Towards high-resolution climate projections for Belgium

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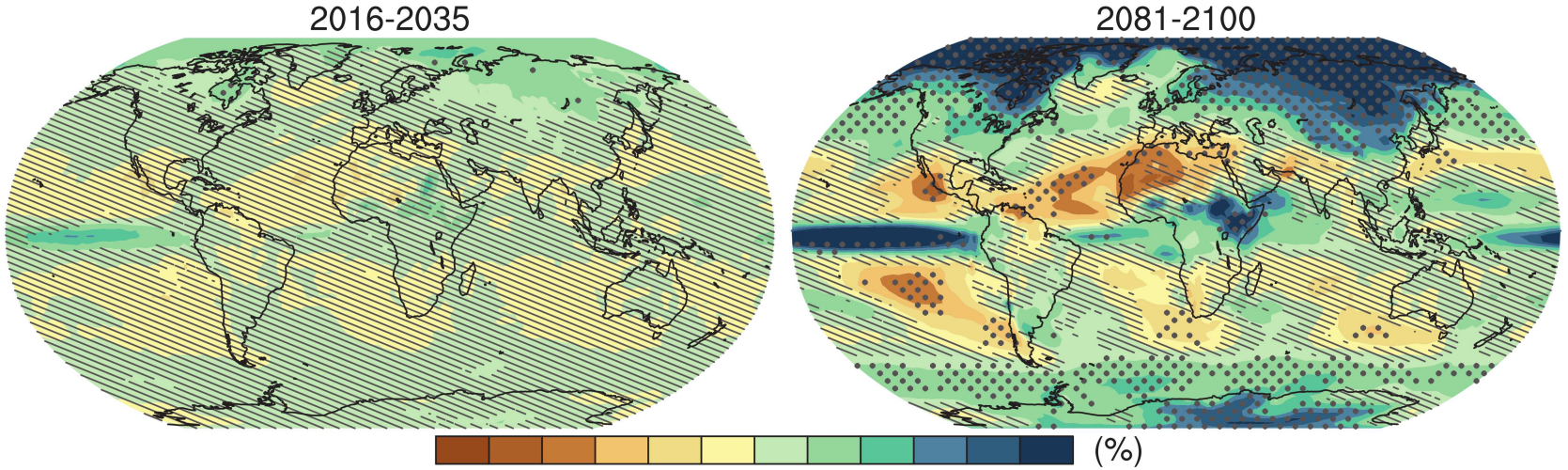
Precipitation projections

- Belgium, Germany, France
- Mean values and uncertainties

Method

- Global models (GCMs / ESMs)
- Ensemble of simulations

Winter precipitation changes for the representation concentration path 8.5



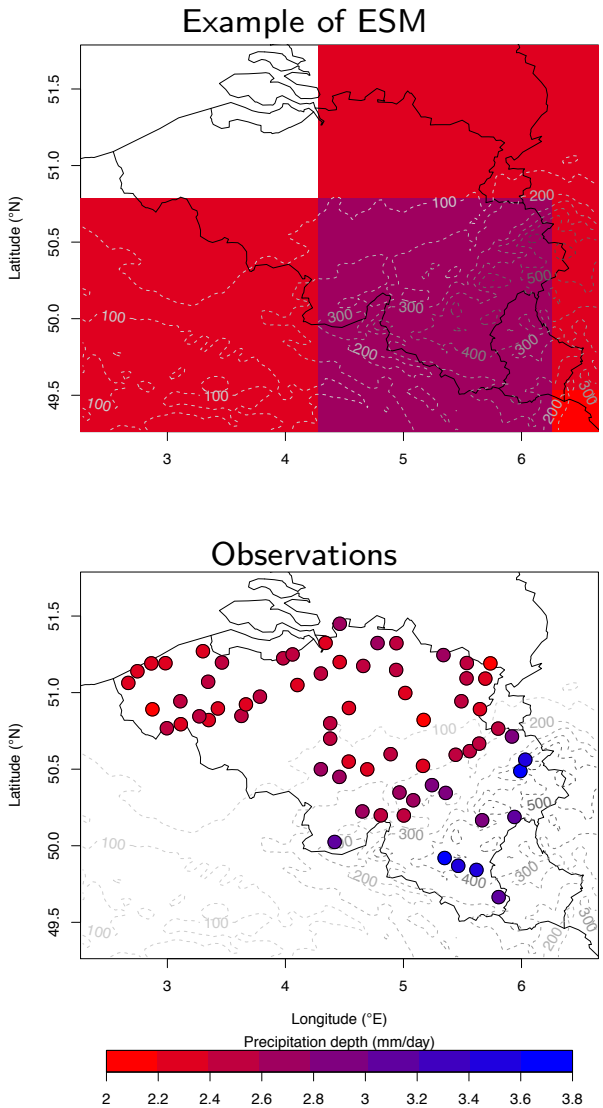
Source : Intergovernmental Panel on Climate Change (2014)

Too coarse grid for :

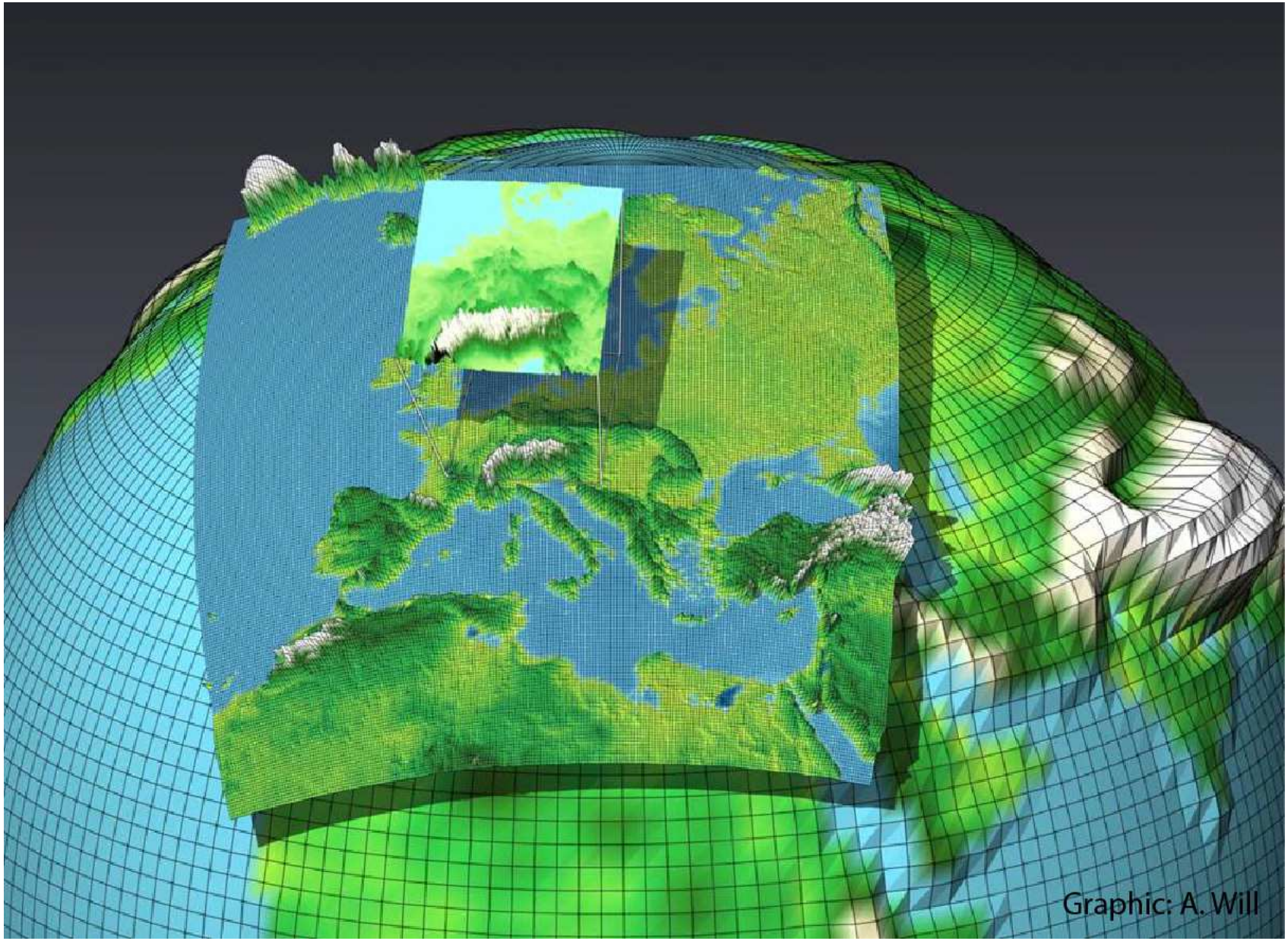
- Urban modelling
- Some hydrological studies
- Extreme precipitation

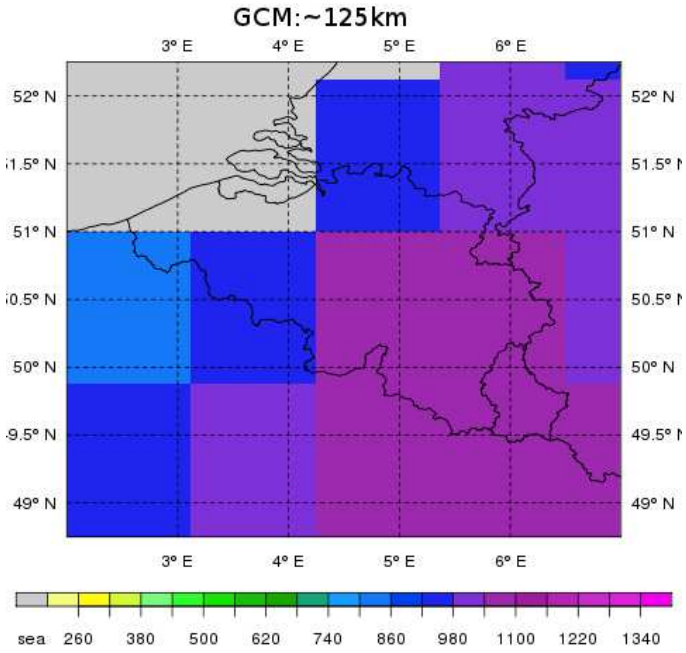
Need for local information

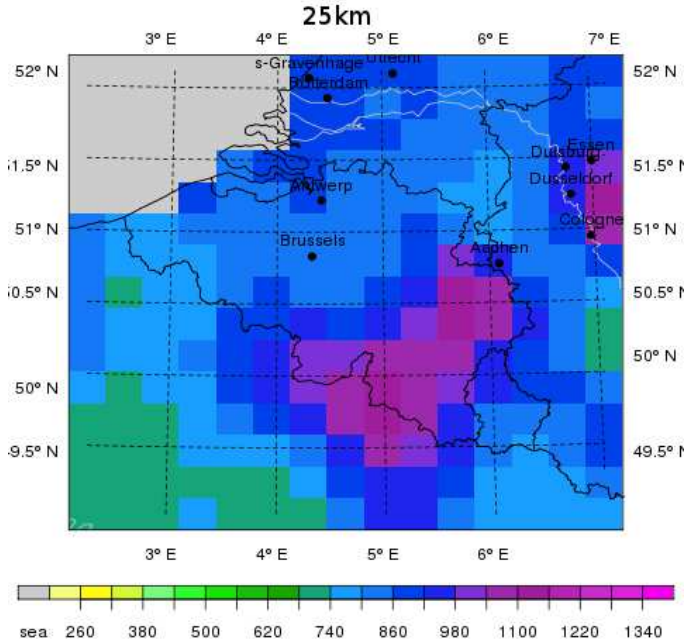
- Statistical downscaling
- **Dynamical downscaling**

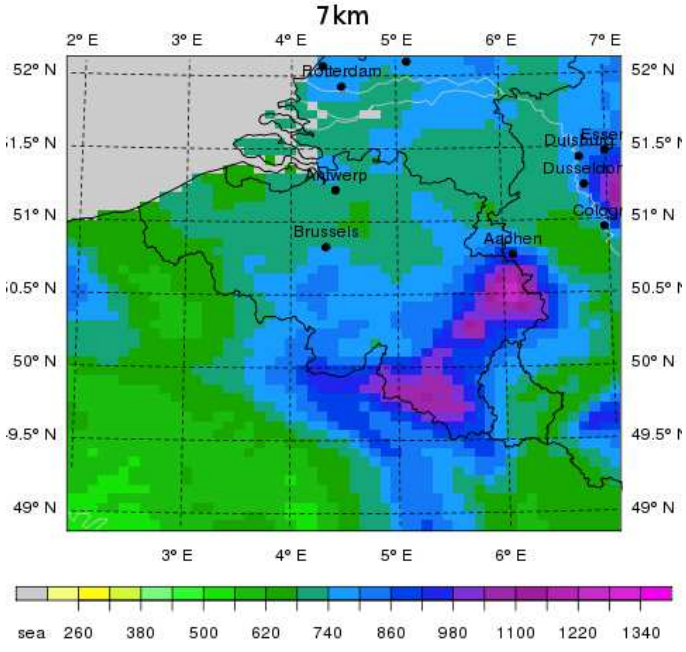


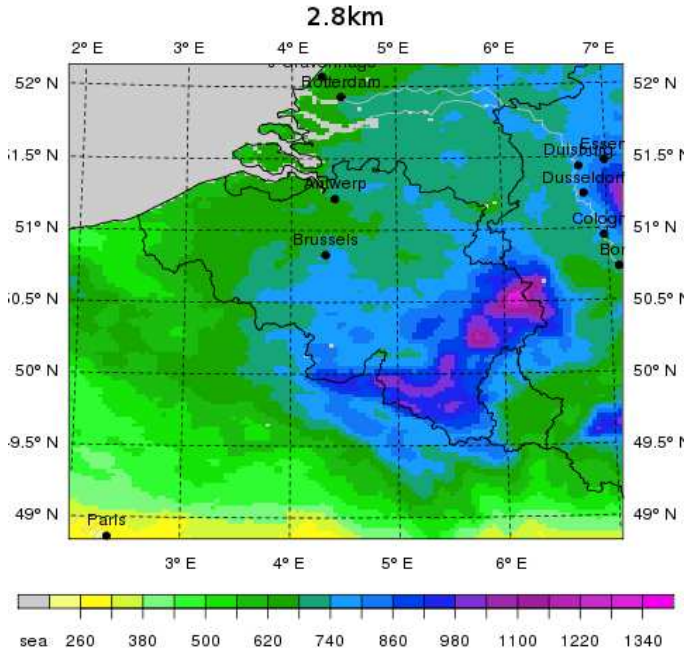
Dynamical downscaling




GCM:~125km
3° E
4° E
5° E
6° E
52° N
51.5° N
51° N
50.5° N
50° N
49.5° N
49° N
sea
260
380
500
620
740
860
980
1100
1220
1340


25km
3° E
4° E
5° E
6° E
7° E
52° N
51.5° N
51° N
50.5° N
50° N
49.5° N
Rotterdam
Antwerp
Brussels
Aachen
Essen
Duisburg
Dusseldorf
Cologne
sea
260
380
500
620
740
860
980
1100
1220
1340

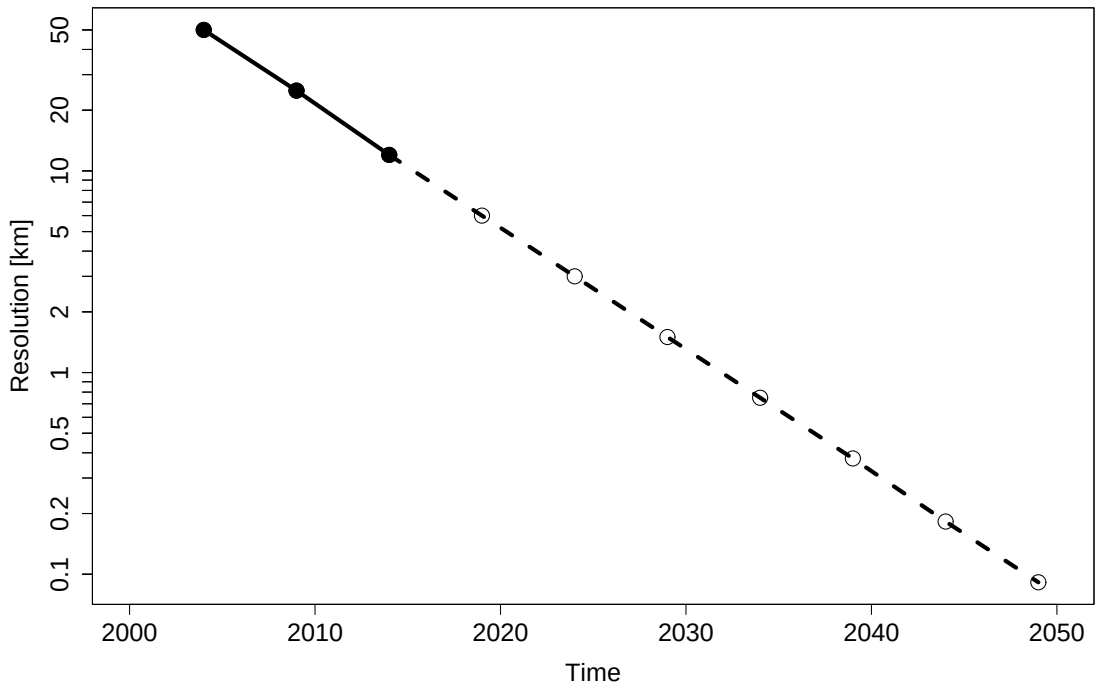

7km
2° E
3° E
4° E
5° E
6° E
7° E
52° N
51.5° N
51° N
50.5° N
50° N
49.5° N
49° N
Rotterdam
Antwerp
Brussels
Aachen
sea
260
380
500
620
740
860
980
1100
1220
1340


2.8km
2° E
3° E
4° E
5° E
6° E
7° E
52° N
51.5° N
51° N
50.5° N
50° N
49.5° N
49° N
Rotterdam
Antwerp
Brussels
Paris
sea
260
380
500
620
740
860
980
1100
1220
1340

Recent and ongoing RCMs projections in Europe

- ENSEMBLES (50km) 2004-2009
- CORDEX (25km) 2009-ongoing
- EURO-CORDEX (12km) 2012-ongoing

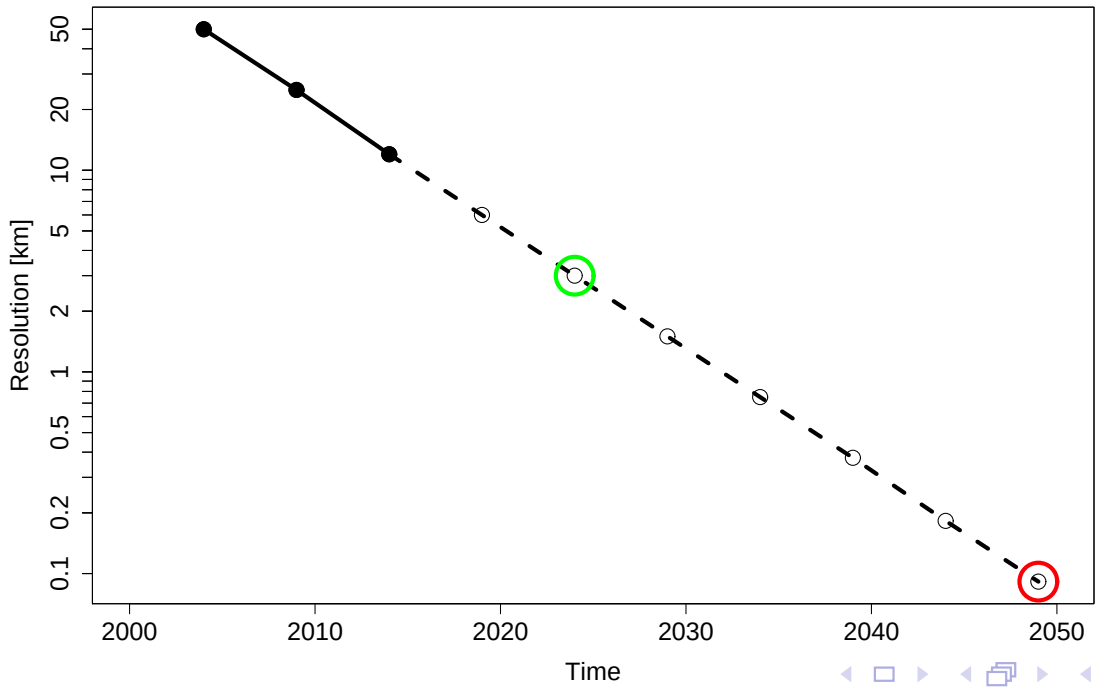
Possible evolution of climate projection resolution (doubled resolution in 5 years)



Which direction for the future ?

