Potential impact of climate change on solar resource in Africa for photovoltaic energy: analyses from CORDEX-AFRICA climate experiments*

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Motivations

- Adaptation planers for solar resource projects need
  - on regional scales and for the next few decades –
  projected trends from climate projections and associated uncertainties to assess climate risks of ongoing solar projects

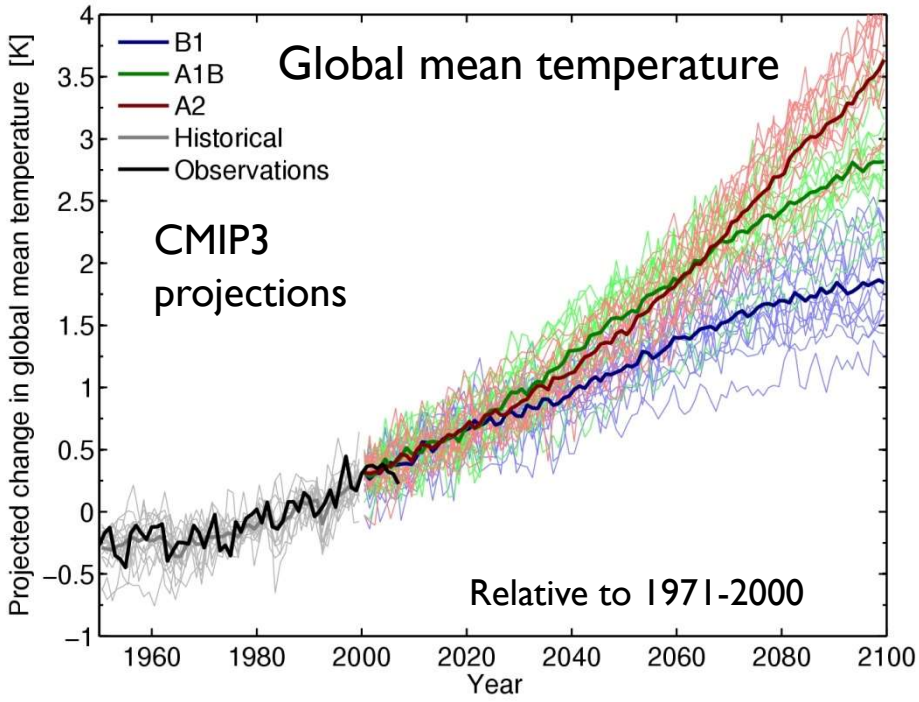
- To improve projections and reduce uncertainties,
  climate scientists need to know
  where uncertainty mostly come from, and then
  where allocation of funds / researches has to be concentrated

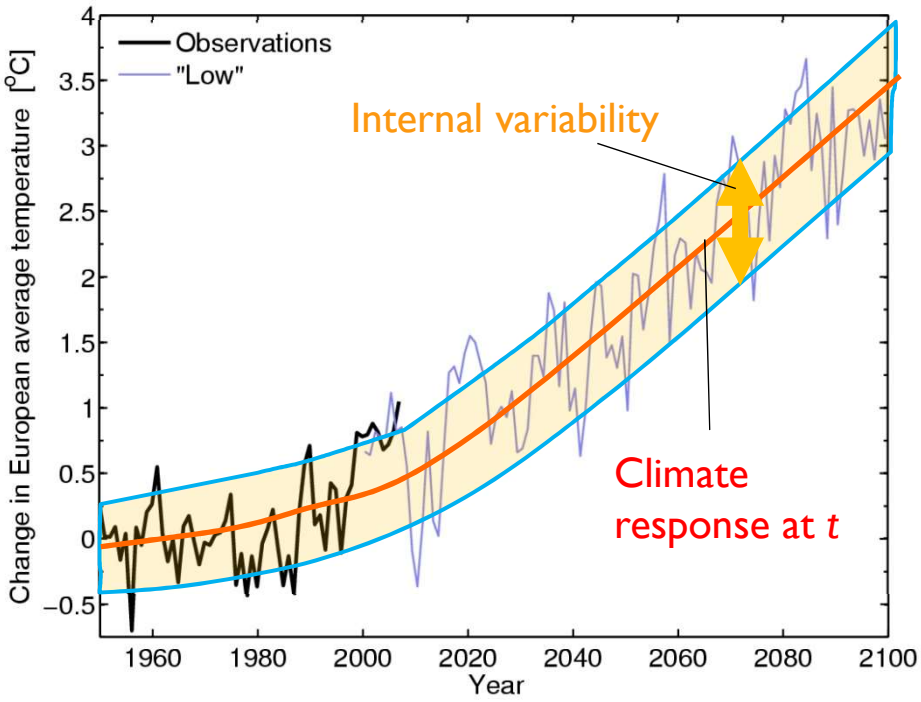
- Questions for Africa :
  - What are the projected trends of the solar resource at local scale for the next few decades ?
  - What are associated uncertainty and
  - what are the largest uncertainty sources ?

