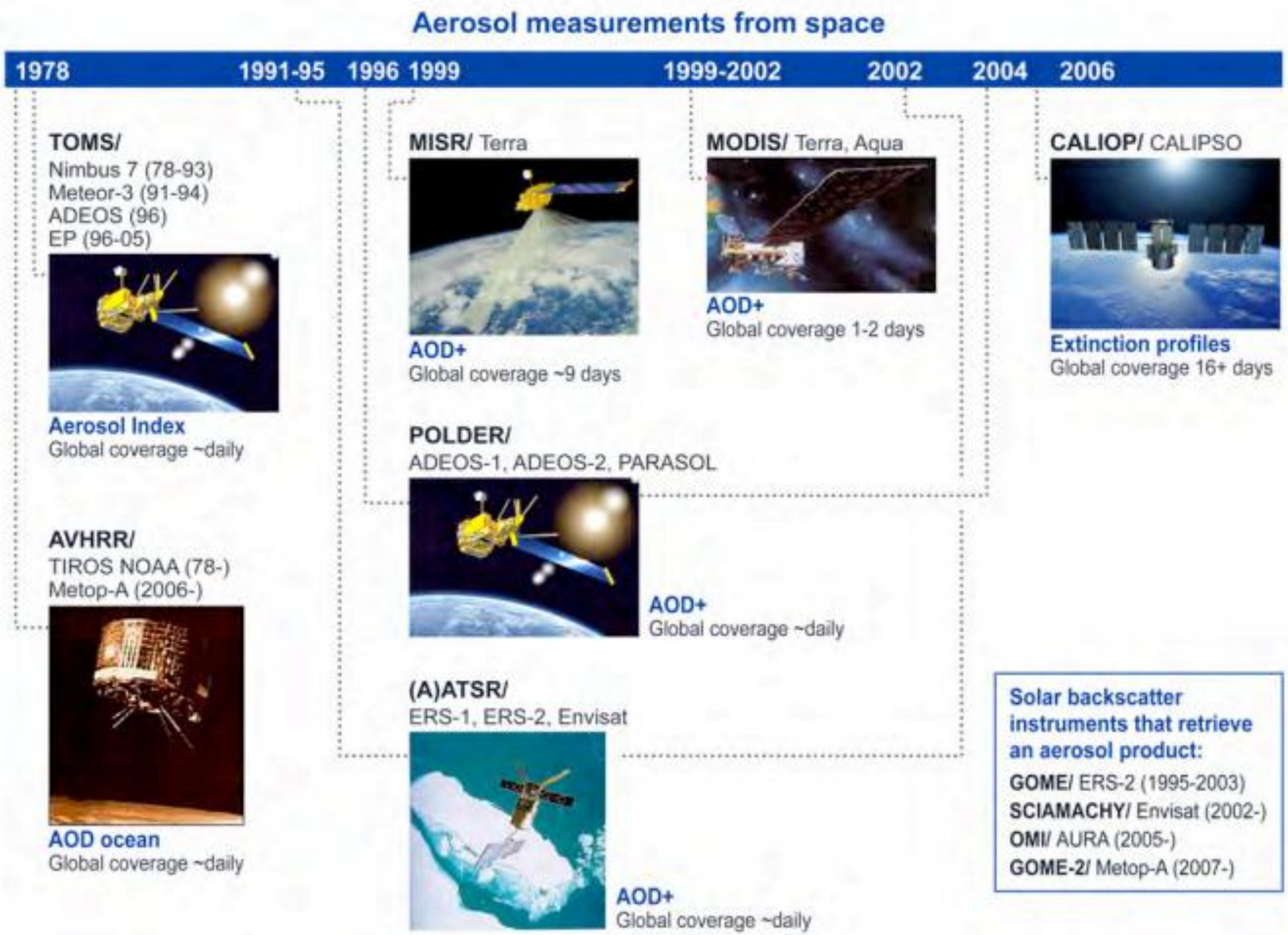

Figure 15 - Aerosol measurements from space

1.5.3 Emission inventories

$$E = A \times EF \times \left(1 - \frac{ER}{100}\right)$$

where *E* is the emissions, *A* is the activity rate, *EF* is the emissions factor, and *ER* is the overall emission reduction efficiency using capture or control techniques (given in %). Emission factor uncertainty is dependent on the kind of emissions released, the number of tests used to determine the emissions factor, using the appropriate percentile within the distribution range, and the number of similar emissions units within a specific area *[http://www.epa.gov/ttn/chief/efpac/abefpac.html]*. Determining emission factors for every source and every pollutant under a variety of operating conditions throughout the world is a daunting task. Therefore, most emission factors are developed from only a limited sampling of the emissions source population for any given category, i.e. source population average. The limited number of samples likely results in emission factors not statistically representative of the actual emissions of a source category [*Seinfeld and Pandis*, 1998].