- Deep convection is resolved at scales $< 4\ km$
- Turbulence (large eddies) at scales $< 100\ m$
- Convection permitting simulations (CPS) for climate projections soon available

Possible evolution of climate projection resolution (doubled resolution in 5 years)

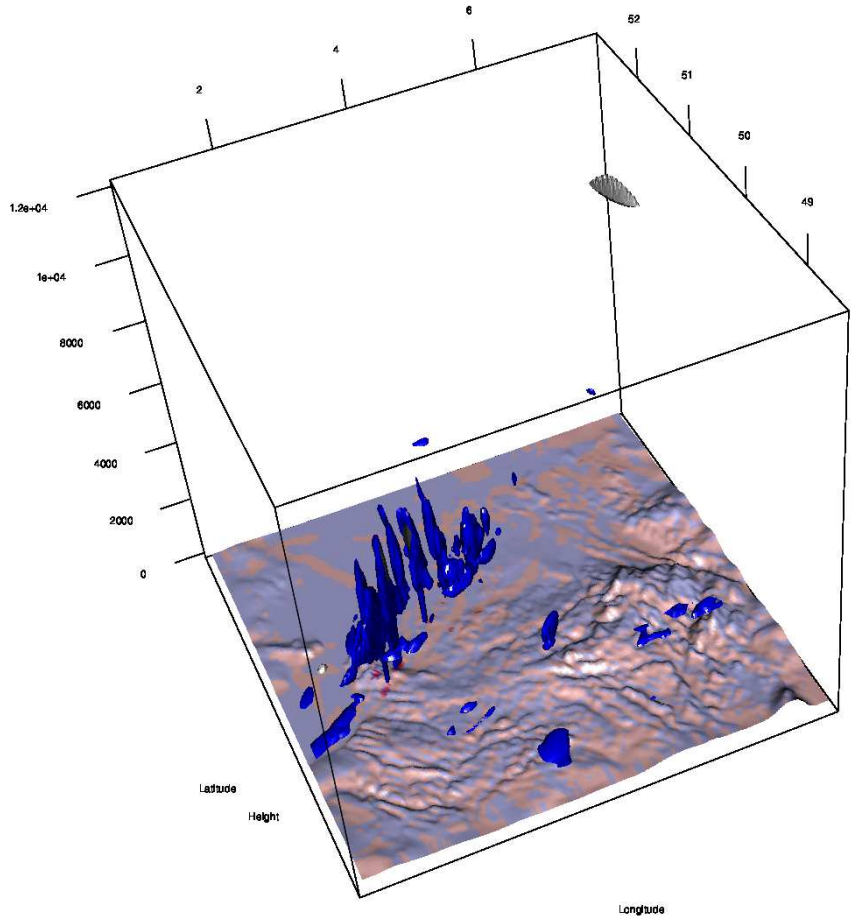


About deep convection

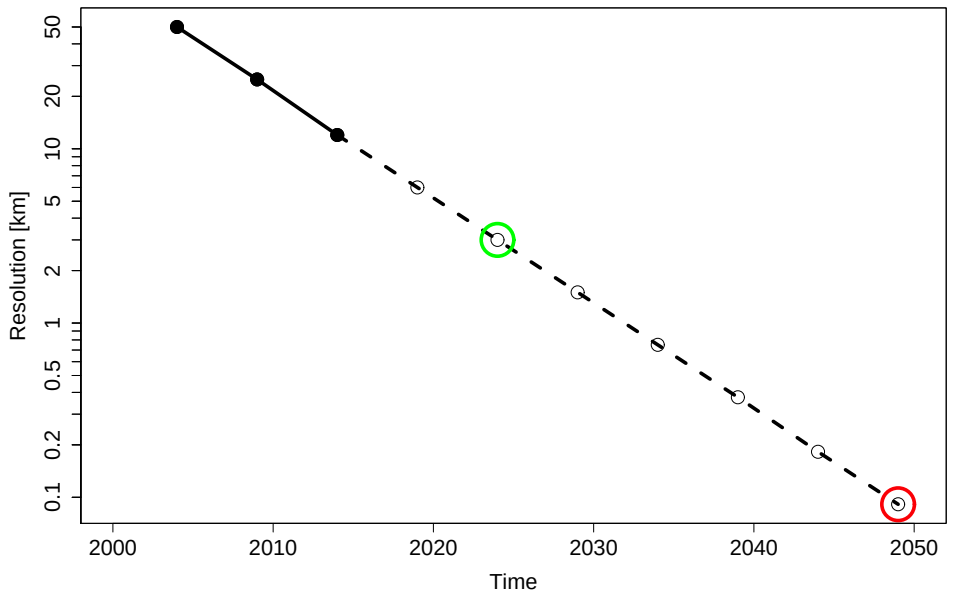
- Vertical instability
- Extends high up in the atmosphere (e.g., $12\ km$)
- Small horizontal scale
- Short temporal scale

Associated weather

- Lightning
- Wind gust
- Hail
- Extreme precipitation



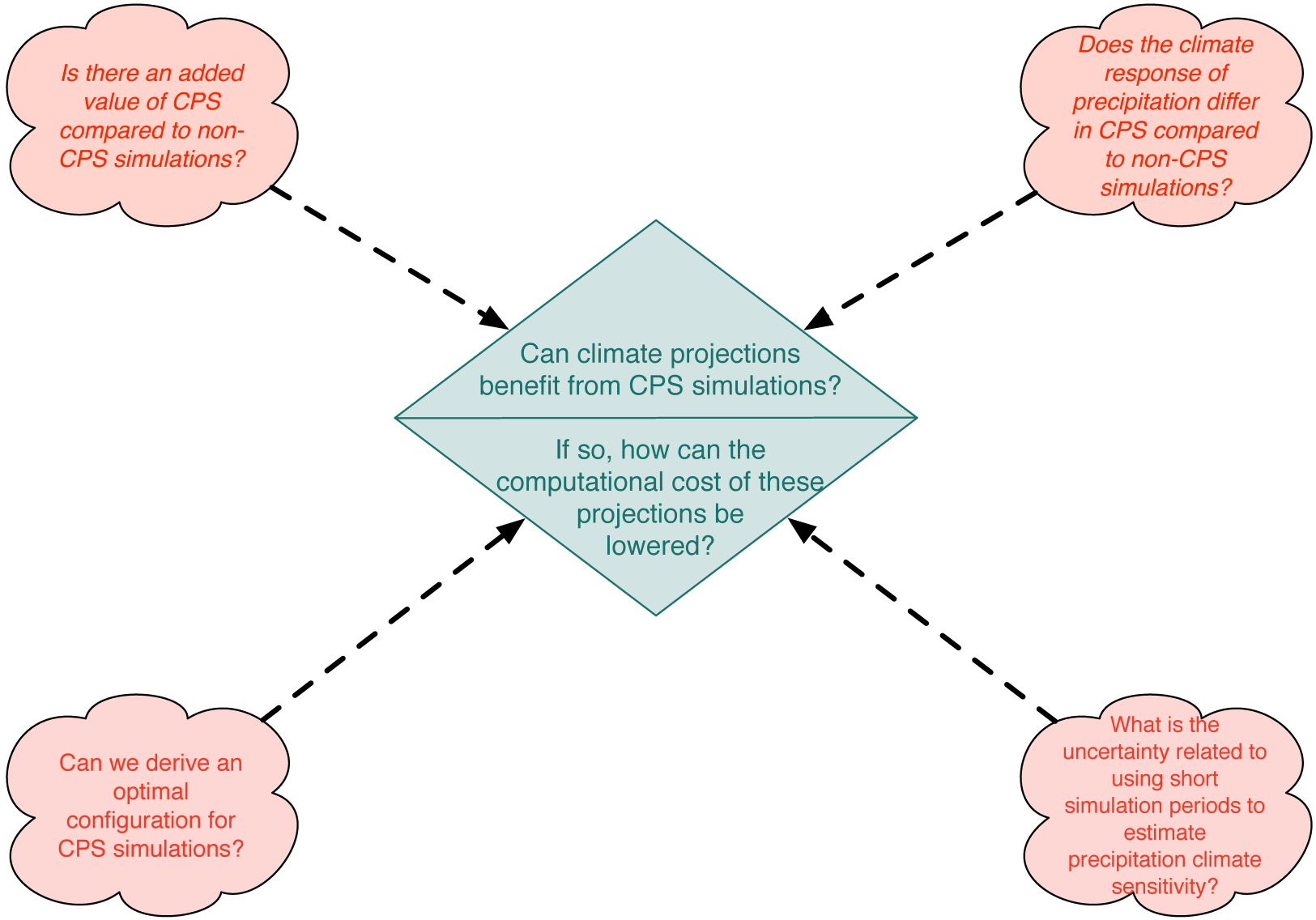
(model simulation for the 16.06.2007)

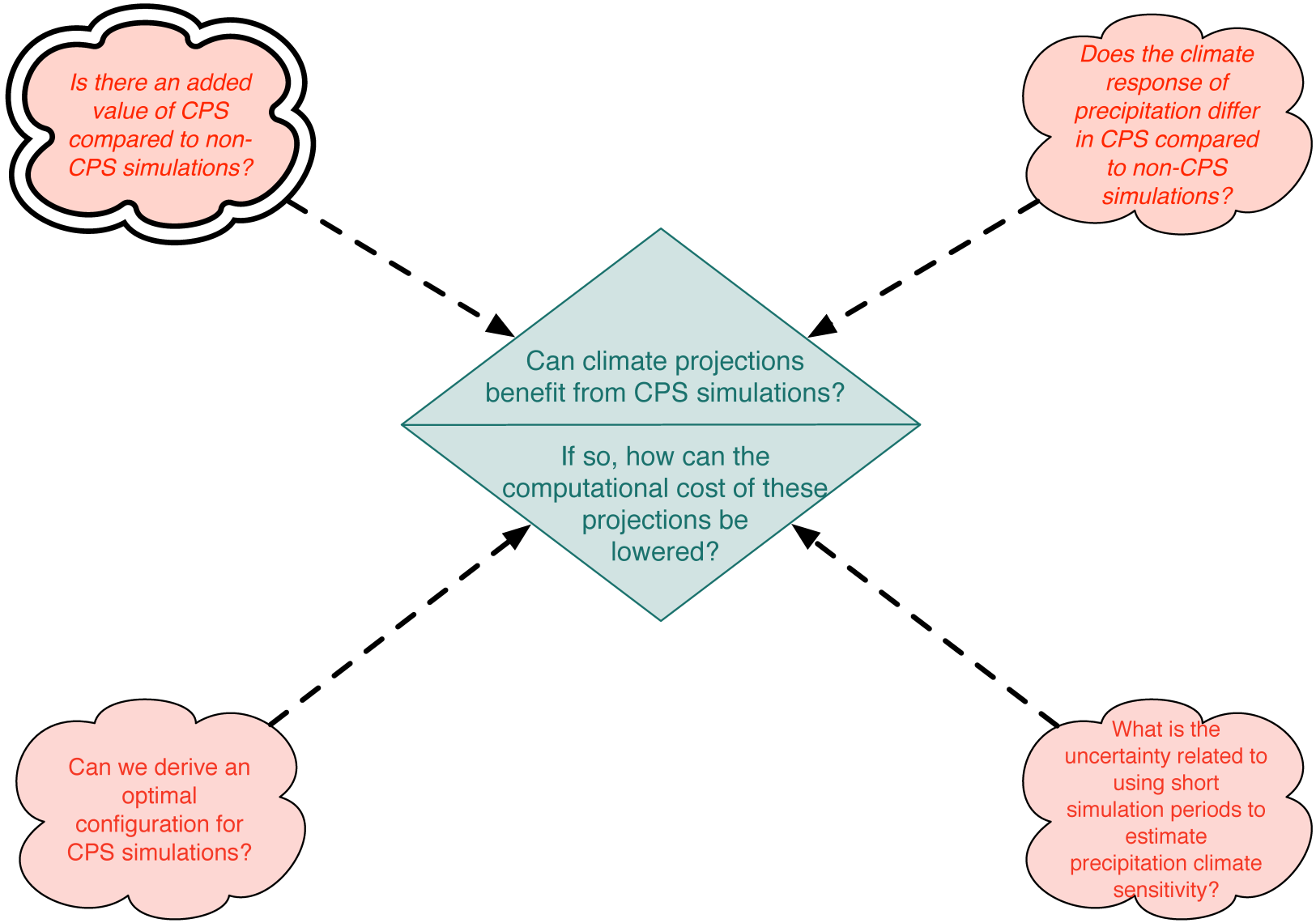


Possible evolution of climate prediction resolution (doubled resolution in 5 years)

Drawbacks - **Computational resources**

- Very high CPU time
- Model output requires storage system with large capacity


Is there an added value of CPS compared to non-CPS simulations?
Does the climate response of precipitation differ in CPS compared to non-CPS simulations?
Can climate projections benefit from CPS simulations?
If so, how can the computational cost of these projections be lowered?
Can we derive an optimal configuration for CPS simulations?
What is the uncertainty related to using short simulation periods to estimate precipitation climate sensitivity?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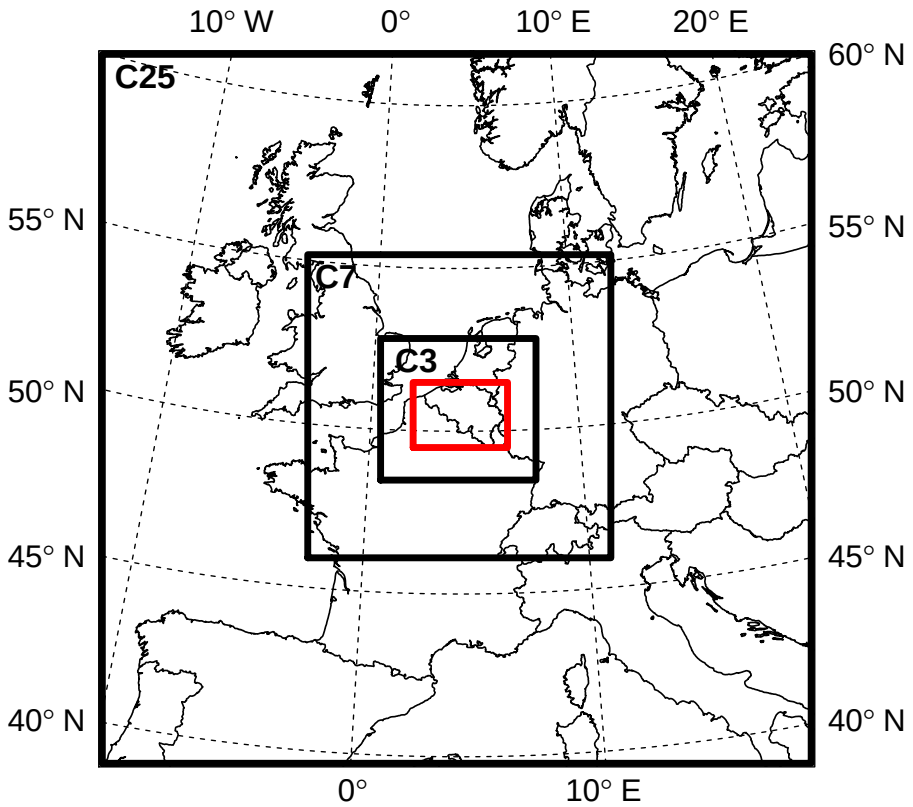
COSMO-CLM :

- Regional climate model adapted from COSMO (weather forecast model)
- COSMO-CLM community (about 200 members)

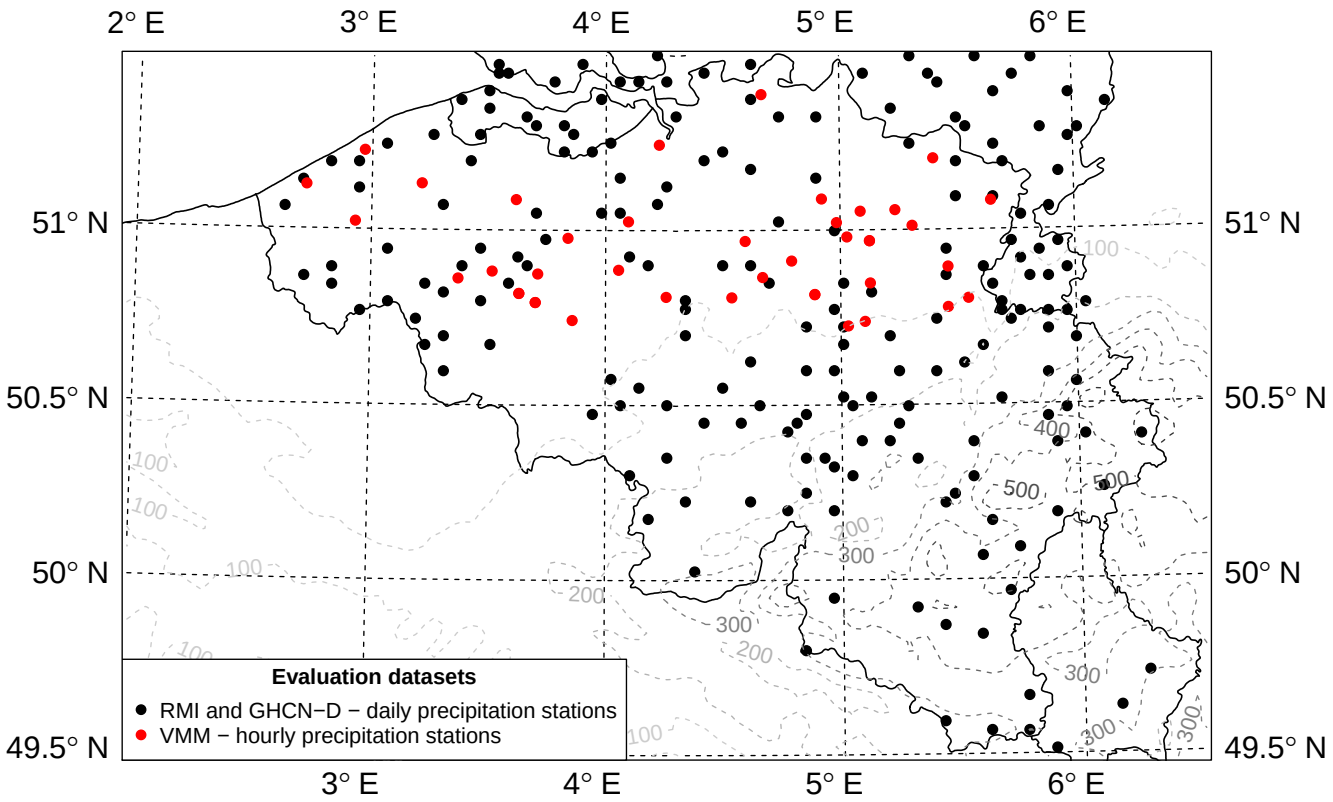
Reference setup :

- Three-step nesting strategy (25, 7 and 2.8km)
- Reanalysis used as global model

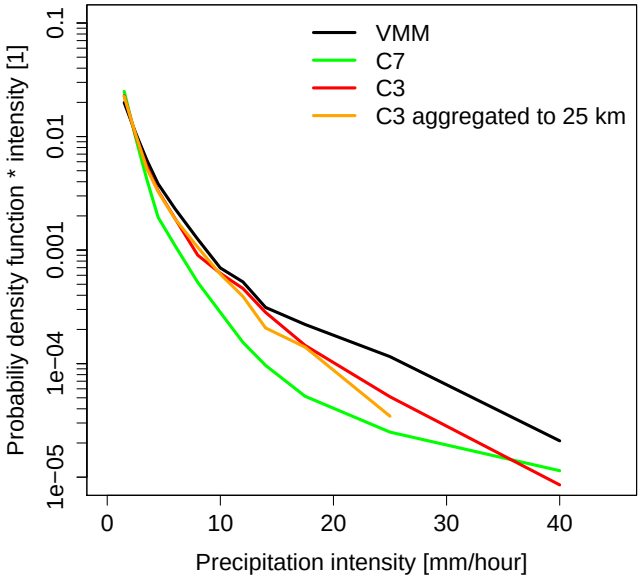


Precipitation observations

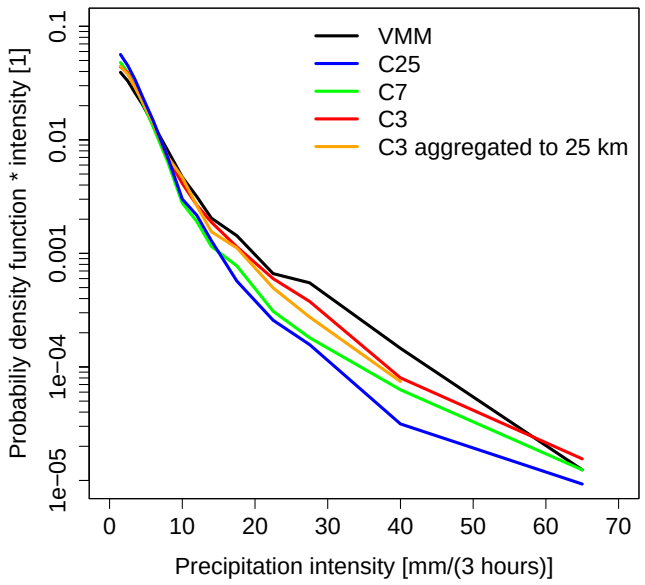
- Hourly : VMM (slight underestimation of the lowest quantiles)
- Daily and dense network from RMI and ECA&D