Mean trends and uncertainty sources in climate projections

are quantified from multi-scenario multi-model multi-member ensembles.
They include scenario uncertainty, model uncertainty and internal variability :

The heuristic partition of Hawkins and Sutton, 2009, 2011 …





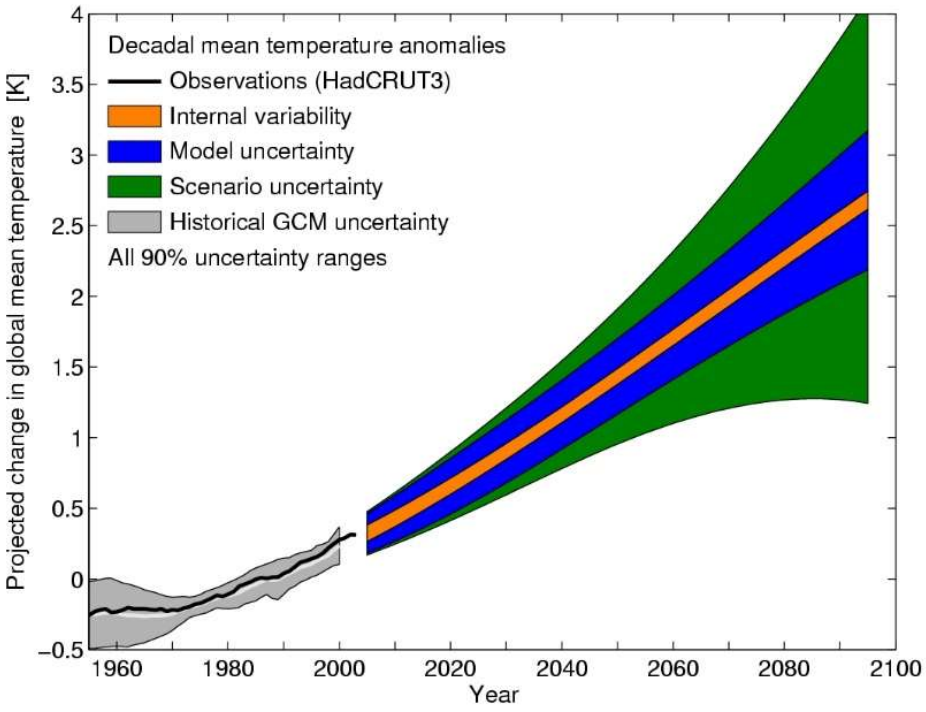
Internal variability – spread in residuals from climate responses (quasi-ergodic assumption)
Scenario uncertainty – spread between multi-model means of climate responses
Model uncertainty – spread between multi-scenario means of climate responses
Climate response of each simulation chain is the long term trend of the variable over CTL+FUT

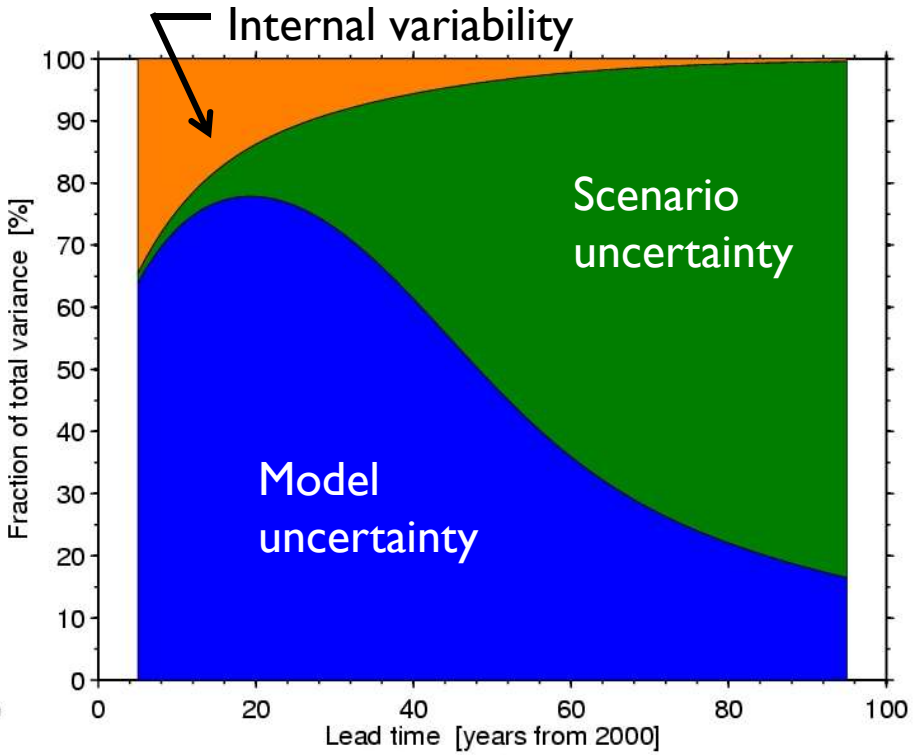
Hawkins and Sutton, 2009, 2011 : heuristic partition

Mean trends and Uncertainty sources in climate projections

are quantified from multi-scenario multi-model multi-member ensembles.

The heuristic partition of Hawkins and Sutton, 2009, 2011 lead to the iconic figures





Internal variability – spread in residuals from climate responses (quasi-ergodic assumption)

Scenario uncertainty – spread between multi-model means of climate responses

Model uncertainty – spread between multi-scenario means of climate responses

Climate response of each simulation chain estimated from smooth fits to CTL+FUT simulations

What about solar projections for Africa ?