Emission estimation models use empirically developed process equations to estimate emissions from a given source. In general, an emission estimation model is used rather than an emission factor when a large number of equations, interactions, and parameters impact the emissions estimate. In many cases, emission estimation models are used to develop inventories for mobile and non-road source categories since it is difficult to directly measure activity for numerous individual sources operating under a wide variety of conditions.

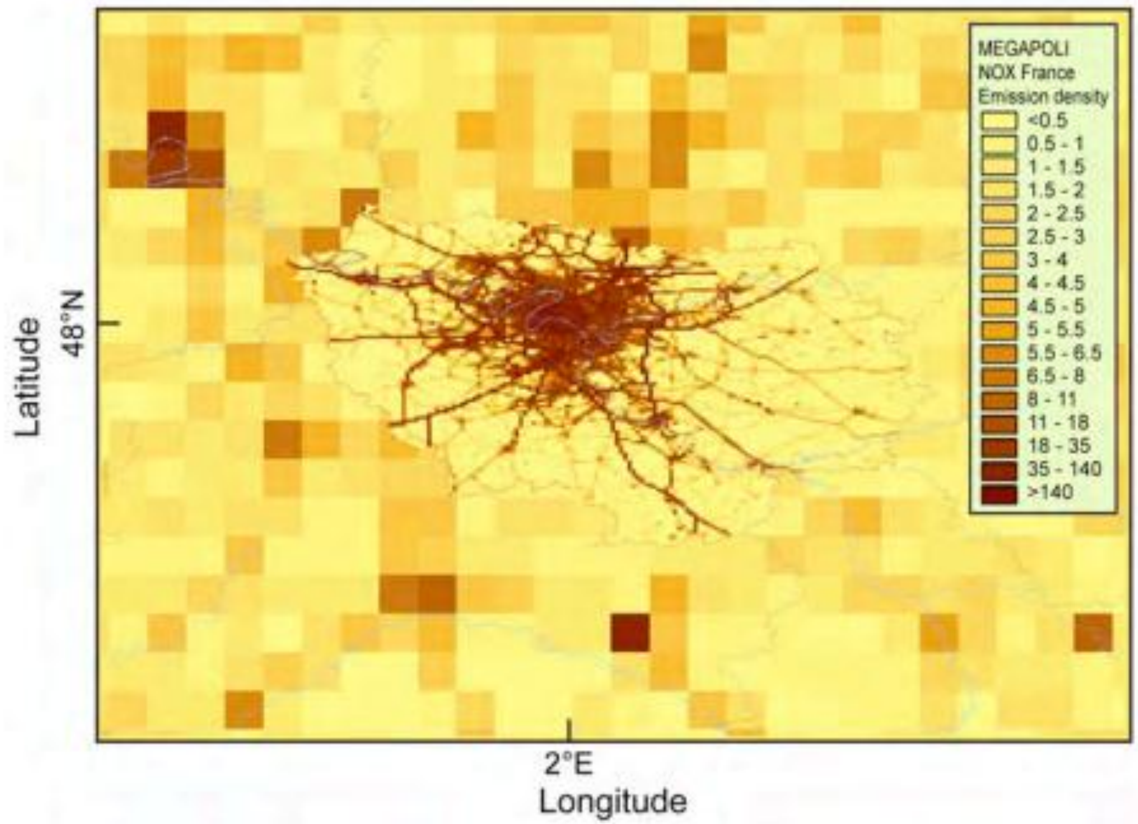

Figure 16: Merging a local bottom-up emisison inventory for Paris [*Airparif*, 2010] into a regional down-scaled Europan emisison inventory [*Denier van der Gon et al.*, 2009; 2011].

