IS-ENES3 Climate Impact Autumn School
Nov. – Dec. 2020

Approaches to impact modelling

Rutger Dankers
Wageningen Environmental Research (NL)
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What is "impact"?

The IPCC provides a specific definition:

*The consequences of realized risks on natural and human systems, where risks result from the interactions of climate-related **hazards** (including extreme weather and climate events), **exposure**, and **vulnerability**. Impacts generally refer to **effects on lives; livelihoods; health and well-being; ecosystems and species; economic, social and cultural assets; services (including ecosystem services); and infrastructure.** Impacts may be referred to as consequences or outcomes, and can be adverse or beneficial.*

Source: IPCC Special Report: Global Warming of 1.5 ºC (2018)

Physical impacts

The IPCC:

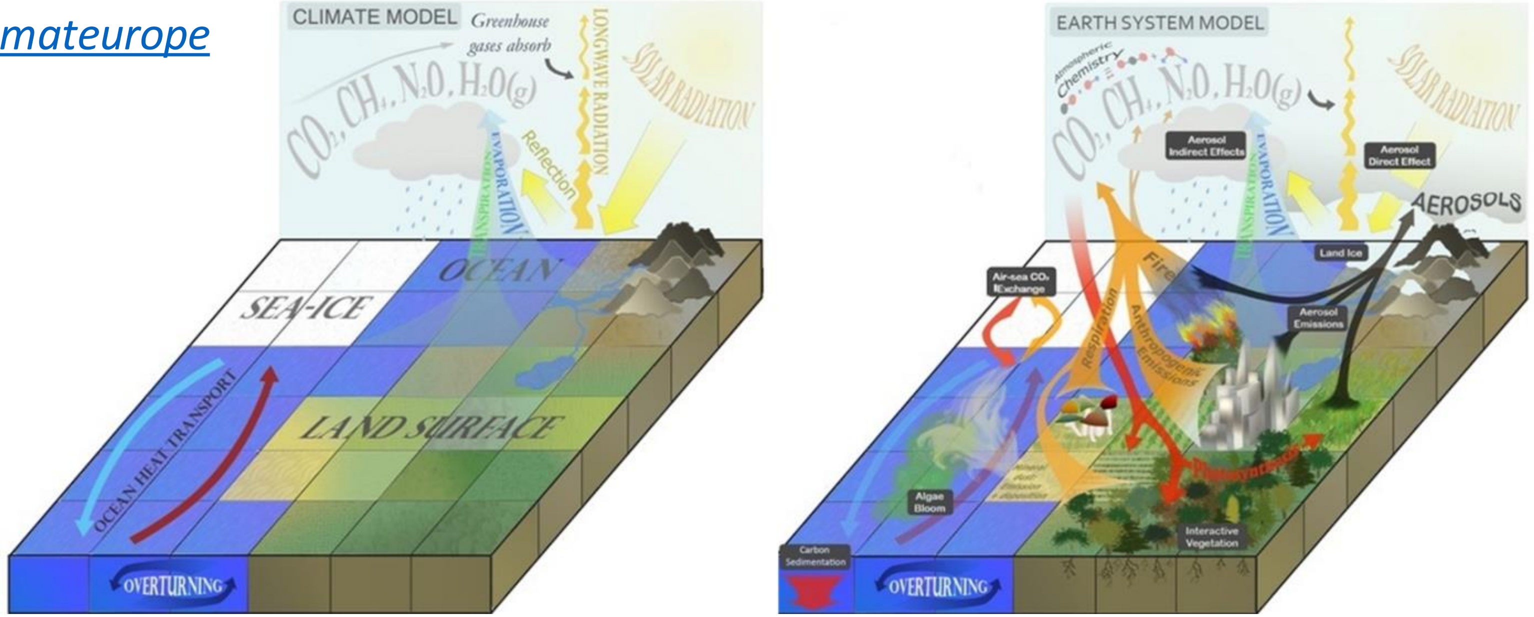
*The impacts of climate change on geophysical systems, including floods, droughts and sea level rise, are a subset of impacts called **physical impacts**.*

Source: IPCC Fifth Assessment Synthesis Report (2014)

Why use impact models?

To provide details on sector-specific impacts of climate change, often not provided by GCMs/ESMs

At the same time, climate models have evolved to include more processes, focusing in particular on feedbacks

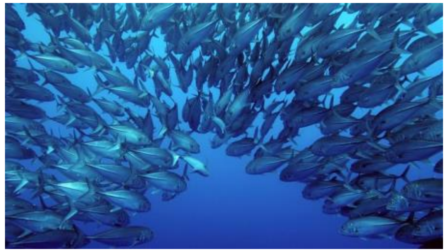


Source: [Climateurope]

is-enes
INFRASTRUCTURE FOR THE EUROPEAN NETWORK FOR EARTH SYSTEM MODELLING

Impact sectors

Examples of sectors where impact models have been used





ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

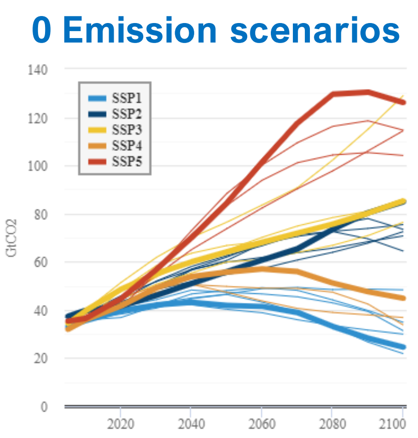
https://www.isimip.org/

Impact models

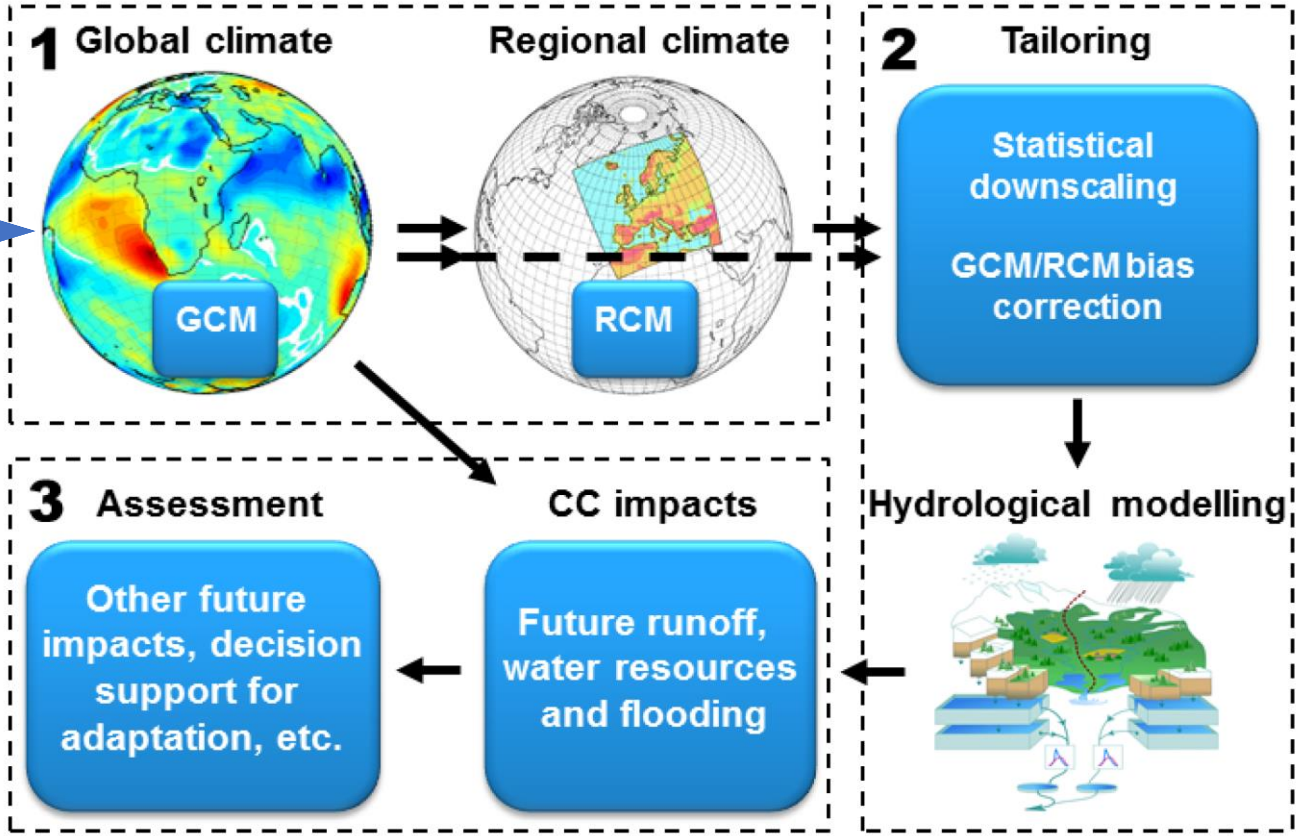
- Often sector-specific
- Often developed for a different aim
  - For example, hydrological or crop forecasting
- Sometimes model the same things
  - For example, many models include a hydrological component
- Rarely give you the full answer
  - For example, further processing, analysing or even modelling may be required to translate physical impacts in risks or losses

Impact model chains

Translating climate information to sectoral impacts



Source: [CarbonBrief]



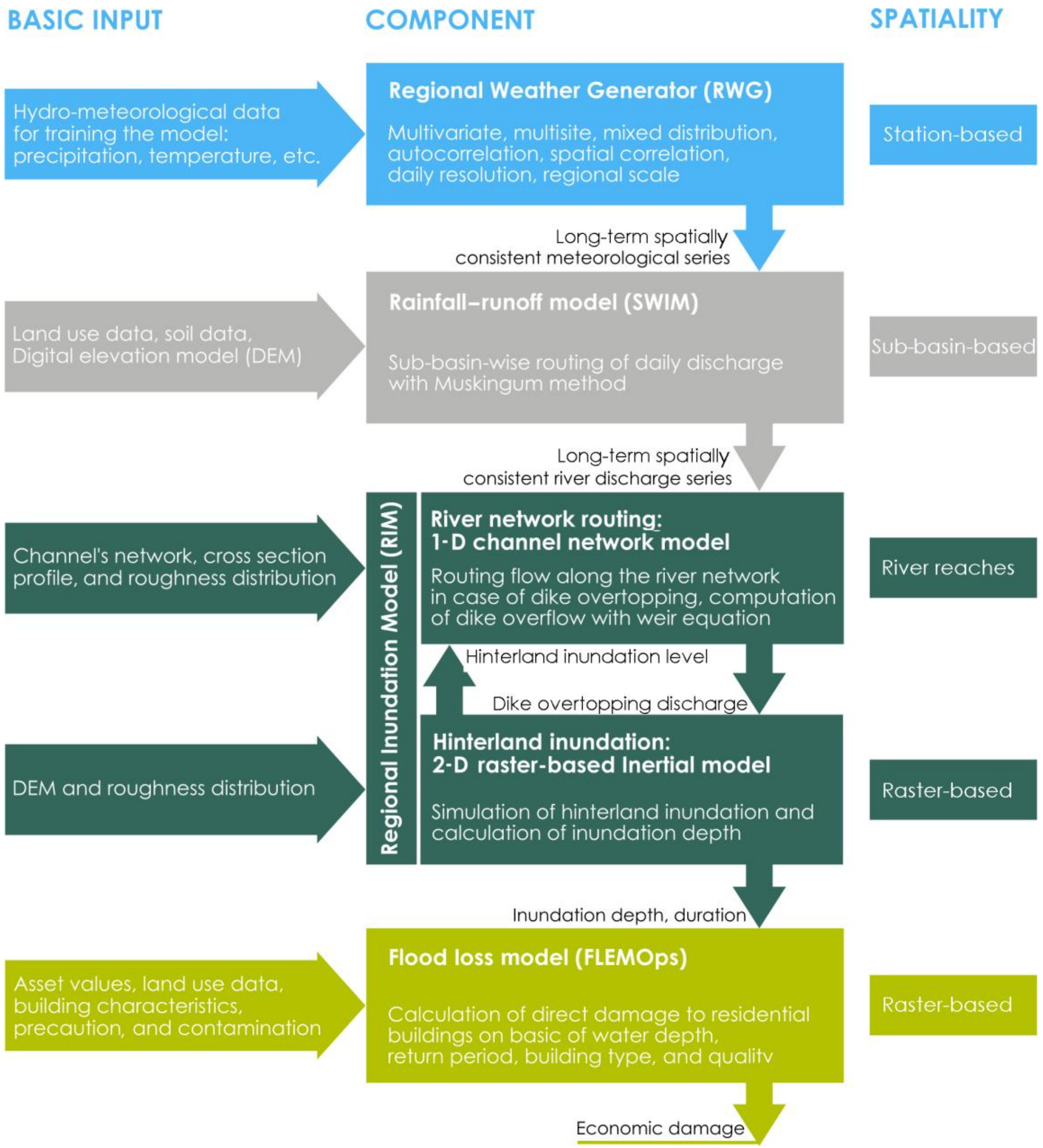
Source: [Olsson et al. (2016)]

Impact model chains

Depending on your objectives, multiple modelling steps may be required, for example:

Climate models → hydrological model → hydraulic model → inundation model → damage model