- Solar resource potential (PVpot) = f(Solar Radiation, surface temperature and wind)

- Data available : the outputs of 19 climate experiments from the recent CORDEX-Africa CMIP5 ensemble

- Dat used here :
  - Transient : 1980-2100
  - High resolution : daily, 0.5°
  - For 1 scenario : RCP8.5
  - 10 GCMs
  - 5 RCMs

RCM \ GCM	HIRHAM5 (v2)	CCLM 4-8-17 (v1)	RACMO 22T (v1)	RCA4 (v1)	REMO 2009 (v1)
ICHEC-EC-EARTH	x		x	x	x
CNRM-CERFACS-CNRM-CM5		x		x	
MPI-M-MPI-ESM-LR		x		x	x
NCC-NorESM1-M				x	
NOAA-GFDL-GFDL-ESM2M				x	
IPSL-IPSL-CM5A-MR				x	
MIROC-MIROC5				x	
CSIRO-QCCCE-CSIRO-Mk3-6-0				x	
CCCma-CanESM2				x	
MOHC-HadGEM2-ES			x	x	

- Uncertainty sources are thus here
  - Model uncertainty from GCMs
  - Model uncertainty from RCMs
  - Internal variability (Low frequency variation of the climate variable around its long term trend)

Partitioning different components of uncertainty

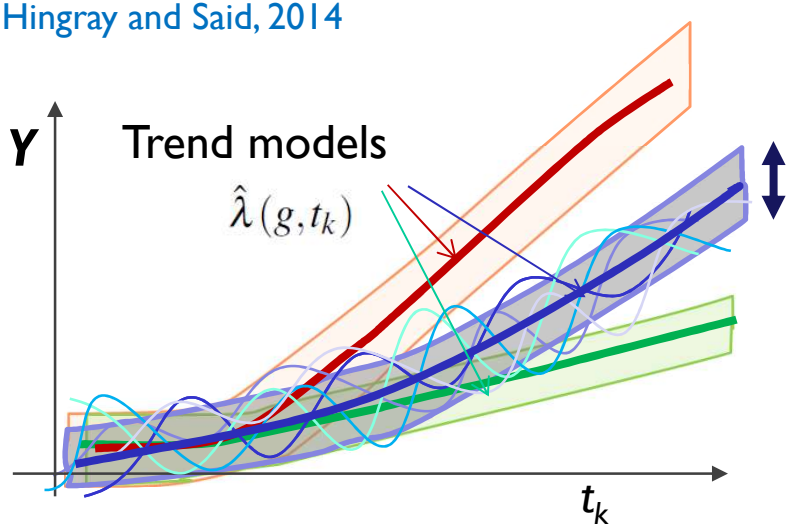
Method : Times Series approach of Hawkins and Sutton 2009
Upgraded with Quasi-Ergodic ANOVA assumption of Hingray et Said, 2014

Step 1// Extraction of the climate response (for model uncertainty) and residuals (for internal variability) for each GCM/RCM simulation chain

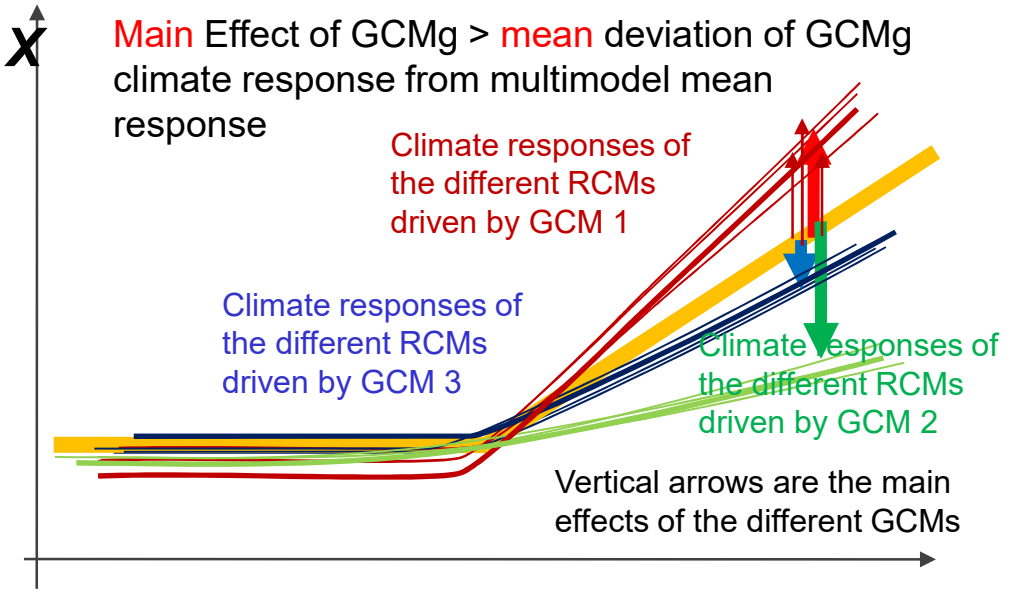
+ Step 2// ANOVA on climate responses

Time Series ANOVA approach

Hingray and Said, 2014



climate response = **trend estimate** at t_k
internal variability = **time variance** of residuals



Spread **between main effects**
- of the different GCMs > GCM Model uncertainty
- of the different RCMs > RCM Model uncertainty