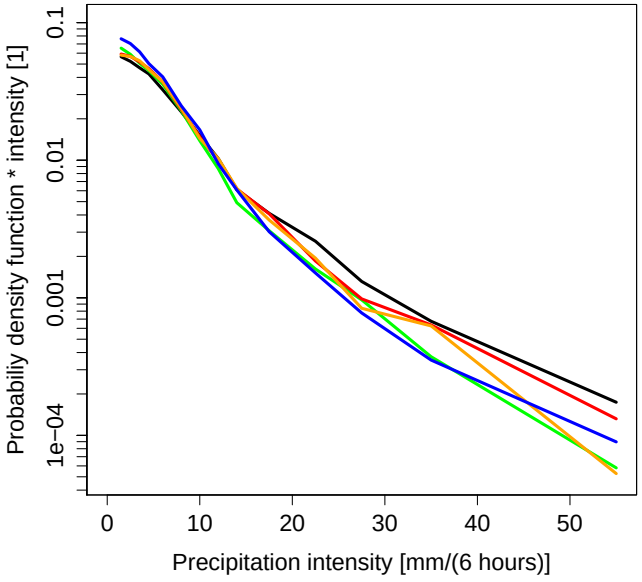
Daily and sub-daily distributions



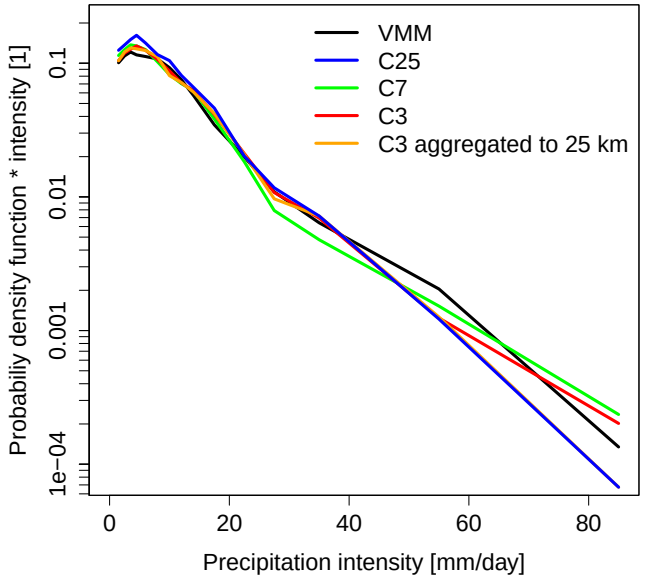
Hourly scale



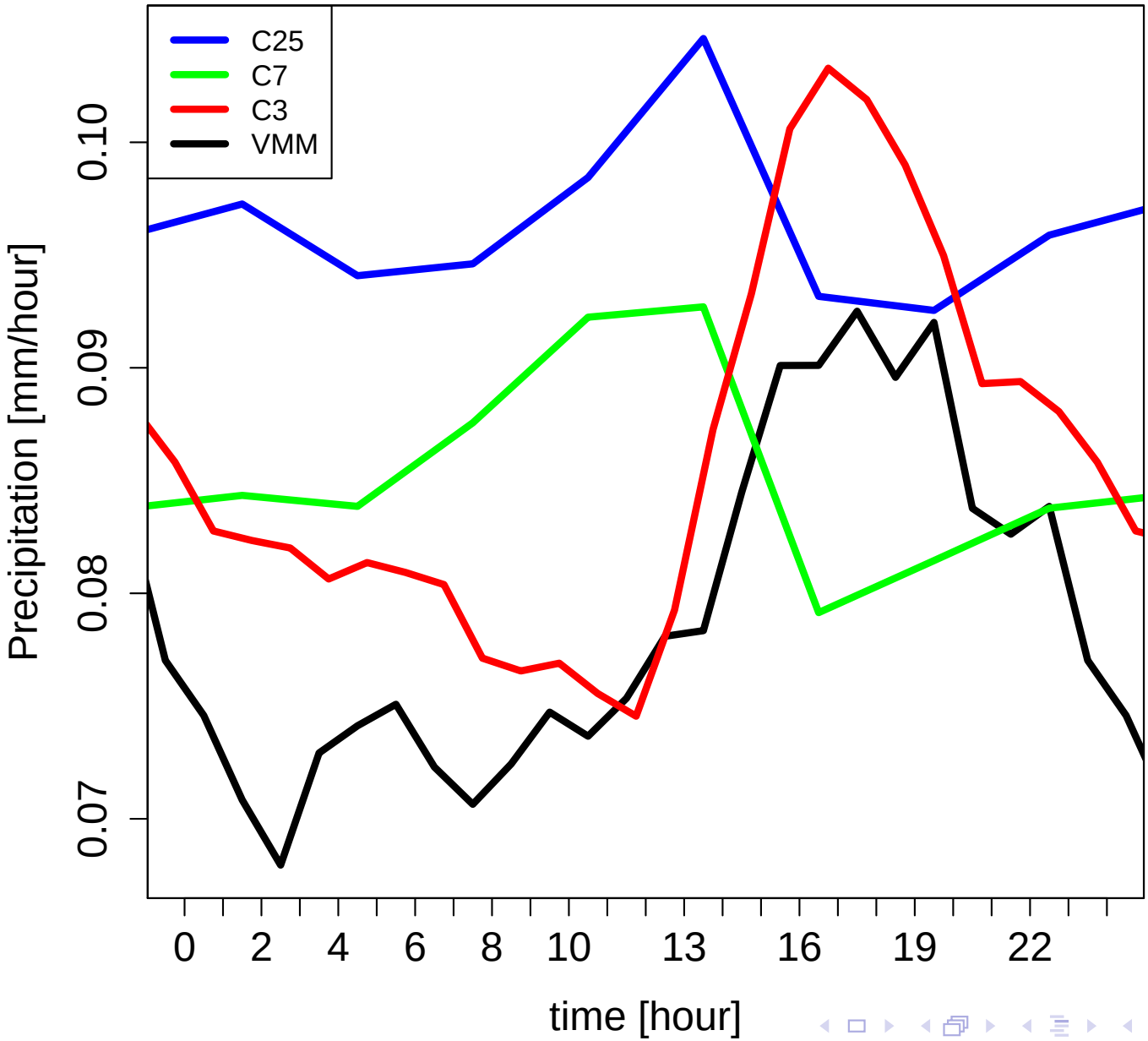
3-hour scale



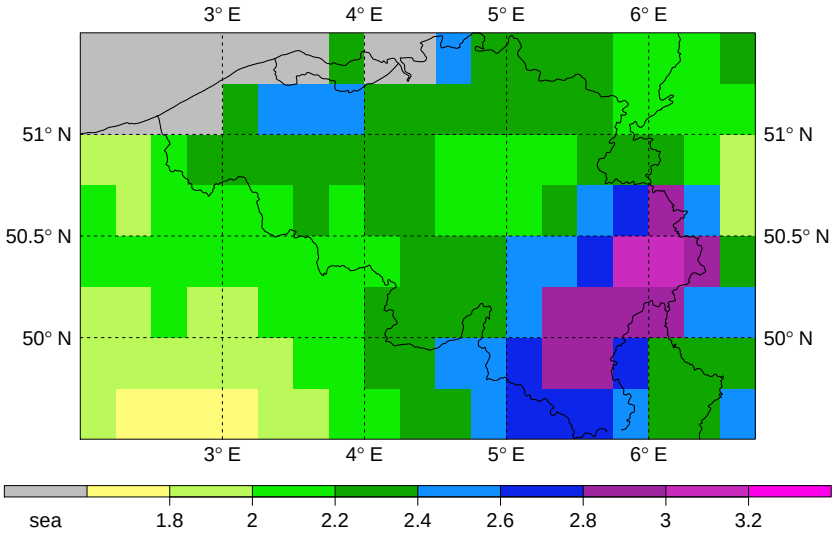
6-hour scale



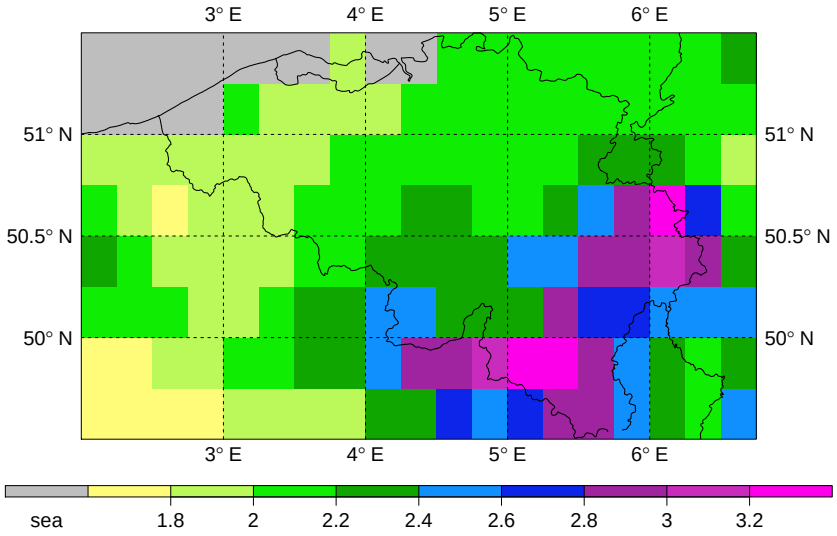
24-hour scale


C25
C7
C3
VMM
Precipitation [mm/hour]
0.07
0.08
0.09
0.10
0
2
4
6
8
10
13
16
19
22
time [hour]

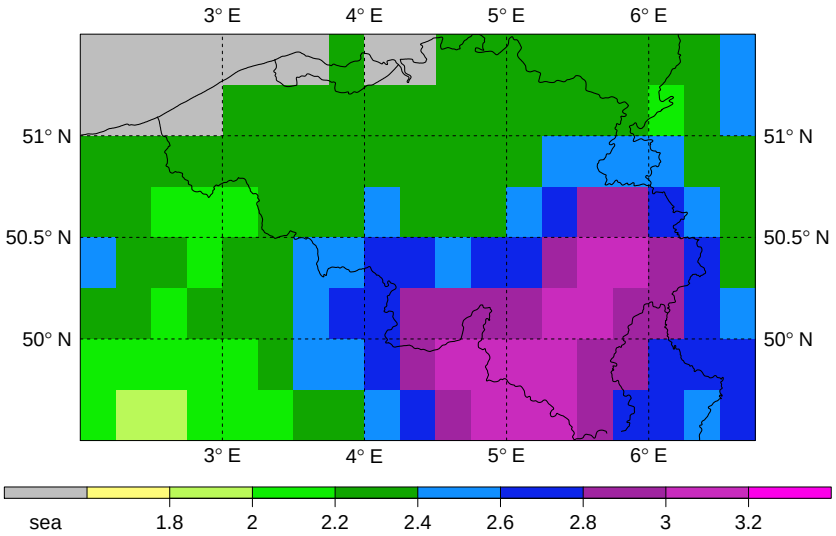
Spatial patterns



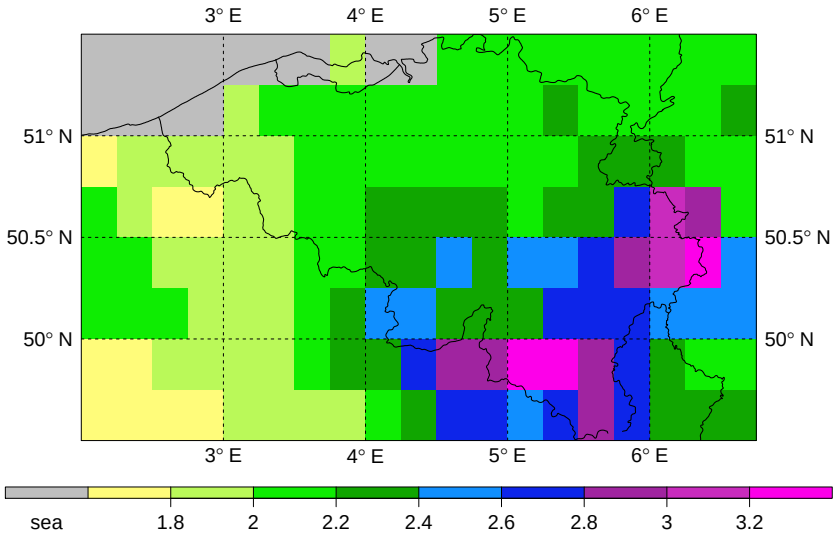
OBS



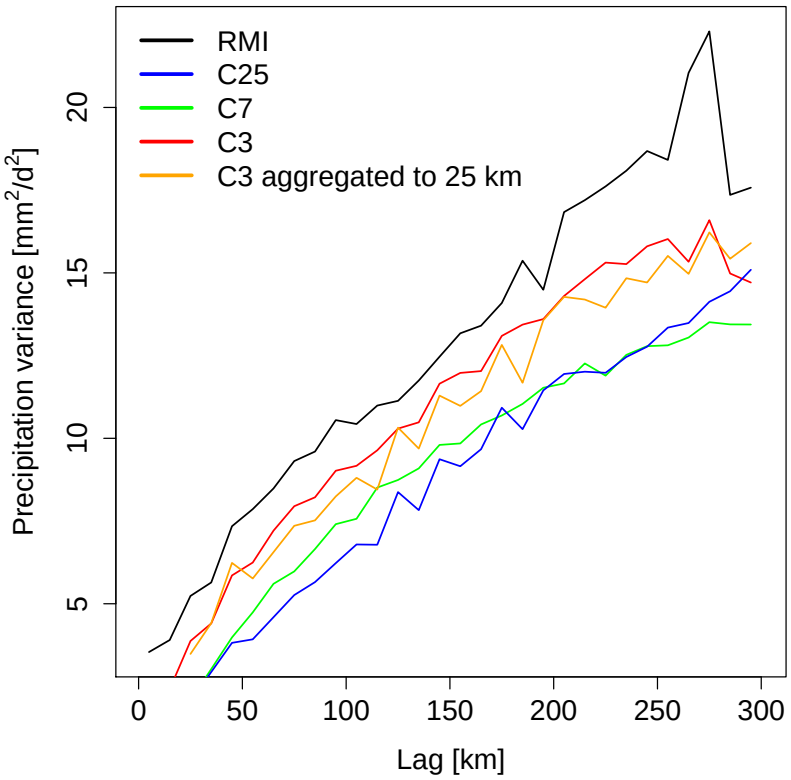
7 km



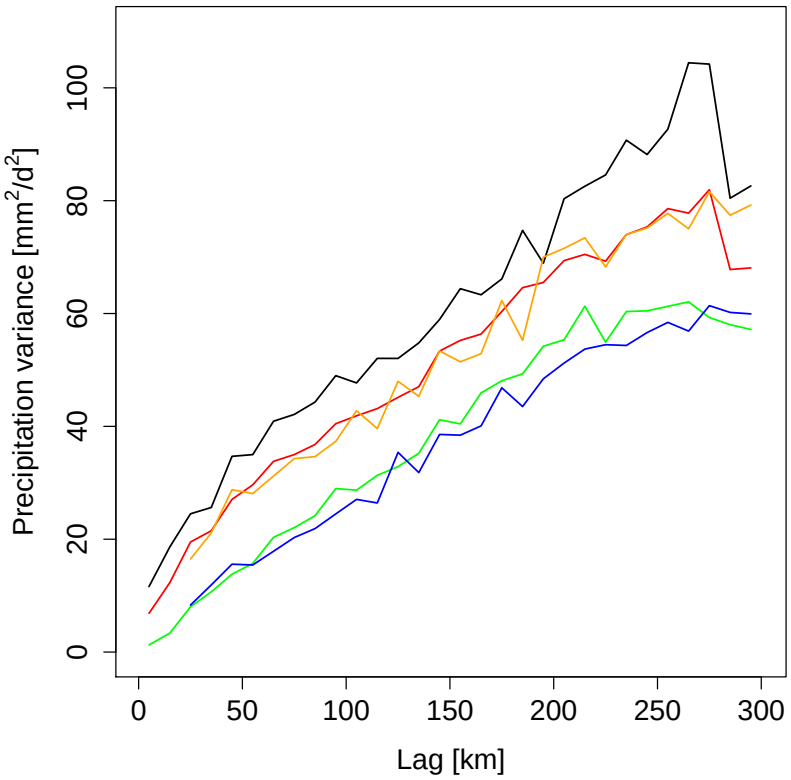
25 km



2.8 km



Average



90^{th} quantiles

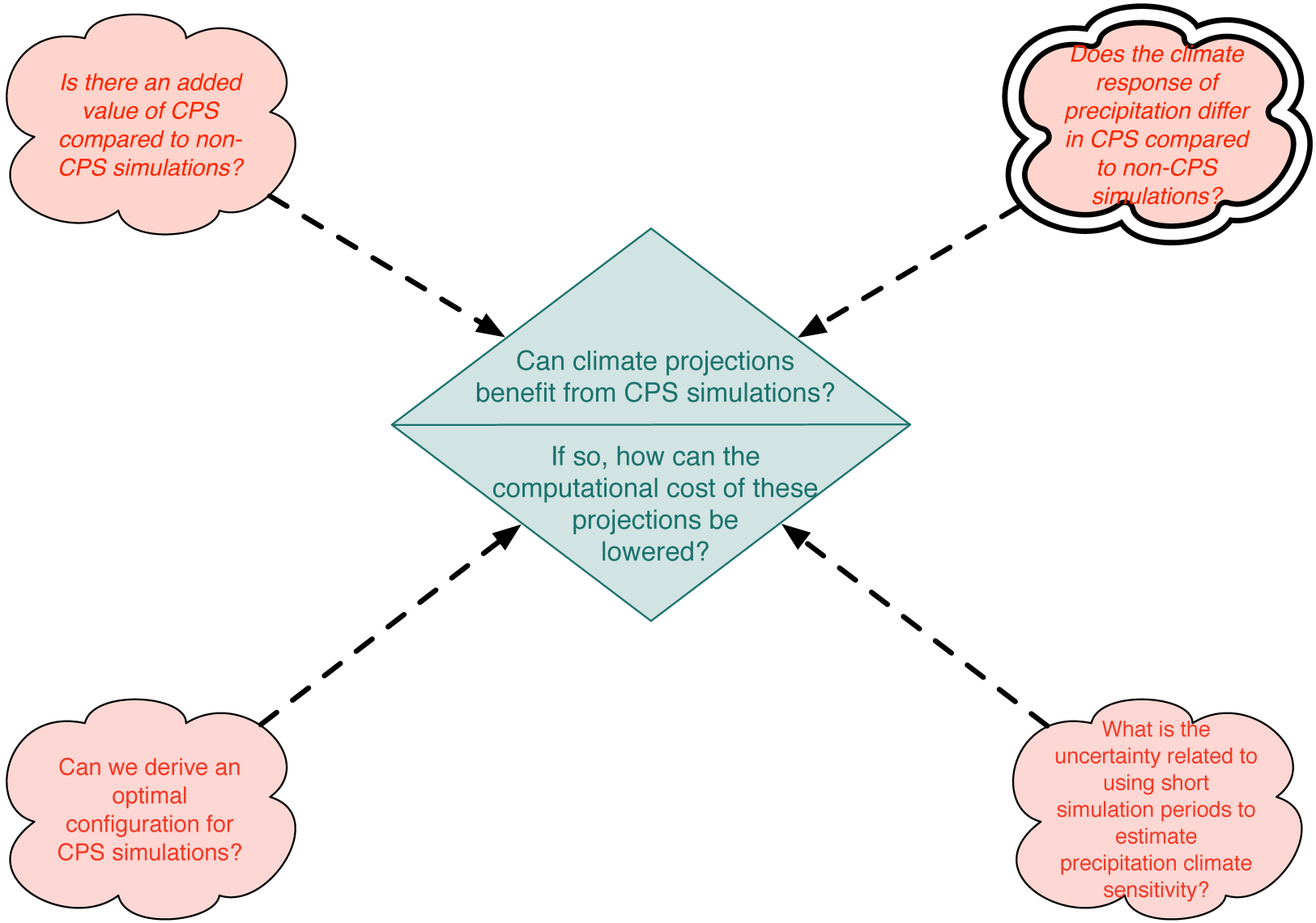
Added value of CPS compared to non-CPS simulations ?

Temporal added value

- Improved representation of the hourly scale
- Improved daily cycle

Spatial added value

- Improved representation of spatial patterns in areas with complex orography
- Improved spatial variance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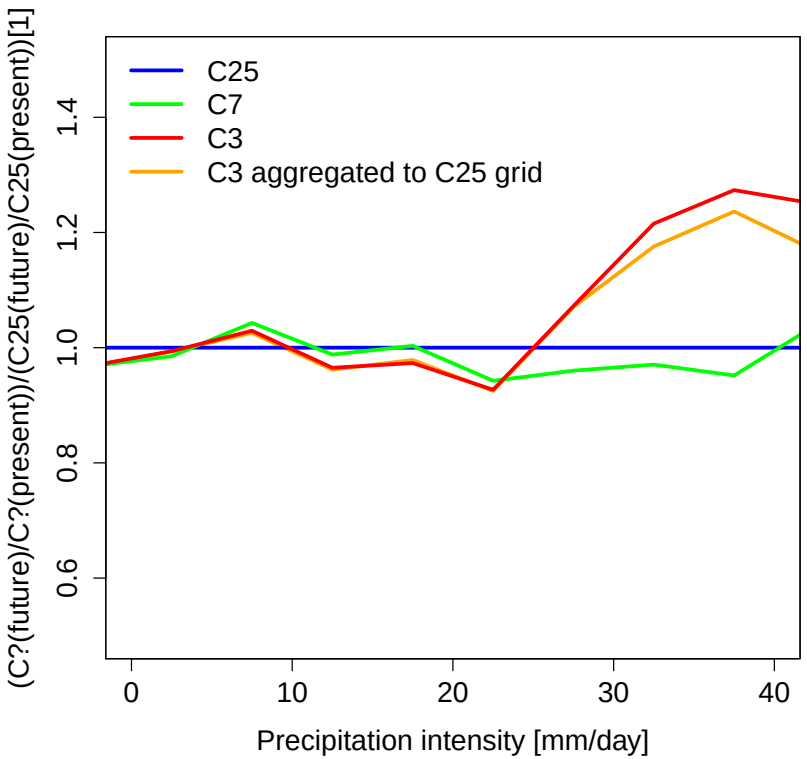
Additional climate simulation

- Global model (with no assimilation of observations)
- Present-day 2000-2010
- Future 2025-2035

Resolution dependency

- Not in the low and medium quantiles
- Up to 25% for the highest quantiles



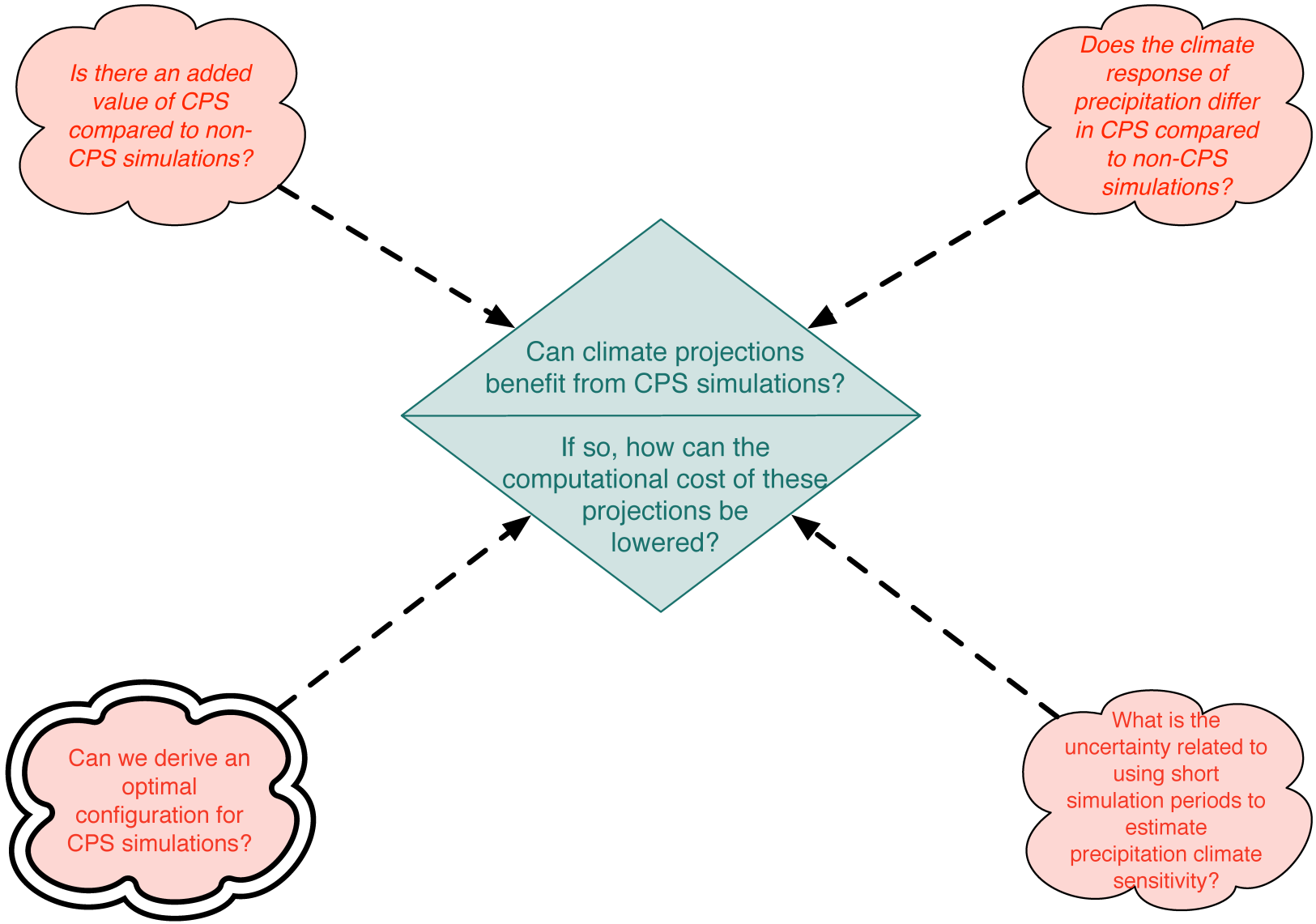
Can climate projections benefit from CPS simulation ?

