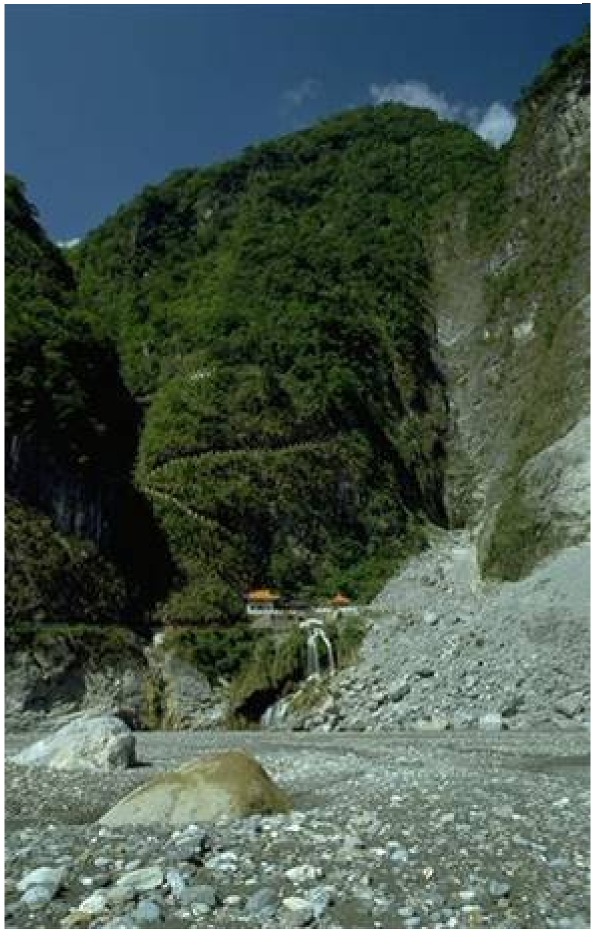
LINKS BETWEEN CLIMATE, HYDROLOGY AND GEOMORPHOLOGY

Simon Dadson, Mike Kirkby, Brian Irvine, Andrew Nicholas, Tim Quine, Juraj Parajka, Thomas Lafon, Ian Ashpole, Phil Harris, Helen Davies, Douglas Clark, Eleanor Blyth, and Chris Taylor





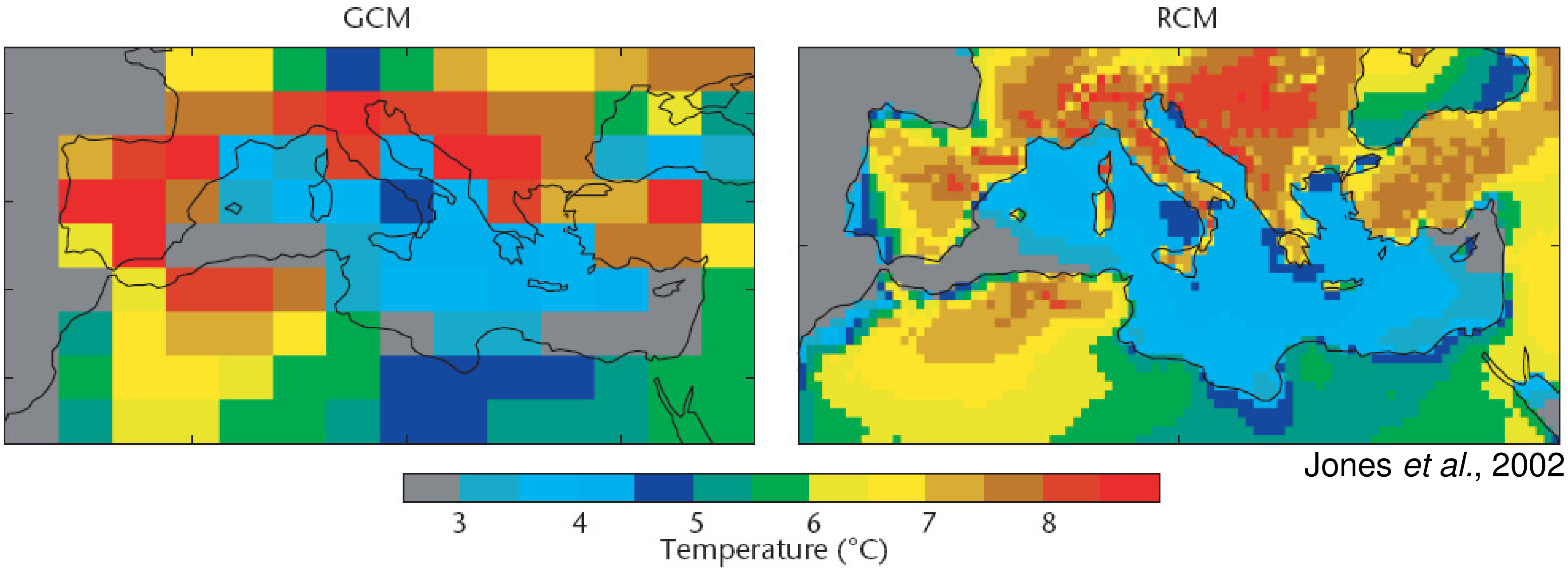
KEY QUESTIONS

1. How can we predict hydrological and geomorphic response to changing climate?

2. Which land-surface processes are important, and at what scale?

3. How well can we quantify feedbacks in the coupled Earth system?

LINKING MODELS ACROSS DIFFERENT SPACE & TIME SCALES



Jones *et al.*, 2002

- Climate change: Future warming of 1.8-4.0 ℃ by 2100.
- Wetter winters & drier summers in NW Europe; more extremes.
- What will be the impact on river flows, soils, and aquatic ecosystems?

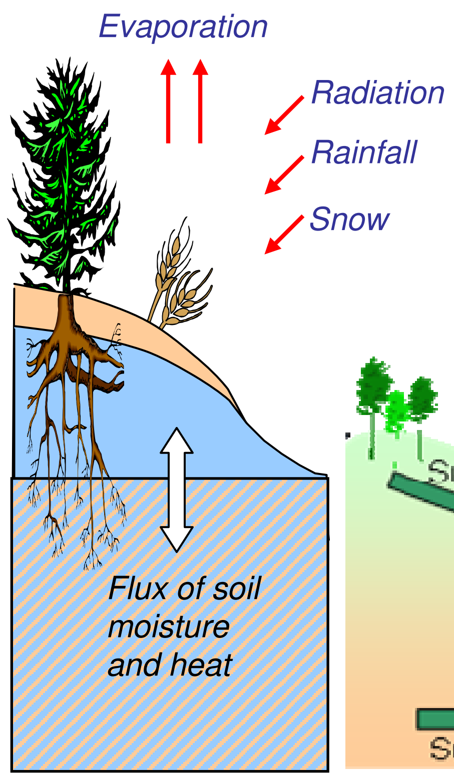
- For Earth Systems Science applications, climate models need hydrology: driver of heat and water fluxes at land surface.
- 25 km RCM offers significant improvement over 2.5° (~300 km) GCMs; still too coarse for hydrology, need to parameterize.

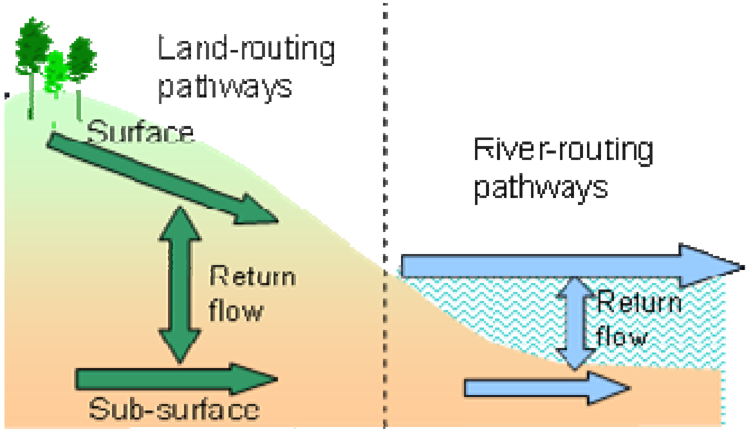
IMPROVING PROCESS REPRESENTATION: JULES

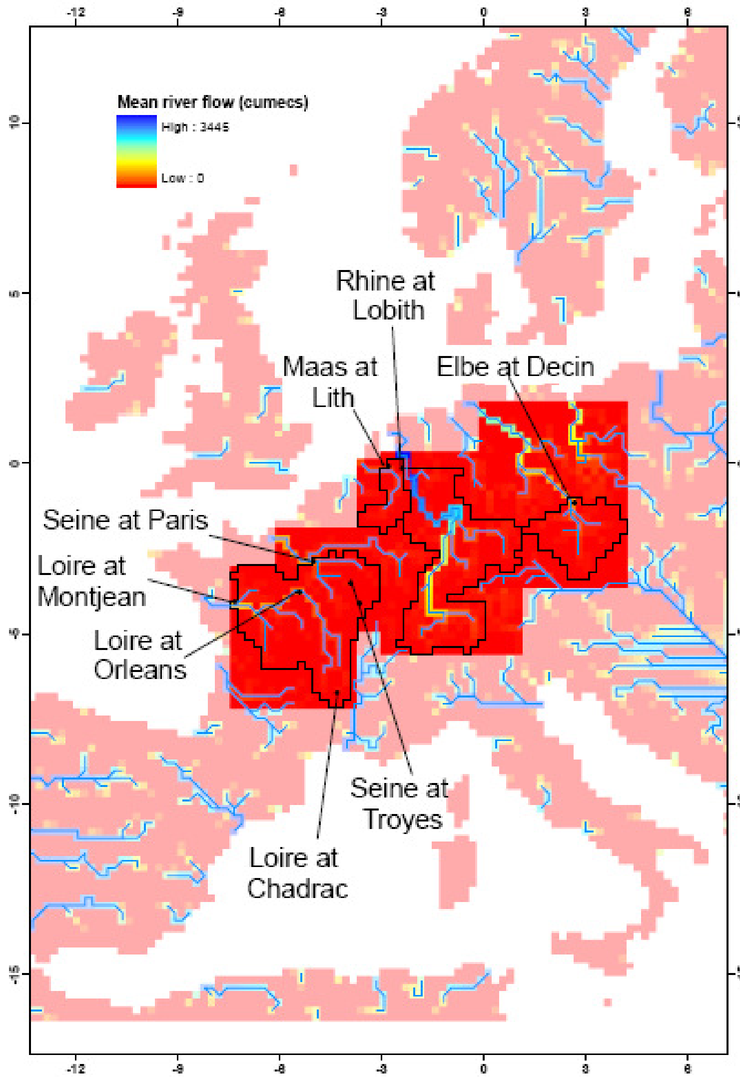
Joint UK Land Environment Simulator (JULES) takes **temperature**, **wind speed**, **humidity**, **LW** & **SW radiation** and **precipitation** from RCM.

Diagnose state of **soil moisture** by using a Pareto distribution of soil moisture store sizes.

