FRESH WATER PARADOX:

DOES SAVING OF WATER MITIGATE CLIMATE CHANGE OR INCREASE THE INSTABILITY OF THE HYDROLOGICAL CYCLE?

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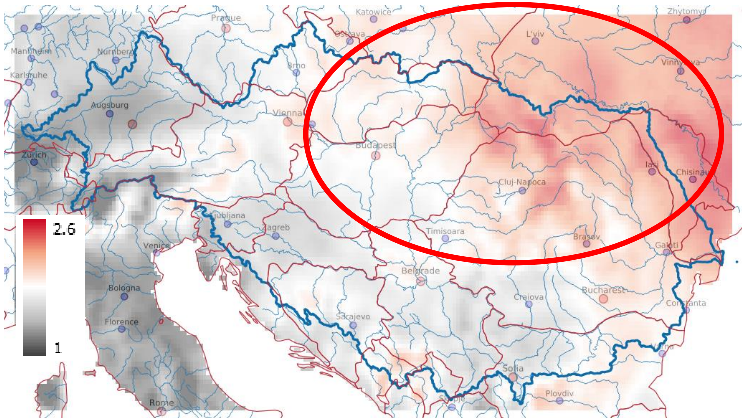
Session UP3.1 Climate change detection, assessment of trends, variability and extremes

BUDAPEST UNIVERSITY
OF TECHNOLOGY AND ECONOMICS
Faculty of Civil Engineering - Since 1782
Department of Hydraulic and Water Resources Engineering

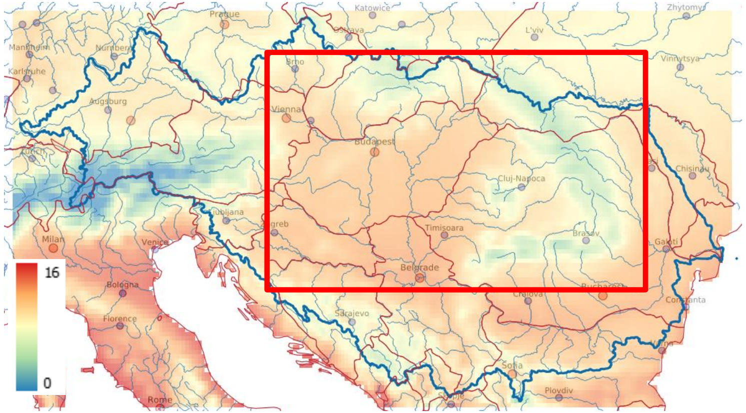
EMS

STUDY AREA, METHOD AND DATA

- **Danube river catchment** (42.0 - 50.3N, 8.0 – 30.0E)
  Amazonas rainforest (0.0 – 6.0S, 62.0-73.0W)
  Spain (38.0 – 42.0N , -5.0 – -1.0W)
- Data: **ECMWF ERA5-Land** (*Sabater, 2019*)
  - *spatial resolution: 0.1°x 0.1° ,*
  - *temporal resolution: monthly.*
- Processing:
  - *Mann-Kendall test for linear trends (for catchment)*
  - *spatial distribution of trends (in grid points)*
  - *evaporation fraction, calculated,*
  - *reference evaporation, calculated, gap shown*
- Analysis, conclusions, discussion
  - *Increasing vulnerability to droughts*
  - *Proposal for HCSi index --- actions to take*



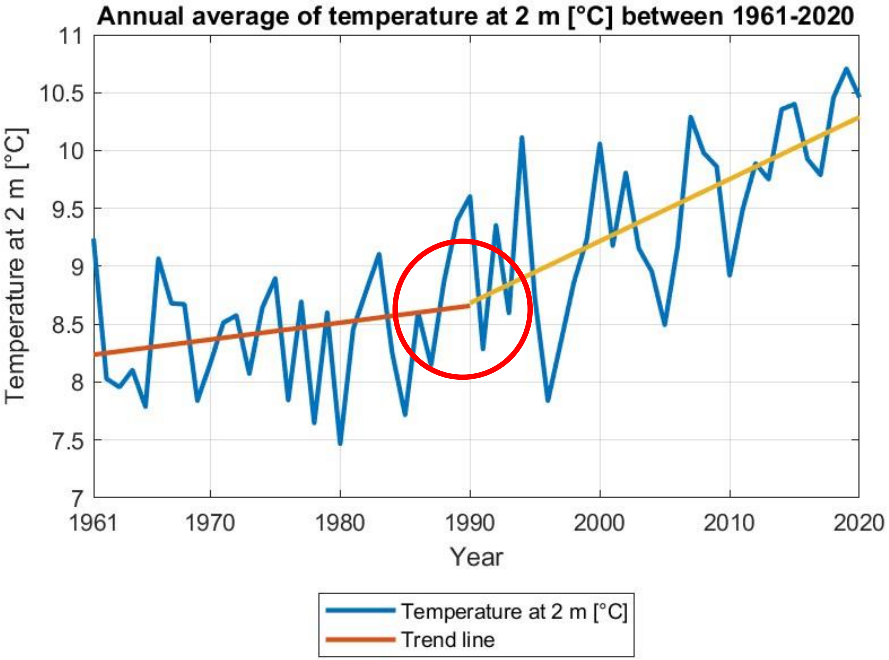
Accrued changes in temperature (°C), 1991-2020.
Spatial distribution of trends. Areas for attention are circled.

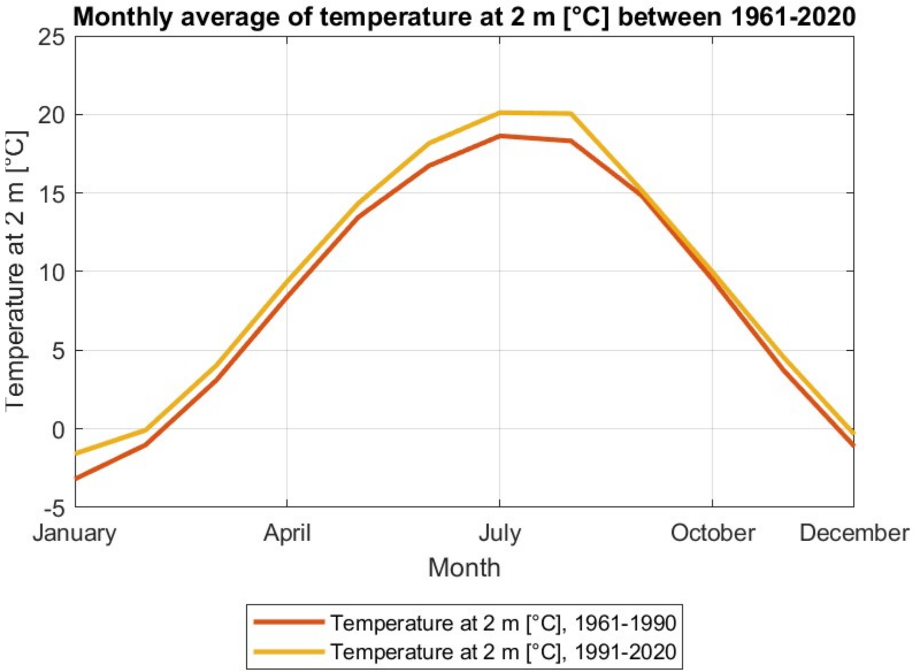


Annual average temperature (°C) between 1991-2020.
Some slides show details of the marked area.