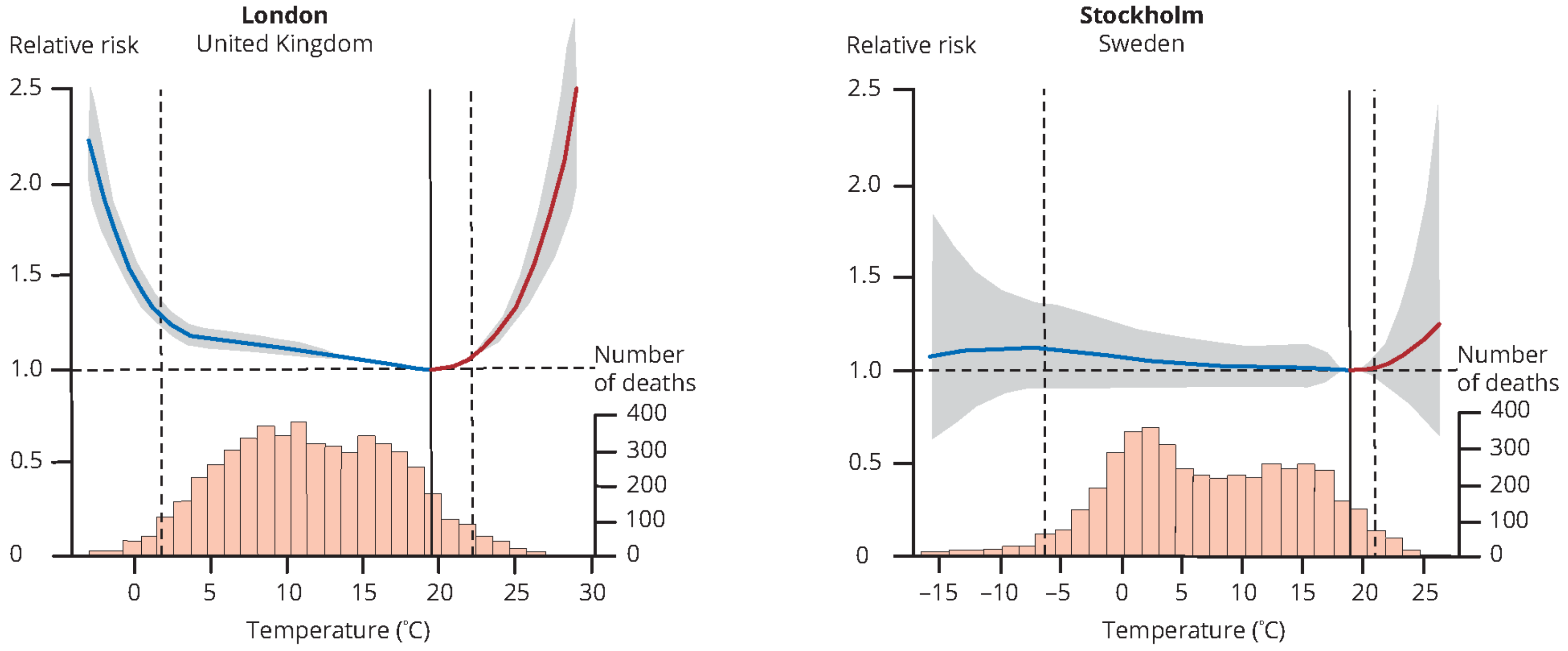
To calculate losses from flooding



Source: Metin et al., 2018

Type 1: statistical models

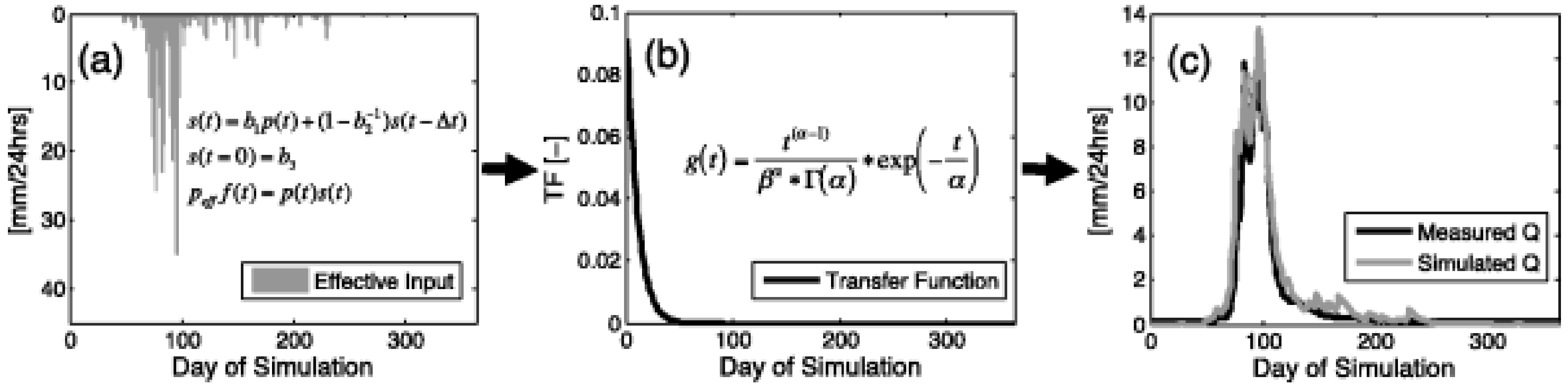
- Establish relationship between weather/climate and impact



Source: EEA

Type 1: statistical models

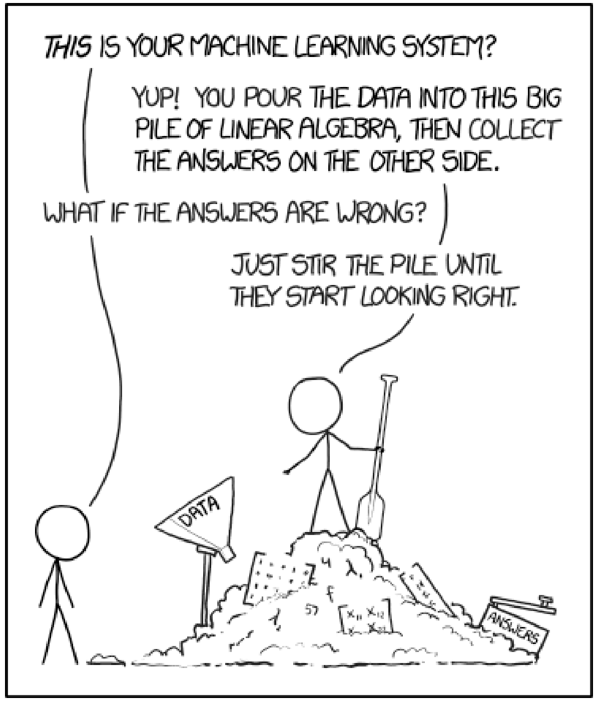
- Hydrological example: transfer function between (effective) rainfall and runoff
- Find parameters by optimisation (calibration) against observed runoff at catchment outlet



Source: Nippgen et al., 2011

Statistical models, pros and cons

+ Easy to understand and run
+ Low data requirements
+ Possible to obtain good fit with historical data
– Limited insight into processes, causes and effects
– Be very careful with application outside historical conditions
– Target impact data not always available, especially for socio-economic impacts (e.g., damages/losses)
– Be aware of multiple predictors, spurious correlations, etc.



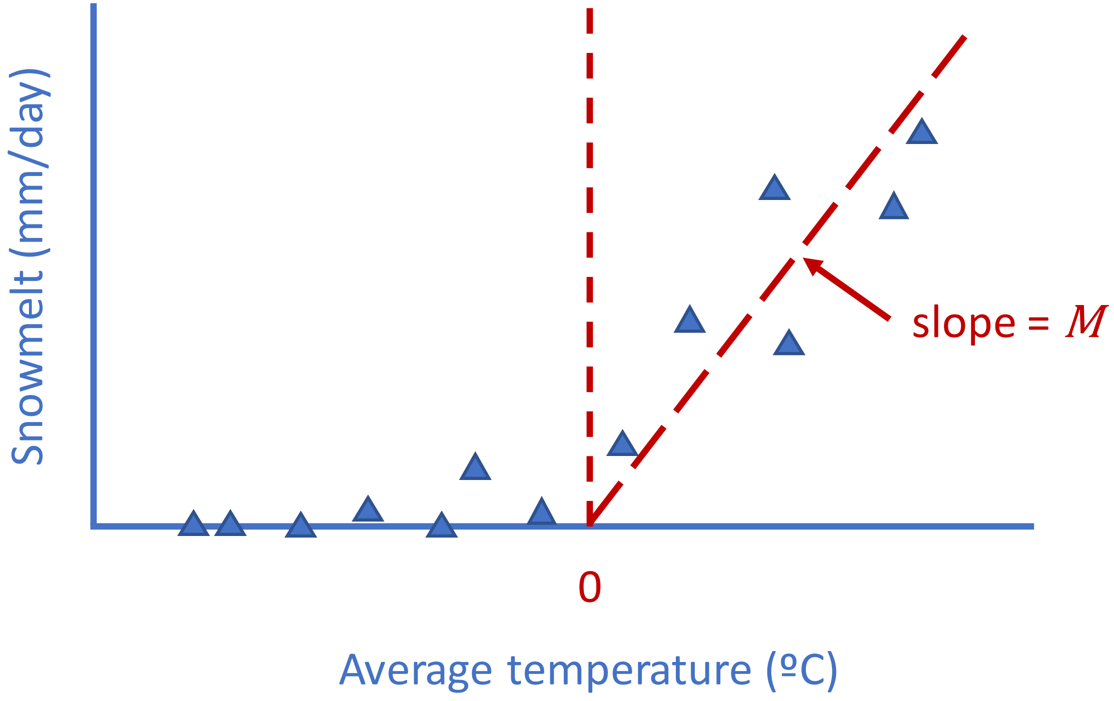
Source: XKCD

Empirical modules

- Note that many sub-models and parameterisations in more complex models are in essence statistical models!
- Example: snowmelt

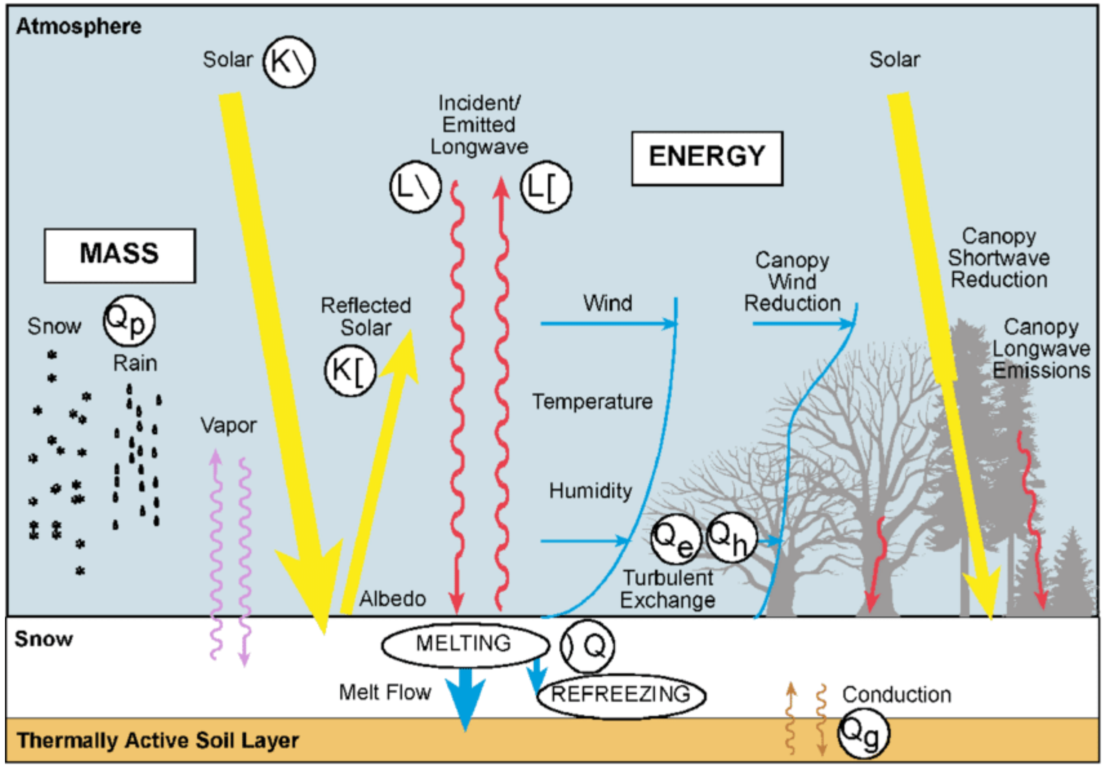
$$\Delta w = 0; \quad T_a \leq T_m \ (\approx 0°\text{C})$$
$$\Delta w = M(T_a - T_m); \ T_a > T_m$$

M is melt coefficient or degree-day factor



Empirical modules

- Note that many sub-models and parameterisations in more complex models are in essence statistical models!
- Example: snowmelt
- In reality snowmelt is a much more complex process

