IS-ENES3 C&E Europe
Autumn School
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Approaches to impact modelling

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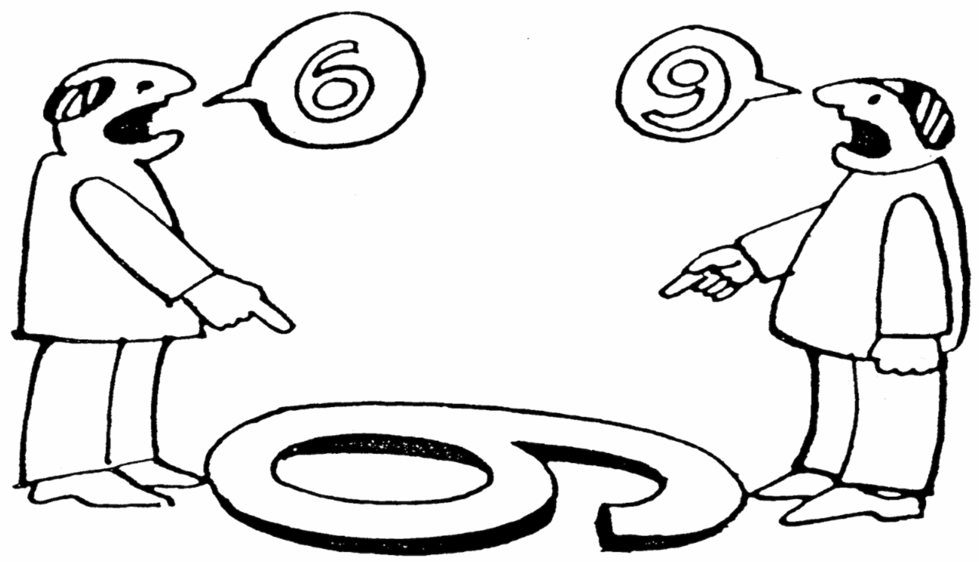
29 November 2022

The IS-ENES3 project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824084

What is an “impact” model?

What constitutes an “impact” depends on your perspective...



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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**.*

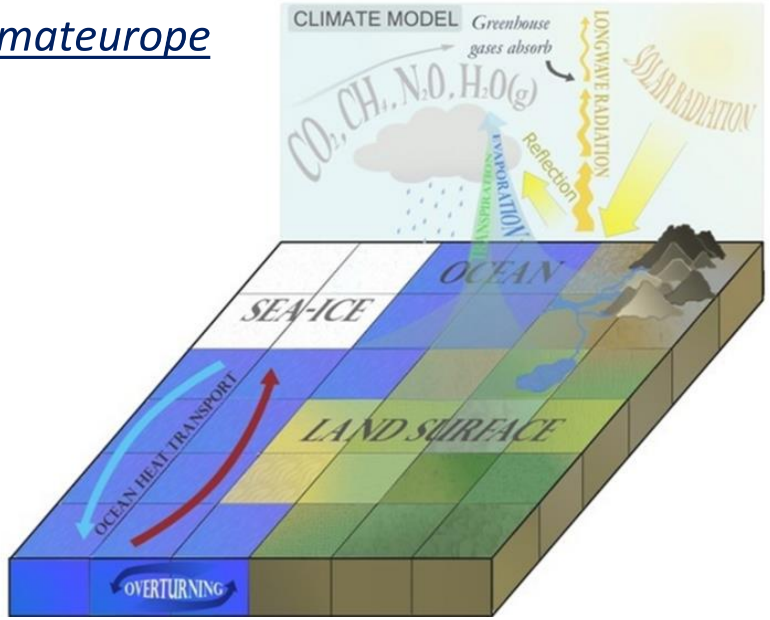
Source: IPCC Fifth Assessment Synthesis Report (2014)

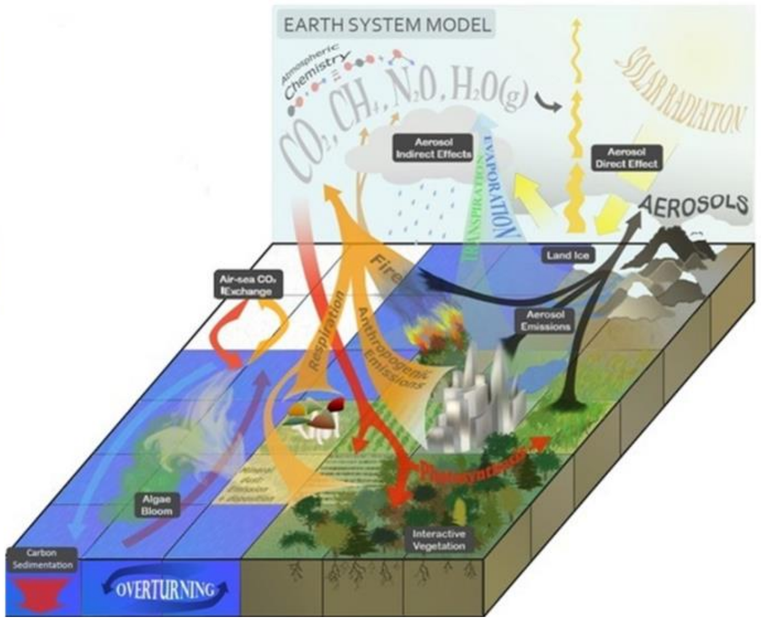
Why use impact models?

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

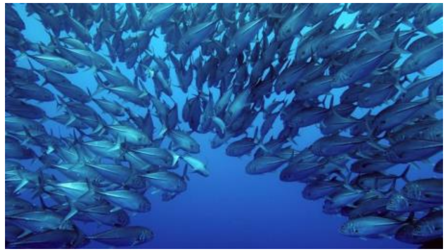
Source: Climateurope





Impact sectors

Examples of sectors where impact models have been used





ISIMIP Inter-Sectoral Impact Model Intercomparison Project https://www.isimip.org/

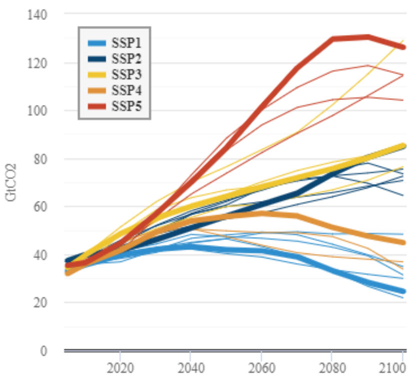
Impact models

- There are many to choose from
- 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

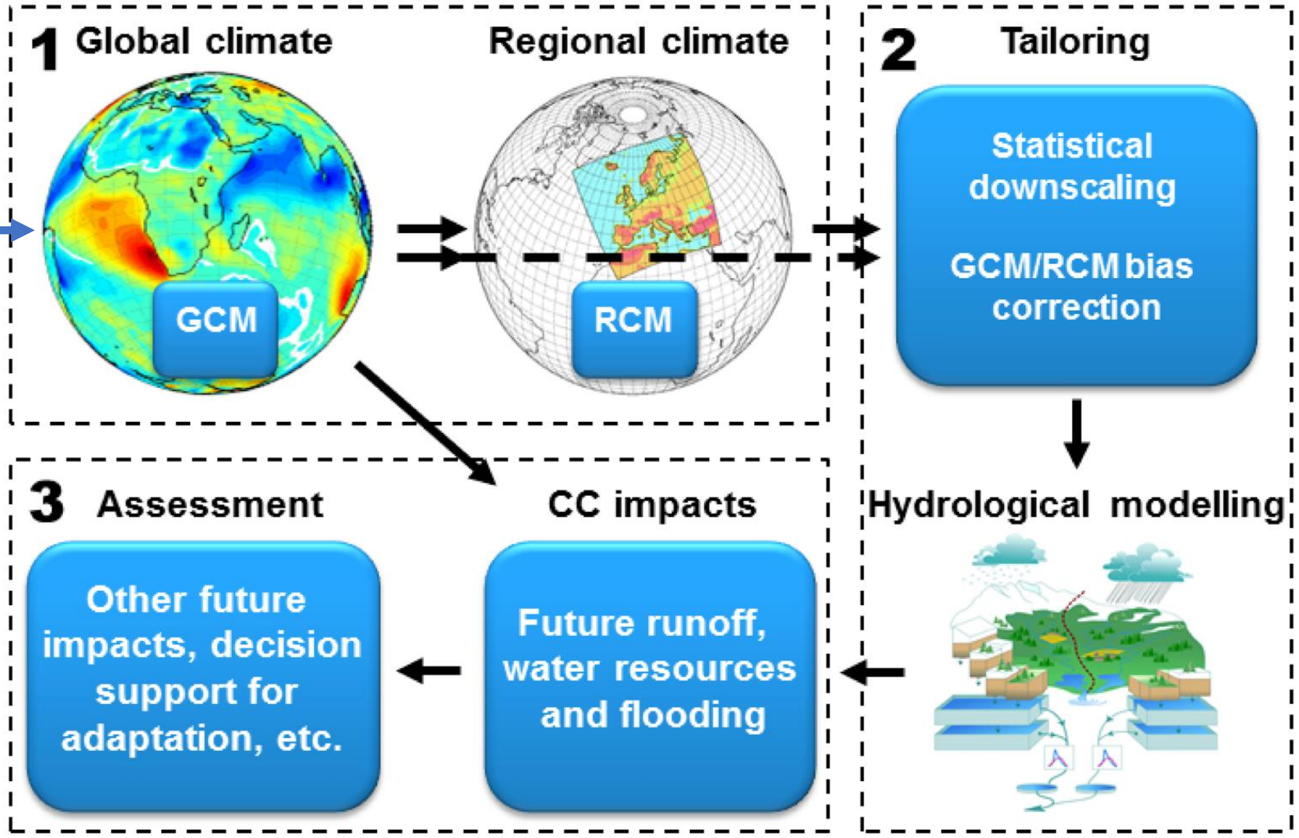
Impact model chains

Translating climate information to sectoral impacts

0 Emission scenarios



Source: CarbonBrief



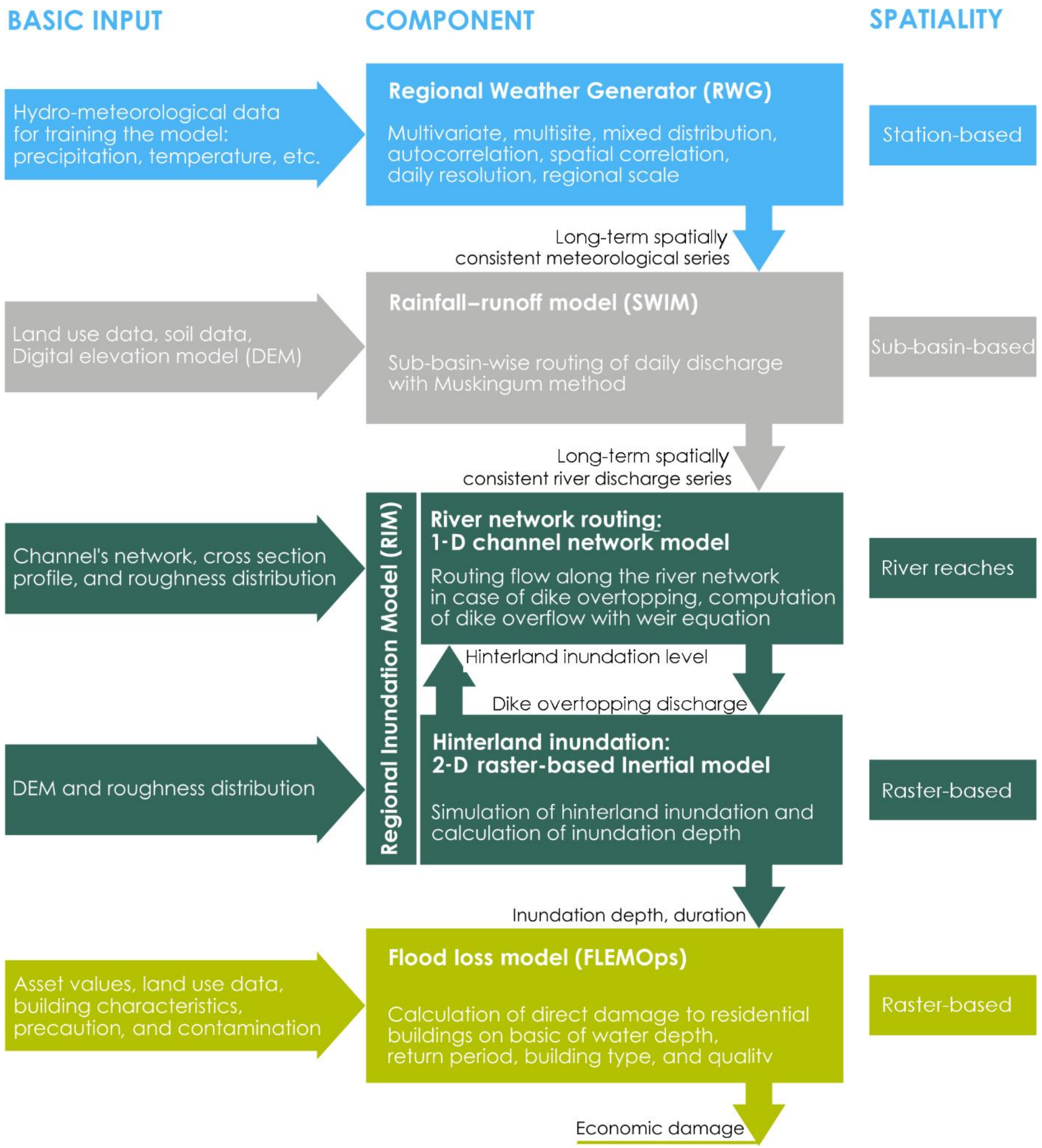
Source: Olsson et al. (2016)