Trends of 2 m air temperature between 1961-1990 and 1991-2020

Warming exceeds 1.5 °C in the Danube catchment (linear trends are shown for 30-year ref. periods)

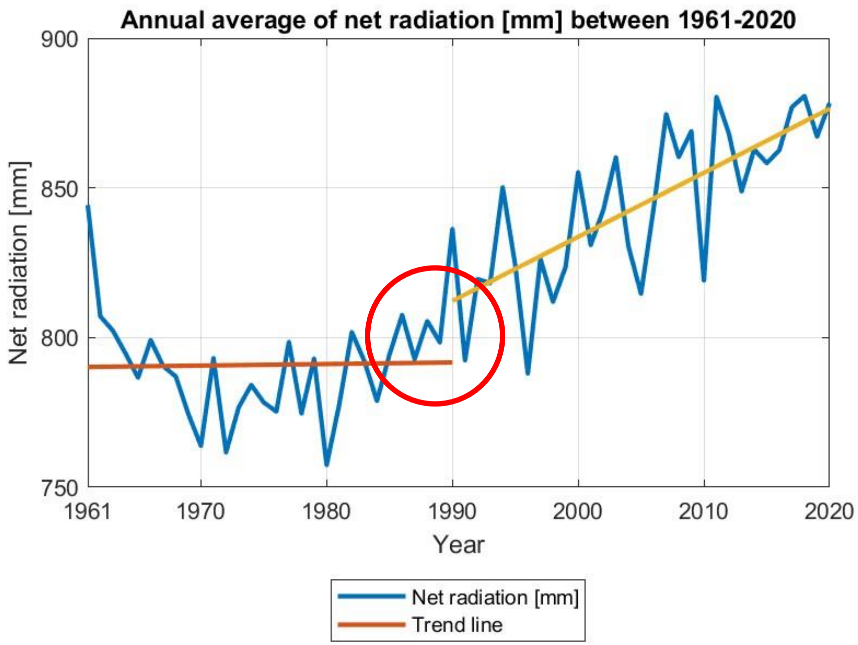


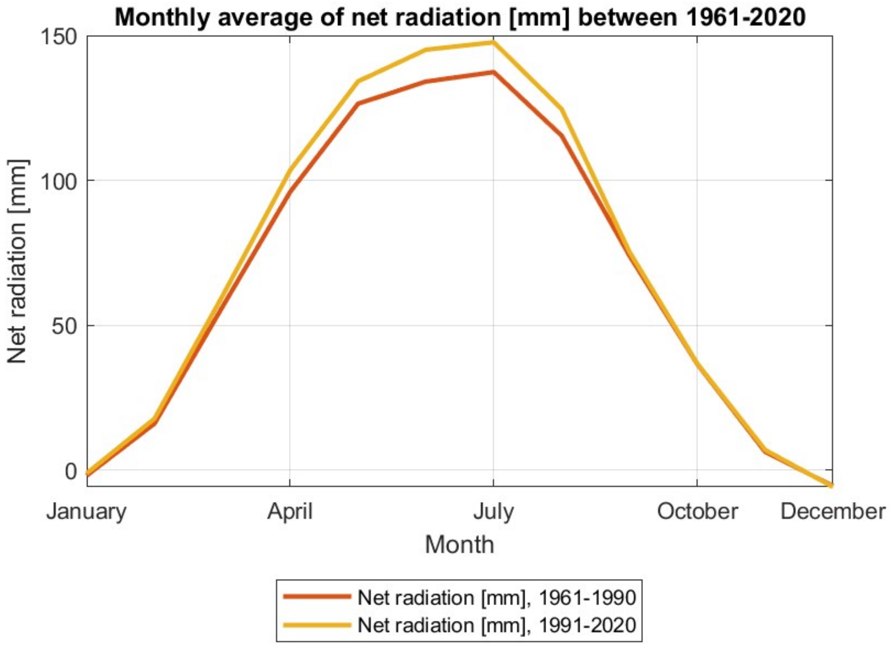


Temperature has increased, both annual and monthly averages. Significant trend in the 1991-2020 period.(Mann-Kendall trend test performed for annual averages of the catchment are masked out from the map.)

Trends of net radiation between 1961-1990 and 1991-2020

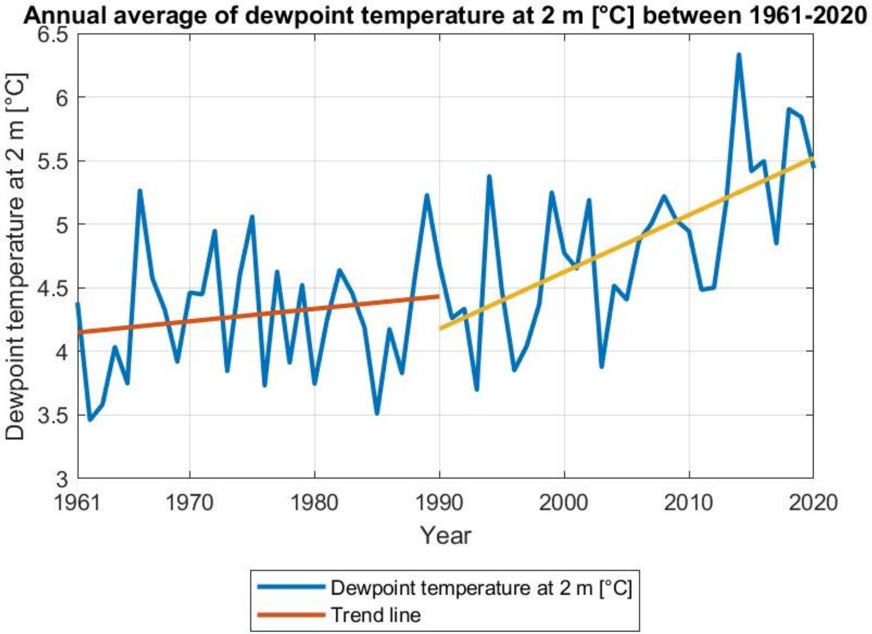
Net radiation was converted from MJ*m^{-2} to water evaporation equivalent (2.5MJ*kg^{-2} -> 1mm)