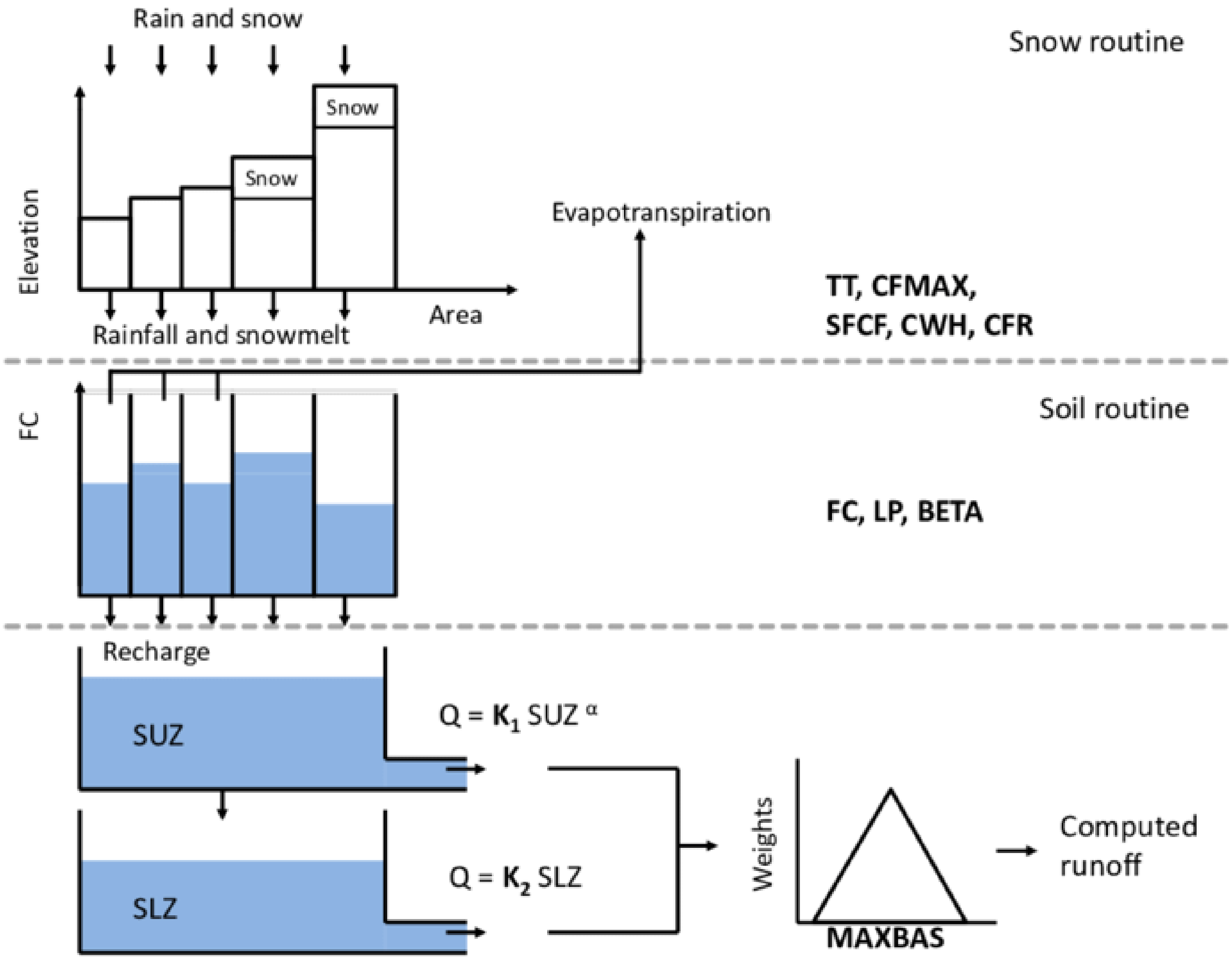


Source: *Fletcher, 2005*

Type 2: conceptual models

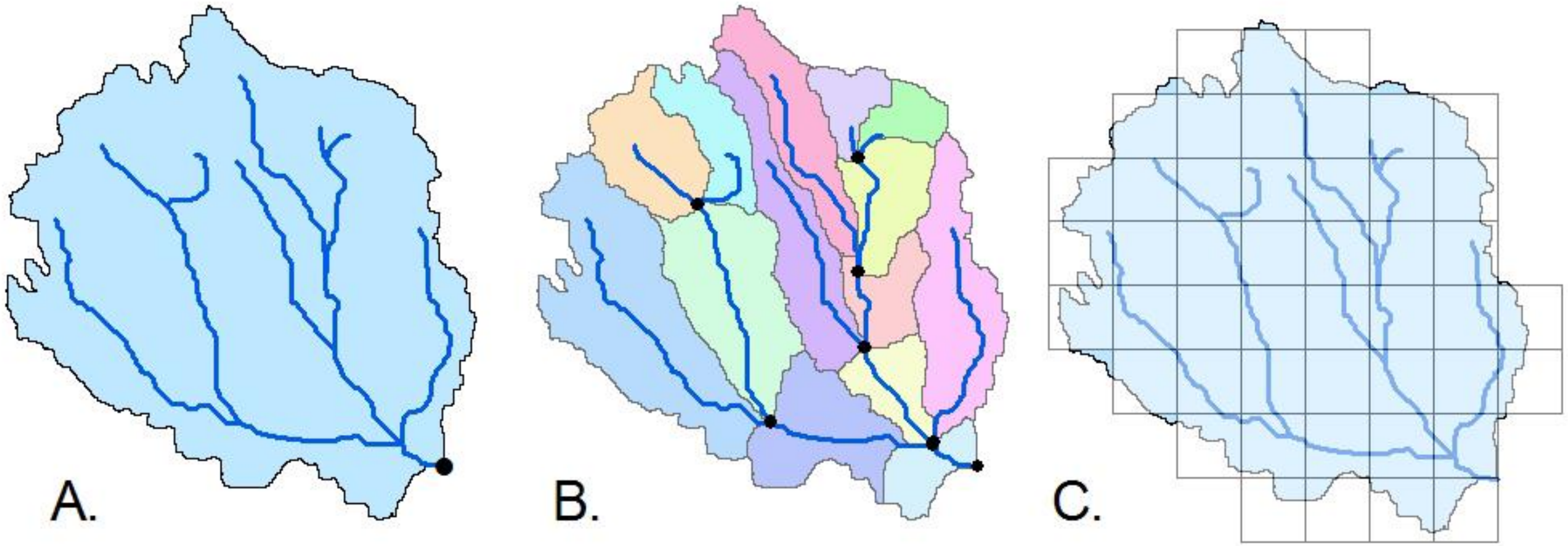
- Include several components (storages and flows) to mimic the most relevant processes
- Often simplified process descriptions
- Example: HBV hydrological model
- Similar schemes can be found in e.g., crop models

Source: Staudinger et al., 2015



Lumped and distributed models

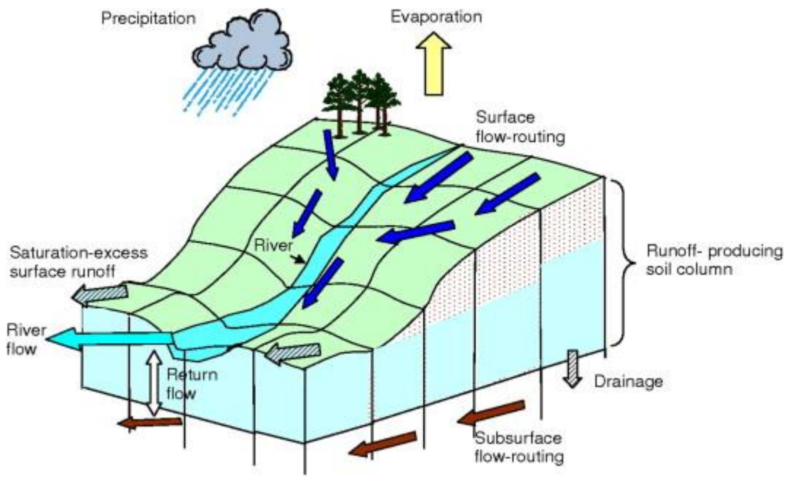
- Lumped: entire catchment taken as single modelling unit
- Semi-distributed: subdivision in sub-catchments
- Fully distributed: spatially explicit



Source: EPA, 2017

Advantages of distributed models

- Account for spatial variability and lateral processes
- Many spatial input datasets nowadays available
- Examples: G2G, PCR-GLOBWB, LISFLOOD, ...
- Note calibration often only possible at catchment outlet
- Effectively still a lumped model at scale of single grid cell, so resolution matters!



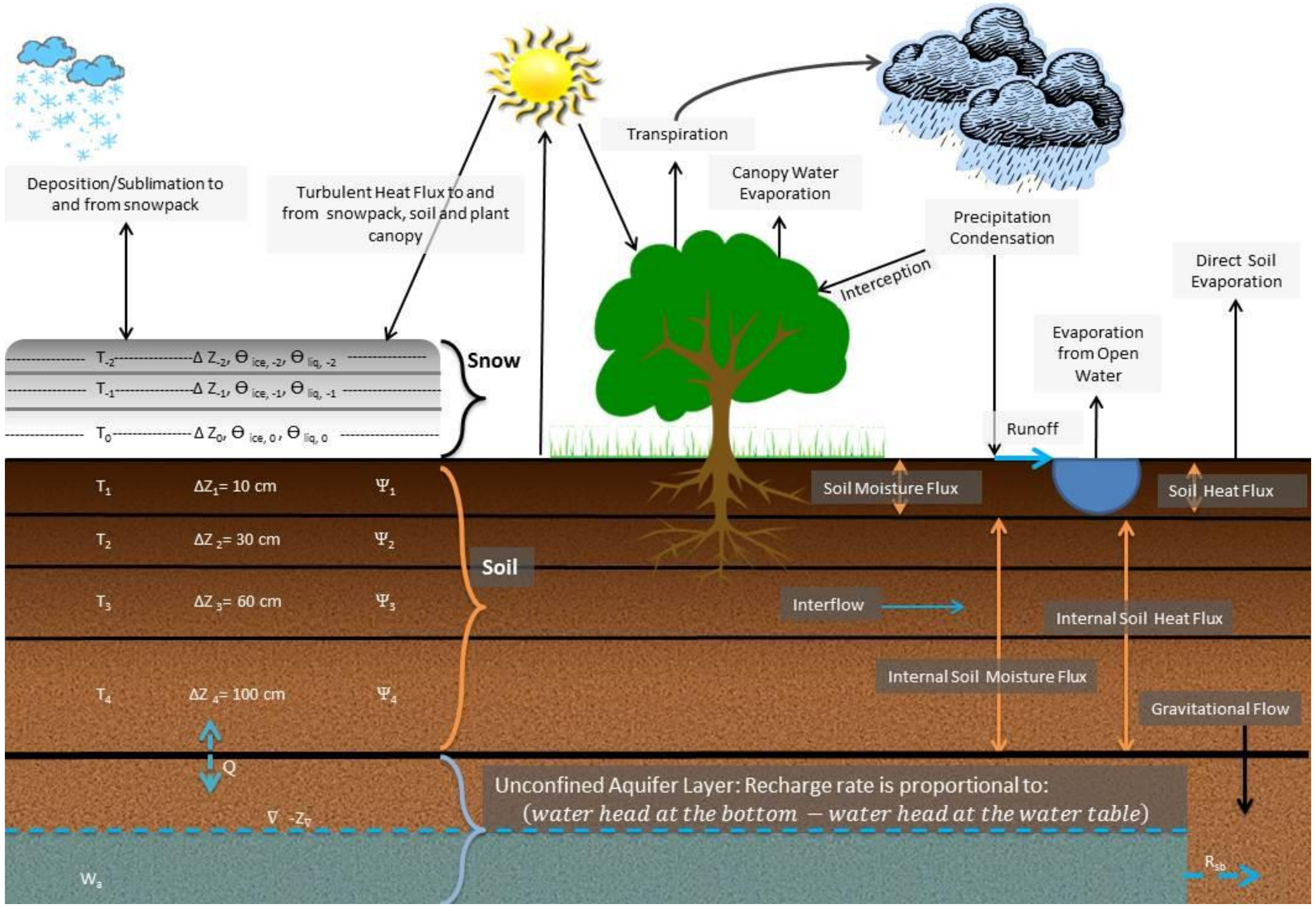
Source: Cole & Moore, 2009

Conceptual models, pros and cons

- \+ Model components resemble the main characteristics of the system, so more robust than statistical models
- \+ Gain insight into processes, scenario analysis, prediction
- \+ Cheaper to run than process models, let alone climate models!
- \+ Run at higher resolution so add detail
- – Calibration usually necessary, so careful with application outside historical conditions
- – Human behaviour and impacts more difficult to model
- – Spatial data not available for all components, esp. subsurface

