Uncertainties in Climate Modelling

Mathieu Vrac

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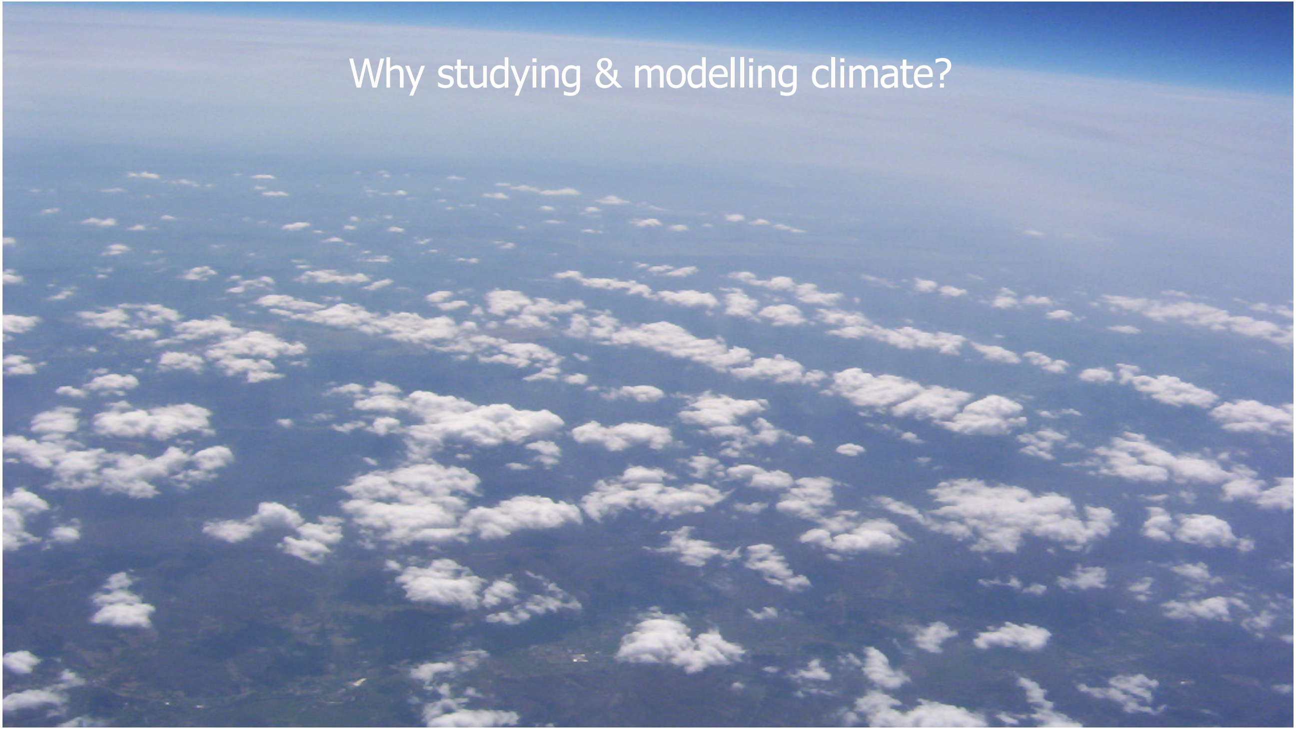
Inauguration du GIS “Quantification des Incertitudes”
October, 18, 2022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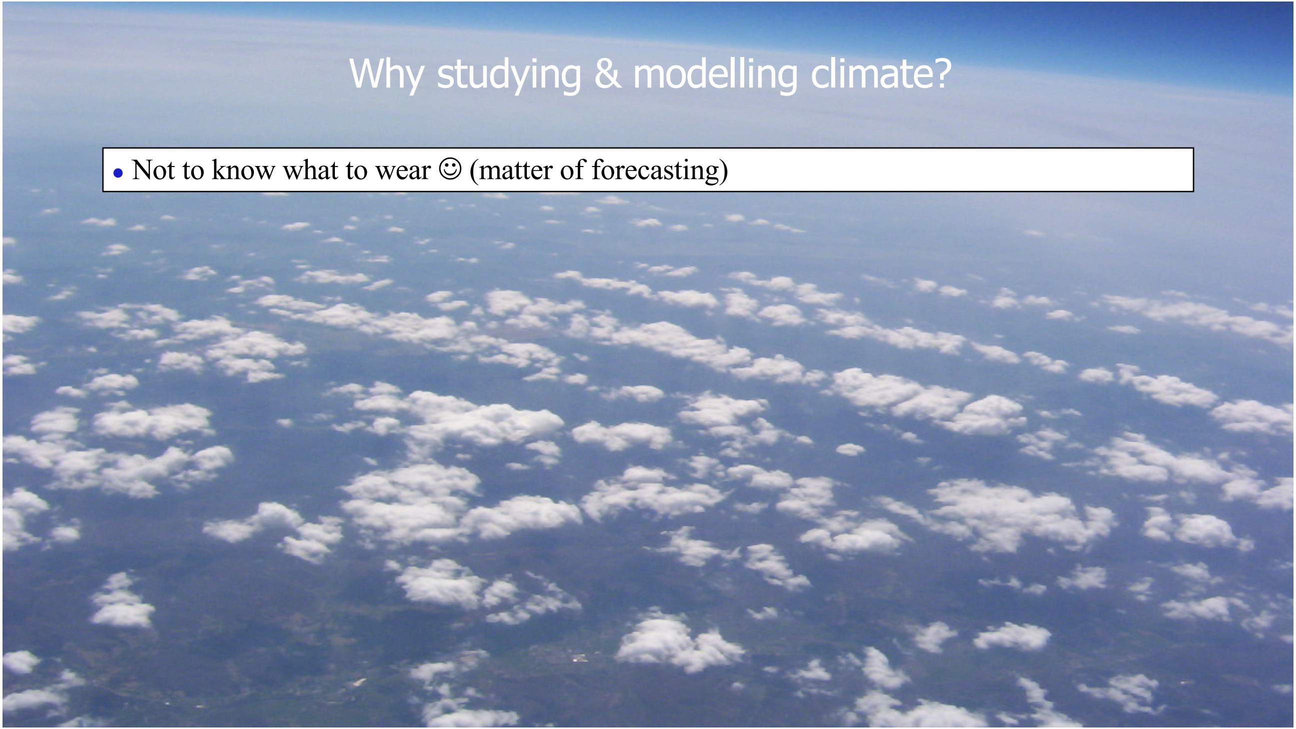

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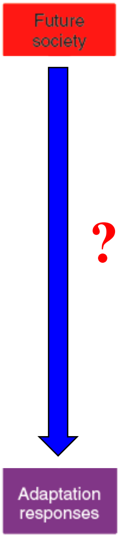
- As in any (physical and statistical) modelling: Uncertainties are present

From scenarios to adaptations/mitigations



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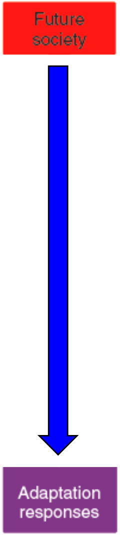

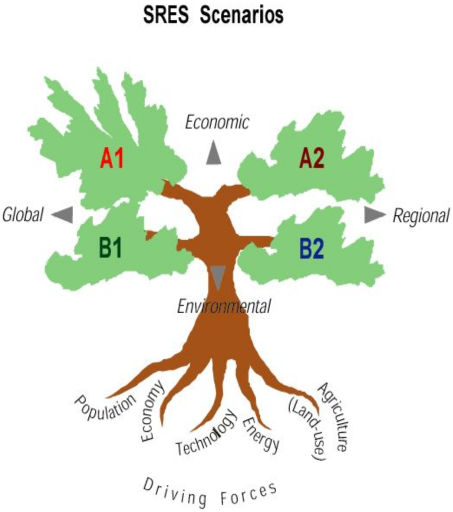

Source: AR4 IPCC (2007)

