Belgian National Committee for Geodesy and Geophysics

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Introducing uncertainty in the impact assessments of climate change on local scale hydrology.

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The recently released AR5 report of IPCC confirms that freshwater-related risks of climate change increase significantly with increasing greenhouse gas (GHG) concentrations and that climate change is projected to reduce renewable surface water and groundwater resources significantly in many areas overall the world. This will intensify competition for water among agriculture, ecosystems, settlements, industry, and energy production, affecting regional water, energy, and food security and increase water insecurity. This calls for paradigm shifts in the water management policy and adaptation of water management at different levels (physical technical, social, institutional). However, many barriers for adaptation exists. One of these barriers is related to a poor understanding of possible impacts of climate change at the local hydrological scale, and a poorly characterized uncertainty associated with such impact studies.

To improve this, we show how uncertainty can be propagated for assessing hydrological impacts of climate change at the local scale. We illustrate the approach for two catchments of the Mediterranean region - which is considered as a hotspot for climate change – and demonstrate how uncertainty can be decomposed in uncertainty coming from the hydrological model and uncertainty coming from the climate model.

Introducing uncertainty in the hydrological impact assessments of climate change at the local scale

Marnik Vanclooster and Haykel Sellami

BNCGG 12/11/2015

Outline

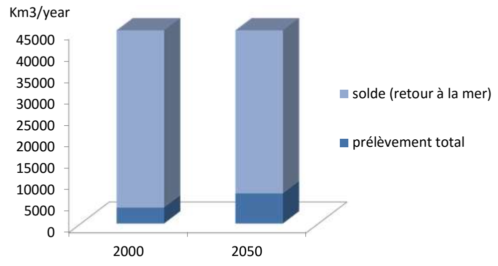
- What do we know about hydrological impacts of climate change? A global perspective.
- Uncertainty: a barrier in the climate adaptation strategy.
- Uncertainty in local scale hydrological studies in the mediterranean area.

What do we know about hydrological impacts of climate change?
A global perspective

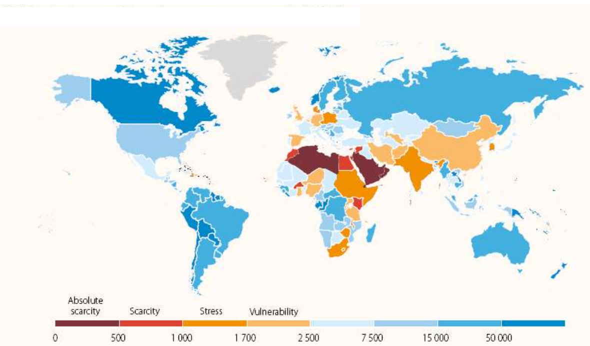
The multi-dimensional aspects of water

- Water is a multifunctional natural resource
- Water is blue , green and grey
- Water is strongly impacted by Climate Change
- Water is at risk
- Water is a cross-cutting theme in the development agenda (food – energy – health -…)

The water problem is not a total stock problem: We are still living on a blue planet!

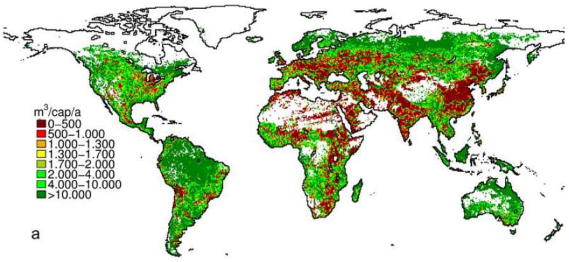


It is a spatial and temporal distribution problem !