Type 3: process models

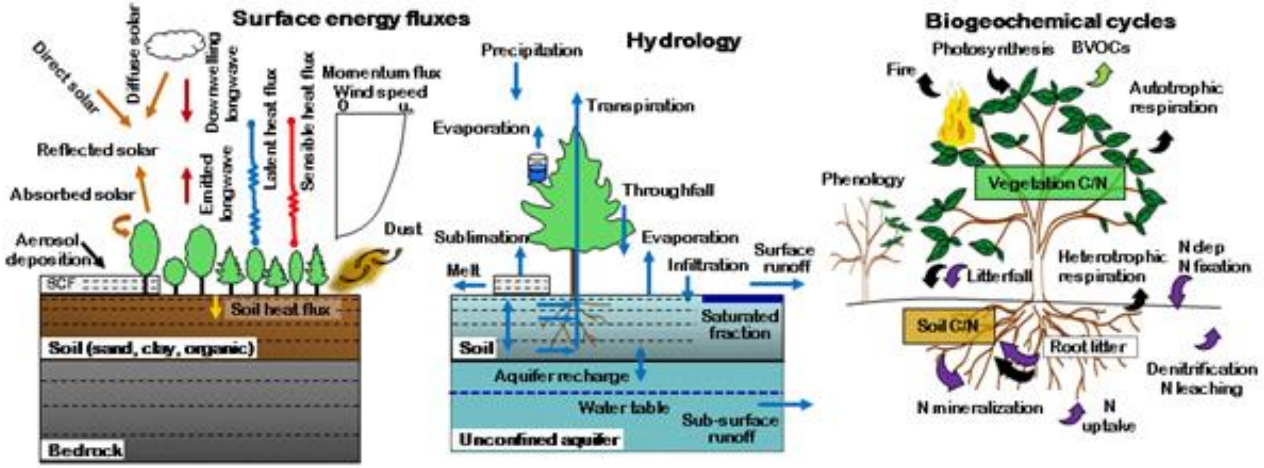
- Complex models aiming to include complete process descriptions, following laws of physics/biology
- Often developed to study processes & interactions between them

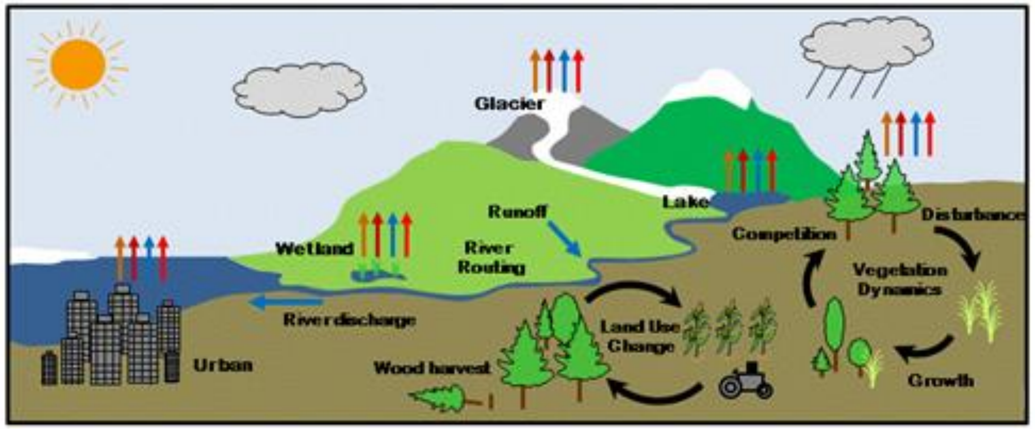


Source: *Noah Land Surface Model*

Type 3: process models

- Often a combination of different sub-models for components of the system (e.g., snow, soil moisture, vegetation)
- Not all modules are always completely physics-based!
- For example, groundwater is often highly simplified

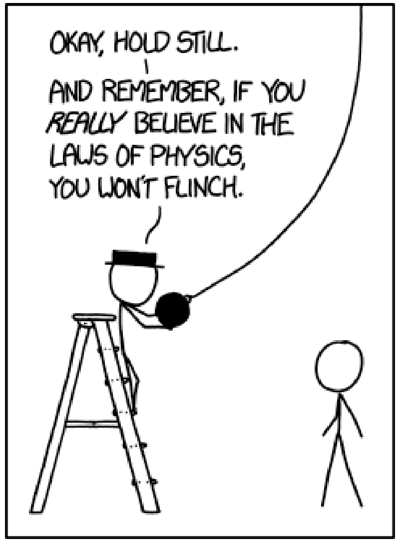




Source: [Community Land Model]

Process models, pros and cons

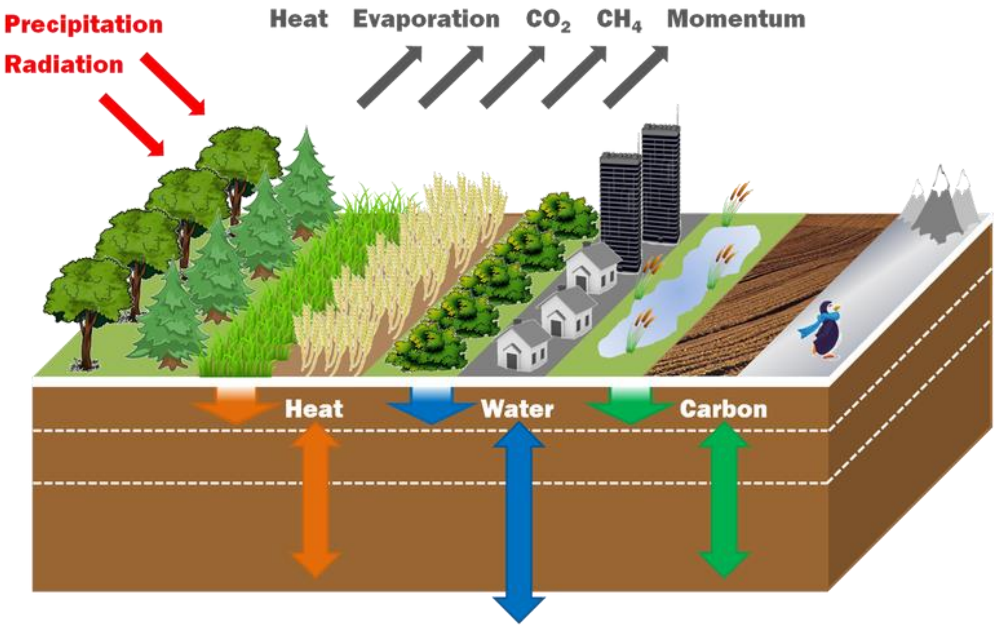
+ Physics-based process descriptions, so even more robust than conceptual models
+ Include all relevant processes, gain insight into interactions
+ Less reliant on calibration and tuning (?)
– Rarely fully process-based in all components
– Computationally more expensive and higher data demands
– Lower predictive skill than conceptual models



Source: XKCD

Different models with different aims

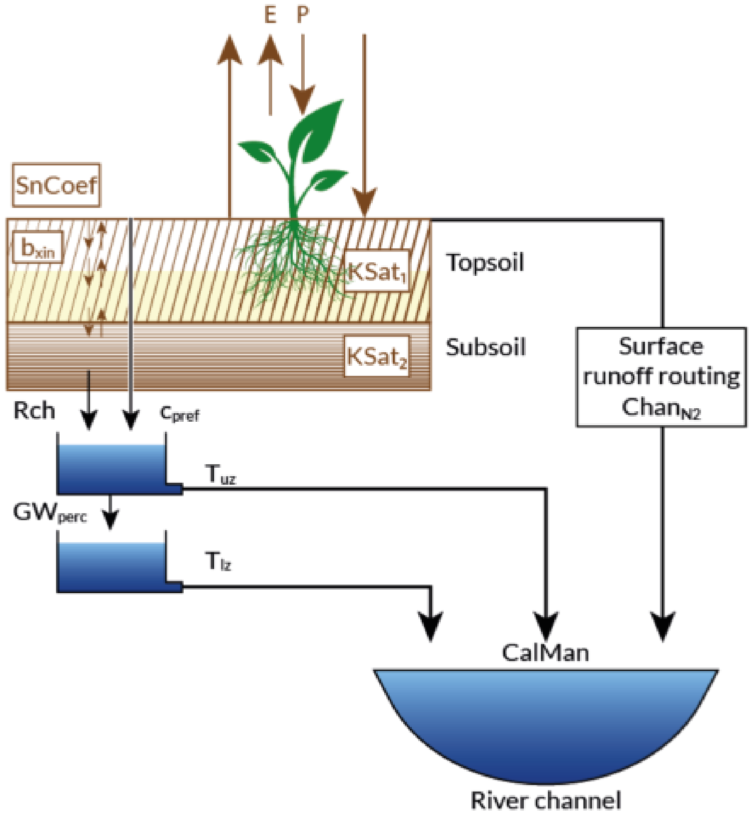
- Hydrological models: close water balance of a catchment
- Land surface models: solve energy and water balance of land surface
- Dynamic vegetation models: vegetation distribution and carbon cycle
- Crop models: crop production, carbon and nutrient cycles



Source: *JULES LSM*

Examples: LISFLOOD

- Spatially distributed hydrological model
- Originally developed for flood forecasting
- Focus on simulation of river discharge
- Calibration required but sometimes regionalisation of parameters
- Scale of applications: small catchments (grid size 100m) to global (0.5 deg)



- Available from: https://ec-jrc.github.io/lisflood-model/

Examples: LISFLOOD

- Used in operational flood forecasting at European and global scale
- Also used extensively in climate impact studies
- Include scenarios of changes in land use and water demand

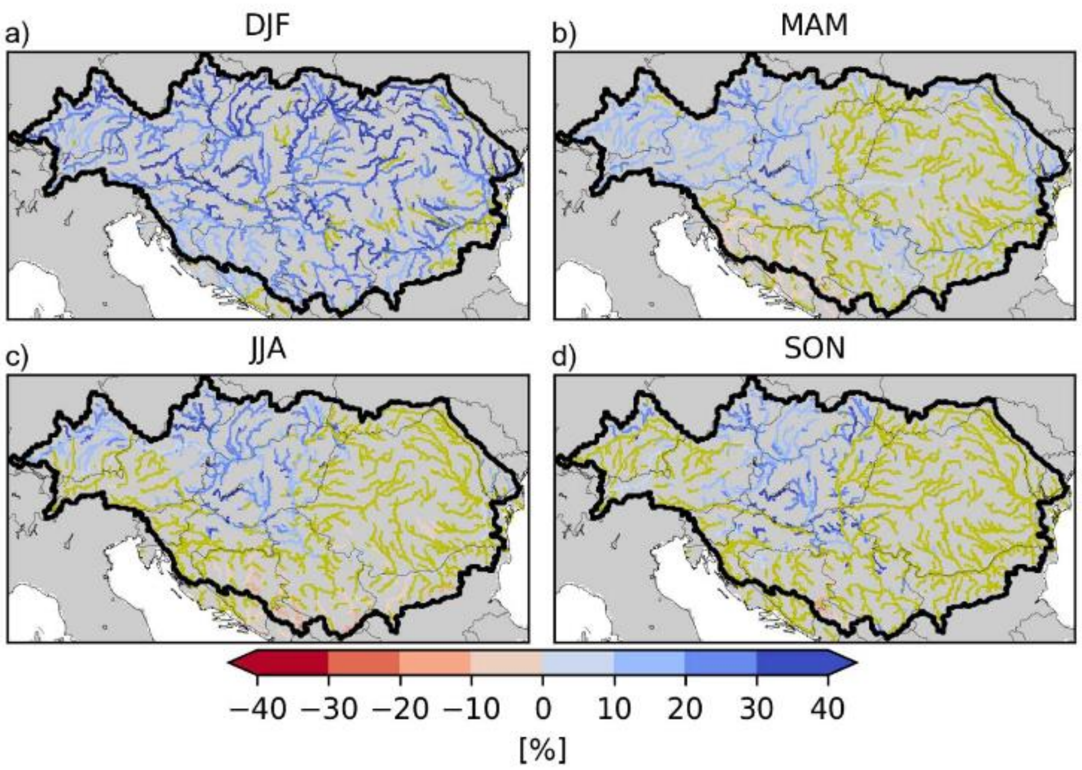
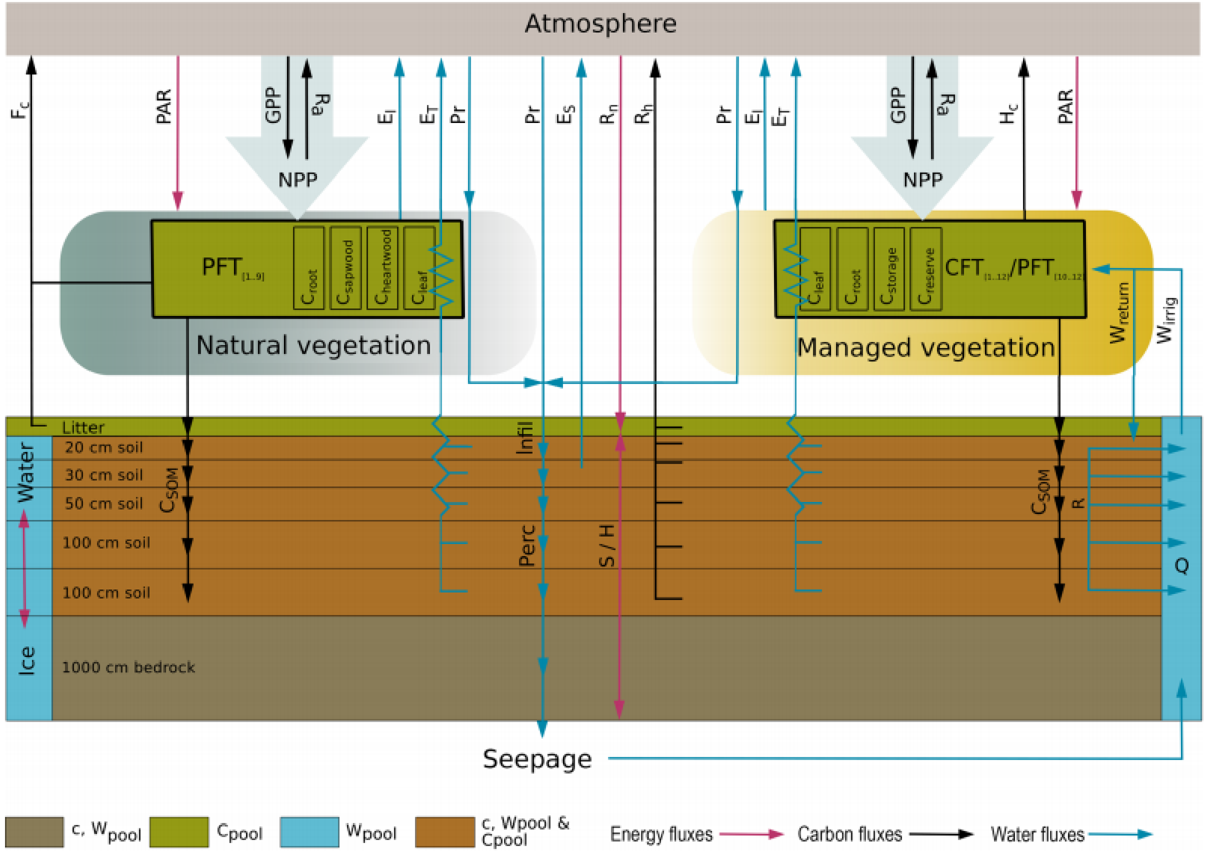


