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

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The WCRP Conference for Latin America and the Caribbean (WCRP-LAC): Developing, linking, and applying climate knowledge
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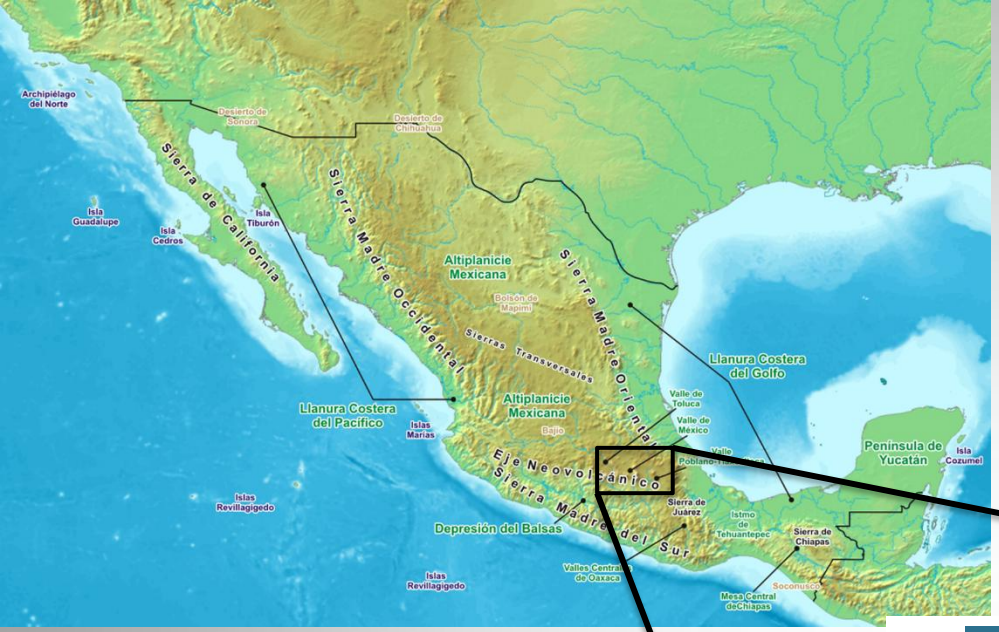
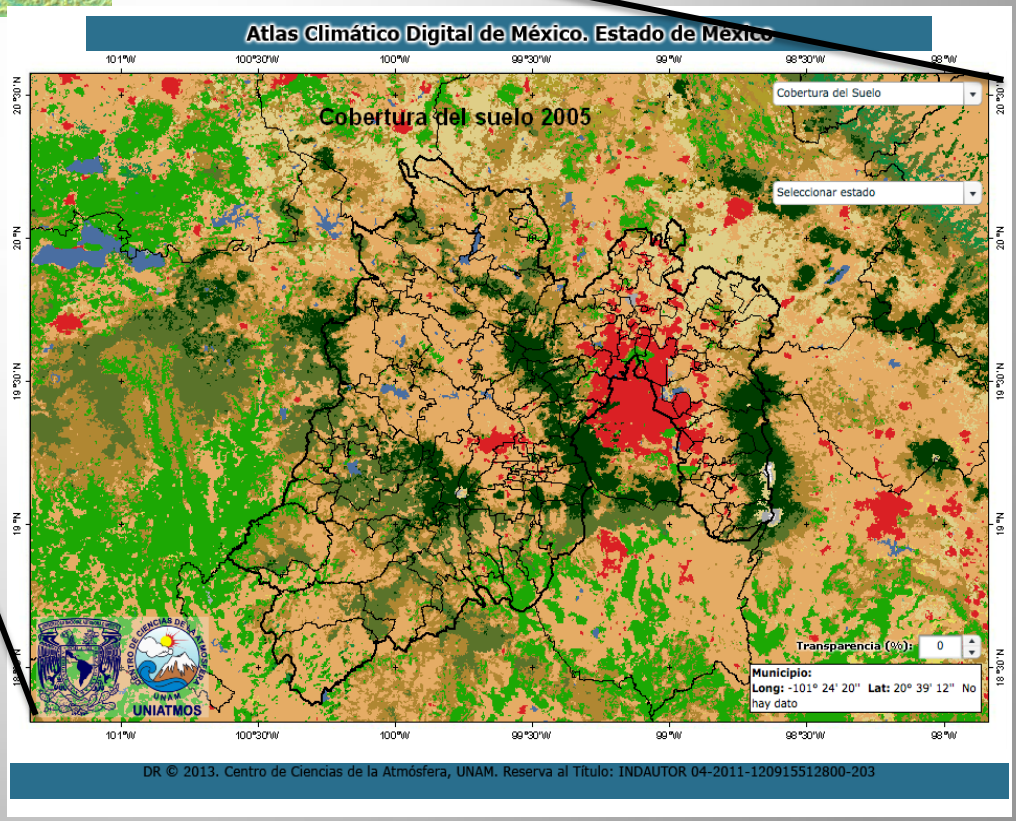
Climate and Weather Natural Variability:

- Centennial and longer : paleo-evidence
- Multi-decadal variability
- Decadal variability: IPO
- Interannual variability: ENSO, AO…
- Annual variability: seasons
- Intra-seasonal variability: e.g.mid-summer drought in Mx

Human activities that may affect ***local climate***:

- Urban Heat Island
- Aerosol pollution (urban, industrial, biomass burning)
- Changes in land use (forests to savanna)
- Changes in agricultural practices (irrigation)





Colors indicate the different types of land cover

Red: Urban area

Dark green: Forests in the mountains that surround Mexico City

Source:
http://uniatmos.atmosfera.unam.mx

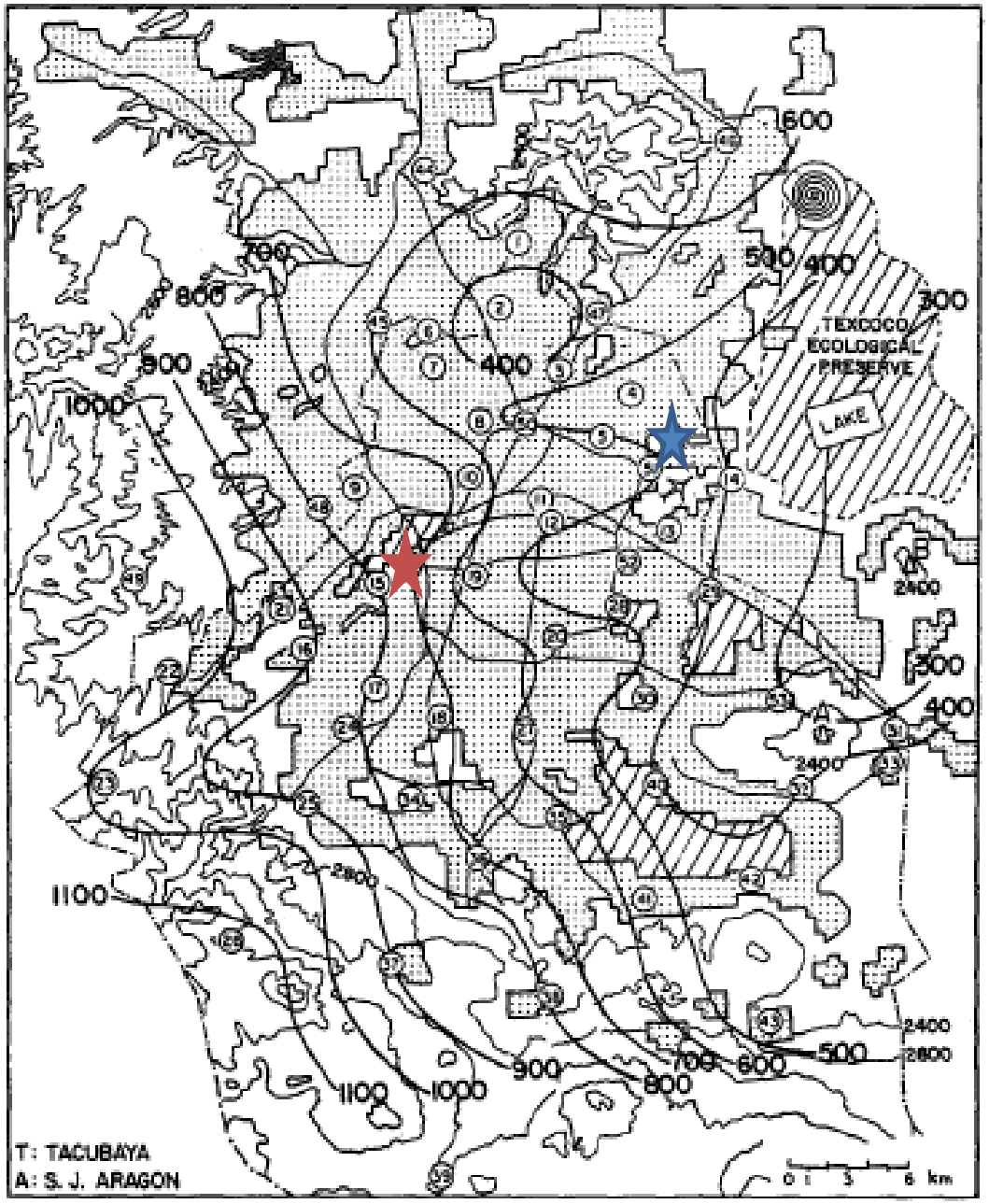


Fig. 1. Location of stations and annual rainfall (mm) for 1992.