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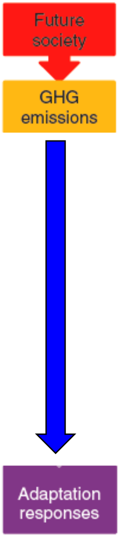

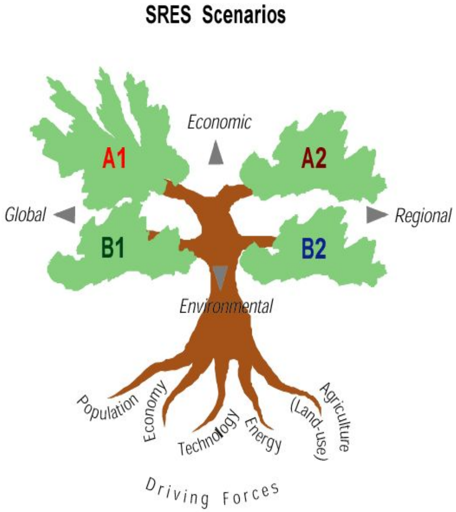

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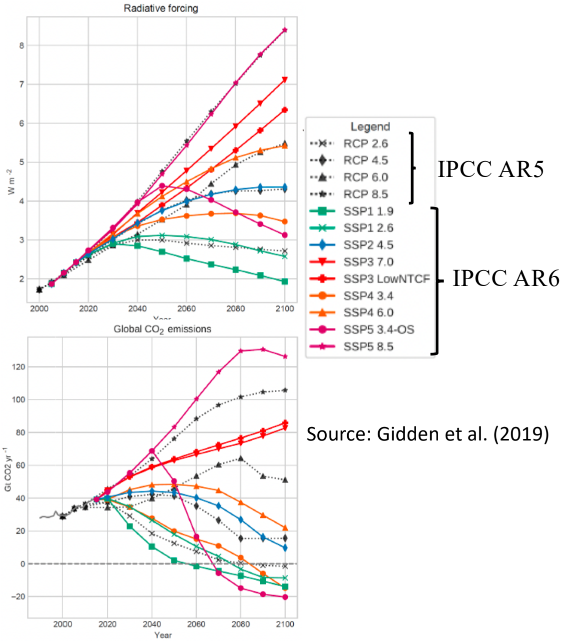

Source: Gidden et al. (2019)

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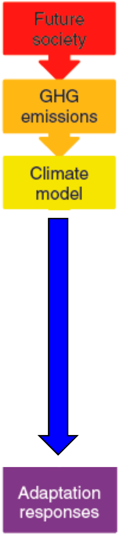
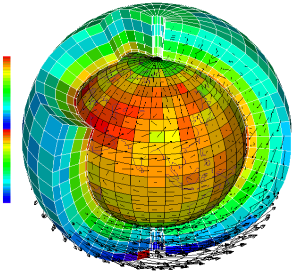
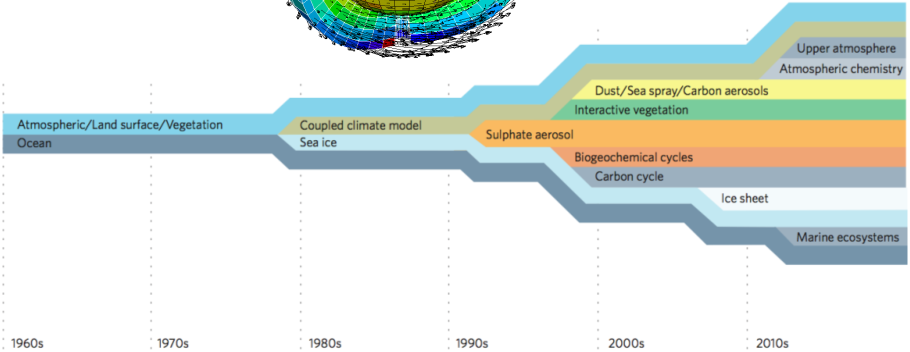




Source: IPSL



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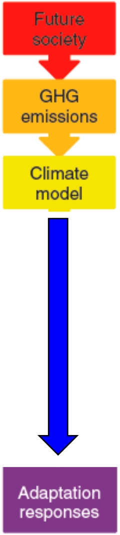

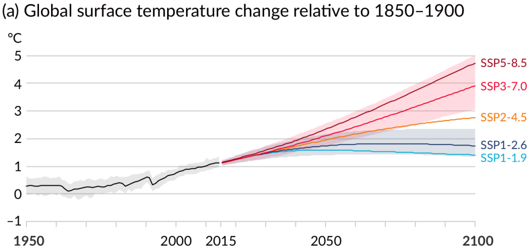

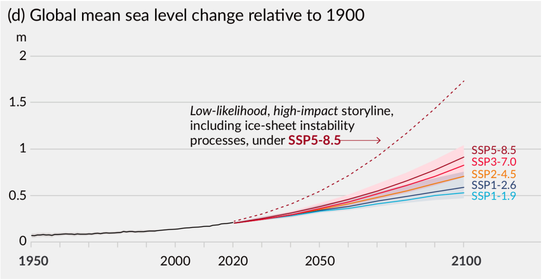

	Obs*	SSP1-2.6**	SSP5-8.5**
ΔT (K)	0.8 ± 0.1	1.0 ± 0.5	3.6 ± 1.2
ΔSL (m)	0.20 ± 0.05	0.47 ± 0.15	0.82 ± 0.19

* Obs = **1995-2014** vs. 1850-1900
** SSP = 2081-2100 vs. **1995-2014**

Source: AR6 IPCC (2021)

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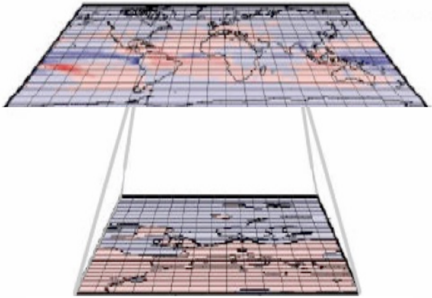

GCM simulations

Downscaling
(RCMs or SDMs)

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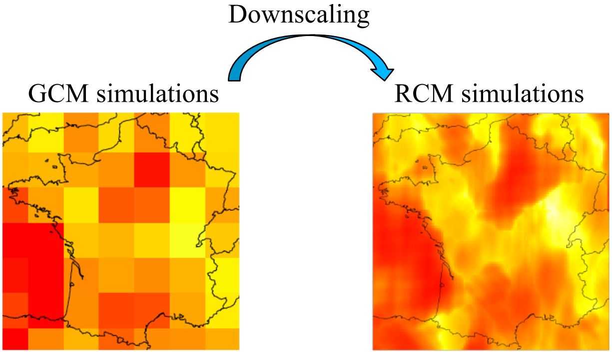

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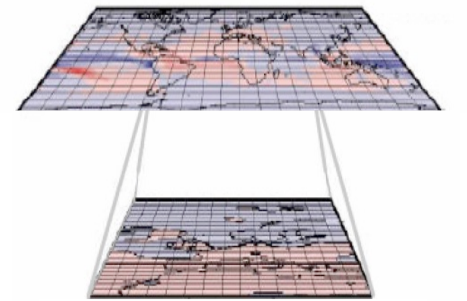

GCM simulations

⇩

Downscaling
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Not always enough!