Figure 26 Impact of 2 degree climate change on mean seasonal streamflow, as compared to the 1981-2010 control climate, showing the combined effect of climate change (CC), land use change (LU) and water demand change (WD). Note: the green colour indicates rivers where the uncertainty in the results is large, with at least 3 out of 11 models indicate opposite results.

Source: [Bisselink et al., 2018]

Examples: LPJmL

- Dynamic Global Vegetation Model for managed land (crops)
- Developed to simulate terrestrial carbon cycle, later include water cycle and agricultural systems
- Focus on vegetation dynamics, crop production and water resources
- Application at regional or global scale



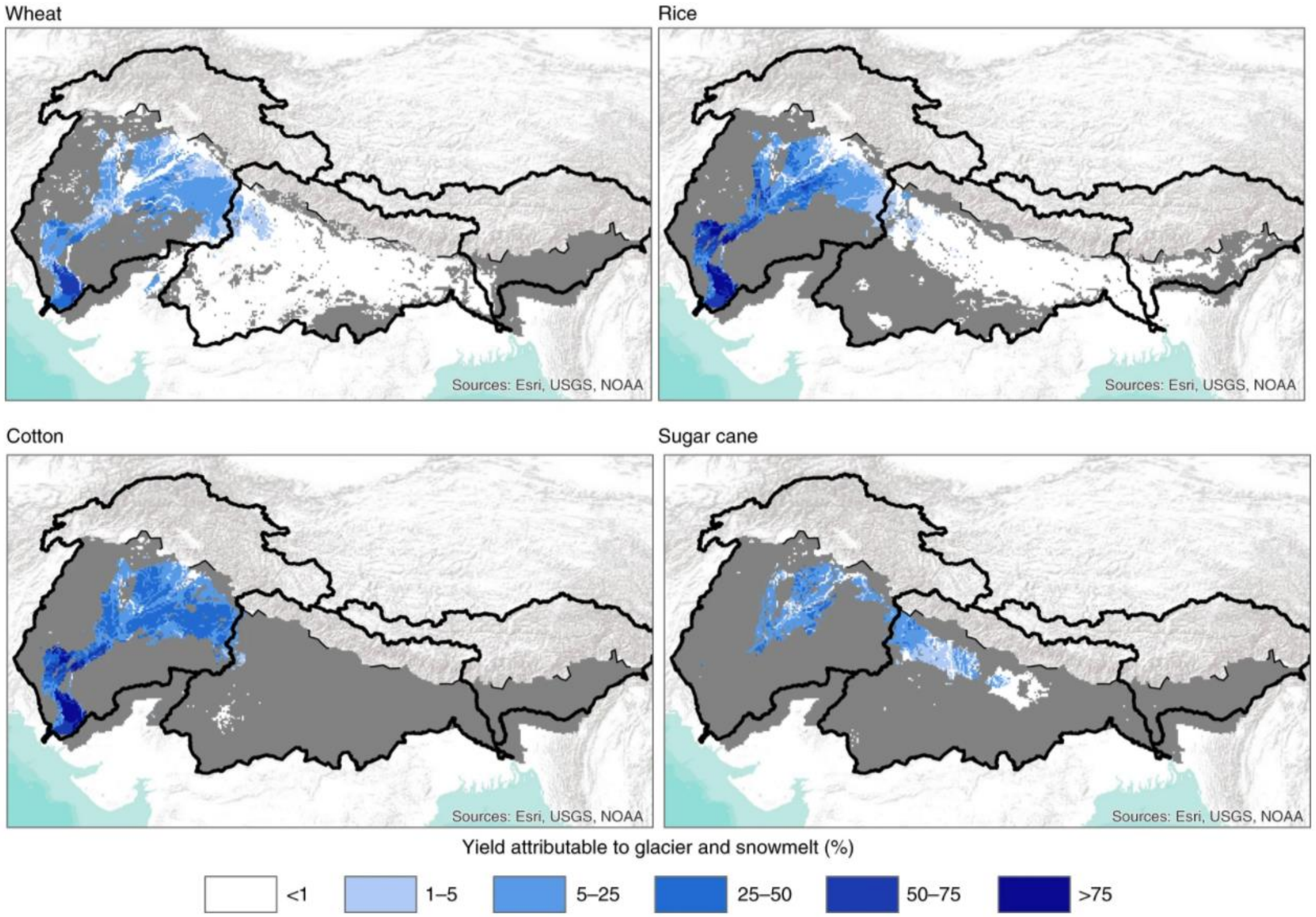
- Available from: https://github.com/PIK-LPJmL/LPJmL

Examples: LPJmL

- Used in studies of vegetation patterns, food production and water resources, and the interactions between these

Fig. 4: The percentage of production attributable to upstream glacier and snowmelt for major crops.

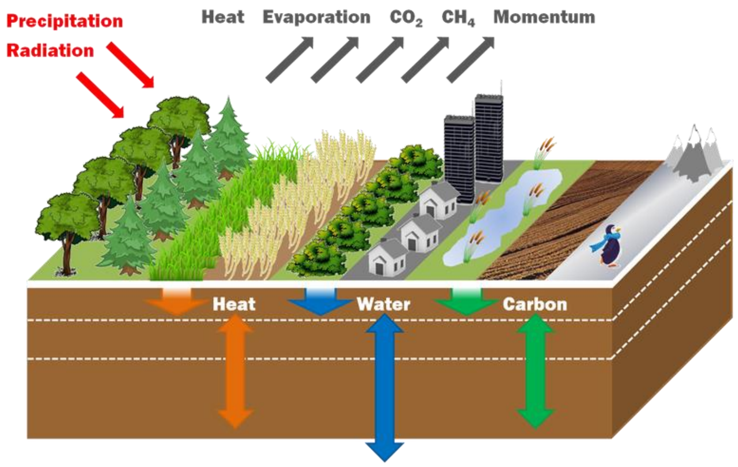
From: Importance of snow and glacier meltwater for agriculture on the Indo-Gangetic Plain



Source: [Biemans et al., 2019]

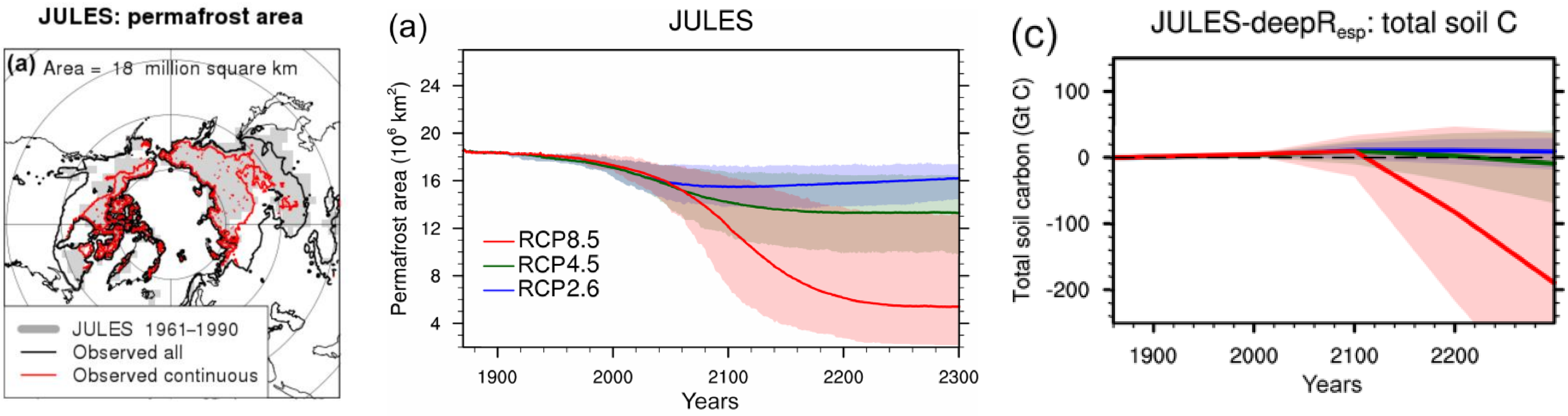
Examples: JULES

- Land surface model (LSM) in weather and climate models
- Original aim to provide boundary conditions to atmosphere
- Focus on energy and water balance, later also carbon cycle, vegetation dynamics, nutrients...
- Many different modules and parameters
- Standard configurations that perform better in a particular setting (e.g., operational NWP or Earth System Modelling)
- Application at point, regional or global scale
- Available from: https://jules.jchmr.org/



Examples: JULES

- Applications as a stand-alone model: hydrology, vegetation dynamics, carbon cycle, crop growth, urban climate, permafrost...
- Include interactions and feedbacks, e.g. effect of vegetation dynamics on hydrology, or permafrost thaw on global carbon cycle

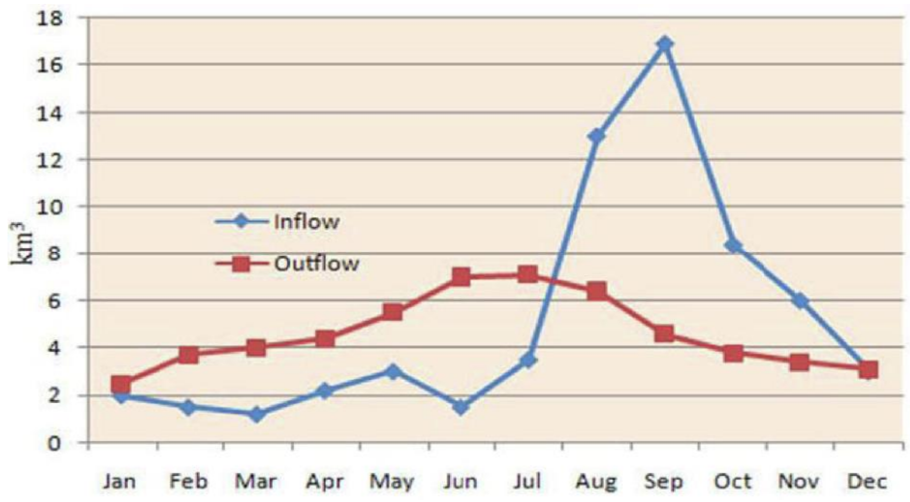


Source: Burke et al., 2017

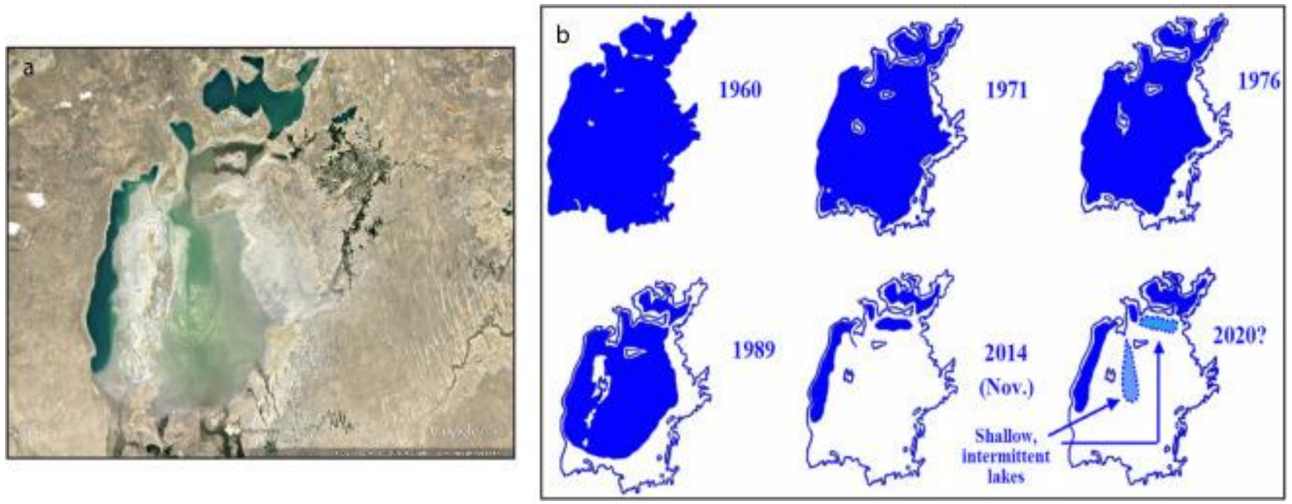
Challenges (1): Human impacts

'Human impacts' can refer to:

1. Influence of humans on natural systems
   - Example: reservoirs in river systems; irrigation; flood protection
   - Human influences can dwarf climate impacts!