YES ! But only for :

- Sub-daily scale, especially for extremes
- Area with complex orography
- Spatial variance
- Estimation of extremes in climate projections

NO ! If one cannot deal with :

- Large datasets (tens of terabytes)
- High computational resources $\rightarrow$ Need of about **270000 CPU** hours for these simulations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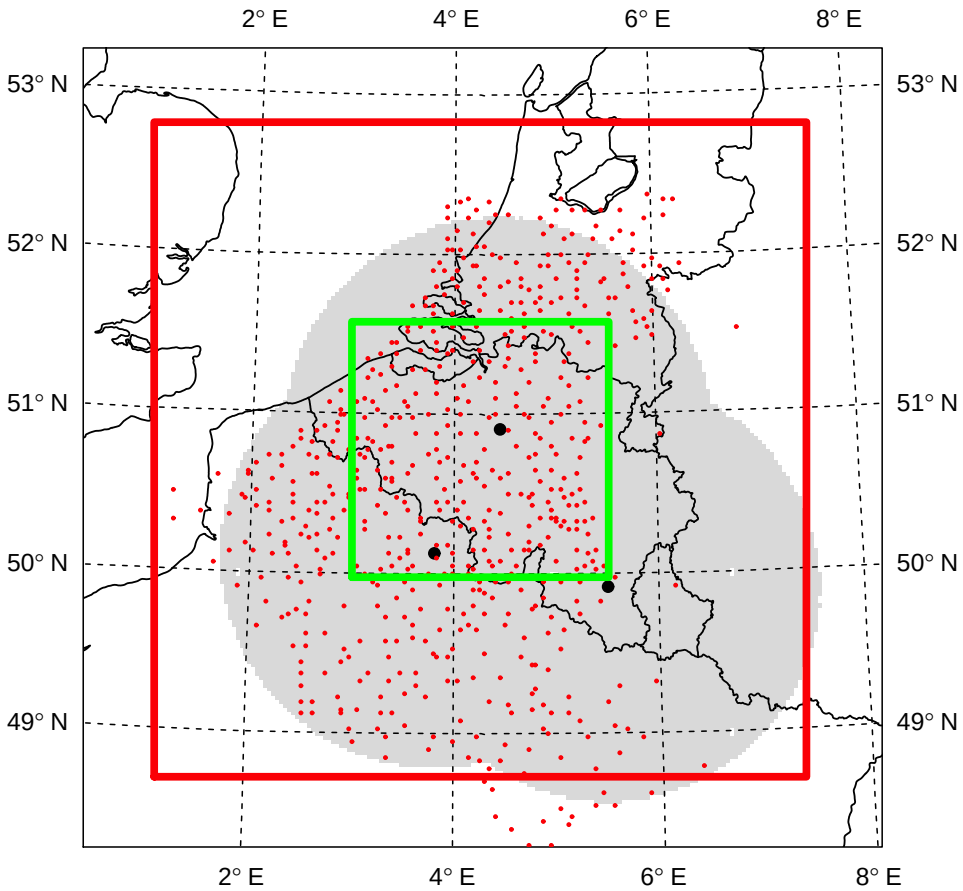
Reference setup :

- Reanalysis used as global model
- 4 month period (Summer 2007)

Observations

- Dense rain gauges network from RMI and ECA&D
- Radar product

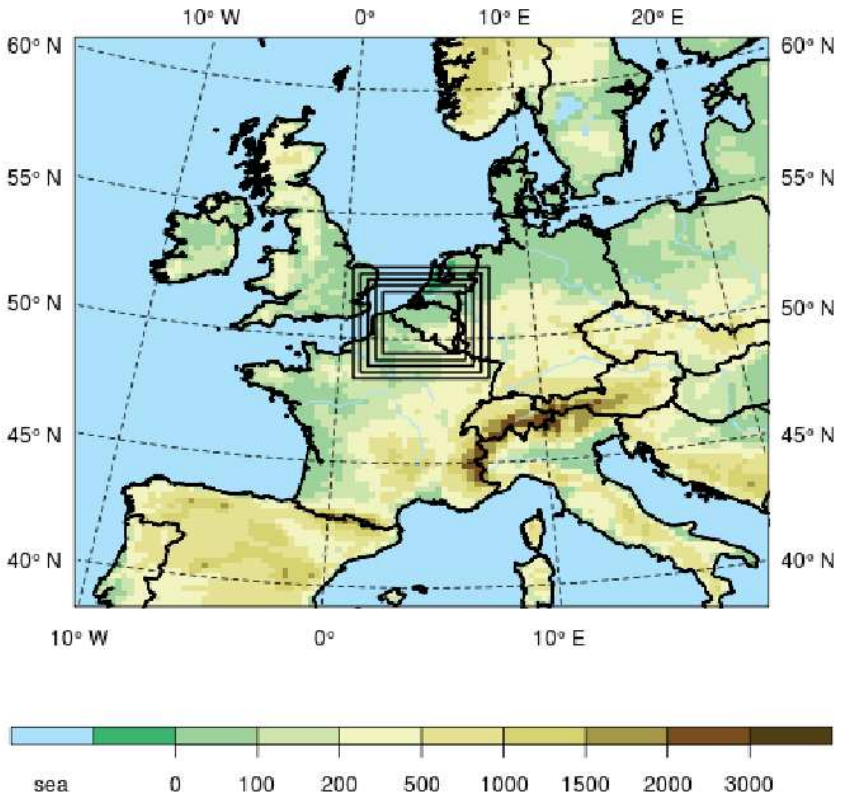


Question : Can we reduce the simulation domain ?

SPA : 2.8km domain size

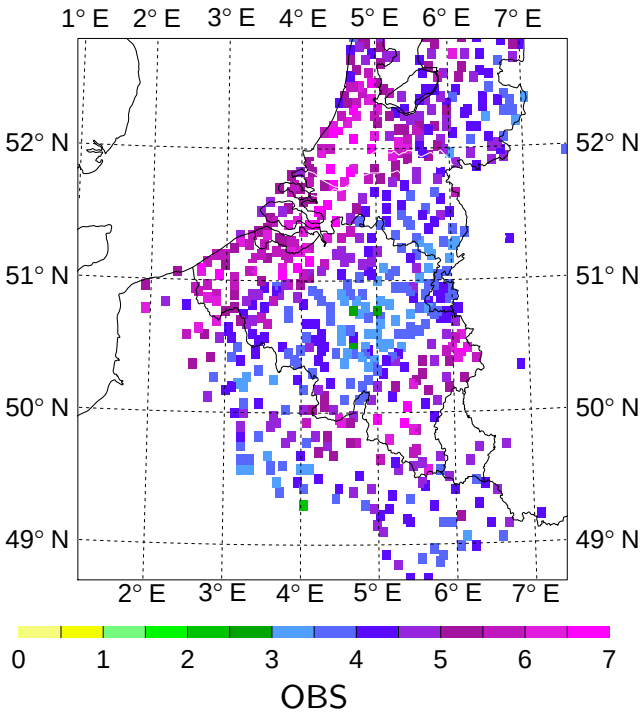
- 5 different domain sizes + REF
- REF is 200x200 grid points
- increment of 20x20

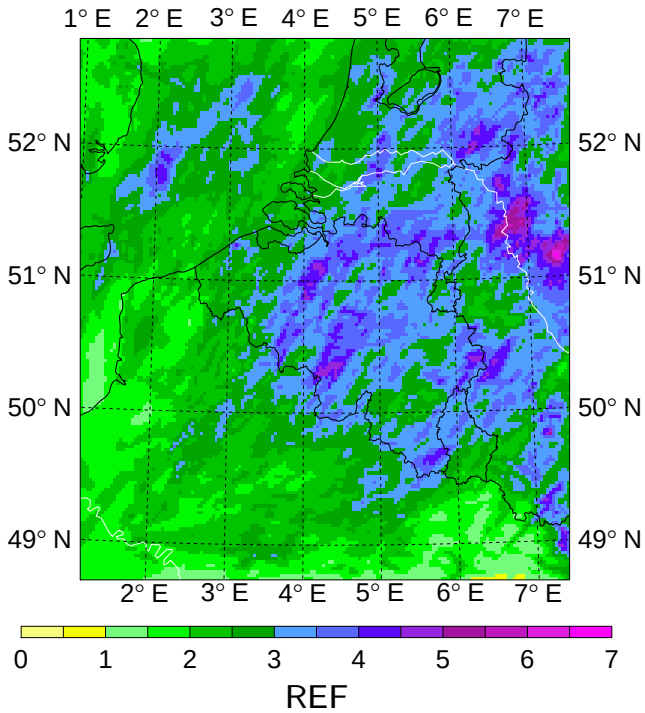
Exp	Grid 2.8km
REF	200x200
SPA180	180x180
SPA160	160x160
SPA140	140x140
SPA120	120x120
SPA100	100x100

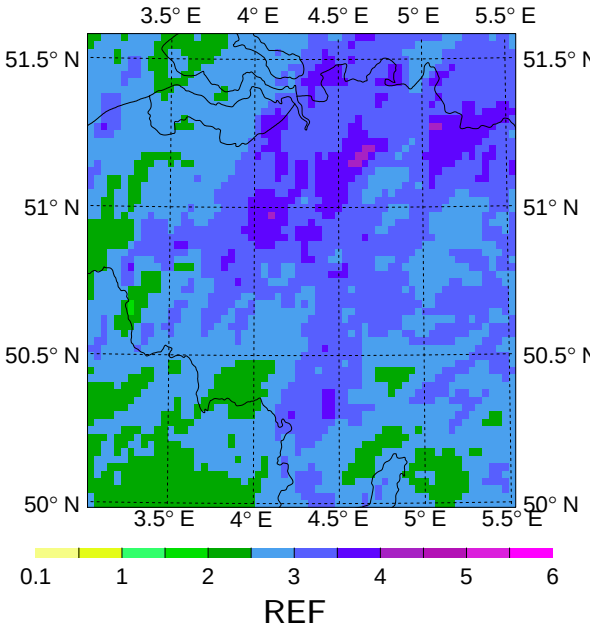


Evaluation REF

- Correct amplitude
- Slight mislocation







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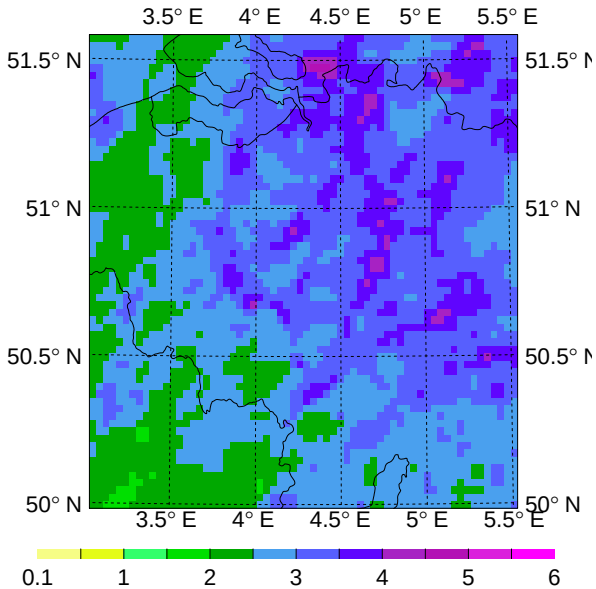
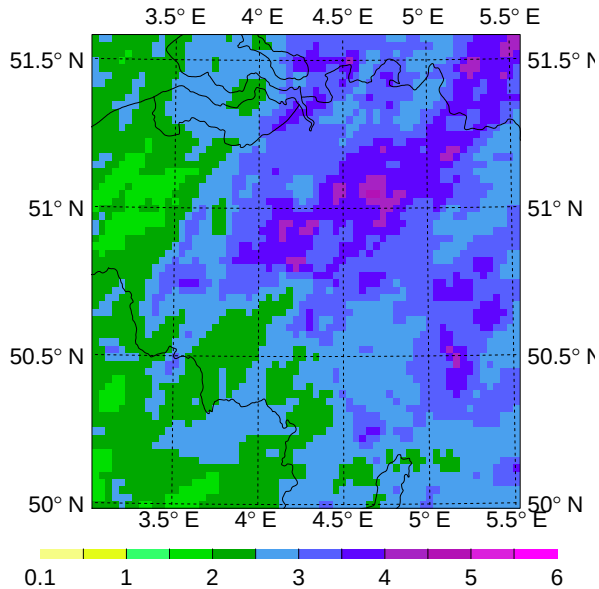
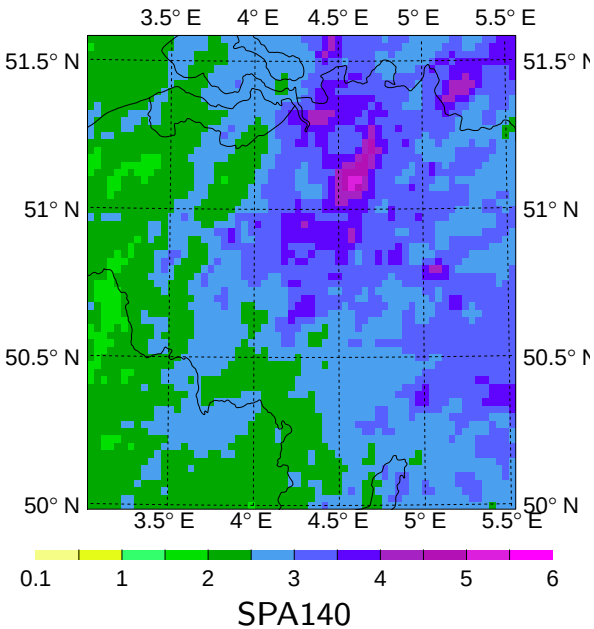


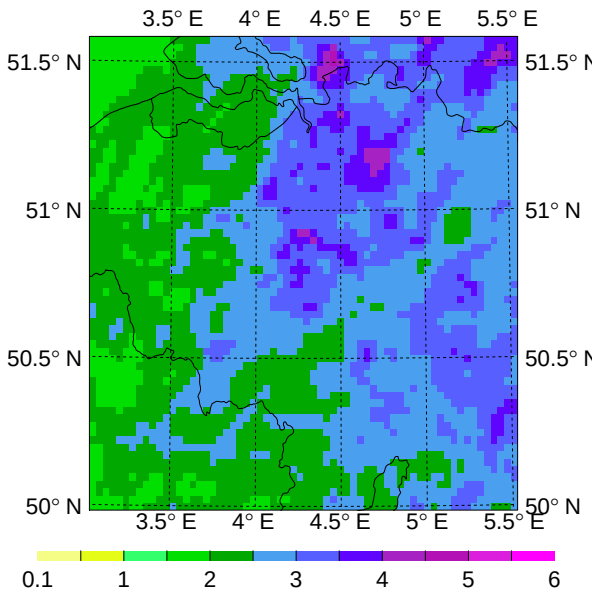
SPA180



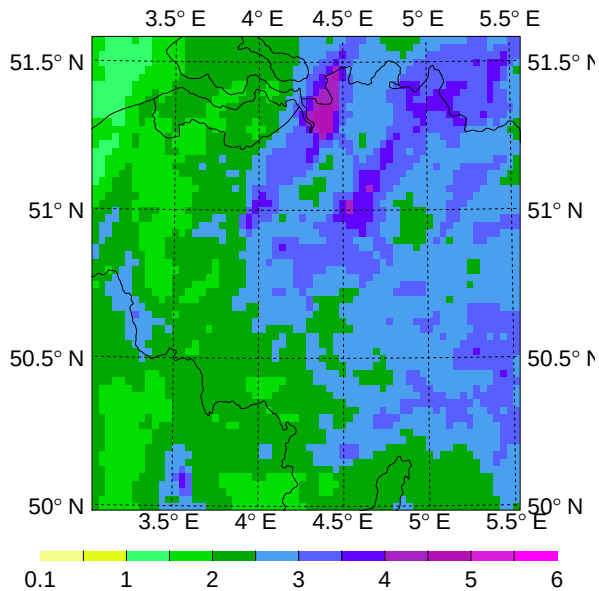
SPA160



SPA140



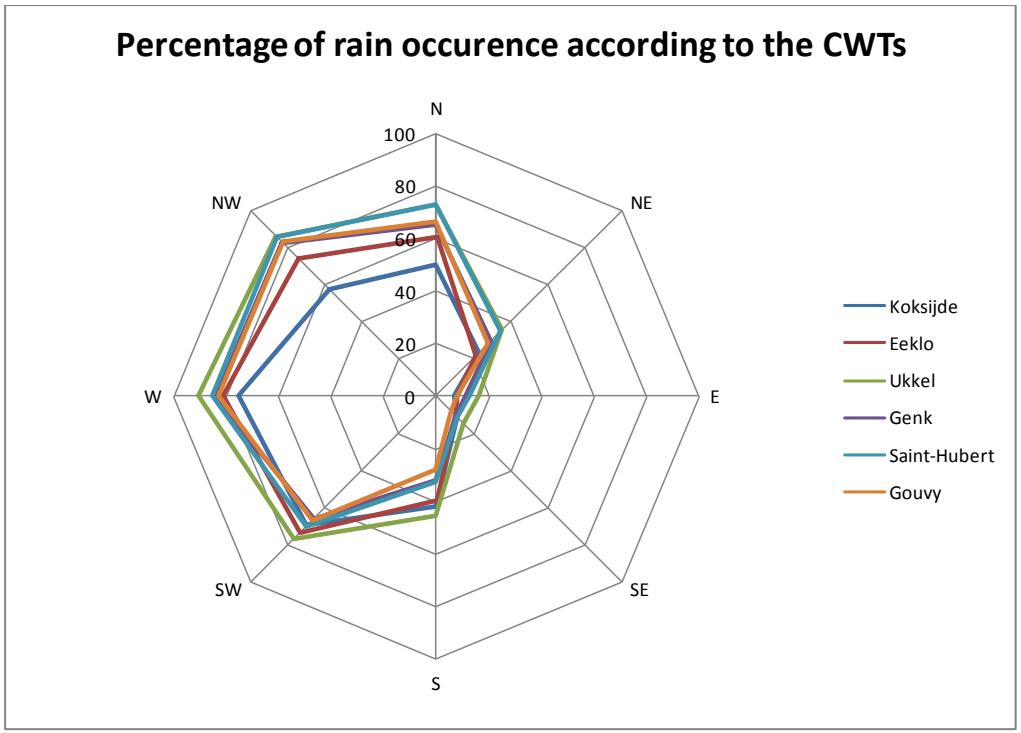
SPA120



SPA100

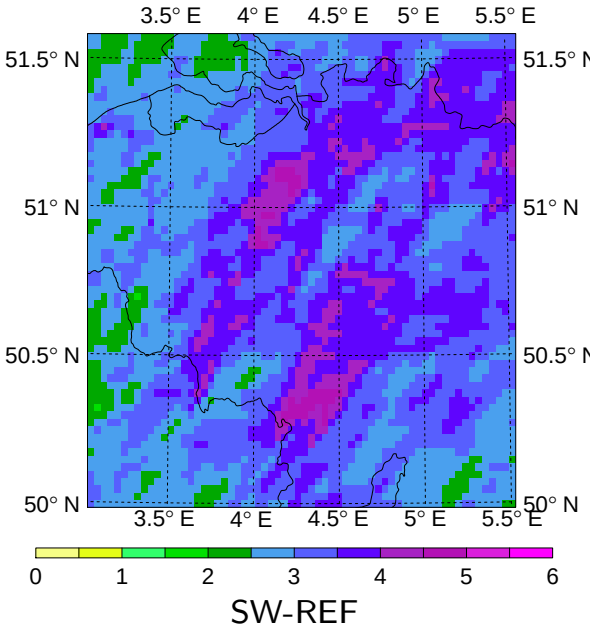
Why does underestimation occur just in the South and the West ?