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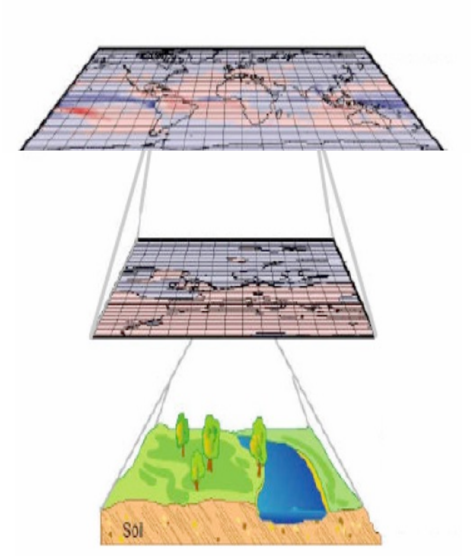

GCM simulations

Downscaling
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Additional DS &/or
“bias correction”

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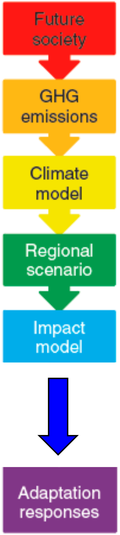

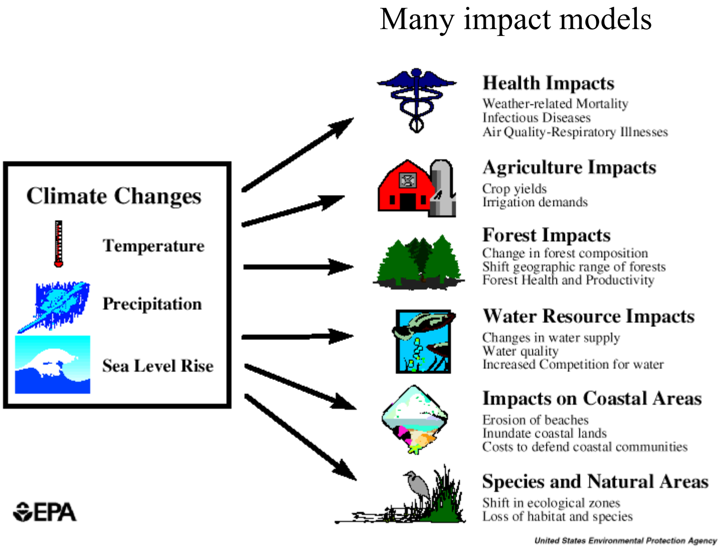

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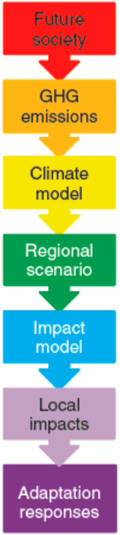
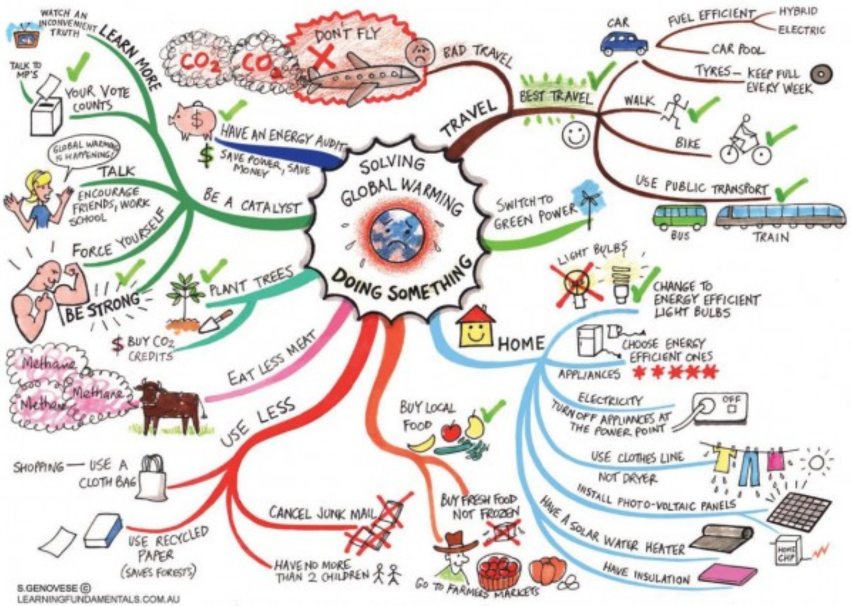
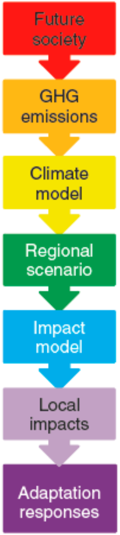




Not that easy: some (!) uncertainties



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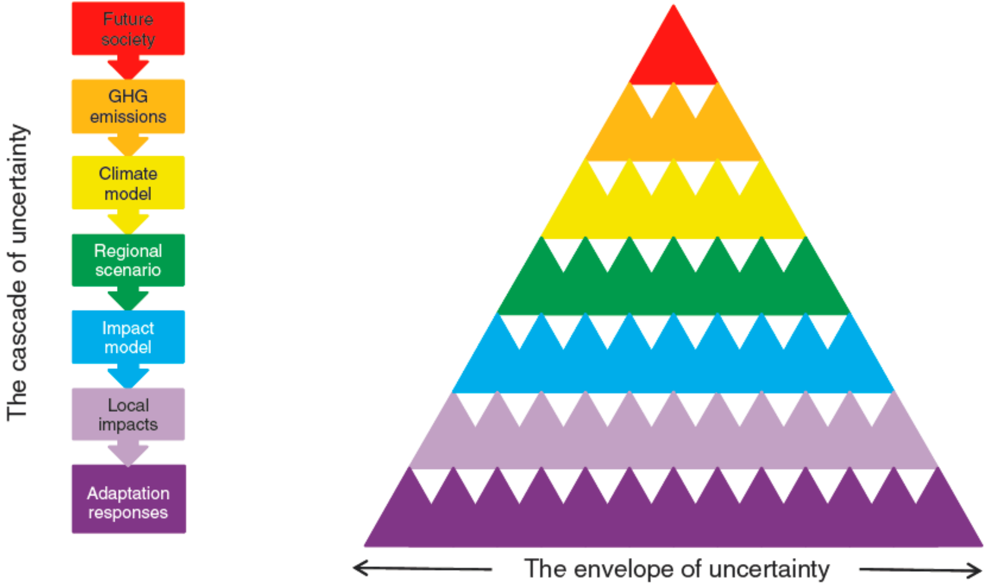

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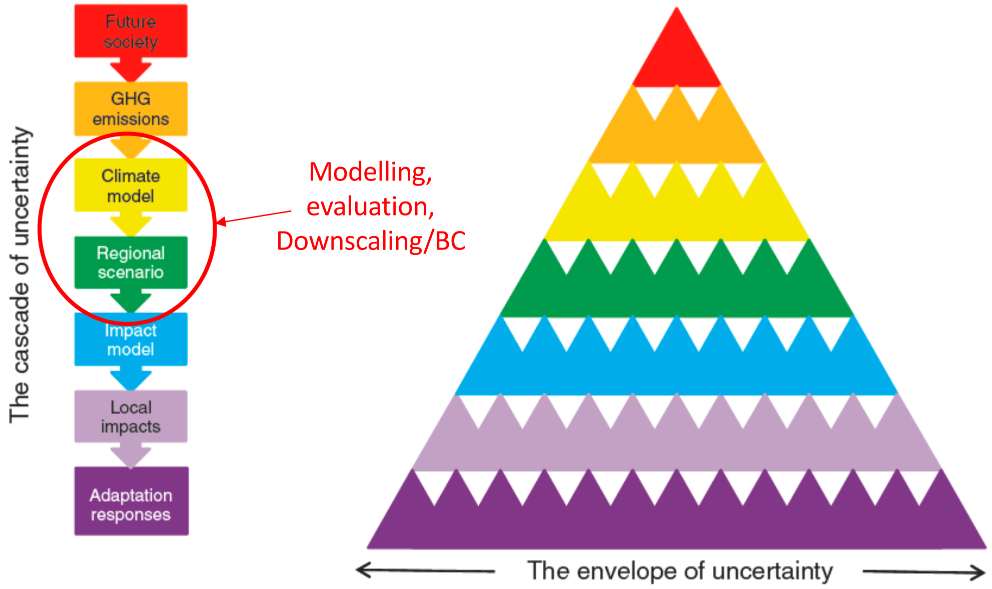