Precipitation within Mexico City

(Jauregui y Romales, 1996)

Database:
1941-1985

★ **San Juan Aragon** (NE)

★ **Tacubaya** (W)

(≈12 km apart)

Changes in observed precipitation in Mexico City:

(Jauregui y Romales, 1996)

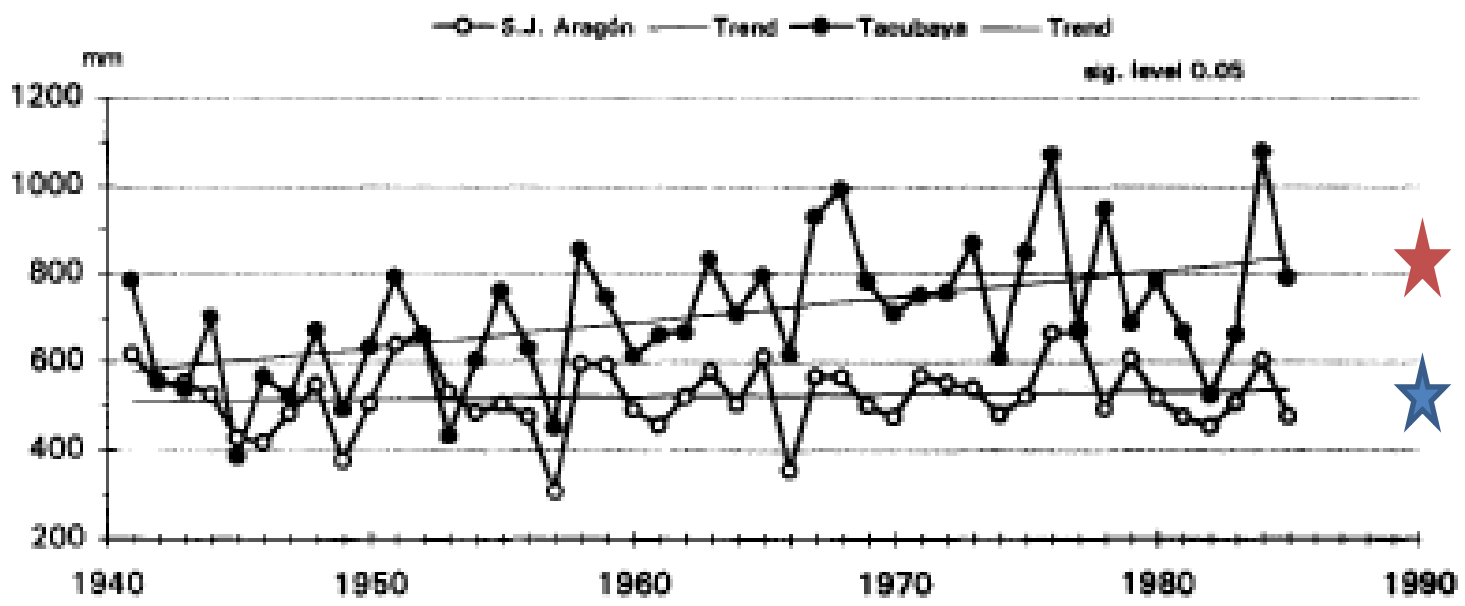


Fig. 2. Wet season (May–October) rainfall trends for Tacubaya and San Juan de Aragón stations. Period 1941–1985.

Increased precipitation (May-Oct) in TAC (West) but NOT in SAG (East)

Changes in observed precipitation in Mexico City: Increased events of intense precipitation (JAS)

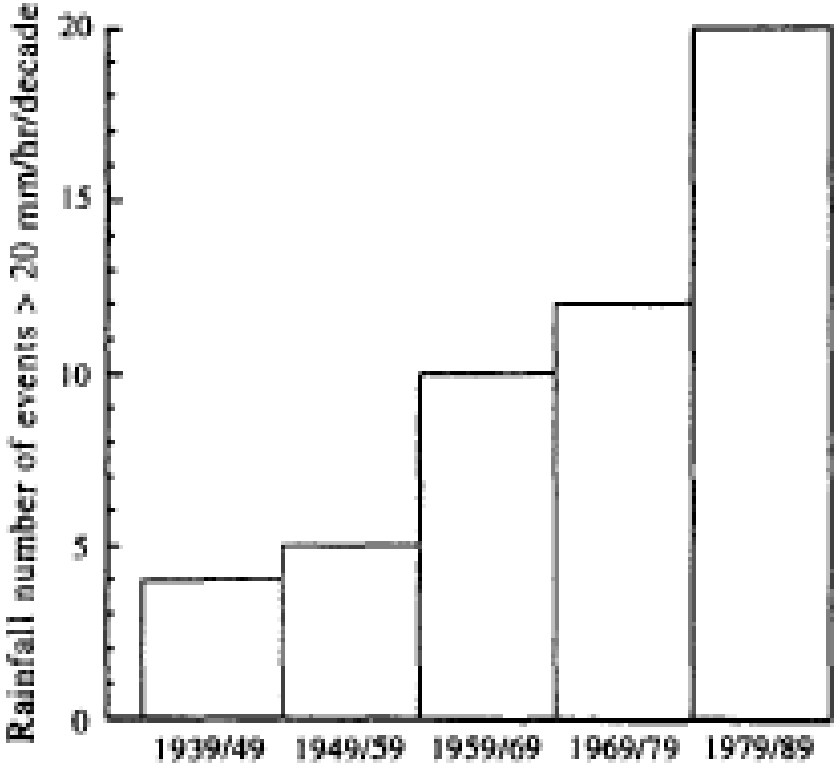


Fig. 3. Frequency of intense rainfall events $> 20\ mm\ h^{-1}$ in Mexico City in July–September 1939–1989.

TACUBAYA (West)

A factor of 5 increase between 1949 and 1989!

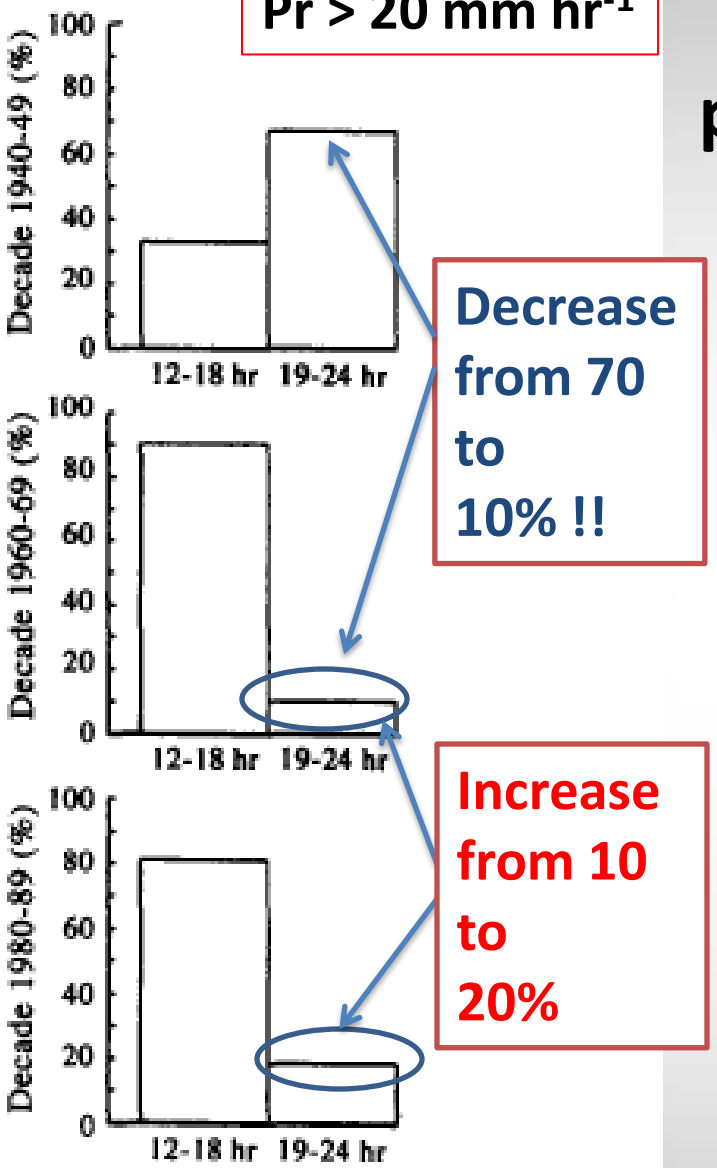
(Jauregui y Romales, 1996)

Changes in observed precipitation in Mexico City:

(Jauregui y Romales, 1996)

TACUBAYA (West)

Pr > 20 mm hr^{-1}



Decrease from 70 to 10% !!

Increase from 10 to 20%

Fig. 4. Frequency of intense rainfall events > 20 mm h^{-1} for three decades by time of day in Mexico City.

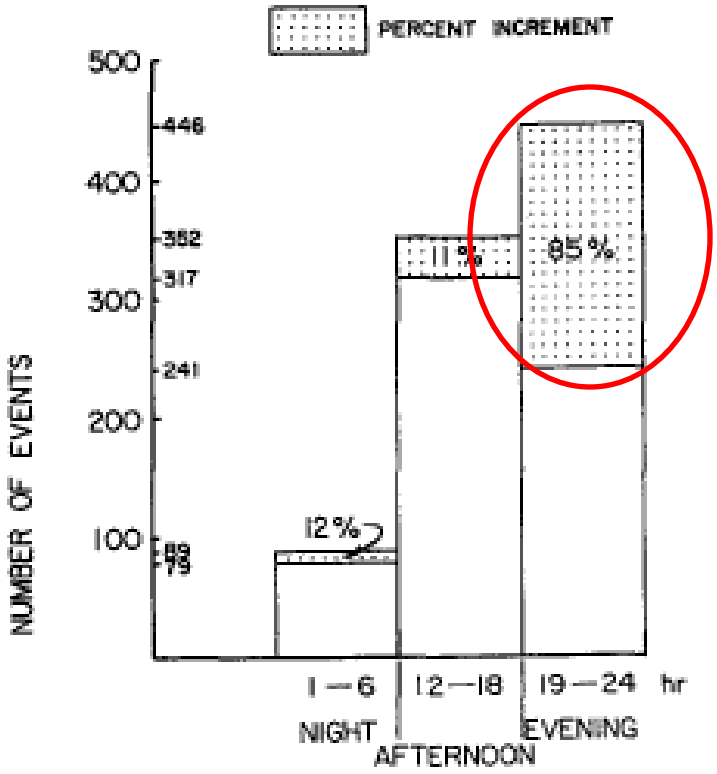


Fig. 5. Frequency of rainfall events (July–September) > 1 mm h^{-1} for two decades 1941–1950 and 1981–1990 for three periods during the day at the Tacubaya Observatory.