- General circulation weather types (CWT)
- Northern flows are characterized by large-scale precipitation
- Southern and Western flows with convective precipitation

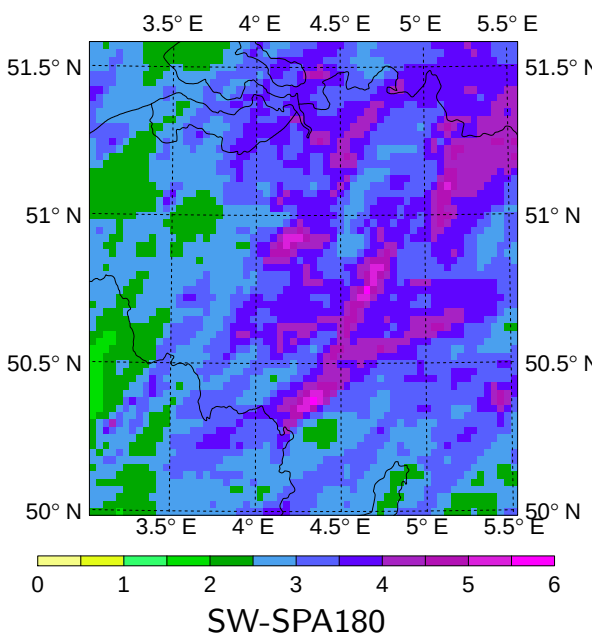


For summer 2007

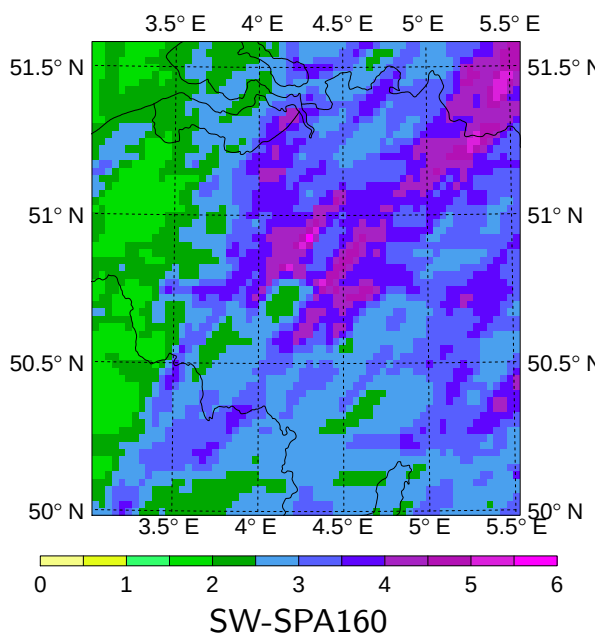
- S-SW-W 48% of precip with 47% convective
- N-NE-E 18% of precip with 32% convective



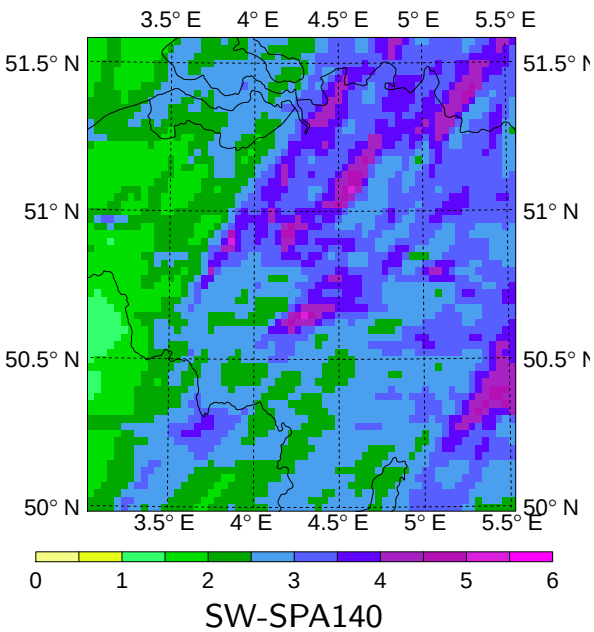
SW-REF



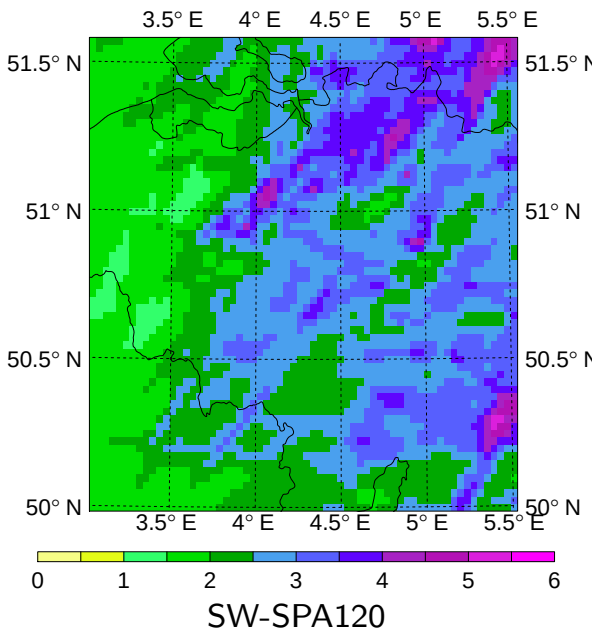
SW-SPA180



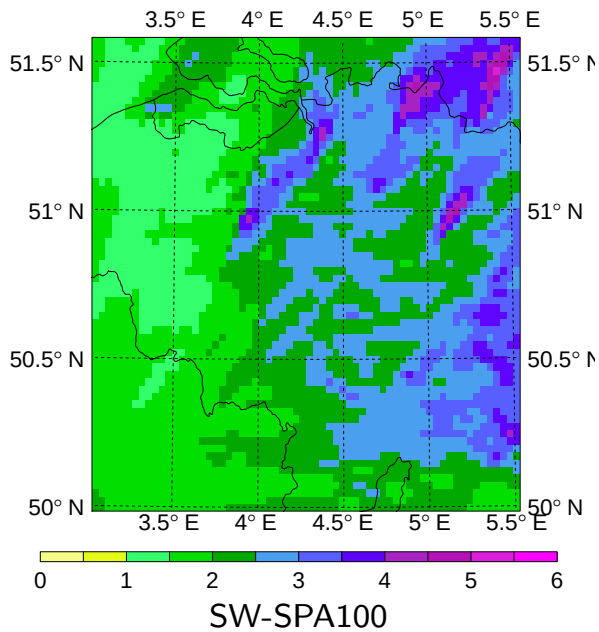
SW-SPA160



SW-SPA140



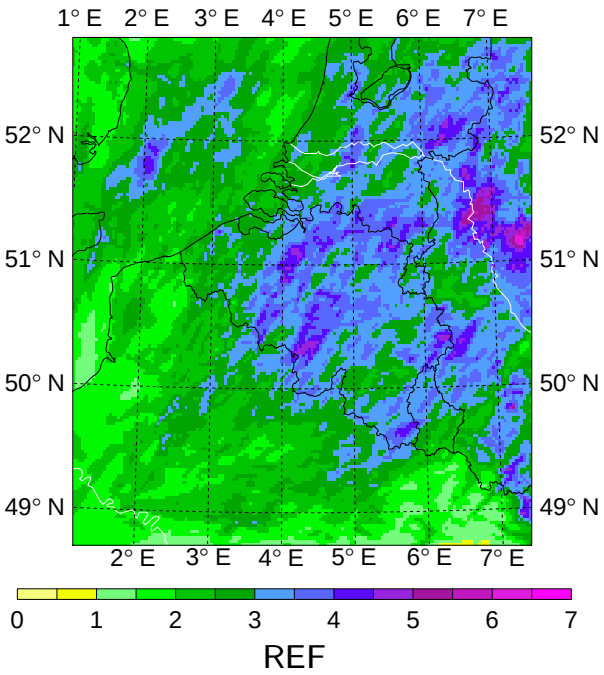
SW-SPA120

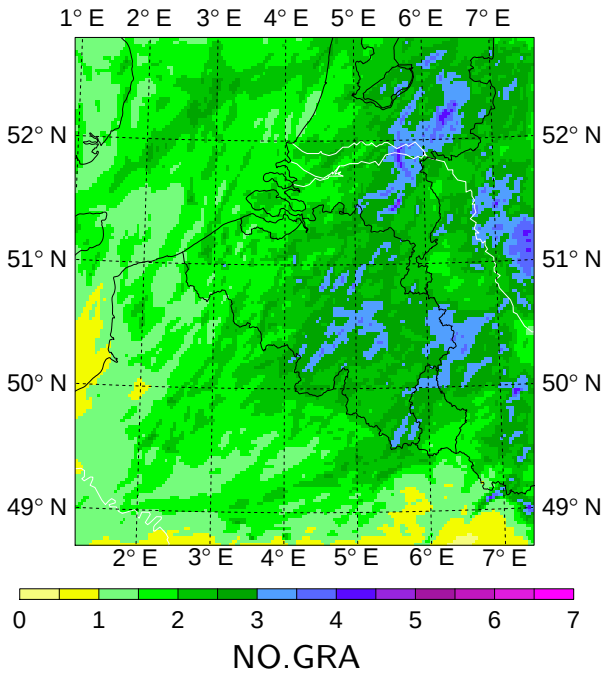


SW-SPA100

Graupel

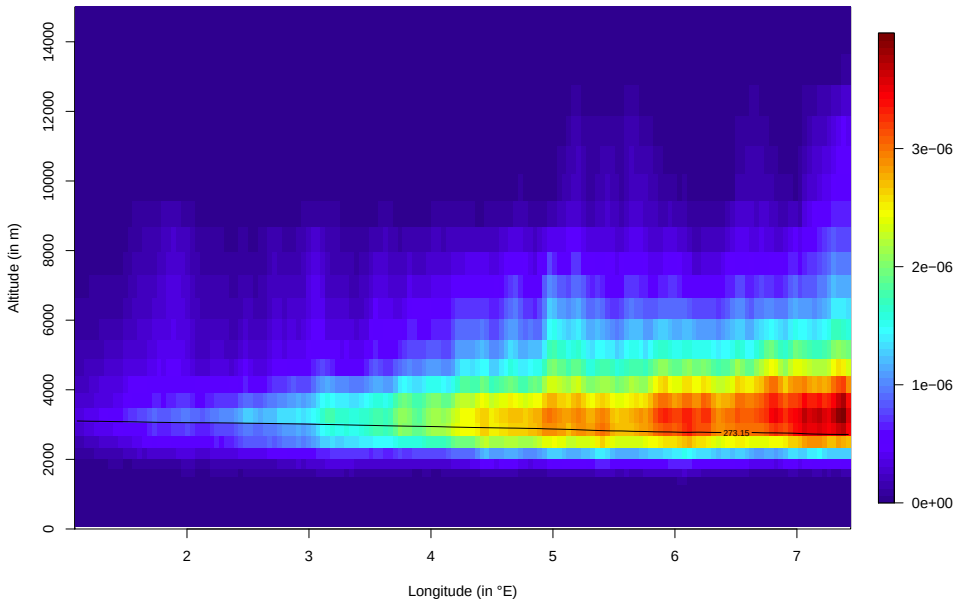
- Without graupel, low precipitation accumulation
- snow + supercooled water → graupel
- Grows in the updraft/downdraft and forms hail
- Slow process → spatial shift of precipitation





Graupel

- Without graupel, low accumulation
- snow + supercooled water $\rightarrow$ graupel
- Growth in the updraft/downdraft and forms hail
- Slow process $\rightarrow$ spatial shift of precipitation



Vertical profile of graupel specific content (Western flow)

Conclusion

- Reduction of the simulation domain possible
- But to a limited extent (spin-up)
- Graupel development is probably responsible for this

Climate predictions

- Usually 30 years (at least 2 times)
- Ensembles (20 models)
- Scenarios (4)
- Needed : $2 \times 30 \times 20 \times 4 = 4800$ years
- Can we decrease this number ?

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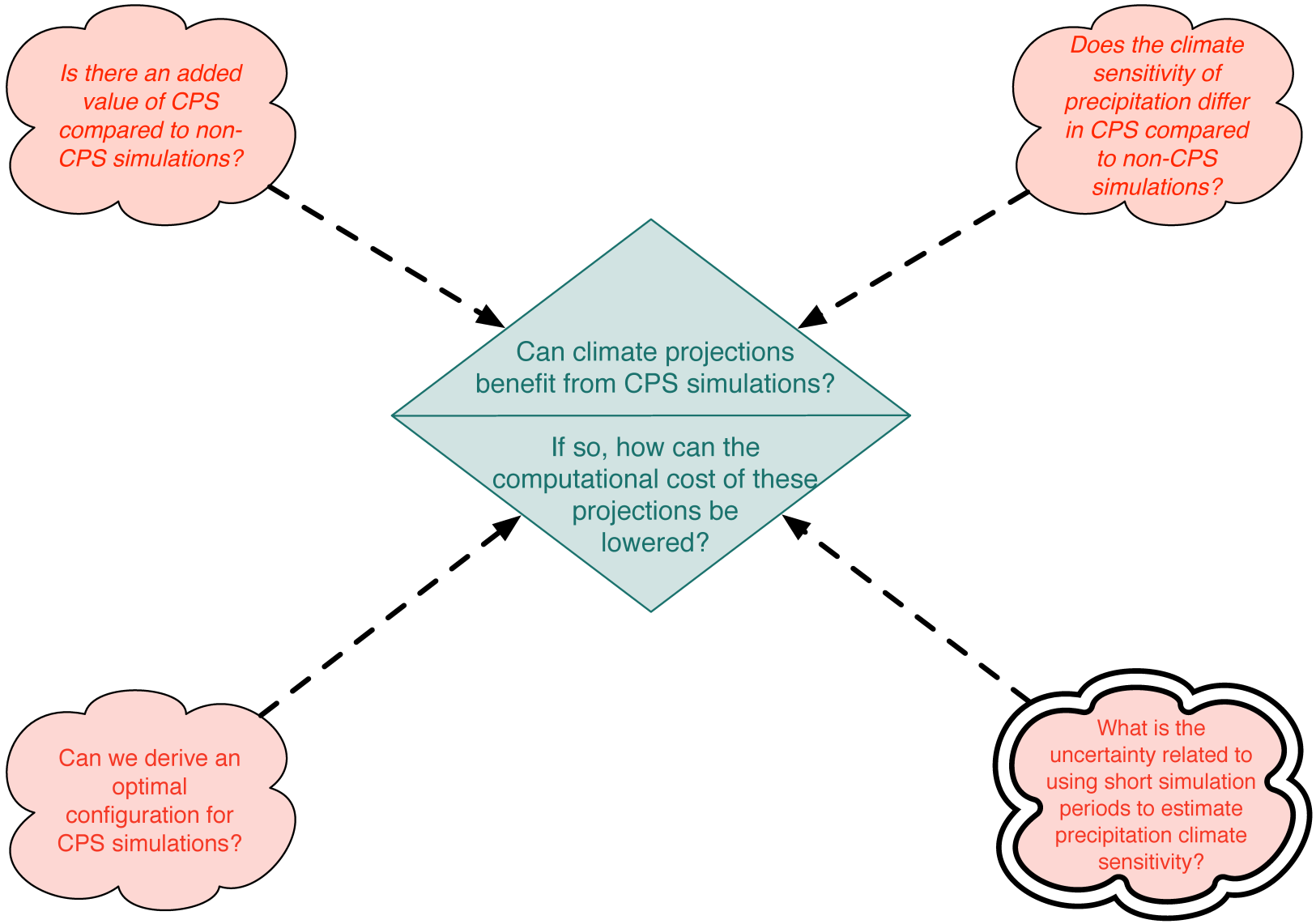
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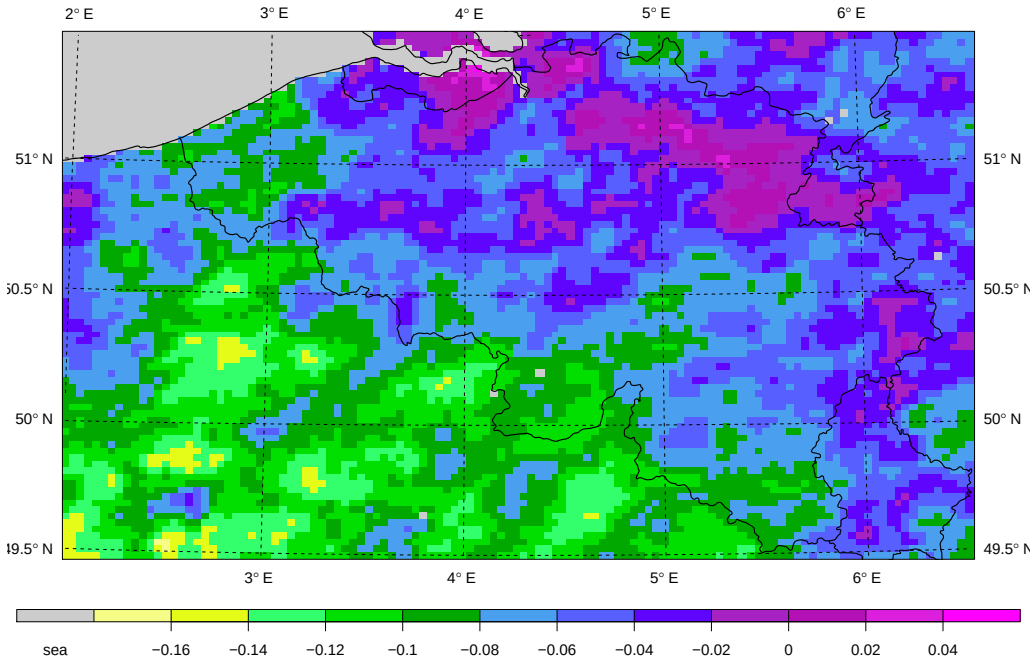


Example

- Precipitation
- (future-present)/present
- 2.8 km resolution

Description

- Mean : -8%
- More extreme negative
- Gradient
- 2 large areas of opposite signs

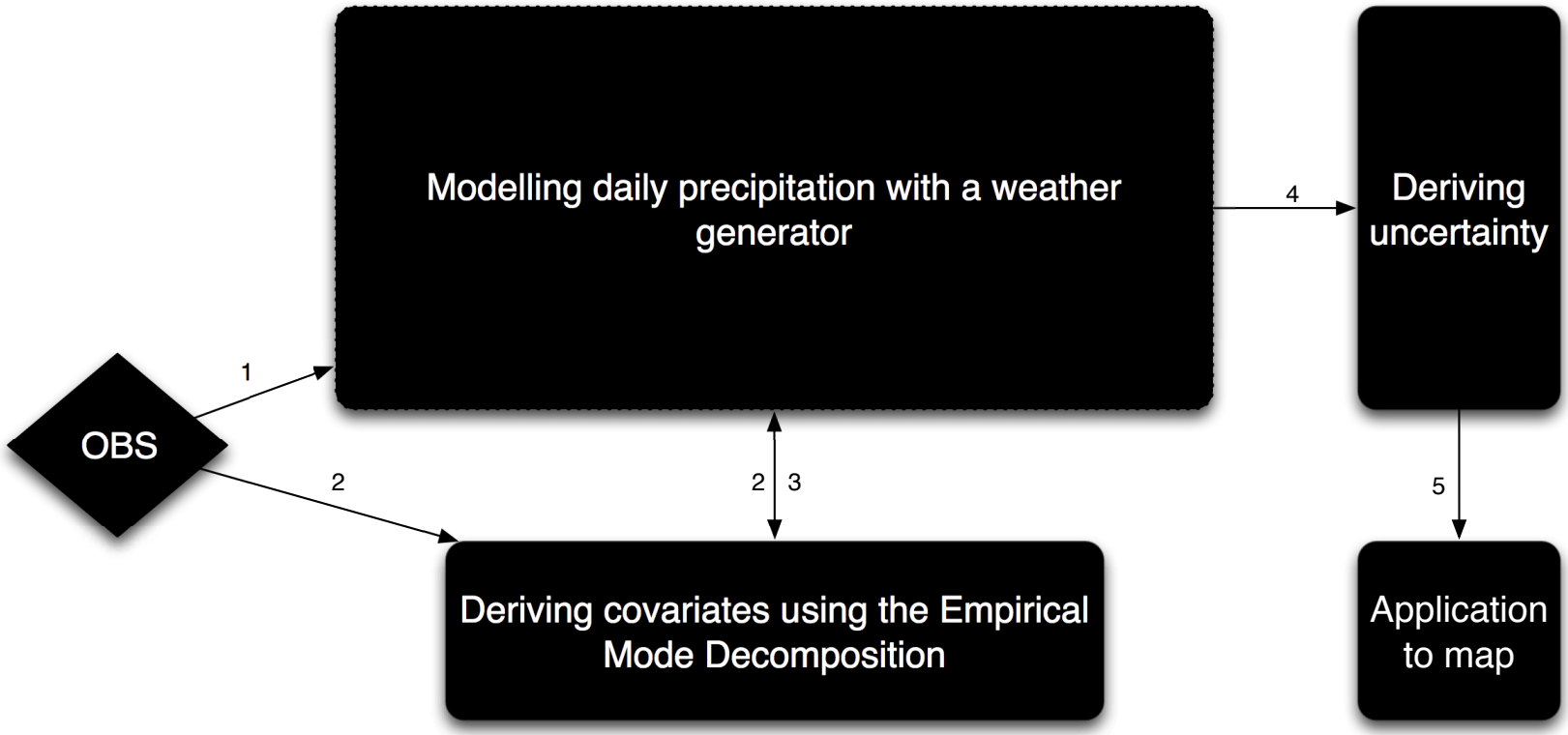
How can we be sure ? Need to derive the uncertainty !

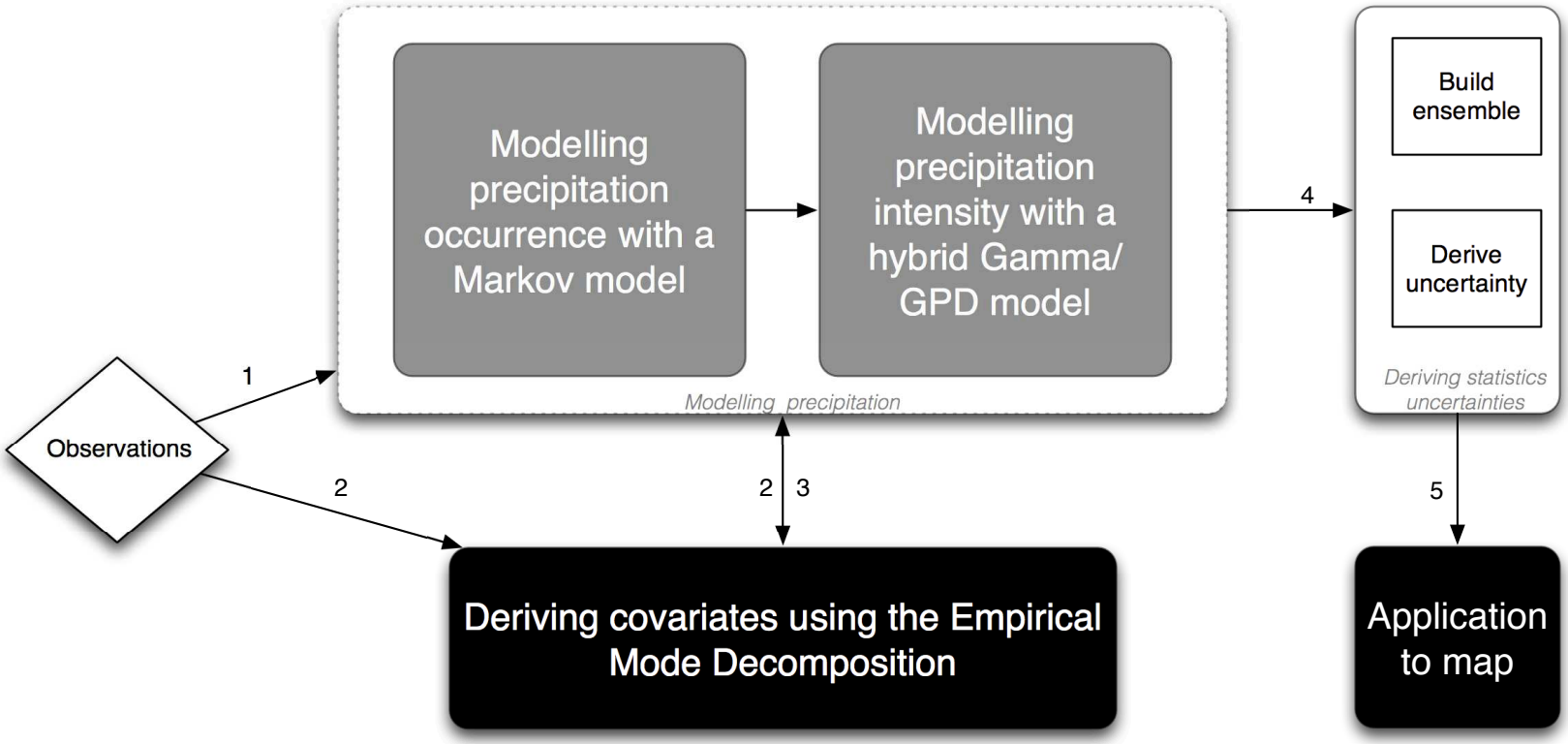
RCMs ensembles

- Usual method
- Provide alternative timeseries with **similar properties (cycles, trends and autocorrelation)**

Producing alternative timeseries $\rightarrow$ weather generator

- Producing realistic timeseries (possible climate realization)
- Derived the uncertainty from their divergence