Partitioning different components of uncertainty

But CORDEX – AFRICA …. Is an incomplete ensemble of projections…
Not all GCM x RCM combinations are available …

RCM \ GCM	HIRHAM5 (v2)	CCLM 4-8-17 (v1)	RACMO 22T (v1)	RCA4 (v1)	REMO 2009 (v1)
ICHEC-EC-EARTH	x		x	x	x
CNRM-CERFACS-CNRM-CM5		x		x	
MPI-M-MPI-ESM-LR		x		x	x
NCC-NorESM1-M				x	
NOAA-GFDL-GFDL-ESM2M				x	
IPSL-IPSL-CM5A-MR				x	
MIROC-MIROC5				x	
CSIRO-QCCCE-CSIRO-Mk3-6-0				x	
CCCma-CanESM2				x	
MOHC-HadGEM2-ES			x	x	

In this typical configuration,
almost all Time Series ANOVA approaches
can lead to biased estimates of trends
and uncertainty components

To fix this limitation, we developed QUALYPSO (Evin et al. 2019),
a bayesian estimation approach
based on data augmentation techniques.

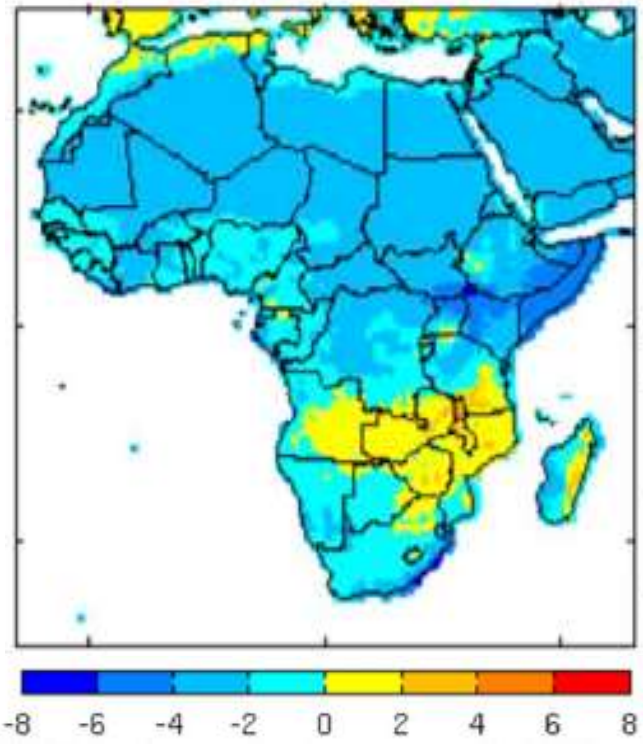
- It reconstructs
  missing GCM x RCM combinations
- It allows for an unbiaised estimate of
  GCM main effects, RCM main effects,
  mean trend… and all uncertainty sources …
- …. conditional on the CORDEX-AFRICA
  ensemble