Spatial distribution of precipitation in Mexico City: effect of topography

Database: 1993-2000

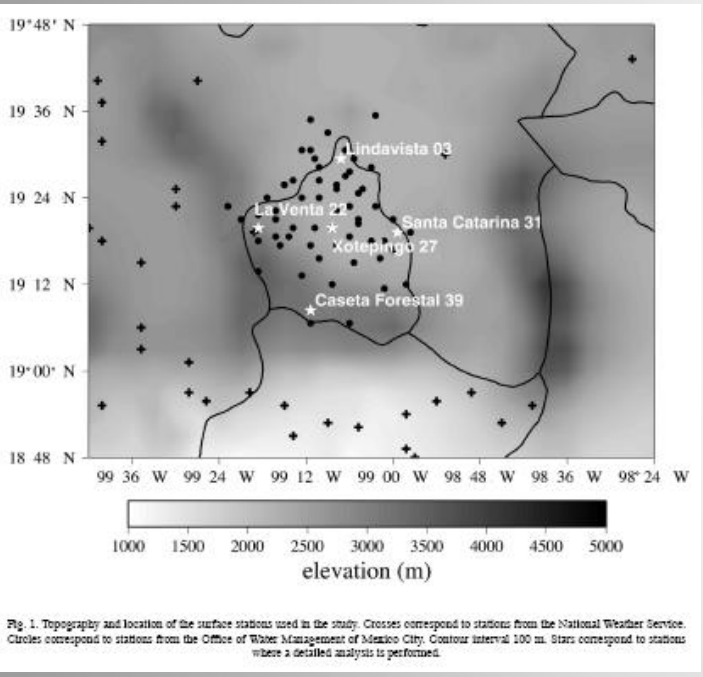
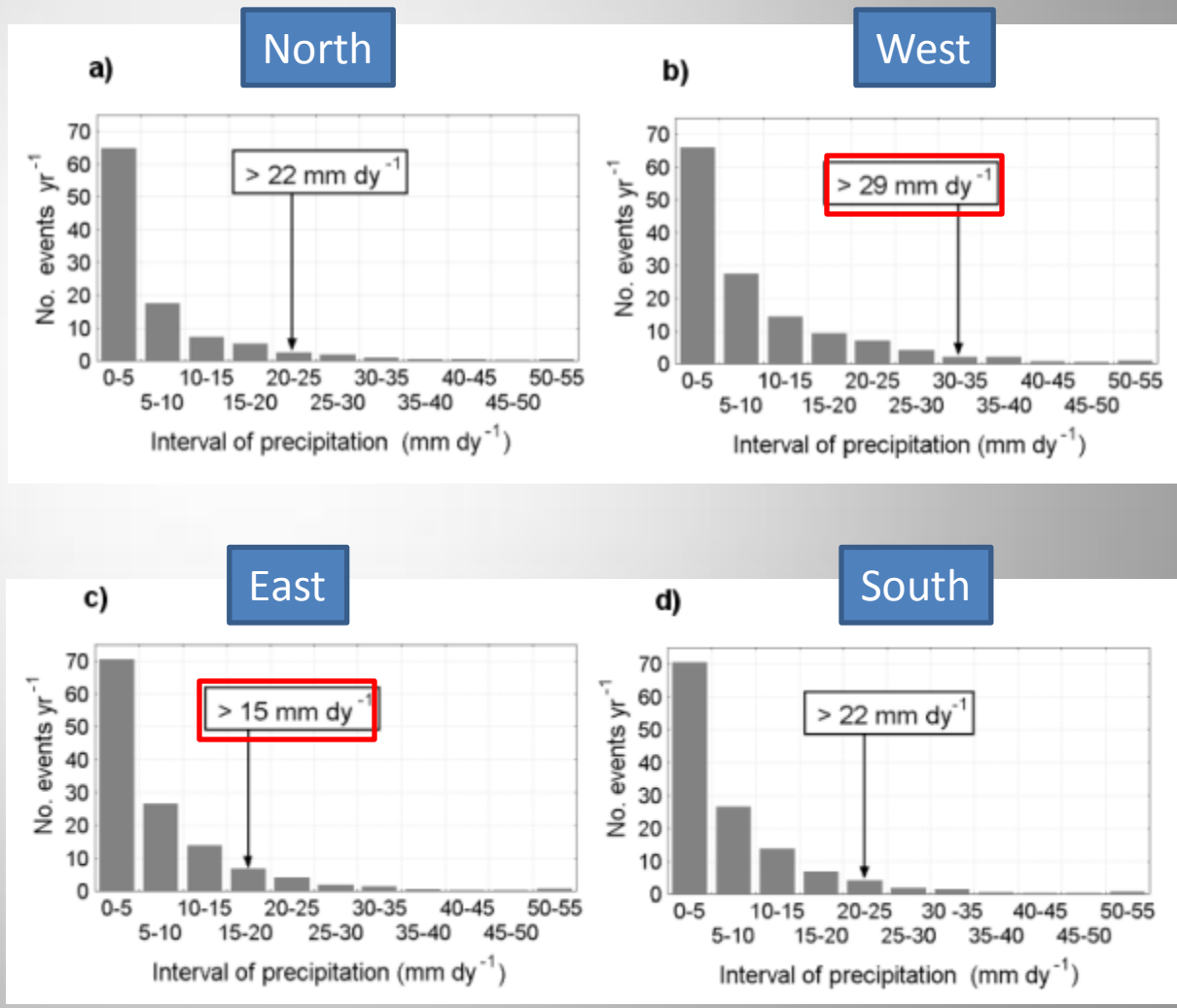


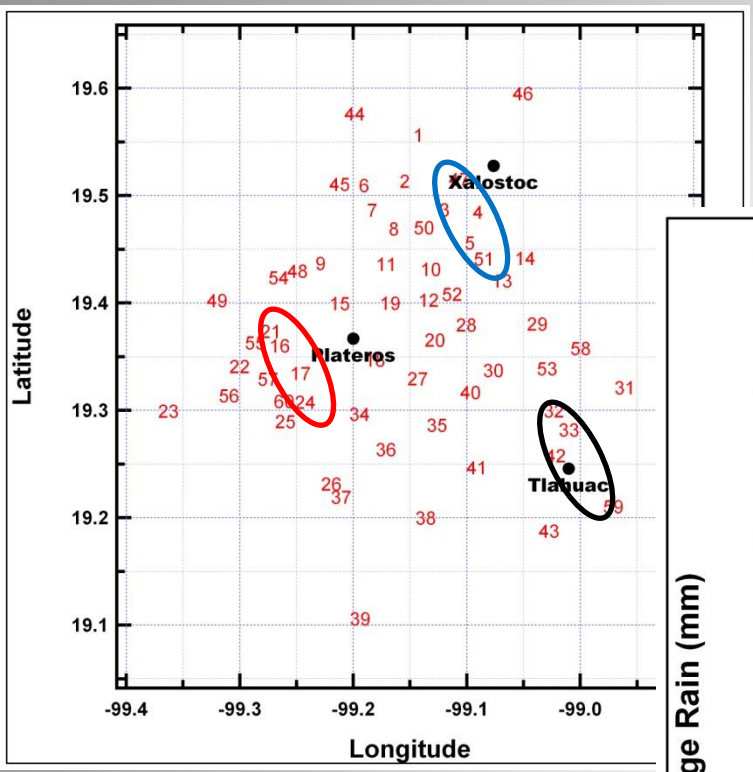
Fig. 1. Topography and location of the surface stations used in the study. Crosses correspond to stations from the National Weather Service. Circles correspond to stations from the Office of Water Management of Mexico City. Contour interval 100 m. Stars correspond to stations where a detailed analysis is performed.