Convert to **surface** and **subsurface flow.**



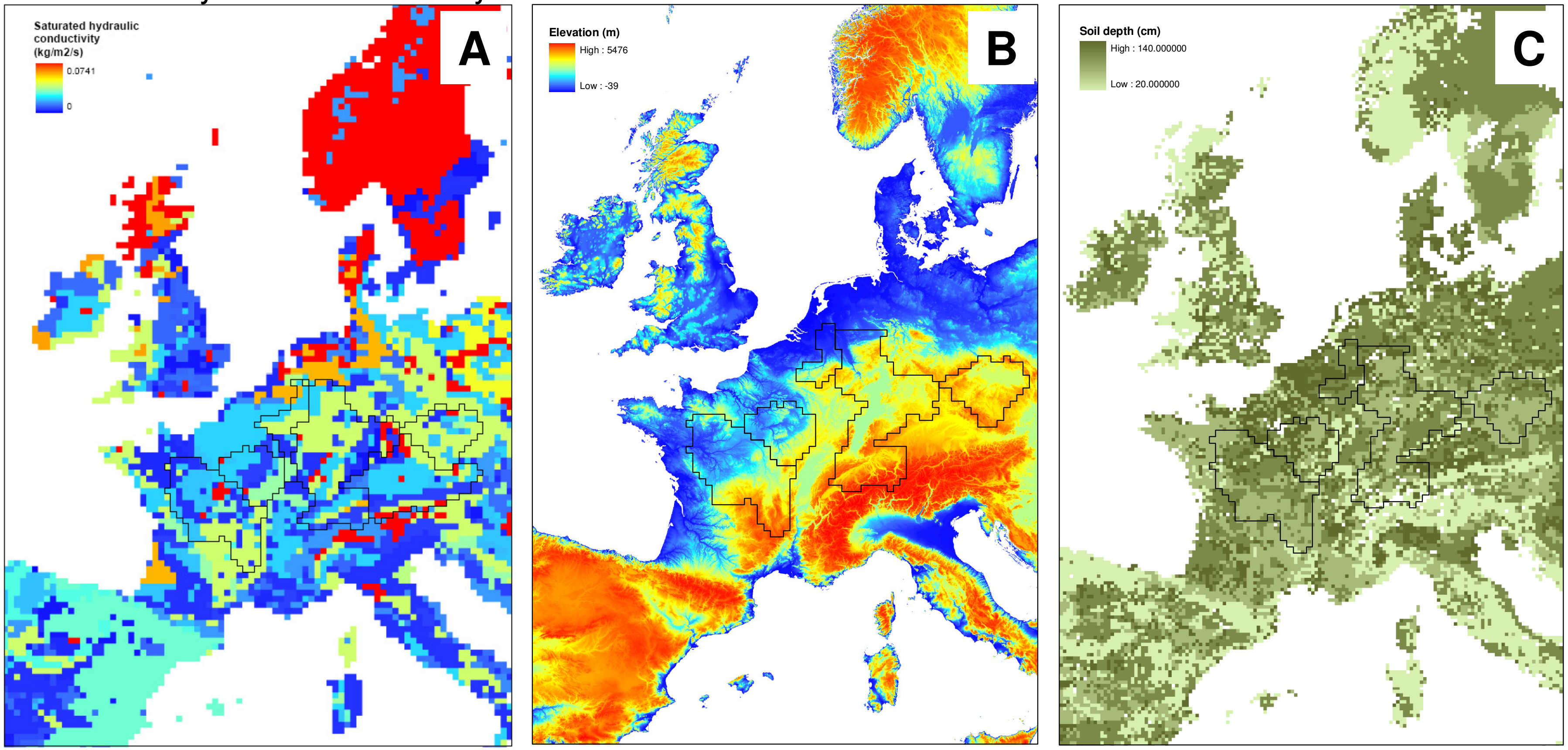




Dadson *et al.*, 2006, 2007

ESTIMATING MODEL PARAMETERS OVER LARGE AREAS

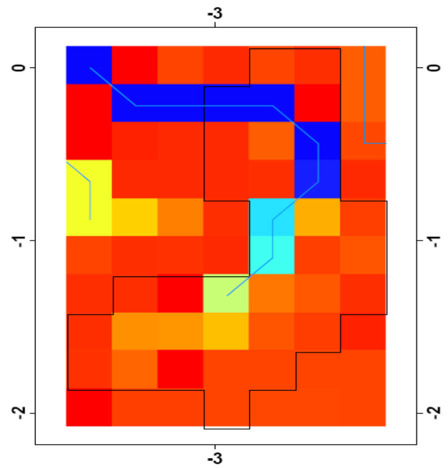
Saturated hydraulic conductivity | Elevation | Soil depth



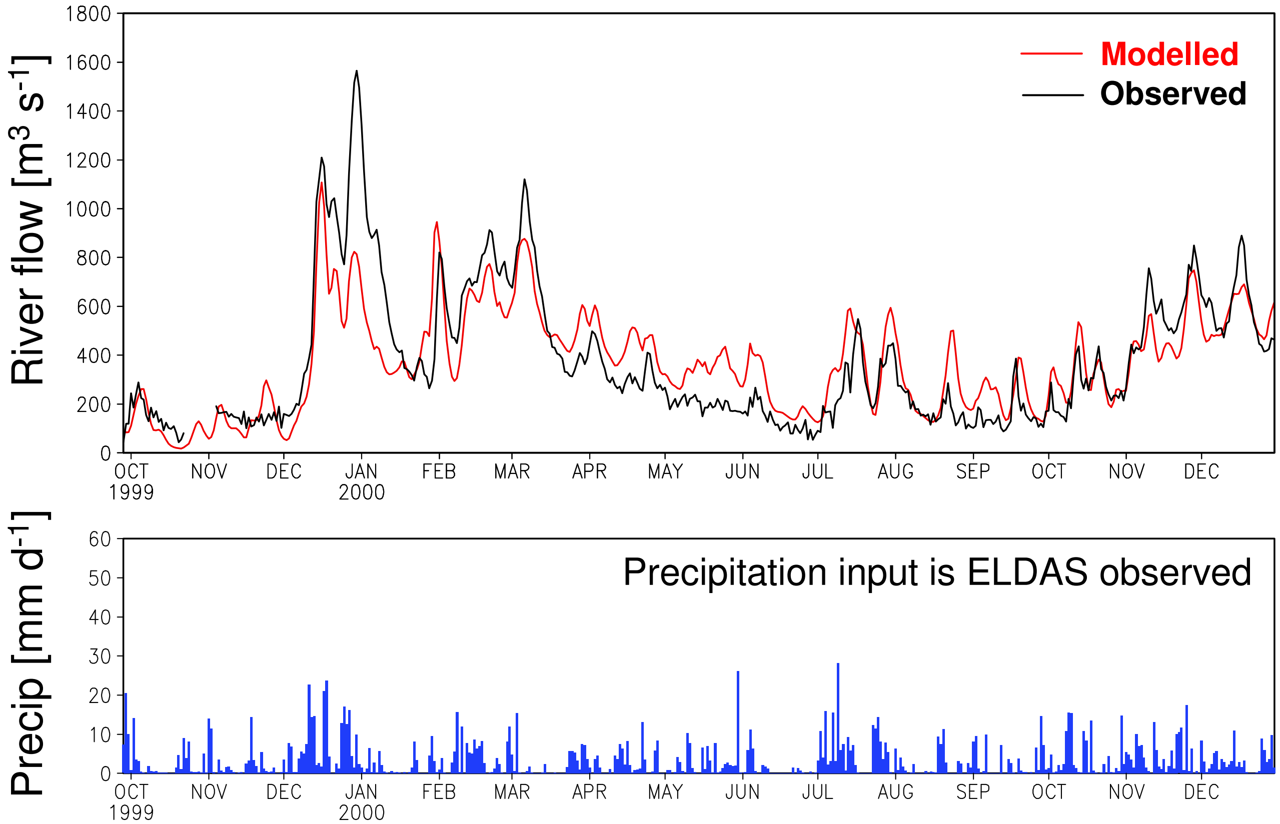
- Orography and river flow paths from Hydro1k;
- Land cover from IGBP (derived from NOAA AVHRR remote sensing; 1 km);
- Soil depth and hydrology from European Soil Database (1 km).

IMPROVED PREDICTIVE CAPACITY

Maas at Lith

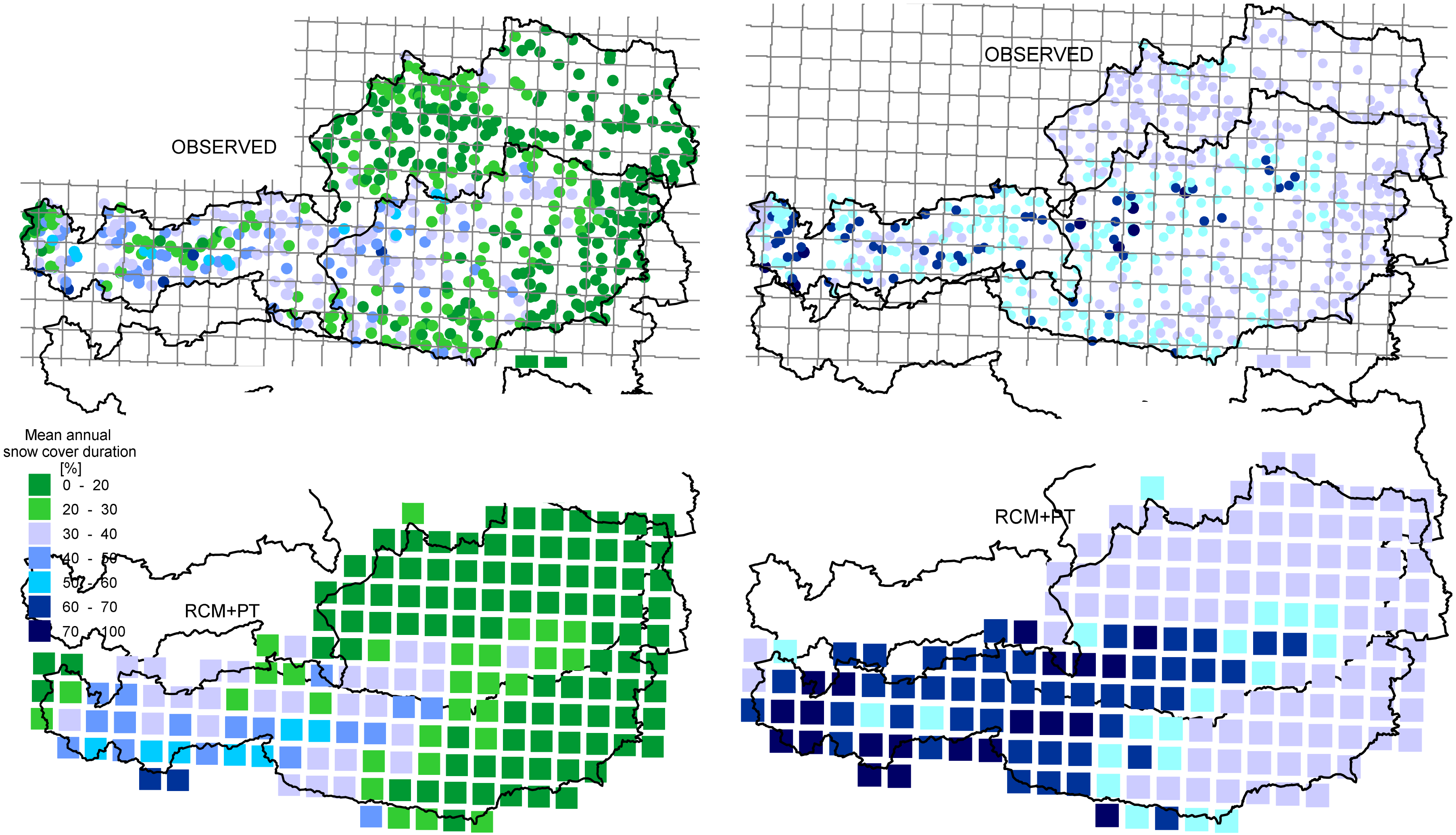


Area = 29 x 10^3 km^2



- Model efficiency is 0.71 (perfect match = 1.0).

