Impact of future climate and land use changes on air quality in and around Mexico City

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Introduction

Global climate change and air quality

Global climate change results in regional effects on

- cloud cover, visible and UV radiation
- temperature, thermal stratification, wind fields
- frequency and intensity of precipitation

➡ **Impact of changed climate on air quality**

For impact assessments it must be considered that

- ➢ so far, most long-term global climate simulations do not include air quality information
- ➢ **data have to be provided on a regional or local scale**

Introduction

Downscaling of global climate change

Depending on the question, different methodologies can be used for obtaining the regional information

Options:

- Direct use of global model output / Change factors
- Downscaling
  - Statistical downscaling
  - Dynamical downscaling (regional model)

Introduction

Downscaling for air quality applications

Facts to be considered with respect to air quality

- Nonlinear behaviour of tropospheric chemistry
- Full 3-d meteorological information required

→ Climate effect on regional air quality can only be investigated by **dynamical downscaling** of global climate scenarios with **regional climate models**

- High numerical effort

Introduction

Reliability of simulation results

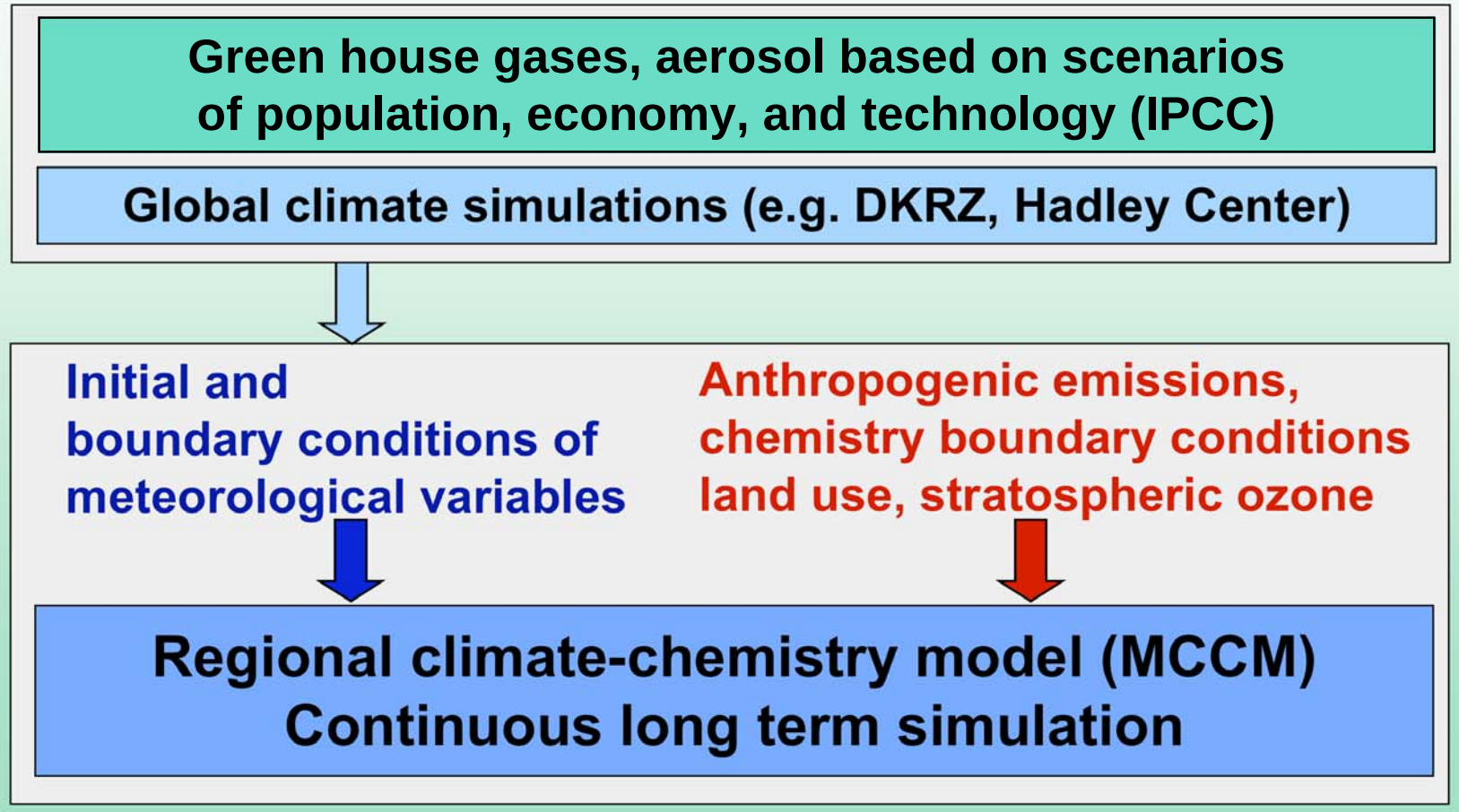
Possible reasons for uncertainties

1. Different possible emission scenarios
2. Further unknown external forcing (anthropogenic or natural)
3. Shortcomings of global climate models
4. Shortcomings of regional climate models
5. Unpredictable internal variations of the climate system
6. Shortcomings of anthropogenic emission inventory

Most uncertainties are independent of the applied downscaling approach

Method

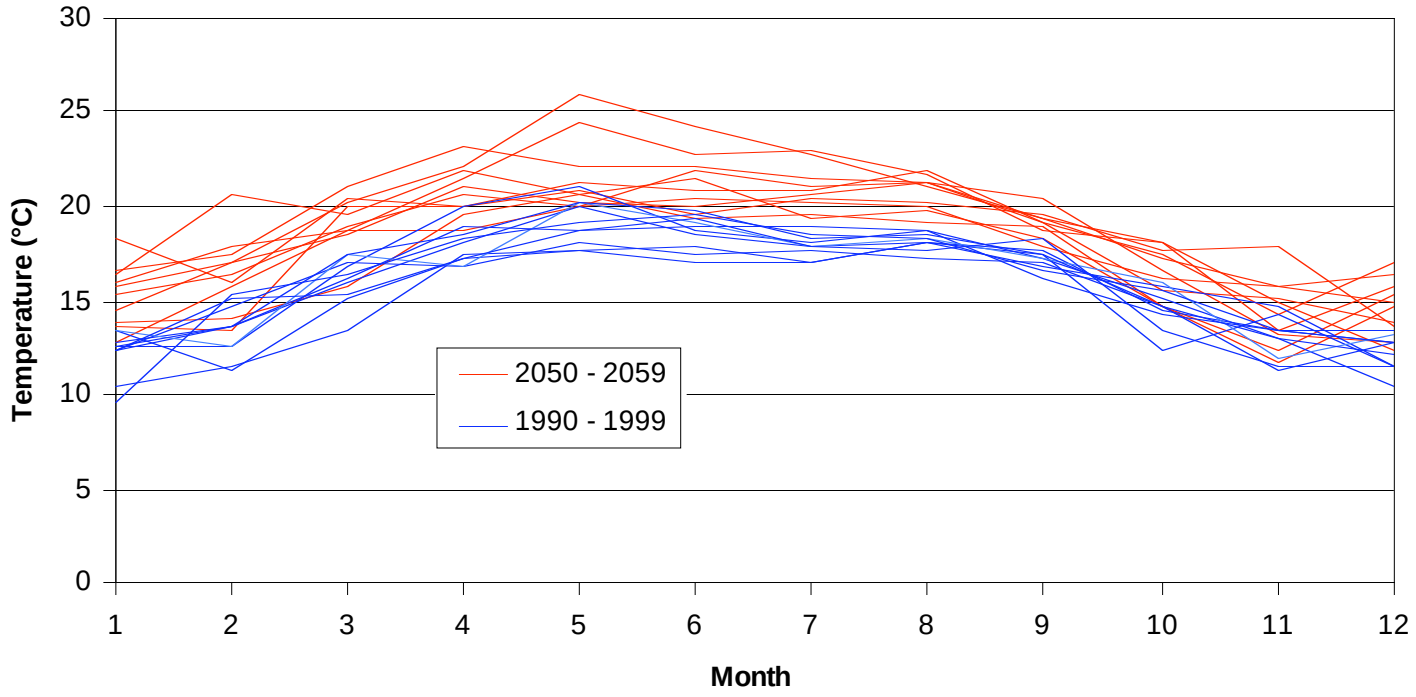
Setup of regional climate-chemistry simulations