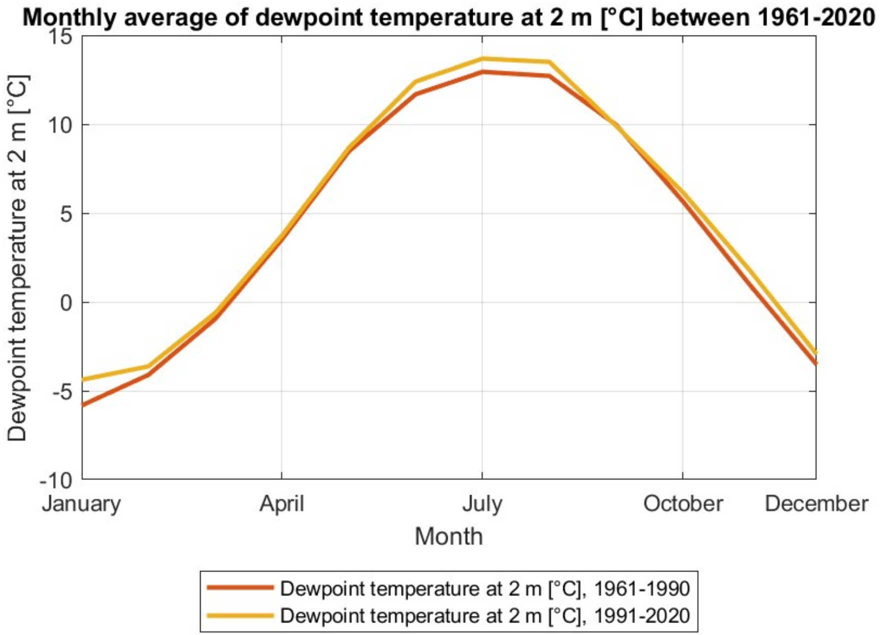




Net radiation has increased since the 1980's, mainly in summer months. Significant trend!

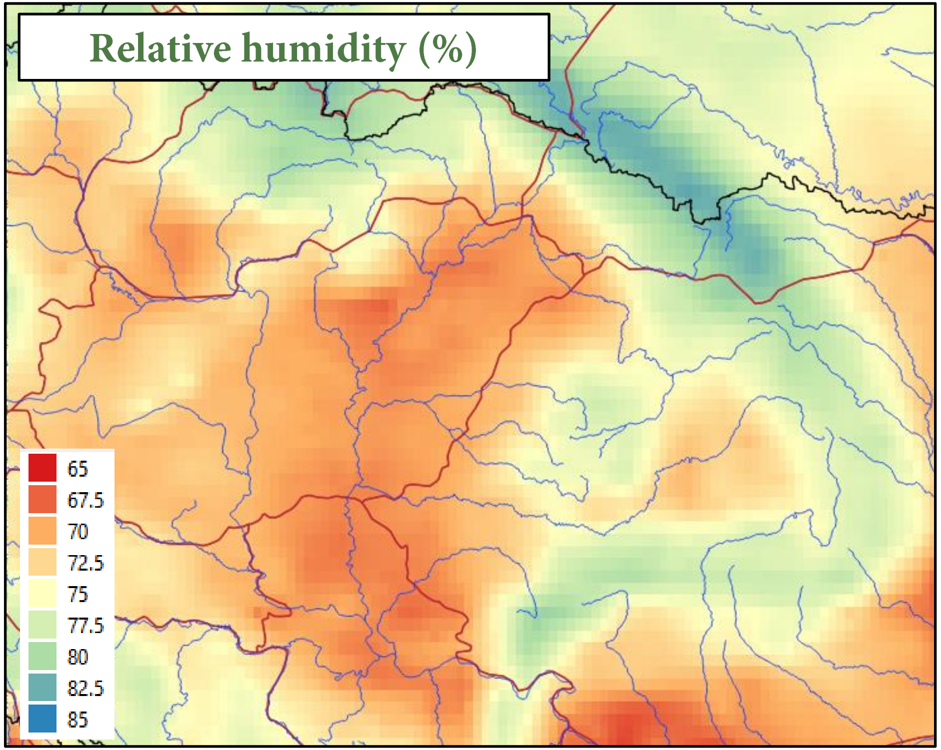
TRENDS OF DEWPOINT TEMPERATURE BETWEEN 1961-1990 AND 1991-2020

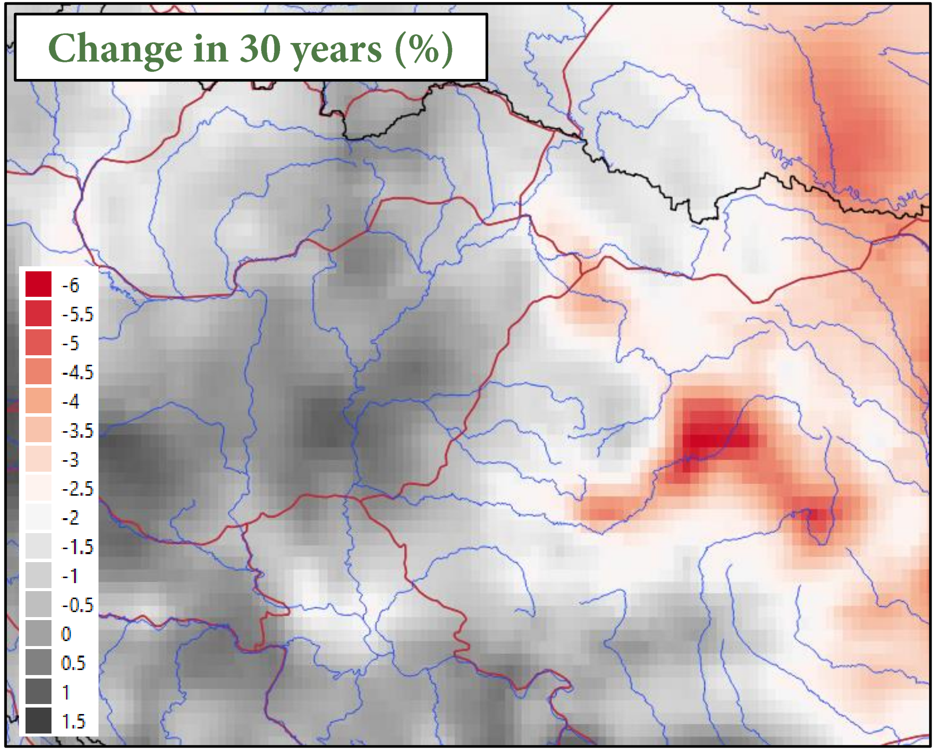




Water content has increased in the atmosphere. Significant trend in the 1991-2020 period.