Renewable water per country, WWDR, 2014

It is a spatial and temporal distribution problem of blue water…



Blue water distribution in 2000, Rockström et al., 2009, WRR

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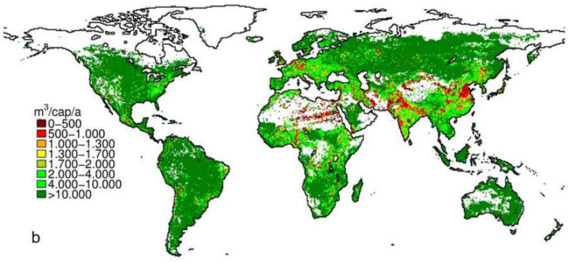
…but not yet for green water.



Green water availability in 2000, Rockström et al., 2009, WRR

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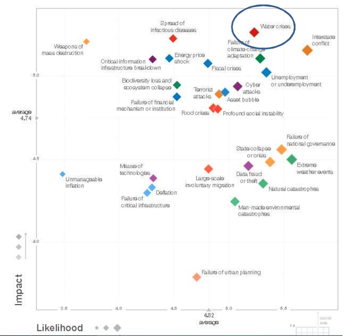
Global risks landscape, 2015



World Economic Forum, 2015

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Newsweek , 1 May 2015

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Newsweek , 1 May 2015

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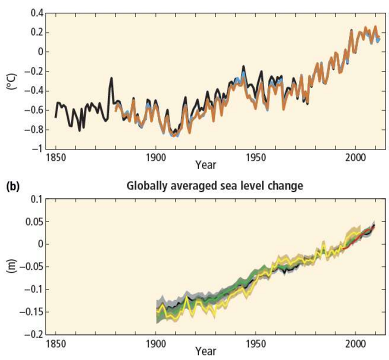
What do we know about CC and water?



Observed temperature and sea level evolution, IPCC, AR5

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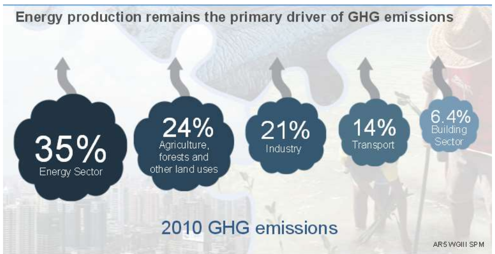
What do we know about CC and water?



Role of different sectors in GHG emissions, IPCC, AR5

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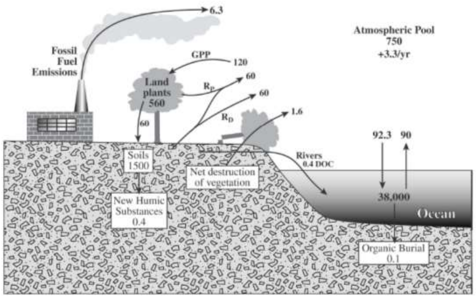
What do we know about CC and water?



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What do we know about CC and water?

SOC is major C stock (3 x more than in terrestrial biomass and 2 x more than atmospheric C)

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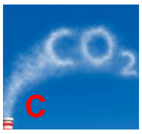

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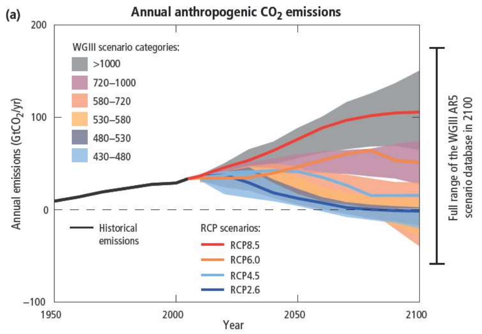
How will CC evolve?



Projected GHG emissions. IPCC, AR5

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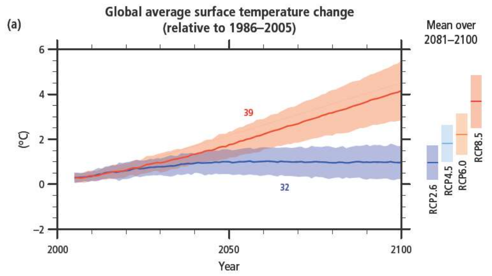
How will CC evolve?