Method

Requirement of simulations over many years

Variability of near-surface temperature from ECHAM5 (T63) around Mexico City



Method

MCCM (Mesoscale Climate Chemistry Model)

Meteorological part

- Based on MM5
- Non-hydrostatic
- Nesting capability
- Soil and snow model

Online chemistry part

- RADM2, RACM, RACM-MIM
- Photolysis model
- Aerosol module MADE/SORGAM
- Biogenic emission module

Input Any met. input suitable for MM5, initial concentrations of chemical compounds and hourly anthropogenic emissions in MM5-format

Output 3-d meteorological fields, snow height, photolysis frequencies, concentrations of chemical compounds in the gas and particle phase, …

Applications
Episodes and sensitivity studies
Real time air quality simulations
Regional climate chemistry simulations

Grell et al. 2000, Atmospheric Environment

Application for Europe

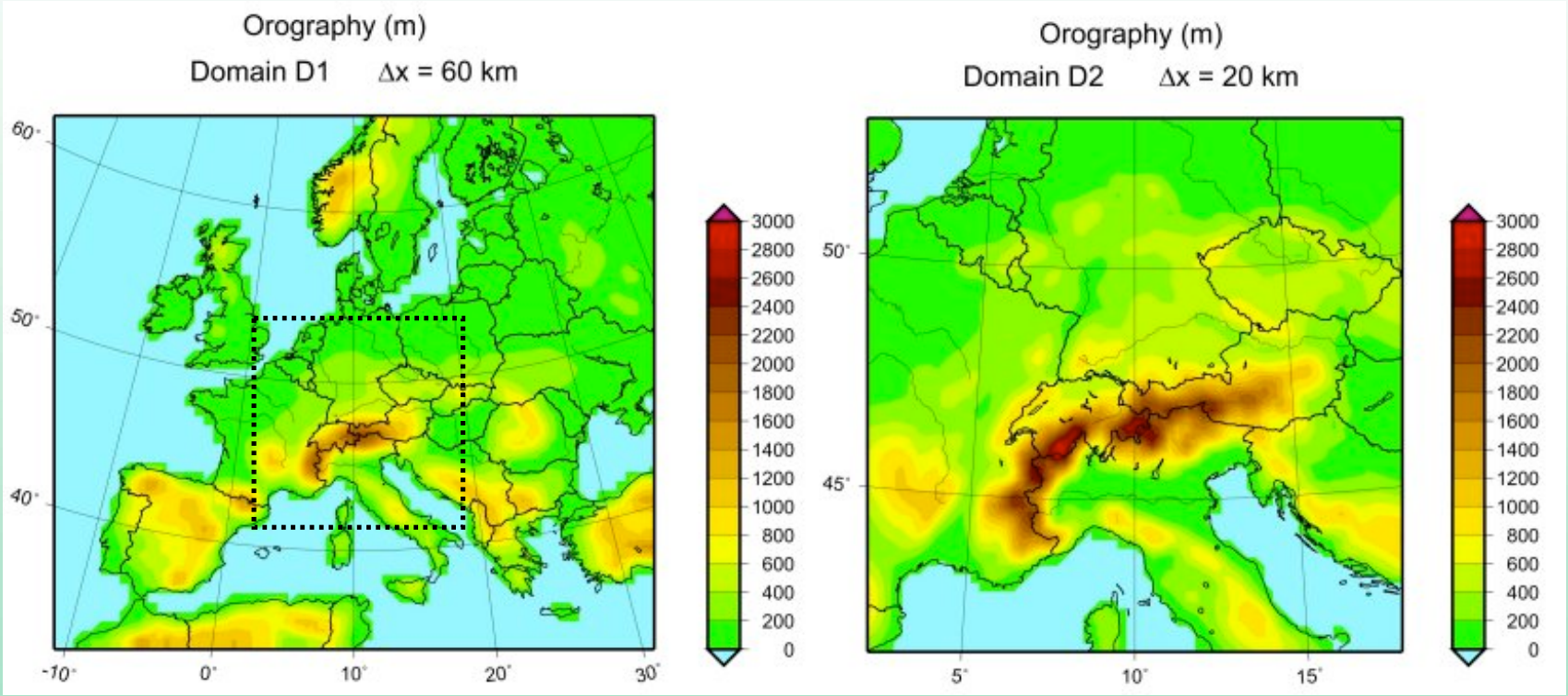
General setup

- Continuous regional simulations with MCCM for two time slices:
  - 1991 - 2000 ´Present´
  - 2031 - 2039 ´Future´
- Met. boundary conditions from transient ECHAM4 (T42) simulation, scenario IS92a (data source: DKRZ)
- Unchanged anthropogenic emissions
- Two nested model domains:
  - Domain D1 (Europe): 60 km resolution
  - Domain D2 (Alps, Germany): 20 km resolution