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

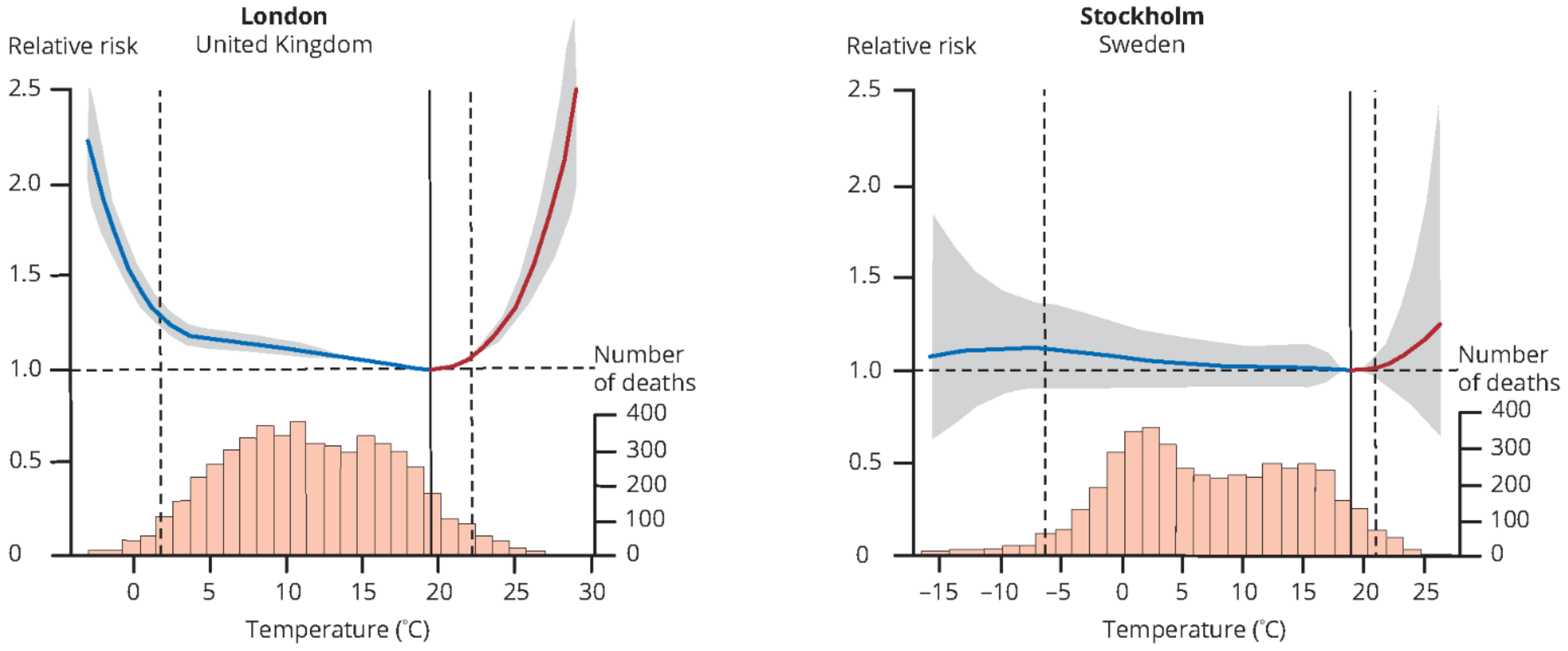
To calculate losses from flooding



Source: Metin et al., 2018

Type 1: statistical models

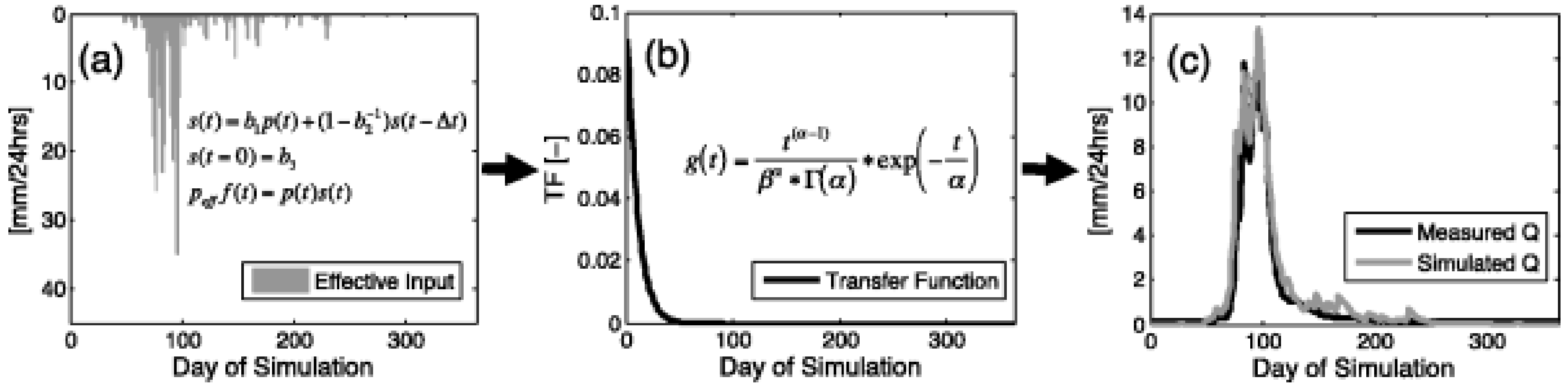
- Establish relationship between weather/climate and impact



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.

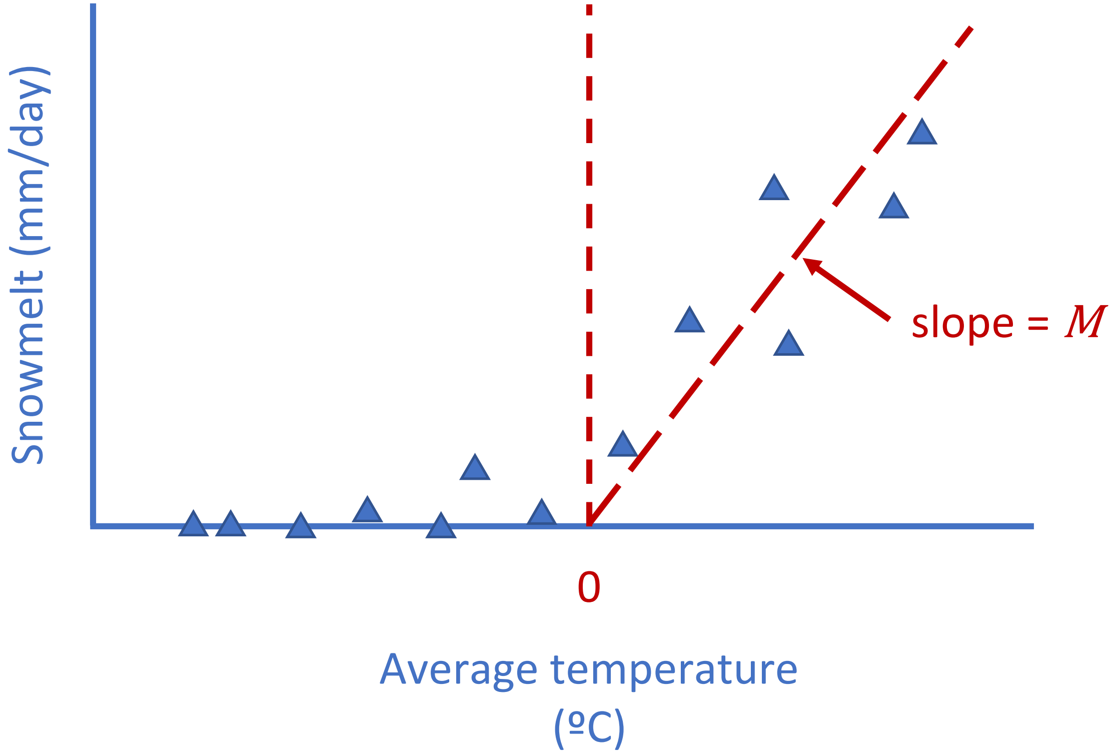
Source: XKCD

Empirical modules

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

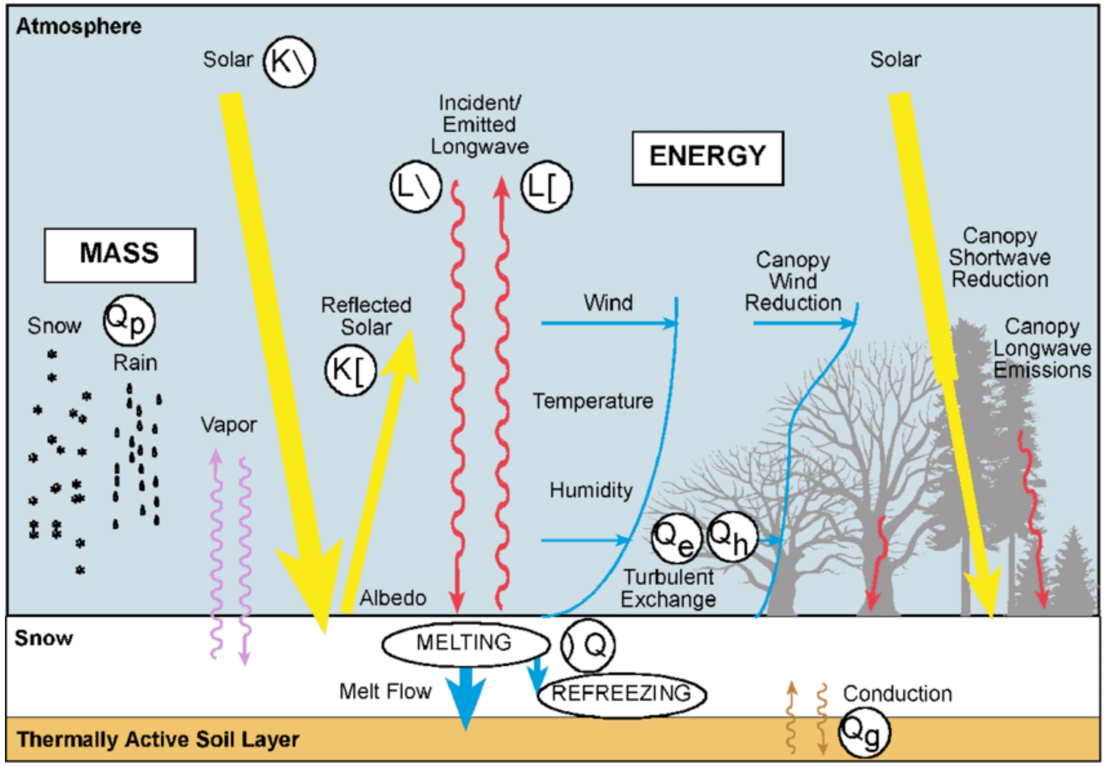
$$\Delta w = 0; \qquad T_a \leq T_m \ (\approx 0°\text{C})$$
$$\Delta w = M(T_a - T_m); \ T_a > T_m$$