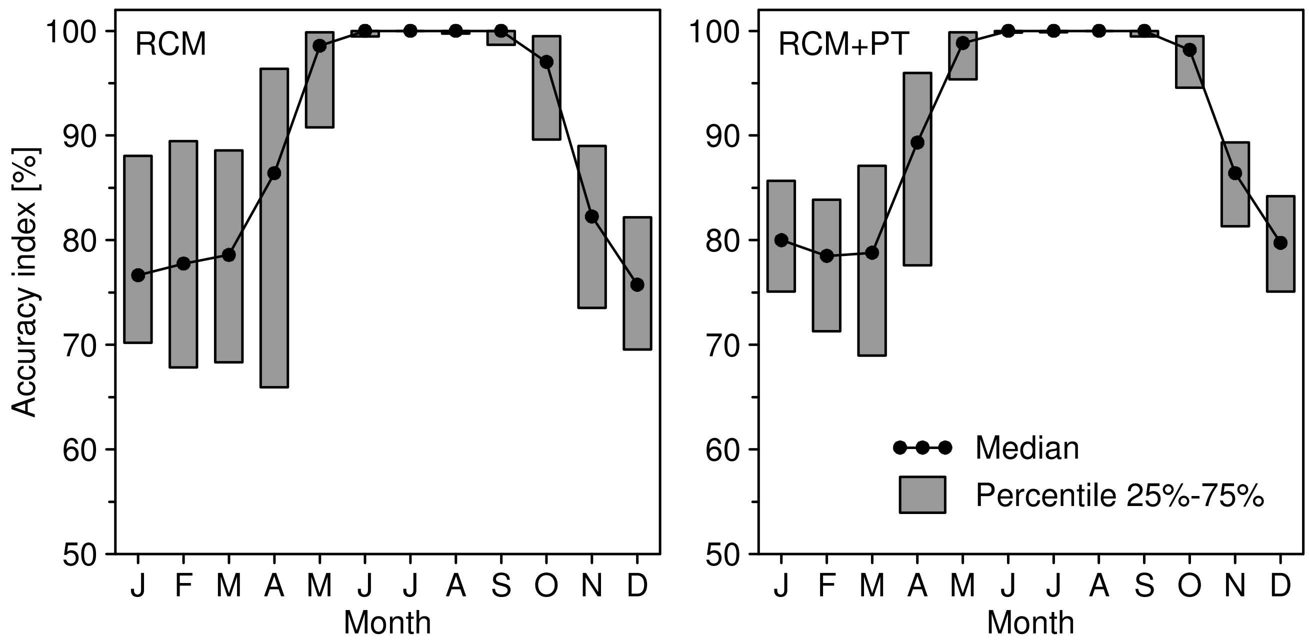
ACCURACY OF SNOW COVER AND DEPTH SIMULATIONS



SNOW COVER

SNOW DEPTH

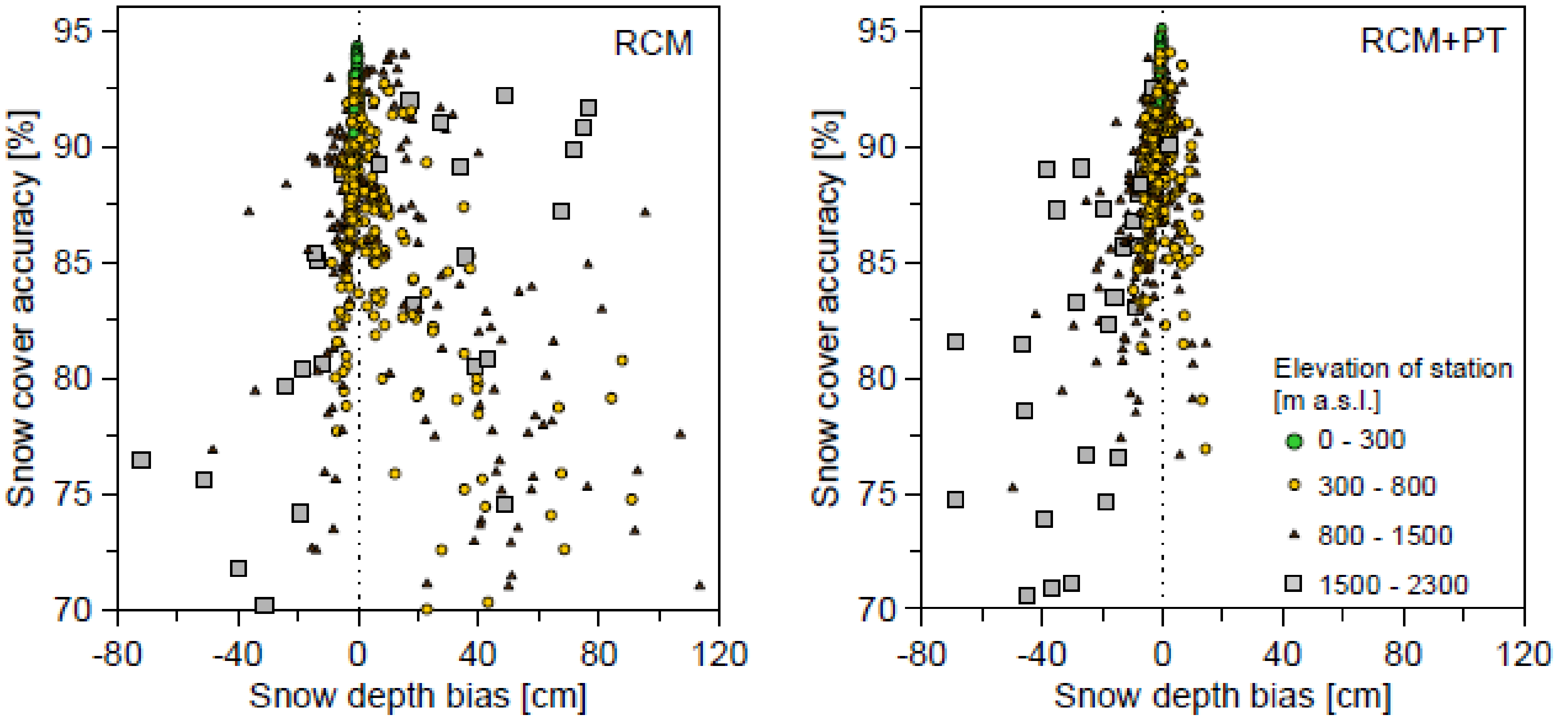
ACCURACY OF JULES' SNOW COVER PREDICTIONS



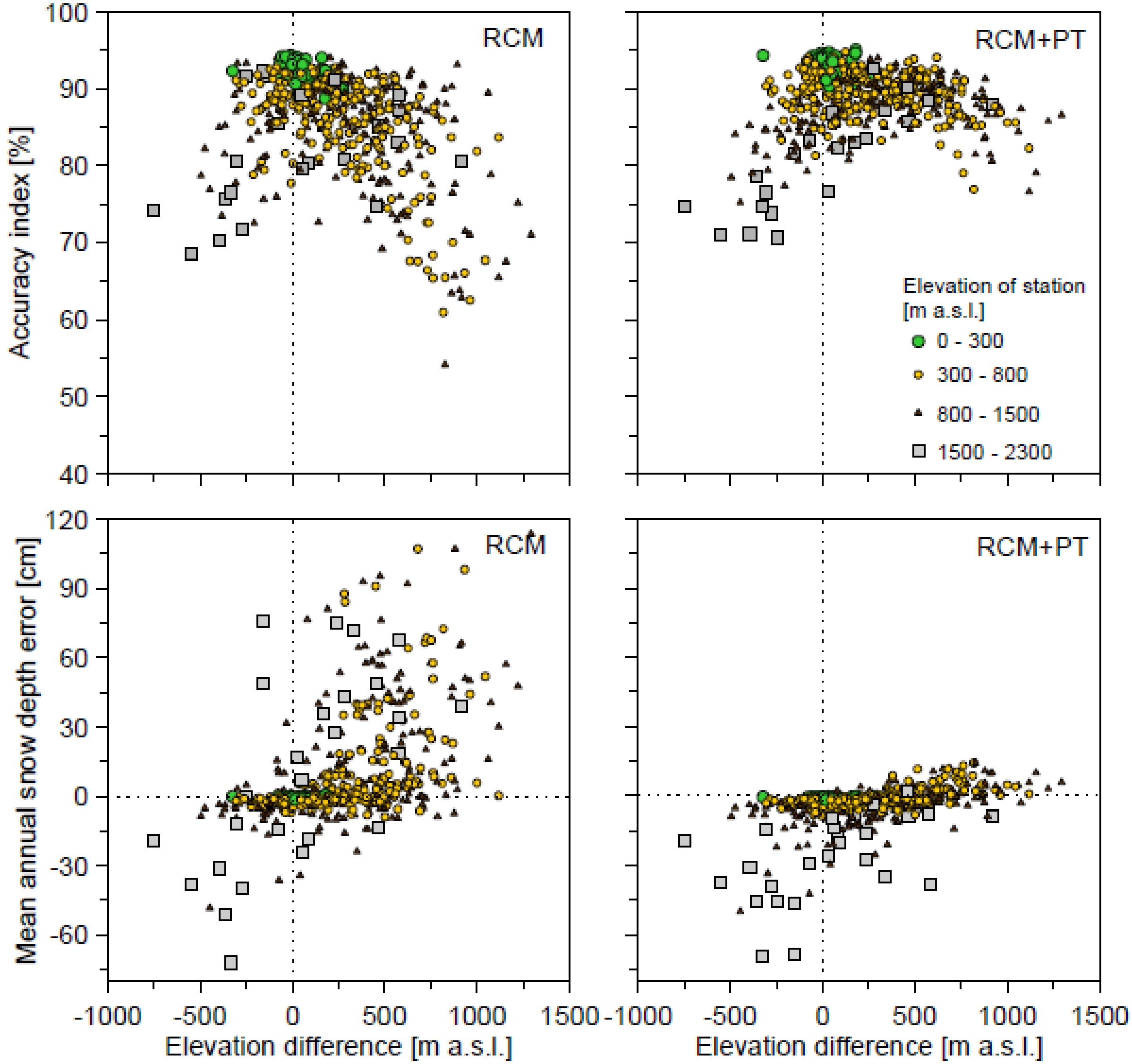
Station-days	JULES: SNOW	JULES: NO-SNOW
Ground: SNOW	A	B
Ground: NO-SNOW	C	D

$$\text{Accuracy index} = (A + D) \cdot 100 / (A + B + C + D)$$

RELATIONSHIP BETWEEN SNOW DEPTH ACCURACY INDEX AND BIAS

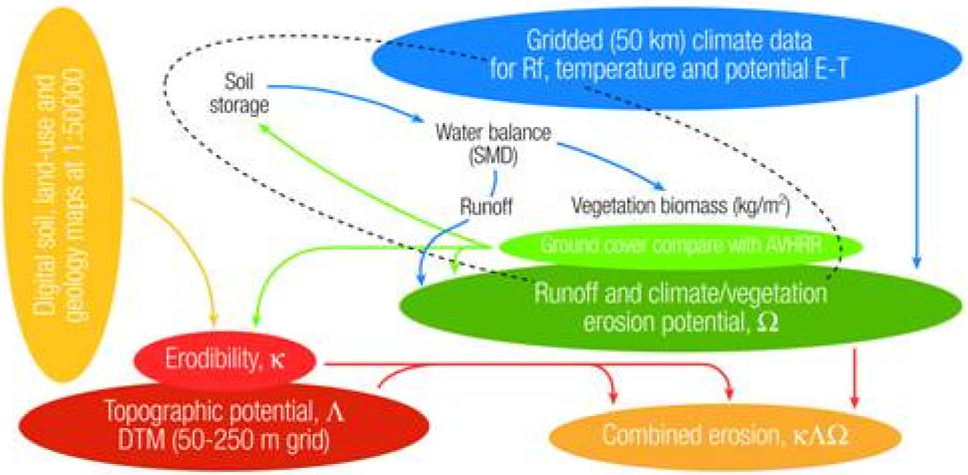


EFFECT OF GRID-BOX ELEVATION ON ACCURACY



PESERA & JULES TO MODEL SOIL EROSION

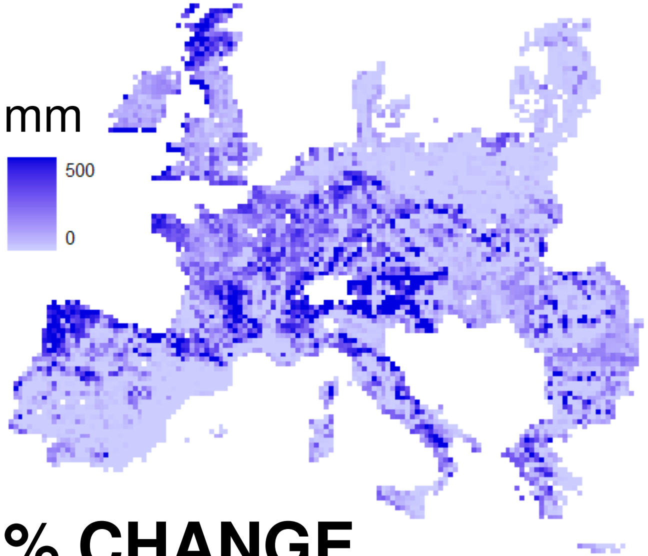
Simon Dadson, Mike Kirkby, Brian Irvine, Andrew Nicholas, Tim Quine



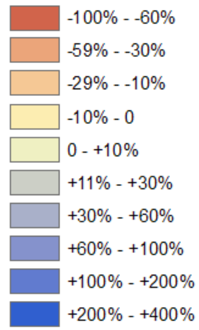
Evaluate sensitivity of PESERA to parameters before driving with climate scenarios
Specific questions:
Which parameters are most important?
What are the interactions between parameters?
Which drives greatest soil erosion: climate change or land-use change?

