The construction of confidence and uncertainties in Regional Climate Modelling

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Content of the talk

   - From GCM to RCM: motivations
   - What are RCM? What for?
   - How to use them?

2. Construction of confidence: some illustrations
   - Perfect model approach
   - Large-scale consistency
   - High-resolution added-value
   - Understanding regional climate variability
   - Testing and evaluating tools
   - RCM drawbacks and how to fix them

3. Performing regional climate change scenarios with RCM
   - Sensitivity tests in future climate
   - Large coordinated programmes: ENSEMBLES, CORDEX

4. Concluding remarks and current challenges in RCM
Regional climate using GCM

- GCMs are the most common modelling tools to study and understand climate variability and to project future climate change.
- GCM can deliver regional climate information taking into account the various sources of uncertainty.
- Projected climate change in Europe (not true everywhere) shows a good agreement between GCMs.

Summer temperature anomaly over France (in K, 1900-2100, 21-year filtering, scenario RCPs and observations, CMIP5 models, Boé and Terray, 2013)

Mean annual precipitation change (%; 2080-2099 vs 1980-1999, scenario A1B, 21 CMIP3 models, IPCC-AR4)
Why do we use Regional Climate Models?

- GCMs have a low spatial resolution (300-100 km) and do not represent well regional climate phenomena
- They do not represent well climate extremes
- They do not follow the past observed temporal chronology (chaos)
- Resolution is low wrt spatial scales of impact studies and decision making

Topography and land-sea mask for France
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**Extreme precipitation in Autumn**
(99 quantiles of daily precipitation, mm/d)

C. Dubois, CNRM, Med-CORDEX
What are Regional Climate Models (RCM) ?

**Definition:** “climate models for regional purposes”

RCM were invented in the 90s: Giorgi and Bates (1989, MWR) … only 25 years ago

RCM include “stretched-grid GCM” and **“Limited-Area Models”**

**Dynamical downscaling concept:**
- Use the computer power on an area of interest to locally increase resolution
- RCM are localized high-resolution version of a GCM
- RCM are cheaper than a GCM at the same resolution

**Main modes of use:**
- perfect-model approach: model academic check, internal variability
- perfect-boundary conditions (Reanalysis-driven): model development, model evaluation, added-value, sensitivity studies and regional climate understanding
- scenario mode (GCM-driven): added-value, climate change downscaling, inputs for impact studies

**Users:**
- Climate researchers
- Researchers of the so-called “impact community”: coastal oceanography, cryosphere, land-surface, hydrology, health, biodiversity, tourism, energy
- Climate services: expertise, support for decision, adaptation
What are Regional Climate Models (RCM)?

- Inner or physical zone (useful)
- Lateral Boundary Conditions
- Relaxation zone
- Surface Boundary Conditions (sea temperature, orography, land composition)

Med-CORDEX domain
Perfect-model approach:
the Big-Brother/Little-Brother experiment

- One high-resolution GCM is run first (the Big-Brother model)
- This GCM run is considered as the true (perfect model approach)
- The GCM small-scales are filtered out (hidden true)
- The filtered GCM is used to drive a RCM with the same physics and the same resolution (the Little-Brother model)
- The RCM is compared to the full-resolution GCM in particular for the small scales

- This allows to test some of the RCM “tenets” (Laprise et al. 2008):
  “RCM are able to reproduce the large scales of the Big-Brother”
  “RCM are able to reproduce the small scales of the Big-Brother”
  “RCM do have some freedom wrt the Big-Brother (internal variability)”
  “GCM-RCM physics consistency plays a role in RCM results”
  “Spectral nudging technique in RCM improve RCM solutions, decrease internal variability, do not degrade small-scales or extremes”
  “Some RCM configurations produce inconsistencies in BB-LB experiment”
  “RCM can manage a factor 10 in resolution jump”

Radu et al. 2008, Colin et al. 2010
Are RCM able to reproduce large scales?

- Perfect-boundary conditions (13 RCMs driven by ERA40 reanalysis, 1961-2000)
- Skills of the RCMs to reproduce the 4 main North-Atlantic Winter weather regimes (Zonal or NAO+, Greenland anticyclone or NAO-, Blocking, Atlantic Ridge)

Sanchez-Gomez et al., 2008
Illustration of the RCM added-value

Extreme precipitation in Autumn
(99 quantiles of daily precipitation, SON, 30-year, mm/d)

C. Dubois, Med-CORDEX
Over the last 30 years in Europe, 81% (±16%) of the trend in surface shortwave radiation is explained by the decreasing trend in sulphate concentration.

This also explains 23% (±5%) of the surface warming trend.

Spatial correlation of the trend: 0.09 in REF to 0.42 in TRANS.

Models: ERA-Int driven run, RCM with (TRANS) and without (REF) the sulphate aerosol trend

Obs (SWdown, 1980-2009): GEBA, homogeneized stations

Nabat et al. 2004
The RCM potential drawbacks:
- The RCM large scales can diverge from the GCM large scales (internal variability)
- The RCM do not always add value even at small scales (noise instead of signal)
- The RCM information do not feedback to the GCM (one-way nesting)
- The whole domain is not always usable (spatial spin-up, mismatch at the outflow)
- For a given driver, RCM results depend on the RCM choice (source of uncertainty)
- RCM inheritate from the GCM drawbacks (“garbage in, garbage out”)

Main solutions:
- Decrease the resolution jump at the boundary
- Improve the quality of the LBC coding
- Improve the quality of the driving GCM
- Use spectral nudging technique to control the large scales
- Carry out ensemble runs to evaluate RCM internal variability
- Use smaller domains
- Use consistent physics in the GCM and in the RCM
- Use two-way nesting
Regional climate change scenario: 
(1) sensitivity tests to resolution