M is melt coefficient or degree-day factor



Empirical modules

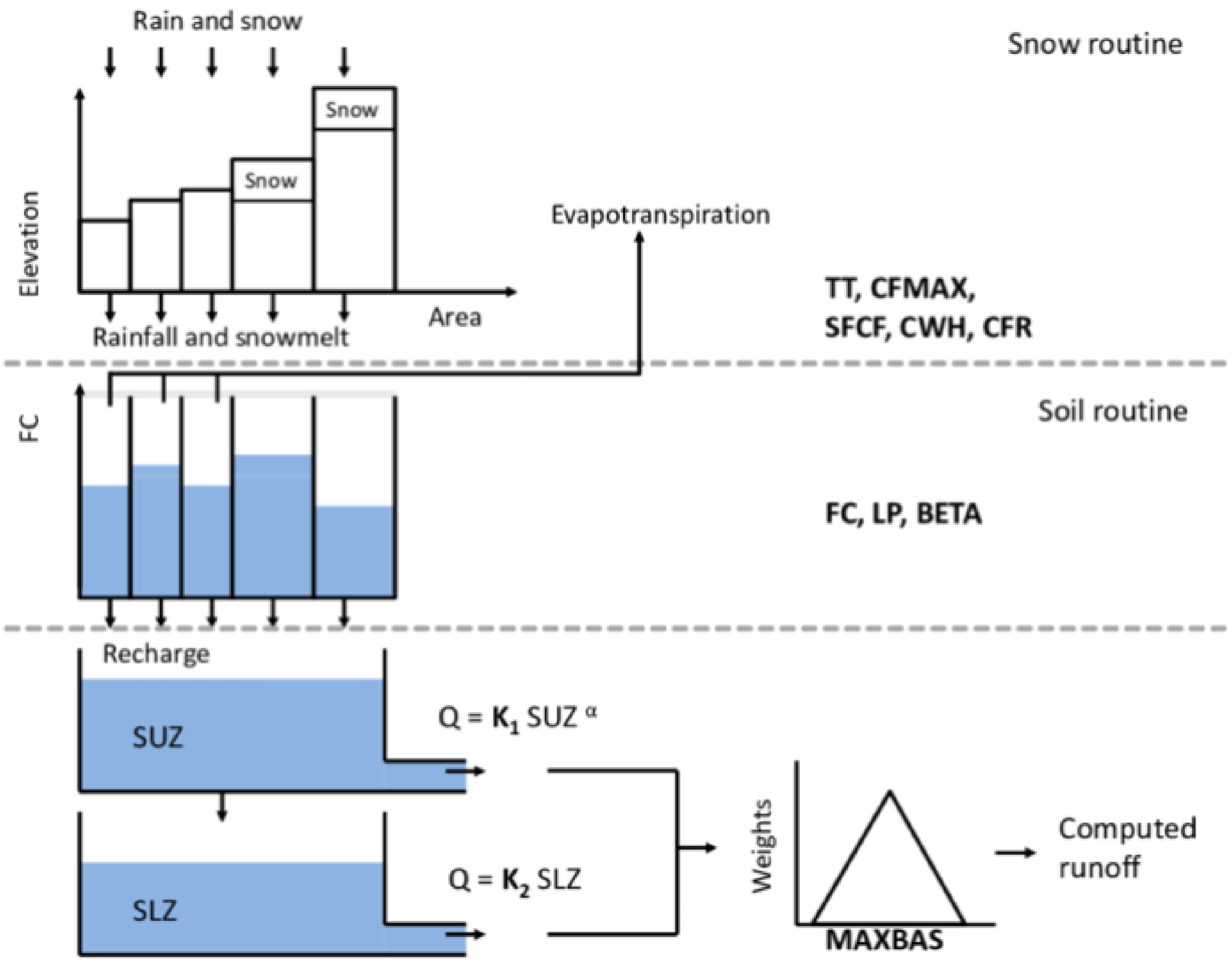
- Note that many sub-models and parameterisations in more complex models are in essence statistical models!
- Example: snowmelt
- In reality snowmelt is a much more complex process



Source: [Fletcher, 2005]

Type 2: conceptual models

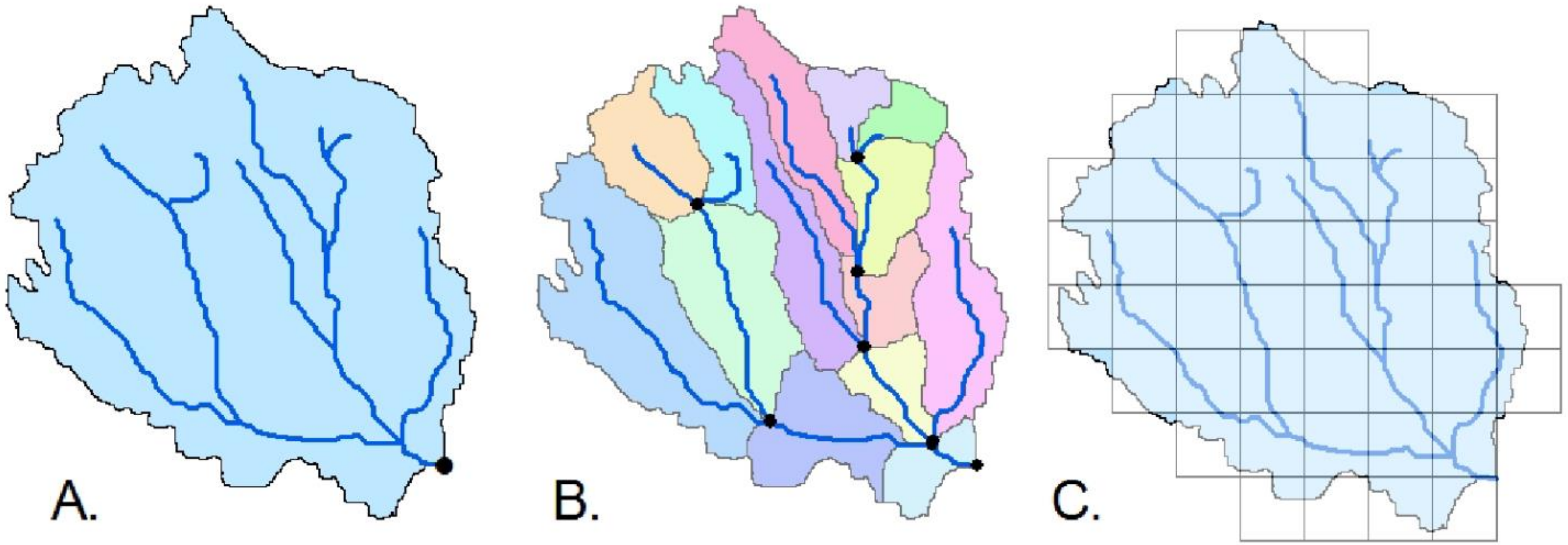
- Include several components (storages and flows) to mimic the most relevant processes
- Often simplified process descriptions
- Example: HBV hydrological model
- Similar schemes can be found in e.g., crop models



Source: Staudinger et al., 2015

Lumped and distributed models

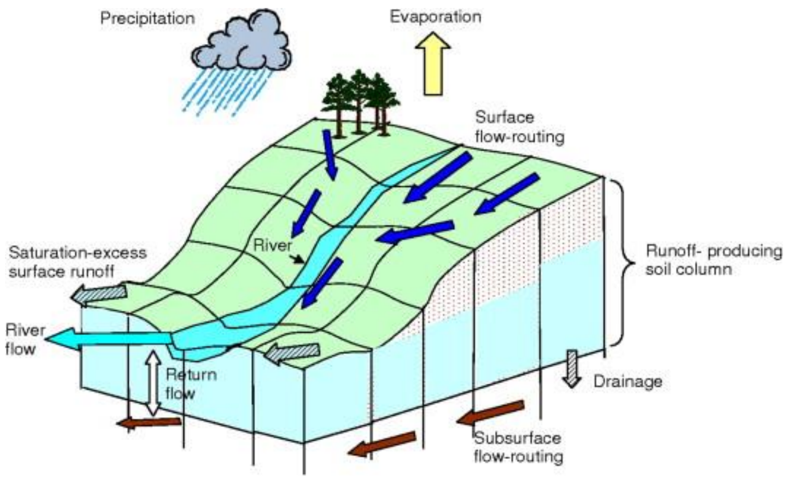
- Lumped: entire catchment taken as single modelling unit
- Semi-distributed: subdivision in sub-catchments
- Fully distributed: spatially explicit



