Identifying and quantifying the impact of non-climatic effects on the water cycle in a semi-arid environment

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Julie Collignan

Jan Polcher, Pere Quintana Segui

Laboratoire de Météorologie Dynamique (LMD)

Budyko framework

Budyko hypothesis: simplified river flow model

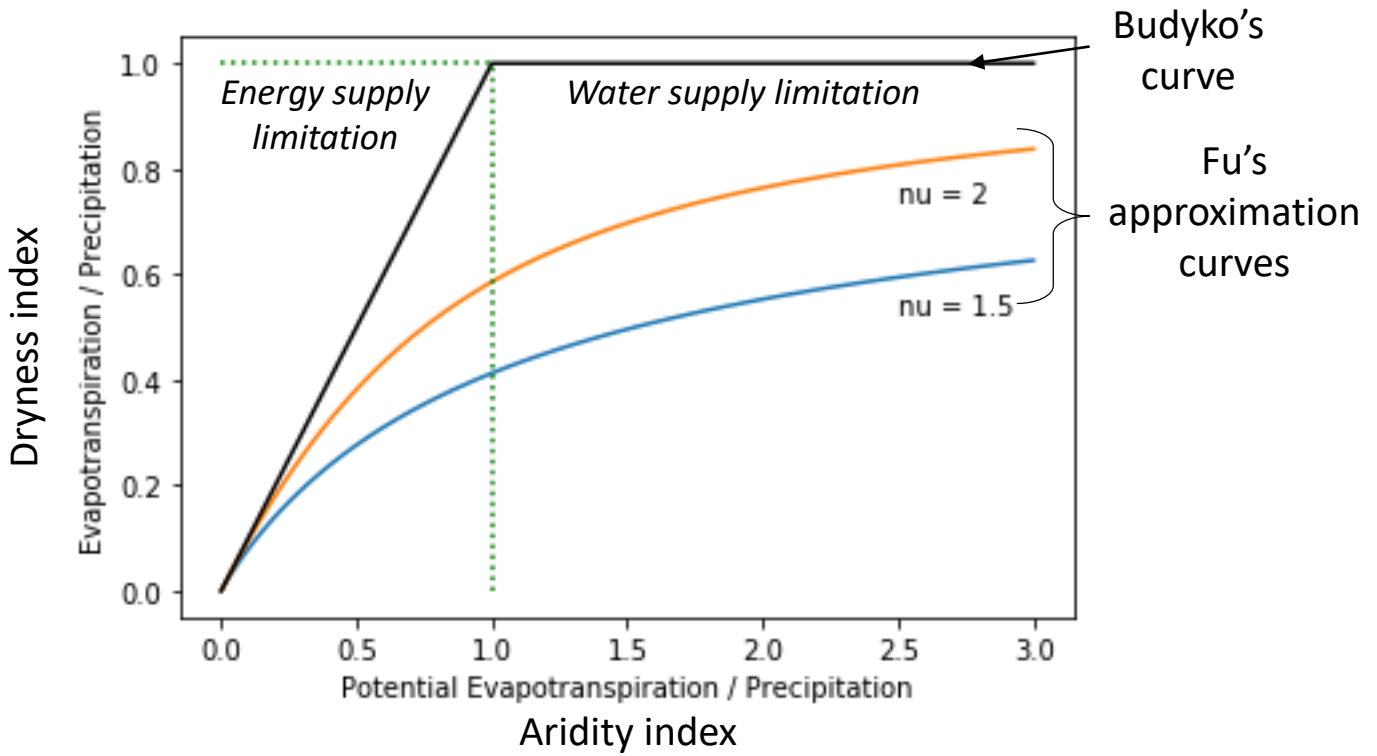
- Budyfo framework:

  Two factors limiting evaporation:
  Energy and ***Water supply***

  - *Analytical approximation*:

    Fu's equation:

$$\frac{ET}{P} = 1 + \frac{PET}{P} - \left(1 + \left(\frac{PET}{P}\right)^{nu}\right)^{\frac{1}{nu}}$$



Using the equilibrium hypothesis $\Delta S = 0$ in the water balance equation:

$$Q = P * \left(1 + \left(\frac{PET}{P}\right)^{nu}\right)^{\frac{1}{nu}} - PET$$