Change in Summer surface temperature (JJA, °C)

Temperature change (Alps>800m, ANN, °C)

Change in Autumn extreme precipitation (SON, mm/d. Quantile 99)

Quantile-Quantile plot (Croatia>800m, ANN, mm/d)

Fig: C. Dubois, Med-CORDEX
RCP8.5, CNRM-CM5 150 km and ALADIN-Climate 12 km, 2071-2100 vs 1976-2005
Regional climate change scenario: (2) large coordinated experiments

ENSEMBLES FP6 european project
Scenario A1B, 7 GCMs, 14 RCMs at 25km, 19 RCM runs, 73 statistically reconstructed runs, quantile-matching statistical correction, 2021-2050 vs 1961-1990

Summer temperature change (°C)

Bivariate climate change pdf in Summer in Poitiers

Adapted from Déqué and Somot (2010), Colin (PhD, 2011), ENSEMBLES FP6
The CORDEX international programme

- Launched by WCRP (first meeting in Toulouse, February, 2009)
- Coordinated by F. Giorgi (ICTP) and the CORDEX SAT
- Scenario: CMIP5, RCP8.5, RCP4.5, 1950-2100
- Many GCMs and many RCMs
- 50 km resolution, 14 official domains
- Priority domain: Afro-CORDEX
- 50 km and 12 km: Euro-CORDEX, Med-CORDEX
- Coupled RCM: Med-CORDEX, Arctic
- Data: ESGF, regional database

Source: CORDEX programme
Concluding remarks and current challenges in regional climate modelling

CONCLUDING REMARKS
• Regional climate models are mature climate modelling tools
• RCM and GCM must be used in complementary approaches
• RCM can add value in specific regions and for specific variables (but not always)
• RCM performances in various modes can be assessed (perfect model, perfect boundary, scenario)
• In addition to climate change scenario downscaling, RCM can serve also to develop climate model, test regional impacts of regional forcings, understand regional climate variability
• GCM-RCM consistency must be checked
• In climate change scenario, RCM is an additional source of uncertainty

CURRENT CHALLENGES
• How to use large coordinated initiatives (CORDEX) to make good science?
• Will climate change signal be modified with explicit convection models (2-km RCM)?
• What is the role of the other components of the regional climate system (RESM)?
• How to manage uncertainty in regional climate projections?
• How to strengthen the links with the GCM community?
• How to strengthen the links with the Statistical Downscaling community?
What are Regional Climate Models (RCM)?

- **Stretched-grid GCM**
  - ARPEGE-Climate
  - LMDZ

- **Limited-Area Model**
  - ALADIN-Climate

**Regional Climate System Model**

- CNRM-RCSM5
  - Atmosphere + Land
  - Hydrology + Ocean
  - Aérosols
How to drive a RCM?

One-way nesting
Lateral forcing

GCM →

Spectral nudging

GCM →

Two way-nesting

$\frac{dT}{dt} = \text{dynamics} + \text{physics} + \frac{T - T_{GCM}}{\tau} + \frac{T_{LS} - T_{LS - GCM}}{\tau_1}$

Lateral nudging all scales but only in the relaxation layer

Spectral nudging inside the domain but only for the large-scales

Nudging coef.
Question of scales

What are the relative scales of GCM and RCM?

1. No RCM effect (except for two-way nesting)
2. RCM should conserve GCM large-scale
3. RCM can conserve, improve (up-scaled added-value) or degrade
4. RCM can add value if its small-scales are realistic (not only noise)

Adapted from VonStorch et al. 2000, MWR
Precipitation: model evaluation at various resolution

Maps of mean precipitation over France (1980-2009, SON, mm/d)

Model: ERA-Int, CNRM-CM5, ALADIN-Climate (50km, 12km)

Obs: SAFRAN, gridded analysis, 8km

Fig: C. Dubois, CNRM, Med-CORDEX
Illustration of RCM evaluation
Mean behaviour

Model

Observation

Temperature (°C) in Winter (DJF)
ALADIN-Climat RCM, 12 km (1961-1990)

Source: Météo-France
Illustration of RCM evaluation: daily distribution and extreme

Quantile-Quantile plot for Paris (1960-1989)

Winter minimum temperature (DJF, °C) Summer precipitation (JJA, mm/d)

Source: Météo-France
Geography of the RCM potential added-value

- Orography induced added-value
- Small-scale land-atmosphere interaction and extreme heat wave
- Snow-atmosphere interaction
- Extreme precipitations
- Islands and land-sea contrast (regional winds)
- Small-scale strong air-sea interaction
- Small-scale cyclogenesis
- Aerosol-radiation interaction
Illustration of the RCM added-value

Mean wind speed over the sea (m/s, 2000-2001)

Wind speed extreme
(quantile-quantile plot of daily wind speed, Gulf of Lions, 2000-2001, m/s)

Herrmann et al., 2011
The main RCM potential drawbacks

- Spatial spin-up
- Internal variability
- Boundary conflict
- Missing information
- Inadequate small-scales
- GCM-RCM inconsistency
How to fix RCM potential drawbacks?

- Spatial spin-up
- Decrease in resolution jump
- Missing information
- Inadequate small-scales
- GCM-RCM inconsistency
- Improved LBC
- Spectral Nudging
- Physics consistency

Boundary conflict
- Improved LBC
- Two-way nesting
- Spectral Nudging

Internal variability
- Spectral Nudging
- Smaller domain
- Ensemble simulations