Forkel und Knoche 2006, J. Geophys. Res., 111, doi:10.1029/2005JD006748

Application for Europe

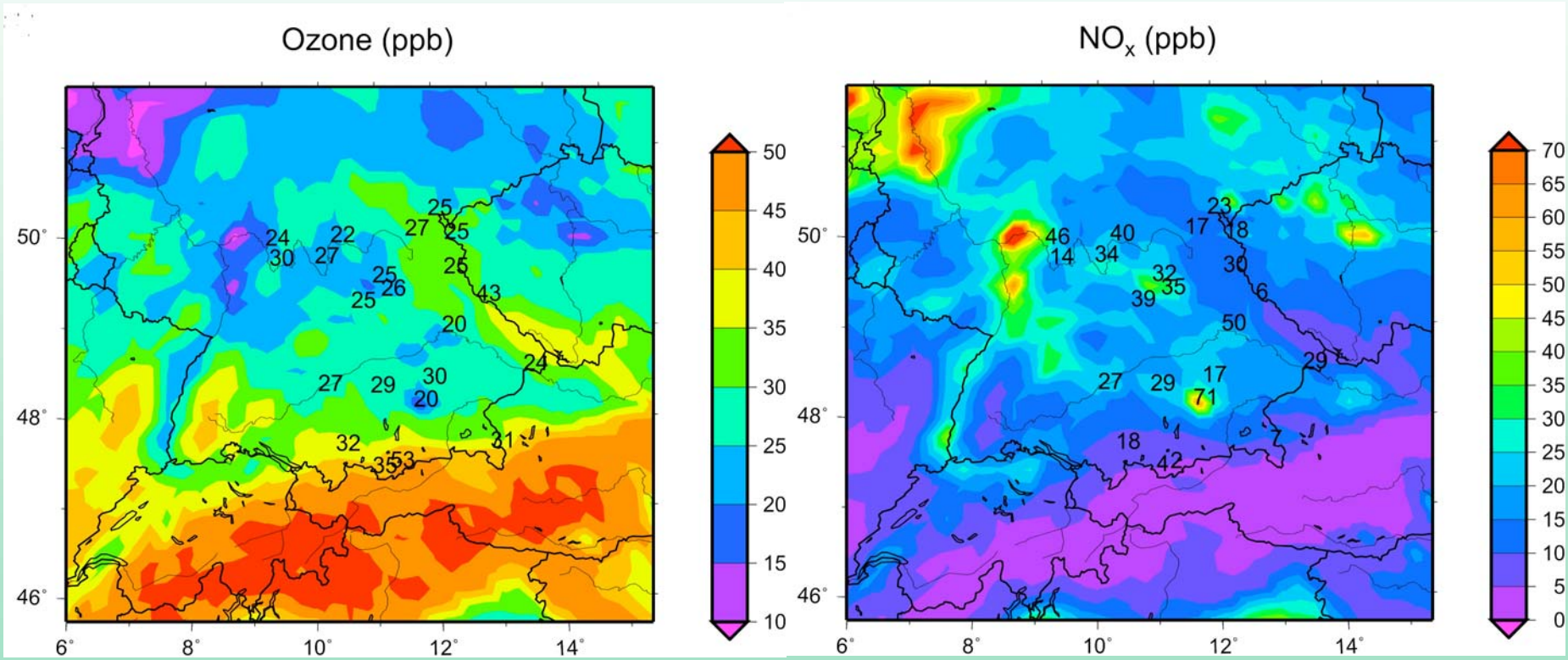
Setup: Model domains



Application for Europe

Validation for 20 km resolution

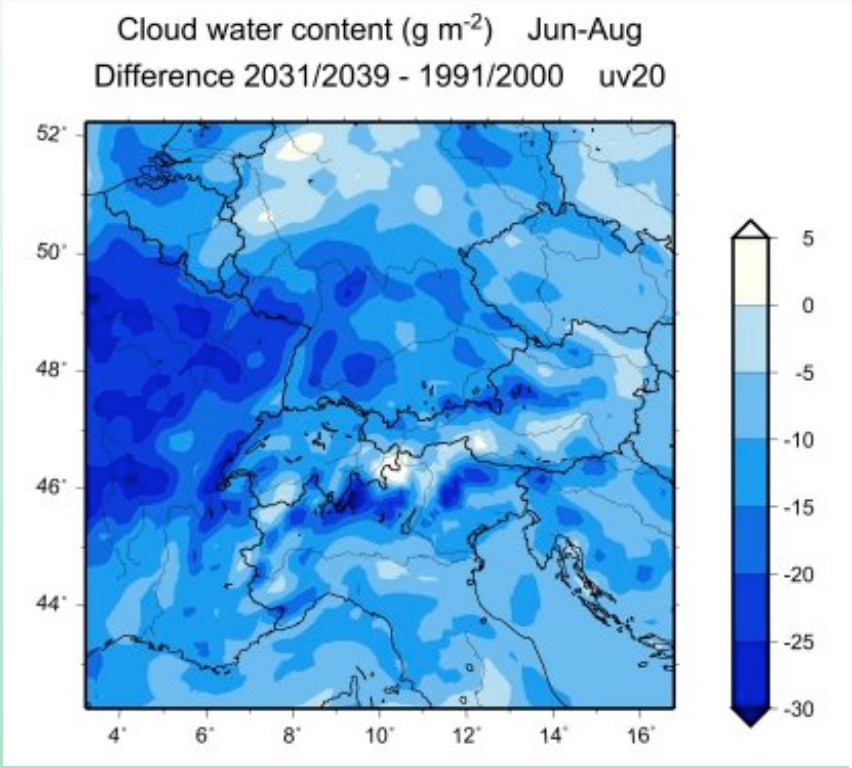
Mean values for the months June-August 1996-2000



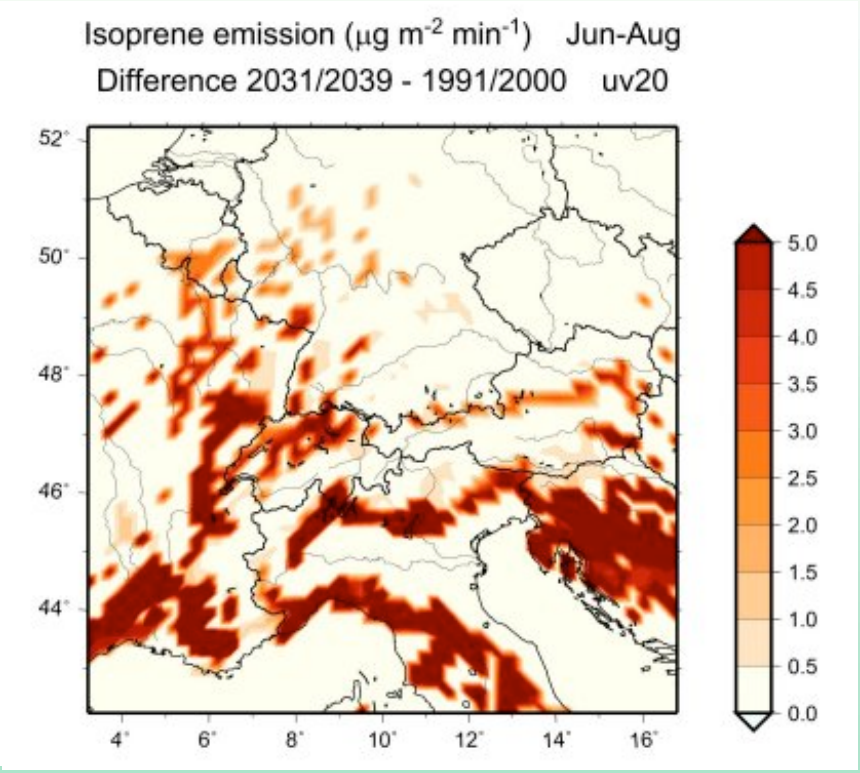
Observations: Bayerisches Landesamt für Umweltschutz