EFFECTS OF CLIMATE CHANGE ON EUROPEAN SOIL EROSION

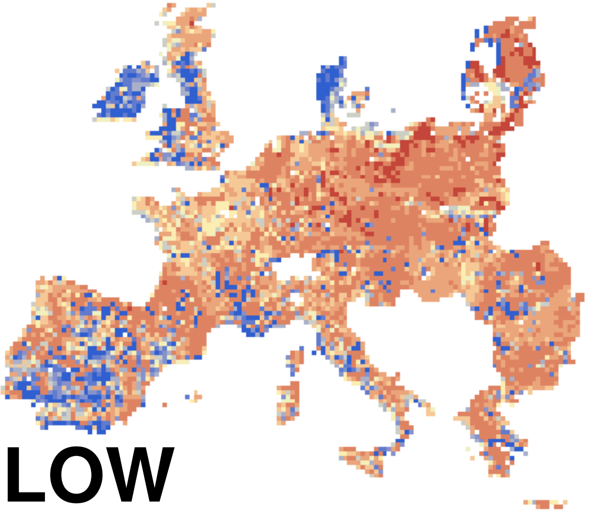
CURRENT



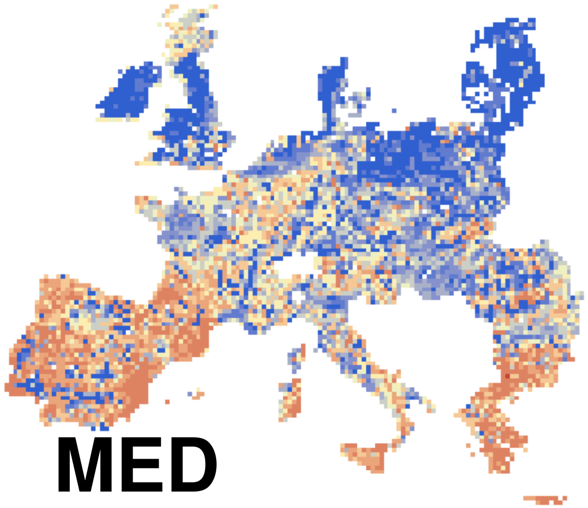
- UKCP / HadRM-PPE
- Change in runoff depends on balance between extra precip and extra evaporation
- Not simple related to climate sensitivity



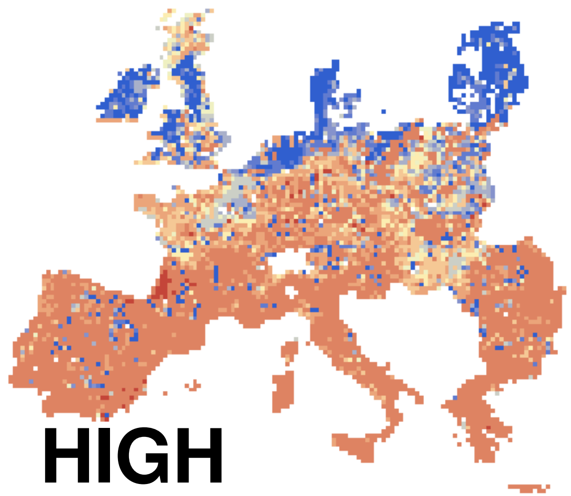
% CHANGE



LOW



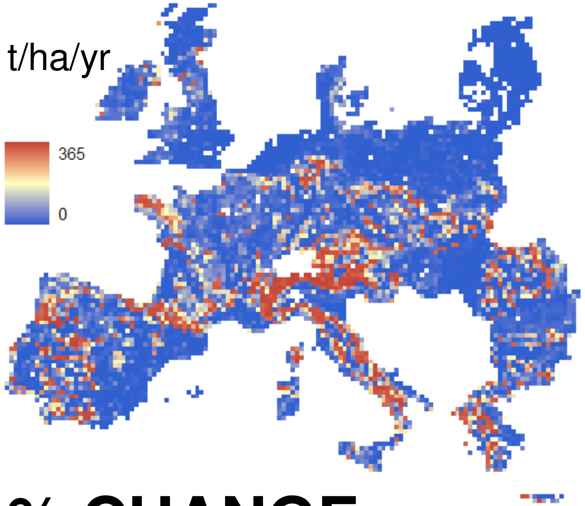
MED



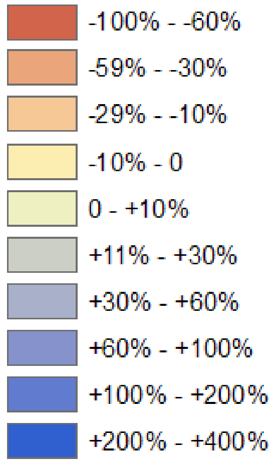
HIGH

EFFECTS OF CLIMATE CHANGE ON EUROPEAN SOIL EROSION

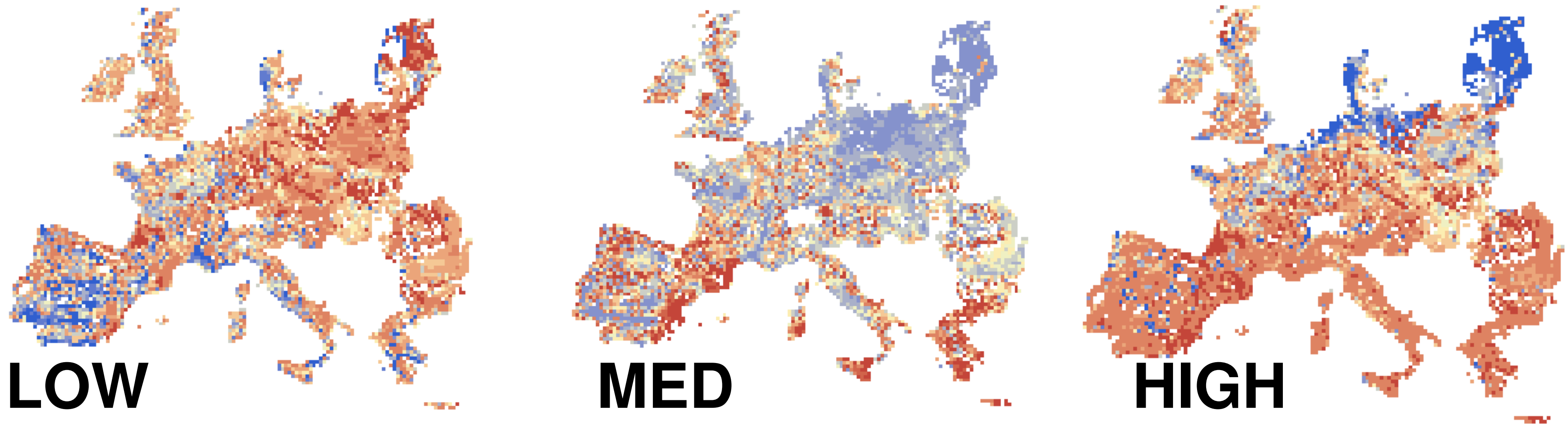
CURRENT



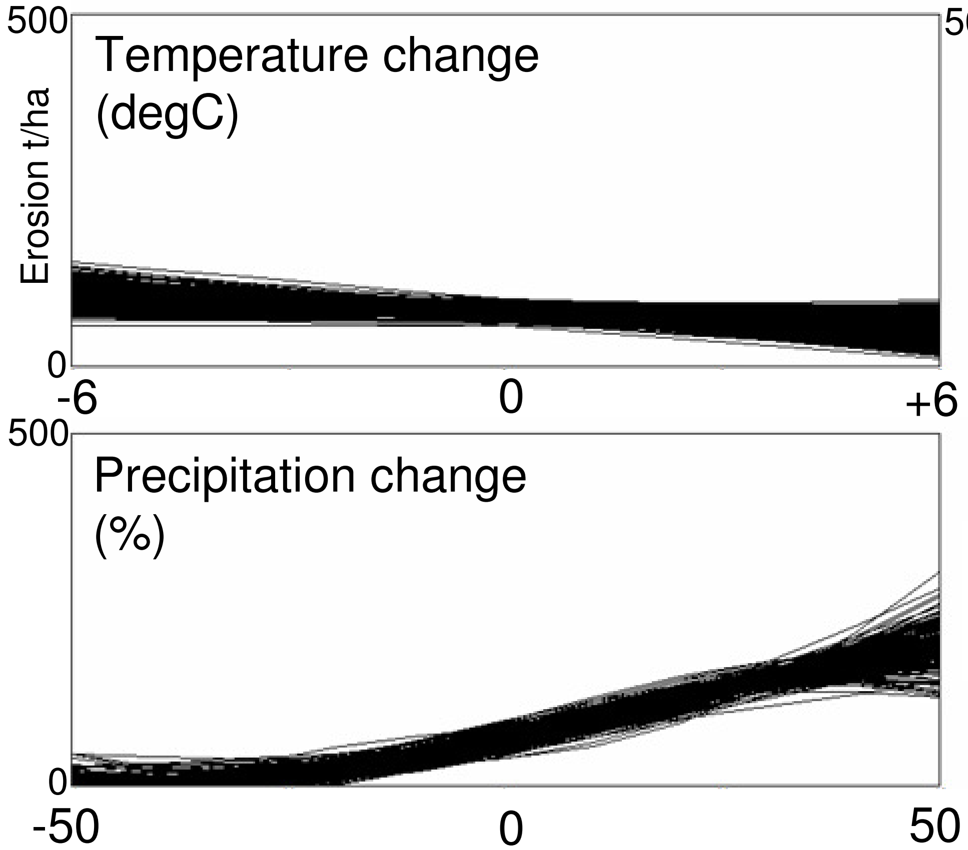
- Change in soil erosion
- Proportional to ~square of runoff
- Must get runoff right to get right erosion prediction