Budyko hypothesis: the watershed parameter

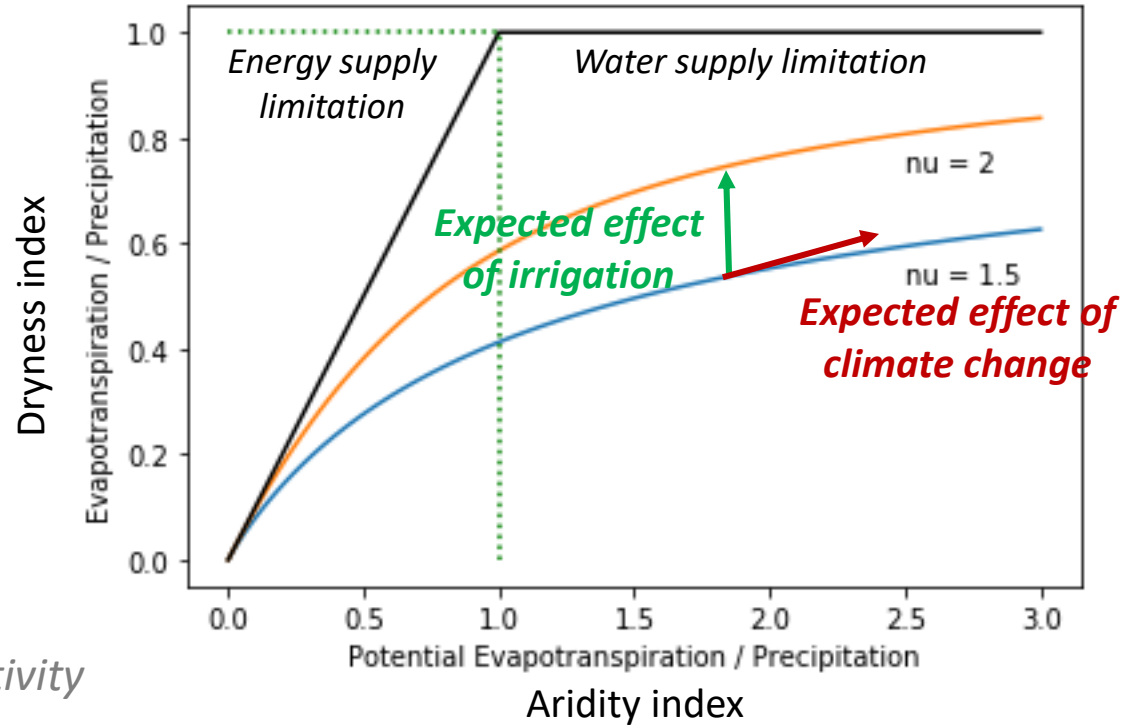
- The watershed parameter *Nu*

$$\frac{ET}{P} = 1 + \frac{PET}{P} - \left(1 + \left(\frac{PET}{P}\right)^{nu}\right)^{\frac{1}{nu}}$$

→ Adjusted **over an area and a time period**

→ Parameter reflecting **watersheds characteristics**
(Some climatic characteristics, vegetation cover, soils…)

Includes effects of human activity



- Hypothesis for this parameter

→ Variations of climate characteristics << changes due to human activities (irrigation, land cover changes…)