Application for Europe

Change in cloud water and isoprene emissions



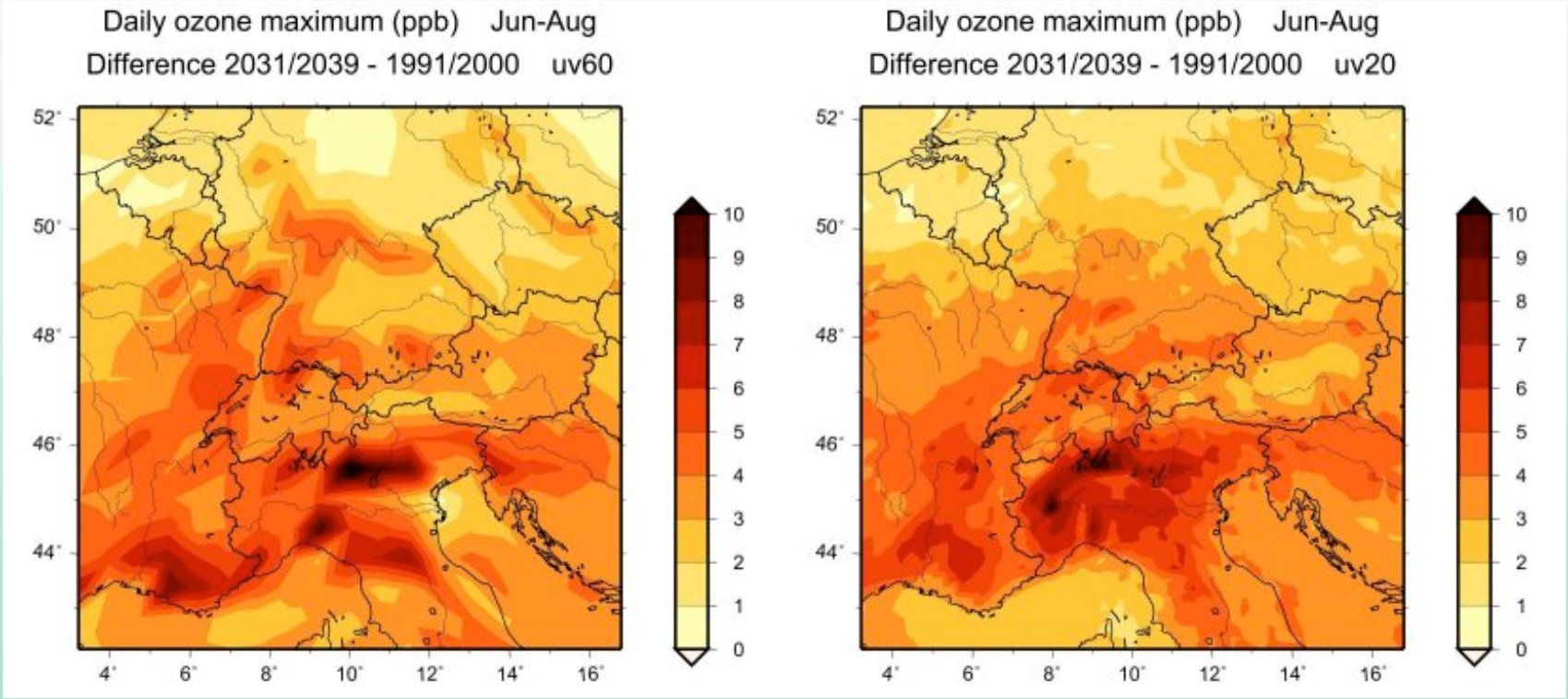
Results in 10 – 20 % increase in solar radiation



Increase by up to 50 % due to 2° higher temperature and increased solar radiation

Application for Europe

Change in tropospheric ozone

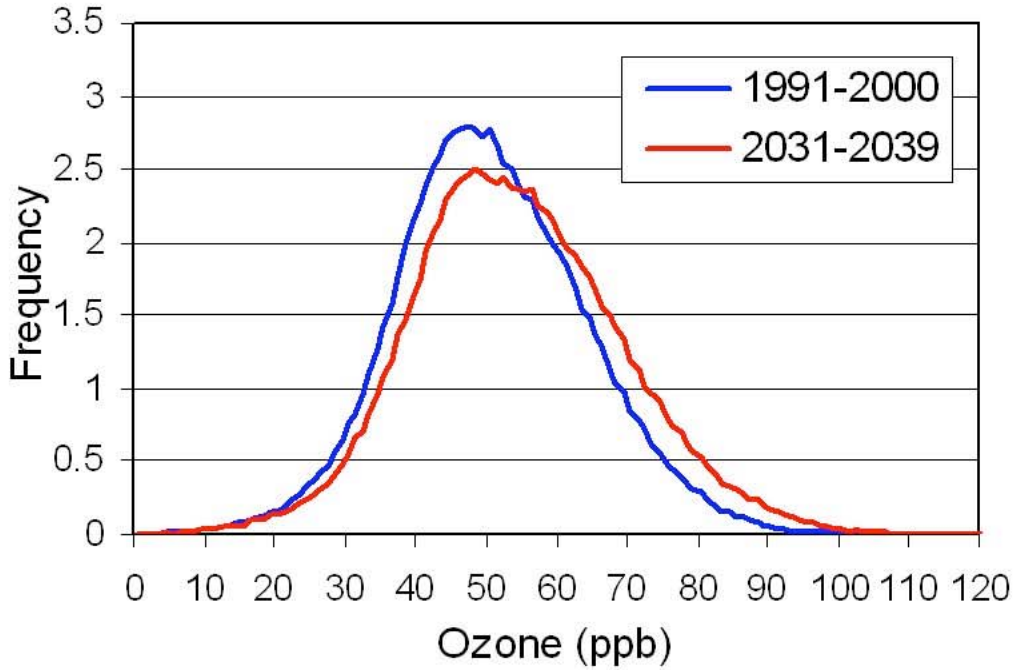


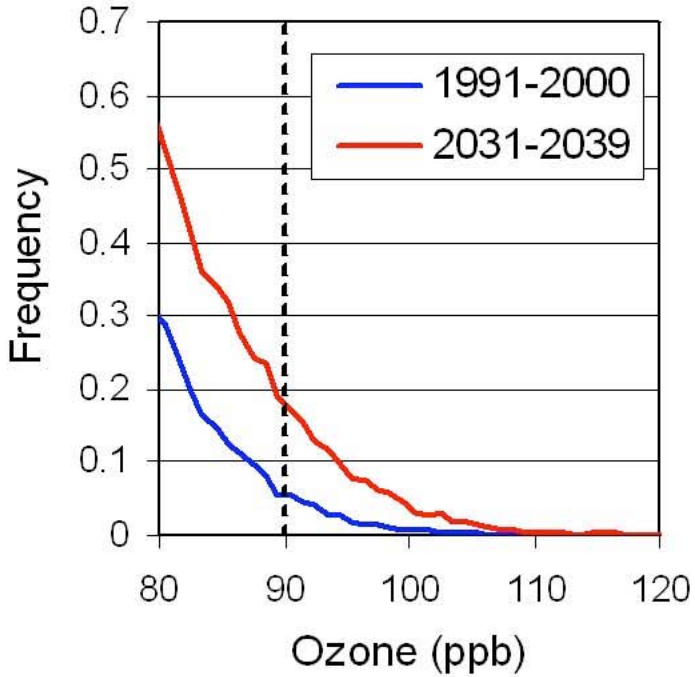
Differences between regional patterns for 60 km and 20 km resolution

Increase of mean daily ozone maximum by 5 – 10 %

Application for Europe

Distribution of daily ozone maxima





Occurrence of maximum ozone concentrations > 180 $\mu g/m^3$ increases by a factor of 4 over Southern Germany