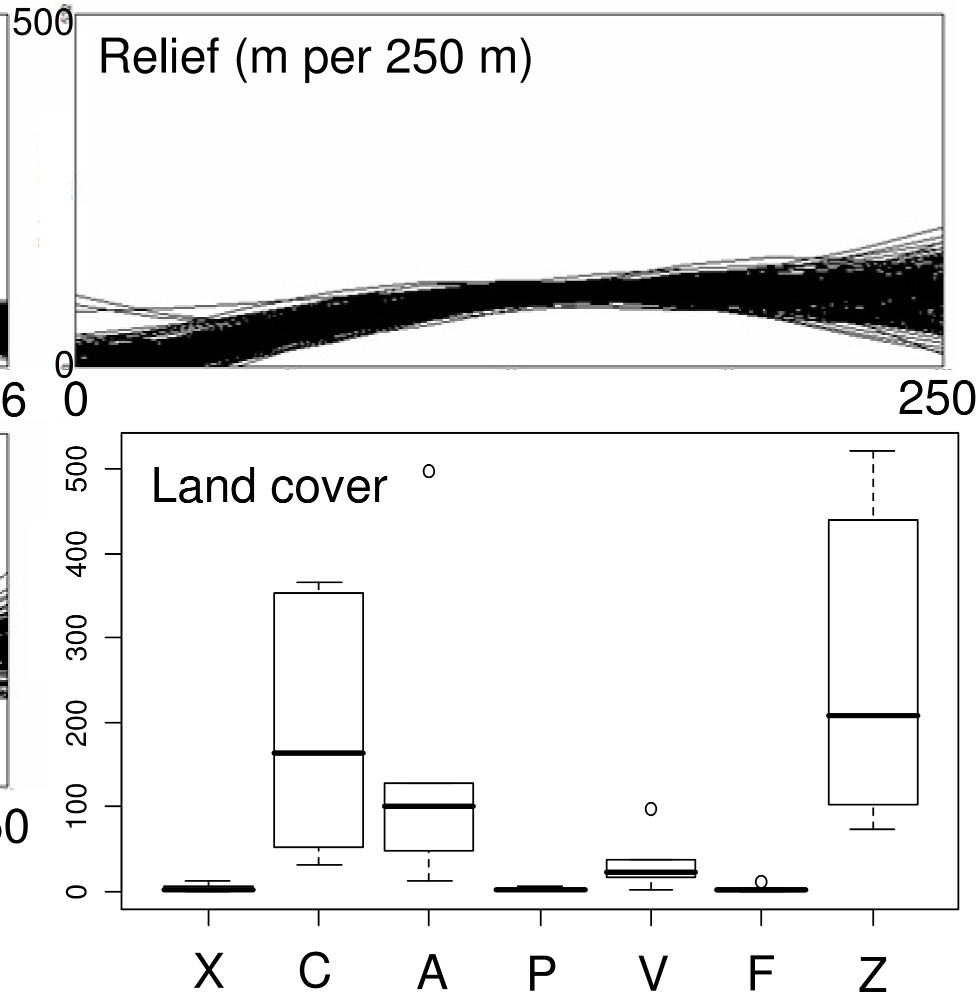


% CHANGE



PESERA SENSITIVITY ANALYSIS



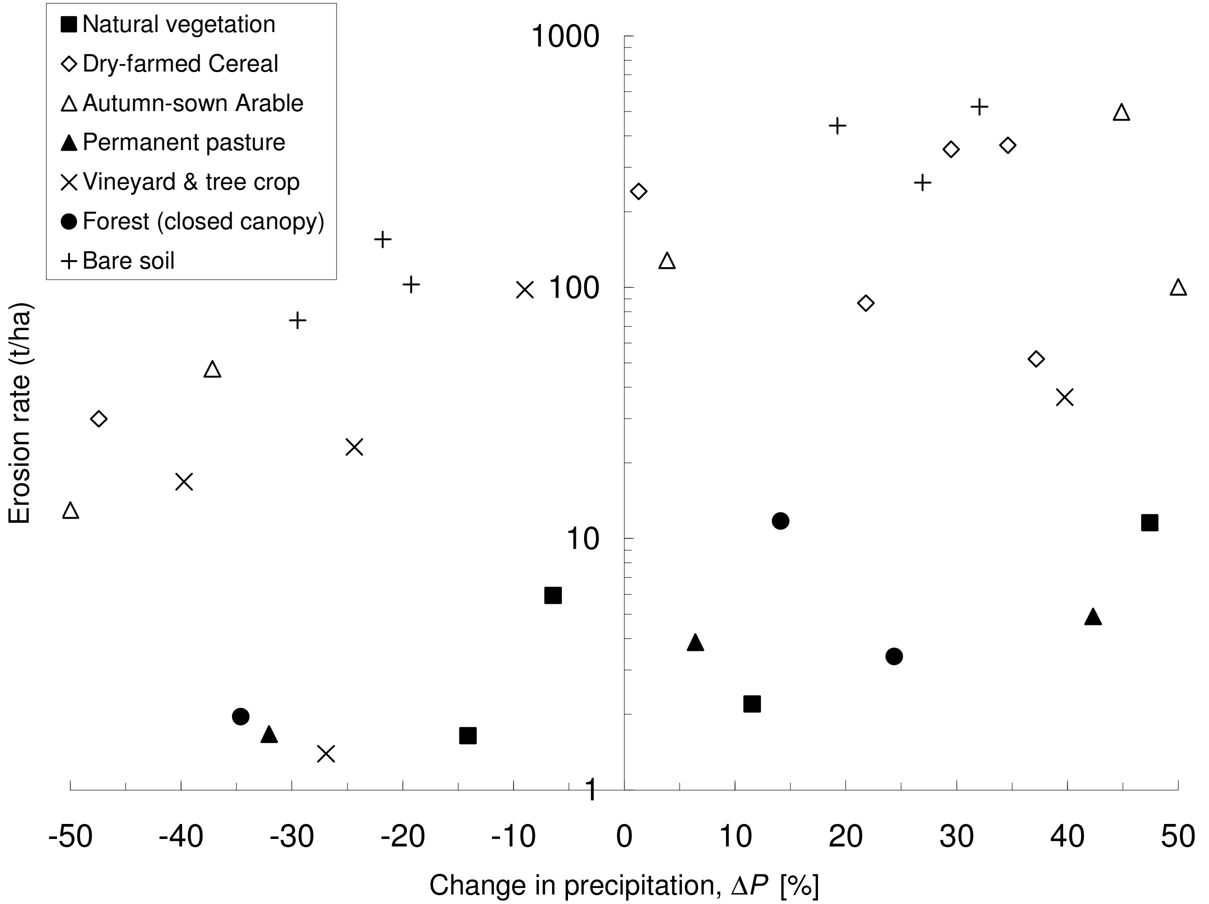


- **Precipitation and land-cover exert the strongest control on erosion rate**

- **Significant interaction term: erosional response to climate change is different for different land types)**

Natural, Dry Cereal, Autumn-sown Arable, Pasture, Vineyard, Forest, Bare soil

PESERA SENSTIVITY ANALYSIS



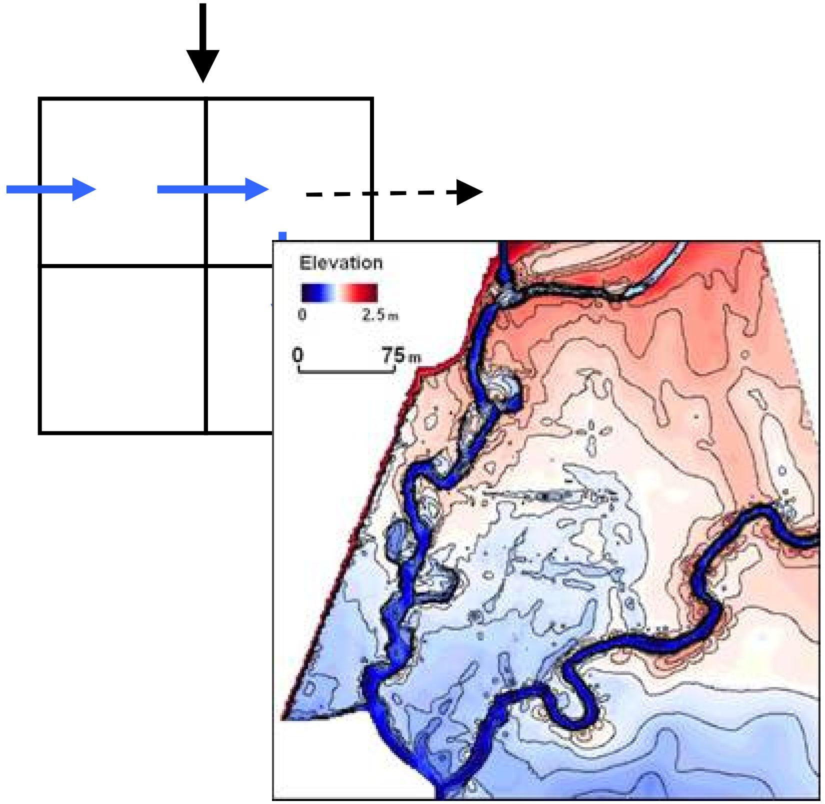
Effect	*Variance*
Temp	1.4
Precip	**22.4**
Relief	7.5
Cover	**30.8**
Temp.Precip	0.0
Temp.Relief	0.0
Temp.Cover	0.2
Precip.Relief	1.4
Precip.Cover	**17.3**
Relief.Cover	11.7

- **Range of land-use responses to climate change may be greater than climate change signal**

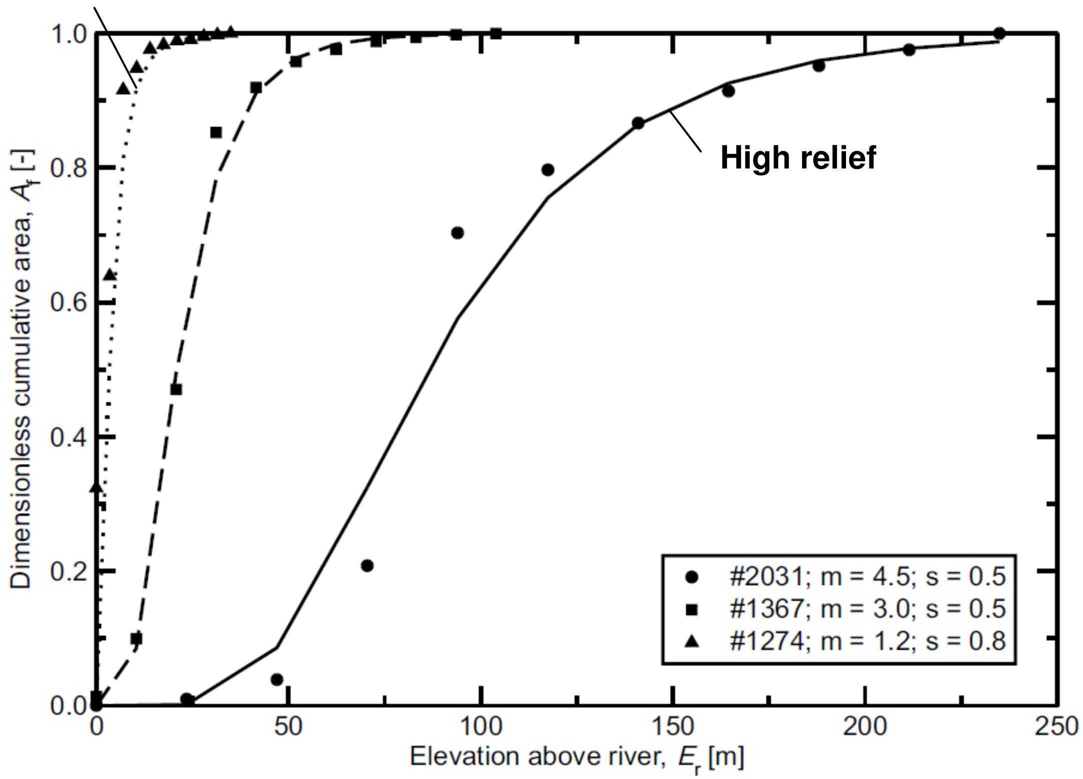
FLOOD INUNDATION BASED ON 1KM HYPSOMETRY