Projected temperature evolution. IPCC, AR5

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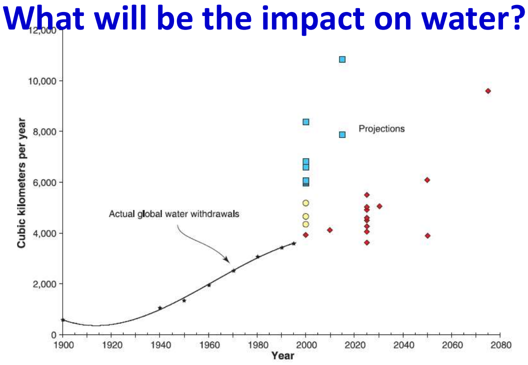
What will be the impact on water?



Estimated global withdrawals. Gleick, P., 2003, Science

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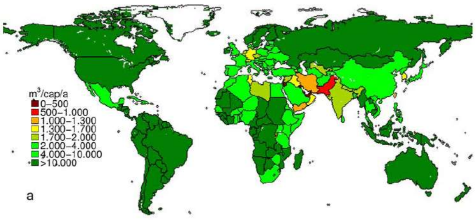
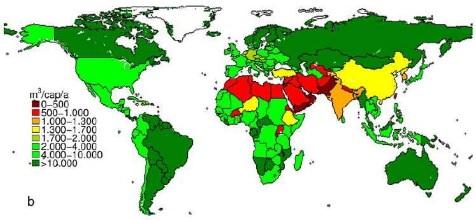
What will be the impact on water?



Blue and green water availability 2000, Rockström et al., 2009, WRR

What will be the impact on water?



Blue and green water availability 2050, Rockström et al., 2009, WRR

What will be the impact on water?

	Blue water shortage (10^9 inhabitants)	Blue and green water shortage (10^9 inhabitants)
Europe	0,16	0,00081
North America	0,05	0,0052
South America	0	0
Asia	5,46	3,35
Africa	0,83	0,57
Oceania	0	0
World shortage	6,50	3,93
World	10,95	10,95

Blue and green water shortage, 2050. Rockström et al., 2009, WRR

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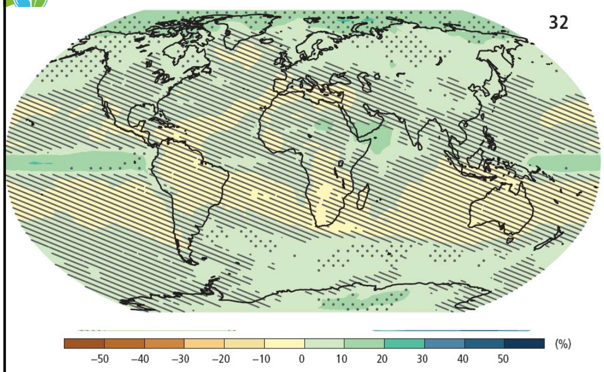

Changed precipitations, RCP 2,6 (2081-2100 vs 1986-2005), IPCC, AR5

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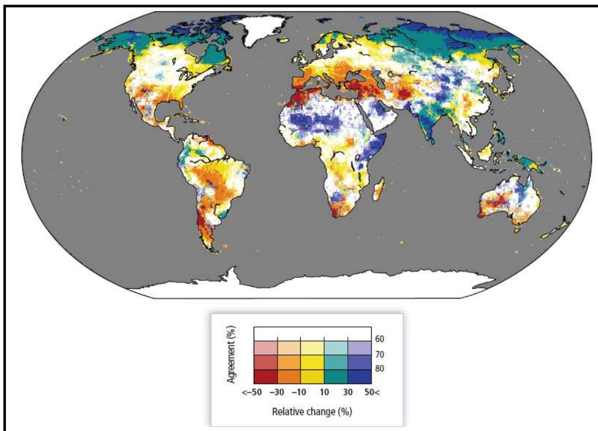