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

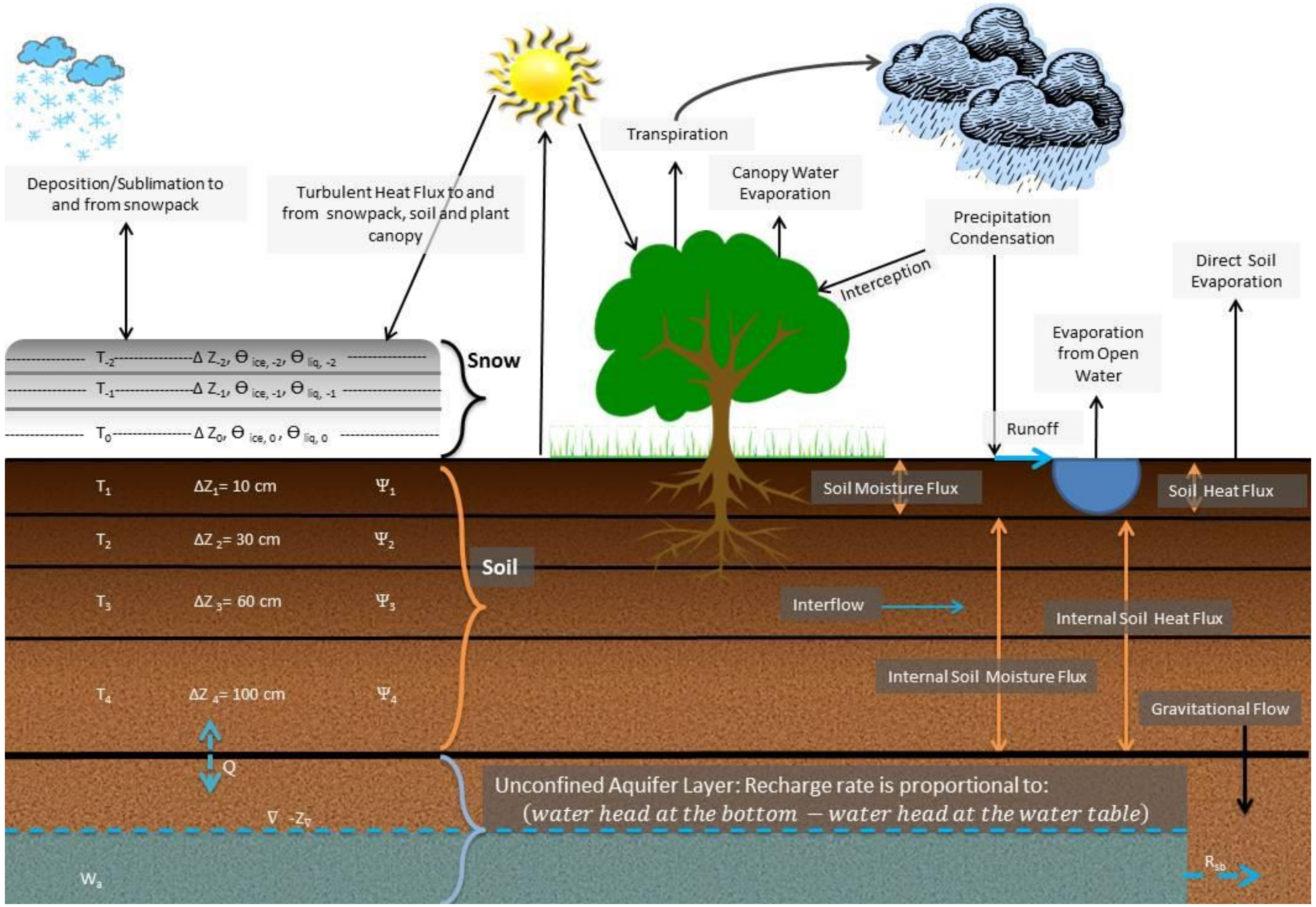
Conceptual models, pros and cons

+ 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

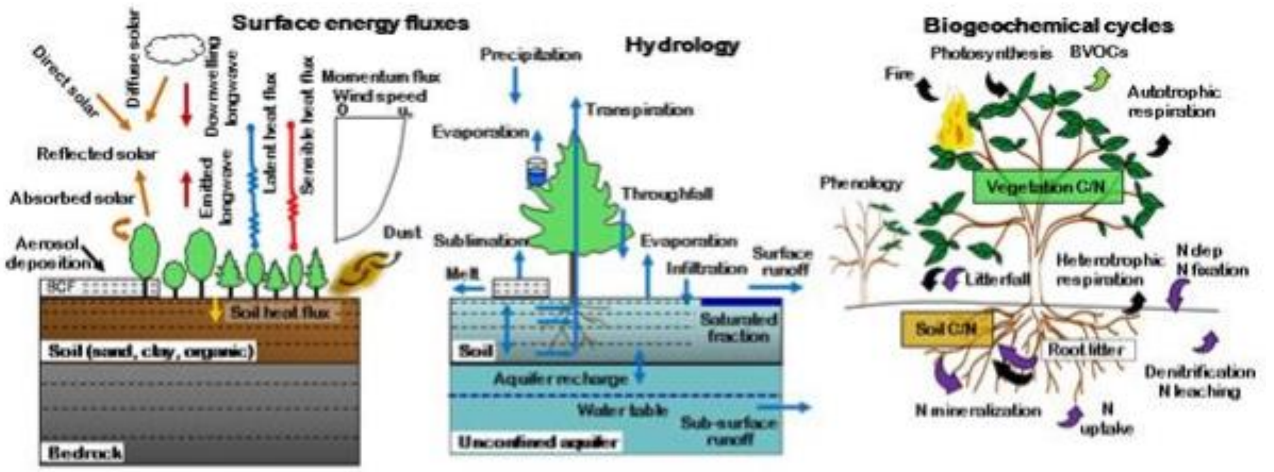


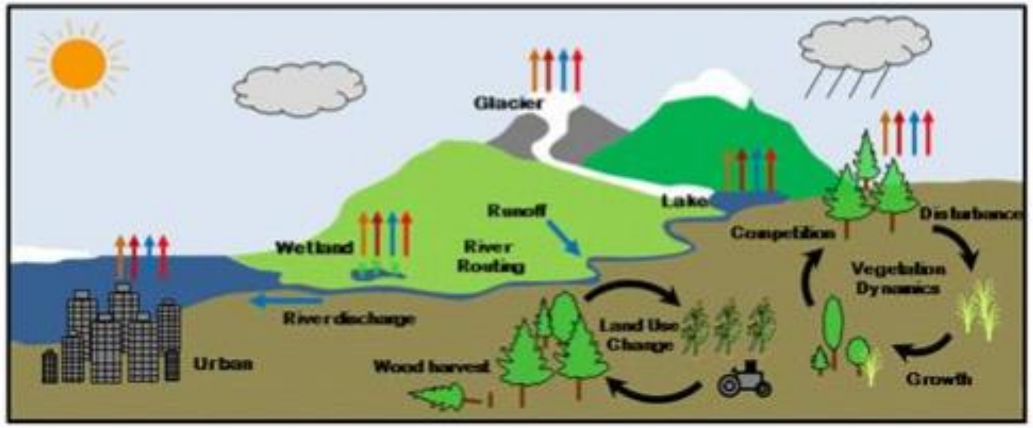
Source: Noah Land Surface Model

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

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

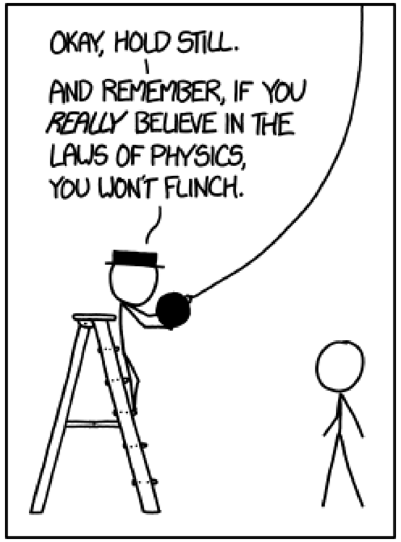




Source: Community Land Model

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

Impact model application

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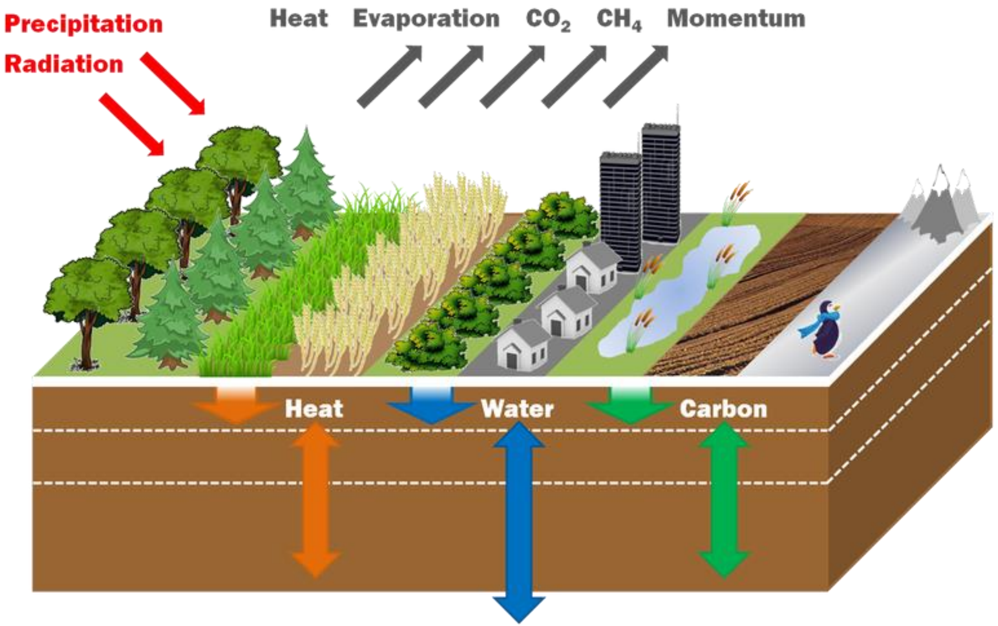
Different models with different aims

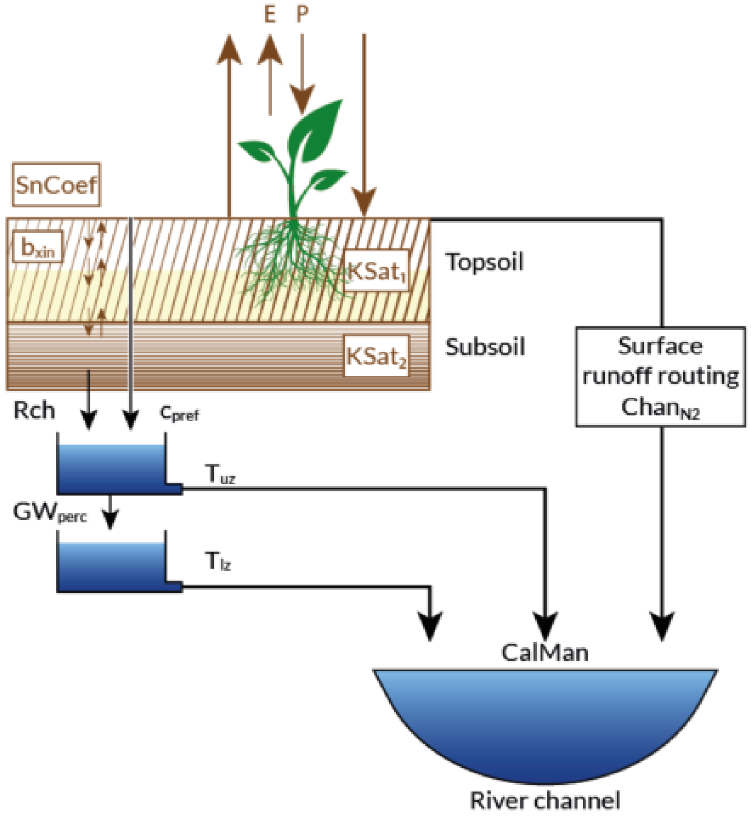
- Hydrological models: close water balance of a catchment
- Land surface models: solve energy and water balance of land surface
- Dynamic vegetation models: vegetation distribution and carbon cycle
- Crop models: crop production, carbon and nutrient cycles



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

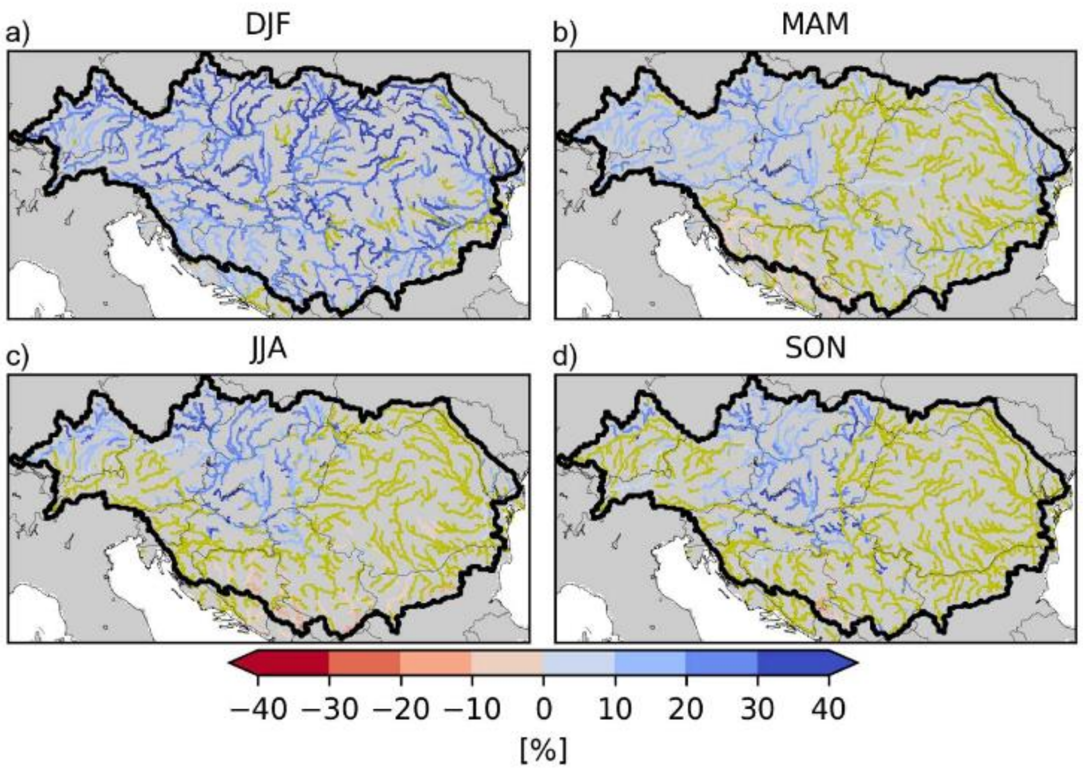
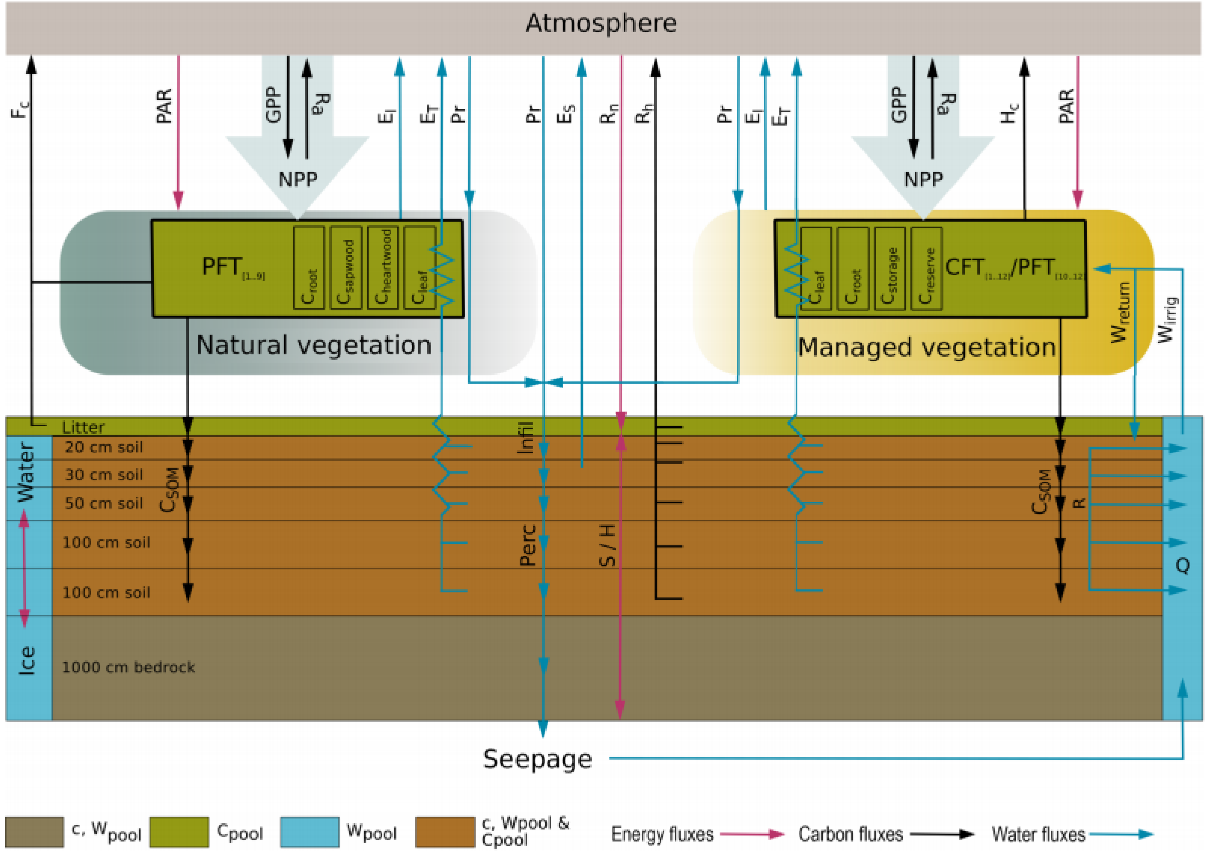