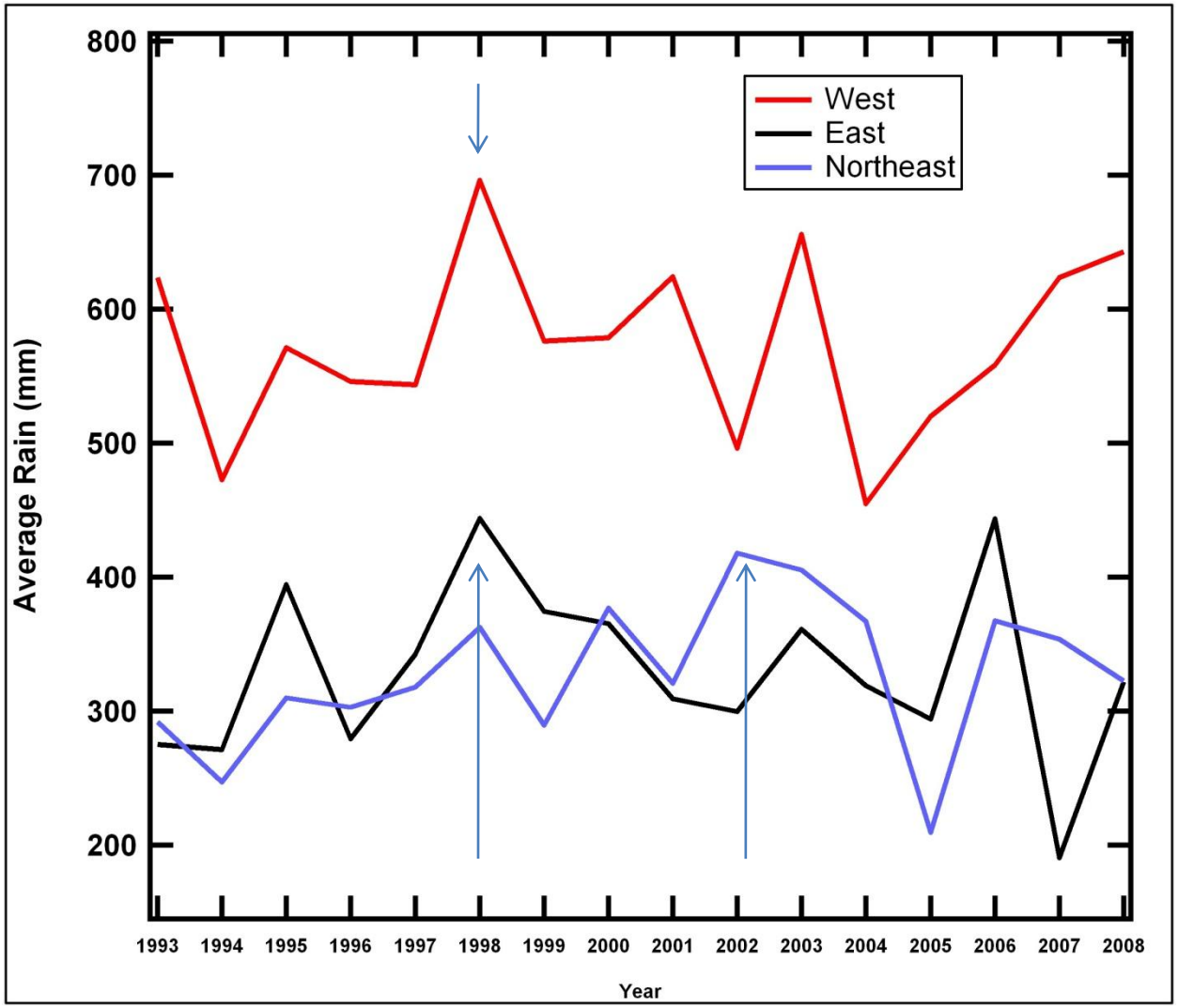
(Magaña et al, 2003)



Spatial distribution of precipitation in Mexico City

Database: 1993-2008 (SACM)

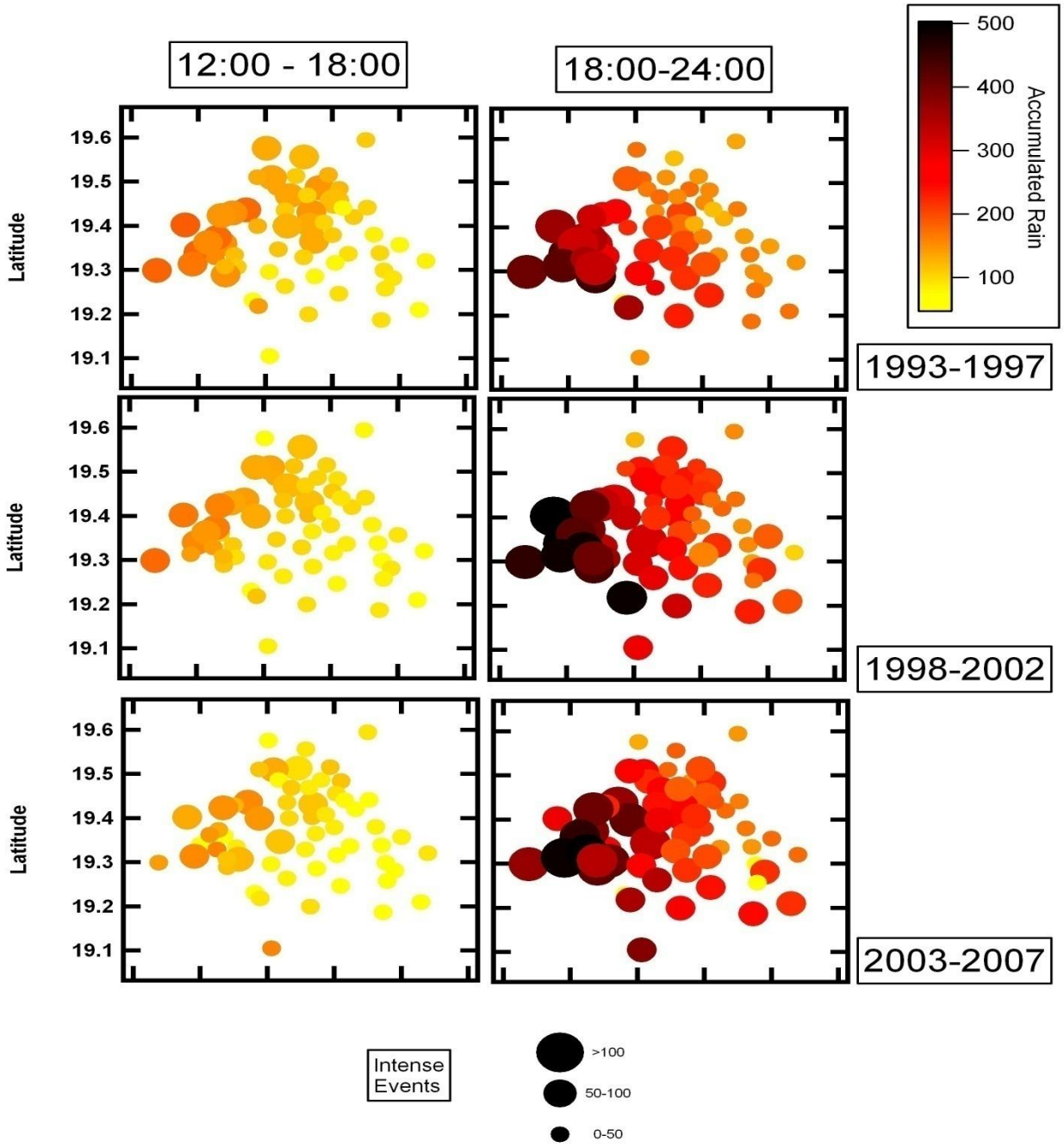




None of the sites have experienced changes in total precipitation amount over the last 15 years.

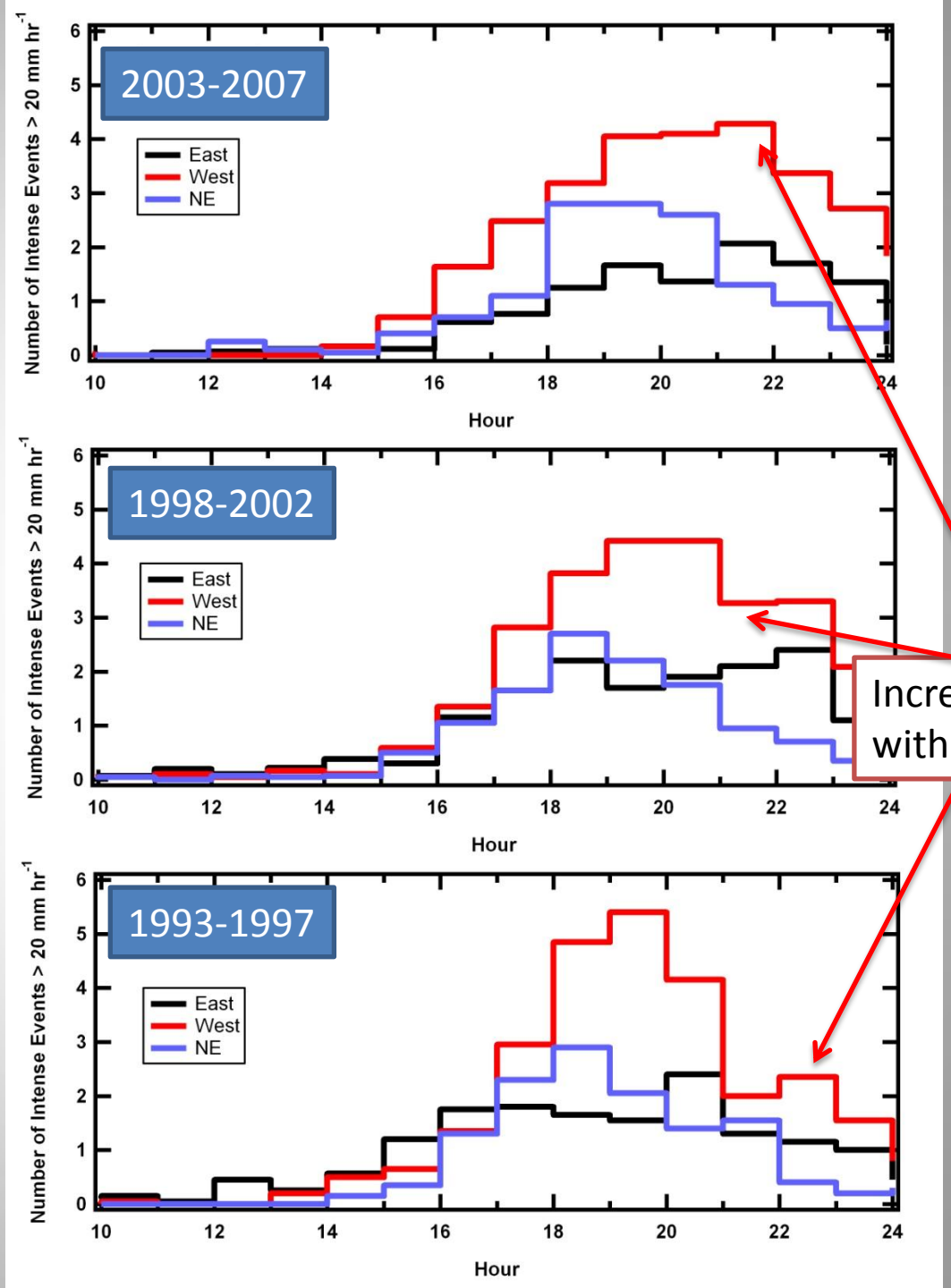
Changes in observed **intense precipitation events** (JAS) (Pr > 20 mm/hr)