Change of annnual streamflow, IPCC, AR5

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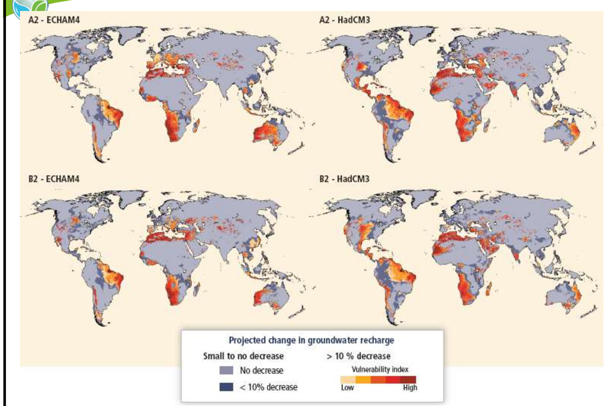

Change of recharge, IPCC, AR5

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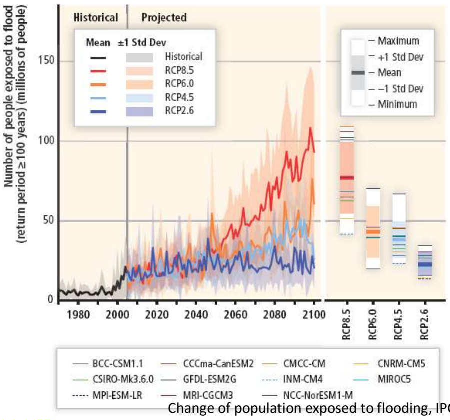

Change of population exposed to flooding, IPCC, AR5

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What will be the impact on water?

- **Freshwater-related risks of climate change increase significantly with increasing greenhouse gas (GHG) concentrations (*robust evidence*, *high agreement)***
- **Climate change is projected to reduce renewable surface water and groundwater resources significantly in most dry subtropical regions (*robust evidence*, *high agreement*). This will intensify competition for water among agriculture, ecosystems, settlements, industry, and energy production, affecting regional water, energy, and food security (*limited evidence*, *medium* to*high agreement*).**
- **So far there are no widespread observations of changes in flood magnitude and frequency due to anthropogenic climate change, but projections imply variations in the frequency of floods (*limited evidence*, *medium agreement*).**
- **Climate change is *likely* to increase the frequency of meteorological droughts (less rainfall) and agricultural droughts (less soil moisture) in presently dry regions by the end of the 21st century under the RCP8.5 scenario (*medium confidence*). This is *likely* to increase the frequency of short hydrological droughts (less surface water and groundwater) in these regions (*medium evidence*, *medium agreement*).**
- **Climate change negatively impacts freshwater ecosystems by changing streamflow and water quality (*medium evidence*, *high agreement*).**

Summary of expected impacts for water , IPCC, AR5

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What will be the impact on water?

- **Climate change is projected to reduce raw water quality, posing risks to drinking water quality even with conventional treatment (*medium evidence*, *high agreement)***
- **In regions with snowfall, climate change has altered observed streamflow seasonality, and increasing alterations due to climate change are projected (*robust evidence*, *high agreement*)**
- **Because nearly all glaciers are too large for equilibrium with the present climate, there is a committed water resources change during much of the 21st century, and changes beyond the committed change are expected due to continued warming; in glacierfed rivers, total meltwater yields from stored glacier ice will increase in many regions during the next decades but decrease thereafter (*robust evidence*, *high agreement*).**
- **There is little or no observational evidence yet that soil erosion and sediment loads have been altered significantly due to changing climate (*limited evidence*, *medium agreement*).**

Summary of expected impacts for water , IPCC, AR5

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What will be the impact on water?

In brief:

A lot of observed and possible impacts….
but also quite some uncertainty.

Uncertainty: a barrier in the climate adaptation strategy.