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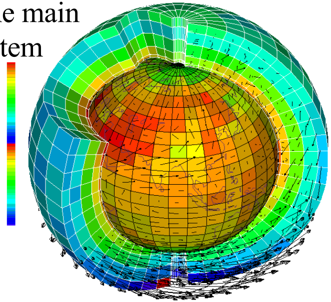
  - **Structure of the model / parametrizations / scale**



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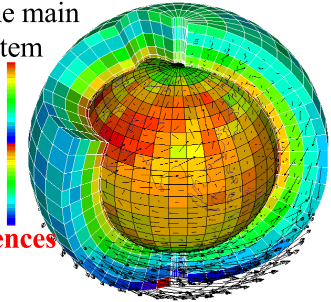

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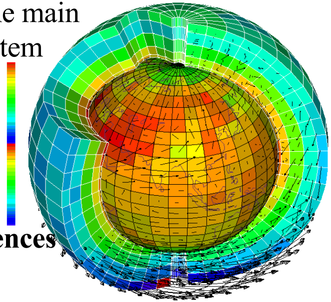

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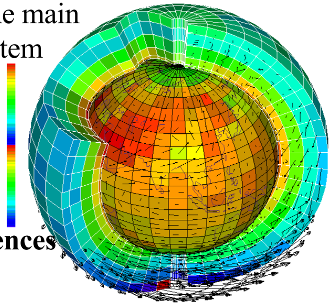

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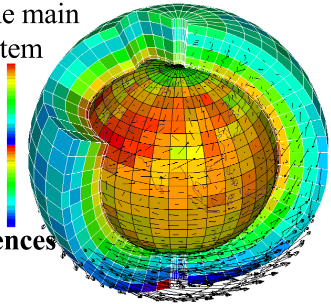

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- Note: Climate ≠ Meteo !! (even though, same variables)

Meteorology ≠ Climate

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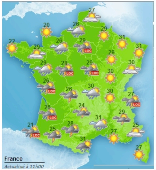

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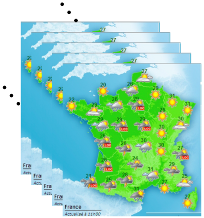

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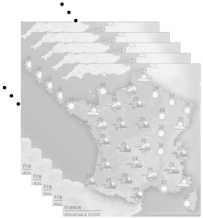
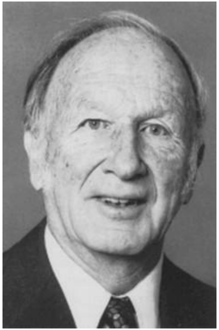


But…



E. Lorenz
(1917–2008)

"Climate is what you expect,
weather is what you get."

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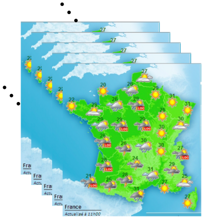

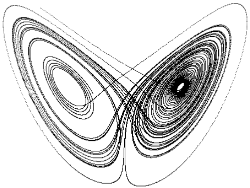

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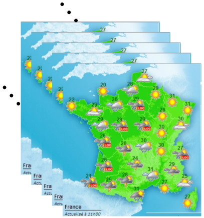

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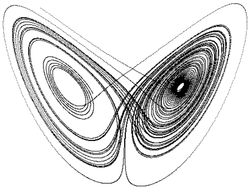

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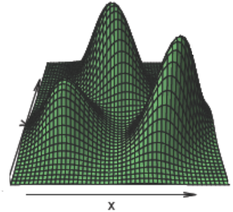

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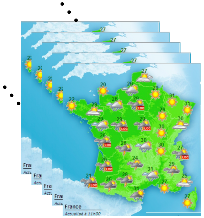

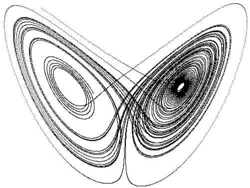

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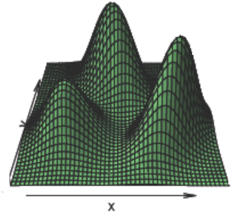

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Main thread of various statistical modellings climate variables & evaluations:

What we need is the correct **pdf or CDF** (or at least properties)

Uncertainty vs. Variability vs. Bias

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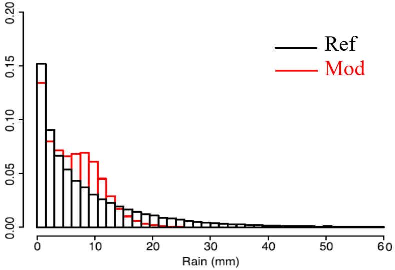
Systematic statistical error (e.g. approximated parametrizations, spatial scale, etc.)

Systematic (distributional) biases
Scale issue (e.g., grid vs. station)



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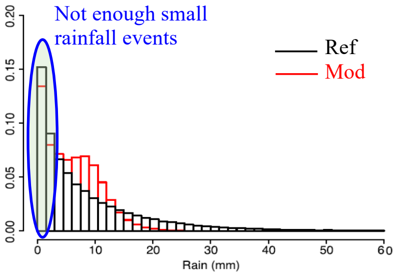

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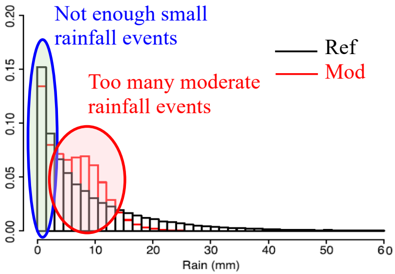

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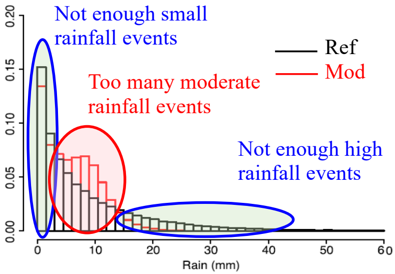

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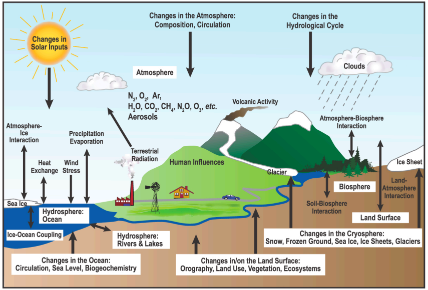
Hyp.: We **don't** have all the relevant knowledge (e.g., predictors and/or processes are not necessarily fully fixed or known) ➔ the results are impacted by this lack of knowledge



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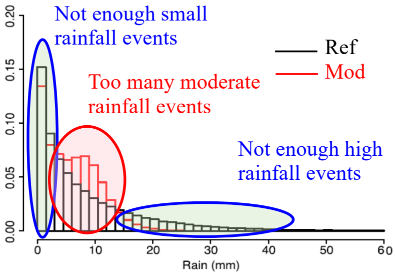

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Hyp.: We have all the relevant information (i.e., predictors) but there is a stochasticity inherent to the system

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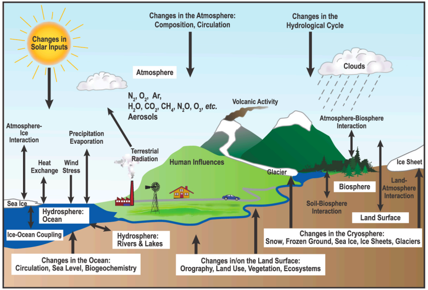
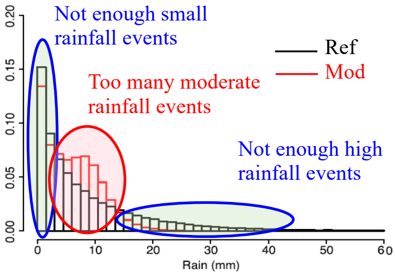
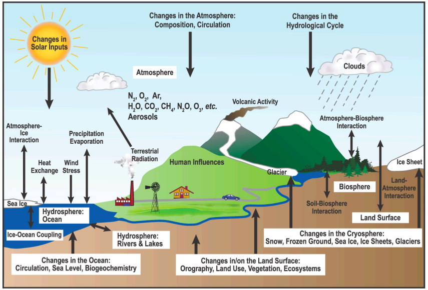


In practice, we have **uncertainties on the variability** (e.g., does the dice have 12 or 6 sides?)



