Effect of aerosols and land use/land cover change on rainfall:
The Mexico City story

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Urban environments have been increasing in size over the last decades, so that currently the majority of the world population resides in cities that have more than 1 million inhabitants (known as "megacities"). These megacities are also major sources of pollution, primarily from vehicles but also from certain industries and waste management plants. Simultaneously, rural areas that originally surrounded the cities have been incorporated into the urban area, introducing changes in the land use of vast extensions. Other areas that originally may have been forests or natural grasses have now been converted to rural areas for crops.

All these forcings (gas and aerosol emissions as well as changes in land use and land cover) while having a global impact on climate, have a more immediate impact on the local air quality and health of the population as well as on the local climate. Gaseous emissions can be converted into aerosol particles in the atmosphere after being emitted by known sources and transported outside the megacities. A typical "mix" of gaseous urban emissions would include carbon monoxide, sulfur dioxide, nitrogen oxides, methane, as well as a variety of other organic compounds, which will depend on the particular characteristics of the fuels used by vehicles and the types of industries in the city. Some of the primary gases and some of the gases produced in the urban atmosphere (e.g. ozone, formaldehyde) have been shown to affect human health directly. But more often aerosol particles are the ones that cause the most damage to the heath of the population. Both primary particles (such as "soot" from inefficient combustion) and secondary particles (inorganic, such as sulfates and nitrates and/or organic) can penetrate different parts of the respiratory system depending on their size and density. Particles have also been linked to cardiovascular problems.

A subgroup of these primary and secondary particles that have a certain size range (from 0.1 up to 1.0 **μ**m) and a certain hygroscopic composition, is known as cloud condensation nuclei (CCN) and constitute the kernels over which cloud droplets form from the water vapor in the Earth´s atmosphere. Also some of these particles can act as ice nuclei (IN), providing a substrate for ice crystals to grow from vapor deposition. Natural CCN and IN exist throughout the atmosphere, but in urban environments the concentrations of man-made particles is much larger than in pristine regions and also particle composition tends to include many more compounds. Therefore, their contribution as CCN and IN can be highly variable and it is not clear *a priori* if they would have an effect on cloud droplet concentrations and the development of precipitation in deep convective clouds.

Changes in land use and land cover due to urbanization modify the radiative balance at the surface, changing the contributions of sensible and latent heat fluxes to the atmosphere. Urbanization leads to the well known "urban heat island" (UHI) effect, whereby cities remain warmer than the surroundings, particularly at nighttime. The UHI has an associated wind circulation that would lead to enhanced precipitation, and some studies in the US have shown such evidence, mainly downwind of cities (e.g. Atlanta, New York, Houston).

Here we will use Mexico City as a case study, a city of about 22 million people that exhibits a well established UHI, located in the tropics (19N) and in an elevated basin (over 2200 m.a.s.l.) almost completely surrounded by mountains that reach up to 3km above the city level. The city has a very large network of measuring stations, for both meteorology and air quality variables. However, these stations are not uniformly distributed throughout the basin; their location is biased towards the western section of the basin, where the center of the city was located decades ago. Since then, the city has expanded to occupy the whole basin, with virtually none of the original land cover left.

We will show that changes have occurred in the frequency of intense precipitation events within the basin over the last 60 years. Moreover, changes have occurred in the *time of the day* in which the intense precipitation falls. These changes in the timing of intense precipitation (that can lead to major disruption within the city) are very difficult to predict, but climatologically, these changes have already occurred. We explore the possible effects of enhanced ambient CCN and changes in land use and land cover as being responsible for the observed changes in timing, using a regional model (WRF) at high resolution.

The intense precipitation events are associated with convective storms that are often very difficult to forecast, because of their relatively small horizontal scale and duration. Mexico City in particular, being surrounded by high mountains, may be a bit easier to study than other megacities, since the mountains “lock” the local forcing, when the large scale forcing is relatively small.

A shift in timing of the intense precipitation in megacities can lead to sudden flooding of streets when more people might be commuting and would be more exposed. In many cases the flooding of streets occurs mainly due to reduced infiltration, overflowing or even broken pipes and/or clogged sewages. Old infrastructure combined with a much larger population is a common problem in modern megacities. In some cases, landslides in the surrounding mountains are triggered by the intense precipitation, affecting usually vulnerable population occupying known high-risk areas: a disaster that is the result of socio-economic variables well beyond the precipitation events themselves.

Projections of future changes in the frequency and intensity of precipitation at megacity scale (which is smaller than what is traditionally called “regional” scale) is very uncertain, particularly when the large scale forcing is small. Nevertheless, some steps *can* be taken to mitigate the effects of these events. We will discuss some actions that may help ameliorate the effects of the intense precipitation and discuss the feasibility of their implementation. Some of these actions range from emission controls for particulates, to enforcing regulations about no-construction zones, to urban planning for future growth and also to the development of now-casting systems to better forecast these convective storms. Some of them would require the coordination of stakeholders and decision-makers at different levels of government as well as the participation of society.