Colors indicate the amount of precipitation associated with those events



Changes in the daily distribution of the number of intense precipitation events (JAS)

(Pr > 20 mm/hr)

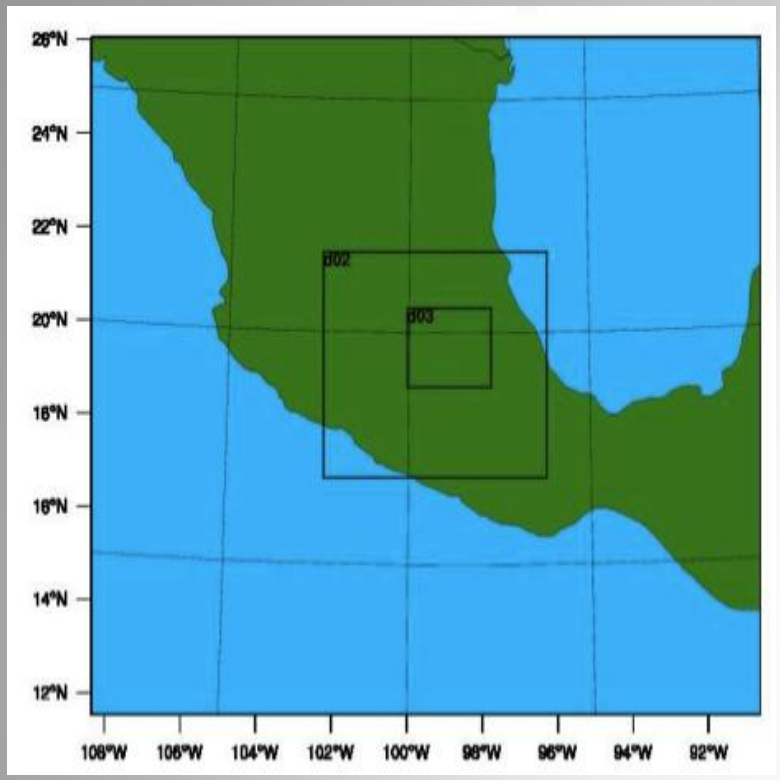


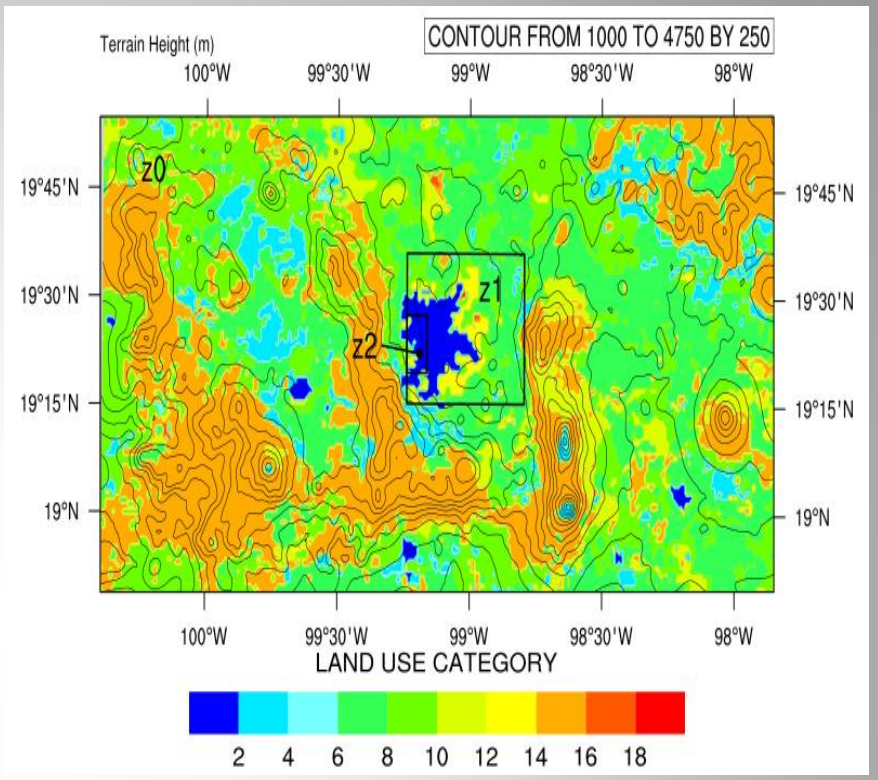
Influence of human activities on local climate

¿What can cause the observed changes in timing of intense events in Mexico City?

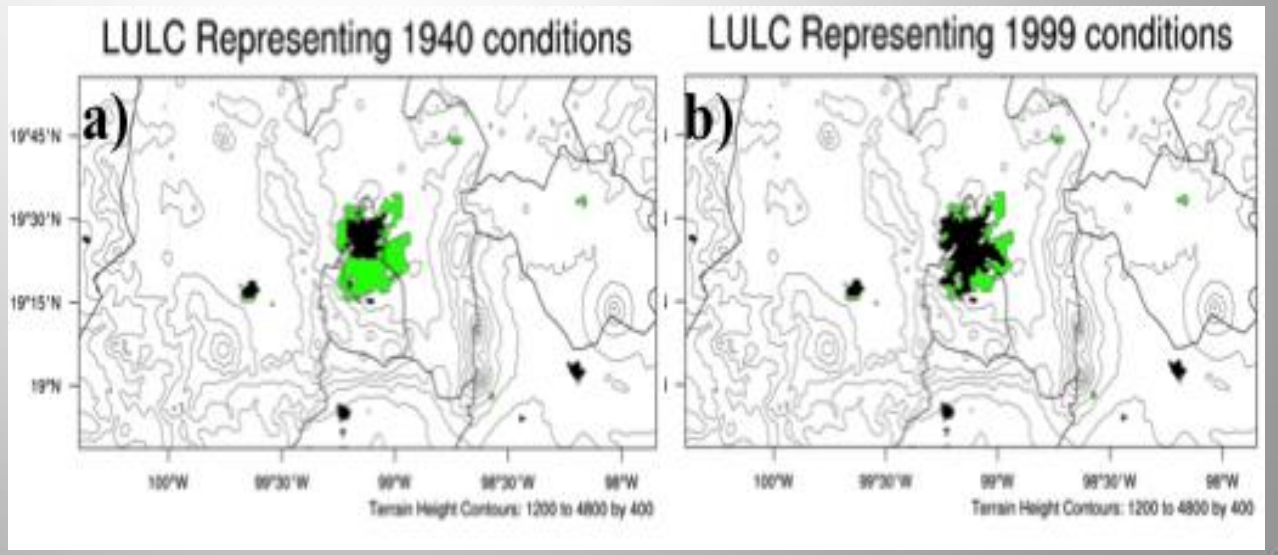
- Changes in surface roughness and low level convergence.
- Changes in the surface layer/boundary layer structure due to localized heating by buildings.
- Changes in land use, as urban regions expand into surrounding rural land.
- Changes in humidity due to loss of natural vegetation.
- Changes in ambient concentrations of CCN e IN due to urban emission sources (Rosenfeld et al. 2008).

WRF simulations: Domains with 9, 3 and 1km horizontal resolution





a) Modified urbanized area simulating the 1490s in Mexico City.
b) Urbanized area from the default USGS 1999 in WRF.



Results of numerical simulations

(10-year ensemble for Sept)