Figure 26 Impact of 2 degree climate change on mean seasonal streamflow, as compared to the 1981-2010 control climate, showing the combined effect of climate change (CC), land use change (LU) and water demand change (WD). Note: the green colour indicates rivers where the uncertainty in the results is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



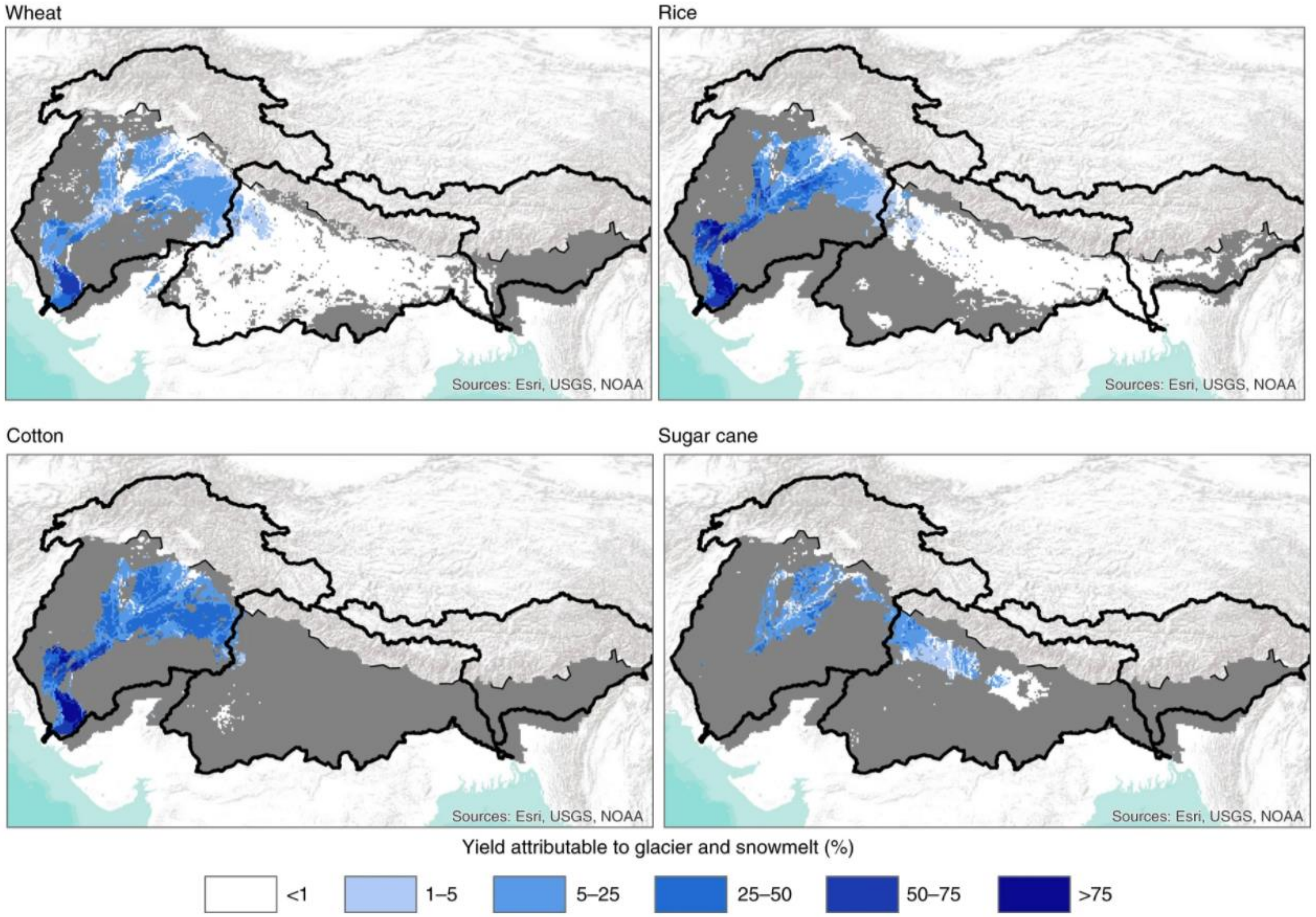
- Available from: https://github.com/PIK-LPJmL/LPJmL

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.

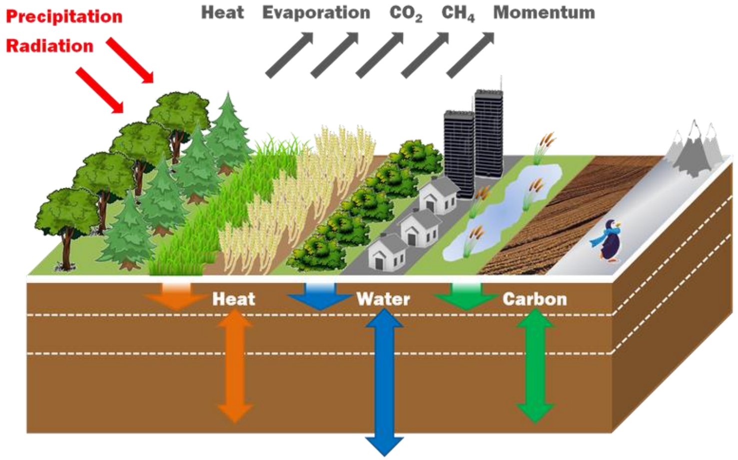
From: Importance of snow and glacier meltwater for agriculture on the Indo-Gangetic Plain