Uncertainty vs. Variability vs. Bias

<u>Hyp.</u>: We **don't** have all the relevant knowledge (e.g., predictors and/or processes are not necessarily fully fixed or known) ➔ the results are impacted by this lack of knowledge

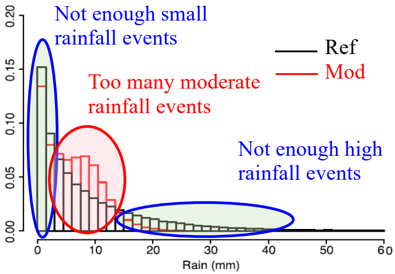


<u>Hyp.</u>: We have all the relevant information (i.e., predictors) but there is a stochasticity inherent to the system

⚠ In practice, we have **uncertainties on the variability** (e.g., does the dice have 12 or 6 sides?)

Systematic statistical error (e.g. approximated parametrizations, spatial scale, etc.)

Systematic (distributional) biases
Scale issue (e.g., grid vs. station)



➢ Not always easy to separate them!

Variabilities, forcings, etc.

Some "wording":

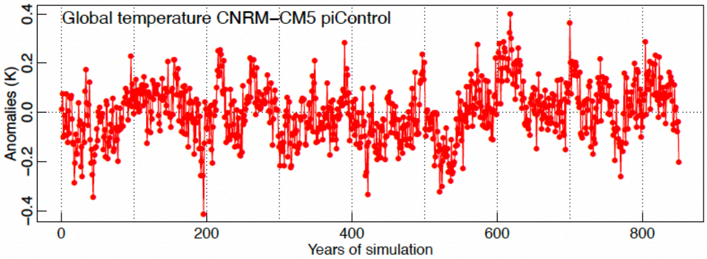
- Climate = Mean state + climate variability
- Climate variability = internal variability + external forcings
- External forcings = Natural forcings + anthropogenic forcings
- Natural variability = Internal variability + Natural forcings

Inter-model variability vs. Internal variability

Stationary climate: lots of variations anyway!

(= mean state + internal variability)

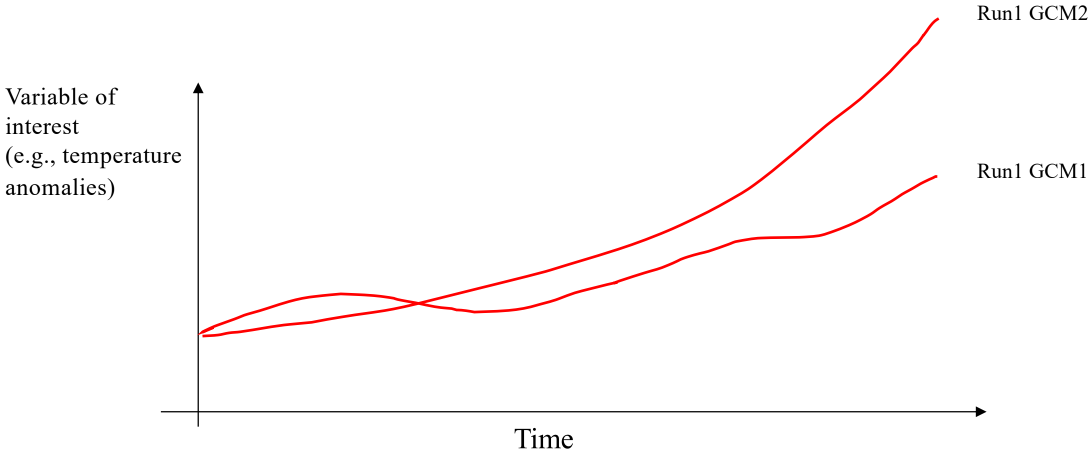
Data: CNRM-CM5



Many internal variabilities:

- from global and multi-decadal (mostly from the ocean)
- to regional and inter-annual (mostly from the atmosphere)

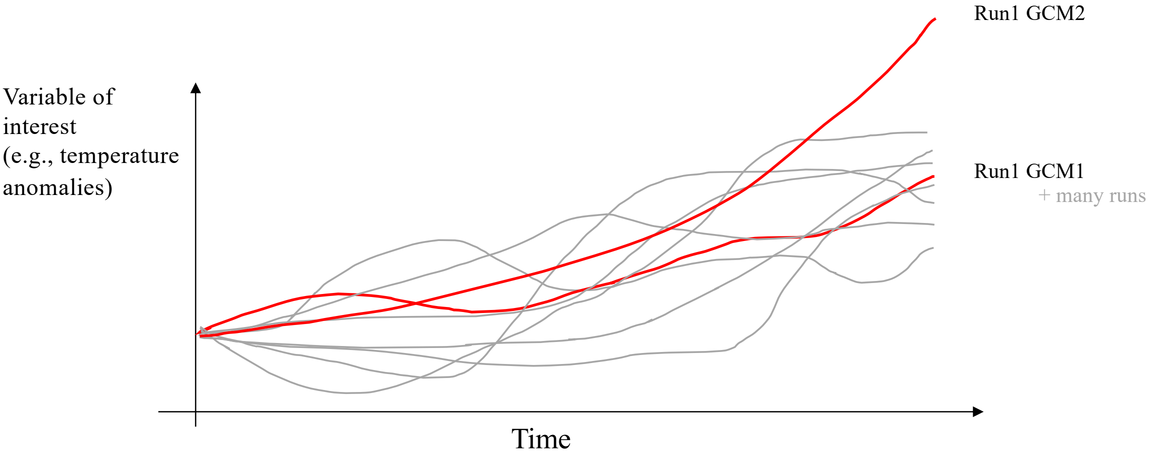
Inter-model variability vs. Internal variability



- Single runs of 2 GCMs (one scenario only)

⚠ This is a schematic view (i.e., not based on actual simulations)

Inter-model variability vs. Internal variability



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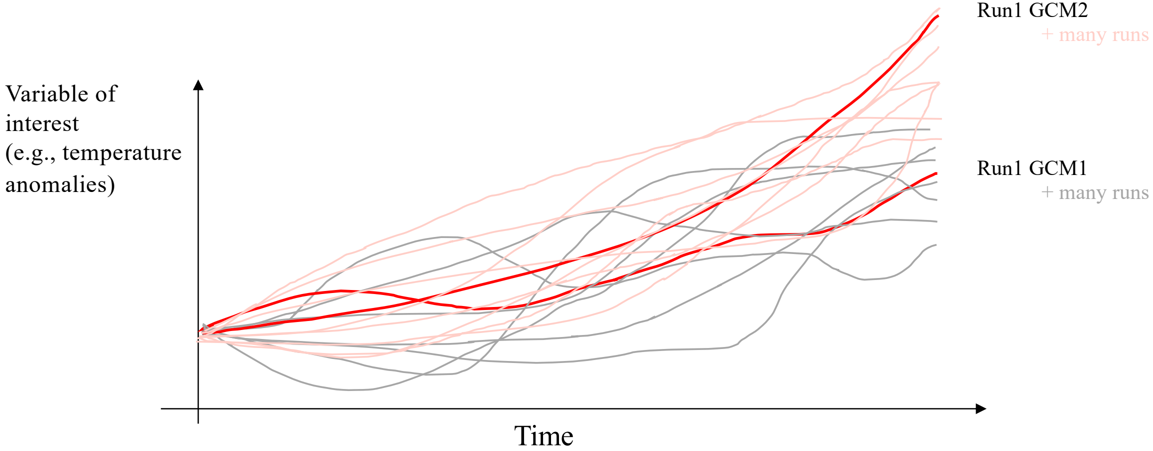