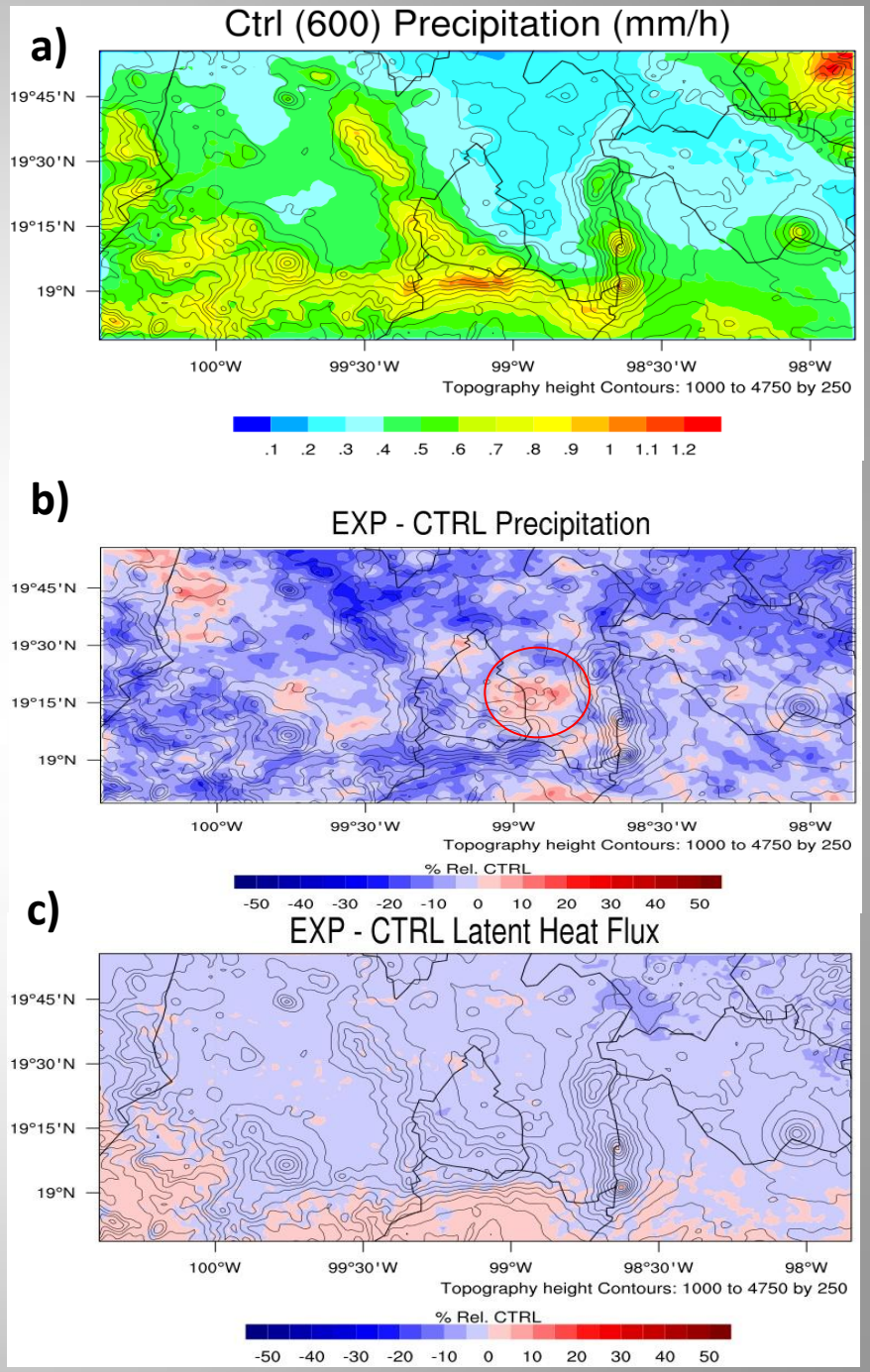
Ctrl: Clean and large urban area

Exp: Polluted and large urban area

a) **Precipitation in CTRL simulation (large E-W gradient)**

b) **Precipitation anomaly (EXP-CTRL), in percentage (dry anomaly in the E of basin)**

c) **Latent heat flux percentage anomaly (EXP-CTRL) (generalized reduced LHF in most of domain)**

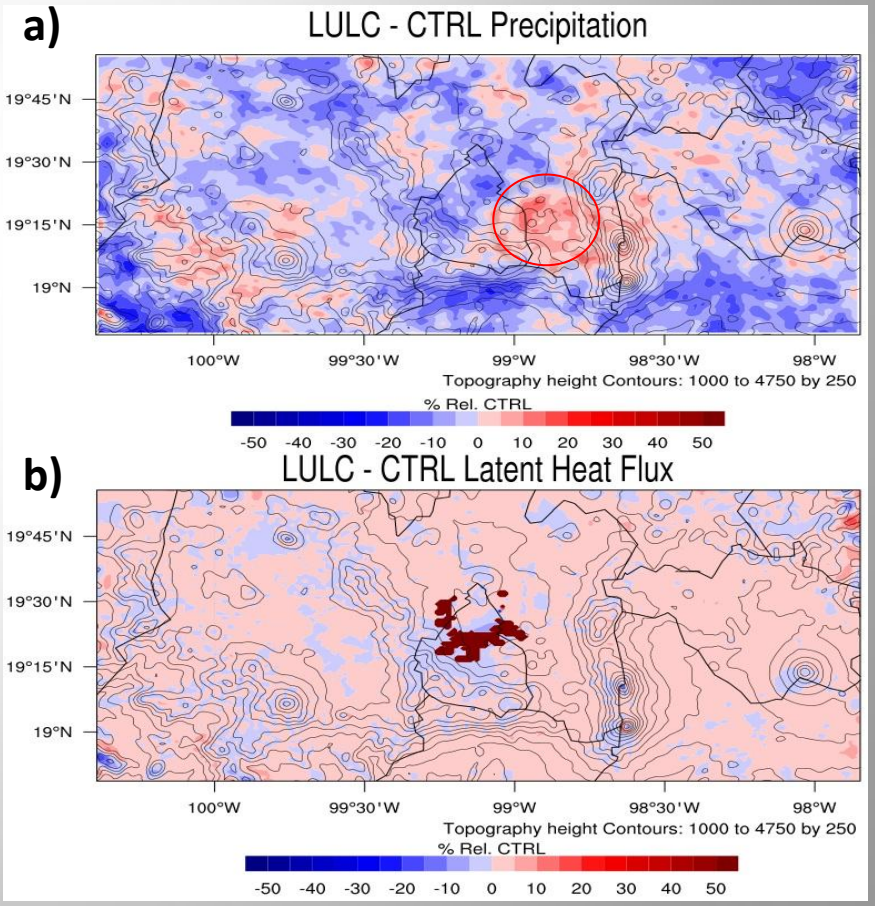


Results of numerical simulations
(10-year ensemble for Sept)

Ctrl: Clean and large urban area
LULC: Clean and small urban area

a) **Precipitation percentage anomaly (LULC-CTRL) (larger dry anomaly in the E of basin)**

a) **Latent heat flux percentage anomaly (LULC-CTRL) (generalized increased LHF in most of domain)**



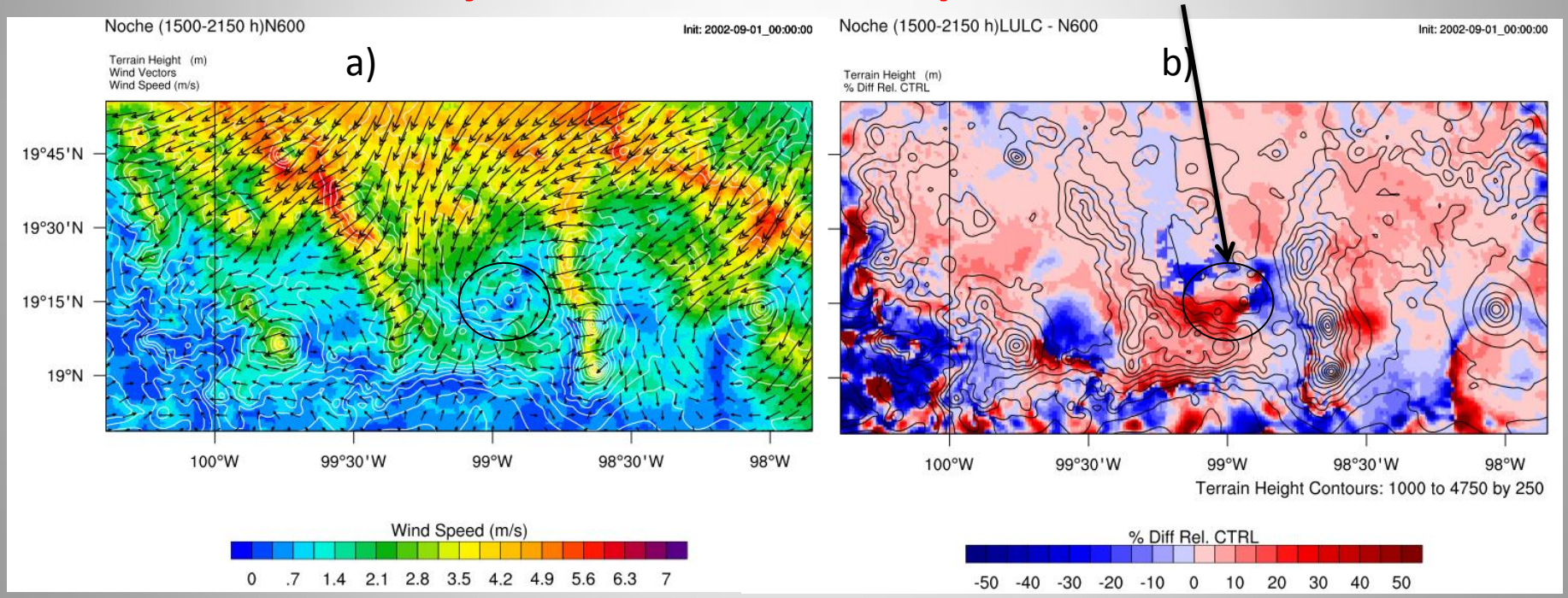
Results of numerical simulations

(10-year ensemble for Sept)

Ctrl: Clean and large urban area

LULC: Clean and small urban area

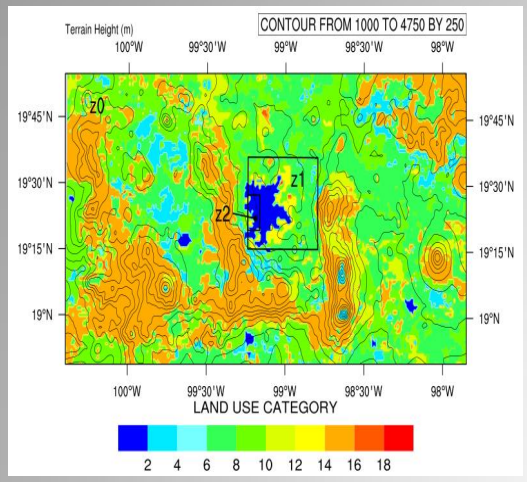
More intense cyclonic vortex develops in the E of the basin!



a) Surface wind fields at 10m for CTRL experiment.

b) Wind speed percentage differences between LULC-CTRL.