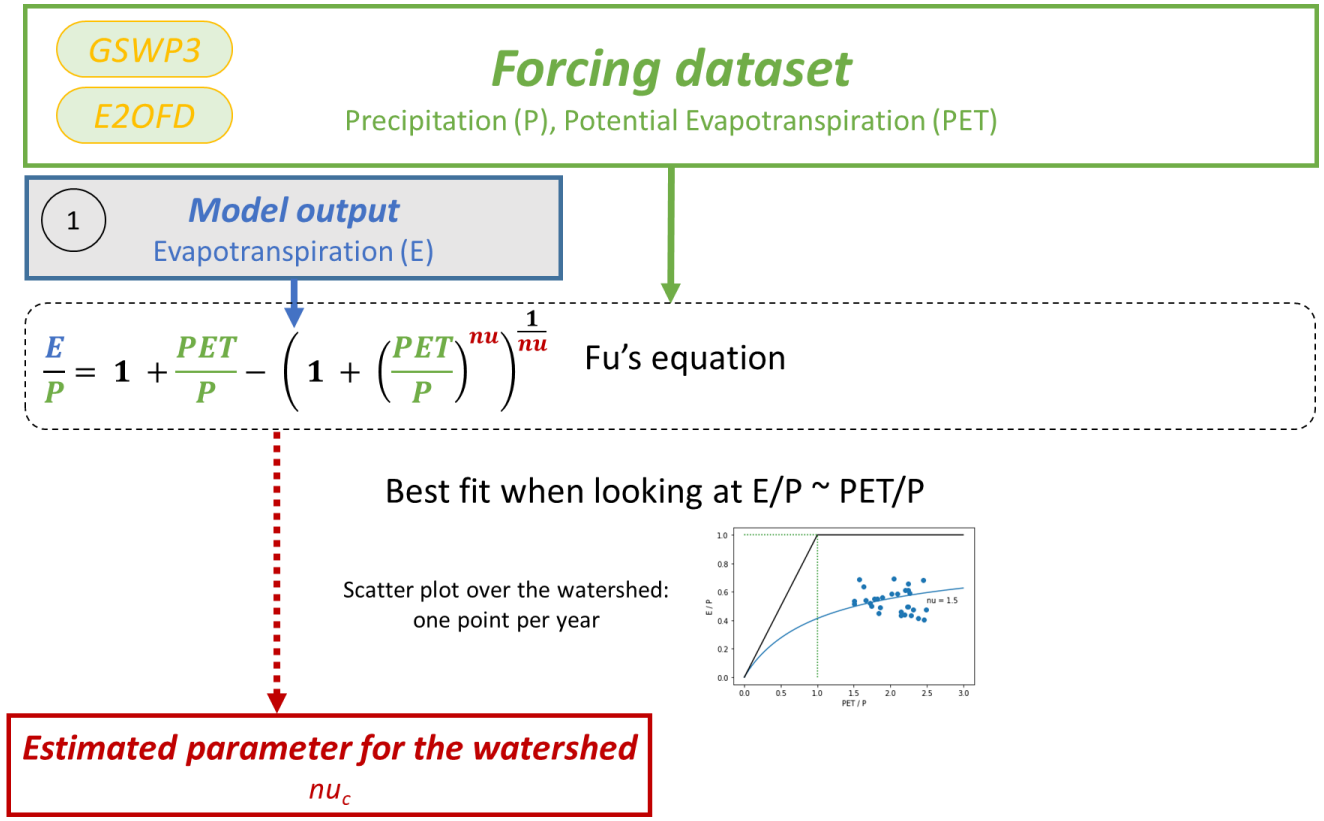
Method

Budyko hypothesis: the watershed parameter

- Calculation of the watershed parameter

1 ORCHIDEE Model

Calculate ET and Q over each watershed



Budyko hypothesis: the watershed parameter

- Calculation of the watershed parameter

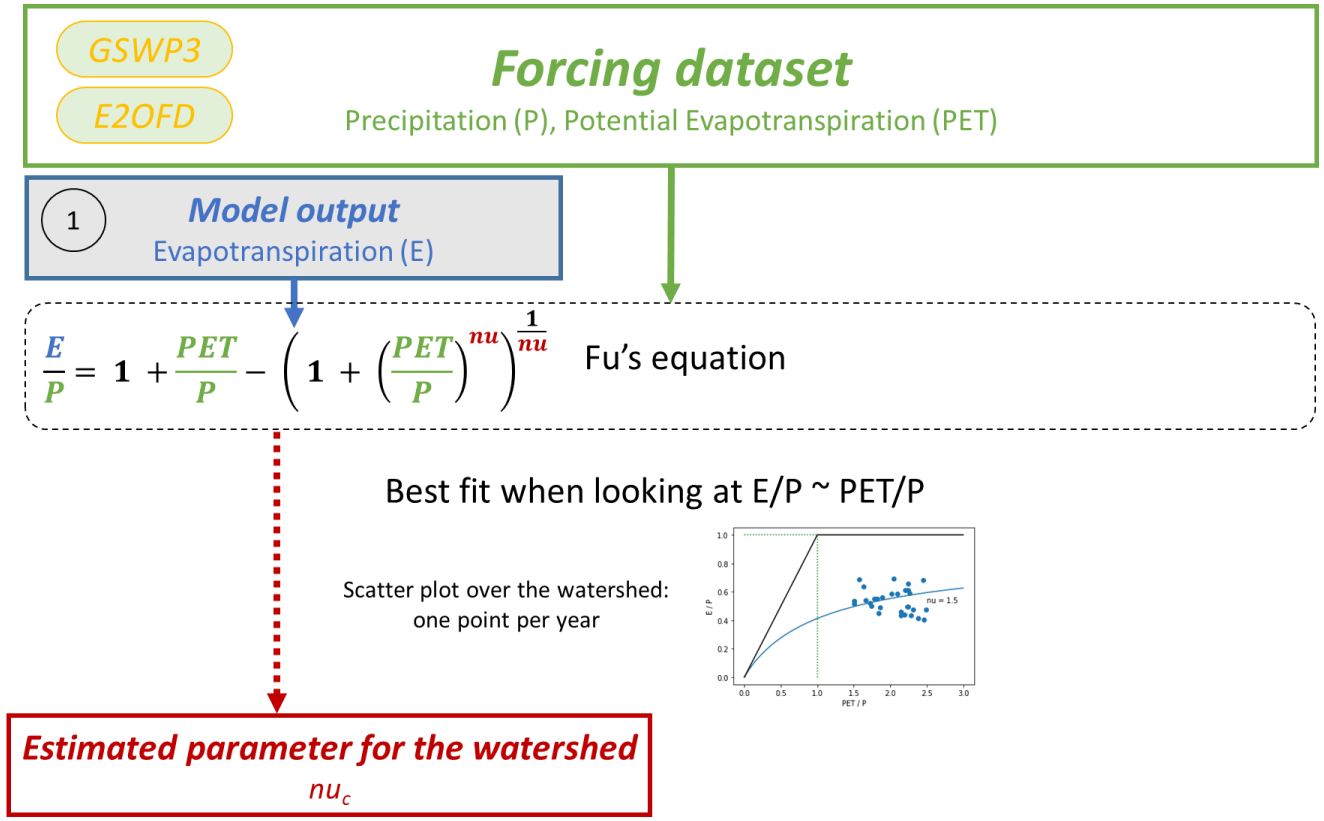
1 ORCHIDEE Model

Calculate ET and Q over each watershed

Only includes climate data and climatic/ atmospheric processes

« Climatic *nu* parameter »

nu_c



Budyko hypothesis: the watershed parameter

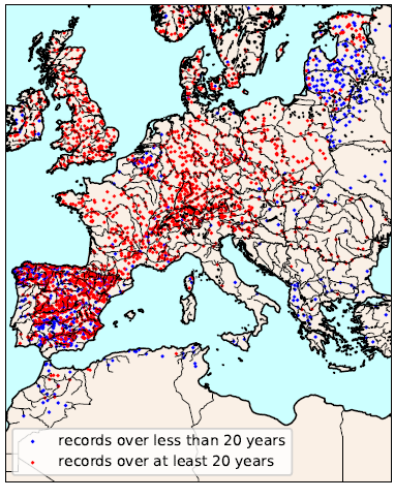
- Calculation of the watershed parameter