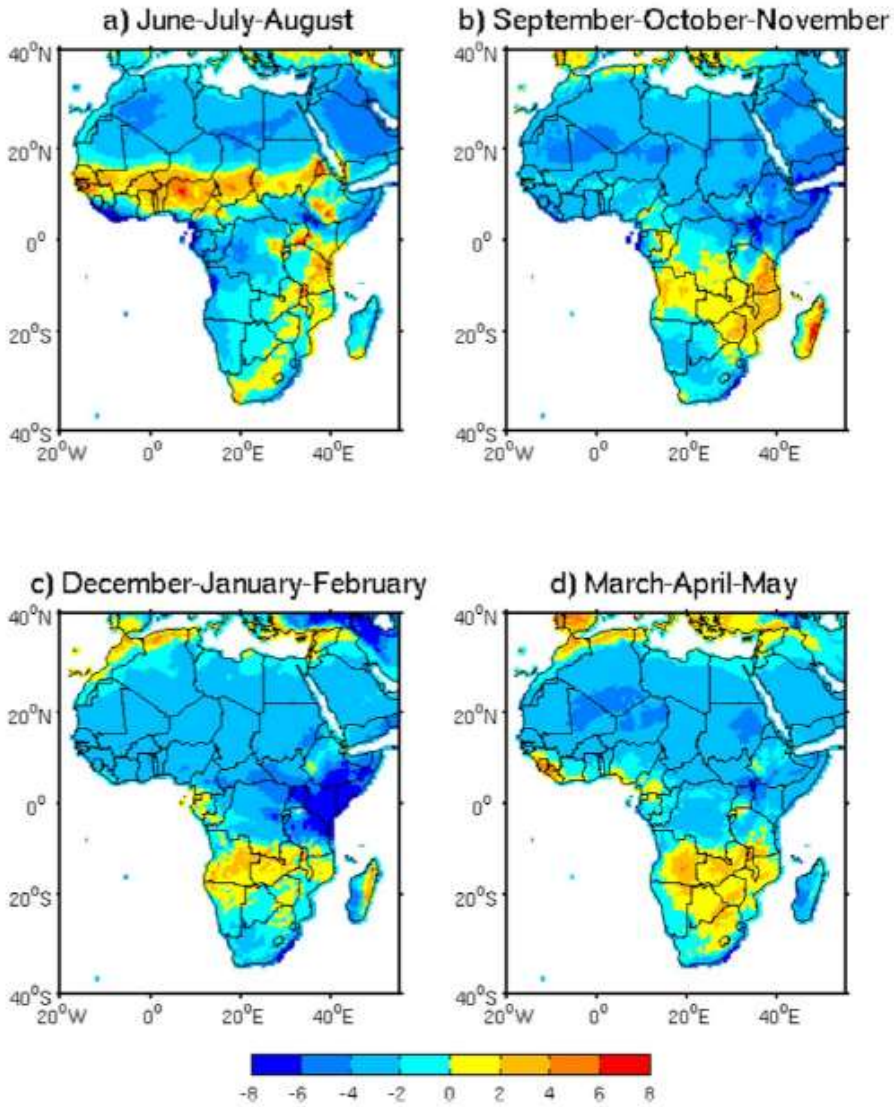
Results for Solar Potential >>

Projected (relative %) changes of PVpot for late century

Mean projected change (%) : (2070-2100 vs 1980-2010)
decrease by 2 to 8% of annual mean
in many places expect in south east

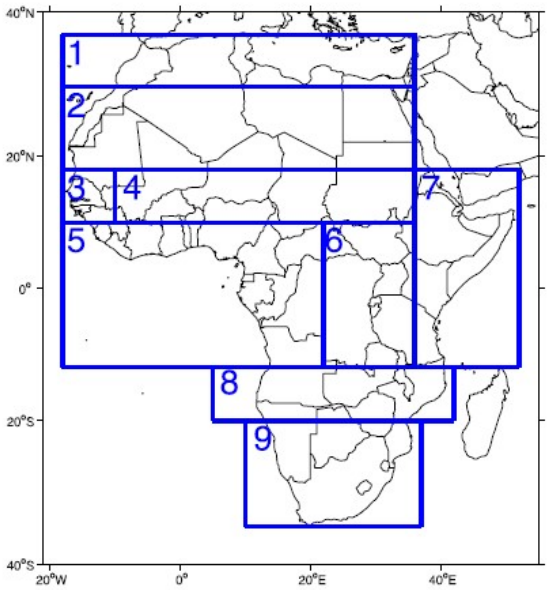
Annual changes

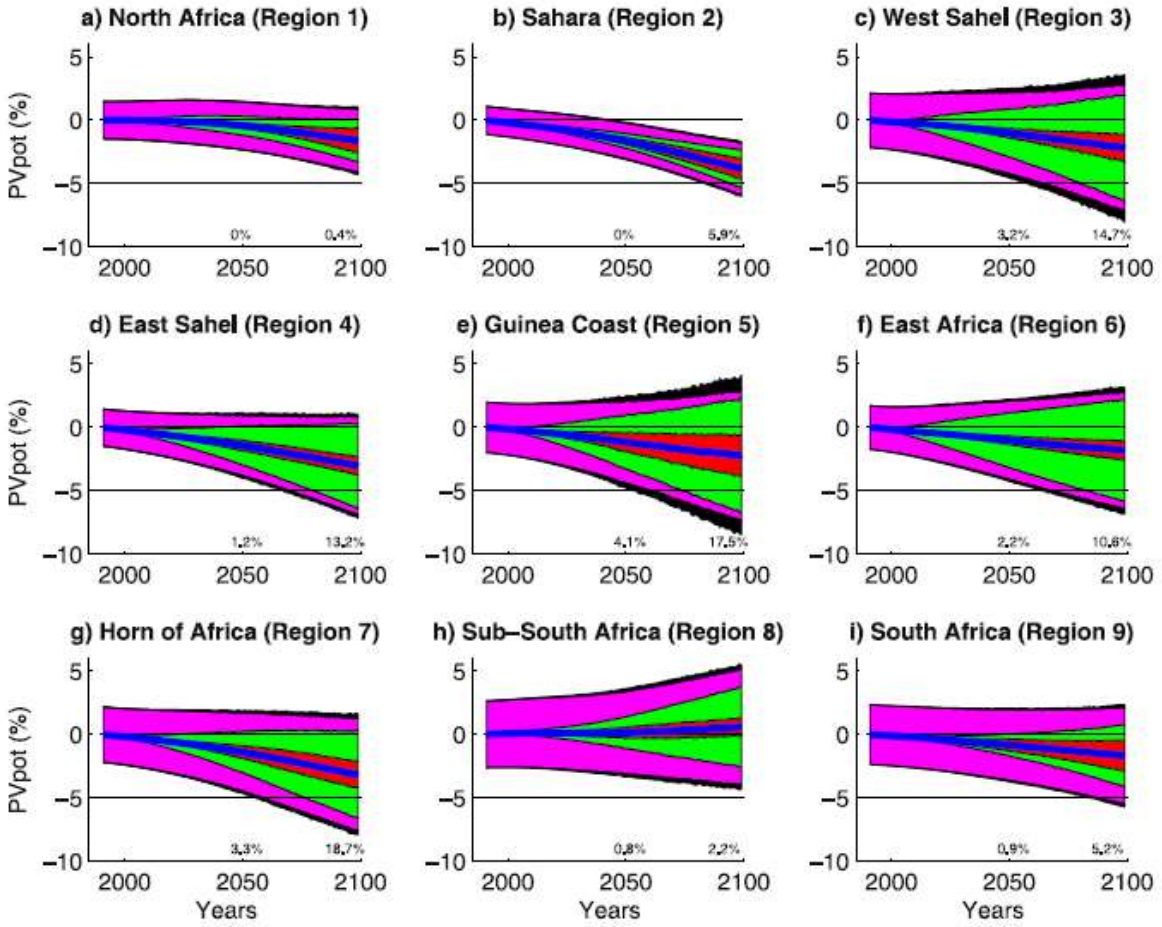




+ Different changes for different seasons
with a likely monsoon induced change in
South Esattern Africa and sahelian region >>