Mitigation and adaptation

Mitigation: Impact for water

- **Some measures to reduce GHG emissions imply risks for freshwater systems (*medium evidence*, *high agreement*).**
  - Hydropower
  - Bio-energy

IPCC, AR5

Adaptation

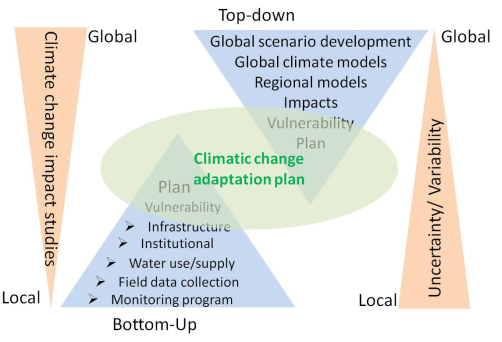
- Paradigm shift:
  - From « predict and provide » towards « adaptive no regret solutions »
  - From « technical » towards « participatory – collaborative solutions »
  - From « cost-benefit » towards « multi-metric evaluations that include risk / uncertainty / cultural and ethics / trade-offs »

IPCC, AR5

Adaptation

- Adapative capacity is place and context specific. There is no single approach for risk reduction that is appropriate across all settings.

IPCC, AR5

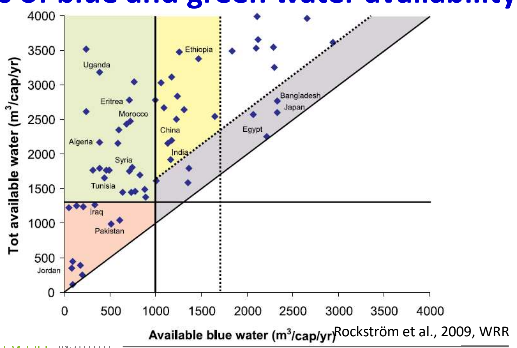


Sellami et al., 2014

Adaptation port-folio for water

- Disaster risk management
- Ecosystem management
- Structural / physical
- Institutional / social
- …

Example: Adaptation to water scarcity in terms of blue and green water availability



Rockström et al., 2009, WRR

Example: Adaptation to water scarcity in terms of blue and green water availability

A	Chronic blue water shortage, blue and green water shortage	Food imports, social and financial insurance systems, investments in unconventional water sources
B1	Green water freedom under chronic blue water shortage	Rainwater management and soil moisture conservation, runoff water harvesting systems, spatial catchment planning, adaptive water management at micro and mesocathment
B2	Green water freedom under blue water shortage	Idem + microcatchment and supplemental irrigation
C	Blue water freedom under green water shortage	Integrated water governance at rivers basin scale. Infrastructure development for irrigation
D	Blue and green water freedom	Simultaneous strategies for irrigation development and water management in rain-fed agriculture

Rockström et al., 2009, WRR

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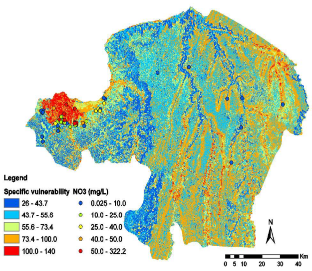
Example: Adaptation potential for urban water supply in terms of groundwater vulnerability for pollution



Mfumu et al., 2015

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Barriers to adaptation

- Lack of technical capacity
- Lack of human and institutional capacity
- Lack of financial resources
- Lack of awareness
- Lack of communication
- Underestimating the deep uncertainty
- Inappropriate consideration of trade-offs

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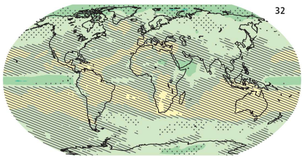
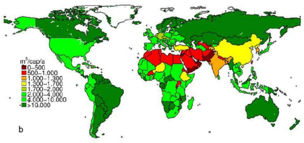
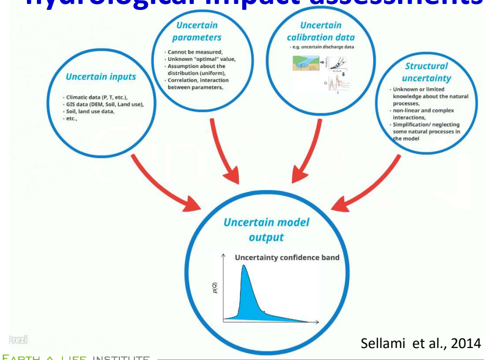
Uncertainty in local scale hydrological studies in the mediterranean area