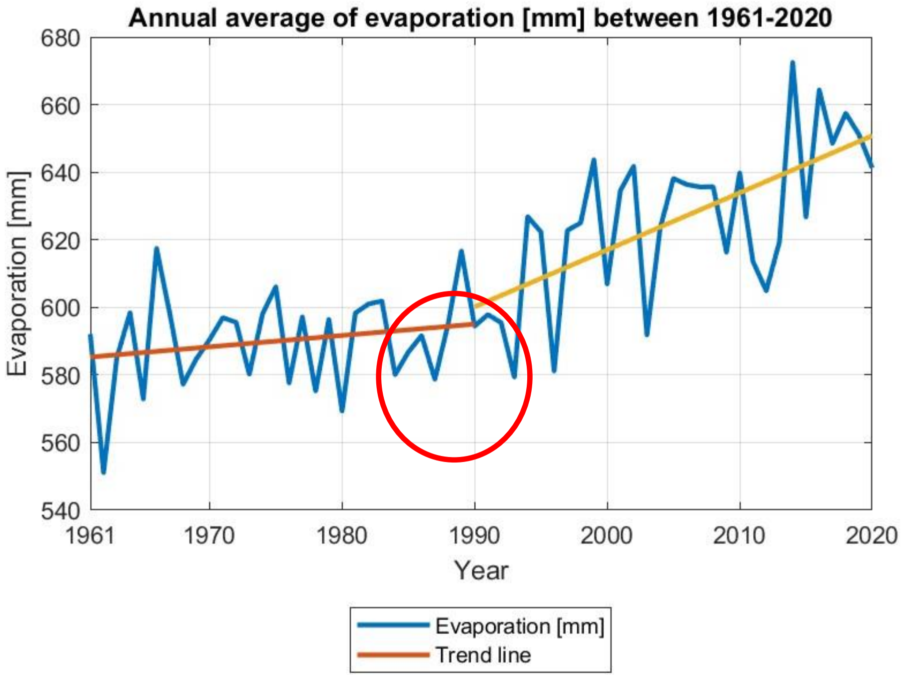
Trends of relative humidity between 1991-2020
Drill down to the Carpathian basin:

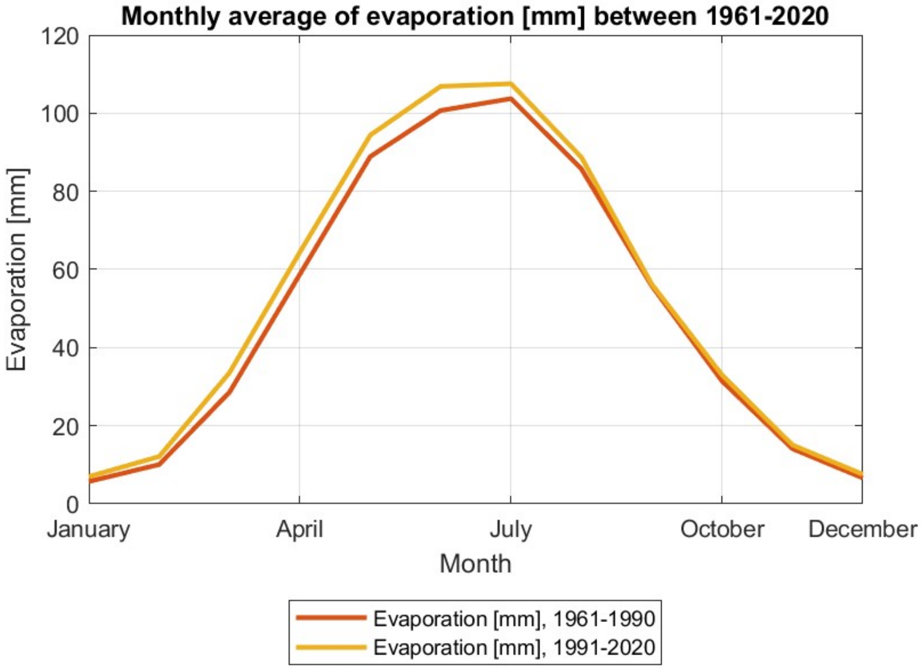




Despite increased evaporation, relative humidity has declined due to higher radiation and temperature.

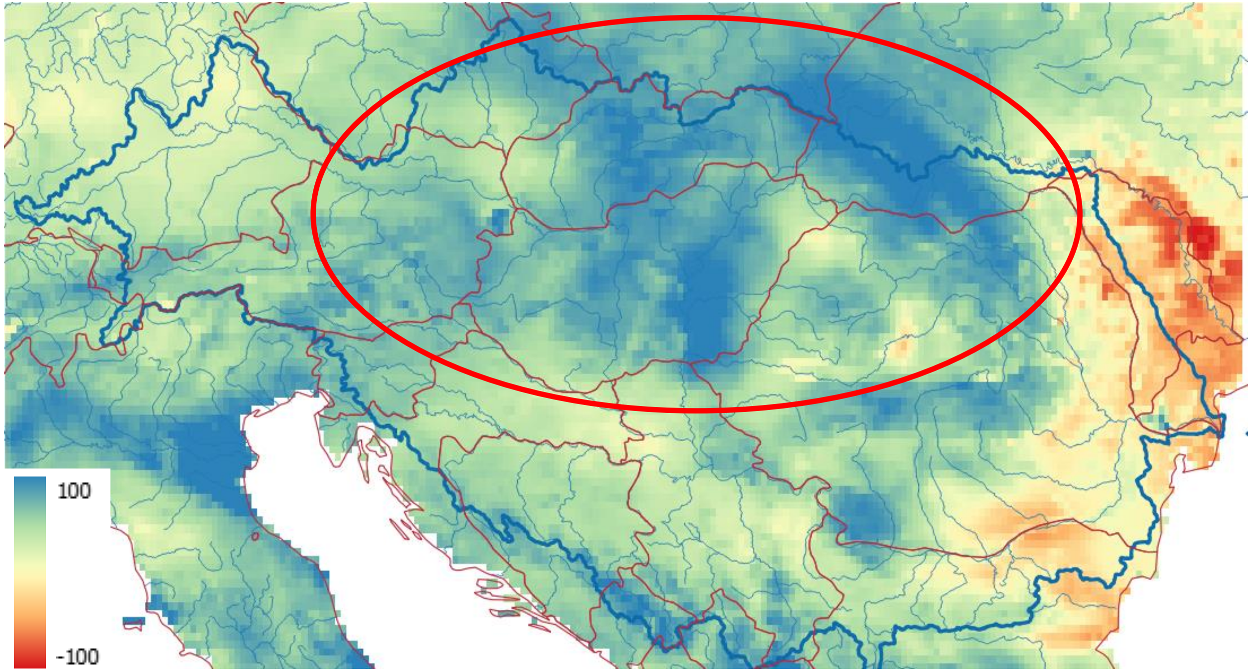
TRENDS OF EVAPORATION BETWEEN 1961-1990 AND 1991-2020

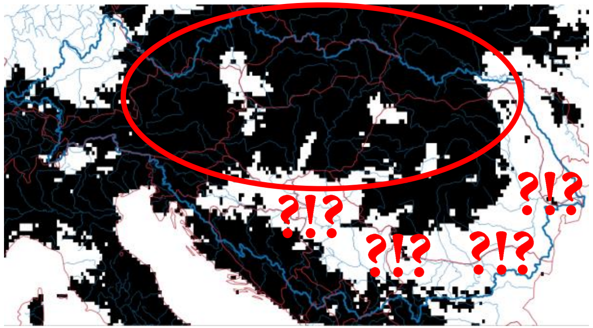




Evaporation has increased, especially in spring and summer. Significant trend in the 1991-2020 period.
(Note: the term evaporation is used here for all components of evaporation, same as evapotranspiration)

SPATIAL DISTRIBUTIONS OF EVAPORATION TRENDS BETWEEN 1991-2020





ˆSignificant trend (MK $p<0.05$) in a grid point is marked by black.