Projected (relative %) changes of PVpot for 9 African regions





Total uncertainty :
Bounds of the whole colored area = 90% confidence interval of projections

And Uncertainty Sources

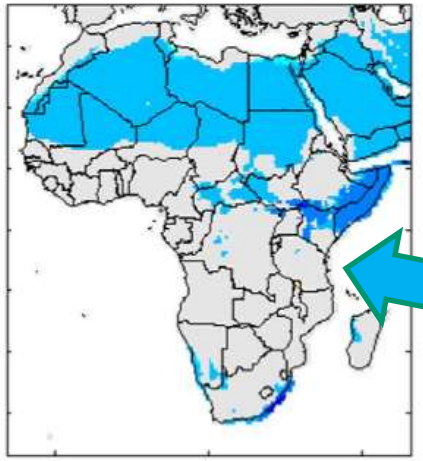
GCM uncertainty
RCM uncertainty
Internal Variability
Method Residual

- Mean decreasing trend in all regions expected in Sub-South Africa (#8)
- Large dispersion for all regions expected in the Sahara. In all regions, even the sign of changes is uncertain…

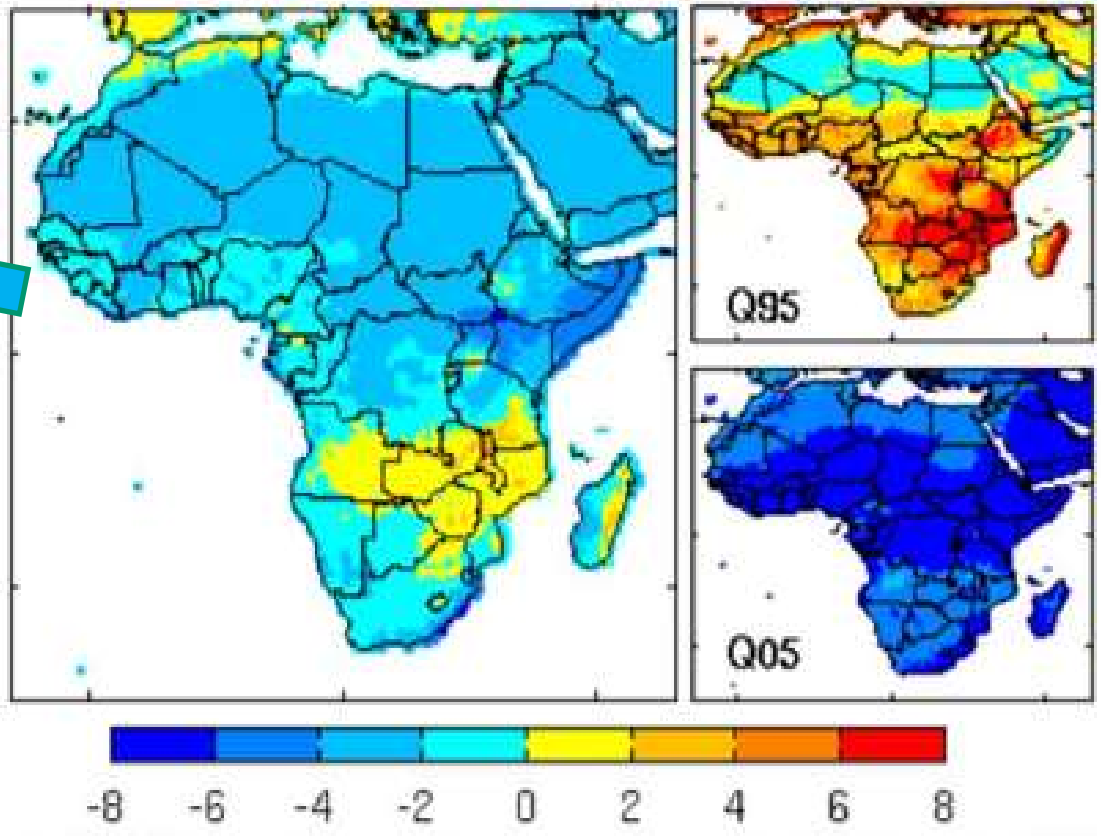
Projected (relative %) changes of PVpot for late century

- As a consequence : Low « Response to Uncertainty » ratio (signal to noise)