Modelling daily precipitation with a weather generator
Deriving uncertainty
OBS
Deriving covariates using the Empirical Mode Decomposition
Application to map
1
2
2
3
4
5


Modelling precipitation occurrence with a Markov model
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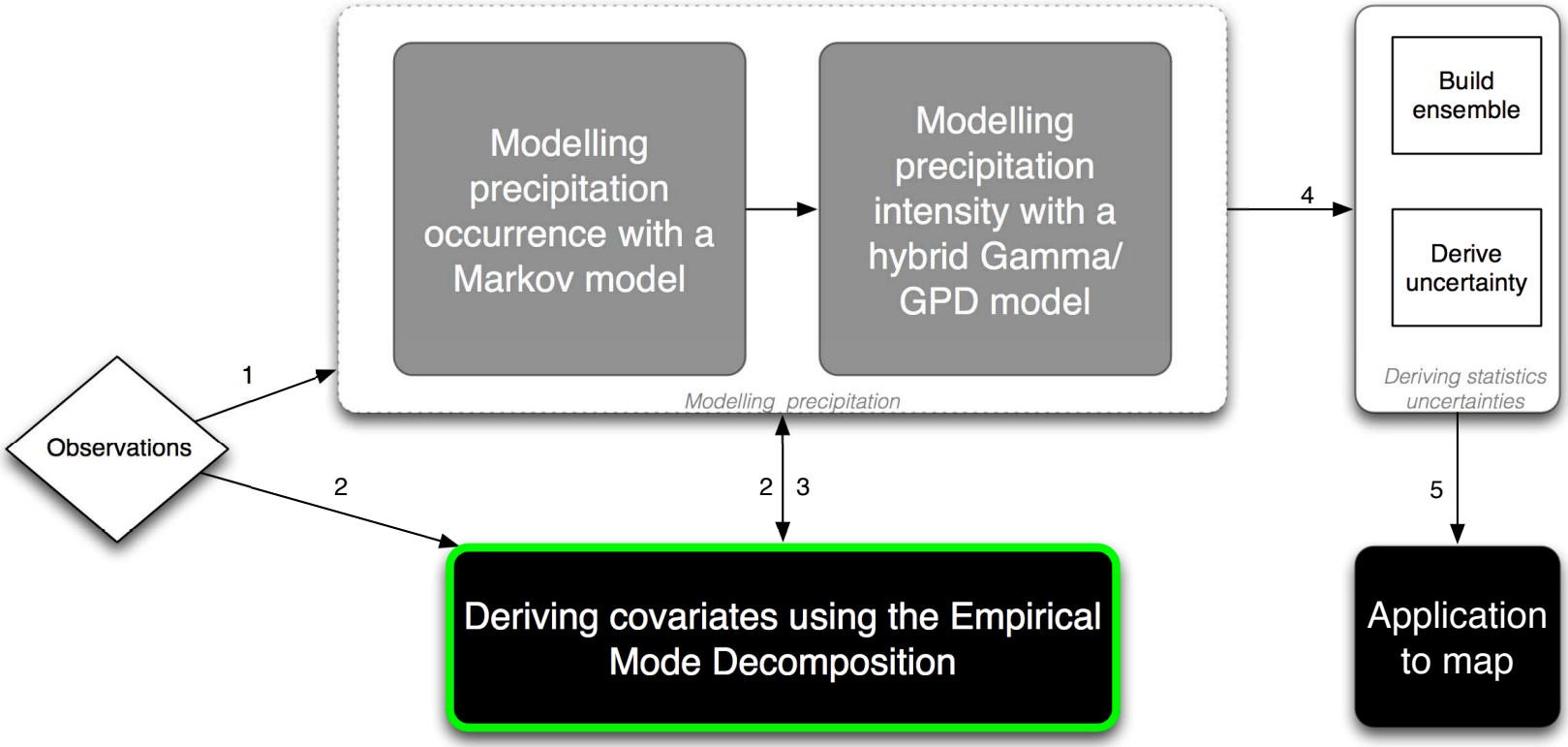
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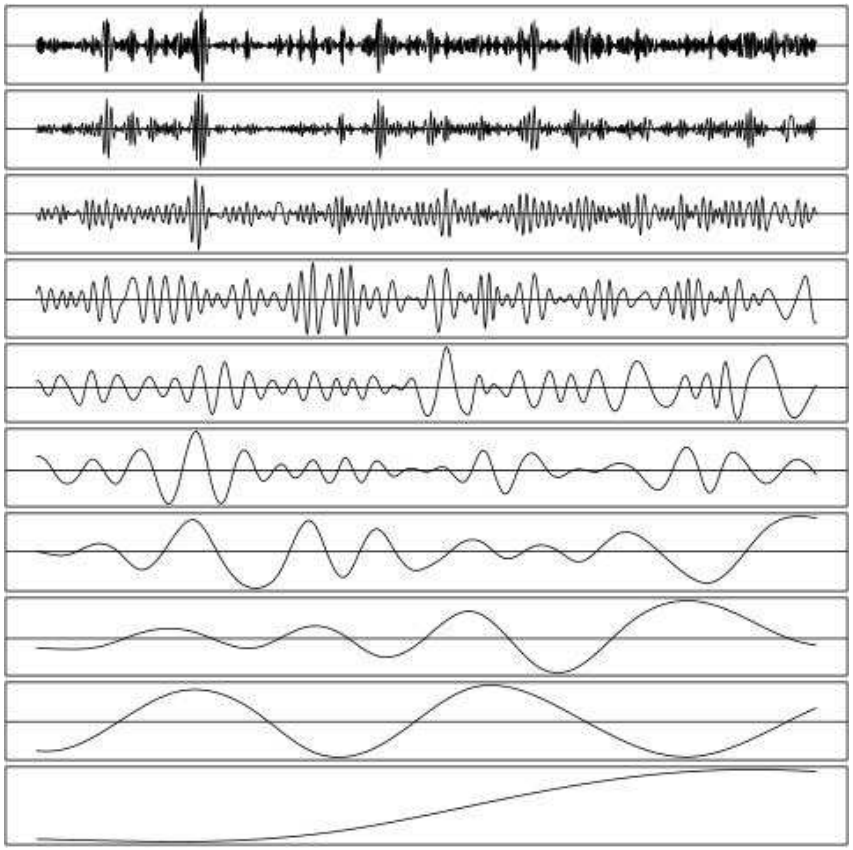
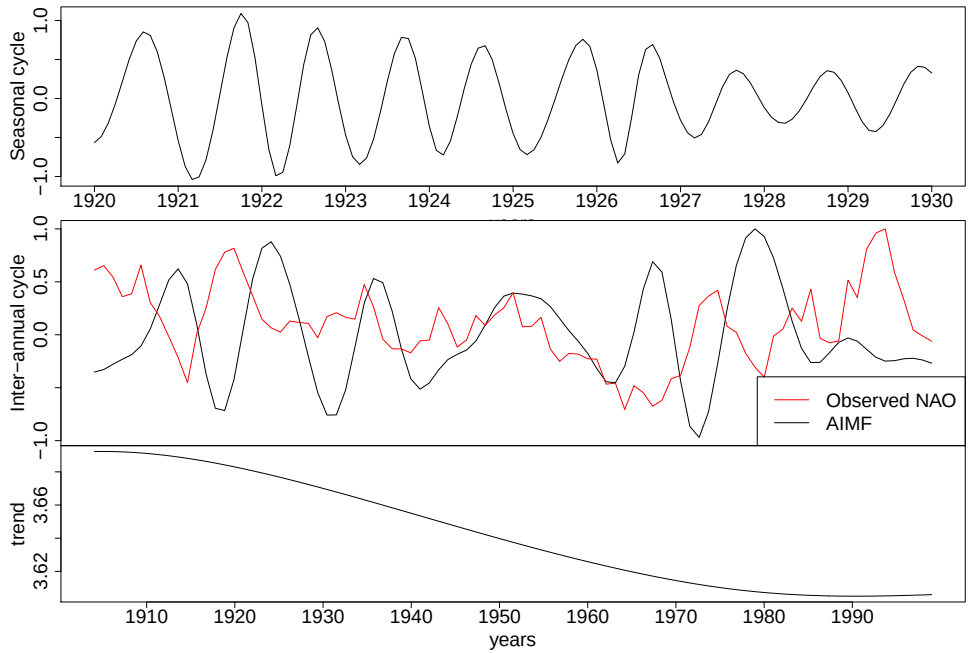


Ensemble empirical mode decomposition

- Decompose signal
- Select only physically meaningful components

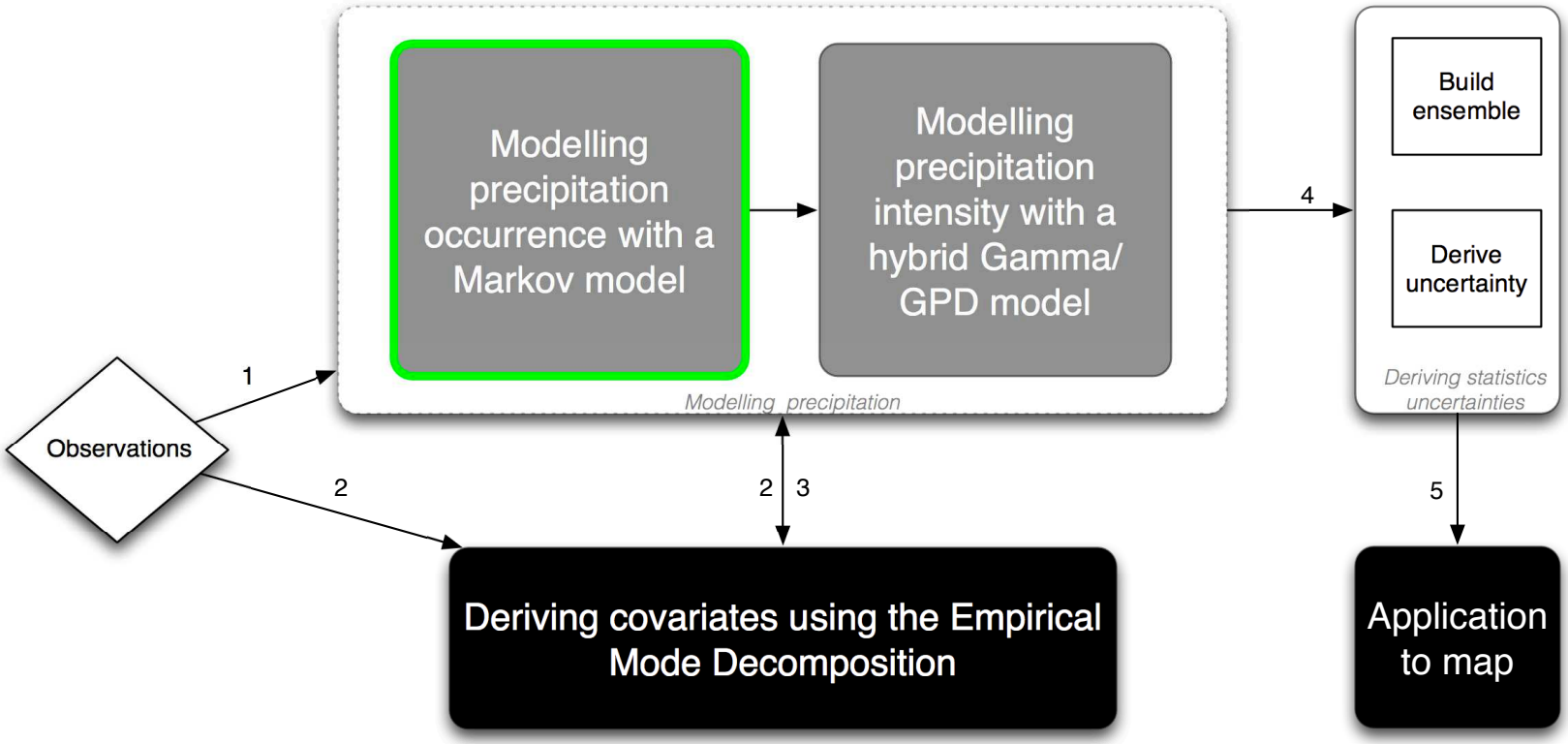
Application to :

- Precipitation occurrence
- Precipitation intensity



Outputs

- Seasonal cycle (12 months)
- Inter-annual cycle (varying period)
- Trends for some locations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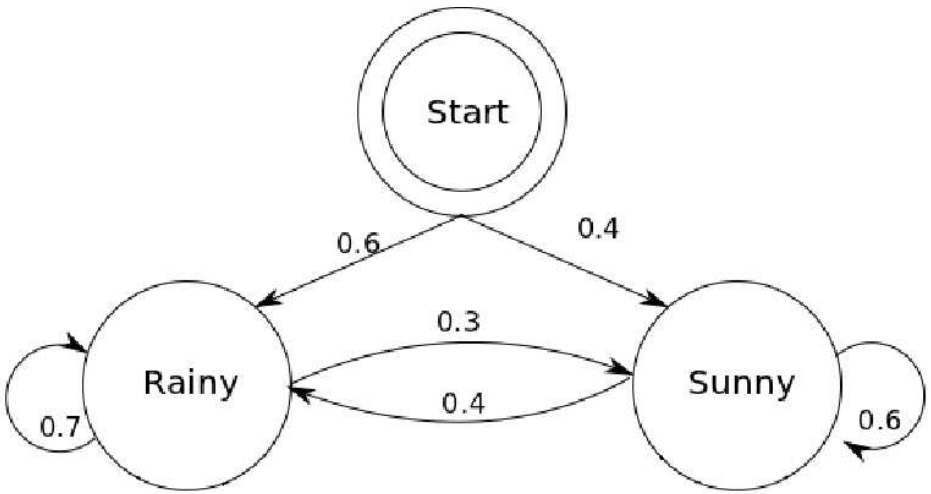
Modelling occurrence

- Markov model
- Stochastic
- Depends on previous step

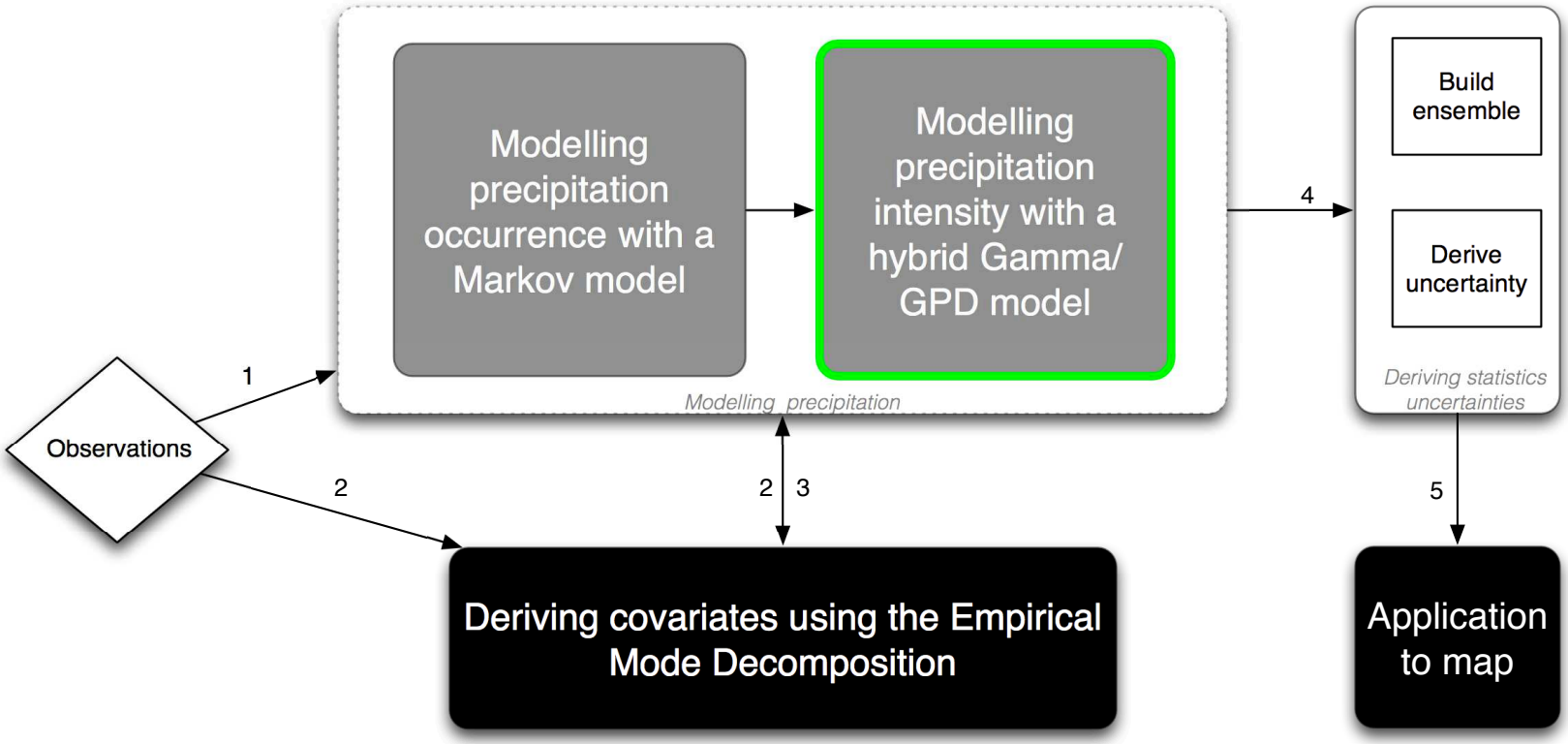


Example

- State : 2
- Order : 1
- No time-dependency

Application

- State : 3 (+extremes)
- Order : 5 (best fit)
- Time-dependency using covariates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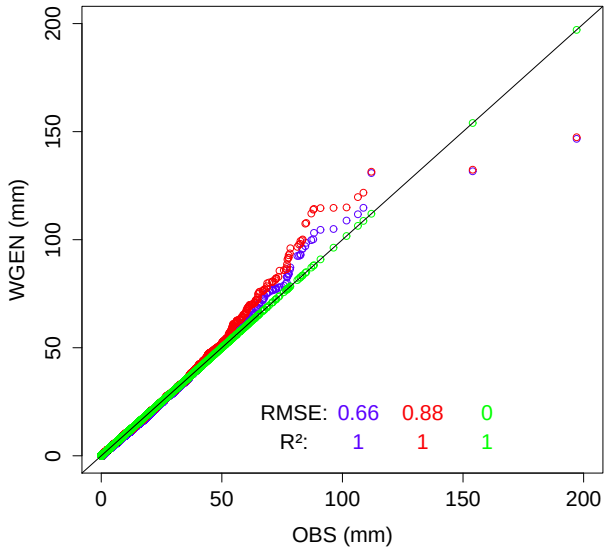
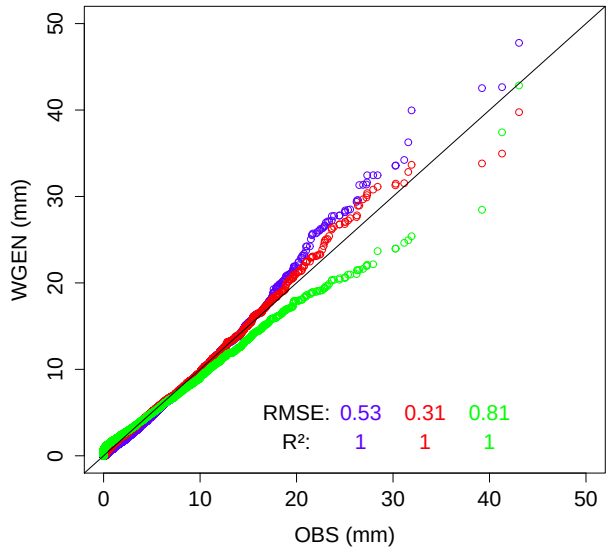
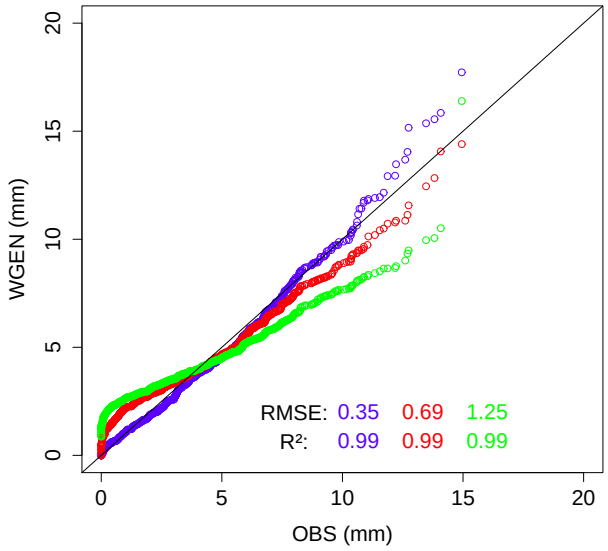
Randomized original timeseries, generated timeseries without cycles and generated timeseries with cycles