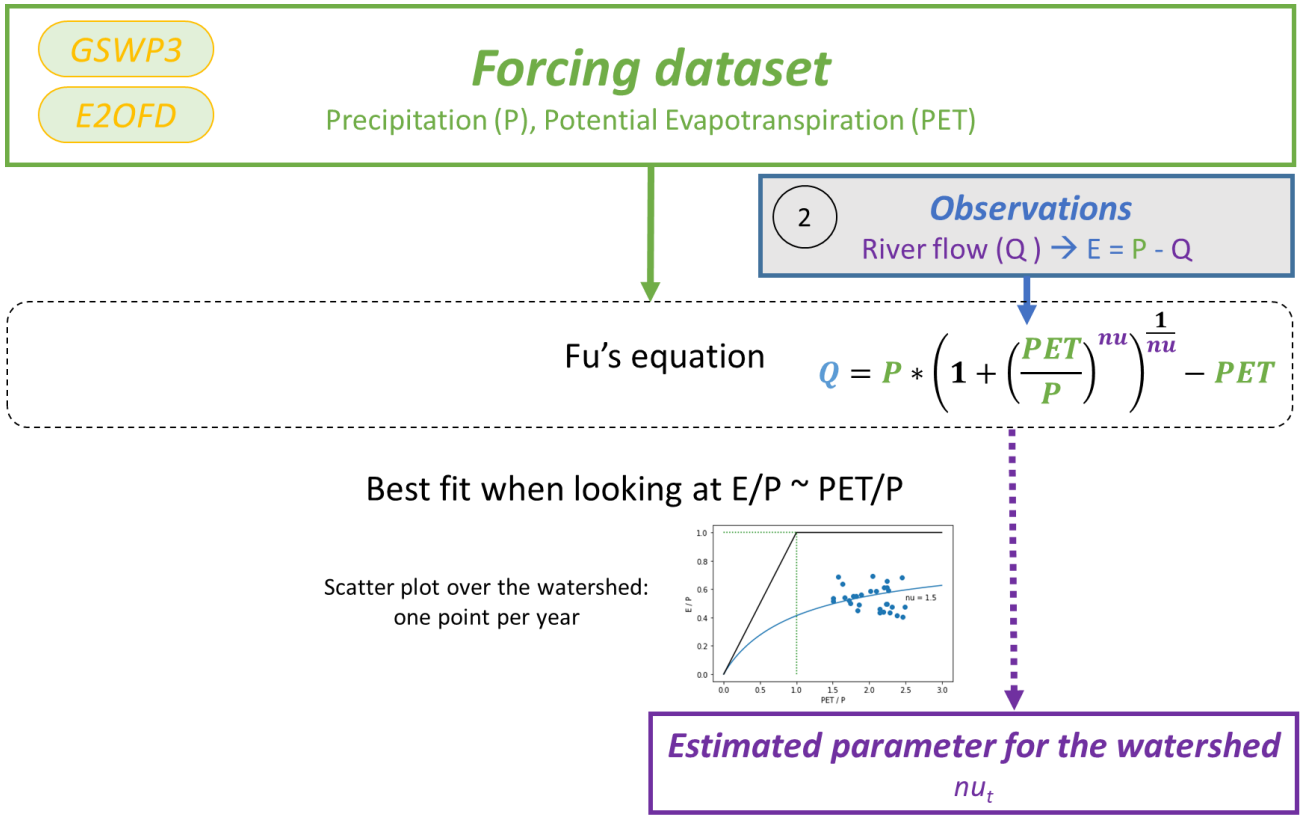
2

Streamflow from observation stations

- GRDC database
- Specific database over Spain

All GRDC stations (1806-2019)
11182 Stations, 7144 with records over more than 20 years





Budyko hypothesis: the watershed parameter

- Calculation of the watershed parameter

2 Streamflow from observation stations

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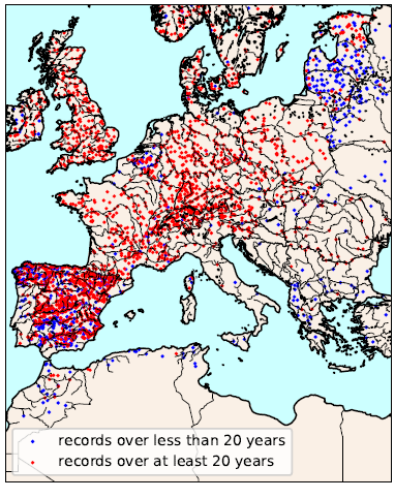


All GRDC stations (1806-2019)
11182 Stations, 7144 with records over more than 20 years

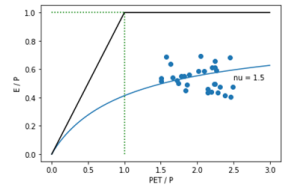
Forcing dataset
GSWP3
E2OFD
Precipitation (P), Potential Evapotranspiration (PET)

2 **Observations**
River flow (Q) → E = P - Q

Fu's equation $Q = P * \left(1 + \left(\frac{PET}{P}\right)^{nu}\right)^{\frac{1}{nu}} - PET$

Best fit when looking at E/P ~ PET/P

Scatter plot over the watershed: one point per year



Estimated parameter for the watershed
nu_t

« Total *nu* parameter »
nu_t

Includes effect of human activity

Budyko hypothesis: the watershed parameter

- Calculation of the watershed parameter

GSWP3
E2OFD

Forcing dataset
Precipitation (P), Potential Evapotranspiration (PET)

1 **Model output**
Evapotranspiration (E)

2 **Observations**
River flow (Q) → E = P - Q

$$\frac{E}{P} = 1 + \frac{PET}{P} - \left(1 + \left(\frac{PET}{P}\right)^{nu}\right)^{\frac{1}{nu}}$$ Fu's equation $$Q = P * \left(1 + \left(\frac{PET}{P}\right)^{nu}\right)^{\frac{1}{nu}} - PET$$

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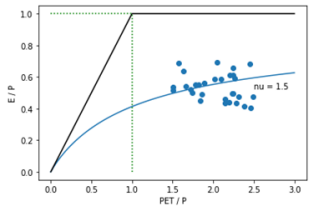
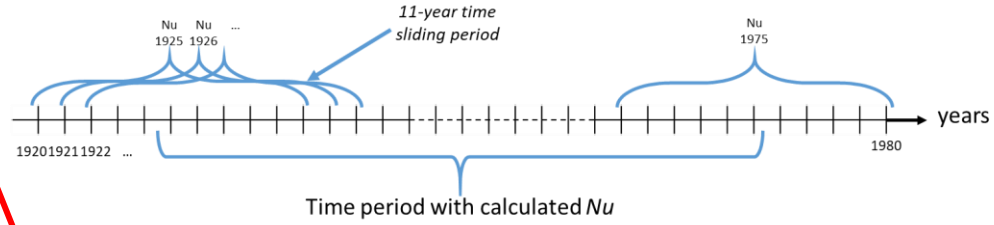


Estimated parameter for the watershed
nu_c

Estimated parameter for the watershed
nu_t

Two ways of fitting the parameter over a time period:

- One fit **over the entire time period**, with all yearly values **at once**
- Fit over an **11-year sliding time-period**
  → Evolution of the parameter over the time period