However, discrepancies often exist between emission inventories developed by down-scaled versus bottom-up approaches as illustrated in four European megacities or urban agglomerations; London, Paris, Rhine-Ruhr area (Germany) and the Po Valley (Italy). The local inventories use local statistics and activity data to estimate the emissions within their domain using a bottom-up approach. The European emission inventory is a down-scaled inventory based on national totals by source sector and then distributed over a grid by using source sector specific spatial distribution proxies [*Denier van der Gon et al.*, 2009]. A ratio comparison of down-scaled versus bottom-up emission inventories for these four cities is shown in Figure 17. A value of 1 in Figure 17 indicates that the local megacity inventory and the regional scale down-scaled inventory have the same estimate for the pollutants from the megacity domain. The differences can be quite dramatic. For example, the PM_{10} emission allocated to London and Paris by the regional scale

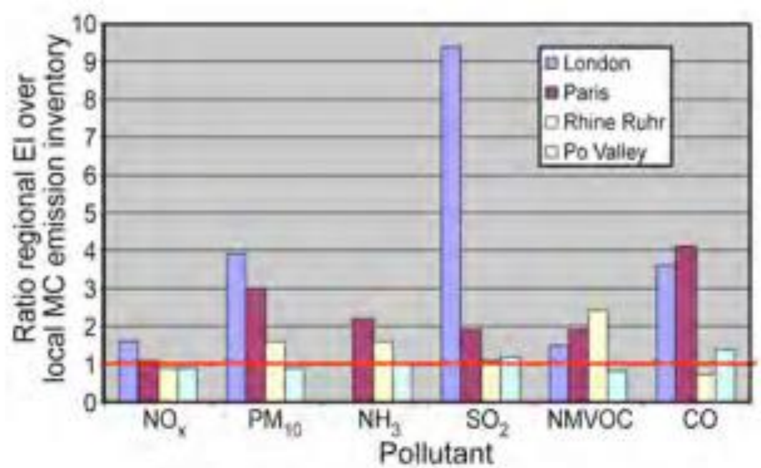

Figure 17 - Ratio of megacity emissions derived from the Regional European scale inventory compared to the local megacity emission inventory [*Denier van der Gon et al.*, 2011]

1.5.4 Modelling

CHAPTER 1 - INTRODUCTION

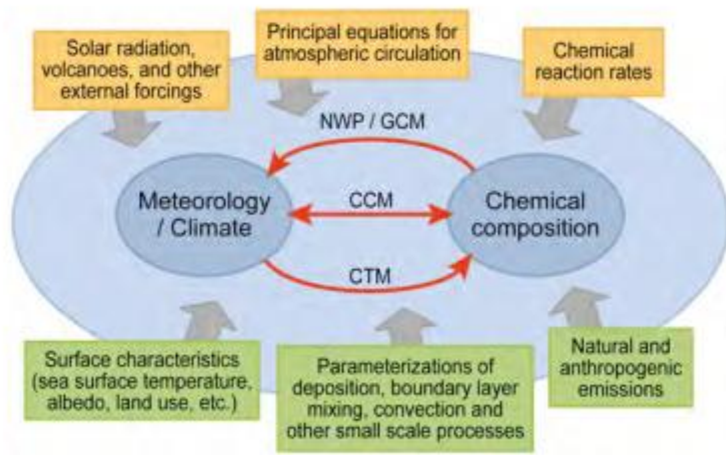

Figure 18 - Concept of atmospheric modelling. Yellow boxes: A priori knowledge that is not calculated by the model itself. Green boxes: Forcings that may or may not be calculated by the model itself but are needed for accurate model output. Blue ovals: Main purpose (or output) of the model. Numerical Weather Prediction models (NWP) and General Circulation models (GCMs) use prescribed fields of chemical species (e.g. aerosols) and calculate meteorology, while chemical transport models (CTMs) take meteorology as input and calculate the chemical composition of the atmosphere. Coupled climate-chemistry models (CCMs) calculate both meteorology and chemical composition and allow for couplings between the two. This figure is not exhaustive but is meant to illustrate the most basic components only

