European-scale convection-resolving climate modeling

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Reducing uncertainties with RCMs

### Pessimism

- The envelope of uncertainty
- The cascade of uncertainty
- GCM
- RCM
- Impact model
- Local impacts
- Adaptation responses

“The range of uncertainty expands at each step of the process [and] spans such a wide range as to be practically unhelpful.”

(Wilby and Dessai 2010)

“Switching from global to regional models piles uncertainty on top of uncertainty.”

(Kerr 2011, Science)

### Optimism

Analysis of RCM / GCM shows the opposite!

- RCMs systematically reduce GCM biases!
- RCMs decrease spread of projections!

ENSEMBLES: Kerkhoff et al., 2014, JAS
CORDEX: Sørland et al., Poster PA-104
Reducing uncertainties with explicit convection

- Switch off convection parameterization
- More closely based on first principles
Diurnal convection over Europe

17:45 (15:45 UTC)

(SEVIRI 10.8μm, June 30 till July 2, 2009; Michael Keller, ETH Zürich)
Convection and flash-flooding

Flooding in St. Gingolph, Valais
May 1, 2015

Flashflood in Wil (Switzerland)
June 15, 2015
Climate simulations at km-scale

Grell et al. 2000:
46x46 gridpoints at 1 km
14 months

Knote et al. 2010:
ca 200 x 150 gridpoints at 1.3 km
several decades

Kendon et al. 2012:
ca 400 x 300 gridpoints at 1.5 km
several decades

This presentation:
Ban et al. 2014, 2015:
500 x 500 gridpoints at 2.2 km
several decades
driven by ERA-Interim and
MPI-ESM-LR (RCP 8.5)

Leutwyler et al. 2016 (submitted, GMD):
1536 x 1536 gridpoints at 2.2 km
one decade completed
driven by ERA-interim
Domain size matters

The statistics of convective cell needs to develop within computational domain!

- A boundary zone of 100-200 km is affected by transition from parameterized to explicit convection.
- Very small domains damage the statistics of convection.
- Our simulations use wide lateral relaxation zone (50 grid points).

Lifecycle of a convective cell:
- Lifetime: 6h
- Propagation: 10 m/s
- Distance: 200 km

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Validation of diurnal cycle

10-year long simulation driven by ERA-Interim;
Validation against 62 rain-gauge stations in Switzerland (JJA)

Alpine domain
2.2km (500x500x60)

Mean precipitation

OBS
Δ = 12 km
Δ = 2 km

Wet-hour frequency

Heavy precipitation

poor representation of diurnal cycle with Δ=12 km
dramatic improvement with Δ=2 km

(Ban et al. 2015, GRL)
Precipitation scaling with climate change

Extended Alpine region (JJA)

- No super-adiabatic scaling. Both daily and hourly precipitation are consistent with Clausius-Clapeyron scaling (6-7% / K).
- At hourly resolution, differences between $\Delta = 12$ km and $\Delta = 2$ km
- Assessment uses all-day percentiles

(Ban et al., 2015; Schär et al. 2016)
European-scale simulations

GPU-version of COSMO model

- Large effort led by O. Fuhrer (MeteoSwiss)
  - runs entirely on GPUs
  - dynamical core rewritten in C++
  - parameterizations use OpenACC
- Also used for operational NWP (Δ=1 km)
- Runs on Piz Daint (Cray XC30, CSCS)

Use for European-scale climate simulations
(PhD of David Leutwyler)

- Δ=2.2 km, 1536 x 1536 x 60 grid points
- Able to run 1 year in 5 days wall-clock time
- 10 years driven by ERA-Interim

Oliver Fuhrer (MeteoSwiss), Xavier Lapillone (C2SM / ETH), et al.;
Thomas Schulthess (CSCS), et al.;
David Leutwyler (PhD ETH), et al.
Cray 1 versus Kepler GPU

Cray 1

- Performance: 160 MFlops
- Main memory: 1 MWord
- Weight: 5.5 tons (Cray-1A)
- Cost: 10 Million $

Kepler GPU

- Peak performance: 1311 GFlops
- Memory: 960 + 1536 MByte L1/2 Cache
- Weight: about 0.5 kg
- Prize: about 3000 $ (GK110)

GPU = Graphics Processing Unit

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Piz Daint = 5272 Nodes

1 Node = 1 GPU & 1 CPU
1 GPU = 15 SMXs
1 SMX = 192 CCs & 64 DPs
1 CC
1 DP

CUDA Core
Double Precis. Unit

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Compute Challenge
Emerging hardware architectures are highly heterogeneous
Kyrill
Jan 18, 2007, 18 UTC
Δ = 12 km

mm/h
Kyrill
Jan 17, 2007, 12 UTC
Δ = 2 km

mm/h
Kyrill

Jan 18, 2007, 18 UTC
Δ = 50 km

mm/h
Simulations at 12 and 2 km

David Leutwyler, ETH Zurich, animations via crCLIM: http://www.c2sm.ethz.ch/research/crCLIM
Simulation of propagating cold pools

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Rotunno et al. 1988

Gravity Currents and Cold Pools

Δx = 2 km

Δx = 12 km

Animation download (CC-BY): dx.doi.org/10.3929/ethz-a-010619320


What is feasible today?

- **Decade-long European-scale domain simulations**
  - Able to run 1 day in 20 minutes (1 year in 5 days)
  - Domain-decomposition with 12 x 12 domains, each running on a GPU/CPU node (144 nodes, 2.8% of PizDaint)

- **CORDEX simulations – Strong scaling: Increase # of nodes for given domain**
  - Resolution of 12 km, 150 year long, domain covering Europe. Able to run 1 year in 18 hours on 10 nodes (poor strong scaling)
  - On dedicated PizDaint (5272 nodes): Large 500-member ensemble feasible

- **Global simulations – Weak scaling: Increase domain size with # of nodes**
  - Exploit excellent weak scaling on dedicated Piz Daint (5272 nodes): At a resolution of 2.8 km, whole planet could be covered.
  - In principle, global convection-resolving AGCM simulations feasible today!
  - Would require online analysis (memory bandwidth is most critical bottle neck).
  
See project crCLIM at ETH: [http://www.c2sm.ethz.ch/research/crCLIM.html](http://www.c2sm.ethz.ch/research/crCLIM.html)
References


Animations: can be downloaded via crCLIM website at http://www.c2sm.ethz.ch/research/crCLIM

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