Can take a detailed hydraulic approach, or derive a generalized theoretical form

Flow routing



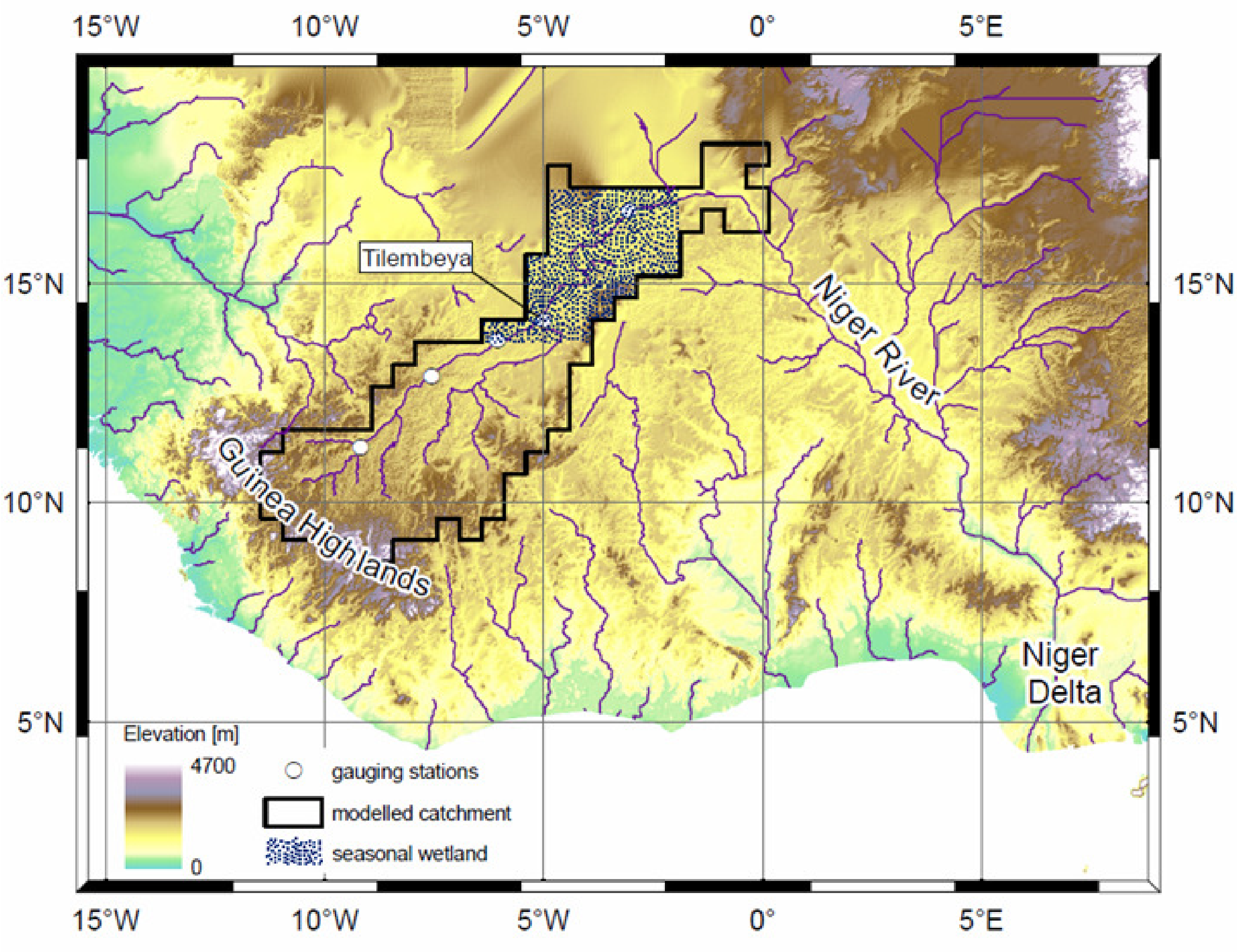
Low relief **Elevation frequency distribution**



Area of inundation is calculated using log-normal c.d.f. fitted to elevation distribution (hypsometry);

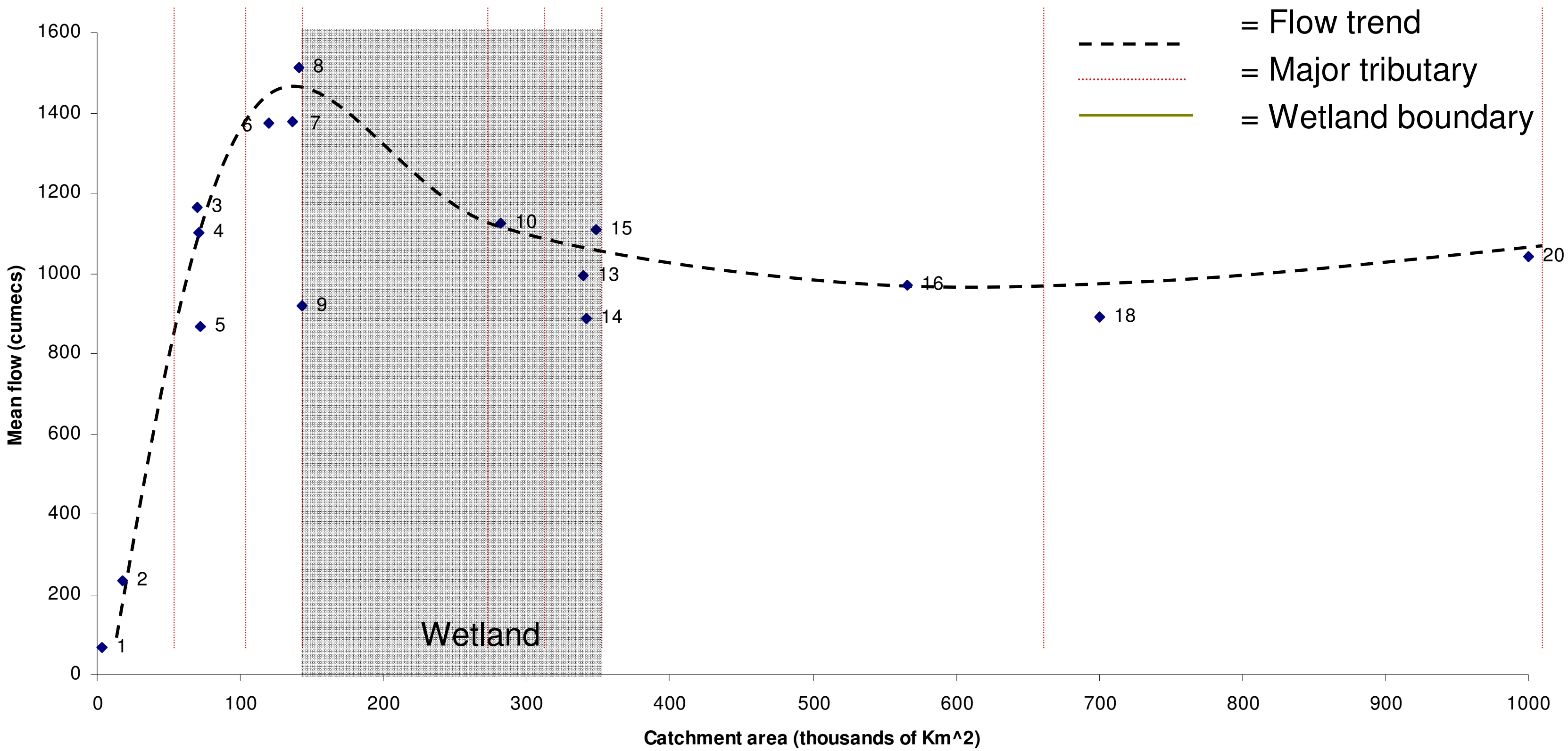
Mean and standard deviation of elevation calculated from 1km sub-grid-scale DEM in each RCM grid-box.

CASE STUDY IN LAND-ATMOSPHERE INTERACTIONS: NIGER INLAND DELTA, MALI



- Rainfall monitored since 1897 at Timbuktu and since 1926 at ten other locations;
- River gauging data available since ~1950s at 22 stations;
- Discharge varies between 600 – 2,300 m^3/s due to rainfall and groundwater fluctuations;
- Significant regulation of river flow due to small hydropower dam at Sélingué (2.2 km^3);
- Releases augment flow by up to 50% in dry season.