Present: 99 station-events/year Future: 384 station-events/year

Application for Mexico

Setup of a preliminary simulation for Mexico

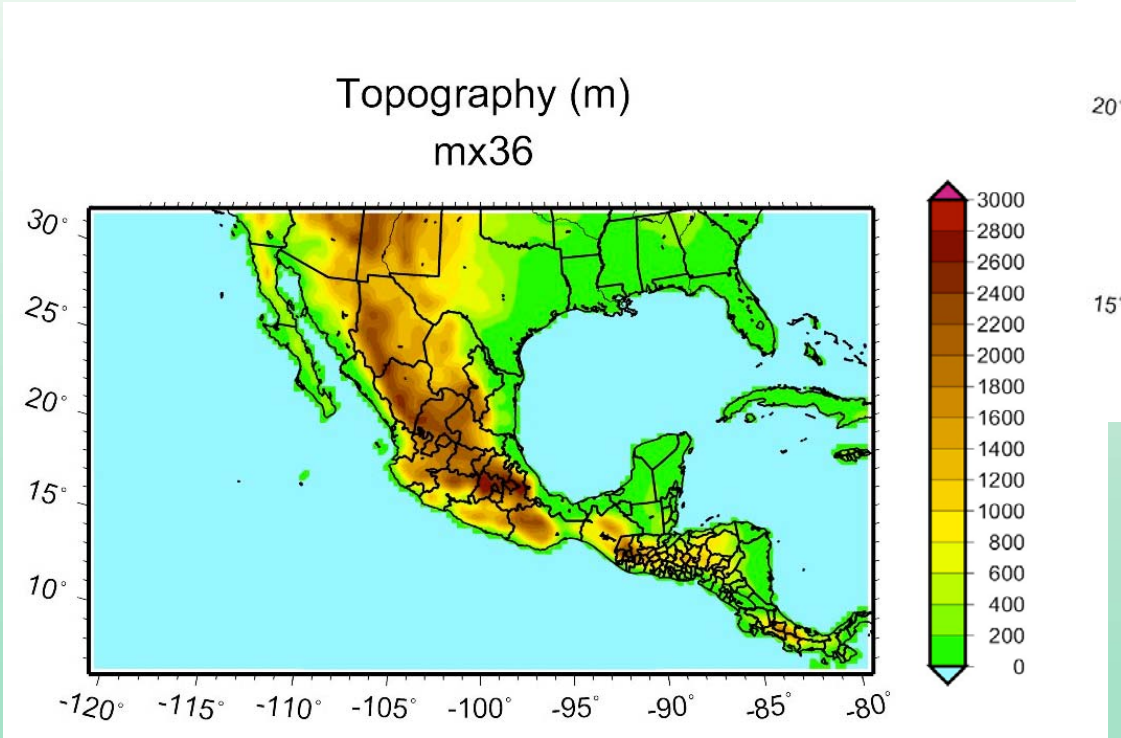
- Horizontal resolution 36 km (88 x 148 grid points), 28 layers
- Continuous simulations for two time slices starting 1990 and 2050, respectively
- Meteorological boundary conditions from ECHAM5 (T63), scenario A1B (data source: DKRZ)
- Anthropogenic emissions from data base with 24 km resolution (prepared by A. Garcia and G. Smiatek)
- Unchanged anthropogenic emissions and land use

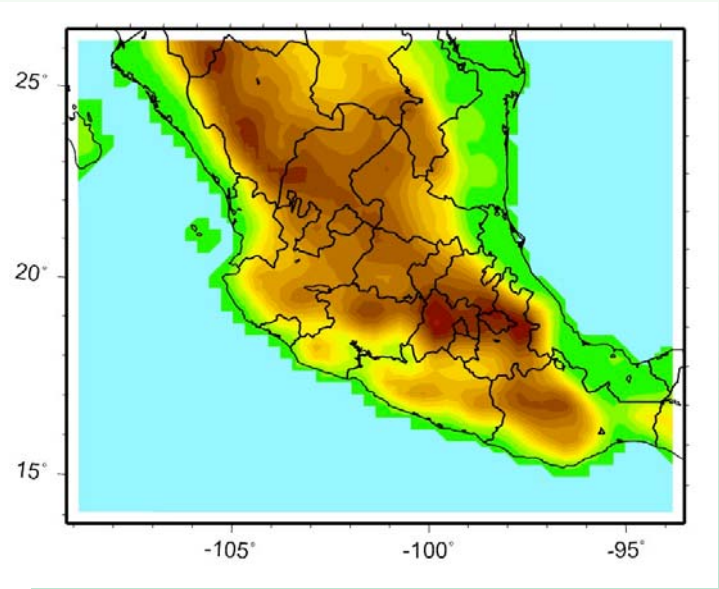
Results are still **very preliminary** as the simulations cover presently only 4 years of each time slice!

Application for Mexico

Model domain for preliminary simulation

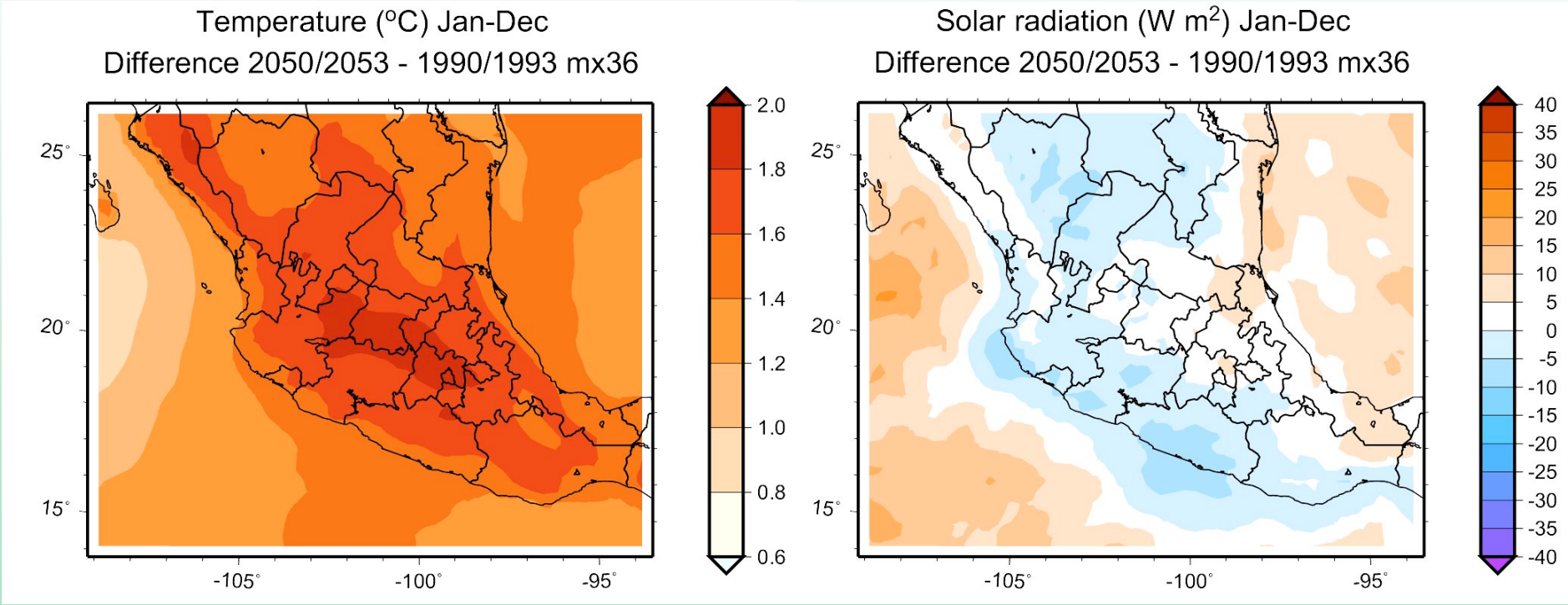
Representation of topography for 36 km:
Still higher resolution will be required





