Review of climate models

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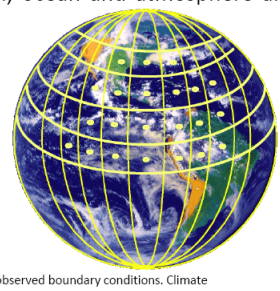
Climate models

Climate models are "*A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes and accounting for some of its known properties….Climate models are applied as a research tool to study and simulate the climate and for operational purposes, including monthly, seasonal and interannual climate predictions.*" (IPCC, 2014).

They are used to predict future changes climate features by means of a set of mathematical equations (Allaby, 2002)
The equations are solved numerically on a grid in which earth, ocean and atmosphere are discretized. Furthermore, several parameterizations are used.



Global Climate Models (GCMs) are generally used to simulate the response of the climate to the increasing greenhouse gas concentrations. But they are characterized by a resolution not suitable to provide information at regional scale (Christensen et al., 1997).

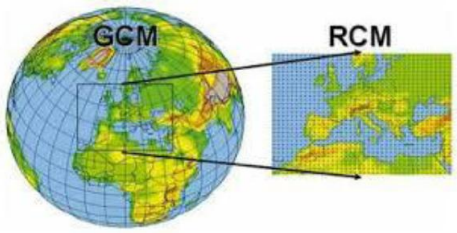
- Allaby M. (2002) Encyclopedia of weather and climate, Revised Edition, Facts On File, Inc, New York.
- Christensen et al (1997) Validation of present-day regional climate simulations over Europe: LAM simulations with observed boundary conditions. Climate Dynamics. 13(7-8):489-506
- IPCC, 2014: Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130.

Regional Climate Models

It is necessary to downscale the information provided by GCMs.

To this aim, a dynamical downscaling can be performed by means of Regional Climate Models (RCMs), which use the output of GCMs as input data.
Nowadays, RCMs can adopt resolutions of very few kilometres (also in the order of 1km), allowing a better description of surface characteristics and, hence, of relevant atmospherical processes (Giorgi et al., 2001; Ban et al., 2014).

RCMs are especially suitable to assess changes expected in terms of extreme weather events, that are of great importance to develop adaptation strategies. Indeed, with respect to the GCMs, they better represent climate extremes (Rummukainen, 2010; Soares et al., 2012).



- Ban N. et al (2014) *Evaluation of the convection-resolving regional climate modeling approach in decade-long simulations*. Journal of Geophysical Research: Atmospheres. 119(13):7889-7907
- Giorgi F. et al. (2001) Regional climate information-evaluation and projections. Climate Change 2001: The Scientific Basis. Contribution of Working Group to the Third Assessment Report of the Intergouvernmental Panel on Climate Change [Houghton, JT et al.(eds)]. Cambridge University Press, Cambridge, United Kongdom and New York, US
- Rummukainen M. (2010) *State-of-the-art with Regional Climate Models*, Wiley Interdisciplinary Reviews: Climate Change, 1(1): 82-96.
- Soares P.M.M. et al (2012) *Assessment of the ENSEMBLES regional climate models in the representation of precipitation variability and extremes over Portugal*. Journal of Geophysical Research: Atmospheres, 117.

RCM adopted at CMCC: COSMO-CLM

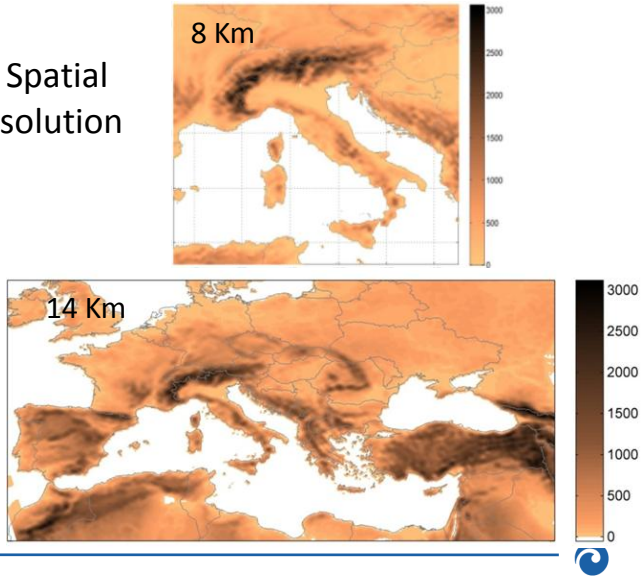
Climate Limited-area Modelling Community