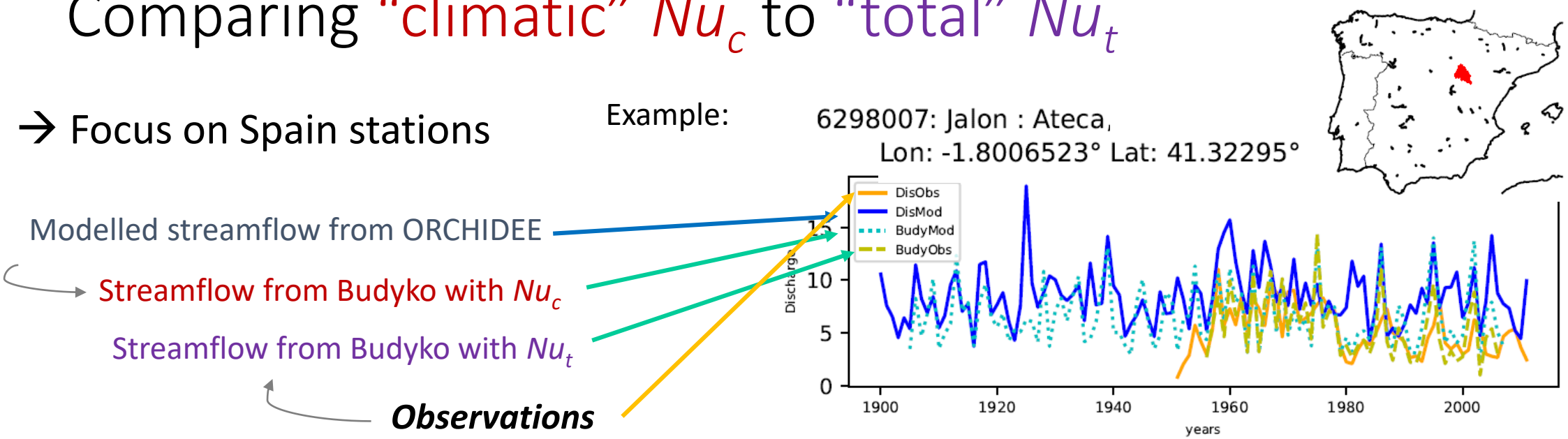


Results

Comparing "climatic" Nu_c to "total" Nu_t

→ Focus on Spain stations

Example:



Modelled streamflow from ORCHIDEE

Streamflow from Budyko with Nu_c

Streamflow from Budyko with Nu_t

Observations

Annual streamflow from 1900 to 2020

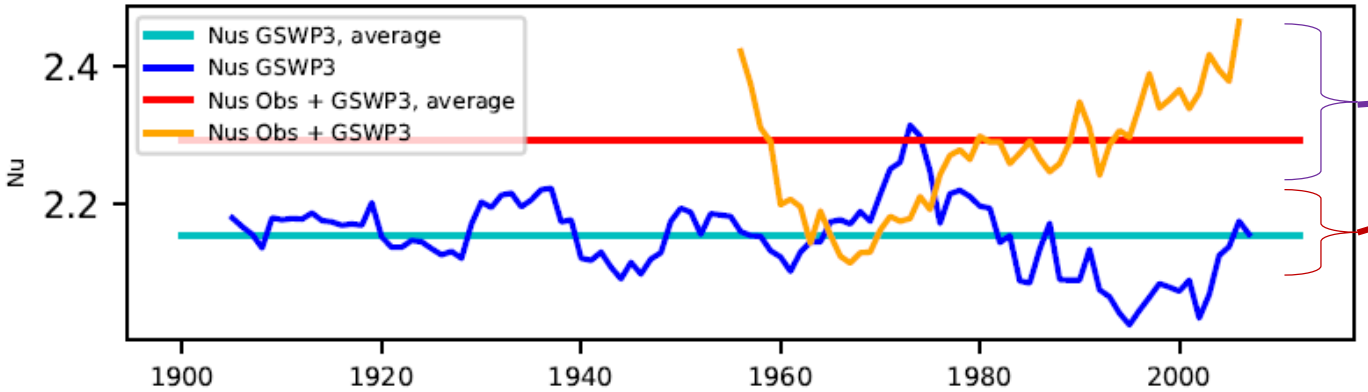
Streamflow → highly climate dependent and high interannual variability

➔ Focus on the analysis of the watershed parameter, partly freed from climate dependence

Comparing "climatic" Nu_c to "total" Nu_t

→ Focus on Spain stations

Example: 6298007: Jalon : Ateca,
Lon: -1.8006523° Lat: 41.32295°



Watershed parameter from 1900 to 2020

Watershed parameter Nu_t

Watershed parameter Nu_c

→ Average
→ Evolution with a 11-years sliding time-range

Comparing "climatic" Nu_c to "total" Nu_t

→ Focus on Spain stations

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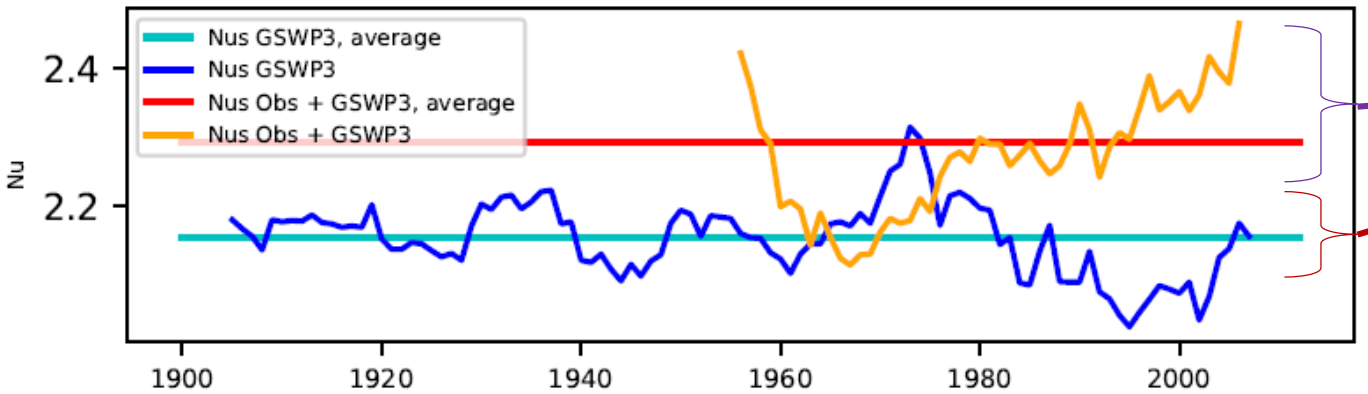