>> Rather large changes could occur but very low robustness between models



Areas with « Response to Uncertainty » ratio larger than one

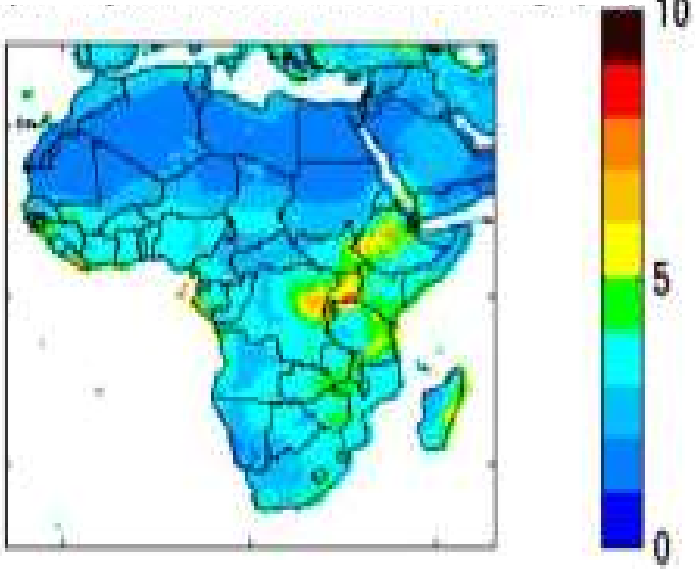


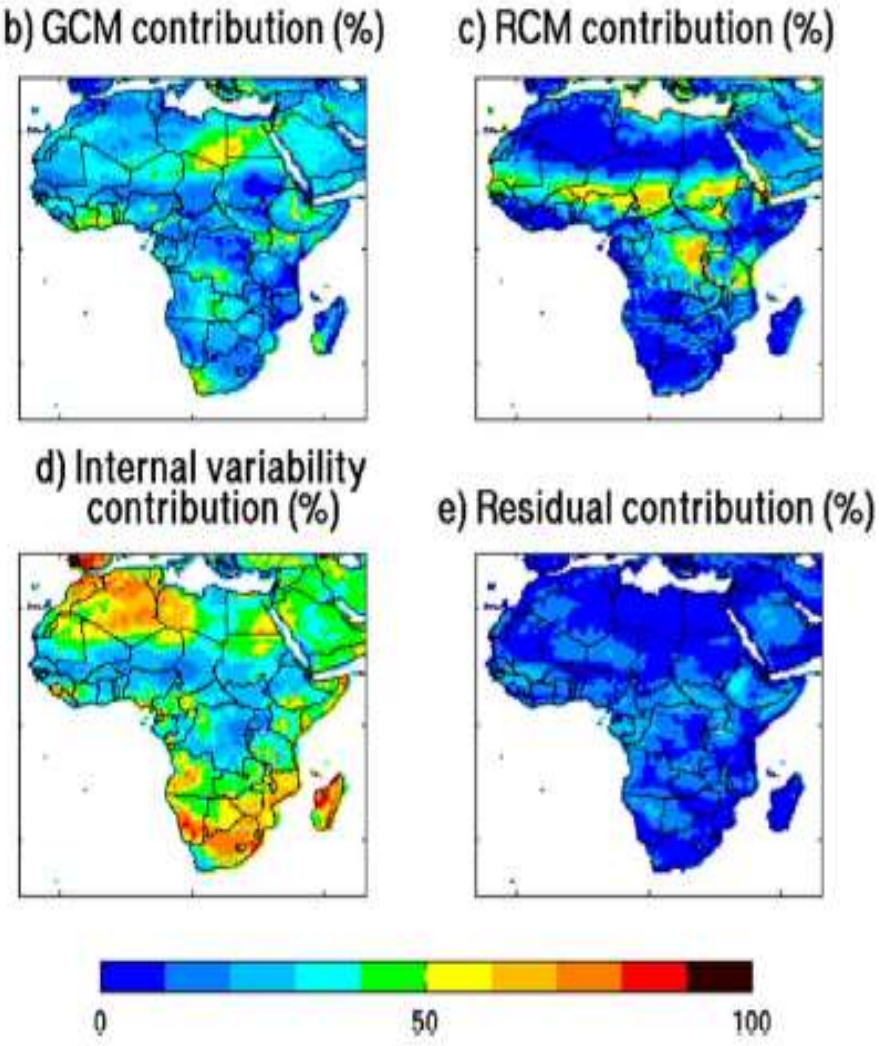
Mean + 05th + 95th percentiles

of projected changes (%) for 2070-2100

What are the main uncertainty sources (2070-2100)

- Total uncertainty standard deviation (%) of PVpot projections





Largest uncertainty source = f(region)