Application for Mexico

Preliminary results: Temperature and radiation

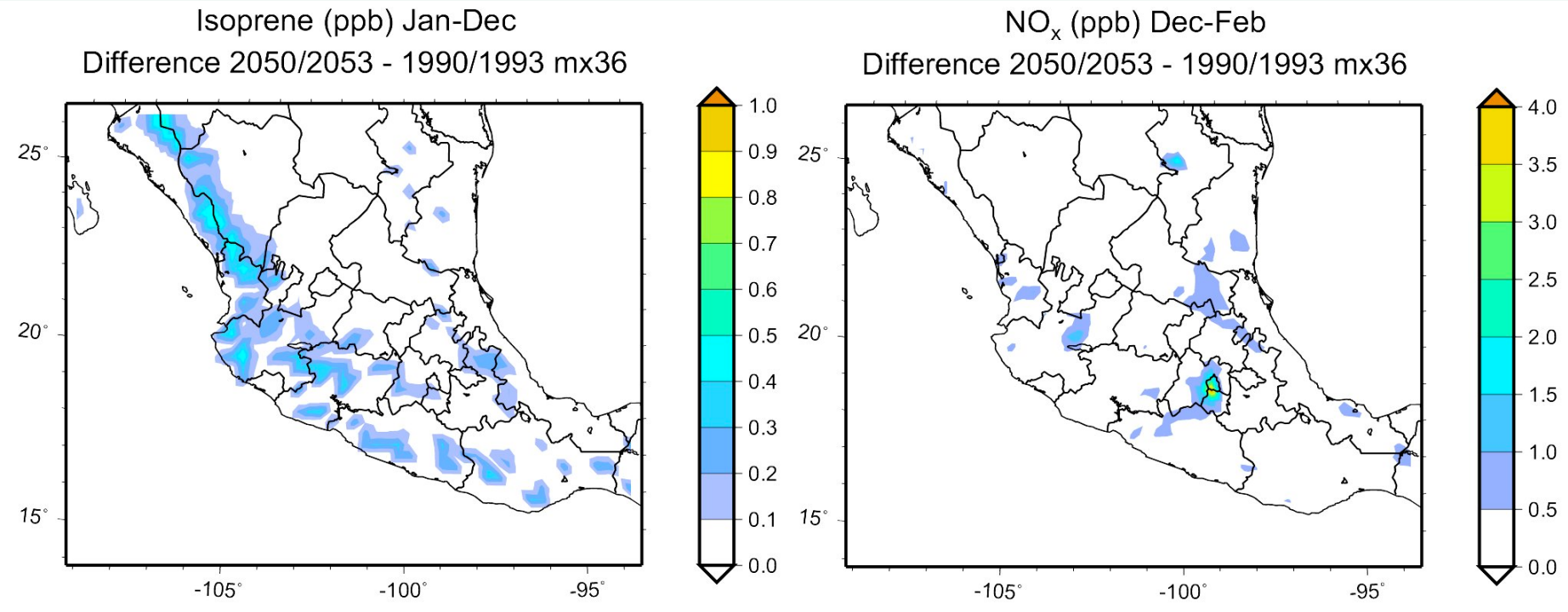


Temperature change probably higher if more years are considered

Change in cloud cover and solar radiation is less pronounced than for Germany

Application for Mexico

Preliminary results: Ozone precursors

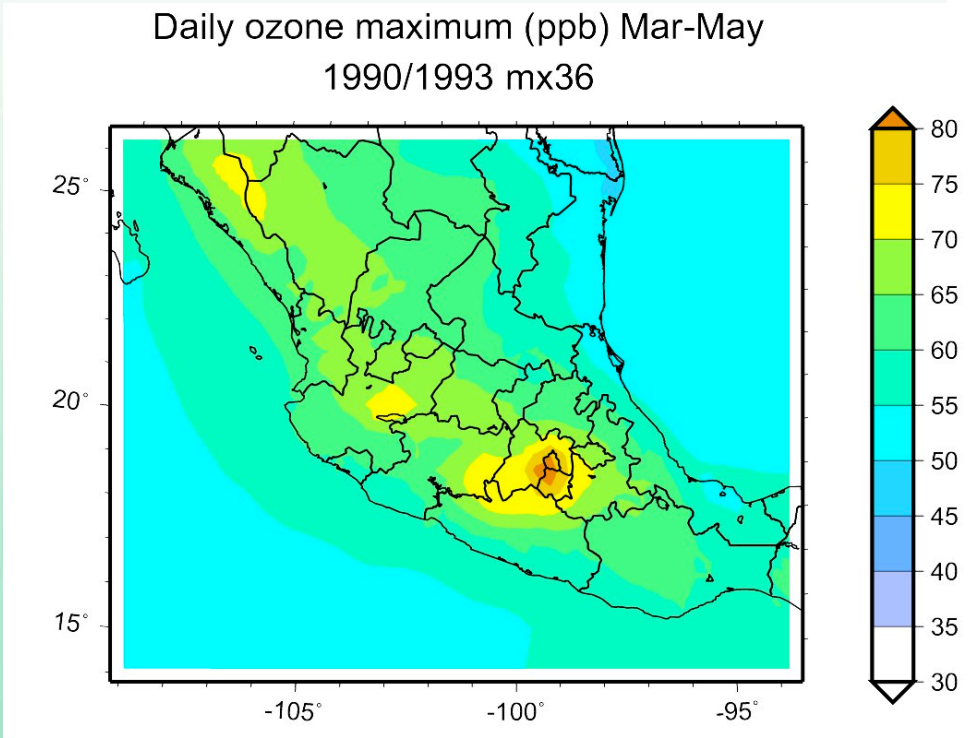


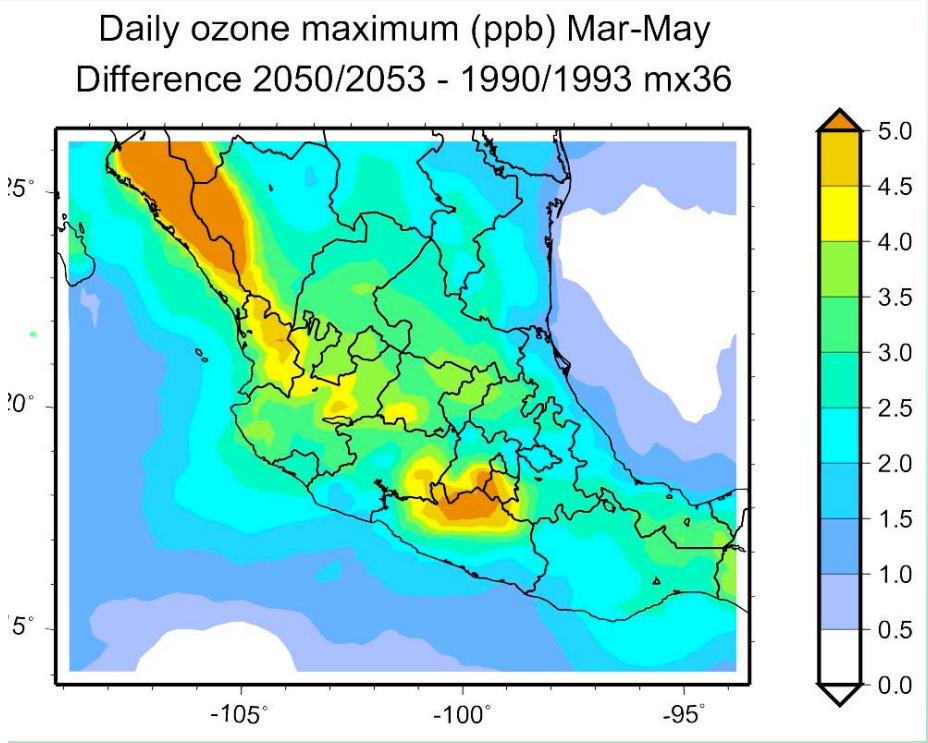
Increase by 30 – 40 %

Relative increase by Mexico City plume is below 5% (strongest during winter)