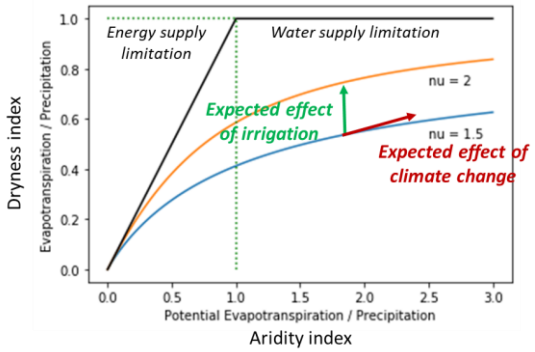
Watershed parameter from 1900 to 2020

Watershed parameter Nu_t

Watershed parameter Nu_c

→ Average
→ Evolution with a 11-years sliding time-range

- No distinctive trend for Nu_c calculated with climatic data only
- For lots of basins over Spain: trend in Nu_t calculated with observations, especially over last 30 years
  → changes in basin characteritics, other than climatic trends



Comparing "climatic" Nu_c to "total" Nu_t

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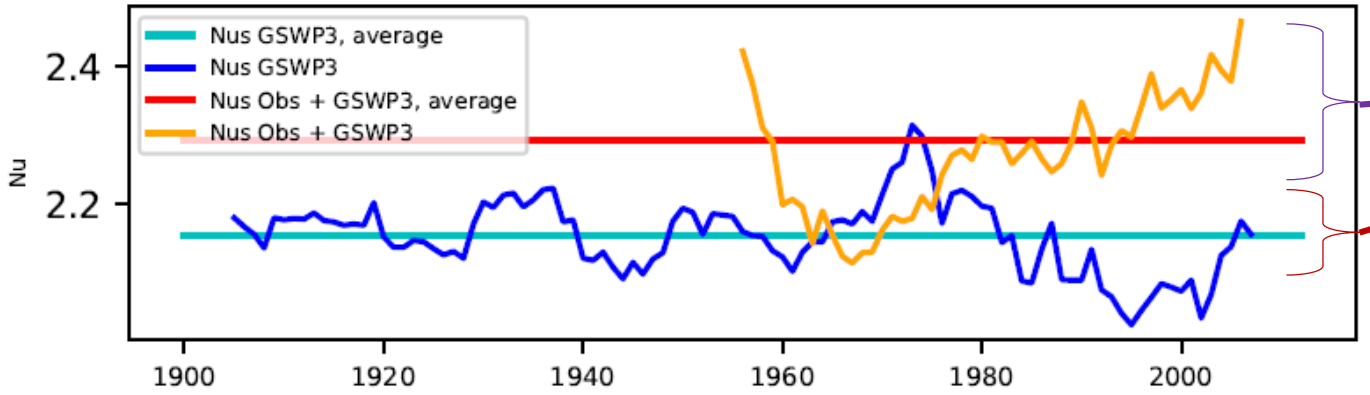
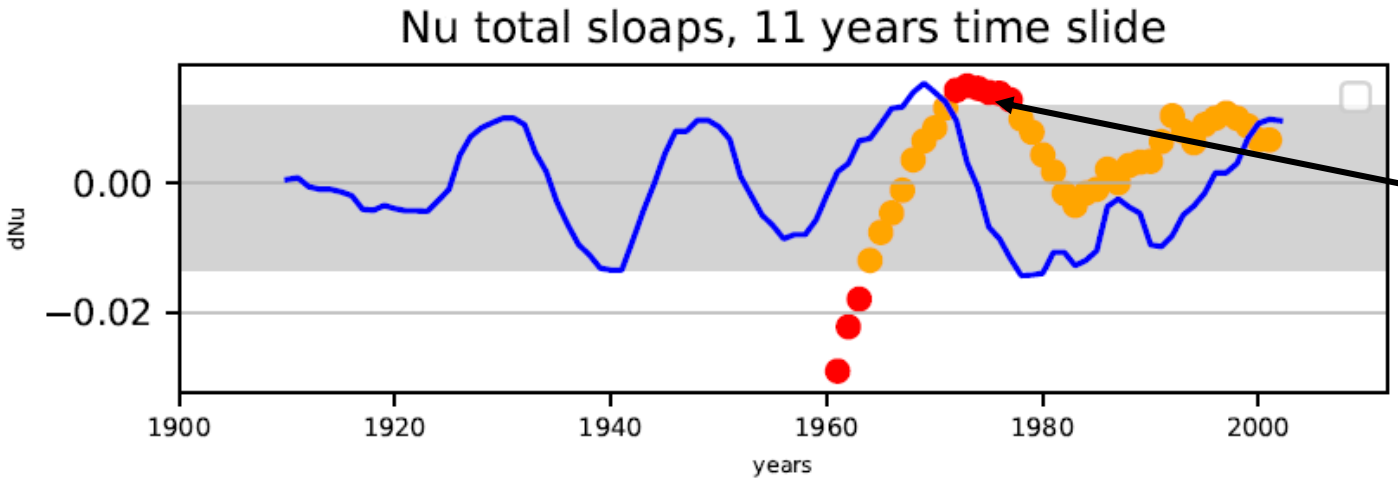