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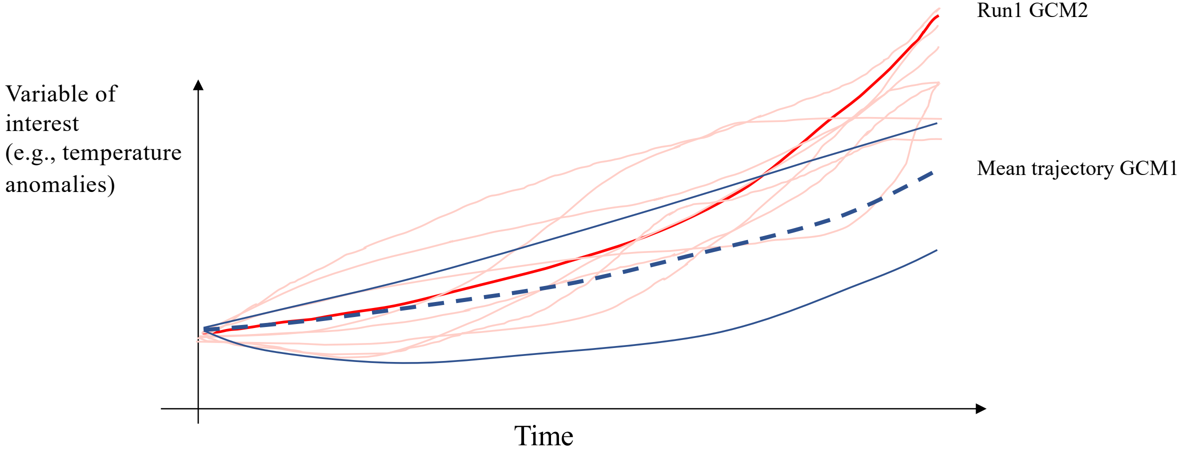

- Multiple runs of 2 GCMs (one scenario only)
  - ✓ Mean trajectories

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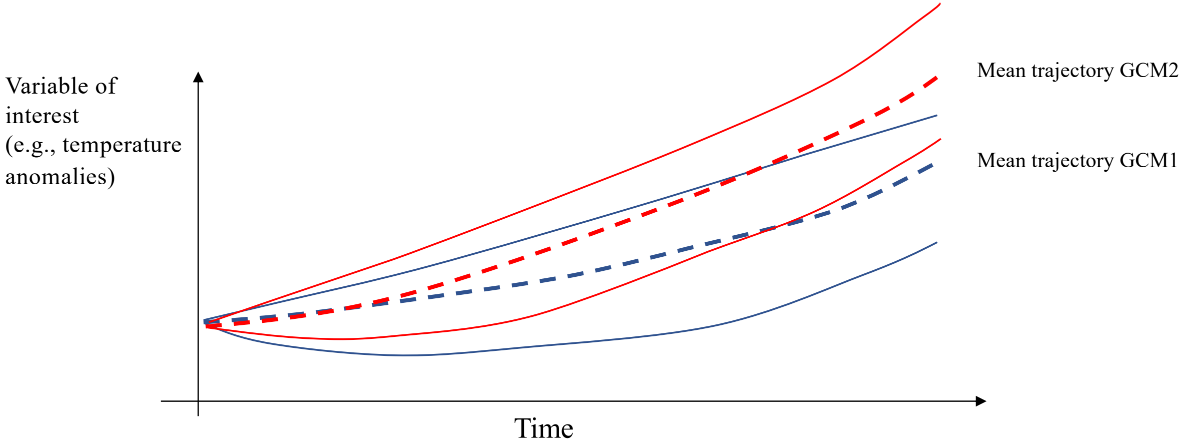

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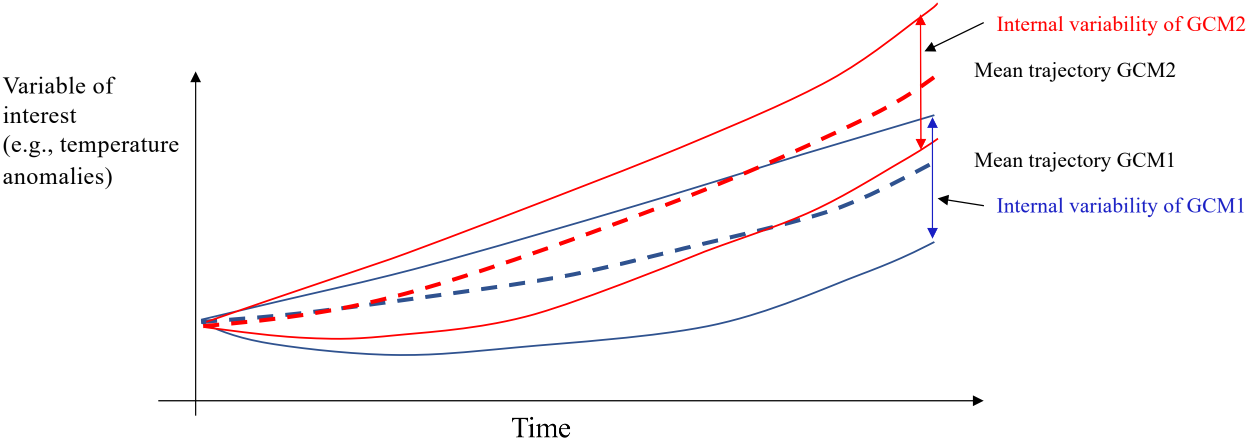
Inter-model variability vs. Internal variability



- Multiple runs of 2 GCMs (one scenario only)
  - ✓ Mean trajectories
  - ✓ Internal variabilities

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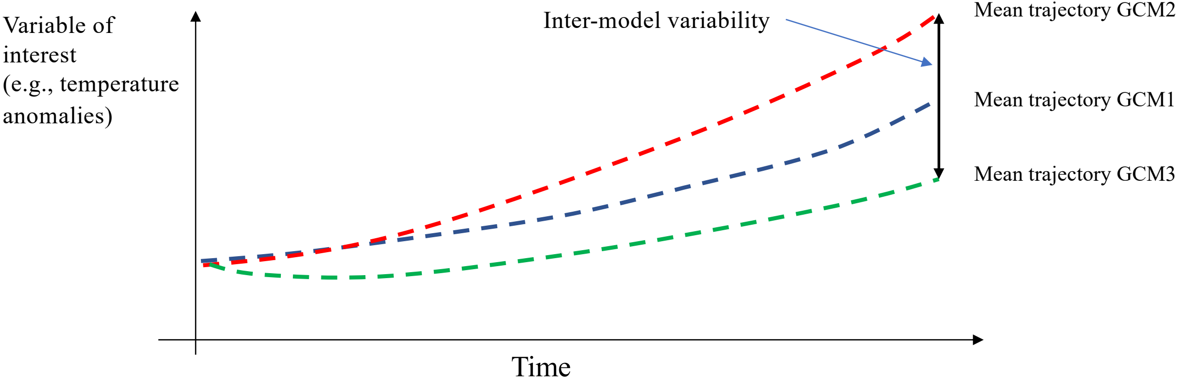
Inter-model variability vs. Internal variability



- Multiple runs of 2 GCMs (one scenario only)
  - ✓ Mean trajectories
  - ✓ Internal variabilities