Application for Mexico

Preliminary results: Ozone maximum





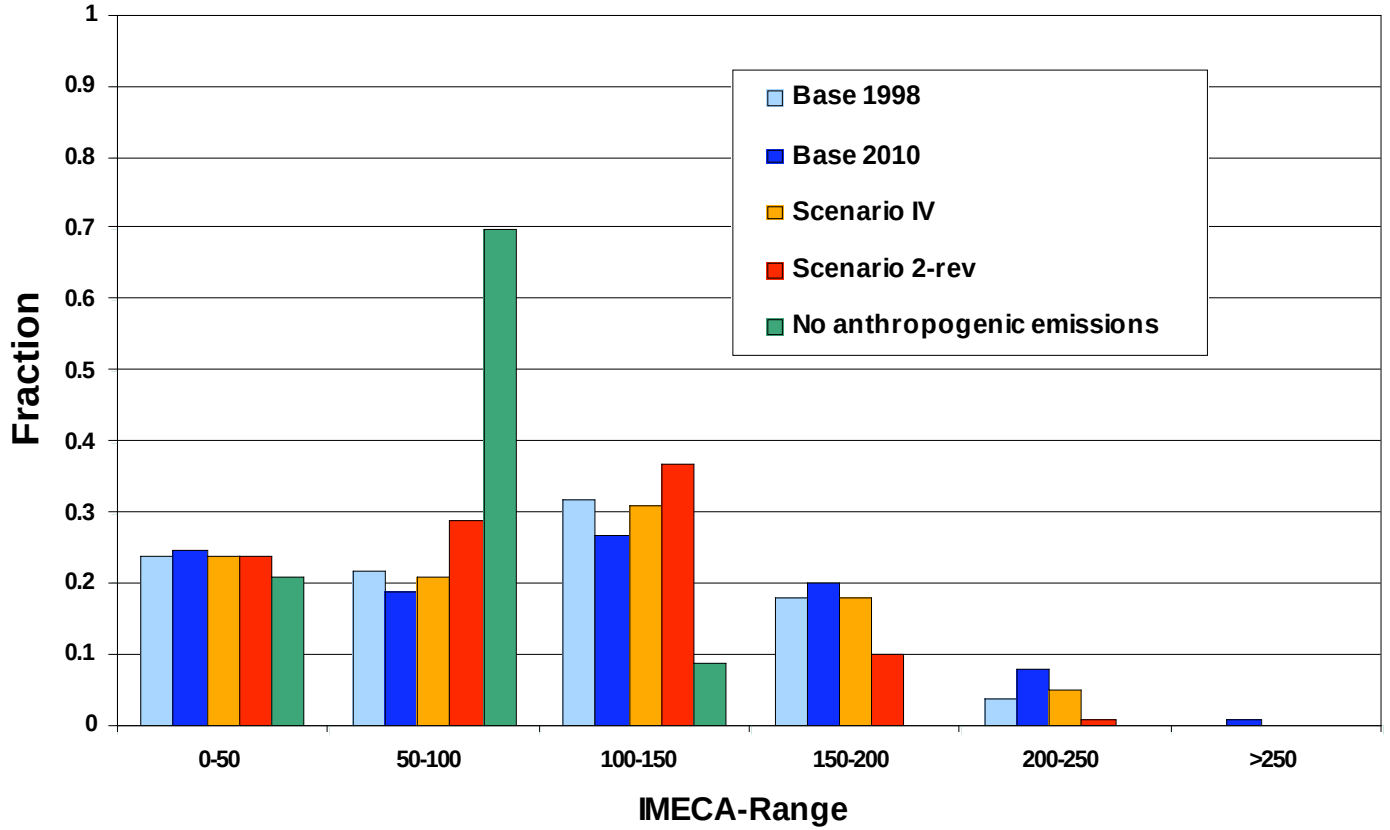
Ozone maxima still underestimated due to limited resolution

Most pronounced changes for areas with both (biogenic) VOC and NO_x

Application for Mexico

Mitigation measures reduce high concentrations

Simulated frequency of different ozone concentration ranges within the Mexico City area during an 8 day episode in May 1998.



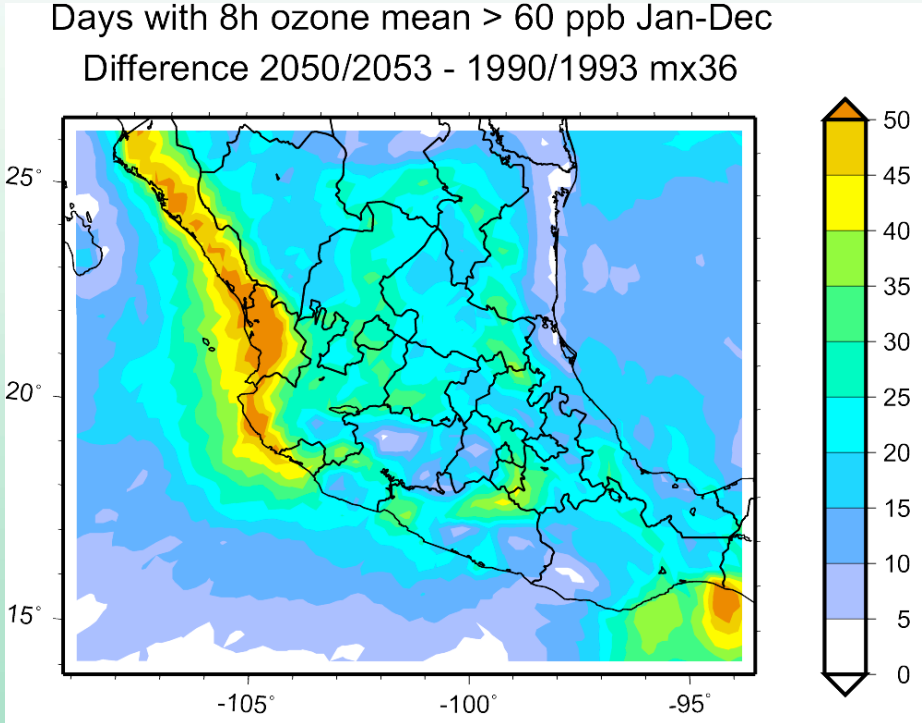
R. Forkel, IMK-IFU, F. Hernandez, SMA Mexico City, R. Iniestra, INE Mexico City