Watershed parameter Nu_t

Watershed parameter Nu_c

→ Average
→ Evolution with a 11-years sliding time-range



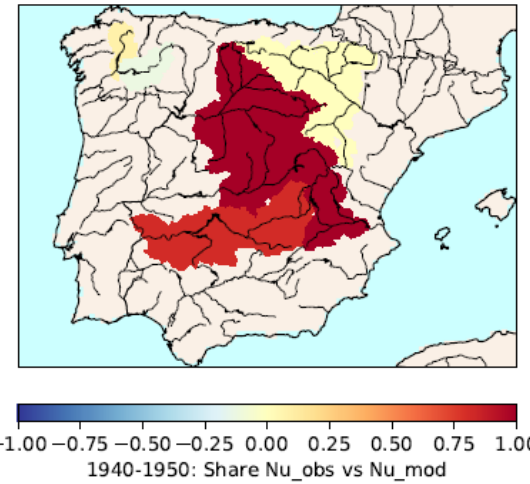
Sloap of Nu_t higher than 95% of all sloaps of Nu_c

Maps:
Nu_t sloaps outside of 95% range of Nu_c sloaps

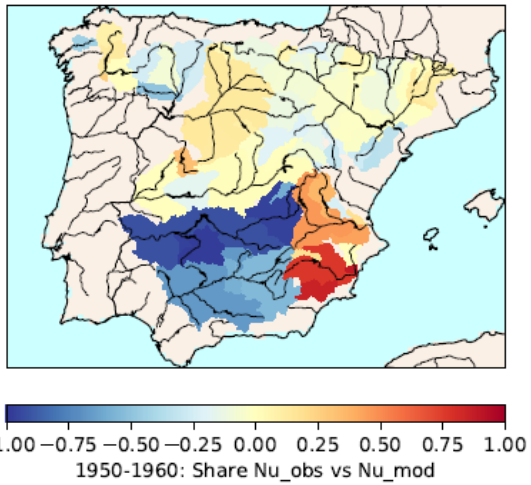
Red: **Rising** sloap of Nu_t **higher** than 95% of all sloaps of Nu_c

Blue: **Droping** sloap of Nu_t higher than 95% of all sloaps of Nu_c

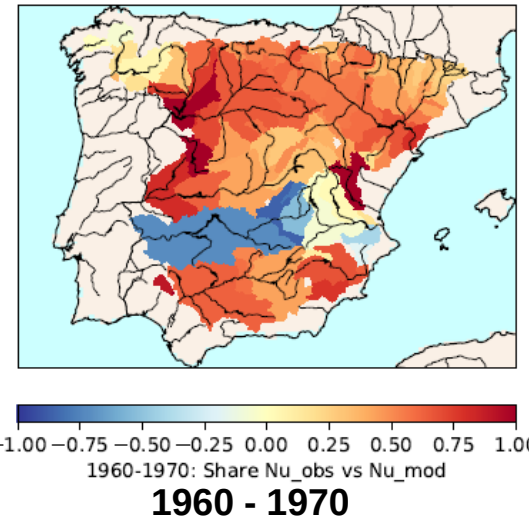
Yellow: Sloap of Nu_t **in range** of sloaps of Nu_c



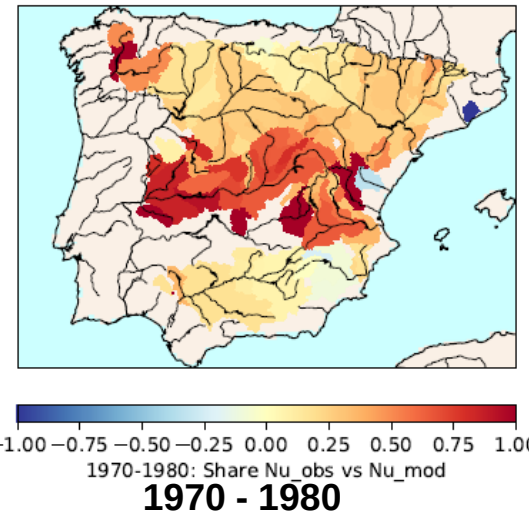
1940 - 1950



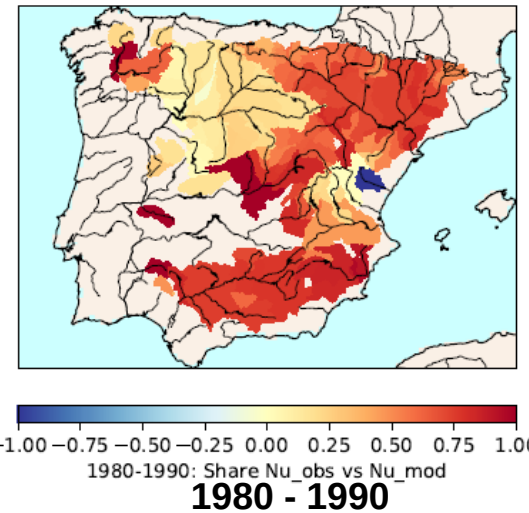
1950 - 1960



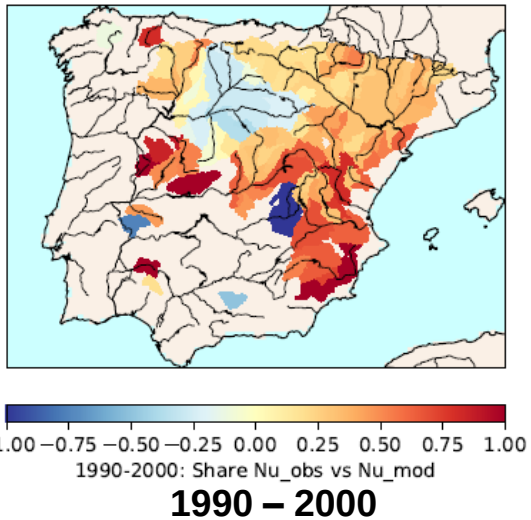
1960 - 1970



1970 - 1980



1980 - 1990



1990 – 2000

How to explain the variations of the watershed parameter?