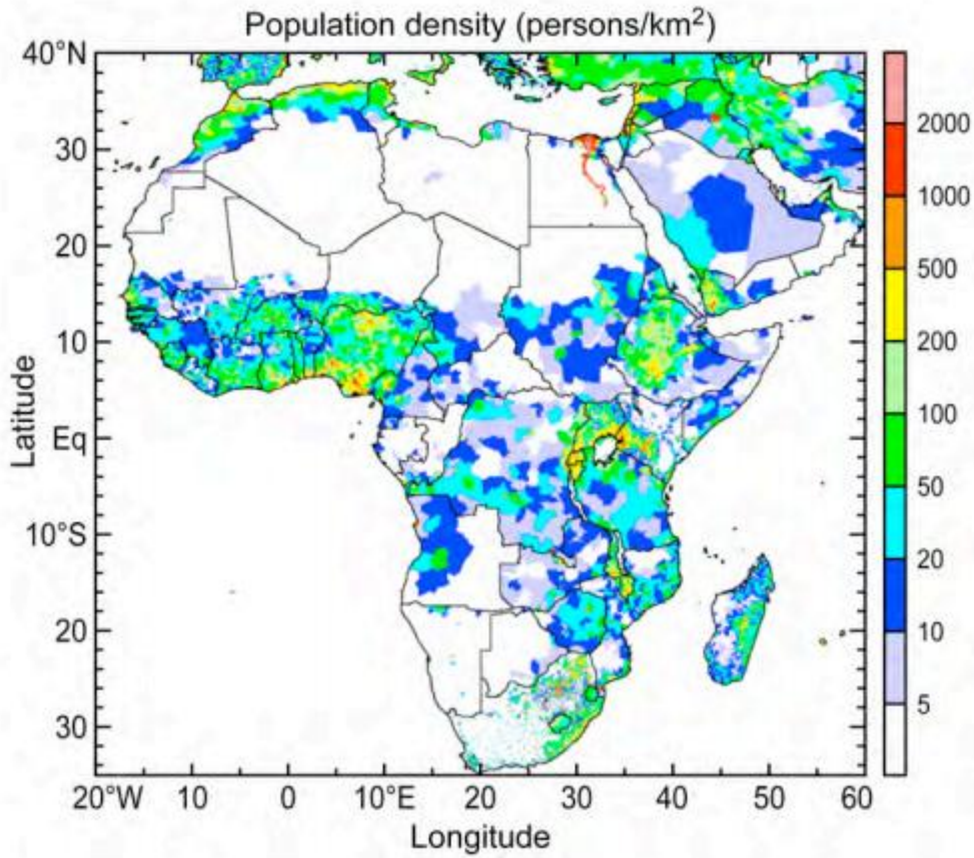

Figure 1 - Map of the population density in Africa (persons per km²), based on 0.25° gridded data for 2000 from the Center for International Earth Science Information Network (CIESIN) at Columbia University *(http://sedac.ciesin.columbia.edu/gpw/)*

Table 1 - The 15 of the 30 world largest cities in Asia in 2010.
Source: the World Urbanization Prospects of the United Nations (2009 Revision)

Rank order	Country	Megacity	Population (Million)
1	Japan	Tokyo	36.67
2	India	Delhi	22.16
4	India	Mumbai (Bombay)	20.04
7	China	Shanghai	16.58
8	India	Kolkata (Calcutta)	15.55
9	Bangladesh	Dhaka	14.65
10	Pakistan	Karachi	13.12
13	China	Beijing	12.39
15	Philippines	Manila	11.63
16	Japan	Osaka-Kobe	11.34
22	Republic of Korea	Seoul	9.77
23	China	Chongqing	9.40
24	Indonesia	Jakarta	9.21
26	China	Shenzhen	9.01
28	China	Guangzhou, Guangdong	8.88