Focus on the mediterranean





Introducing uncertainty in local scale hydrological impact assessments



Sellami et al., 2014

Introducing uncertainty in local scale hydrological impact assessments

- Uncertainty limits the use of a model for making regulatory decisions unless the uncertainty is figured into the decision making process
- The ice-berg analog: we attempt to consider the uncertainty that we can assess
- The selection and implementation of techniques designed to account for uncertainties are themselves subject to significant uncertainty

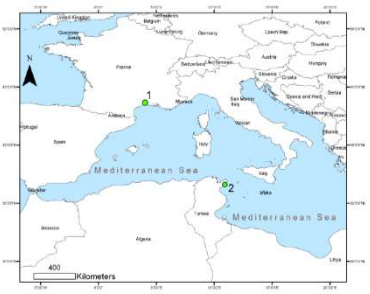
Introducing uncertainty in local scale hydrological impact assessments

$$Q = F\left(P_{HM}(H(P_{DS}(P_{UDS})))\right)$$

$$dQ = \frac{dQ}{dF}.\frac{dF}{dP_{HM}}.\frac{dP_{HM}}{dH}.\frac{dH}{dP_{DS}}.\frac{dP_{DS}}{dP_{UDS}}.\,dP_{UDS}$$

$$dQ = \frac{\partial F}{\partial P_{HM}}dP_{HM} + \frac{\partial F}{\partial H}dH + \frac{\partial F}{\partial P_{DS}}dP_{DS} + \frac{\partial F}{\partial P_{UDS}}dP_{UDS}$$

Introducing uncertainty in local scale hydrological impact assessments



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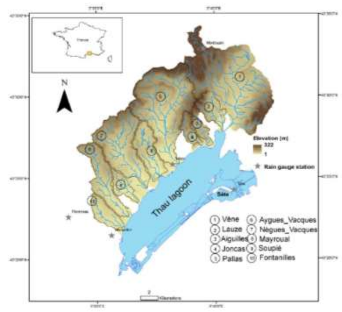

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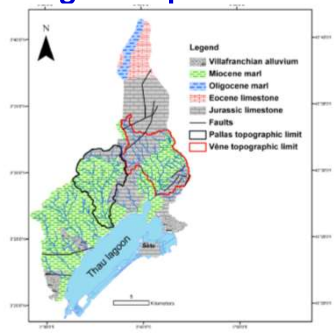

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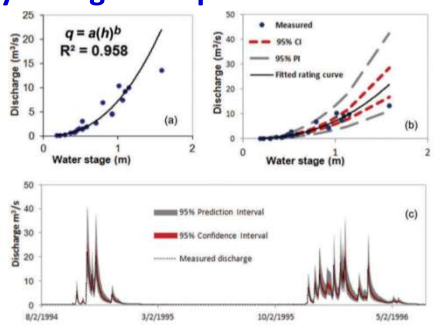
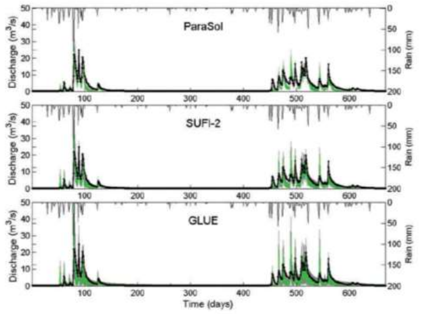