◂Accrued changes in evaporation (mm) in period 1991-2020.

Evaporation has increased significantly in most of the catchment area, except south and south-east.
Is this good or are these areas already „running out of water" ?!? to evaporate and cool the surface?

Summary of Trends, Analysis and Discussion

1. Annual average values of key **forcing parameters show a significantly increasing trend** by Mann-Kendall test (alfa=0.05): net radiation, air temperature, dewpoint temperature between 1991-2020.
2. **Evaporation is also increasing with a significant trend** as a response to the increased forcing. Precipitation and run-off do not show significant trends. Should they follow forcing or the opposite, will they decline?
3. **Continents are warming faster (*IPCC 2019*).** Could this be a symptom of the decreasing performance of evaporative cooling? Note, the inevitable role of water in the process! **Saving water is an incorrect response!**

Significancy of trends in the Danube watershed during 1991-2020 calculated with Mann-Kendall trend test

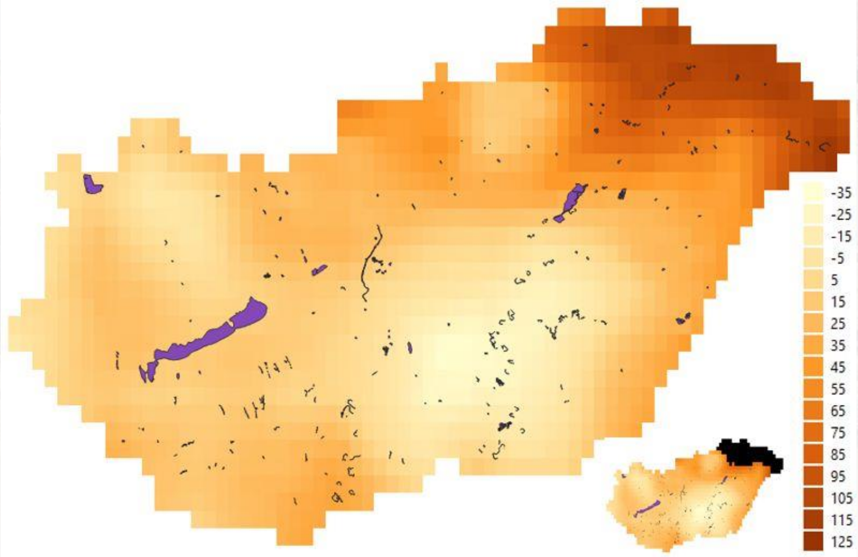
ERA5 parameter	Name of the parameter	p	H trend?	probability of existing trend %
ssrstr	Net radiation	0.0001	1	99.99
t2m	Air temperature (2m)	0.0001	1	99.99
d2m	Dew point temp (2m)	0.0001	1	99.99
tp	Total Precipitation	0.7753	0	22.47
e	Evaporation	0.0013	1	99.87
ro	Run-off	0.4978	0	50.22

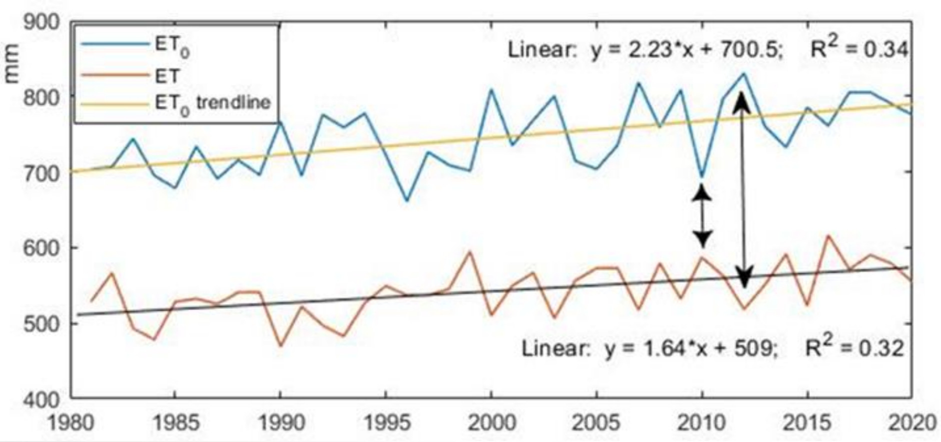
Material	Specific heat kJ/kg° C	Latent heat of evaporation kJ/kg
Air	0.72	210
Hydrogen	14.20	460
Nitrogen	1.04	199
Vapour	1.72	-
Water	4.19	2256 (at 100°C) **2501** (at 0°C)
Ice	2.10	
Glass, sand	0.80	-
Concrete	0.85	

~500 x

~5 x

THE GAP BETWEEN EVAPORATION AND REFERENCE EVAPORATION IS GROWING ! DRILLDOWN TO HUNGARY:



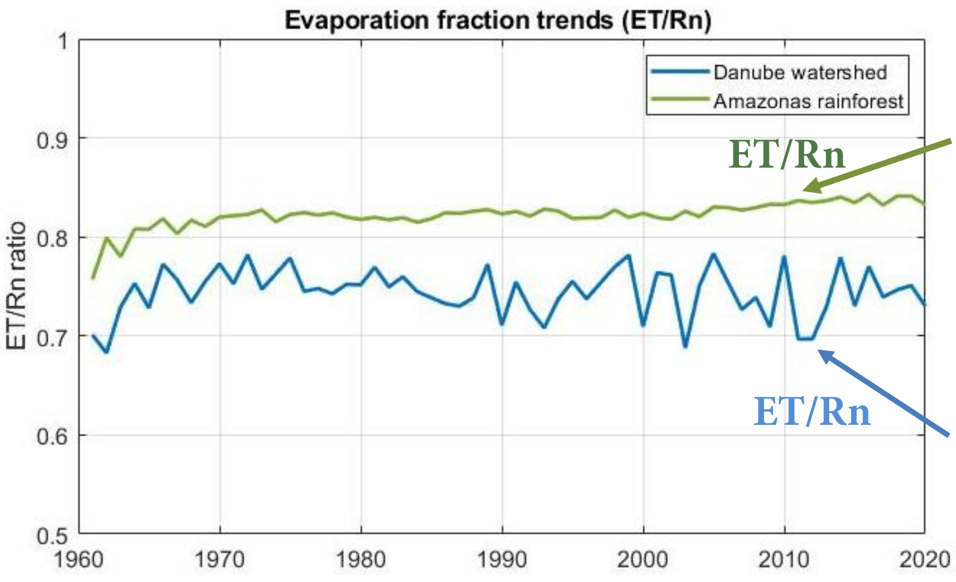


Trends of evaporation (ET) and Reference Evaporation (ET0) estimated by Penman method in Hungary. Estimates are in line with FAO method (*Lakatos et al. 2020*)