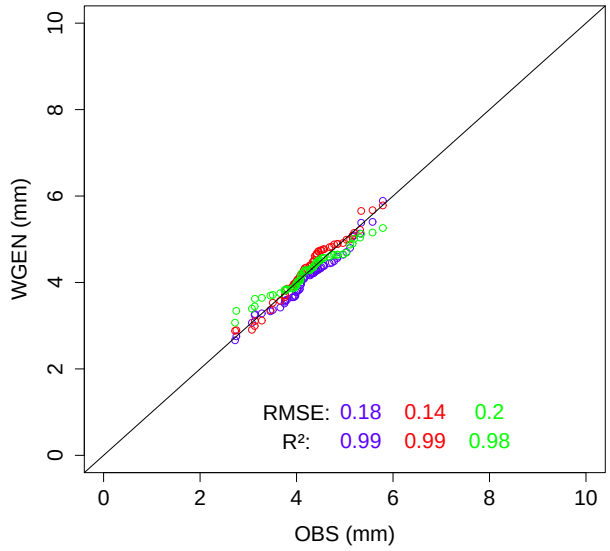
1 day



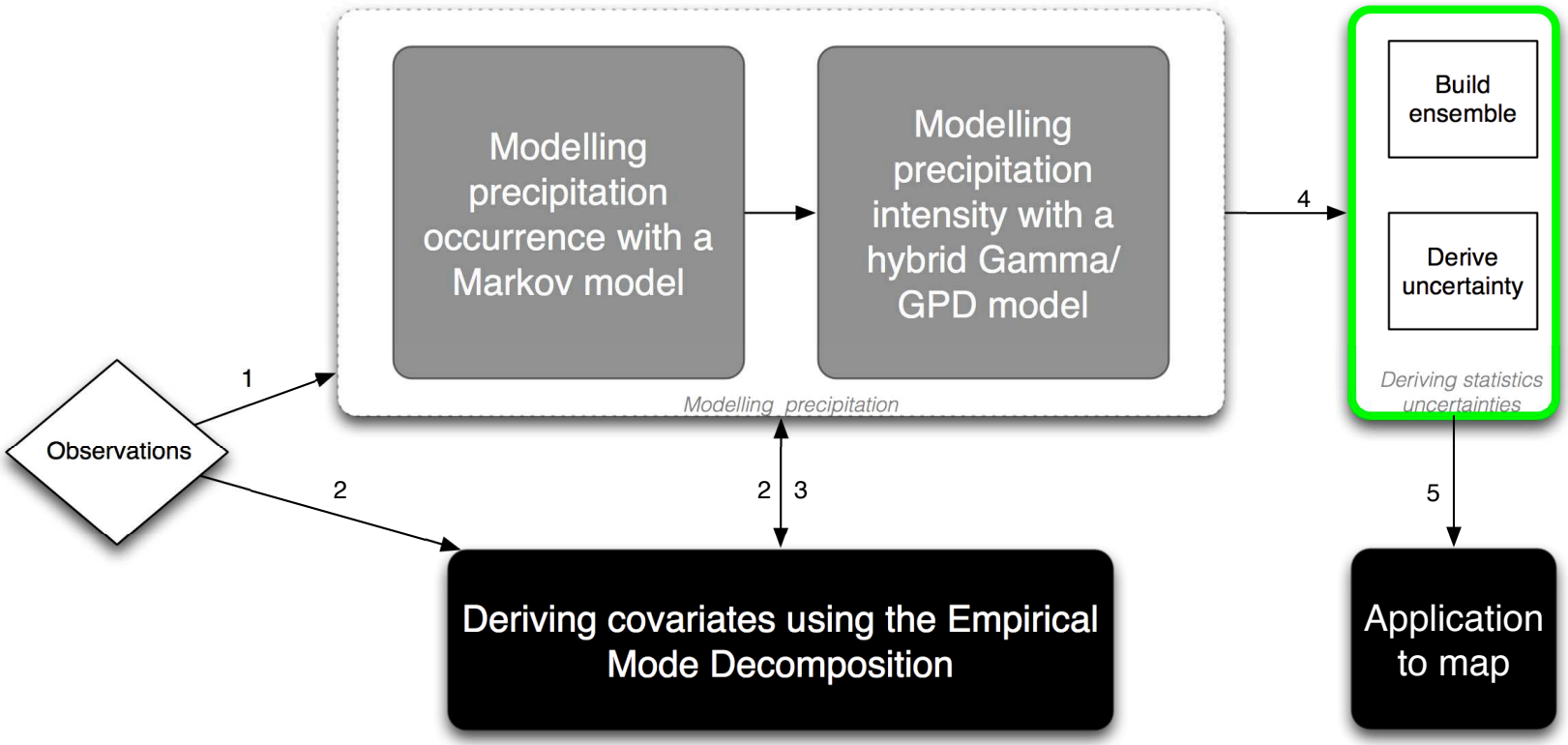
5 days



30 days



365 days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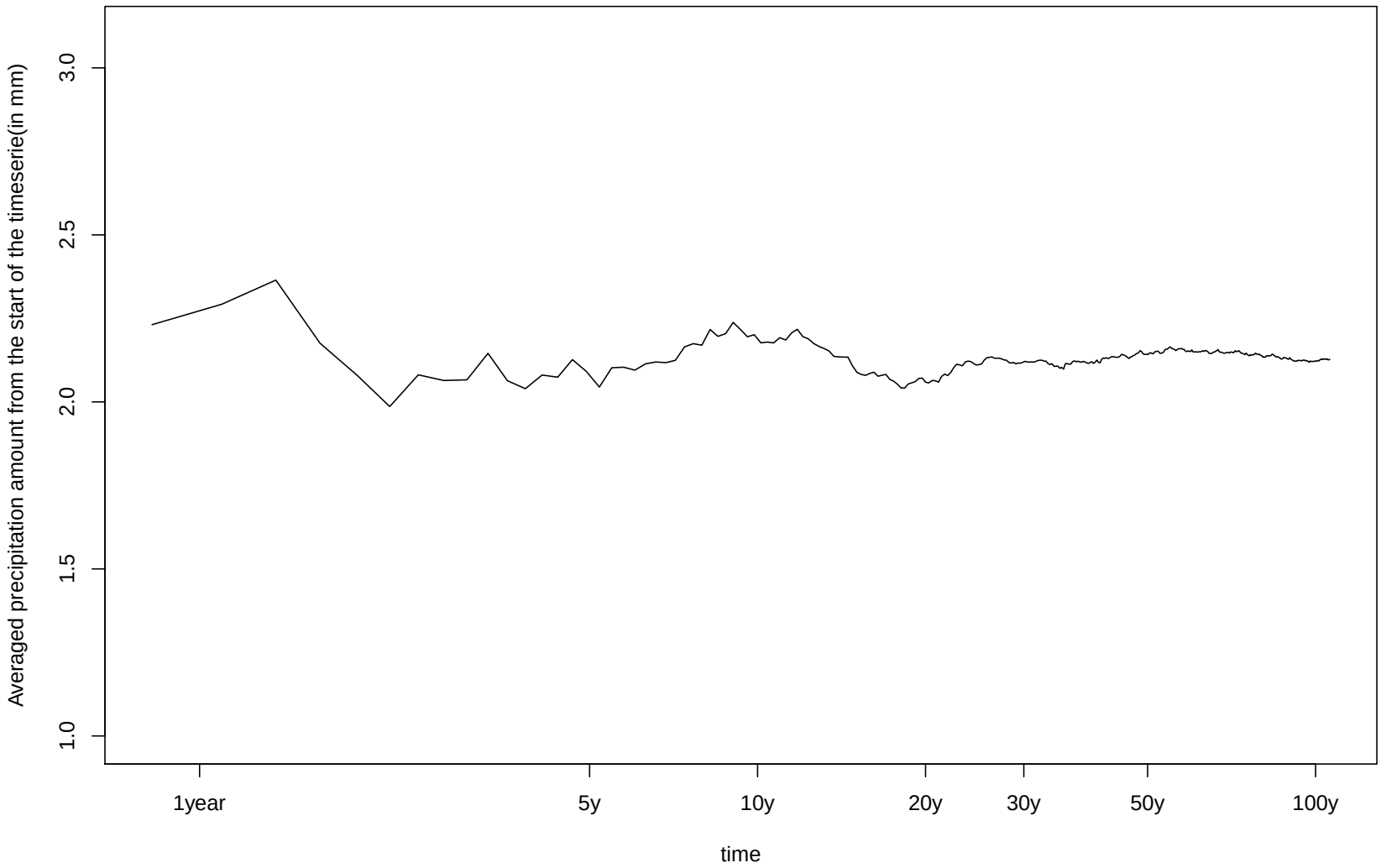
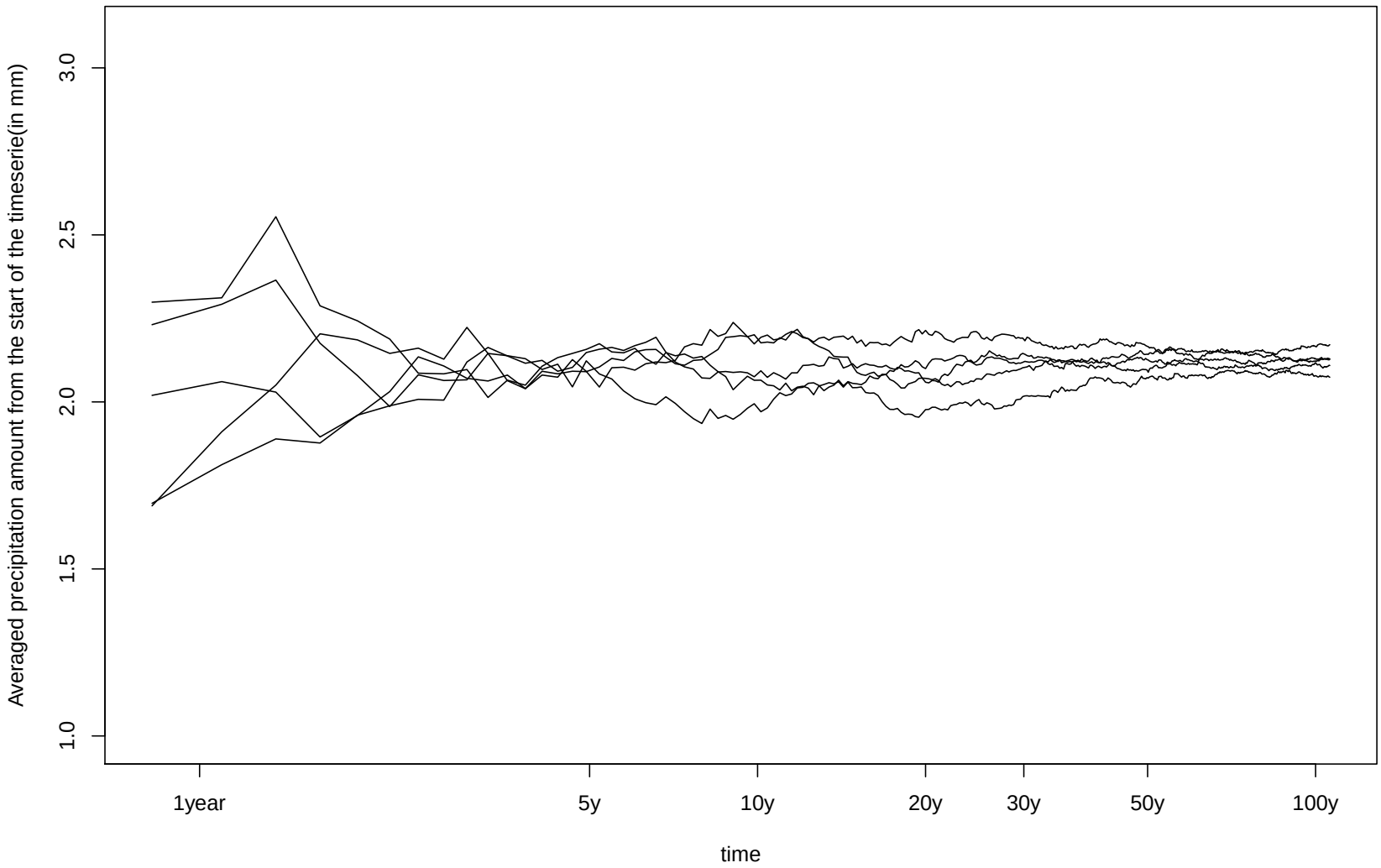
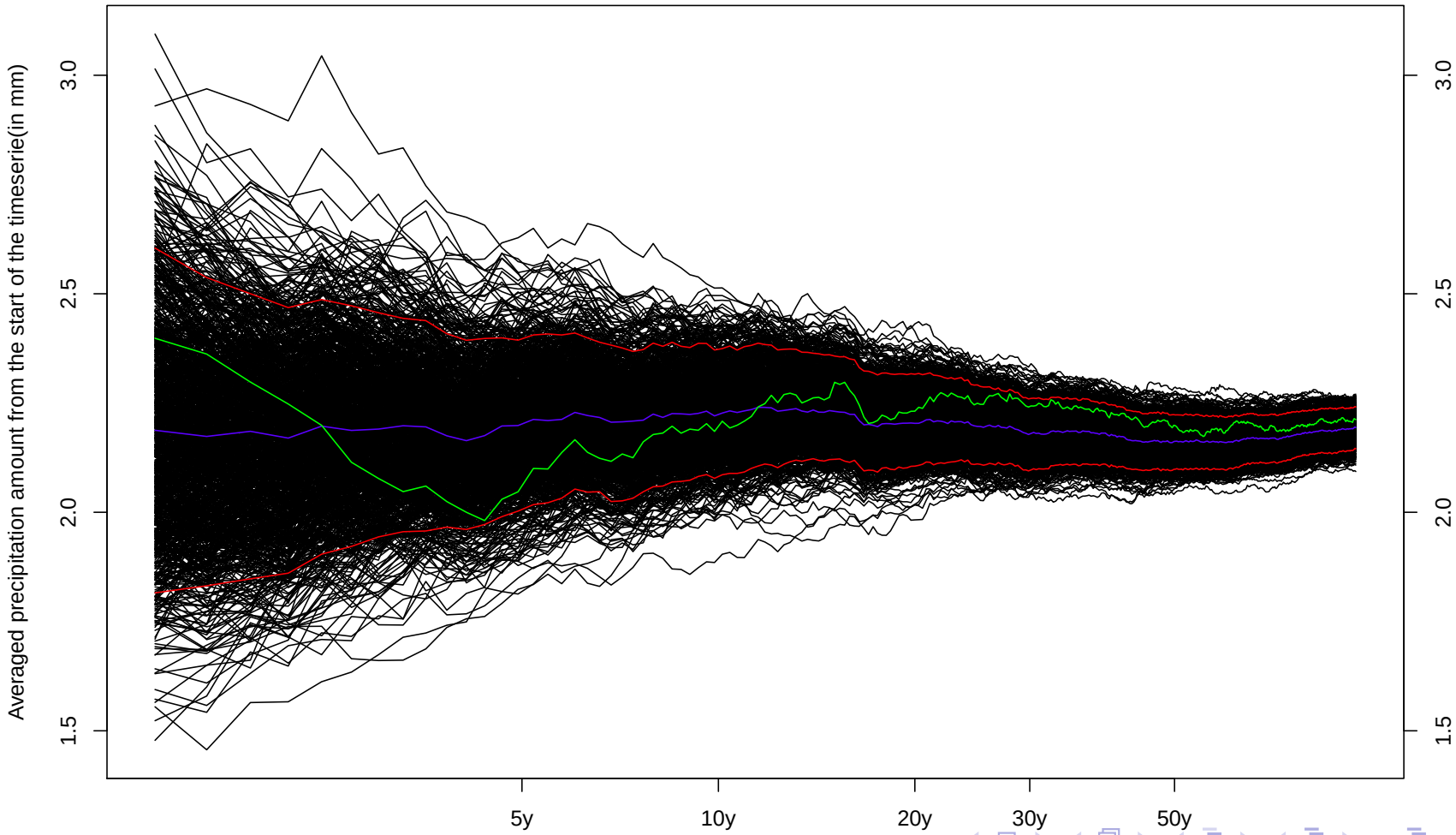
Averaged precipitation integrated from the start of the timeserie till time t (1 possible realization)

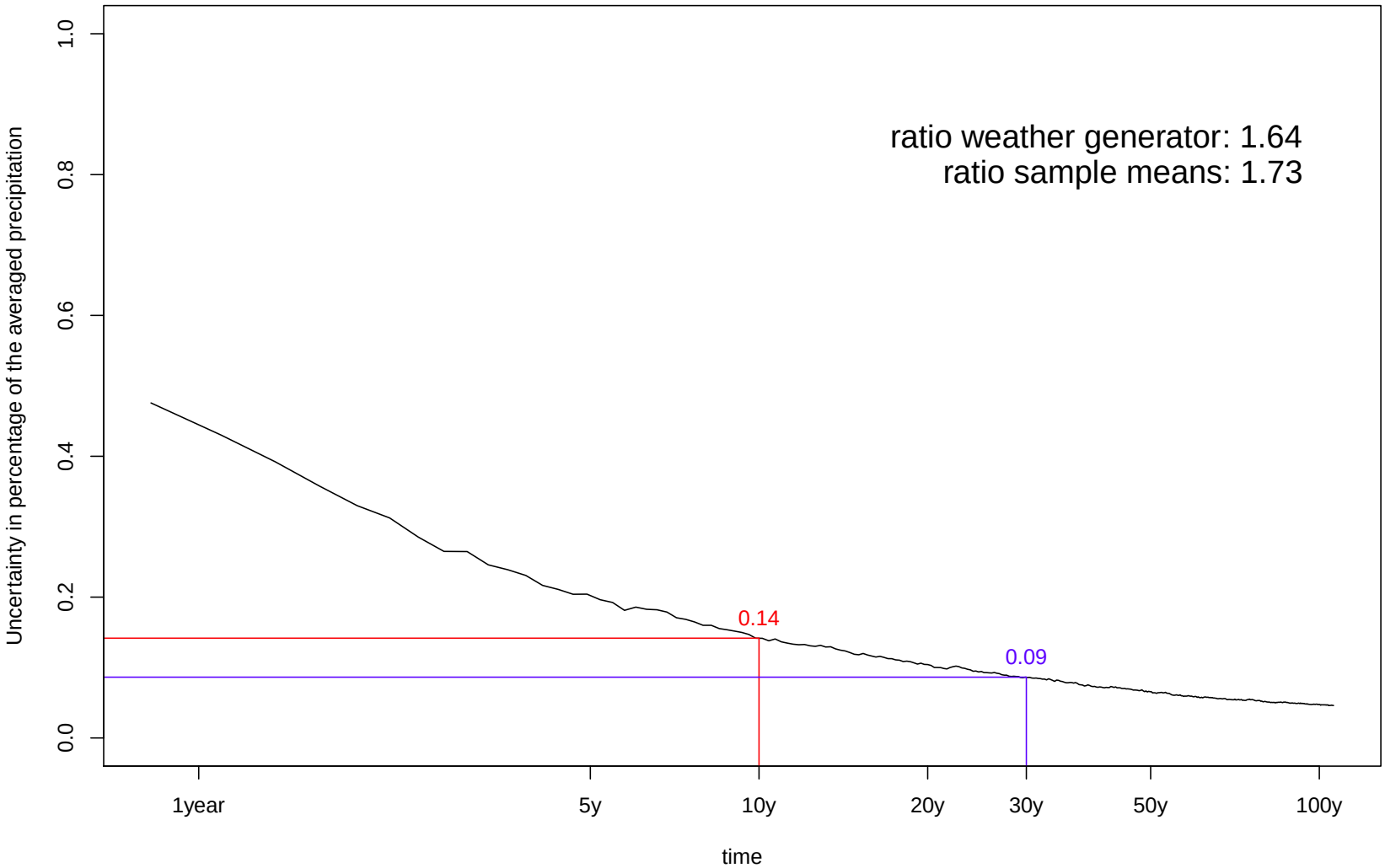


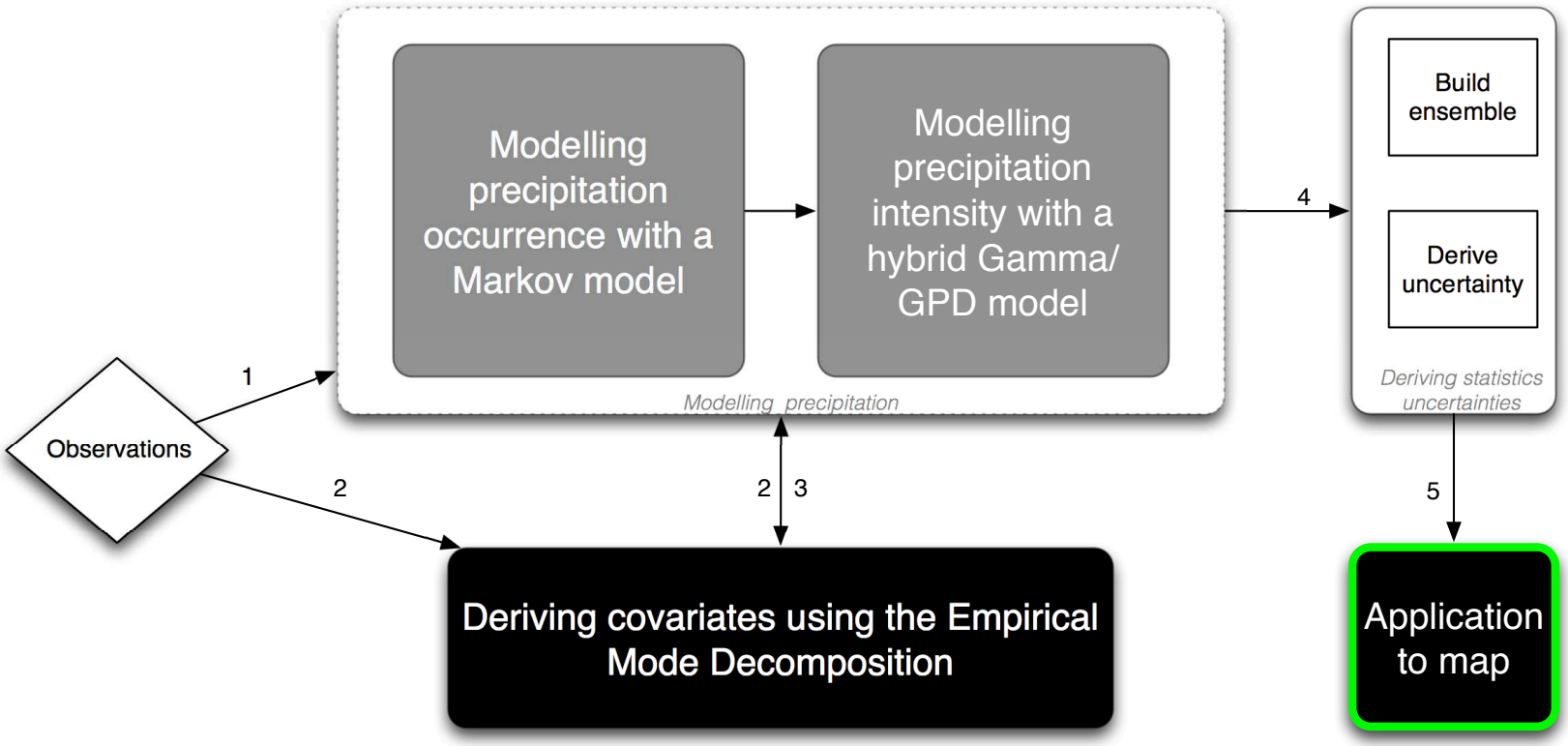
Averaged precipitation integrated from the start of the timeserie till time t (5 possible realizations)