Source: Biemans et al., 2019

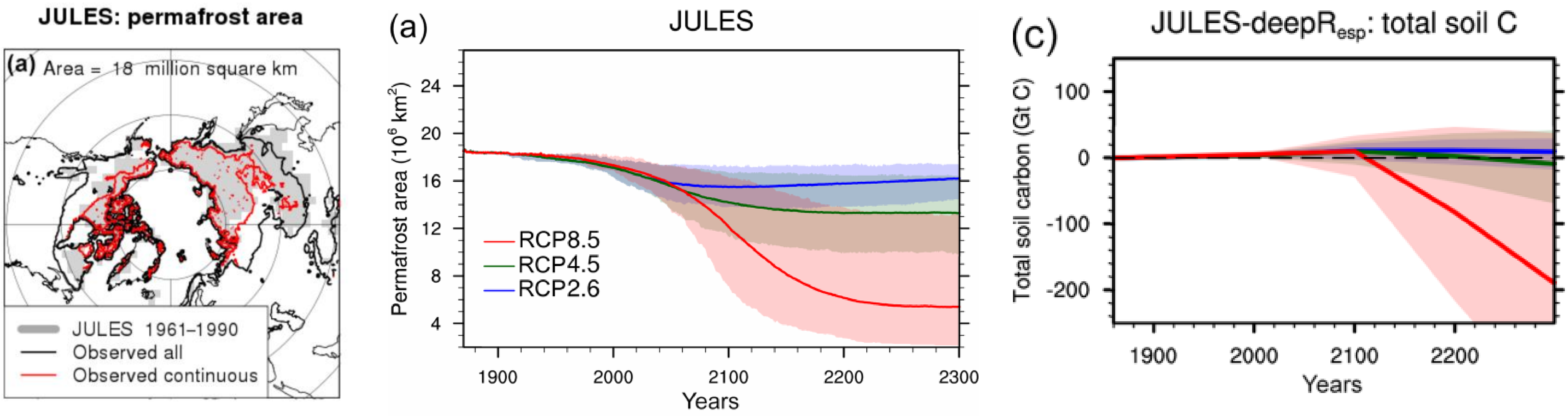
Examples: JULES

- 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/



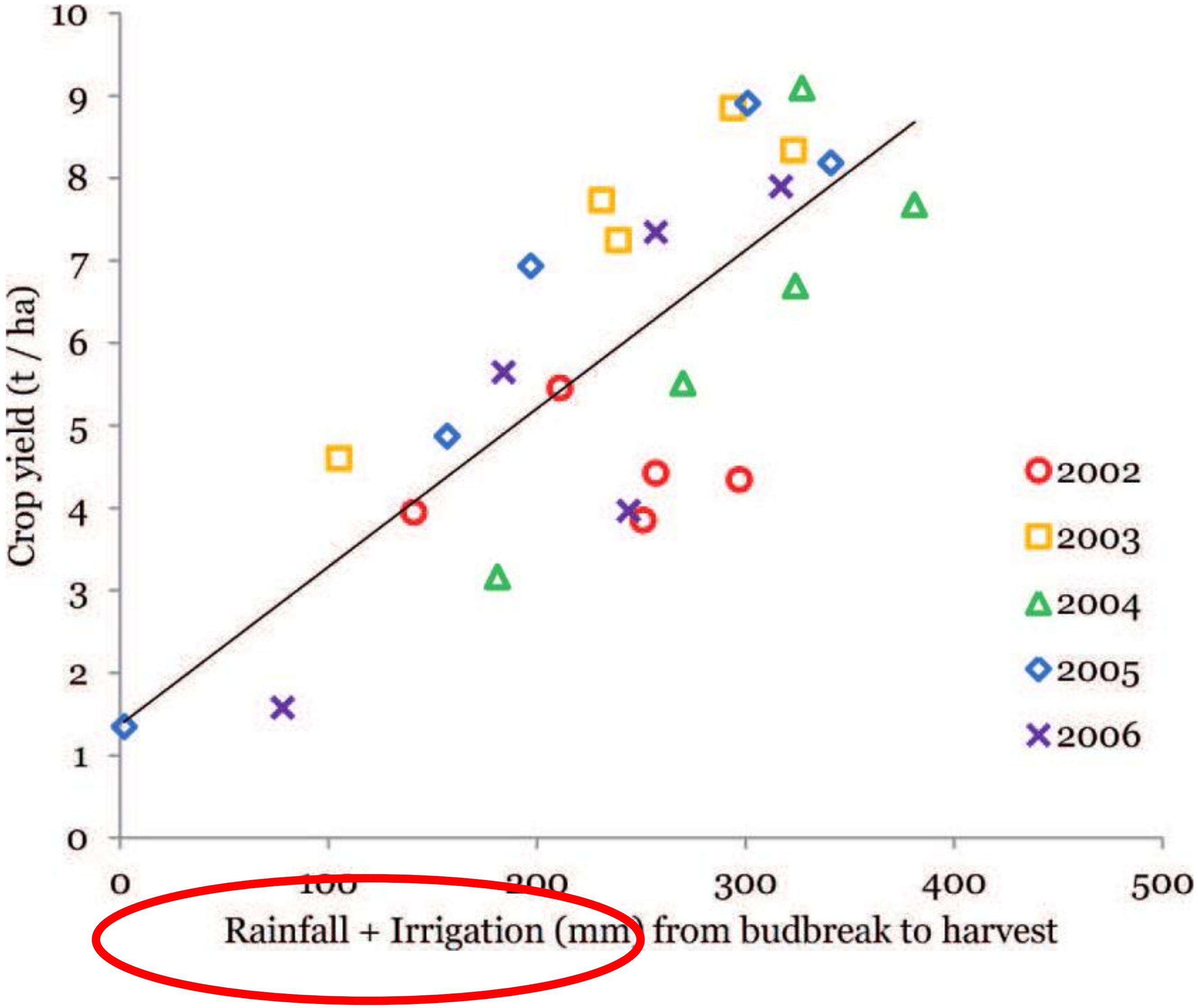
Examples: JULES

- 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

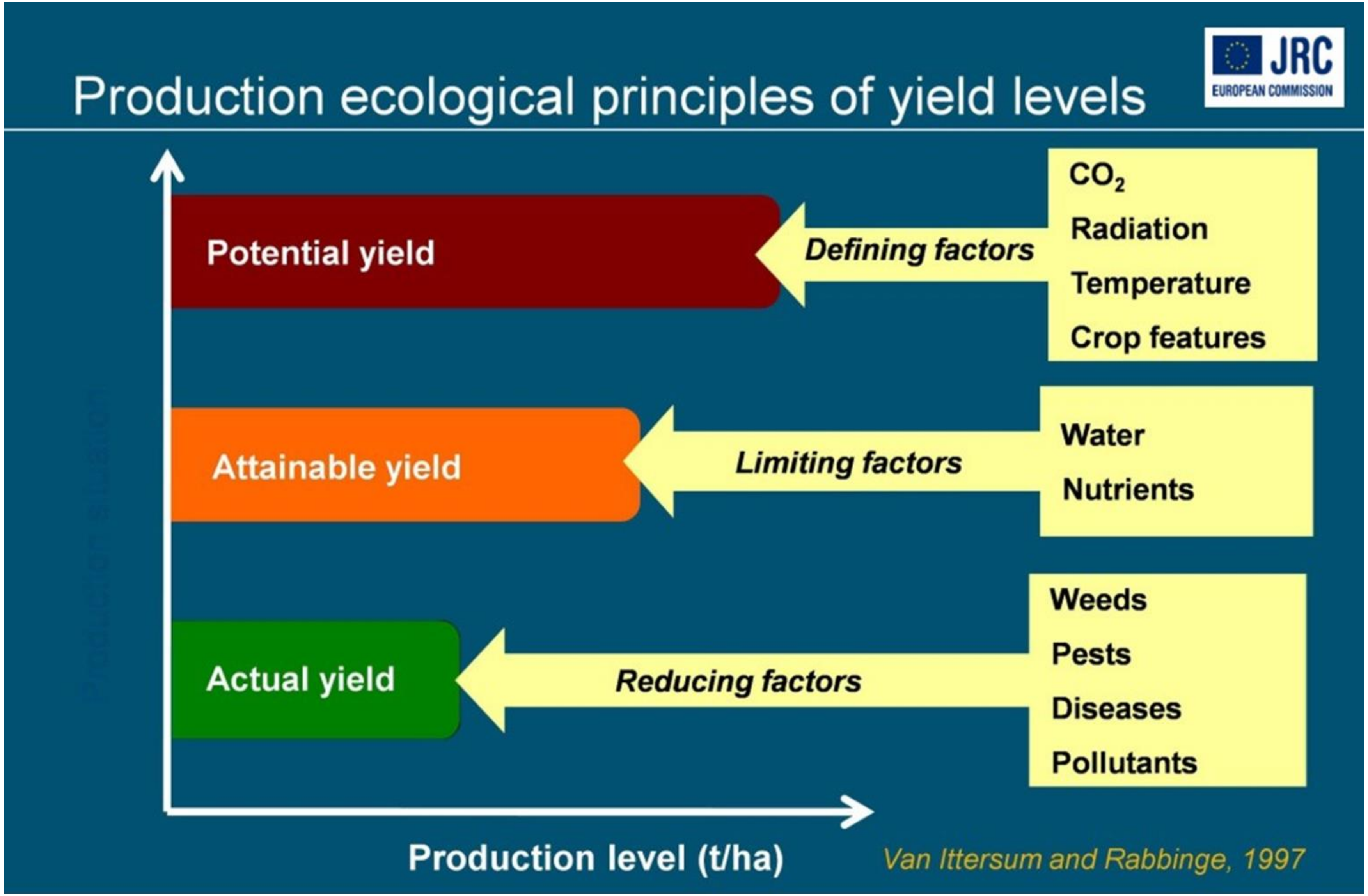
Example: statistical models



- harvest in a cv. Cabernet sauvignon vineyard in Madrid, Spain (Beaza & Junquera, 2019)

Examples: agriculture

Influence of weather/ climate on crop production

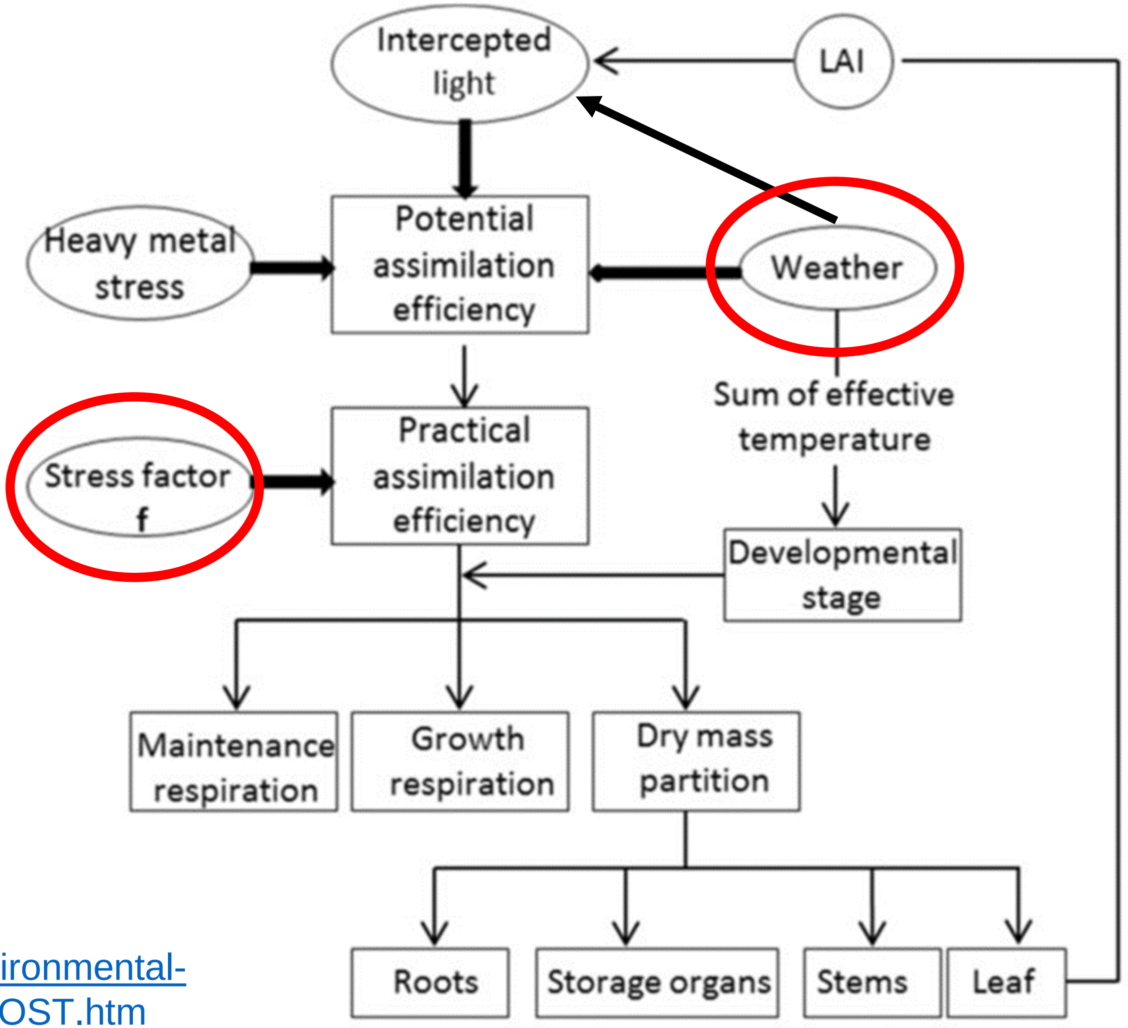


Examples: WOFOST

Basic ideas behind WOFOST

Process model with some parameterisations (statistical elements)

Originally developed for project on World Food Production, now used for more detailed studies

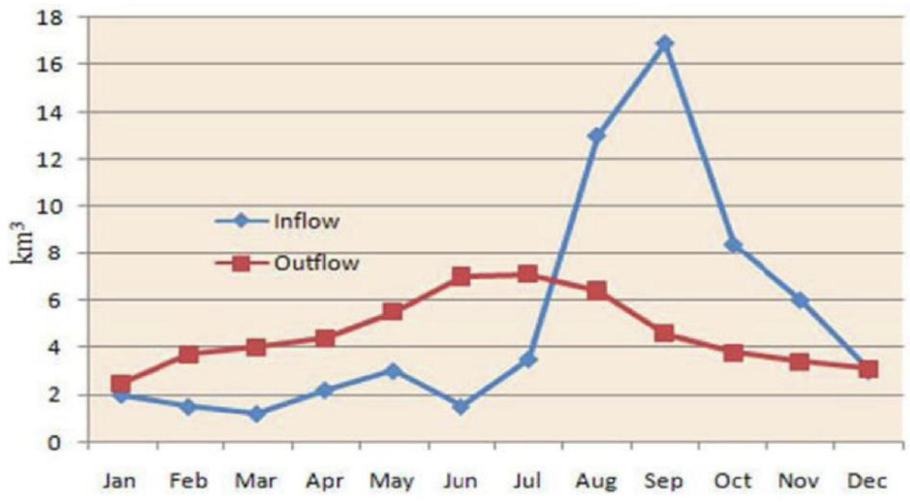


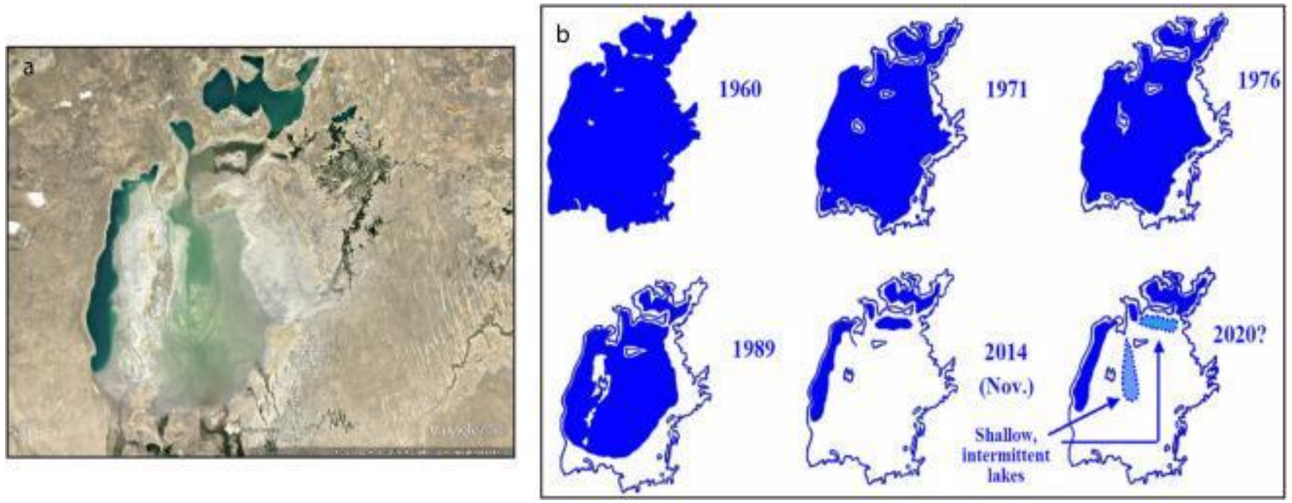
https://www.wur.nl/en/Research-Results/Research-Institutes/Environmental-Research/Facilities-Tools/Software-models-and-databases/WOFOST.htm

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!