Spatial distribution of the gap between evaporation (ET) and reference evaporation (ET0).
Changes in North-East Hungary (marked in black) show a significant trend (*Báder & Szilágyi, 2023*)!
=> With increasing evaporation, **latent heat transfer is increasing, but is still more needed for stability?**

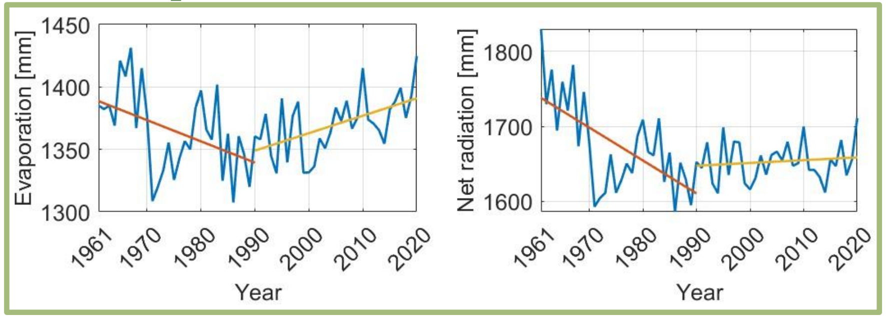
CAN WE USE EVAPORATIVE FRACTION (=ET/RN) AS AN EFFICIENCY INDICATOR?

LETS SEE 2 AREAS:

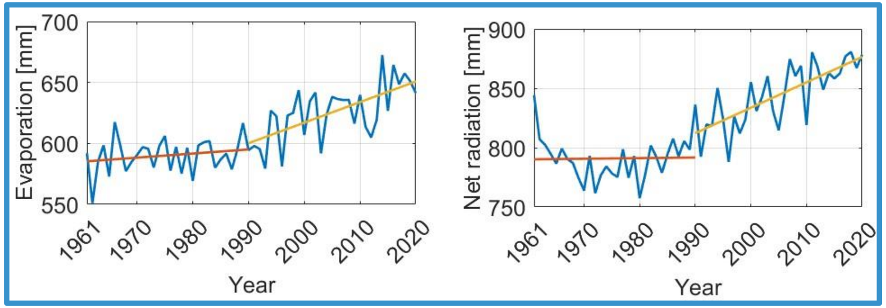


Annual average of evaporation (ET)

Annual average of net radiation (Rn)



Amazonas1

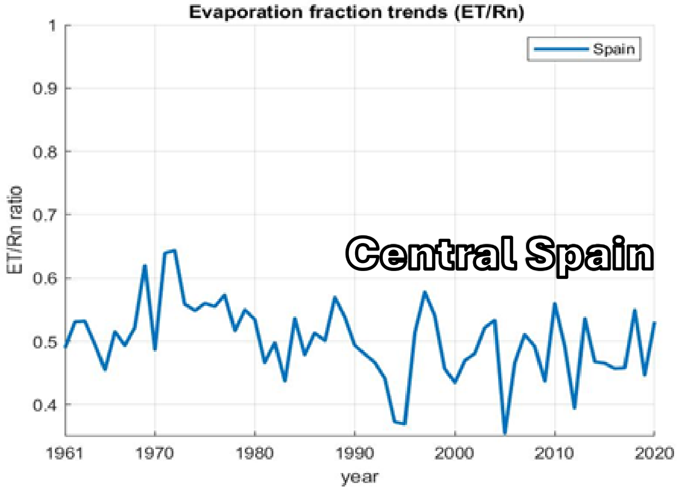


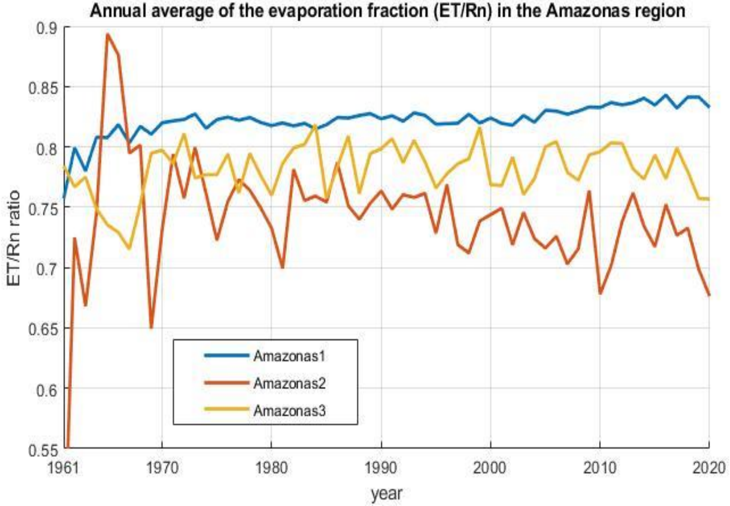
Danube watershed

Annual average EF (ET/Rn) in Danube catchment vs. Amazonas rainforest during 1961-2020.

Note: ET rate in Amazonas is more than double compared to Danube, the EF ratio is still stable, above 0.8! → *Suggestion: use ET/Rn as a Hydro-Climate Stability indicator (HCSi)!*

FURTHER EXAMPLES OF EF (ET/RN):





ACCRUED CHANGES IN EVAPORATION AND PRECIPITATION IN THE DANUBE WATERSHED (817 000 KM^2) BTW. 1991 - 2020

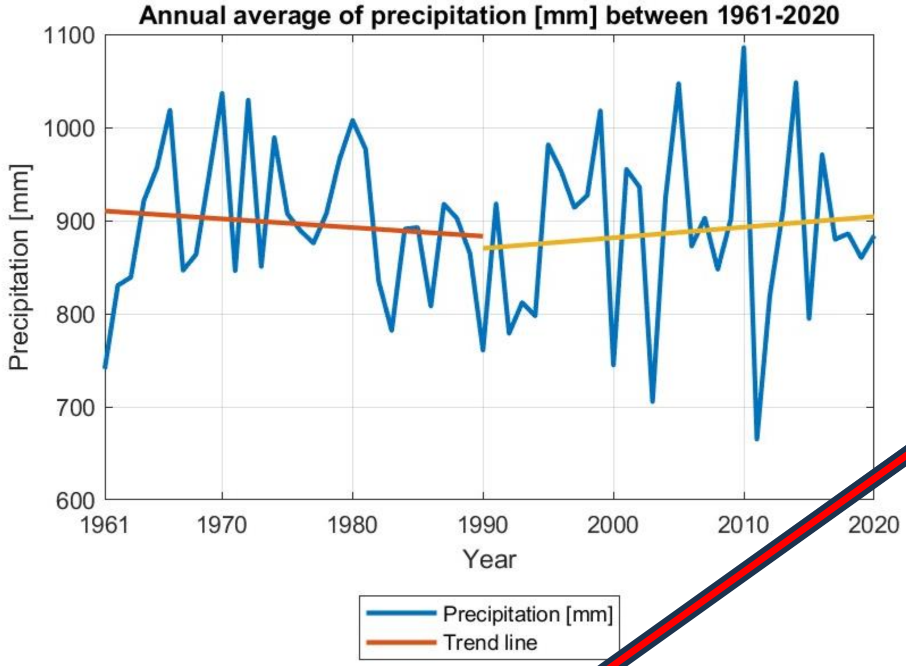
Parameter	Yearly change		Change in the last 30 years
	mm/year	million m^3/year	km^3
ET (evaporation)	1.59	**1302.29**	39.07
P (precipitation)	0.37	302.77	9.08