Sellami and Vanclooster, 2013

Introducing uncertainty in local scale hydrological impact assessments



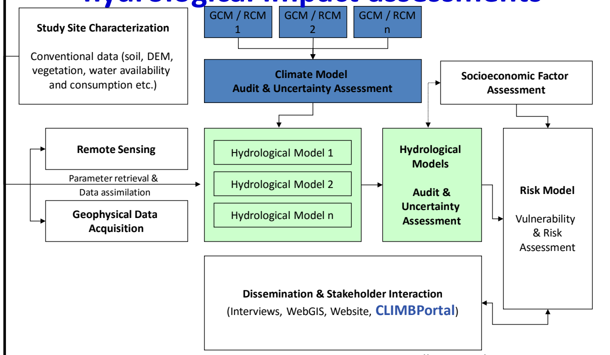
Introducing uncertainty in local scale hydrological impact assessments

Statistical criteria	Method	Deterministic rating curve		Uncertain rating curve	
		Vène	Pallas	Vène	Pallas
NS*	SUFI-2	0.69	0.73	-	-
	GLUE	0.71	0.76	-	-
	ParaSol	0.58	0.67	-	-
R^{2*}	SUFI-2	0.81	0.78	-	-
	GLUE	0.83	0.81	-	-
	ParaSol	0.79	0.69	-	-
p factor (%)	SUFI-2	38	48	47	54
	GLUE	50	61	67	75
	ParaSol	19	28	21	29
R factor	SUFI-2	0.38	0.36	0.44	0.41
	GLUE	0.46	0.44	0.67	0.59
	ParaSol	0.13	0.10	0.20	0.18

Introducing uncertainty in local scale hydrological impact assessments: Uncertainty decomposition (GLUE)

Source	Vene	Pallas
Hydrological model parameter	72 %	86 %
Rating cruve	28 %	14 %

Introducing uncertainty in local scale hydrological impact assessments

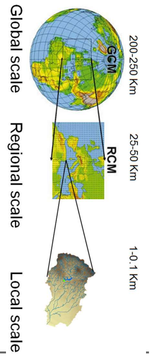


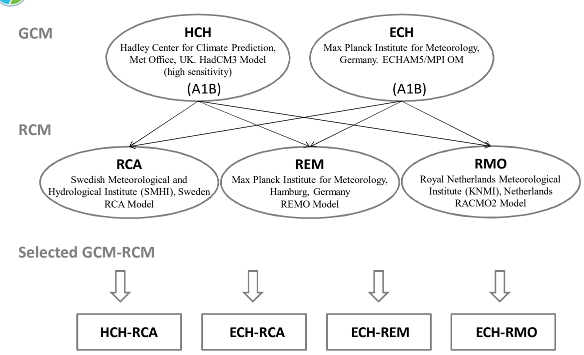
Sellami et al., 2014

Introducing uncertainty in local scale hydrological impact assessments

The objectives of "Climate Models (CMs) Auditing and Downscaling" were pursued in five (5) steps:

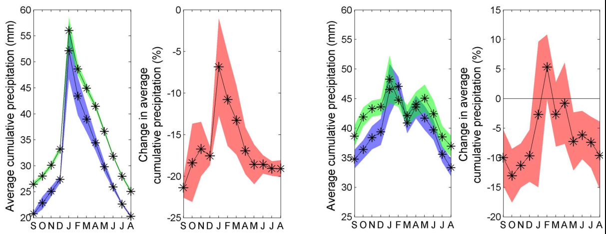
1. Climate Model selection (i.e. use a common subset of 4 regional climate models for hydrological simulations in all target basins)
2. Large-scale bias correction (RCM scales, ~ 25 km)
3. Catchment-scale bias correction (250-3500 km^2)
4. Small-scale interpolation and downscaling (i.e. provide high resolution input for hydrological models, about 1 km)
5. Overall uncertainty of climate forcing (i.e. evaluate the uncertainties related to the climatic component)





Introducing uncertainty in local scale hydrological impact assessments

Chiba catchment (Tunisia) Thau catchment (France)



General decrease in precipitation (1971-200 Vs 2041-2070)