- The COSMO-CLM (Rockel et al., 2008) is the Climate Mode of the COSMO model system.
- It is a non hydrostatic regional climate model, developed by the CLM-Community.
- It is designed for simulations on time scales up to centuries and spatial resolutions down to 1 km.
- It is the only limited area numerical model system in Europe which has a range of applicability encompassing:
  1. operational numerical weather prediction (COSMO);
  2. regional climate modelling of past, present and future (CLM);
  3. the dispersion of trace gases and aerosol (ART);
- It is applicable for downscaling in all regions of the world and of most of the Global Climate simulations available.
- Recently, urban parameterization schemes have been implemented in COSMO-CLM, e.g TEB (Town Energy Budget) scheme (Masson, 2000), to take into account important processes related to the presence of urban characteristics (Trusilova et al., 2013).

Rockel et al, 2008 "The regional Climate Model COSMO-CLM (CCLM)", Meteorologische Zeitschrift, 17 (4): 347-348
Masson, 2000 "A PHYSICALLY-BASED SCHEME FOR THE URBAN ENERGY BUDGET IN ATMOSPHERICMODELS", Bound.-Layer Meteor., 94,357–397.
Trusilova et al., 2013 " Implementation of an Urban Parameterization Scheme into the Regional Climate Model COSMO-CLM". *J. Appl. Meteor. Climatol.*, 52, 2296–2311.

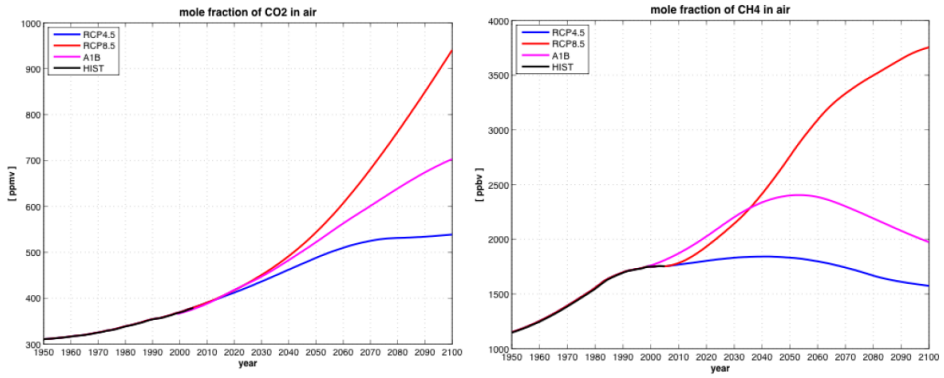
COSMO-CLM Downscaled data

COSMO-CLM Downscaling: Spatial extent and resolution



Emission scenarios

XX century → 20C3M protocol of IPCC.
XXI century → A1B, RCP4.5 and RCP8.5 IPCC emission scenarios.



A1B: Rapid economic growth, low population growth, rapid introduction of new technologies, balanced use of natural resources and technologies.
RCP4.5: high income growth, low population growth, gains in clean energy and efficiency resulting from aggressive carbon pricing. Stabilization of radiative forcing at 4.5 W/m^2 in 2100.
RCP8.5: high emissions scenario, high population growth, slow per capita income growth, coal intensive energy scenario. Rising radiative forcing pathway leading to 8.5 W/m^2 in 2100.

COSMO-CLM Downscaled data

XX century

- Reanalysis using ERA-Interim, to assess the model performance with "perfect" boundary conditions, for the period 1971-2010.
- CMCC-CM, "sub-optimal" forcing following the IPCC 20C3M protocol, for the period 1971-2006.

XXI century

- CMCC-CM, SRES A1B scenario, for the period 2006-2100
- CMCC-CM, RCP4.5 scenario, for the period 2006-2100
- CMCC-CM, RCP8.5 scenario, for the period 2006-2100

Need of bias correction

The output of RCMs can be used as input for impact models.

The direct use of RCM simulations in impact studies is challenging due to model bias originated from different sources of error:

- ✓ boundary problems transferred from GCMs to RCMs
- ✓ model approximations
- ✓ insufficiently resolved surface properties (e.g.orography)
- ✓ errors due to numerics and parameterizations

There is a need to perform bias correction

Different bias correction approaches are available to reduce these errors, among which Linear Scaling (monthly correction values obtained as ratio for precipitation and difference for temperature) and Quantile Mapping (the idea is to correct monthly the PDF of the RCM to agree with the observed PDF fitting a Gamma distribution for precipitation and Gaussian distribution for temperature)