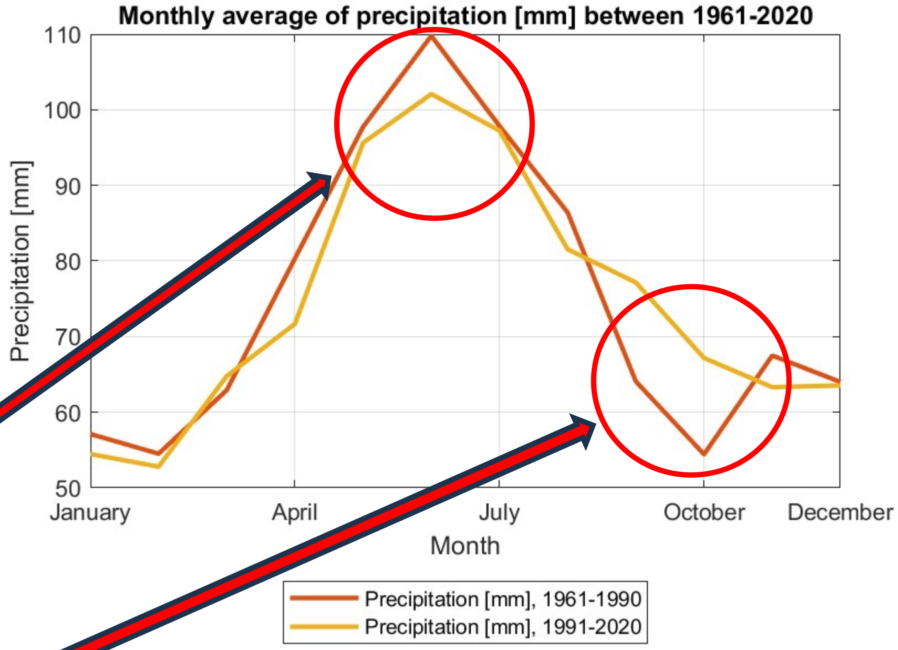
Climatic water balance has changed unfavourably, final comments:

Evaporation has greatly increased! Traditional water retention and irrigation are insufficient to supply this demand, and the importance of water retention in the soil and landscape is growing.

No significant increase or decrease in runoff was observed in the Danube basin (*Pekárová et al., 2021*). The water mass measured by gravimetry shows a decreasing trend (*Boergens et al., 2020*).

TRENDS OF PRECIPITATION BETWEEN 1961-1990 AND 1991-2020 IN THE DANUBE CATCHMENT BASE:



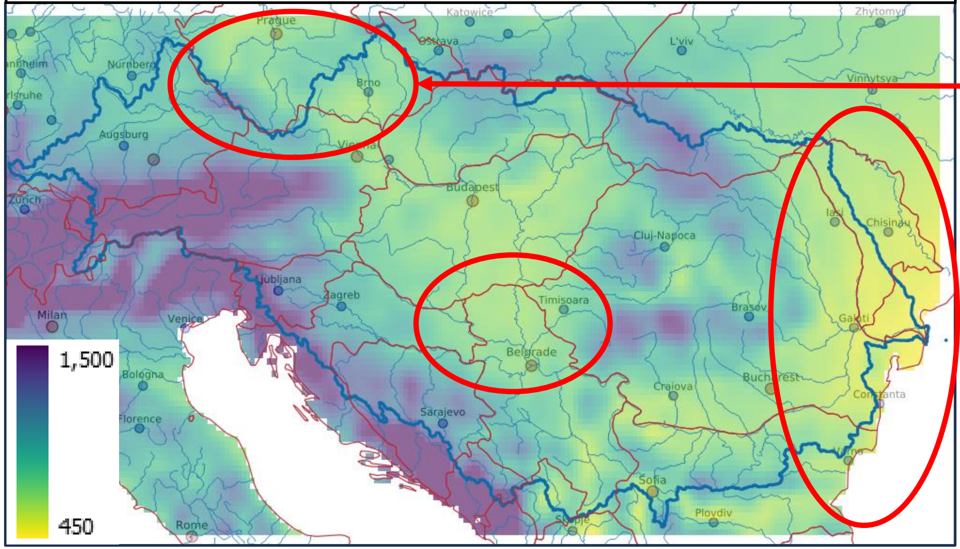


Precipitation is decreasing in summer and increasing in autumn, but no significant trend.

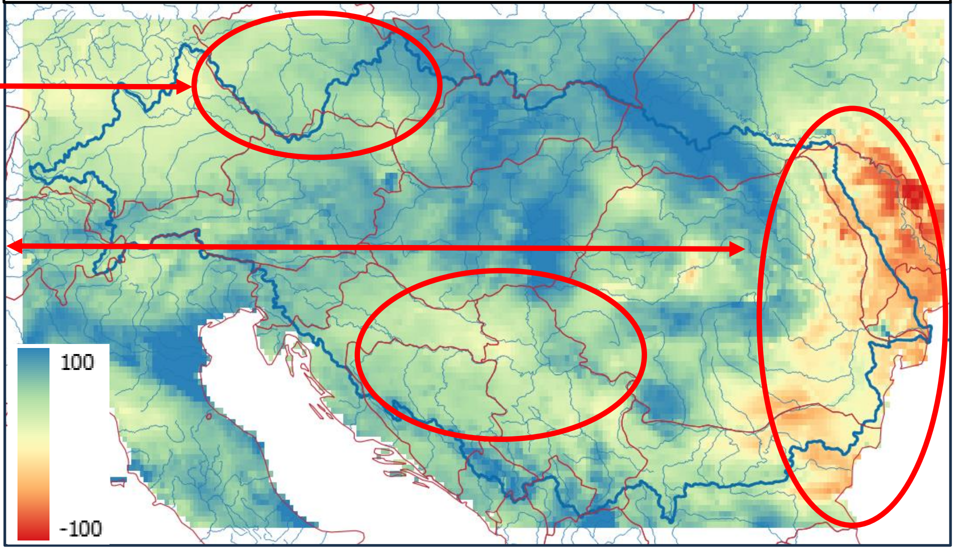
Storage for next year is inevitable. The role of groundwater and soil reservoirs becomes vital!