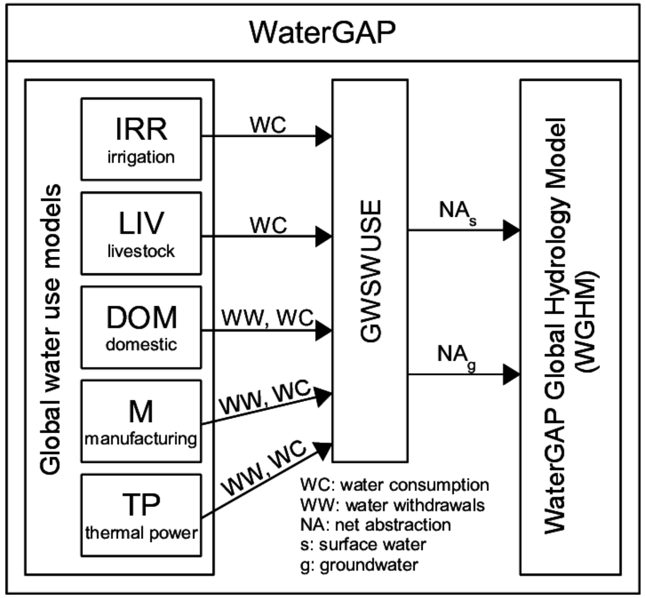
Source: Abd Ellah, 2020

Source: McDermid &Winter, 2017

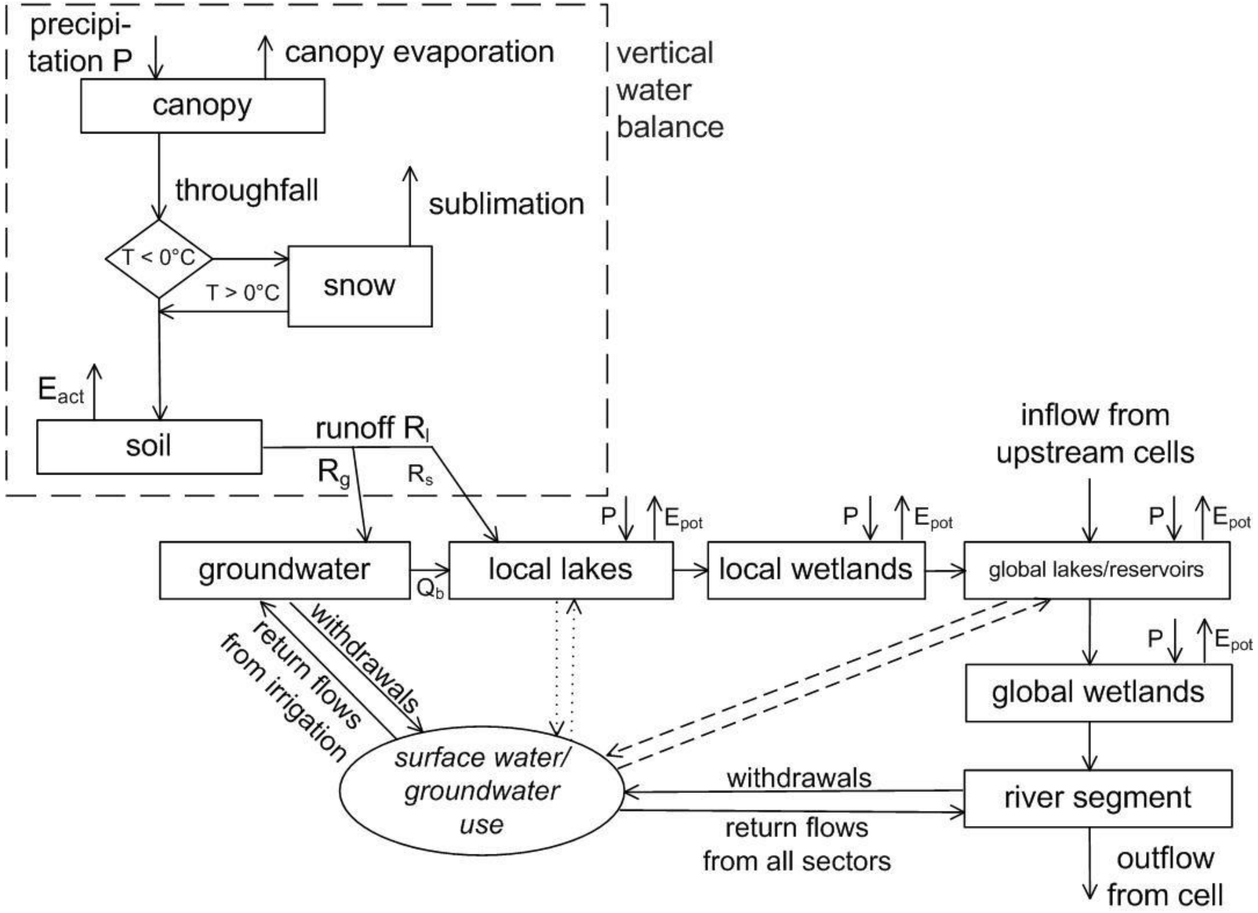
Challenges (1): Human impacts

Increasingly models include these human influences

- Example: WaterGAP model



Source: Müller Schmied et al., 2014

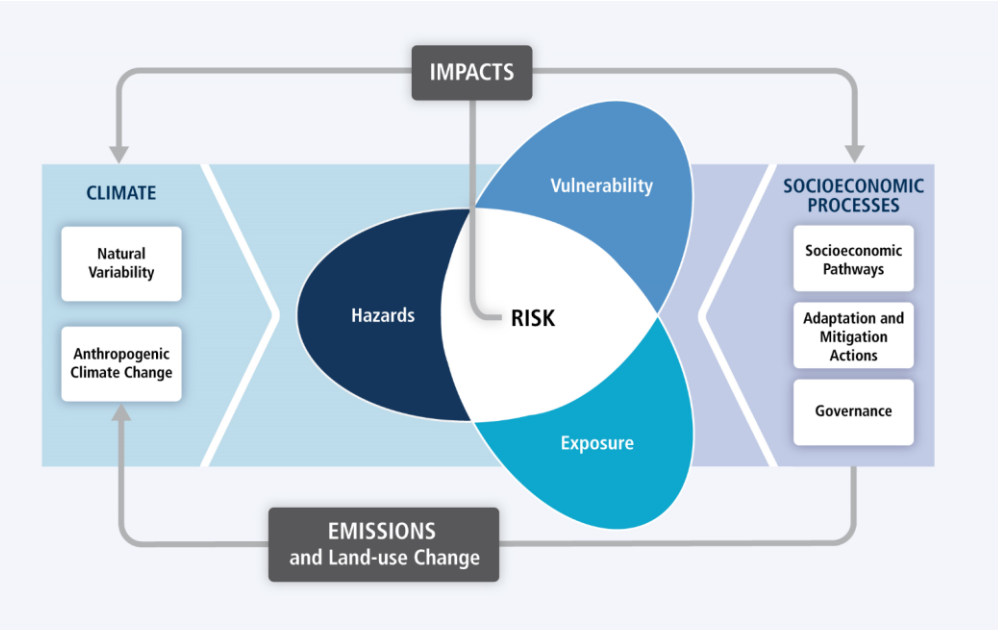


Source: Döll et al., 2012

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

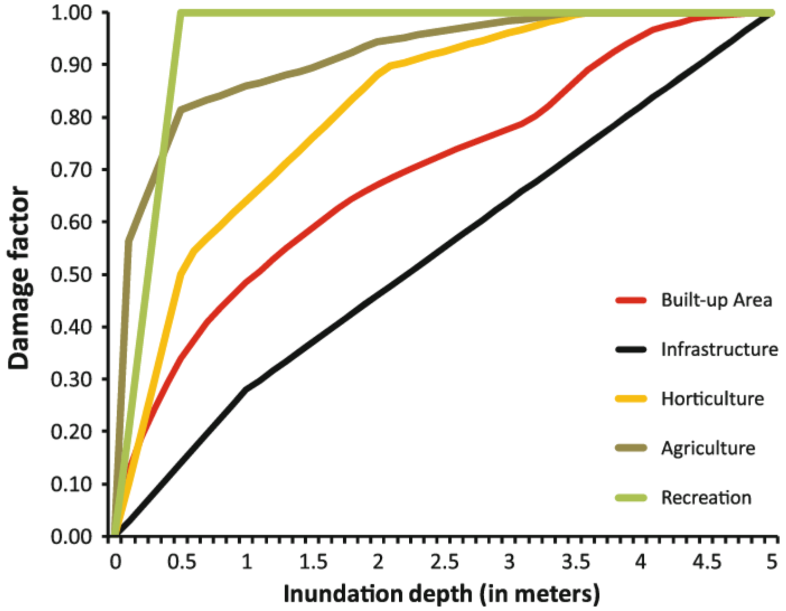


Source: IPCC, 2014

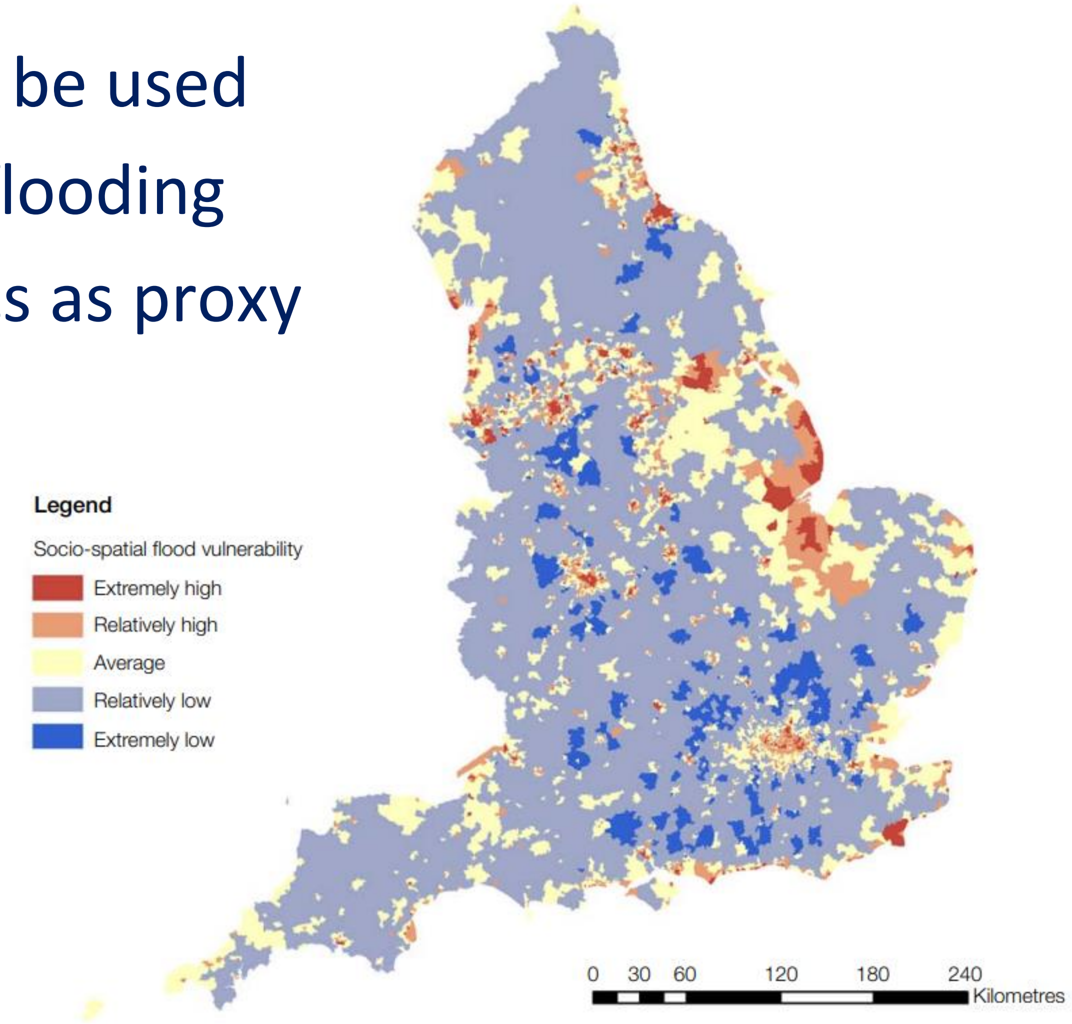
Challenges (1): Human impacts

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

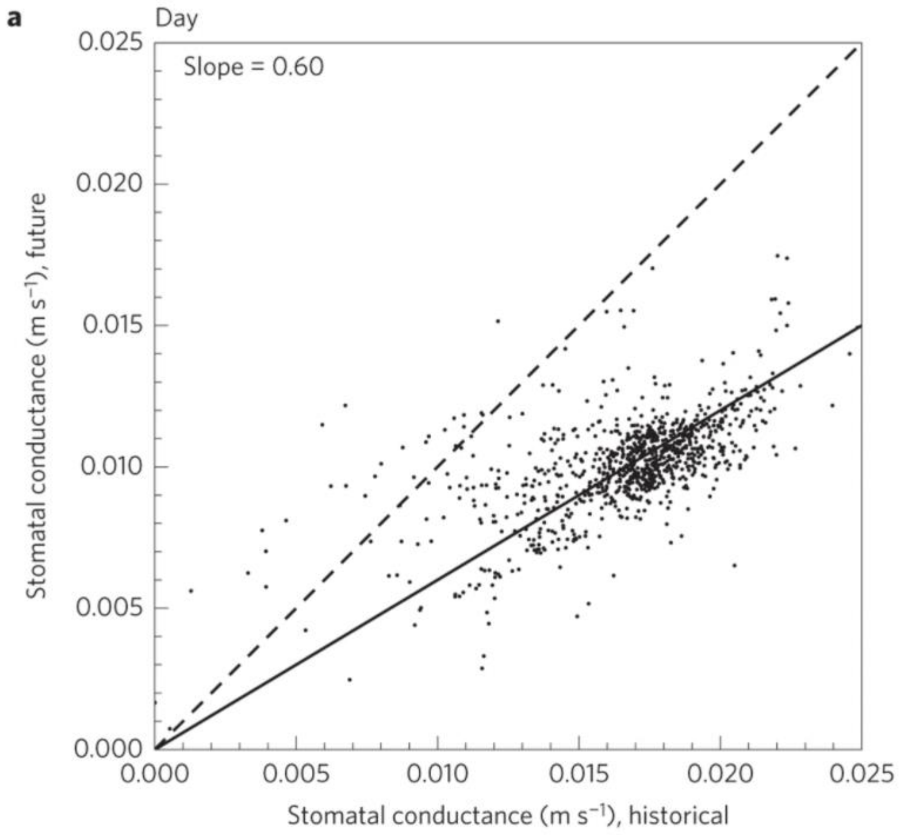


Source: Lindley et al., 2011

Challenges (2): Missing processes

Other relevant processes may be missing, too!

- Example: vegetation response to climate change affecting hydrology



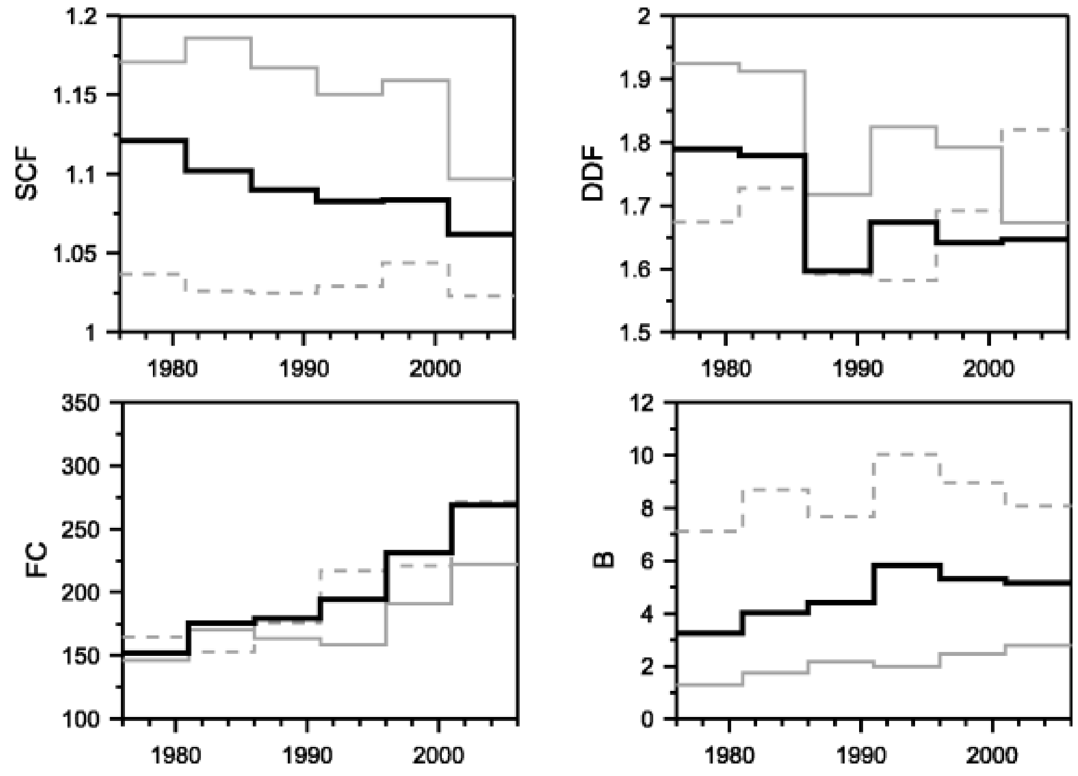
Source: [Milly & Dunne, 2016]