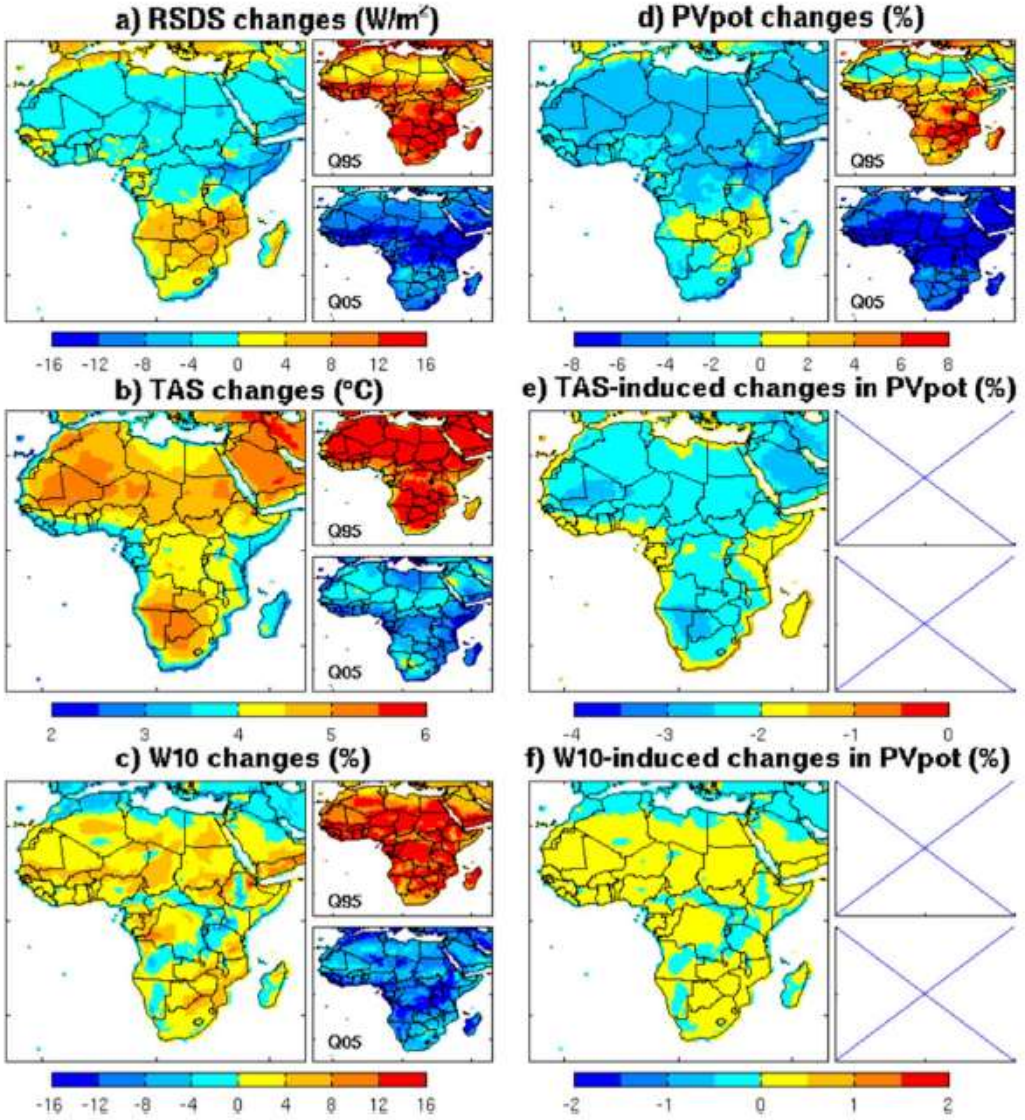
- Internal Variability in North-West, Africa Horn and South
- RCM in central Africa and a large latitudinal band at the southern Saharian border
- GCM not as large except in some regions: Eastern Sahara, Ethipian Highlands, Guinean Golf…
- Residual contribution is negligible : confirm the additivity assumption of GCM and RCM effects

Temperature and wind induced changes

- Changes in PVpot (d, top right) are firstly explained by changes in solar radiation (RSDS – , a) top left)

- 1 or 3 percentage points of decrease (TAS-induced, e) are induced by temperature warming (TAS change, b)

- No-wind induced change is conversily expected



Conclusions and perspectives

- High resolution CORDEX ensembles allow for improved projections
- CORDEX-Africa ensemble allow disentangling different sources of uncertainty : GCM, RCM, internal variability
- But to have a robust and unbiased estimate of climate responses and uncertainty components in ensembles with missing chains, robust estimation methods are required. Recommandation :
  - Use transient simulations and a time series ANOVA approach
  - Use multiple runs ensembles if available
  - Use data augmentation approaches
- Projections of Solar Potential in Africa :
  - Tend to decrease. A part is induced by warming.
    Could be detrimental for some solar projects
  - A risk : poor robustness of projections.
    Even the sign of change is uncertain in some areas
  - Is internal variability well simulated in models : to be checked …
  - Large RCM uncertainty in many places >> RCMs have to be improved…
- Similar analyses to be carried out for other regions and / or other variables

Thank you for your attention

Bichet et al. 2019. Potential impact of climate change on solar resource in Africa for photovoltaic energy: analyses from CORDEX-AFRICA climate experiments
https://iopscience.iop.org/article/10.1088/1748-9326/ab500a

And more on partitioning model uncertainty and internal variability components

Hawkins and Sutton, 2009. The potential to narrow uncertainty in regional climate predictions. BAMS doi:10.1175/2009BAMS2607.1

Hingray et Saïd 2014. Partitioning internal variability and model uncertainty components in multimodel multimember ensembles of projections
J.Climate. doi:10.1175/JCLI-D-13-00629.1
QEANOVA matlab package : http://www.lthe.fr/RIWER2030/download_fr.html

Precision of uncertainty estimates : QEANOVA versus Single Time ANOVA
Hingray et al. 2019. Precision of uncertainty components estimates in climate projections
Clim.Dyn. https://doi.org/10.1007/s00382-019-04635-1

Incomplete ensembles
Evin et al. 2019. Partitioning uncertainty components with data augmentation
J.Climate. https://journals.ametsoc.org/doi/pdf/10.1175/JCLI-D-18-0606.1

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