SPATIAL DISTRIBUTION OF PRECIPITATION AND ACCRUED CHANGE BETWEEN 1991 – 2020

Average annual precipitation (mm), 1991-2020.



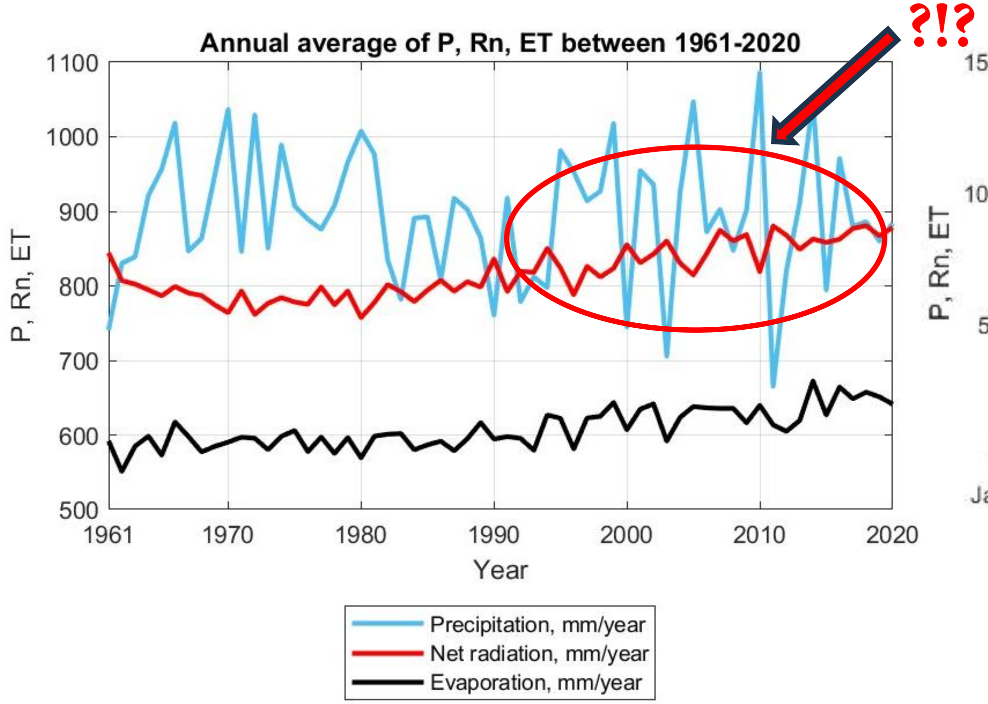
Accrued change of precipitation (mm), 1991-2020.

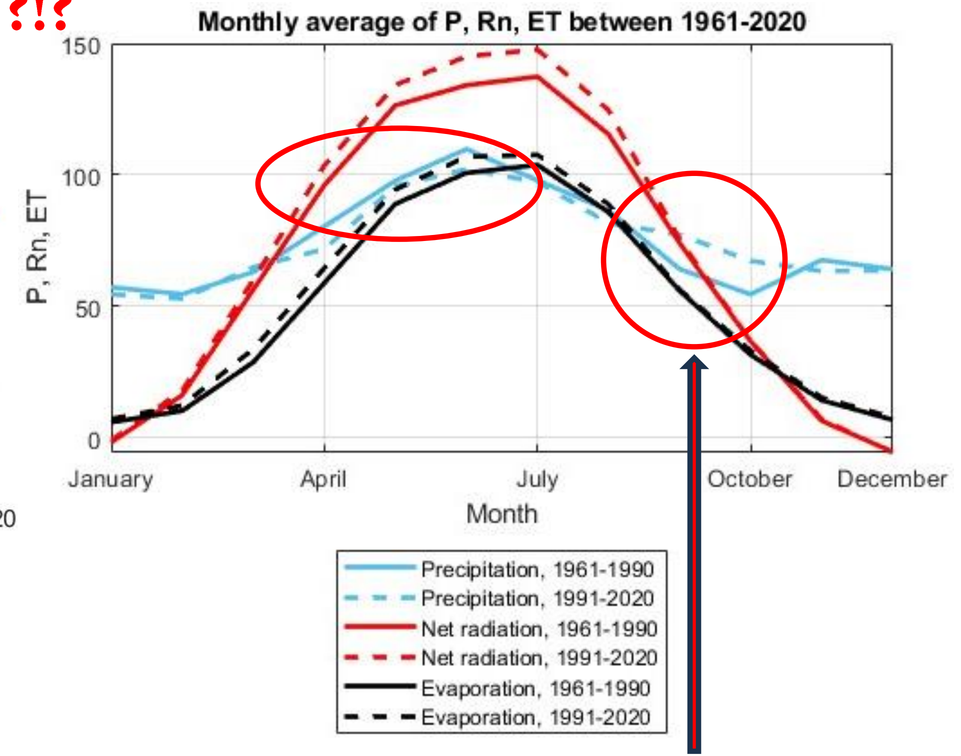


Dry areas receive less precipitation, the trend is decreasing. „Dry becomes drier” *(Putnam & Broecker, 2017).*

Storage for next year is inevitable. The role of groundwater and soil reservoirs becomes vital!

SUMMARY: MAIN COMPONENTS IN THE ENERGY DISTRIBUTION PROCESS





Precipitation is decreasing in summer and increasing in autumn. Conditions for the energy distribution process are getting worse!

Increasing demand (Rn, ET), decreasing supply for water (P) !!!

SUMMARY AND KEY MESSAGES:

1. Recent temperature, radiation, and evaporation trends in the Danube area ring the bell and call for urgent actions!
2. **Evaporation is not a loss, but a vital environmental service!** Water is the key medium for the distribution of climatic energy due to its unique properties in heat transfer.
3. Evaporative fraction (ET/Rn) can be used as a **predictive** Hydo-Climate Stability (HCSi) index. **Benefits**:
   - easy to derive from current datasets and reuse earlier studies, as HCSi = ET/Rn = 1/(1+Bo);
   - intuitive interpretation focusing on energy transfer.
4. Further research and education are needed to adopt an integrated view of the hydrological cycle and atmospheric circulation. A key to success in mitigating climate change.

Motto:
Blue-green infrastructure
and
Blue-green landscape use
(implemented not only promoted)

Fresh water paradox: Does saving of water mitigate climate change? (NO) Or increase the instability of the hydrological cycle?

Thank you for your attention !

SUSTAINABLE DEVELOPMENT AND TECHNOLOGIES NATIONAL PROGRAMME OF MTA

SUSTAINABLE TECHNOLOGIES SUB-PROGRAMME

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