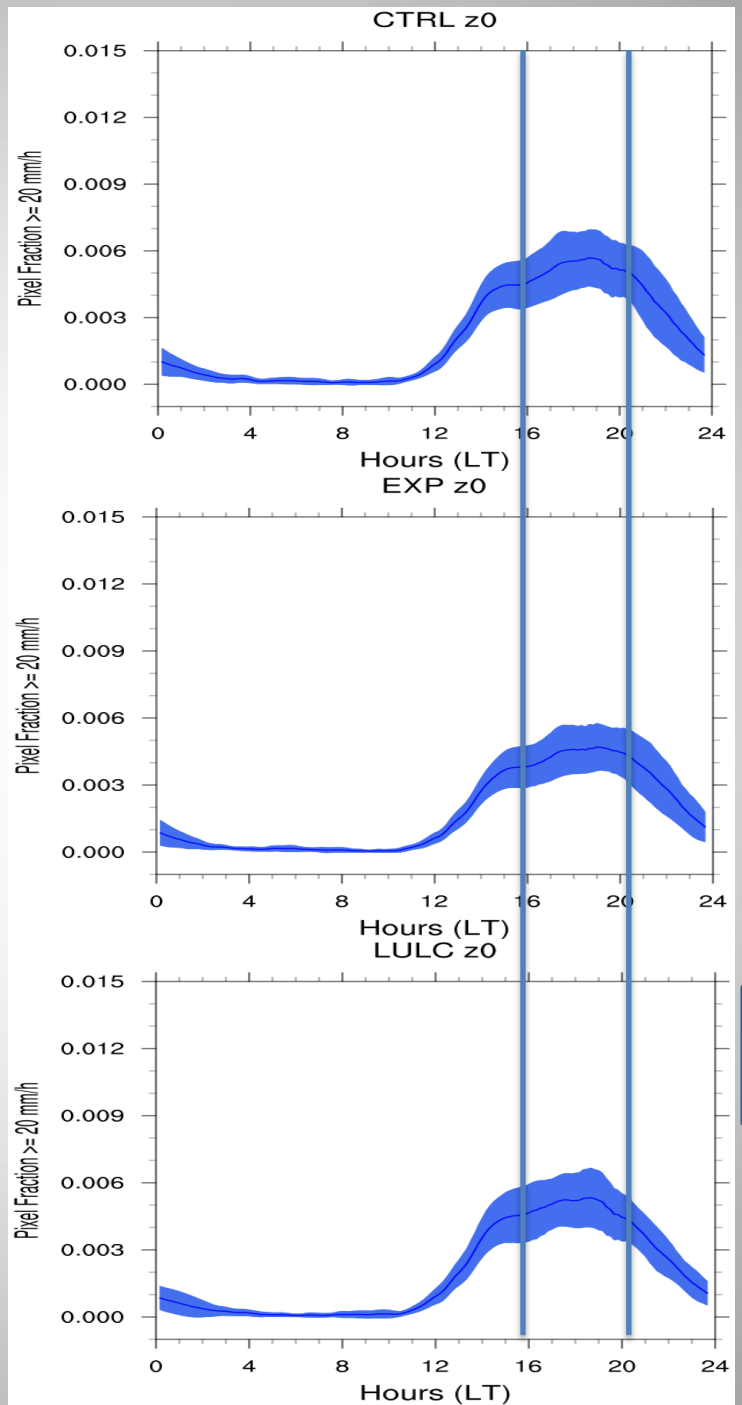
10- year ensemble



z0: Innermost simulation domain

Diurnal evolution of the ensemble average fraction of intense precipitation events (10-min resolution), showing the *ensemble average*, for the CTRL, EXP and LULC simulations.

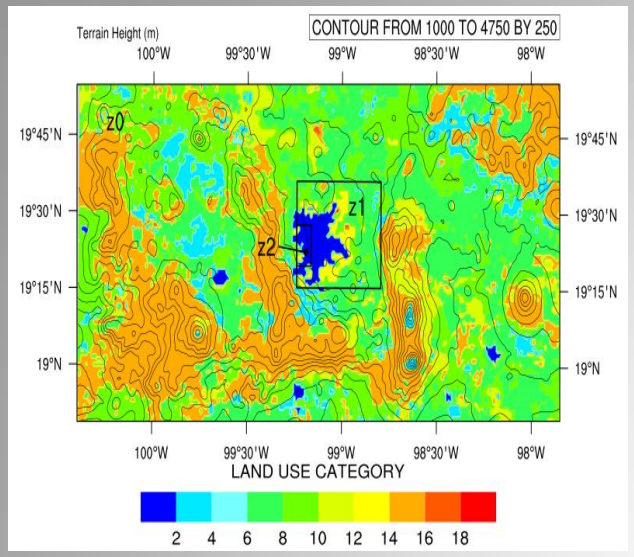
The shading indicates the variability between individual members of the ensemble.



Clean & large urban region

Polluted & large urban region

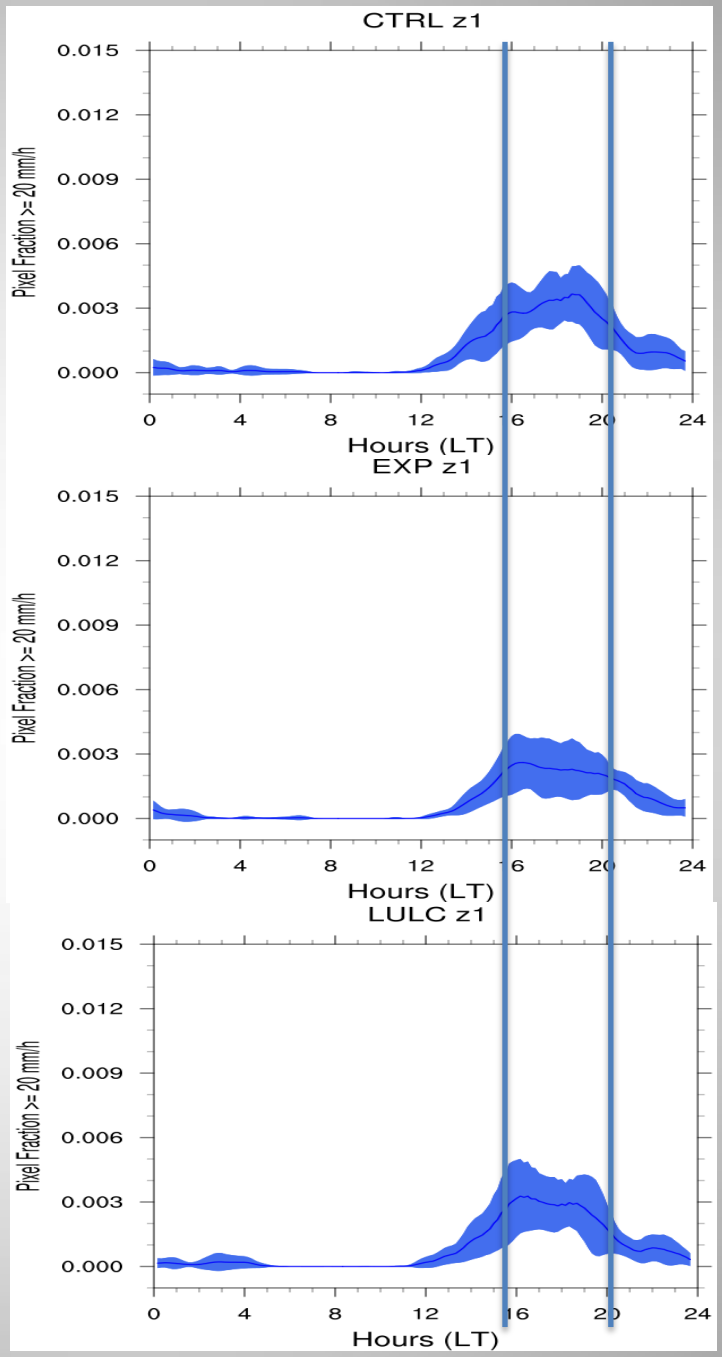
Clean & small urban region



z1: Mexico City basin

Diurnal evolution of the ensemble average fraction of intense precipitation events (10-min resolution), showing the *ensemble average*, for the CTRL, EXP and LULC simulations.

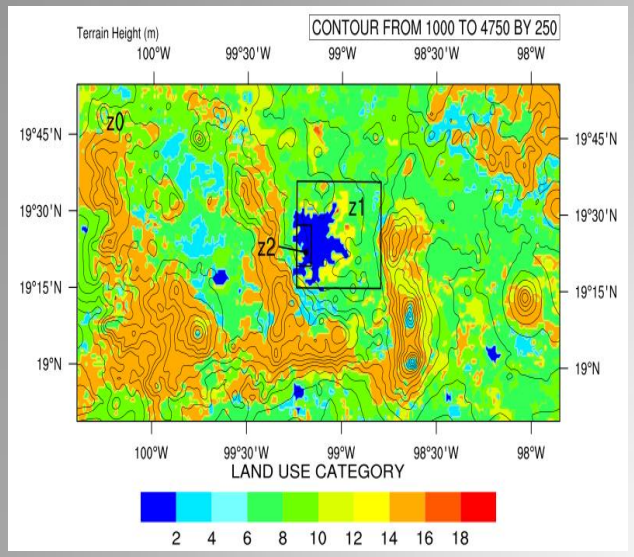
The shading indicates the variability between individual members.