+ Inter-model variability

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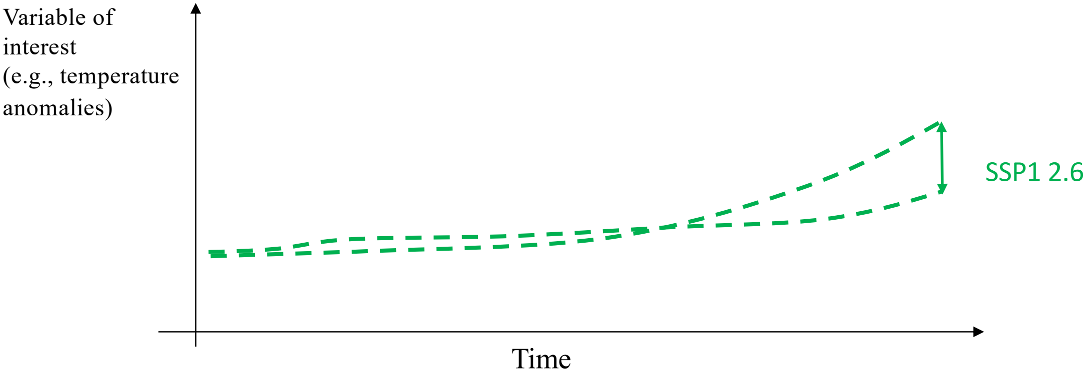
Inter-model variability vs. Internal variability



- Multiple runs of GCMs & multiple scenarios

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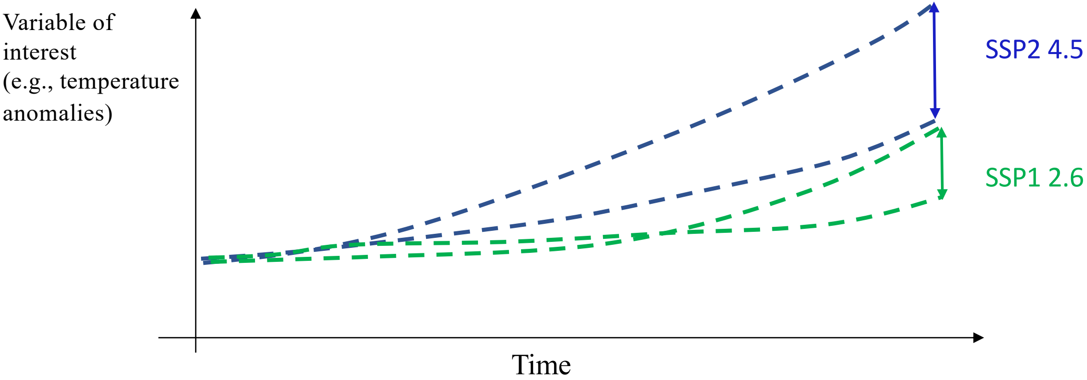
Inter-model variability vs. Internal variability



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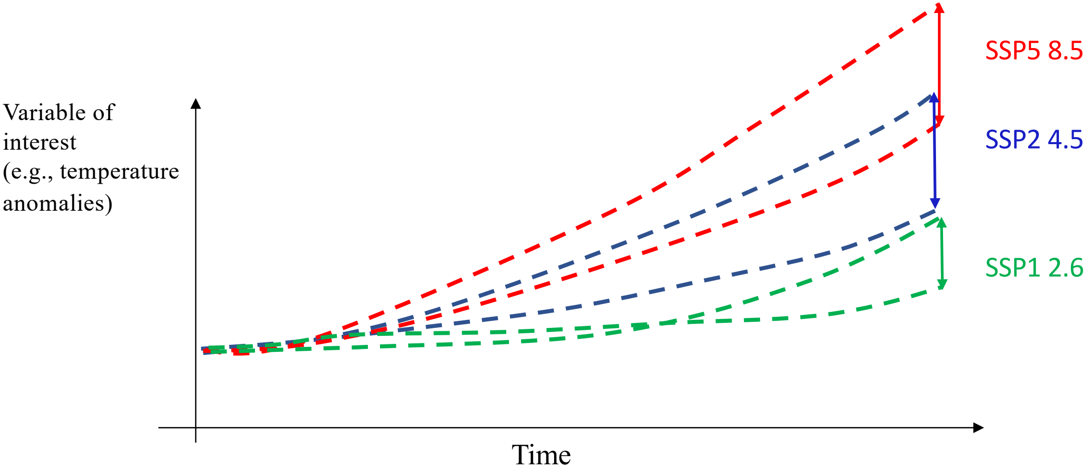

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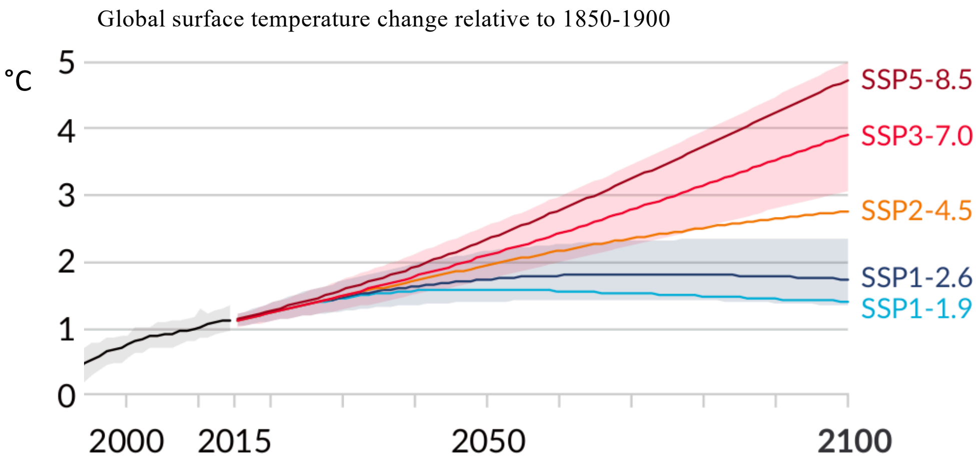
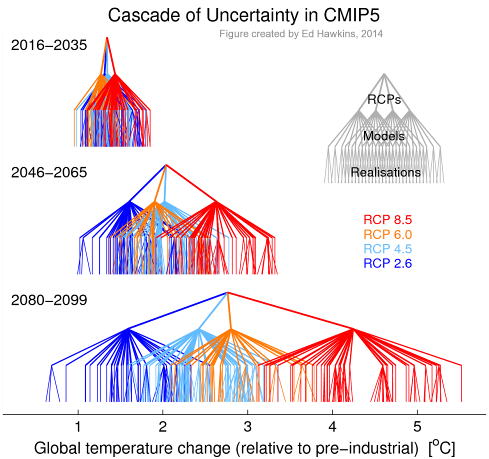


- Multiple runs of GCMs & multiple scenarios
- How to quantify the contribution of the different variabilities/uncertainties?

⚠ This time, this is based on actual CMIP6 simulations (adapted from AR6 IPCC, 2021)

Contributions of the different uncertainties…



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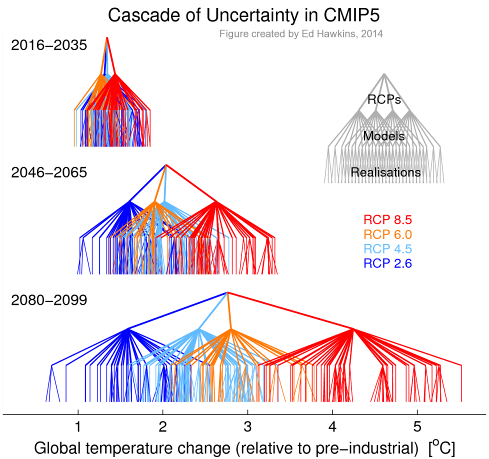
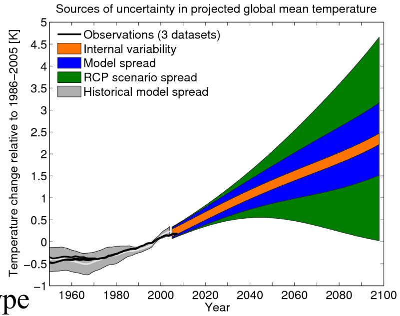
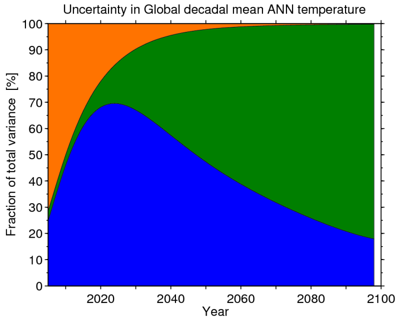