Source: Abd Ellah, 2020

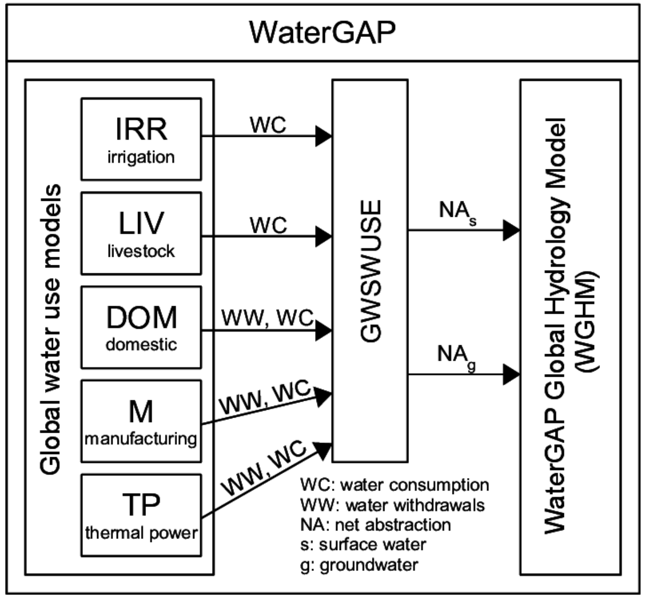


Source: McDermid &Winter, 2017

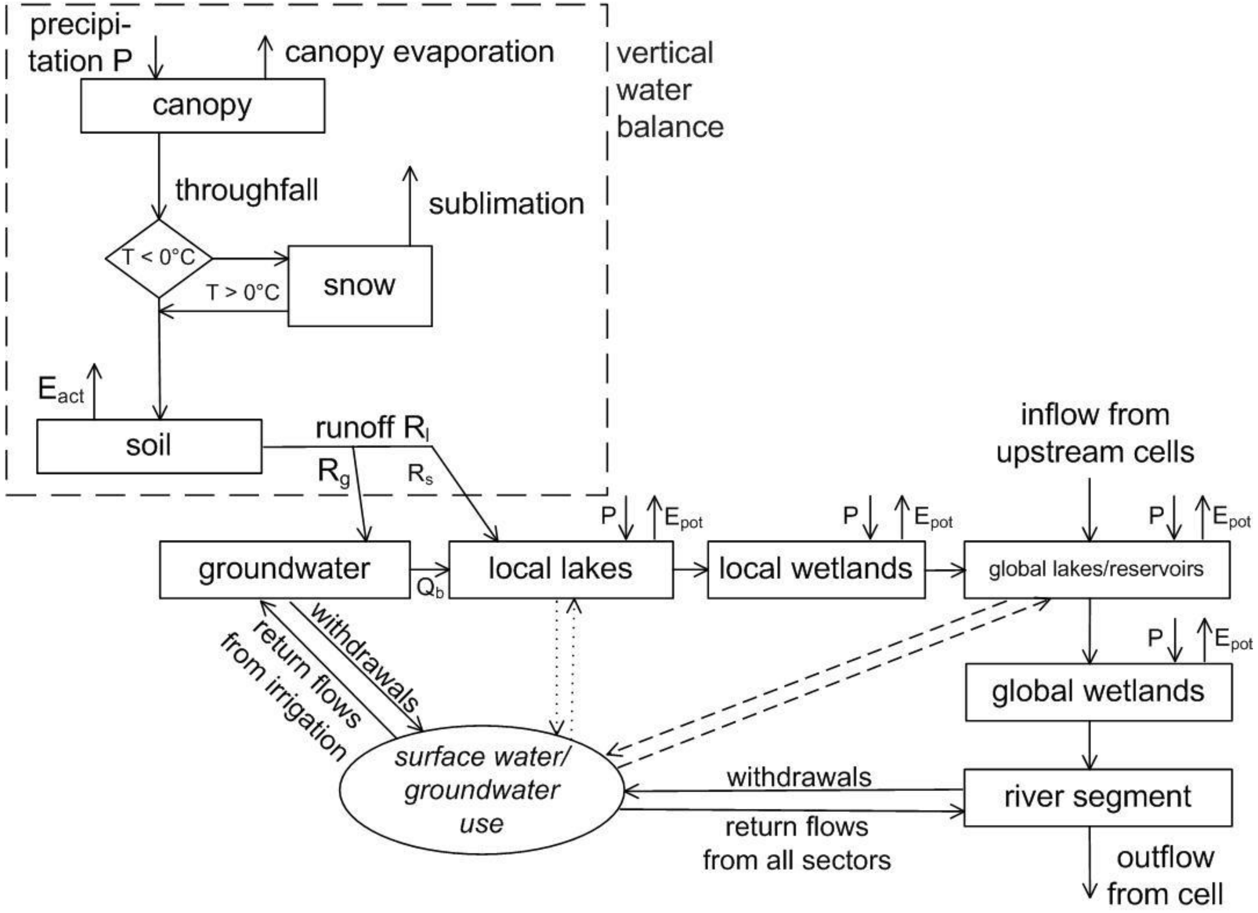
Challenges (1): Human impacts

Increasingly models include these human influences

- Example: WaterGAP model



Source: [Müller Schmied et al., 2014]

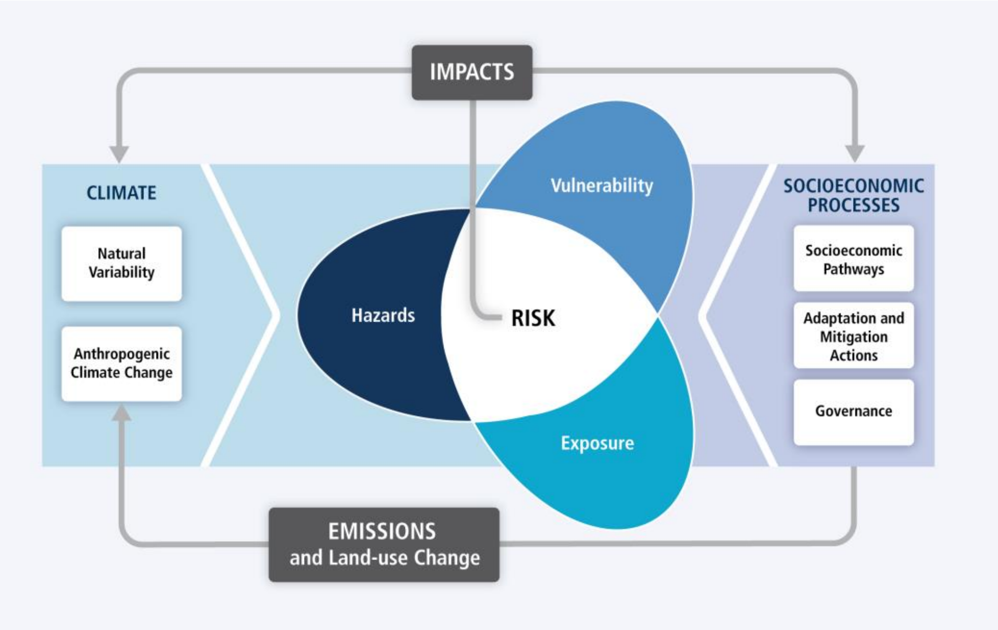


Source: [Döll et al., 2012]

Challenges (1): Human impacts

'Human impacts' can refer to:

2. Influence of climate & environmental change on humans
   - Dependent on human or asset exposure and vulnerability
   - Esp. vulnerability difficult to define and data hard to find; usually proxy indicators
   - Data on societal and economic impacts not routinely collected

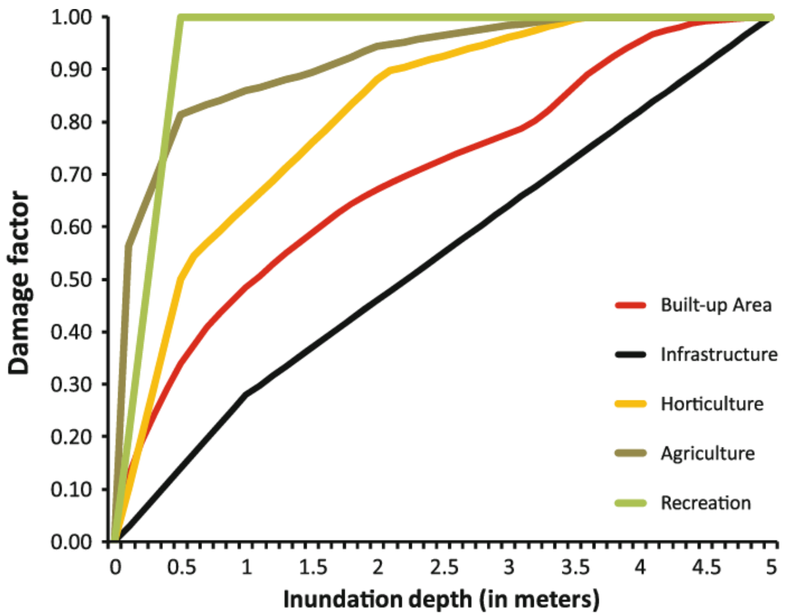


Source: IPCC, 2014

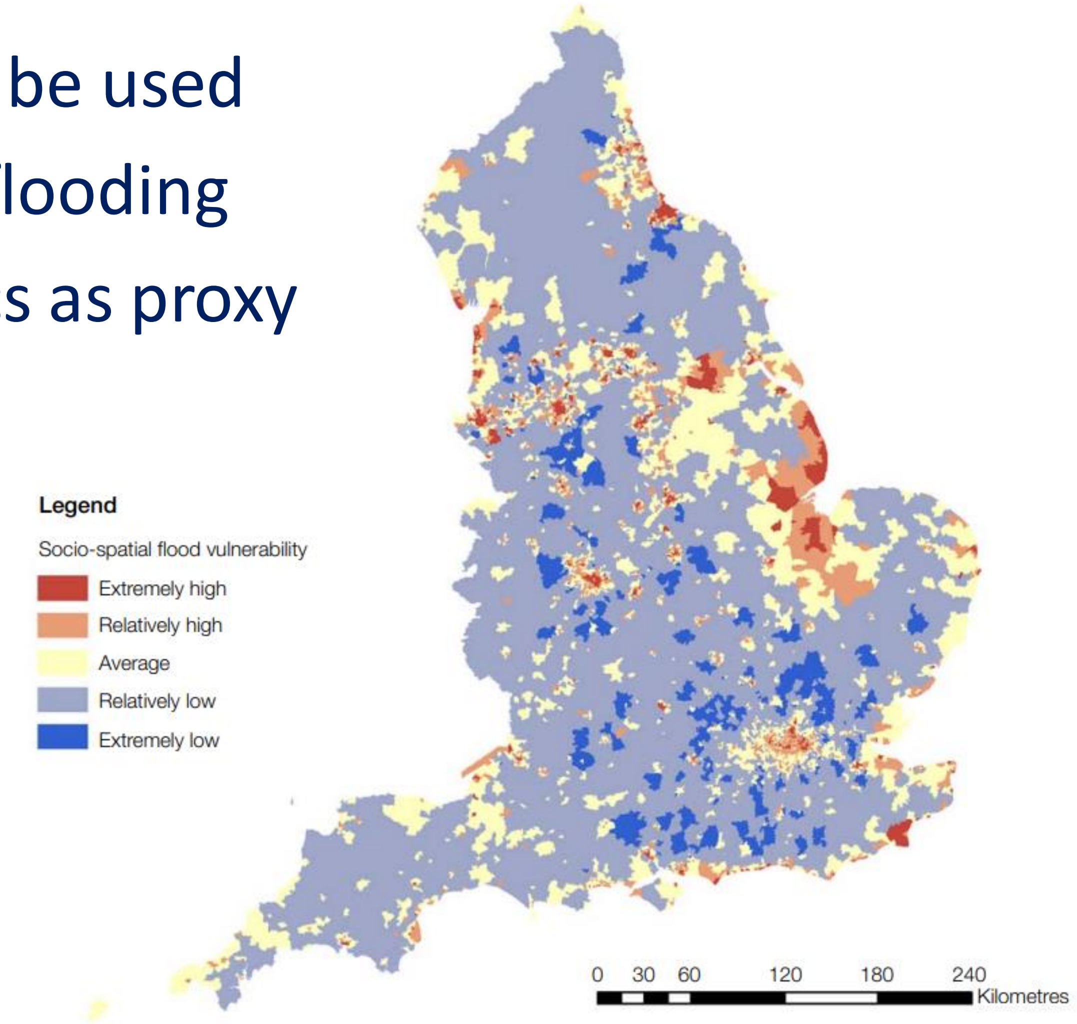
Challenges (1): Human impacts

Empirical data or proxy indicators can be used

- Example: depth-damage curves for flooding
- Demographic and economic statistics as proxy for vulnerability