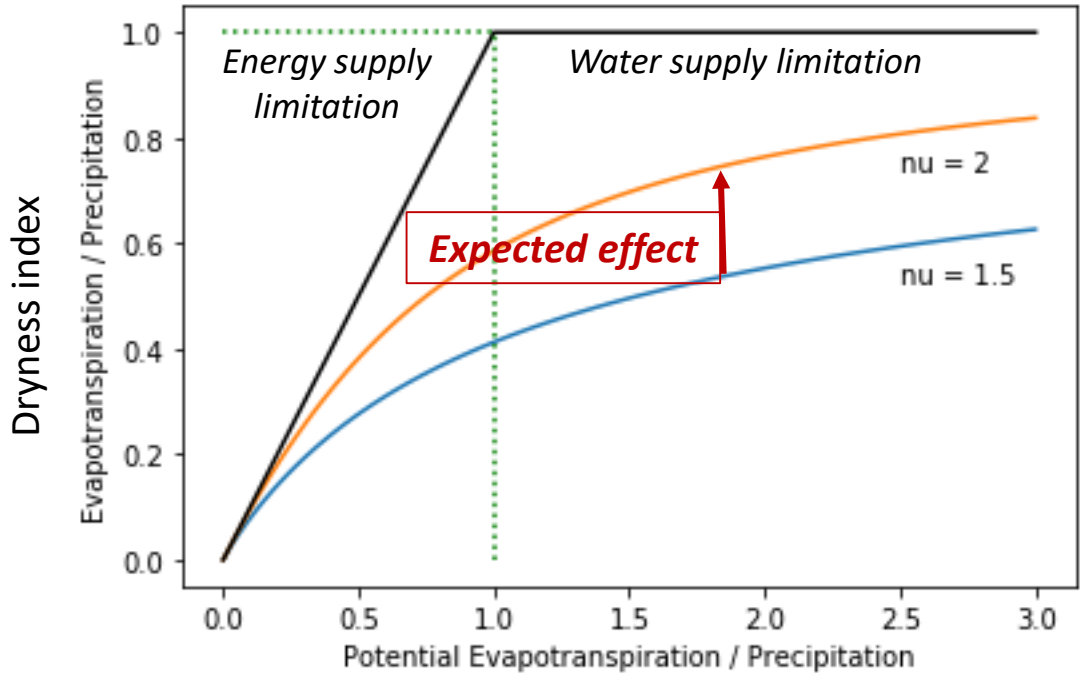
Hypothesis

- Rising value of the parameter for given PET and P (climatic variables)
  = **Increase of apparent ET**
  = **Decrease of apparent runoff (streamflow)**

➔Water uptakes not explain by climate variables variation only

➔Hypothesis:

- Irrigation
- Dams?
- Water transfers towards other basins
- Increase in vegetation cover



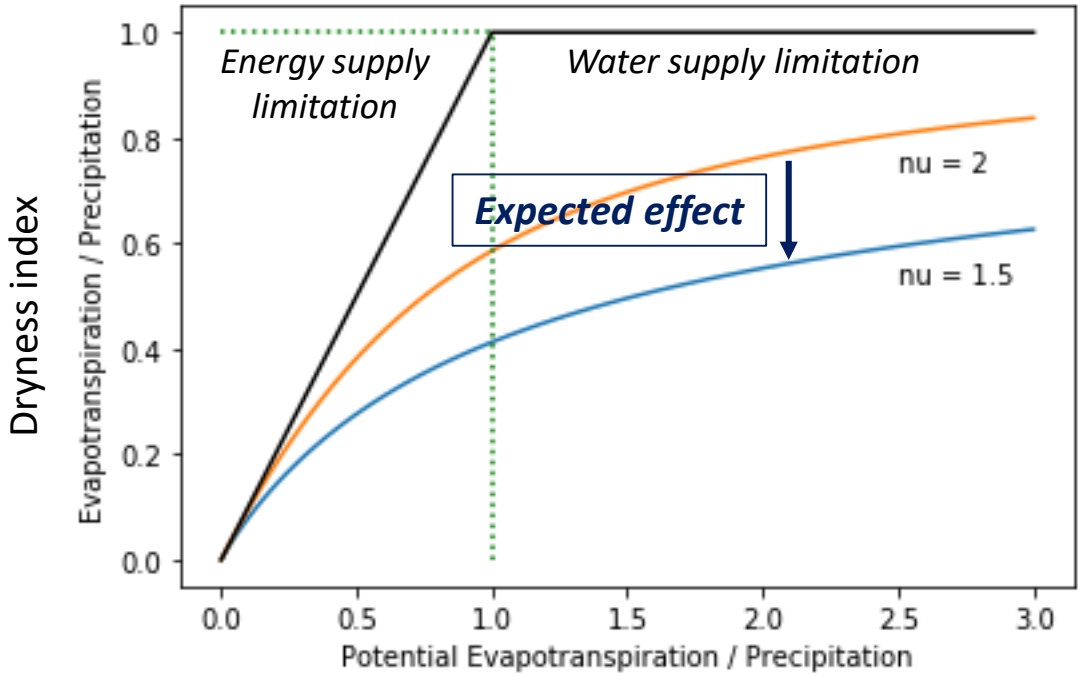
Hypothesis

- Decreasing value of the parameter for given PET and P (climatic variables)
  = **Decrease of apparent ET**
  = **Increase of apparent runoff (streamflow)**

➔Water inputs not explain by climate variables variation only

➔Hypothesis:

- Glacier melting
- Water transfers from other basins
- Decrease of vegetation cover
- Pumping from ground water
- Soil sealing
- River management



Keys findings

Impact of anthropogenic changes?

- **Climatic variations** of the watershed parameter **smaller** than variations due to **missing processes** (anthropogenic changes…)

- Raising variations **correlated** to construction and development of **water regulation** infrastructures (volume of water stored in dams…)
- Apparent **concordance in space and time** with **irrigation** development and **groundwater uptake** (Guadiana basin)
- Test of the model with forced **evolving vegetation cover**: very little impact on variation of the watershed characteristics
  → **Non-significant effect** of land cover change compared to other factors

- Difficulties to separate and attribute impacts: confounding effects of different factors over same areas
  → need to include missing processes in models to separate and test effects of each factors independently