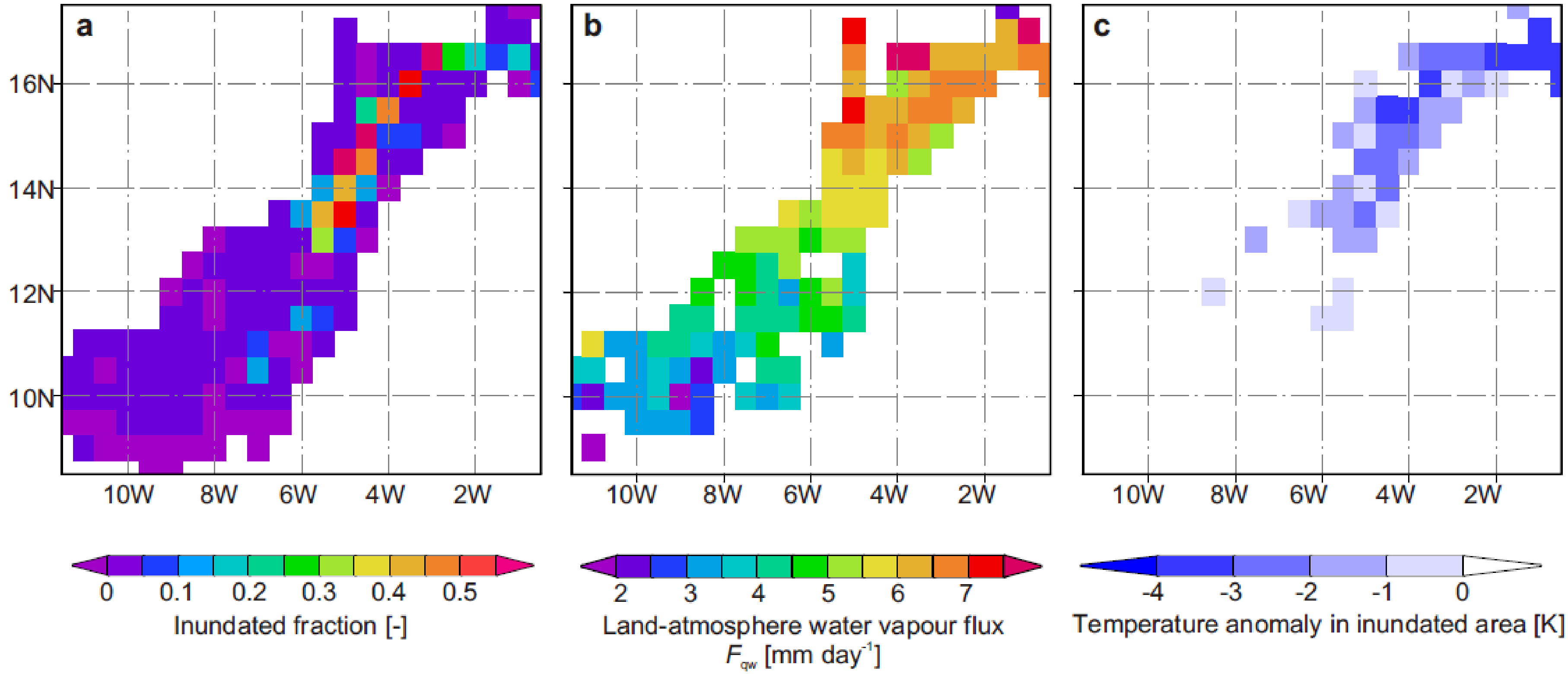
DOWNSTREAM VARIATION IN MEAN FLOW



Key research questions

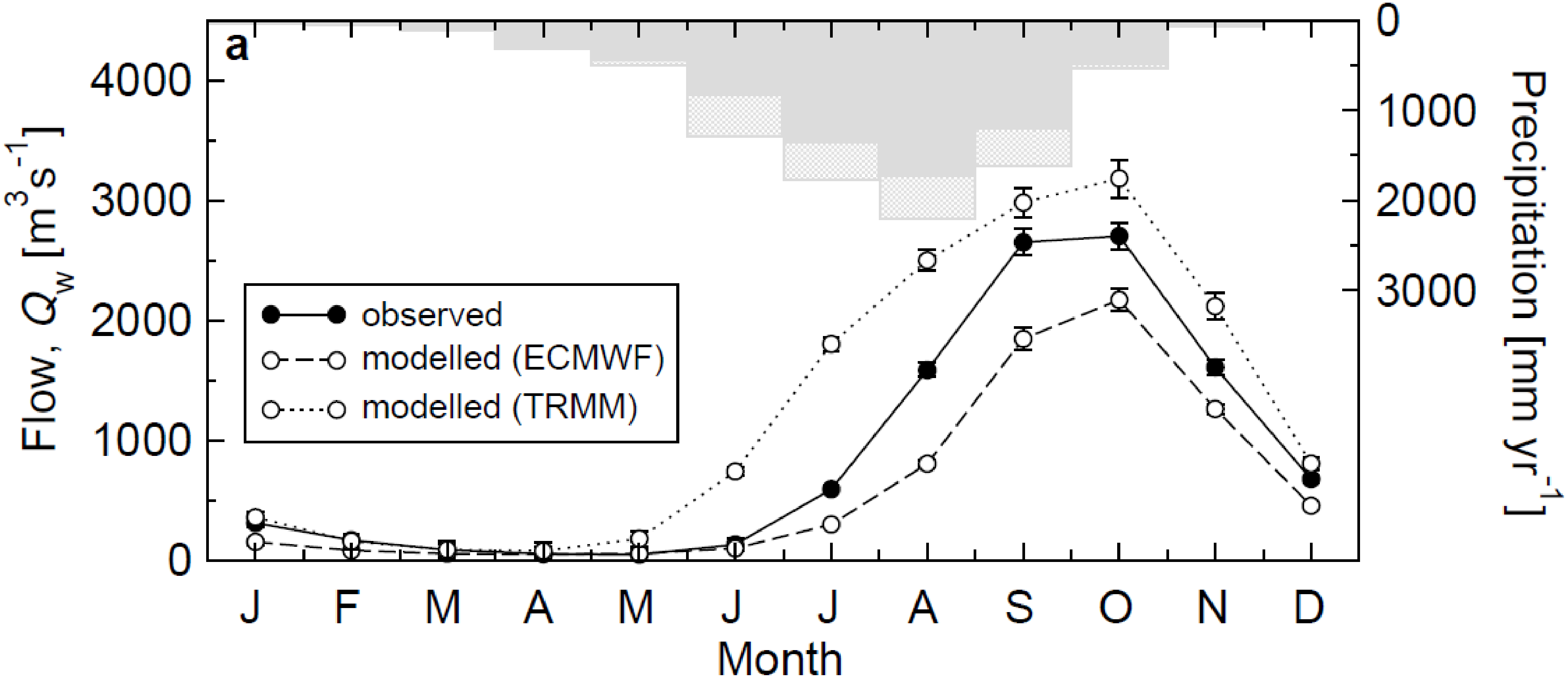
What is the hydrological and atmospheric significance of wetlands?
Can we predict the hydrology of Niger Inland delta using climate models?
How important is floodplain morphology in modelling climate?

RIVER FLOWS & EVAPORATION



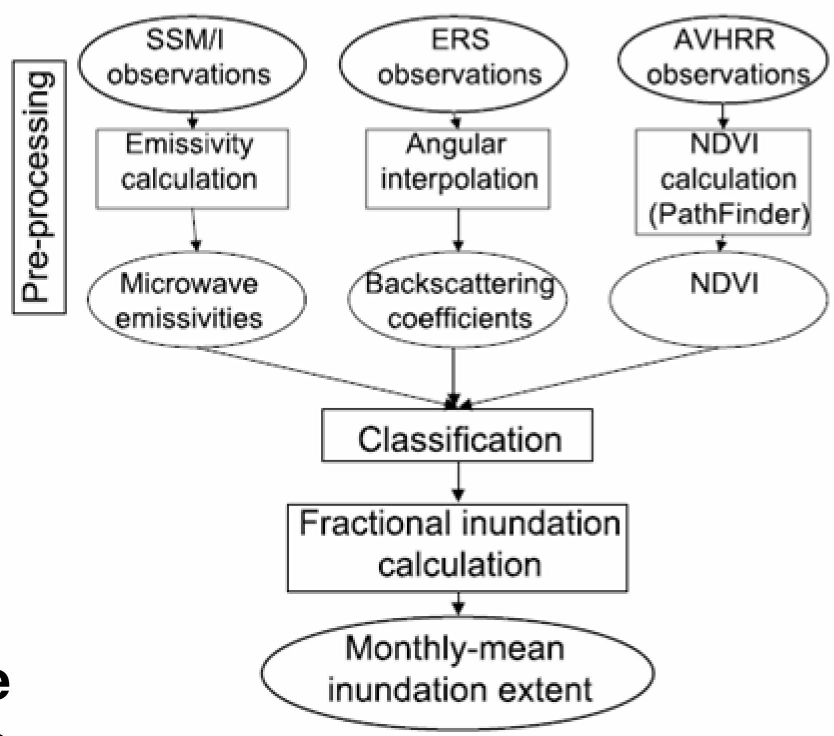
- **Area of greatest inundation follows topographic low;**
- **Inundation drives water vapour flux and temperature anomaly;**
- **Seasonal flooding provides up to 50 percent of water vapour to atmosphere.**

COMPARISON OF MODELLED AND OBSERVED FLOWS



- **Timing of flows accurately reproduced by the model;**
- **ECMWF forcing gives 31% underestimate of flow (limited penetration inland of W. African Monsoon) R^2 = 0.79;**
- **TRMM-corrected forcing gives 41% overestimate of flow R^2 = 0.70.**

REMOTE EARTH OBSERVATION FOR FLOOD MONITORING



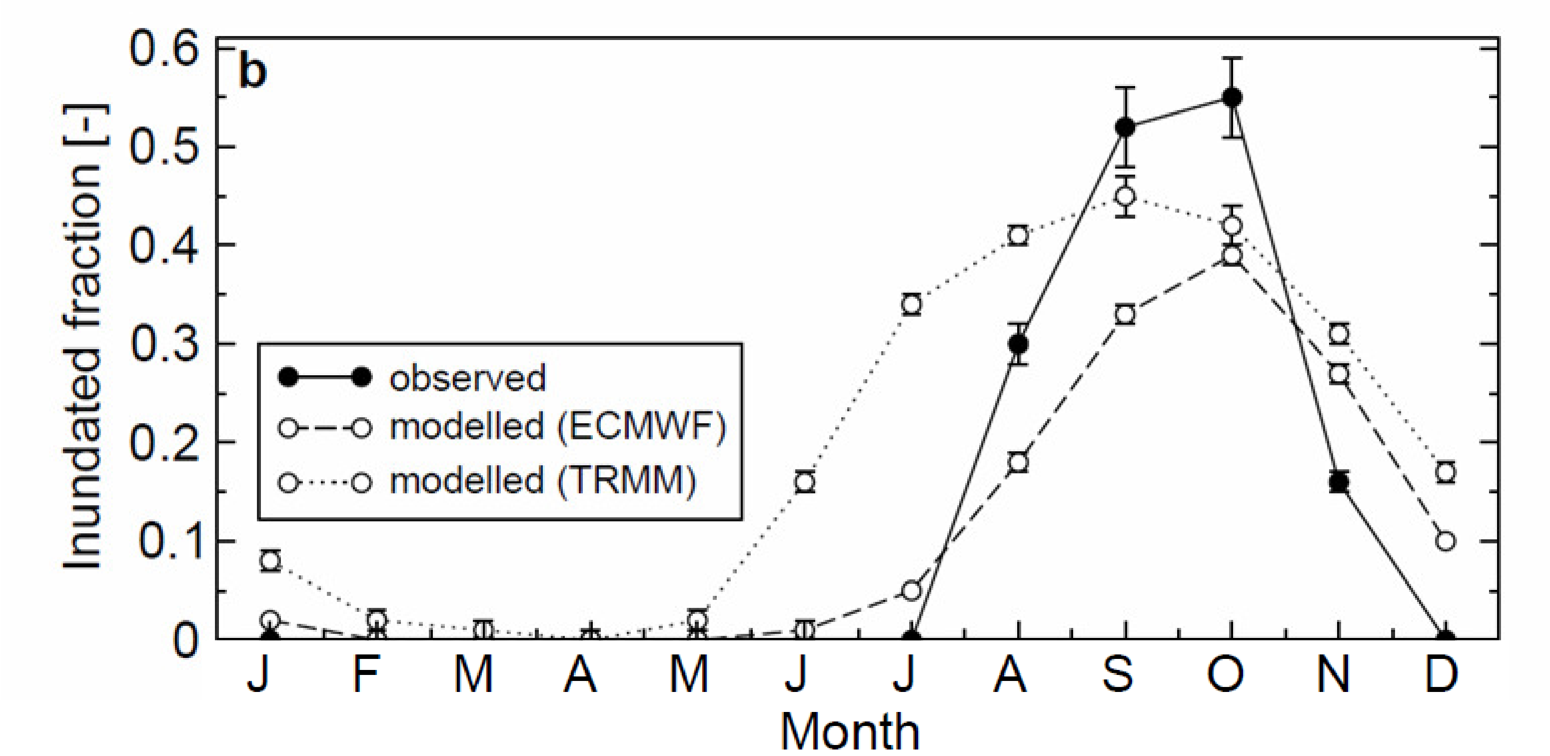
- **Passive microwave emissions (19 - 85 GHz) strongly controlled by presence of water;**

- **Visible (red, near-infrared) and active microwave (5.25 GHz) used to resolve ambiguities relating to vegetation;**