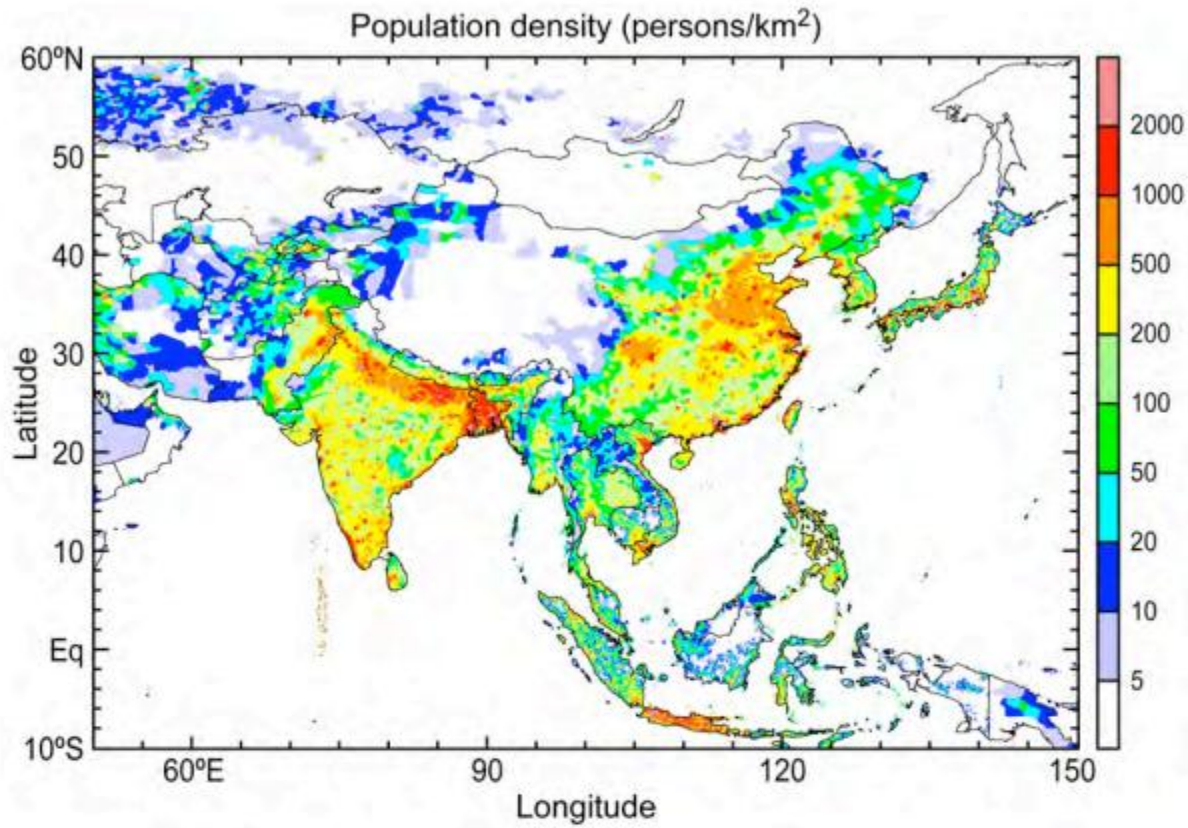

Figure 1 - Map of the population density in Asia (persons per km2), based on 0.25º gridded data for 2000 from the Center for International Earth Science Information Network (CIESIN) at Columbia University [*http://sedac.ciesin.columbia.edu/gpw/*]

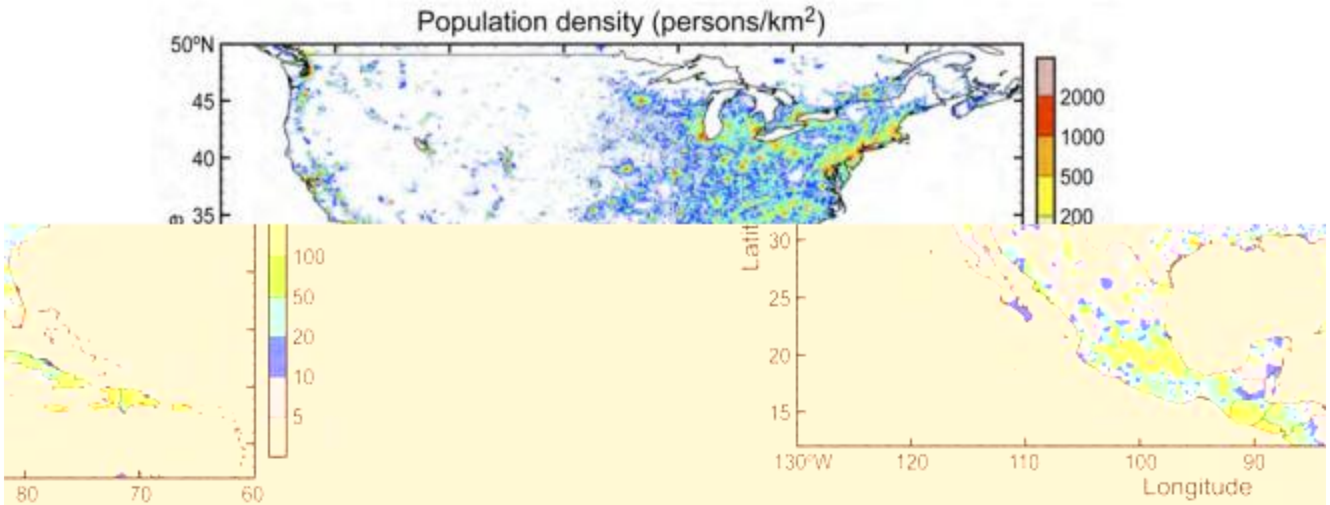

Figure 1 - Map of the population density in North America (persons p
from the Center for International Earth Science Information N
[http://sedac.ciesin.columbia.e