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...

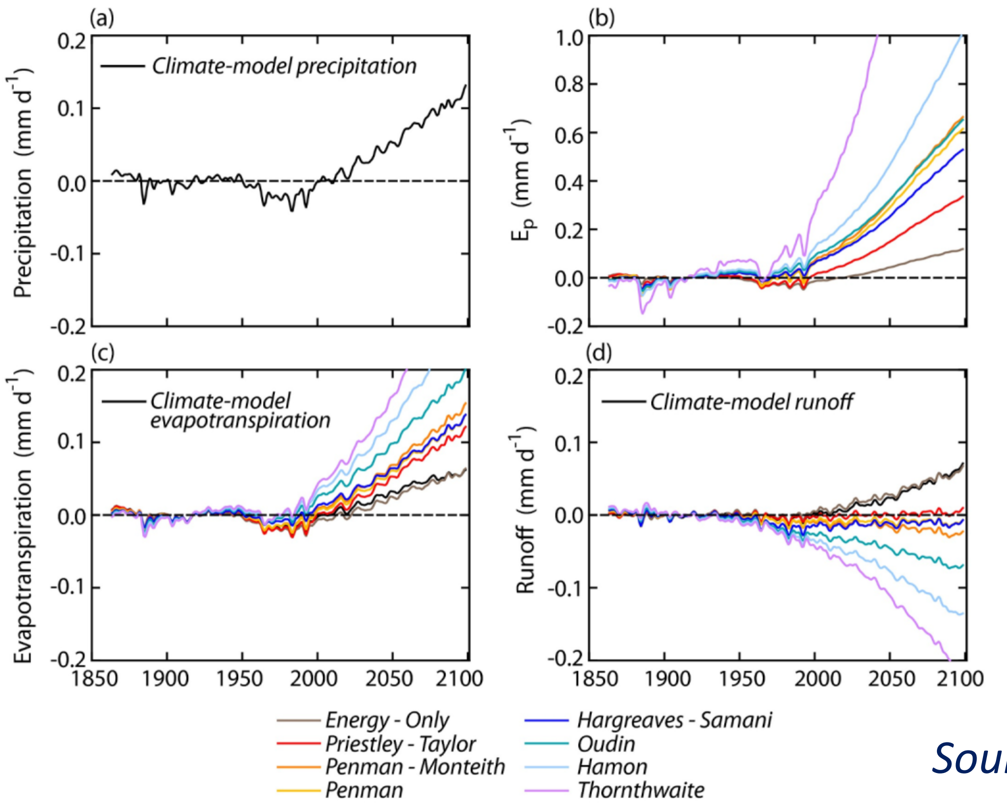


Source: Merz et al., 2011

Challenges (3): Model uncertainty

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

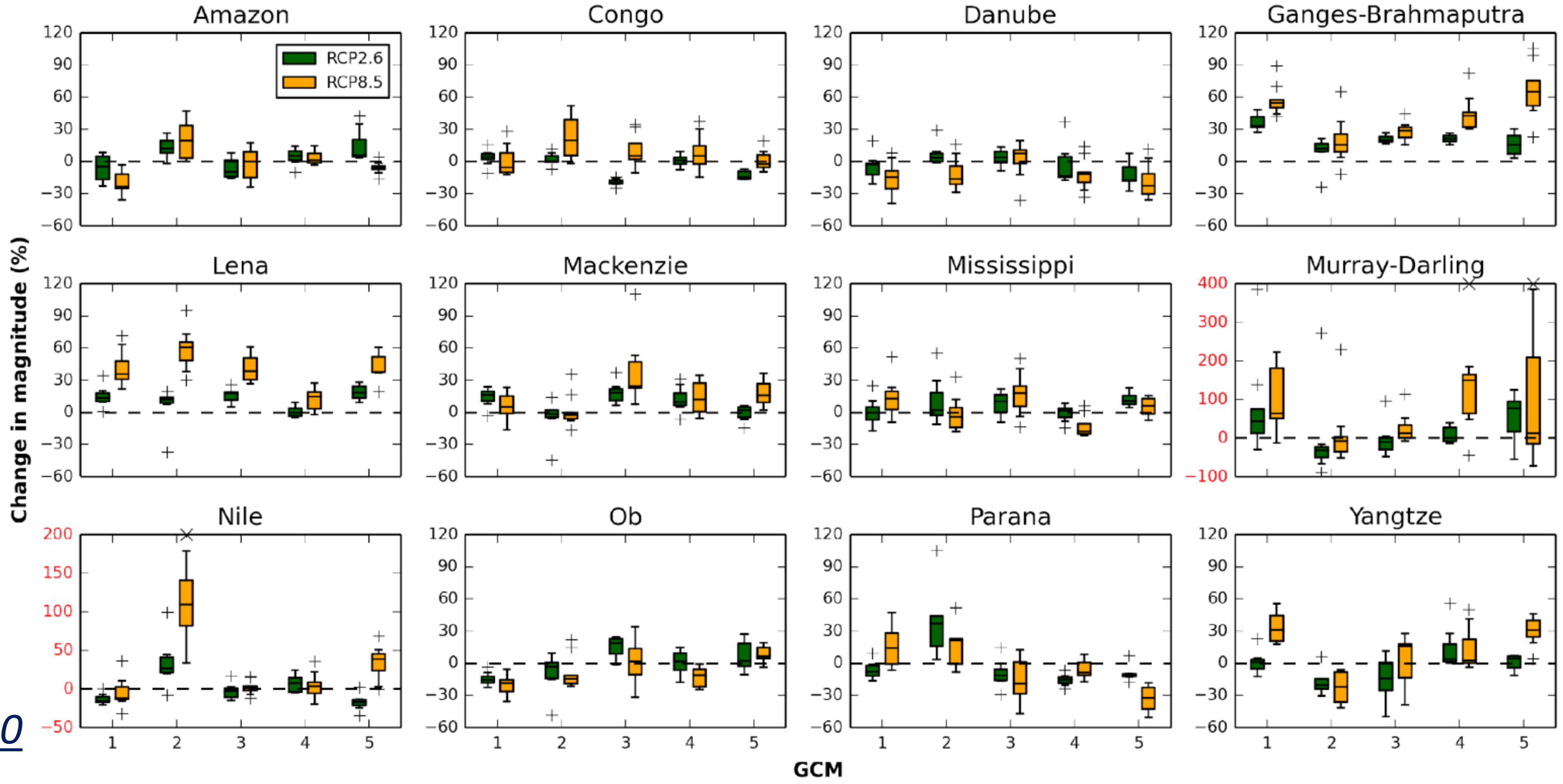
- Example: different approaches to calculate pot. evapotranspiration



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]()

Model application

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

Model application: problems

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
- Model performance is disappointing
- Model output is not exactly what is needed, further postprocessing required
- You run out of time/funding, so you can only produce some preliminary results...

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!

ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

https://www.isimip.org/

Questions & answers