Comisión Ambiental Metropolitana

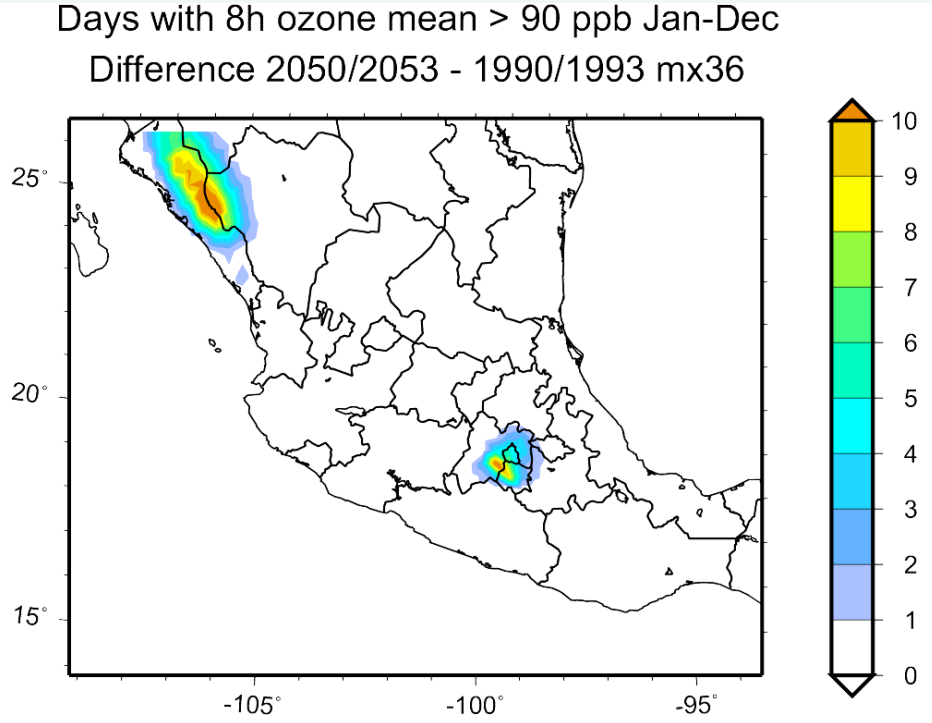
Application for Mexico

Future conditions enhance high concentrations

Threshold 60 ppb



Threshold 90 ppb



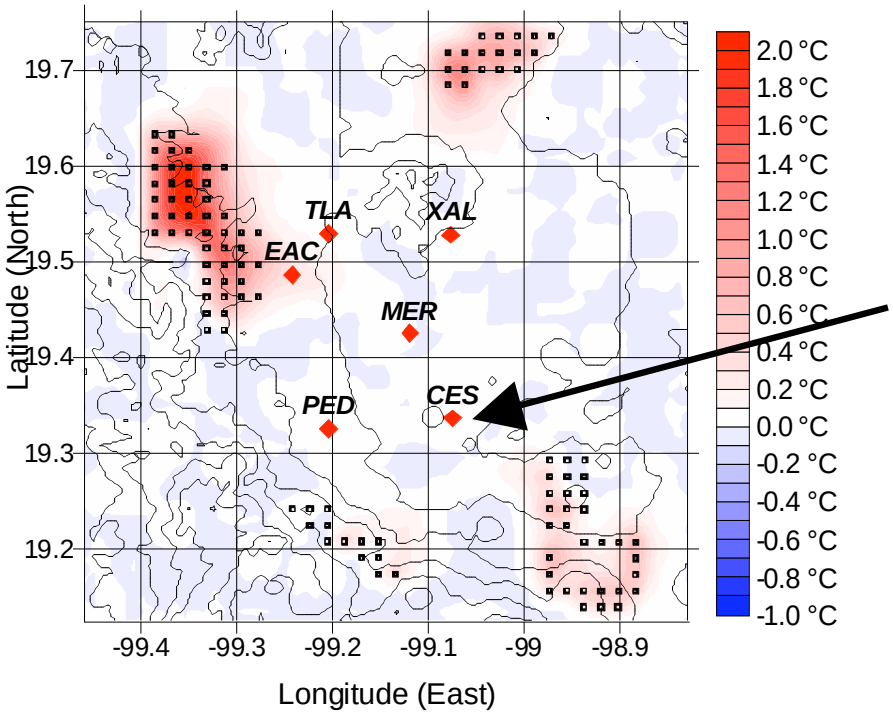
No increase possible any more for the Mexico City plume

Indication of increase of extreme values of maximum ozone

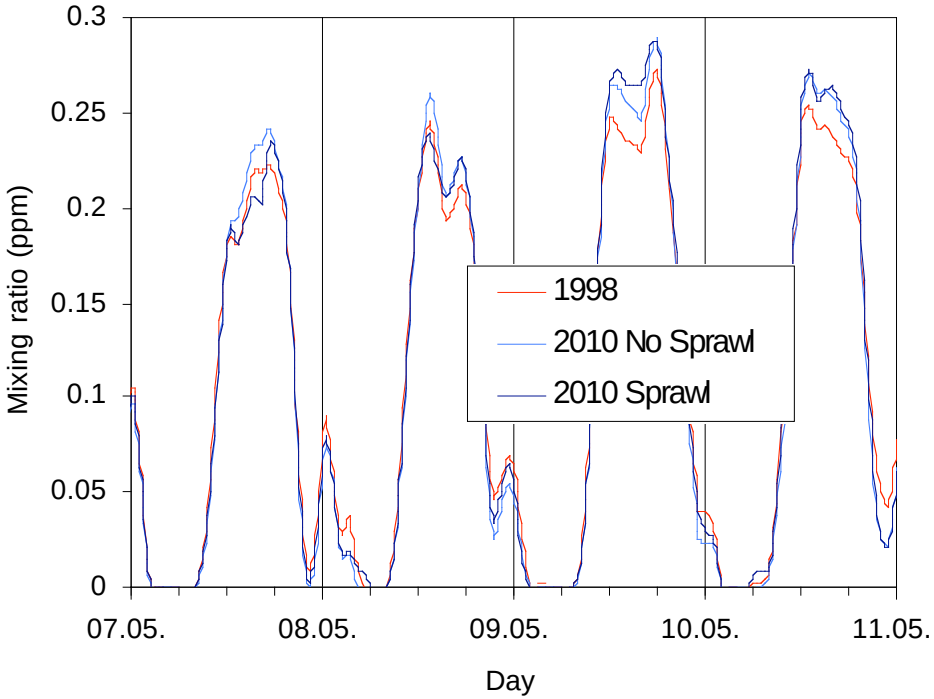
Application for Mexico

Effect of land use changes

Temperature difference with and without urban sprawl



Ozone Cerro de la Estrella



Locally land use change can induce similar effects as climate change or changes in anthropogenic emissions. Can either compensate or enhance climate effect

Application for Mexico

Summary of preliminary results

So far, the small number of simulated years permits **only limited interpretation.**

- Increase of mean temperature by 2 degrees
  (may be higher when more years are considered)
- Change in solar radiation is only small
- Increase of isoprene mostly due to higher temperature
- Increase of mean daily ozone max. by 5 – 10 %,
  only 5 % increase in the Mexico City area
- Number of days with high ozone mixing ratios increases

Discussion

General conclusion

- Dynamical downscaling with MCCM permits a consistent description of climate impact on regional air quality
- Preliminary results for Mexico indicate slightly different mechanisms than for Europe but there are also common features
- Land use changes can result in significant effects on the regional scale
- Climate effect can compensate the effect of future mitigation strategies

Discussion

Requirements for further work

- Simulate more years
- Validation for present day conditions
- Nesting (<10 km) for the Mexico City area
- Inclusion of improved information on BVOC emissions
- Include particulate matter / Feedback on radiation
- Include land use change scenario
- Precursor emission scenarios
- Chemical boundary conditions
- ….