r km^2), based on 0.25° gridded data for 2000
work (CIESIN) at Columbia University
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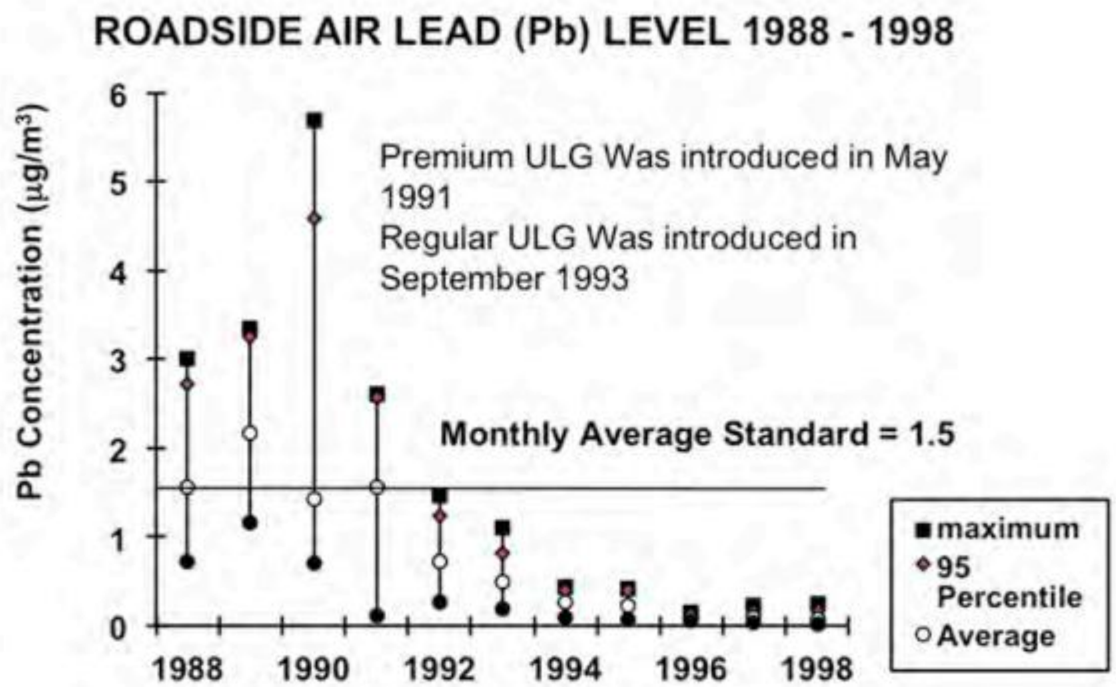

Figure 6 - Annual average curbside lead concentration in Bangkok from 1985-1998 [*Supat,* 1999]