ANOVA type analyses

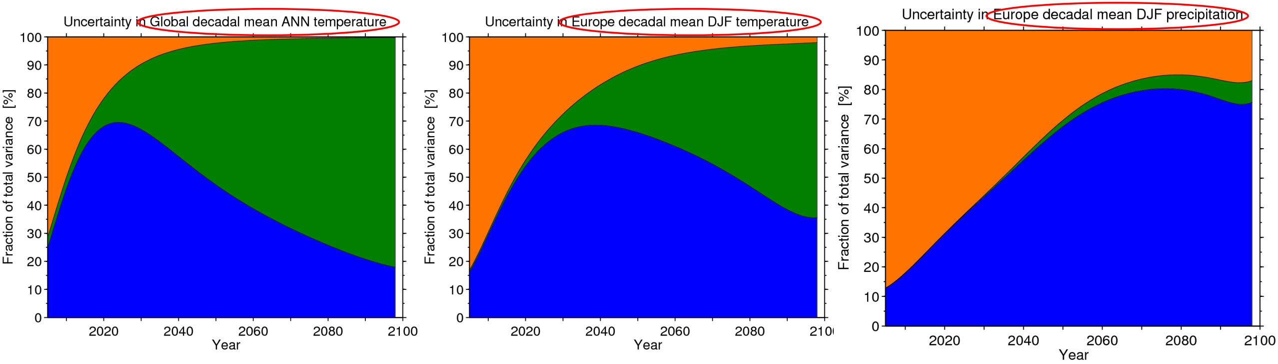


Source: Hawkins (2014)

For temperature:

- Short term: uncertainty on *internal variability* is predominant
- Medium term: uncertainty on *modelling* dominates
- Long term: uncertainty on *scenario* is the largest

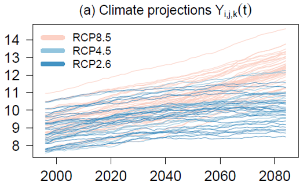
… Different for each variable & region



Source: Figures from E. Hawkins, to find on his blog.

A recent tool to characterize contributions

QUALYPSO : partitioning uncertainty components in an ensemble of climate projections (Evin et al., 2019)



- **Provides**: **Uncertainty sources**; individual **climate response** of each model: uncertainties as a function of **global warming level** (e.g. in a +2°C world)
- **Suits**: Incomplete ensembles with multimodel simulation chains (GCM x RCM x …) for any kind of projections (weather, hydrology, ecology)
- **Links**: Package R "QUALYPSO" available on CRAN

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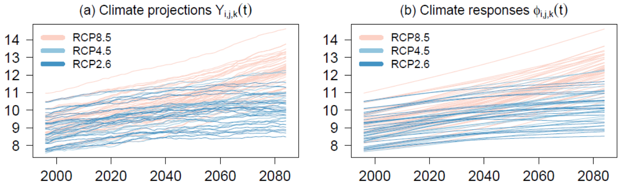

extraction of climate responses with a cubic spline model

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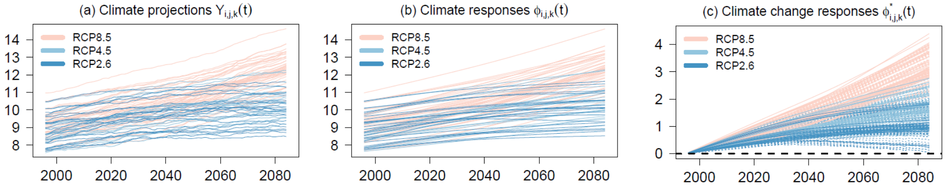

extraction of climate responses with a cubic spline model

climate change responses w.r.t. a reference period (e.g. 1980-2010)

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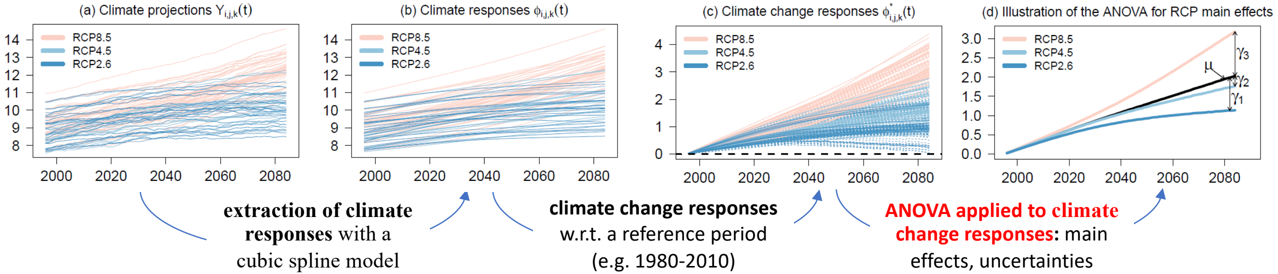

μ = mean response in change from the whole ensemble inter-modeles / inter-scenarios

γ_1, γ_2 and γ_3 = individual effects of the 3 RCP scenarios wrt μ (e.g., γ_3 => RCP8.5 implies a T change of +1°C wrt μ)

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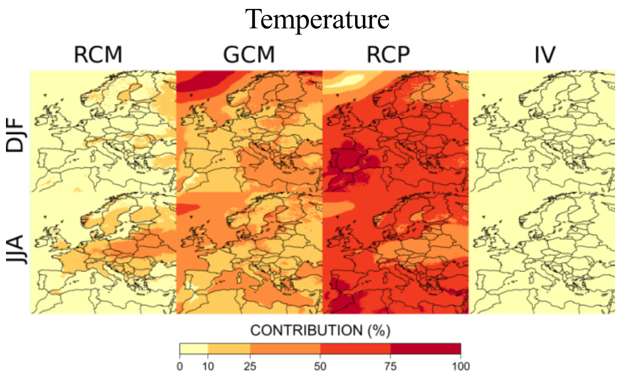
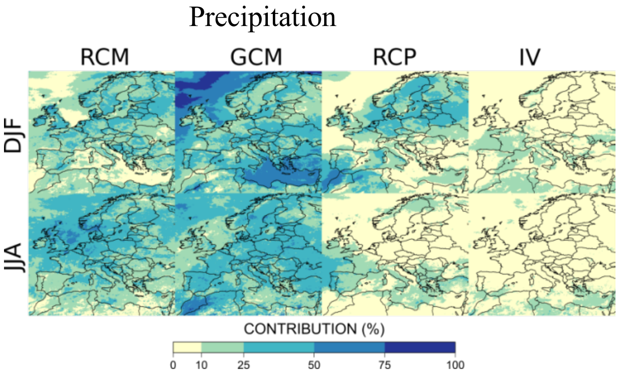
Examples for seasonal changes (2071-2099 wrt 1981–2010) of precipitation and temperature in Europe





Source: Evin et al. (2021, ESD)

Uncertainty vs. Variability vs. Bias

Present in most components of the modelling chain…

- Global Climate Models (GCM)
- Regional Climate Models (RCM, "Dynamical doswnscaling")
- Statistical Downscaling Models (SDM, including Mach. Learning)
- Bias Correction (BC) methods
- Impact models (hydrology, ecology, economy, etc.)

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For evaluation

For fit & evaluation

+ uncertainties on **references**

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… & in most processes

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- Univariate distributions and basic properties
- Multivariate dependencies
- Temporal properties (persitence, reccurrence, etc.)
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- Univariate distributions and basic properties
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- Extremes (return levels/period, HW, storms, etc.)

- Especially in a climate change context! (trends, non-stationarity, etc.)

Thank you…