Clean & large urban region

Polluted & large urban region

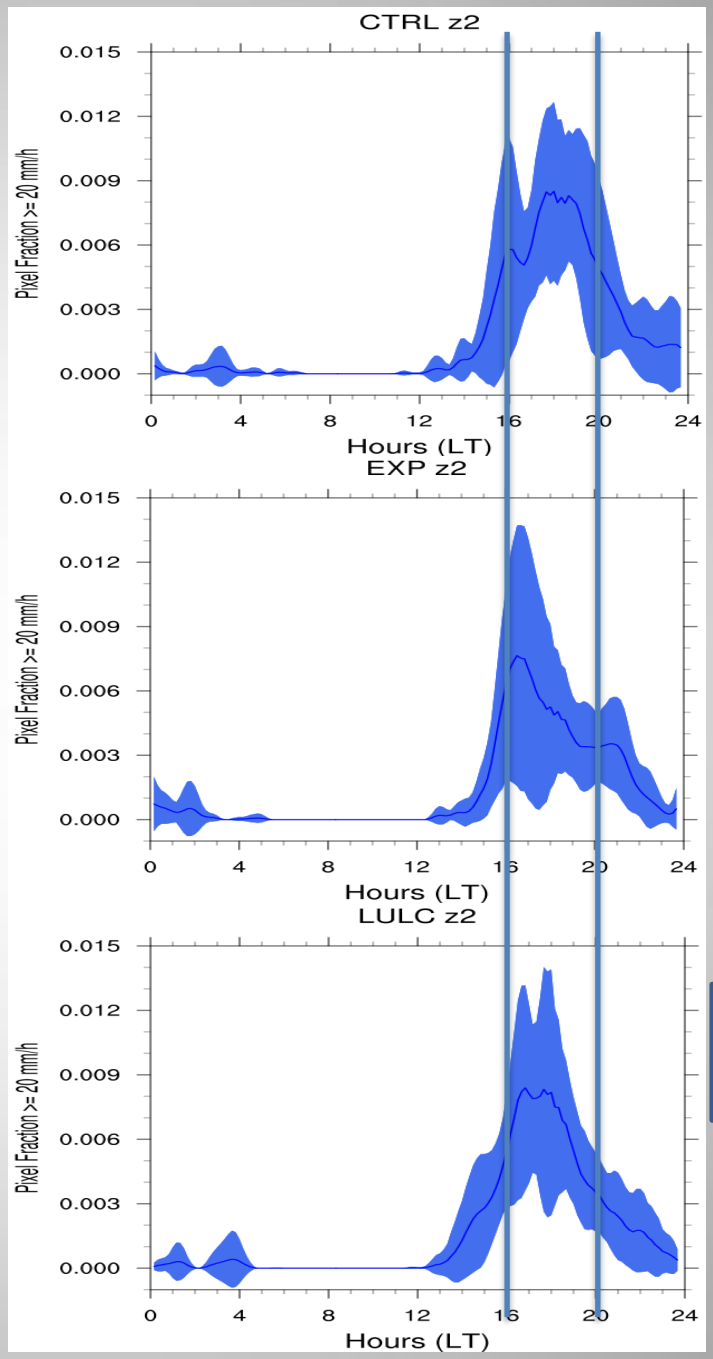
Clean & small urban region



z2: western sector of MC basin

Diurnal evolution of the ensemble average fraction of intense precipitation events (10-min resolution), showing the *ensemble average*, for the CTRL, EXP and LULC simulations.

The shading indicates the variability between individual members.



Clean & large urban region

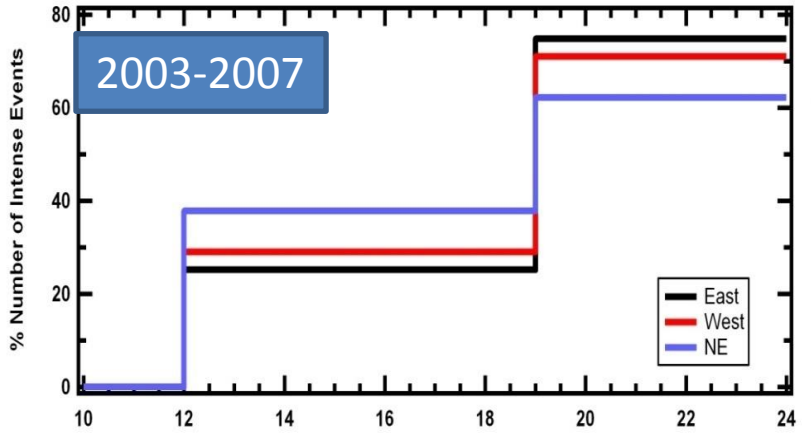
Polluted & large urban region

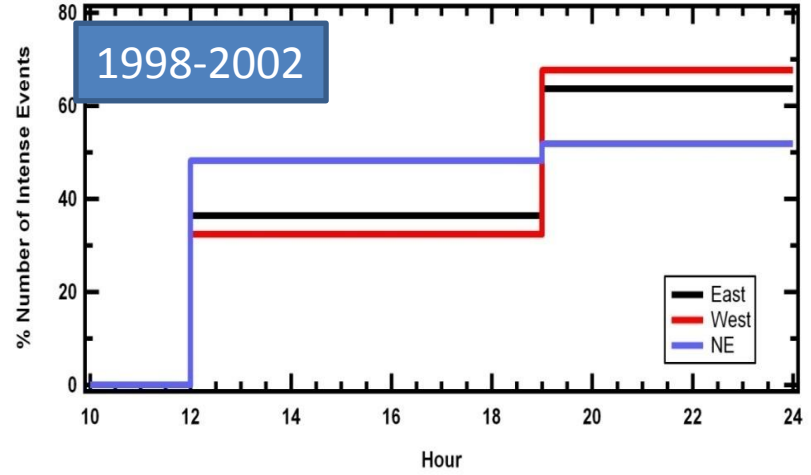
Clean & small urban region

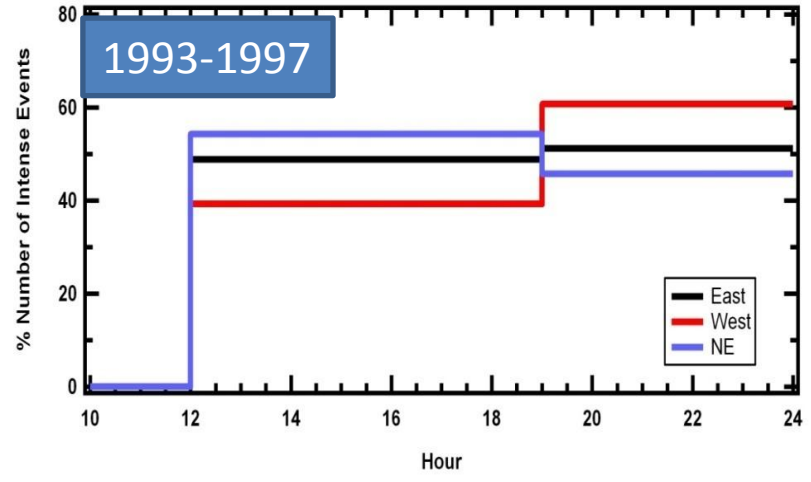
Changes in the observed timing of the number of intense precipitation events (Pr > 20 mm/hr)

7pm to midnight:

- NE from 40 to 60%
- W from 60 to 90%
- E from 50 to 90%







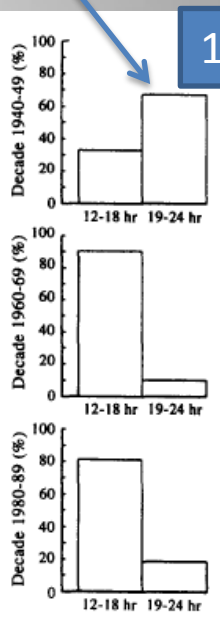


Fig. 4. Frequency of intense rainfall events $> 20\ mm\ h^{-1}$ for three decades by time of day in Mexico City.

(Jauregui y Romales, 1996)

Conclusions

- Observations indicate that changes in the hourly distribution of intense precipitation events (Pr > 20 mm/hr) have continued in the basin where Mexico City is located (1993-2008), as originally shown by Jauregui and Romales (1996).
- The majority of the intense events have shifted and are now observed between 19 a 24hr. The timing of intense events is going back to the conditions observed in the 40s.
- No trends in total precipitation have been observed within the basin in the last 15 years.

Conclusions (cont.)

- **All simulations reproduce the large gradient in precipitation observed in the basin.**
- **Numerical simulations introducing LULC changes consistent with *smaller urban area*, result in the frequency of intense events *earlier* than in the CTRL simulation by about 3 hours.**
- **Numerical simulations introducing LULC produced a very complex response in atmospheric circulation, generating an accelerated low level cyclonic vortex in the eastern region of the basin.**

Conclusions (cont.)

- **Simulations representing a more polluted atmosphere result in suppression of monthly mean precipitation rates over most of the computational domain (as in Rosenfeld et al, 2008), having the potential to shift the precipitation towards *earlier in the day*.**
- **In summary, simulations suggest that *cleaner air and larger urban area* shift intense precipitation events *towards later in the day*, consistent with observations.**

Conclusions (cont.)

- Finally, it´s worth mentioning that aerosol pollution has decreased in MC from a peak in the 80s. Results from simulations with lower droplet concentrations are consistent with the observed trends in the timing of intense events in the recent decades.

What does it mean for LAC megacities in the future, particularly in the tropics?

- ***Old infrastructure*** combined with a ***much larger population*** and ***unplanned growth*** are all common problems in modern megacities.
- ***A shift in the timing*** of the intense precipitation in megacities can lead to ***sudden flooding*** of streets when more people are commuting and ***exposed***. There is a ***need*** to study those intense events before further expansion, requiring ***networks of raingauges*** (could be added to existing air pollution networks)
- ***Projections*** of future changes in ***the frequency and intensity of precipitation*** at megacity scale are very uncertain.

What does it mean for LAC megacities in the future, particularly in the tropics?

- ***Unplanned urban growth***: Many cities actually have growth plans and no-construction zones in areas at risk of landslides, but they are ***not enforced.***
- ***Rainwater recovery***: Replace streets (tar/cement) with permeable materials and build separate sewage system for rainwater to be recycled
- ***Nowcasting systems***: Need for met. services to start developing systems to forecast heavy precipitation (and other severe weather phenomena).

What does it mean for LAC megacities in the future, particularly in the tropics?

- ***Reduction in emissions***: Precursor gases and primary particles intervene in precipitation development and may change timing of intense events.
- ***Land cover changes***: Increased urbanization may lead to changes in timing of intense events, so urban growth planning should consider this issue.
- ***Education***: Many cities have gutters clogged by trash that prevent water from flowing into sewers and lead to street flooding. Promote the usage of forecasts/nowcasts, many cities do not have trustworthy agencies that produce them.

Thank you!