Averaged precipitation integrated from the start of the timeserie till time t (1000 possible realizations) with 90% quantiles enveloppe (red), average (blue) and historical realization (green)




ratio weather generator: 1.64
ratio sample means: 1.73
0.14
0.09
Uncertainty in percentage of the averaged precipitation
0.0
0.2
0.4
0.6
0.8
1.0
1year
5y
10y
20y
30y
50y
100y
time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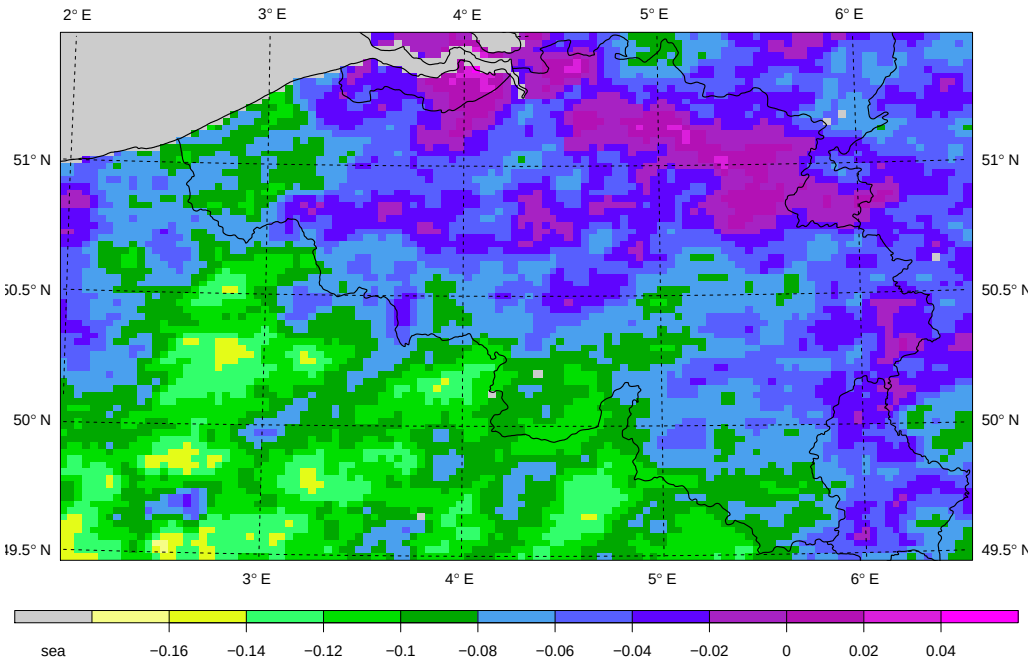
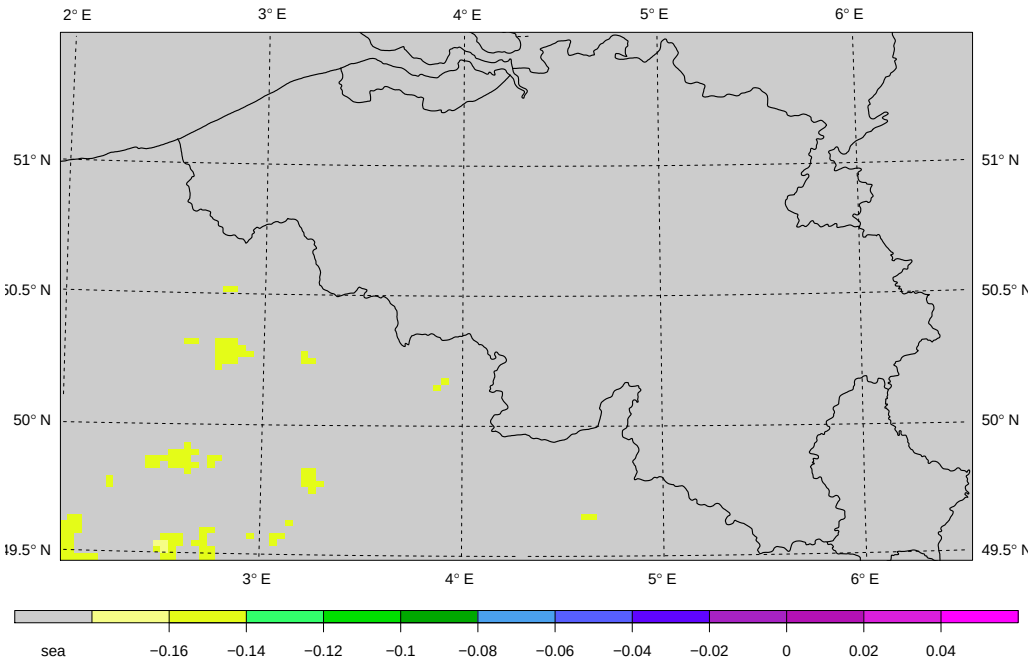


What does it say ?

- Mean : -8%
- More extreme negative
- Gradient
- 2 large areas of opposite signs

What can we really say ?

- Removing all values lower than 14%
- No more significant information



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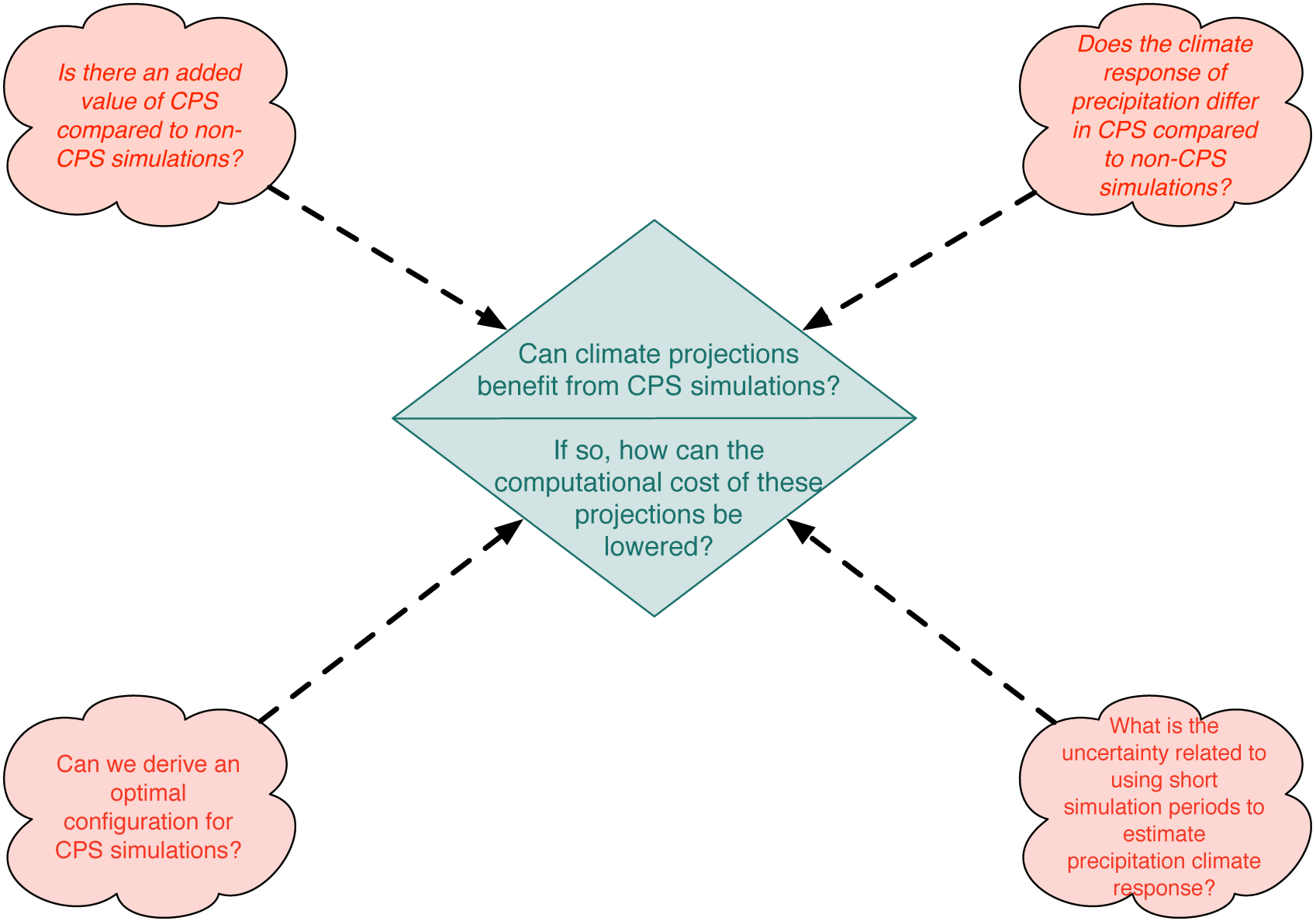
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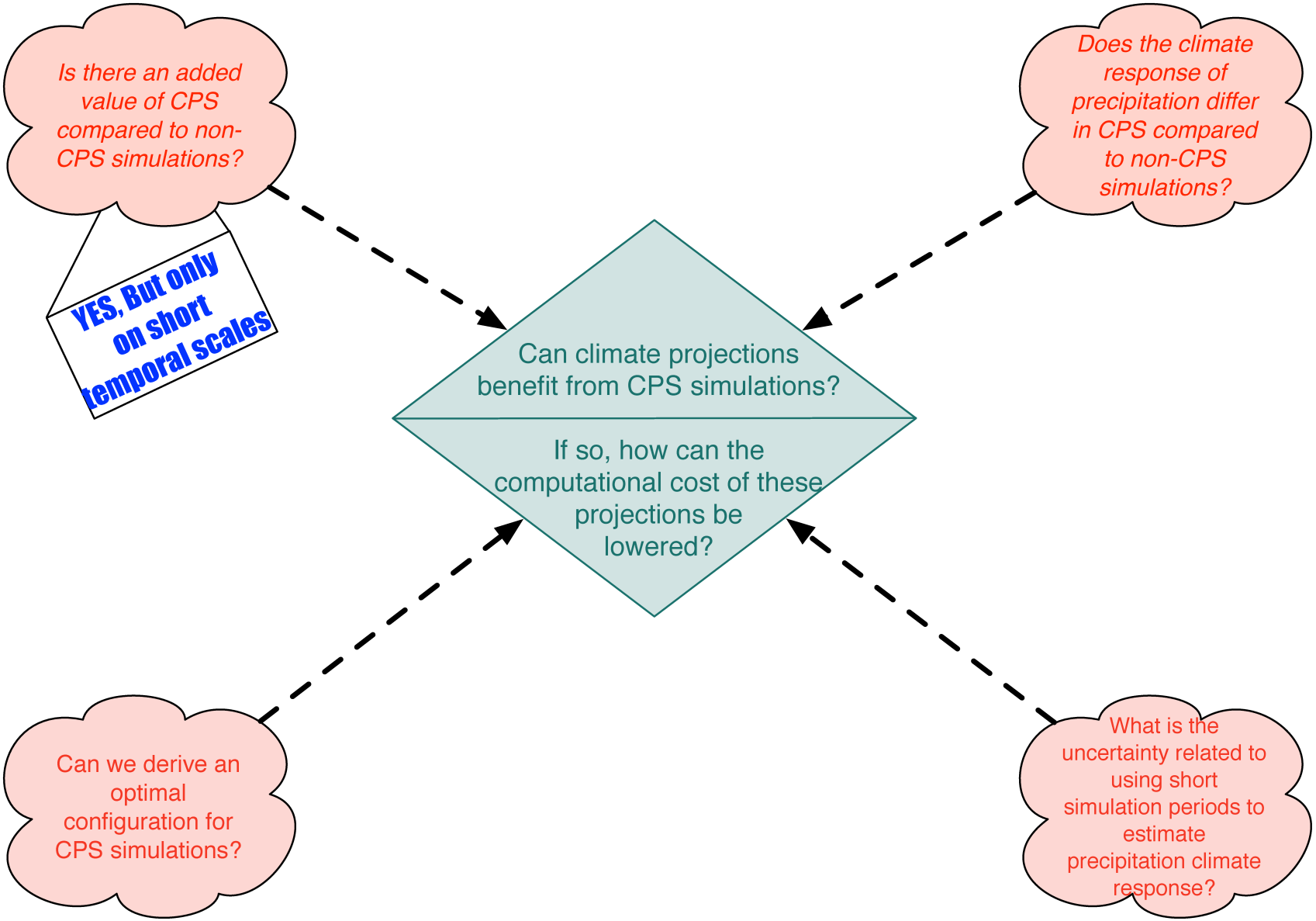
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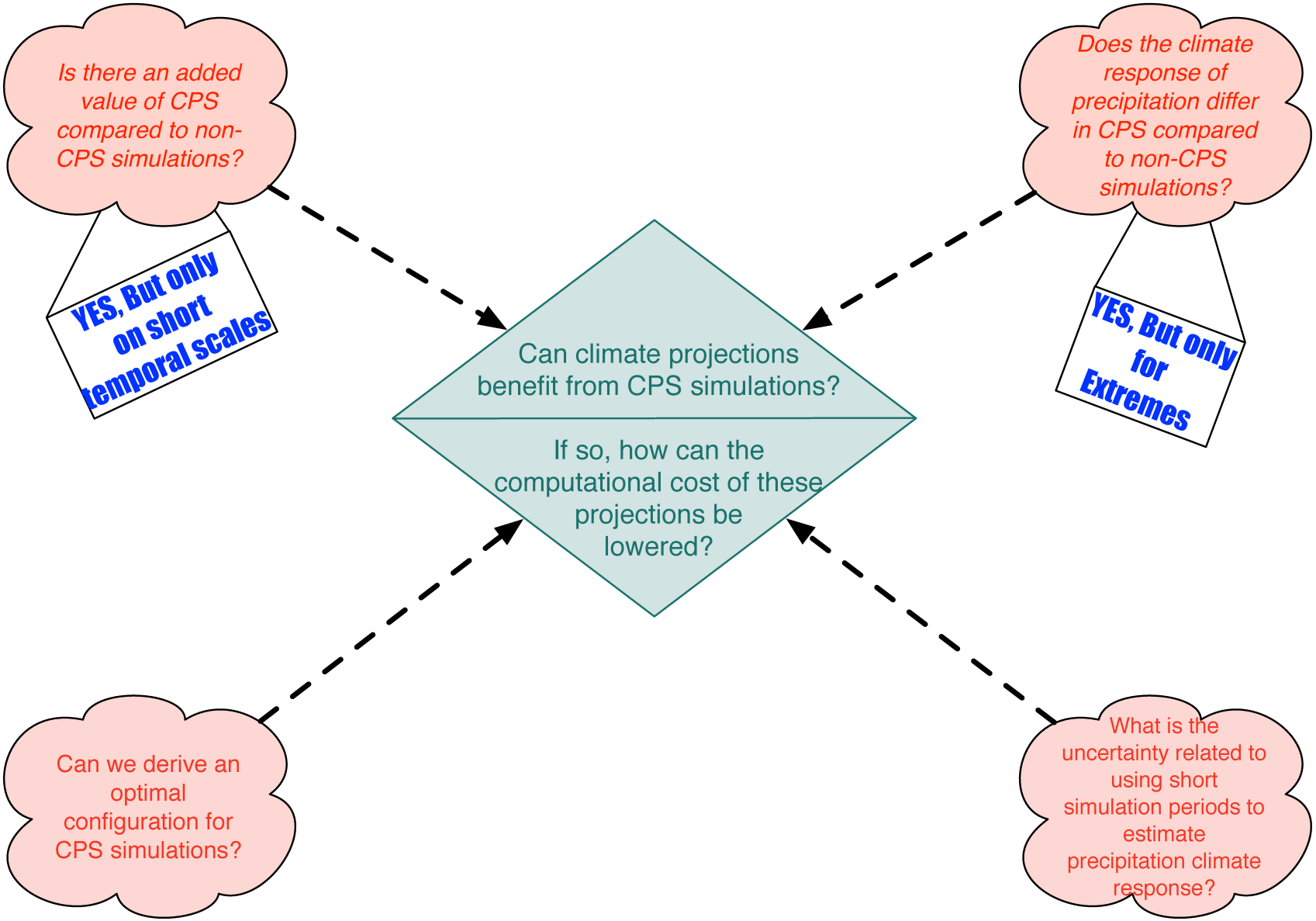
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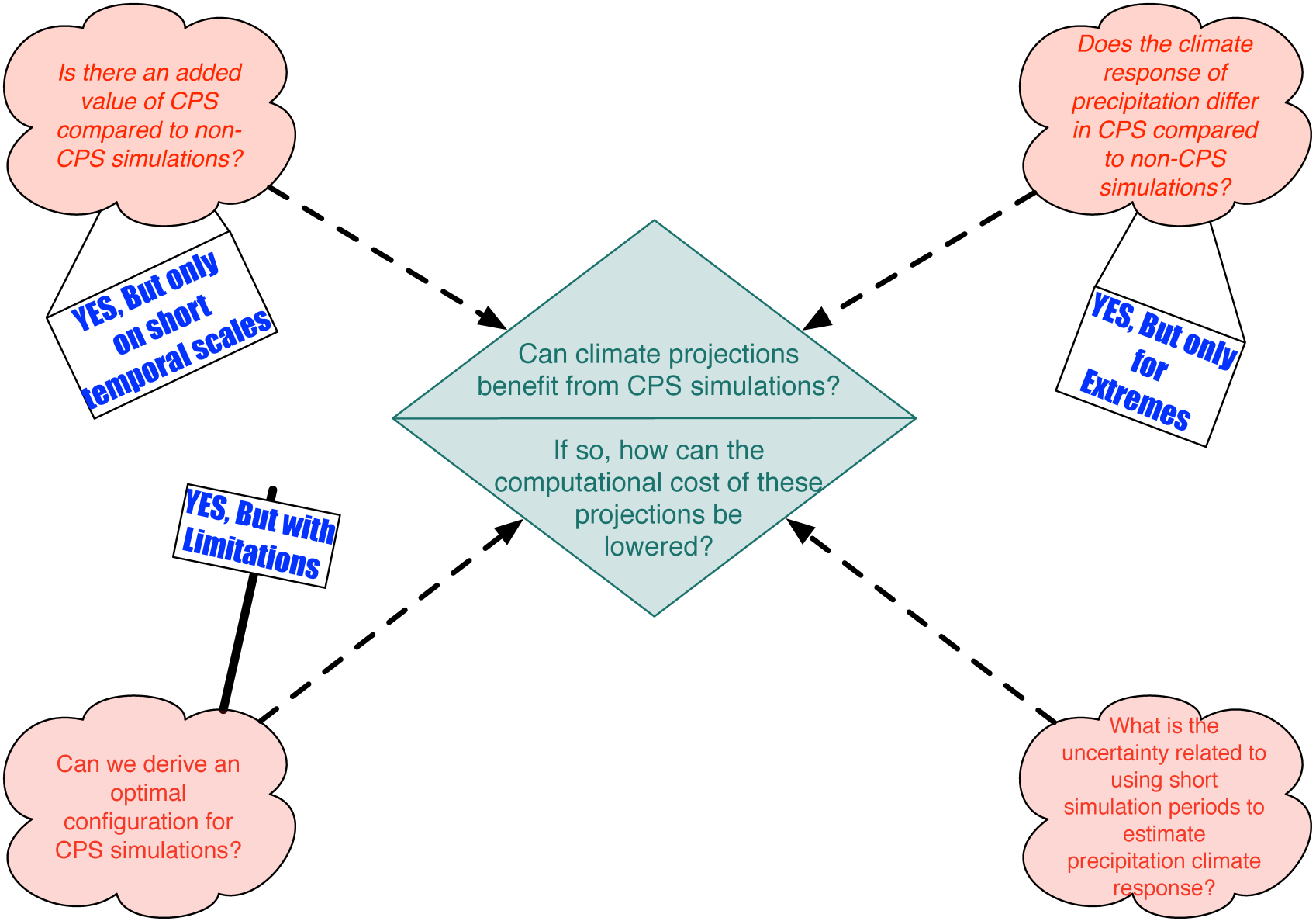
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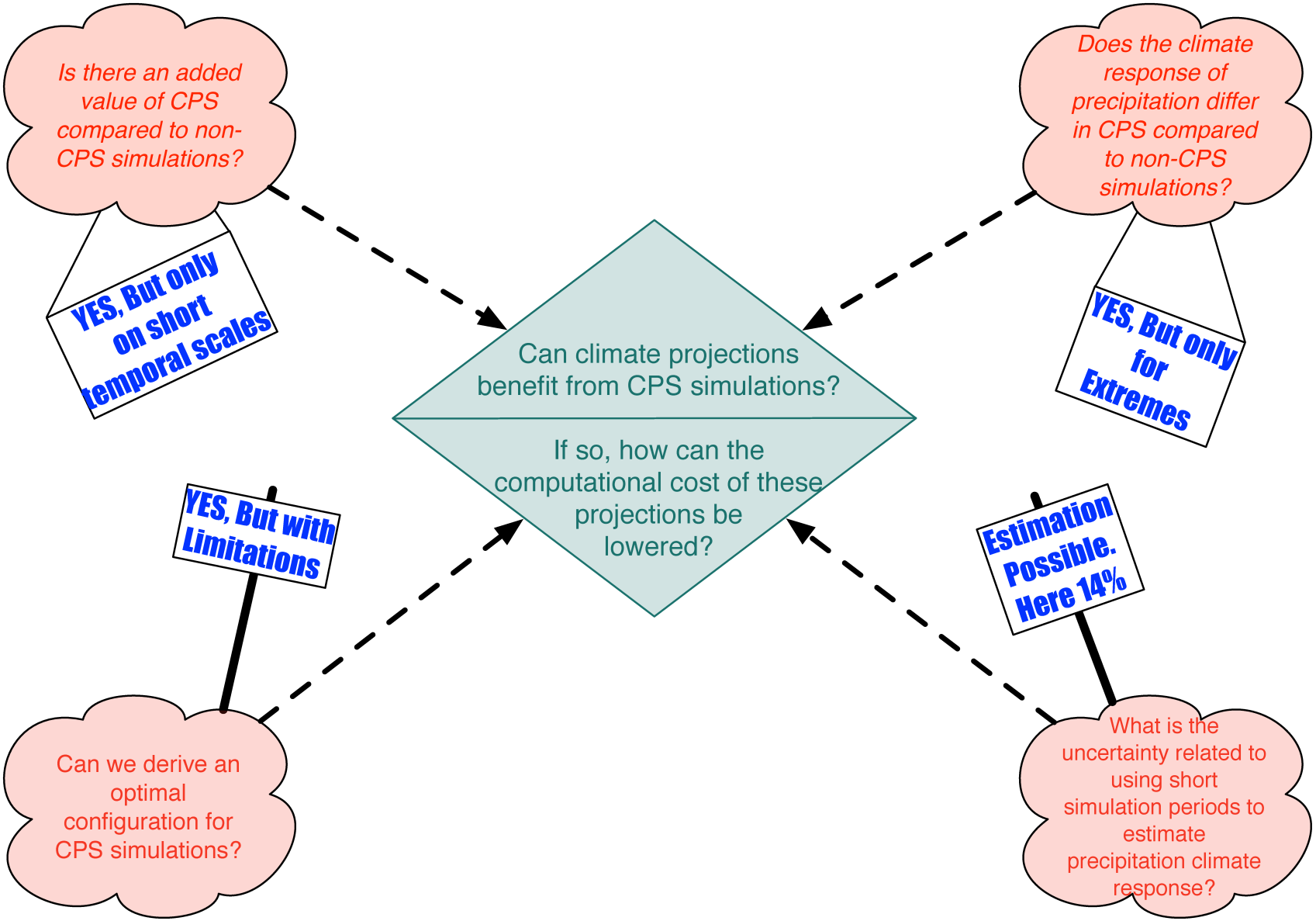
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Estimation Possible. Here 14%
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Thank you for your attention !