- **Prigent *et al.*, *JGR* 112 (2007).**

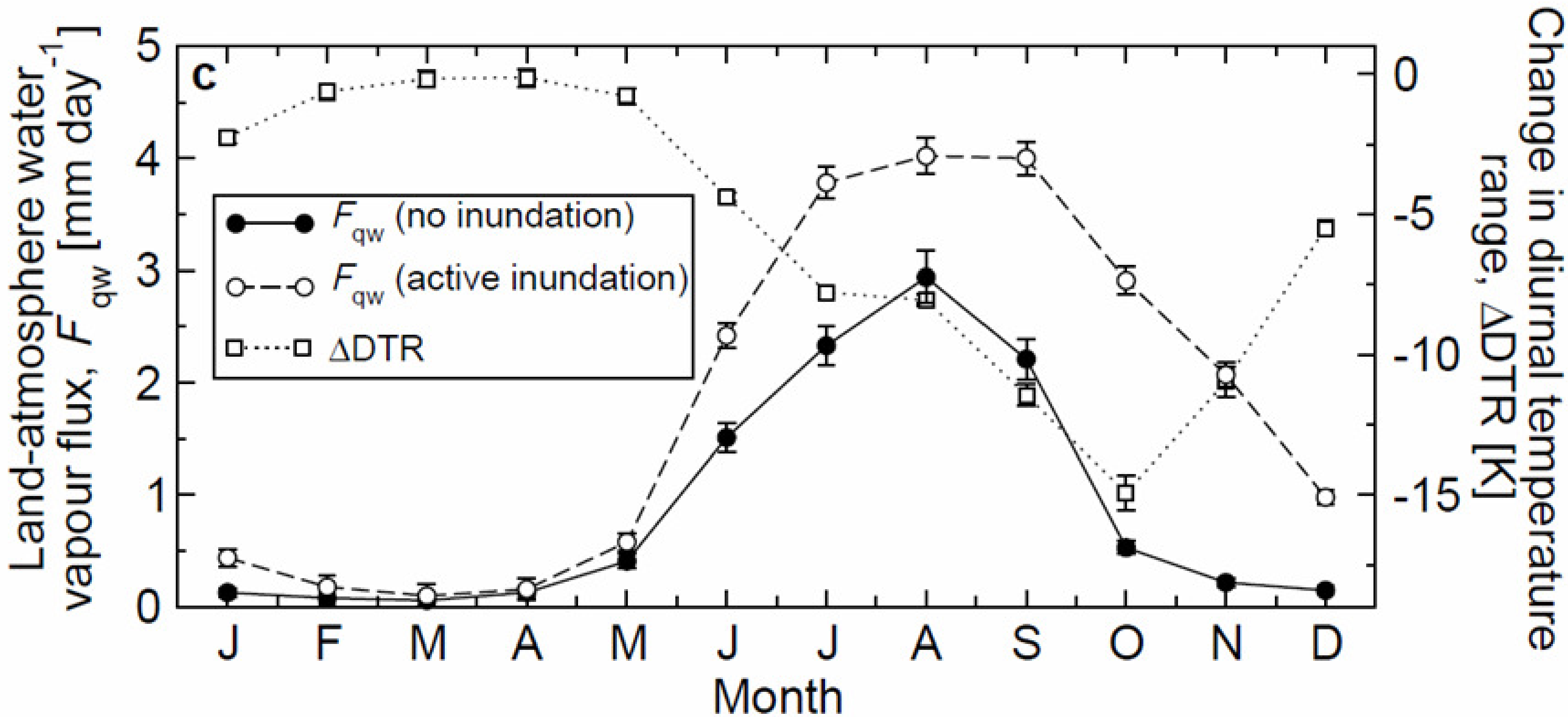
Compare with model result

COMPARISON OF MODELLED AND OBSERVED INUNDATION



- **Satellite observations of inundation fraction from Prigent *et al.*, 2007 (passive & active microwave, near infra-red);**
- **ECMWF forcing gives better match with timing R^2 = 0.79, but peak inundation is 29 % lower than observed;**
- **TRMM forcing gives better peak inundation, but timing is worse.**

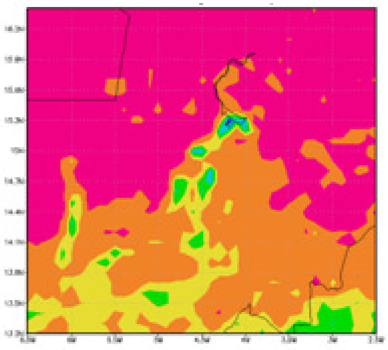
MOISTURE FLUX & TEMPERATURE ANOMALY



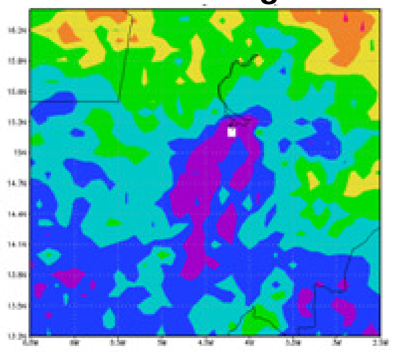
- **Evaporation doubles when inundation scheme is used (11 – 22 mm/day);**
- **Effect is greatest between Sept-Nov, when peak inundation coincides with high temperatures;**
- **Evaporation reduces mean surface temperature by approximately 5 K and diurnal temperature range by up to 10 K.**

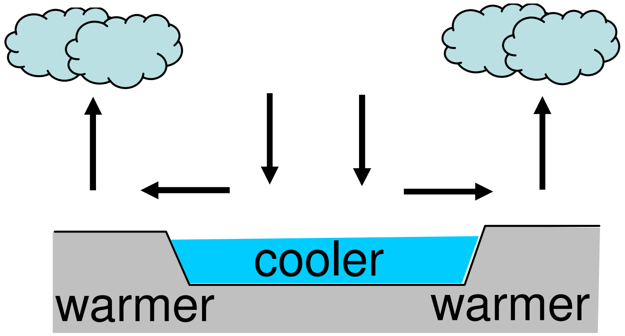
OBSERVED LAND-ATMOSPHERE FEEDBACK

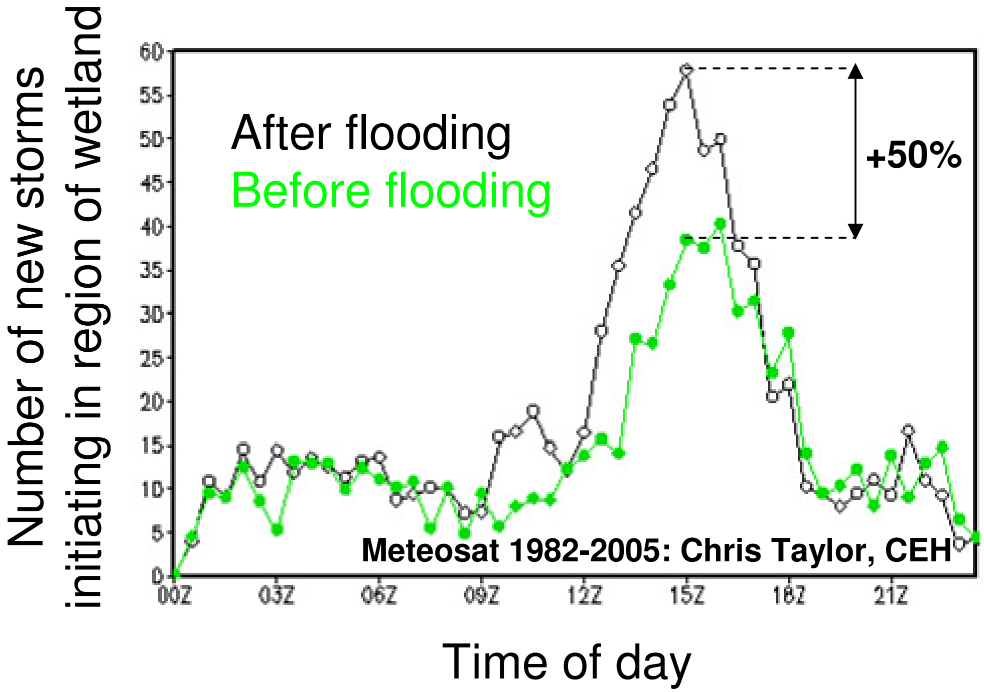
Small wetland → fast warming rate



Large wetland → slow warming rate







- **Wetland generates 50% more daytime storms;**
- **Development of a “wetland breeze”;**
- **Significant supply of rainfall across West African region**
- **More than just a hydrological phenomenon...**

FOOD SECURITY, BIODIVERSITY, AND ECOSYSTEM SERVICES

2m cattle; 4m sheep & goats; extreme pressure on fish stocks

Proposed new dam at Fomi:

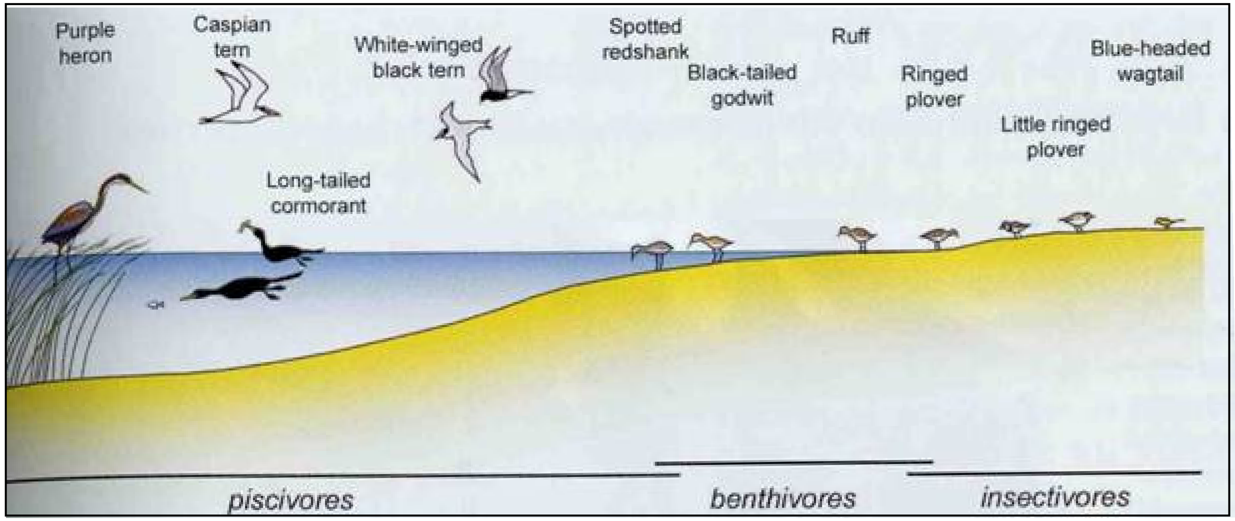
- reduce fish catch by 36%
- reduce cattle numbers by 10%
- reduce rice production by 40% (34,000 t),
- **but** increase rice production in newly irrigated areas by 320,000 t (to meet 90% of domestic rice demand)

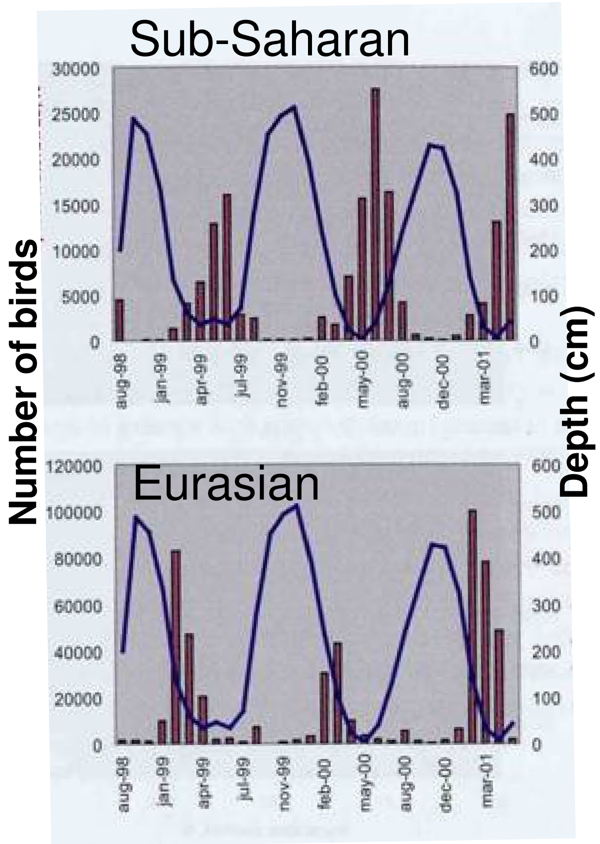
How can policymakers balance need for mitigation of & adaptation to climate change with food security, wetland biodiversity, and other ecosystem services?

LINKS BETWEEN CLIMATE, HYDROLOGY, AND GEOMORPHOLOGY

- Complex links between atmosphere, hydrosphere and lithosphere
- Use of a modelling framework such as JULES can give a clearer view of the role of individual processes
- Interactions between processes may be more important than simple drivers

NIGER INLAND DELTA: NATURAL HABITAT





- **One of few free-flowing floodplains in Sahel.**
- **Key Ramsar wetland: biodiversity hot spot:**
  - **Largest known colonies of heron, cormorant;**
  - **3-4 million staging waterbirds, resident and from Europe**
  - **& Asia.**
- **Complex relation between flooding and ecology (timing of low & high flows).**
- **Biodiversity vs. food security - planned dam at Fomi:**
  - **may reduce fish population by up to 40%;**
  - **but will allow 90% of rice demand to be met domestically.**

Source: Zwarts *et al.*, 2005