Source: [Koks et al., 2014]

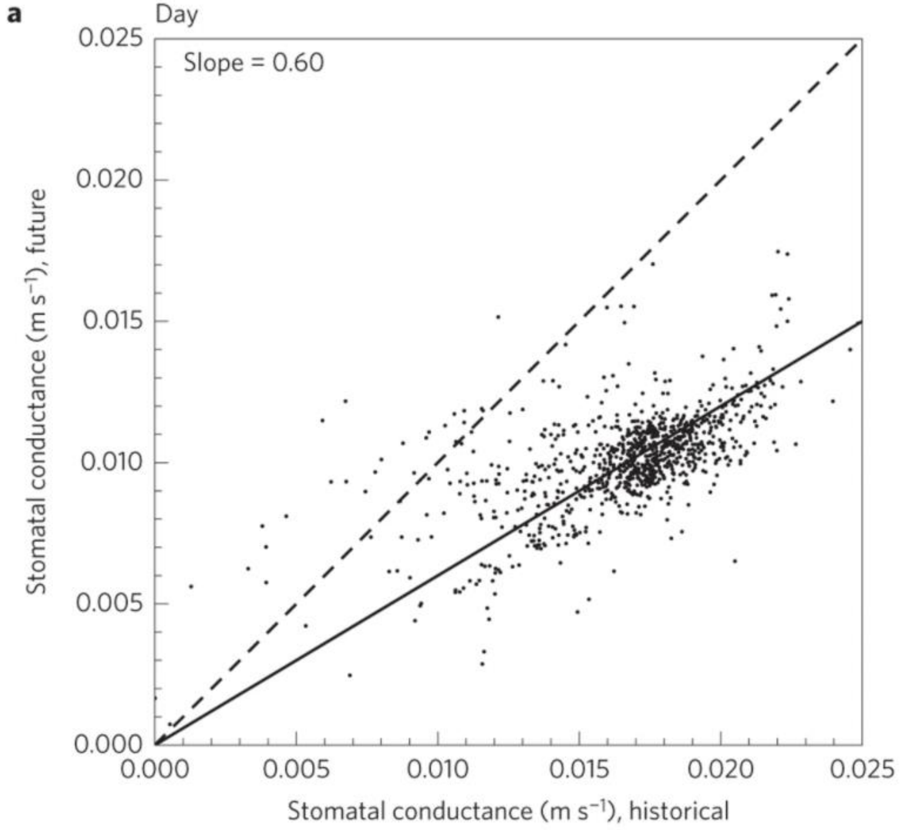


Source: [Lindley et al., 2011]

Challenges (2): Missing processes

Other relevant processes may be missing, too!

- Example: vegetation response to climate change affecting hydrology



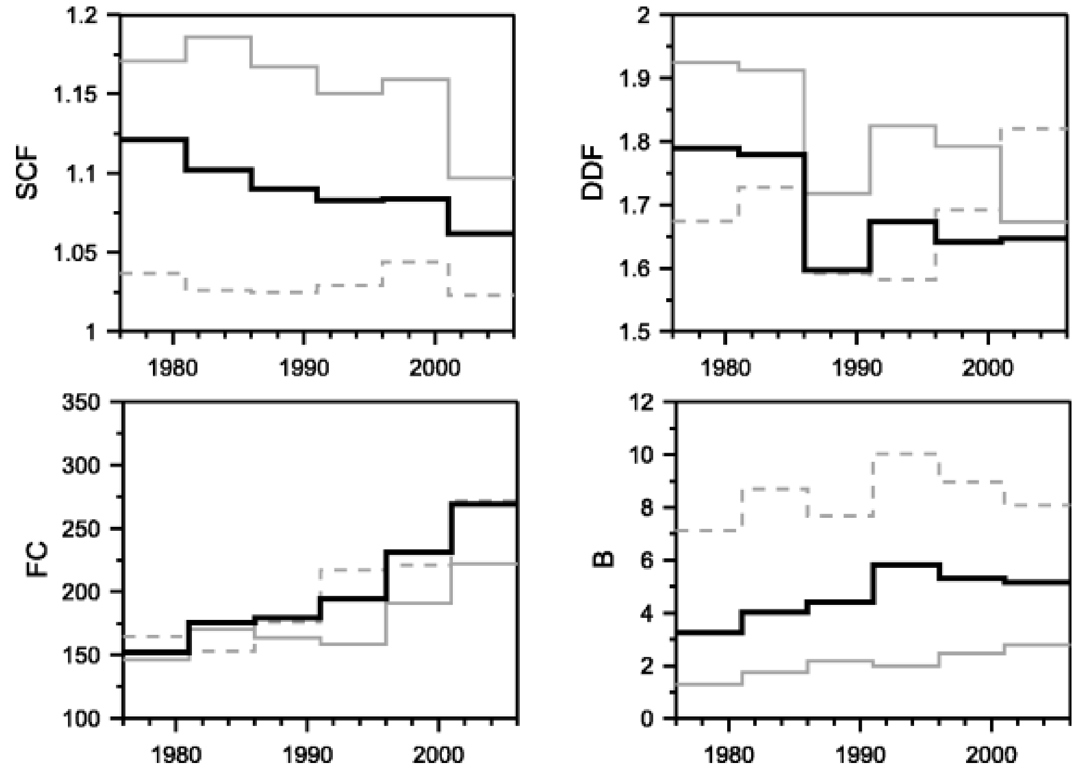
Source: Milly & Dunne, 2016

Source: INSTAAR, University of Colorado

Challenges (3): Stationarity

Many models rely on tuning / calibration, but are parameter values still valid under different climate conditions?

- Non-stationarity affects some parameters more than others
- Use split-sample tests, time-varying parameters, covariates (e.g., climate indices), sensitivity analysis...

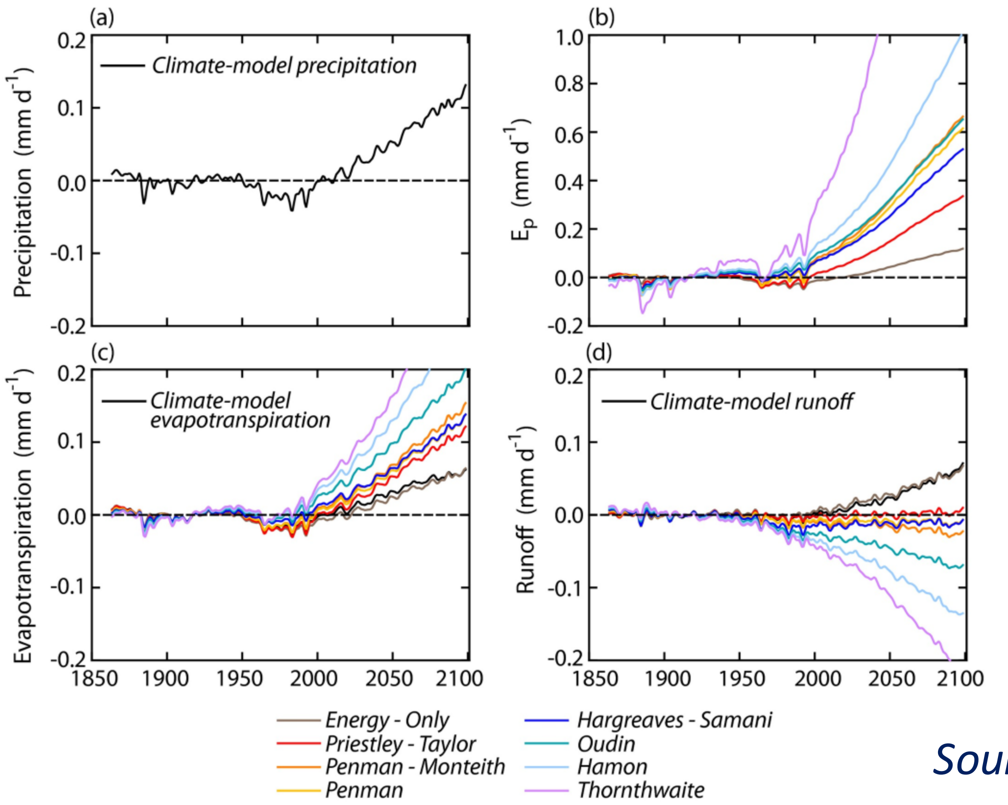


Source: [Merz et al., 2011]

Challenges (3): Model uncertainty

Which model or formulation to choose? Different approaches will have their strengths and weaknesses, but may yield different results...

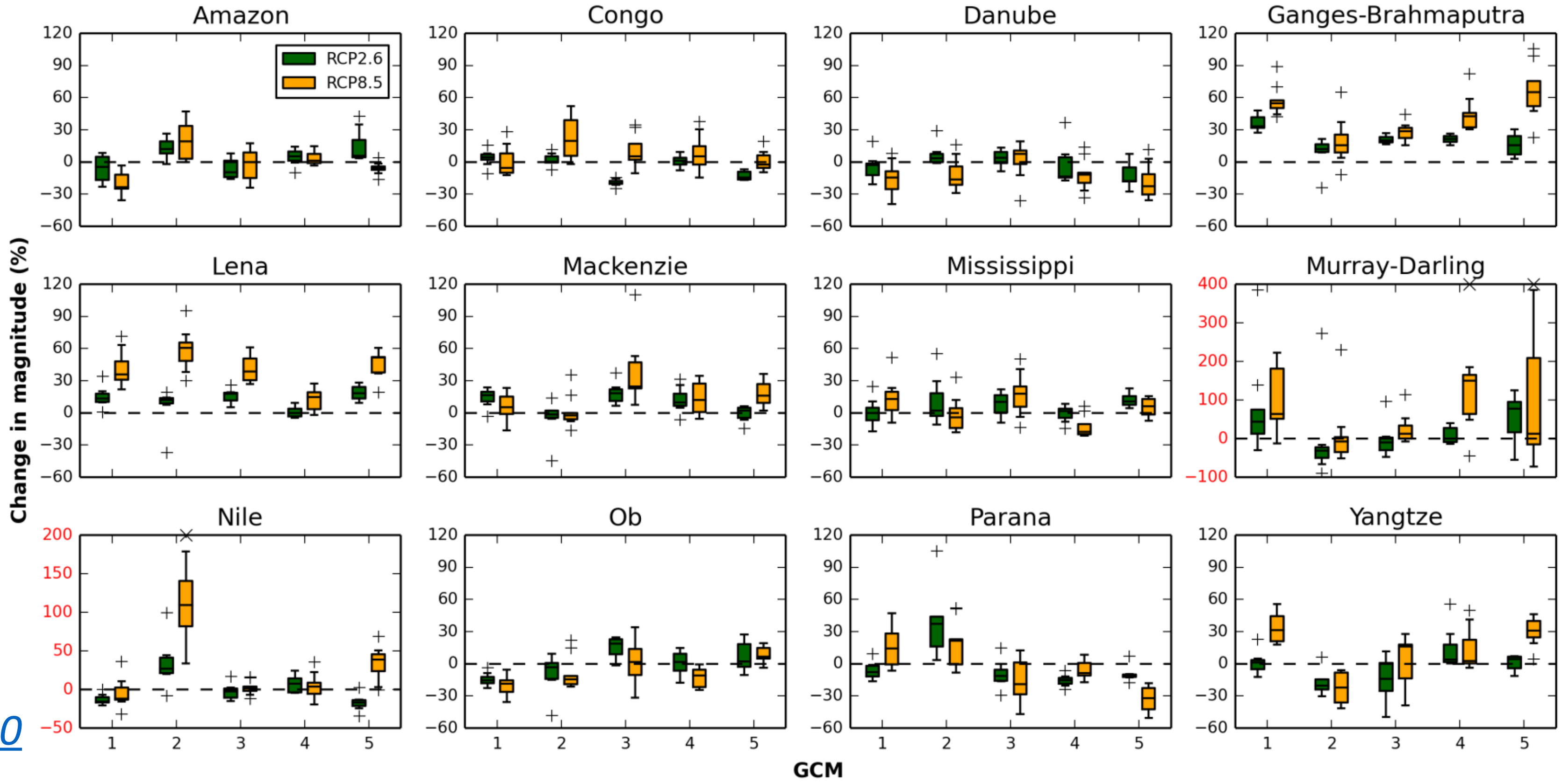
- Example: different approaches to calculate pot. evapotranspiration



Source: [Milly & Dunne, 2017]

Challenges (3): Model uncertainty

Evidence from intercomparison studies suggest that impact model uncertainty adds to the overall uncertainty, in addition to that of the driving climate models