Sellami et al., 2014

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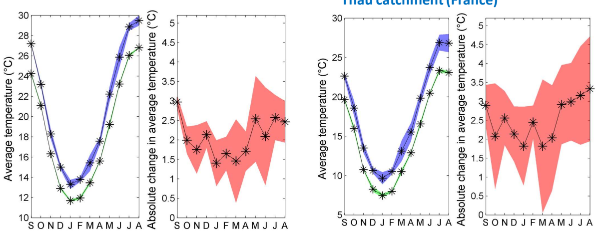
Introducing uncertainty in local scale hydrological impact assessments

Chiba catchment (Tunisia) Thau catchment (France)



General decrease in temperature (1971-200 Vs 2041-2070)

Sellami et al., 2014

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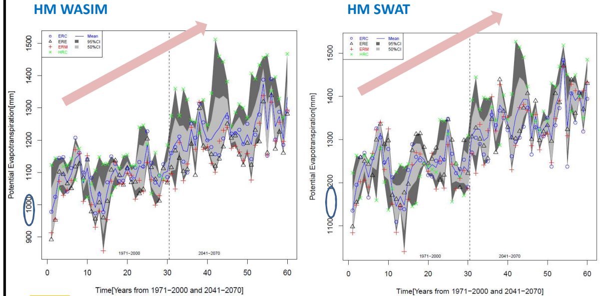
Introducing uncertainty in local scale hydrological impact assessments

HM WASIM HM SWAT



\+ Similar trend: general increase in PET (1971-200 Vs 2041-2070)

\- Uncertain projected magnitude (model structure uncertainty)

Sellami et al., 2014

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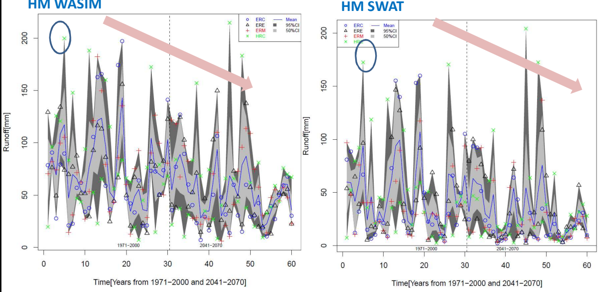
Introducing uncertainty in local scale hydrological impact assessments



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Sellami et al., 2014

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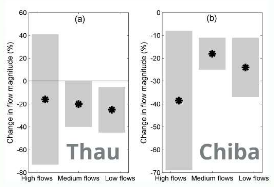

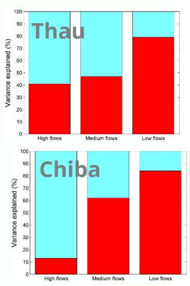

- Climate models uncertainty prevails over hydrological parameter uncertainty during the wet period,
- Hydrological parameter uncertainty becomes more important than climate models uncertainty during the dry period.

Sellami et al., 2014

Conclusions

- Water is a multifunctional critical natural resource for cross sectoral development, currently associated with high global and regional risks.
- CC will very likely have strong impacts on future water resources and associated functions and services. These possible impacts are now better assessed (AR5), but still subjected to obvious uncertainties.

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Conclusions

- A broad set of water management adaptation strategies exist, and the considerations of uncertainty implies the adoption of no-regret solution in the future.
- Adaptation cannot be defined in a generic way and should therefore be local and context specific. This implies versatile DSS, evaluation frameworks, toolkits, information systems, …
- Uncertainty is often a strong barrier to adaptation.

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Conclusions

- The mediterranean remains a hot-spot for CC issues.
- At the local scale, model parameter uncertainty, observation uncertainty, input uncertainty and model structural uncertainty can be addressed. This is done in academic studies, but this is still difficult to fully implement in operational context.
- Uncertainty decomposition of local predicted hydrological impacts in two Mediterranean basins confirms that holistic uncertainty propagation approaches are indeed needed. Uncertainty components are space and time specific.

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