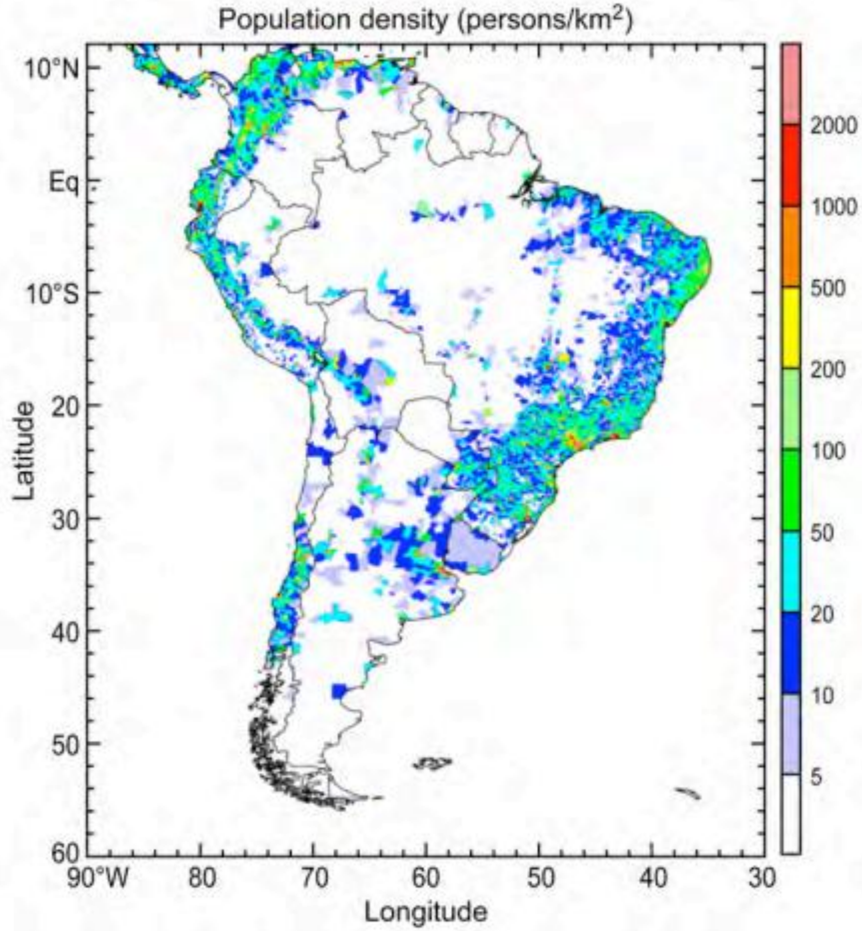

Figure 1 - Map of the population density in South America (persons per km²), based on 0.25° gridded data for 2000 from the Center for International Earth Science Information Network (CIESIN) at Columbia University ***[http://sedac.ciesin.columbia.edu/gpw/]***

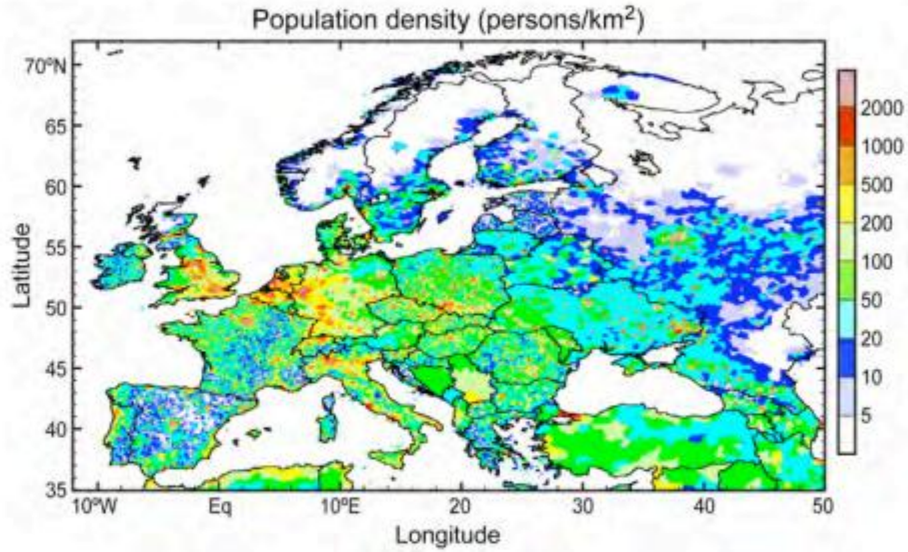

Figure 1 - Map of the population density in Europe and western Asia (persons per km^2), based on 0.25° gridded data for 2000 from the Centre for International Earth Science Information Network (CIESIN) at Columbia University *[http://sedac.ciesin.columbia.edu/gpw/]*

Table 1 - Populations and Characteristics of European Megacities and Major Population Centres

Megacity / MPC	Population[1] (Million)	Latitude	Longitude
Paris, France	10.4	49.4	1.9
London, England	8.6	51.3	0.0
Po Valley, Italy	ca.20	~45-46	~11-12
Ruhrgebiet, Germany and Benelux Region (Belgium, Netherlands, Luxemburg)	28 (BeNeLux) + 5.7[3] (Ruhrgebiet)	~49-54	~2-8
Moscow, Russia	10.5	55.0	37.5
Istanbul, Turkey	10.4	40.1	28.1

[1] *Population Source (unless otherwise noted): Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat World Urbanization Prospects: The 2009 Revision, Web: http://esa.un.org/unpd/wup/index.htm*

Figure 1 - The locations of the international collaborative research activities described in this chapter.
ADAPTE: Adaptation to health impacts of air pollution and climate extremes in Latin American cities; CalNex 2010: Air Qualit[redacted]