Source: [Dankers & Kundzewicz, 2020]

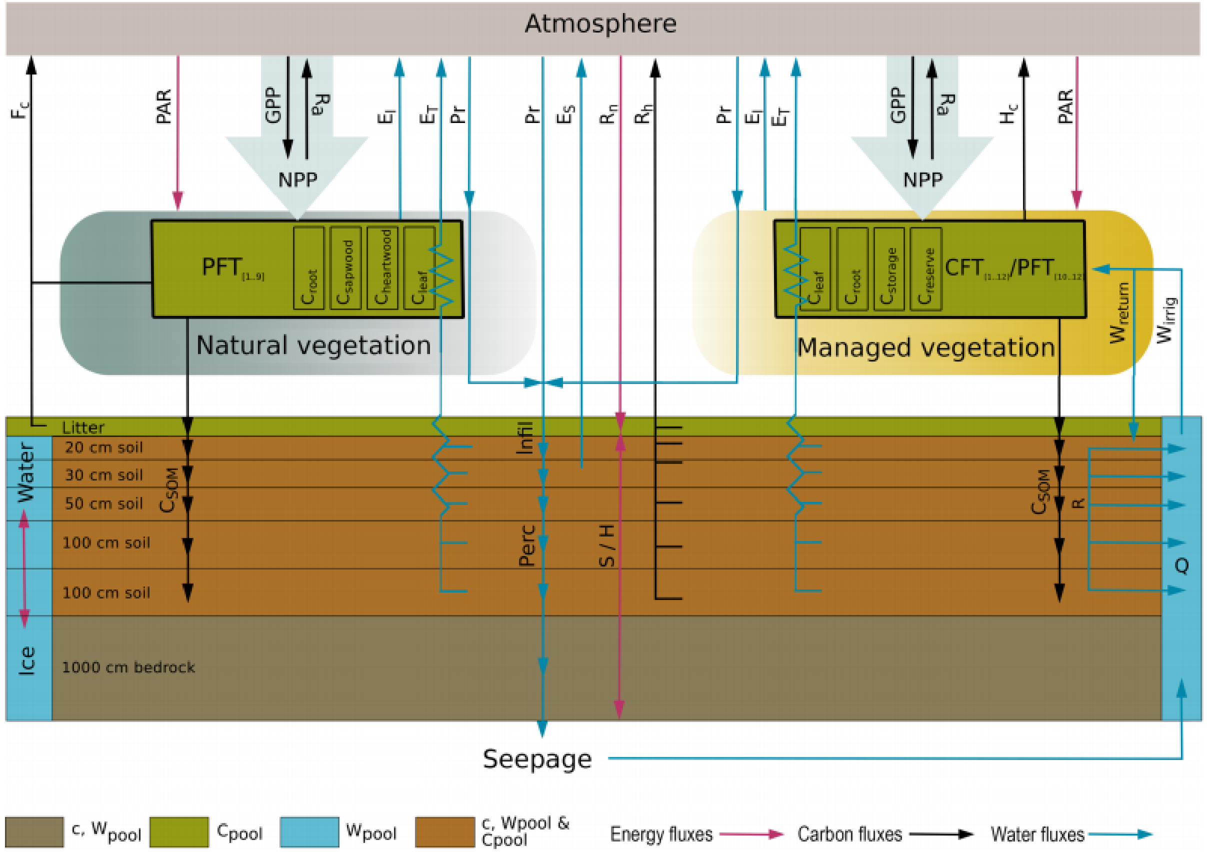
Case study: Central Asia

Case study: Central Asia

- Part of transboundary Syr-Darya and Amu-Darya river basins
- Originating from high mountains (Pamirs), highly glacier and snow fed
- Huge hydropower potential in the upstream parts (located in Tajikistan, Kyrgistan)
- Very dry, so highly dependent on water supply from upstream.
- Heavily irrigated (mainly cotton and wheat), overexploitation leading to drying up of Aral Sea

Case study: Central Asia

- Set up LPJmL to understand links between source and use of water, and between water and food systems
  - Provide overview of water use (where, when, which crops) and water supply (precipitation, glacier/snow, groundwater)
  - Scenarios of climate change
  - Scenarios of water management options
  - Impacts on food production, water use & availability



- **Work in progress!**

Case study: Central Asia

Typical process for setting up a climate impact modelling study:

- Determine the research questions; how will the results be used
- Decide on modelling plan
- Collect all necessary input and validation data
- Spinup model
- Adjust and/or calibrate model as required
- Evaluate performance under historical conditions
- Run model for a range of climate models and scenarios
- Postprocess, analyse and summarise output
- Interpret outcomes, draw conclusions

Case study: Central Asia

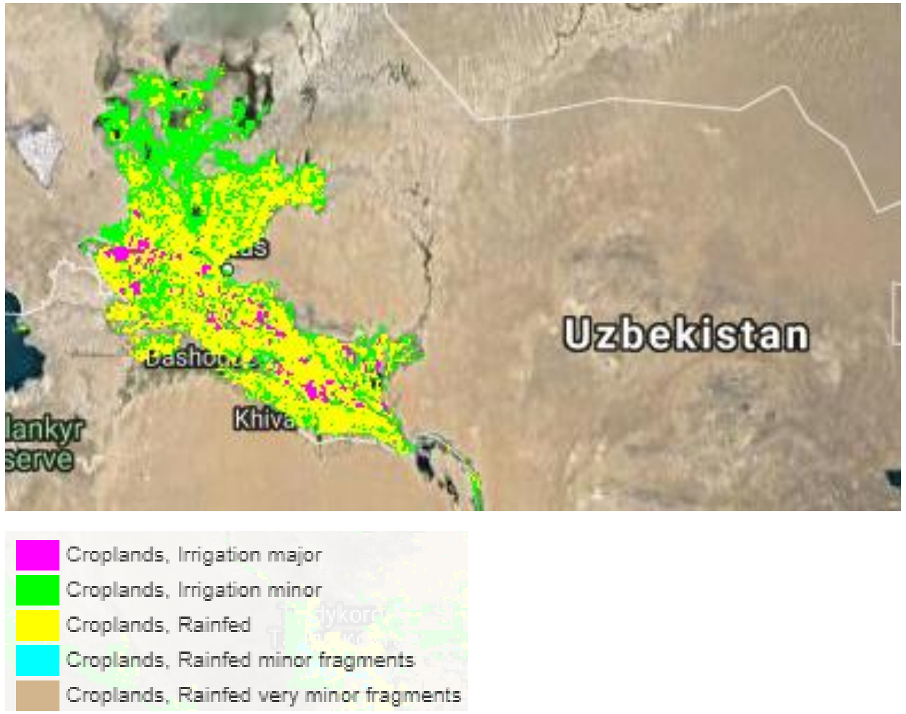
Typical problems you may encounter:

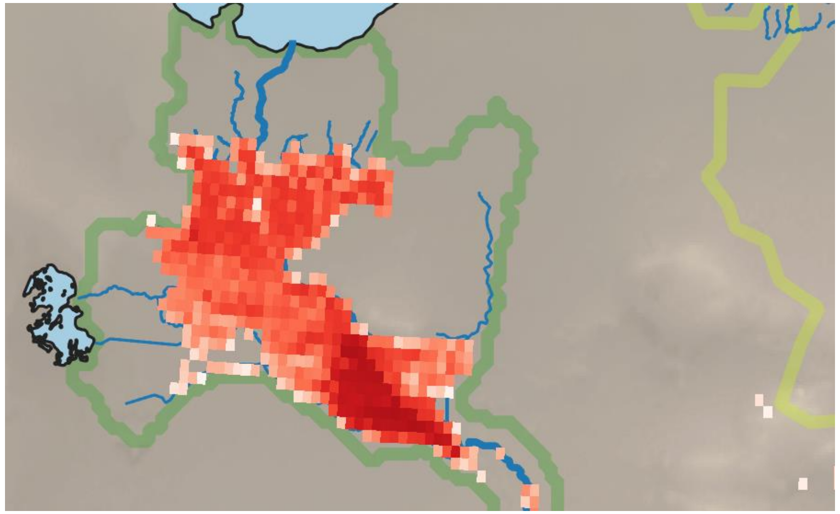
- Local specific data often hard to get
  - e.g., for some regions we know where the irrigation canals are, but how much water is being withdrawn? And which areas are connected to these canals?

Case study: Central Asia

Typical problems you may encounter:

- Local specific data often hard to get
- Global data not always of good quality





Areas of irrigated cotton, MIRCA2000 database

Case study: Central Asia

Typical problems you may encounter:

- Local specific data often hard to get
- Global data not always of good quality
- Vegetation/crop data and soil classes may not match with what is used or needed in the model
  - e.g., the MIRCA2000 dataset has a class for cotton, but not LPJmL. What crop functional type comes closest?

Case study: Central Asia

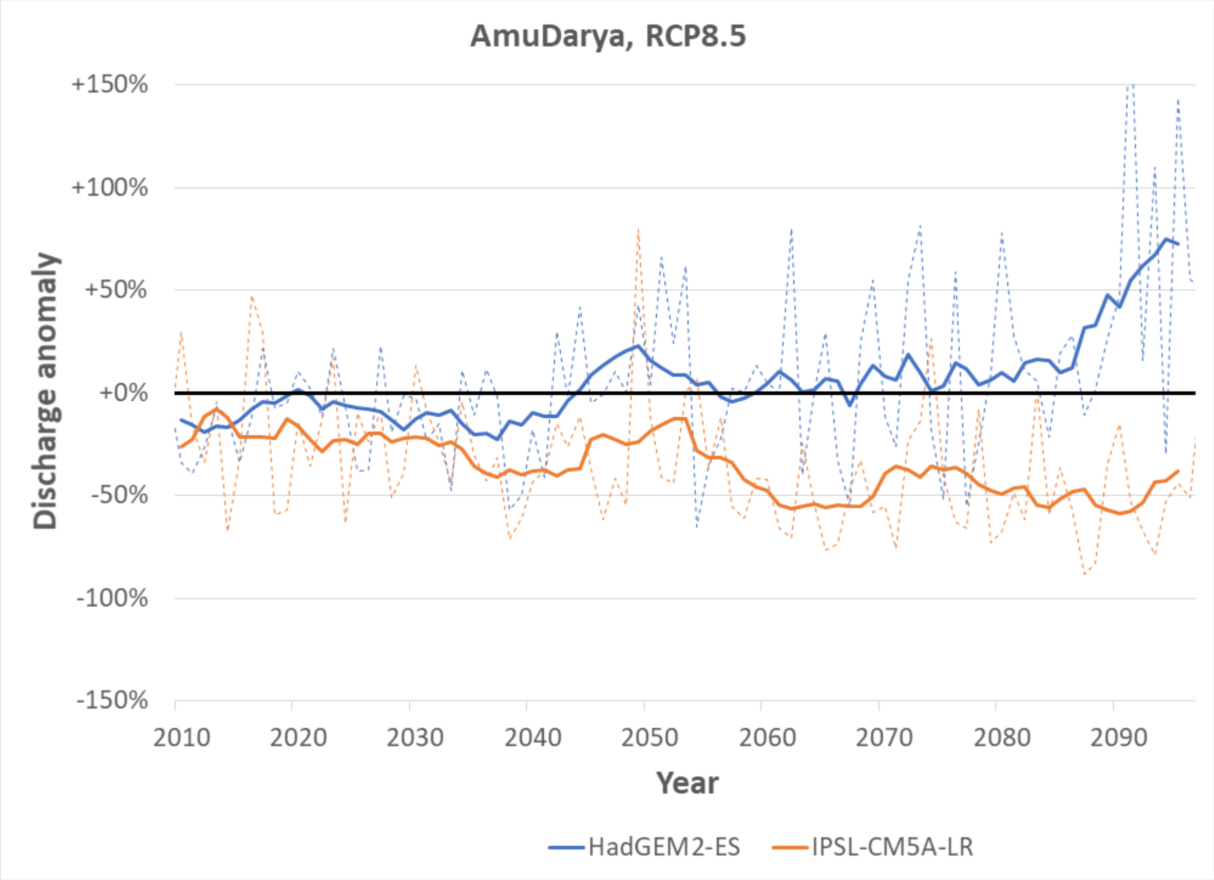
Typical problems you may encounter:

- Local specific data often hard to get
- Global data not always of good quality
- Vegetation/crop data and soil classes may not match with what is used or needed in the model
- You run out of time/funding, so you can only produce some preliminary results...

Case study: Central Asia

Typical problems you may encounter:

- ... and you end up with unclear or conflicting projections



Conclusions & Recommendations

- Impact models can add more detail on projected climate impacts in a particular sector and/or area
- Easier to run and more flexible than GCMs/ESMs
- Be clear about the ‘impact’ you want to model
- Be careful with applying models outside of the historical range, especially for statistical models / models heavily reliant on calibration
- Ask yourself if potentially relevant processes or interactions are missing
- More detail and better performance in the past are no guarantee for “trustworthy” future projections!

Conclusions & Recommendations

- Explore parameter uncertainty & stability through sensitivity analysis
- Explore modelling uncertainty using multi-model approaches
- Be clear about any assumptions going into the modelling process
- Assist your user in interpreting the results!

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Questions & answers