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Projected changes in hydrological extremes and adaptation options

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Hydro-climatological climate change impacts

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How climate change affects hydrological balance and extremes?

- dynamical and thermodynamical effects

Dynamical:

- changes in temporal structure of rainfall leads to lengthening of periods with low/none precipitation in many regions
- further changes possible due to changes in atmospheric circulation

Thermodynamical:

- acceleration of hydrological cycle
- increasing temperature increases evapotranspiration and further leads to reduction of runoff, and soil, snow and ground water storage
- increasing temperature increases water holding capacity of the atmosphere

Central Europe does not belong to the most affected regions, still the climate change may have serious impacts through:

- increase in precipitation maxima and consequent flooding and rainfall erosion
- increasing likelihood of drought and increase in drought severity
- increase risk of severe heat waves

Map ES.1 Key observed and projected climate change and impacts for the main biogeographical regions in Europe

Arctic region
- Temperature rise much larger than global average
- Decrease in Arctic sea ice coverage
- Decrease in Greenland ice sheet
- Decrease in permafrost areas
- Increasing risk of biodiversity loss
- Some new opportunities for the exploitation of natural resources and for sea transportation
- Risks to the livelihoods of indigenous peoples

Coastal zones and regional seas
- Sea level rise
- Increase in sea surface temperatures
- Increase in ocean acidity
- Northward migration of marine species
- Risks and some opportunities for fisheries
- Changes in phytoplankton communities
- Increasing number of marine dead zones
- Increasing risk of water-borne diseases

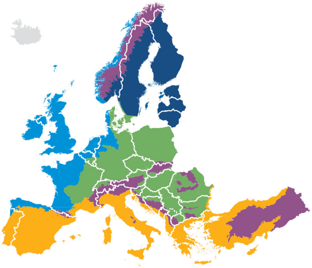
Atlantic region
- Increase in heavy precipitation events
- Increase in river flow
- Increasing risk of river and coastal flooding
- Increasing damage risk from winter storms
- Decrease in energy demand for heating
- Increase in multiple climatic hazards

Boreal region
- Increase in heavy precipitation events
- Decrease in snow, lake and river ice cover
- Increase in precipitation and river flows
- Increasing potential for forest growth and increasing risk of forest pests
- Increasing damage risk from winter storms
- Increase in crop yields
- Decrease in energy demand for heating
- Increase in hydropower potential
- Increase in summer tourism

Mountain regions
- Temperature rise larger than European average
- Decrease in glacier extent and volume
- Upward shift of plant and animal species
- High risk of species extinctions
- Increasing risk of forest pests
- Increasing risk from rock falls and landslides
- Changes in hydropower potential
- Decrease in ski tourism

Continental region
- Increase in heat extremes
- Decrease in summer precipitation
- Increasing risk of river floods
- Increasing risk of forest fires
- Decrease in economic value of forests
- Increase in energy demand for cooling

Mediterranean region
- Large increase in heat extremes
- Decrease in precipitation and river flow
- Increasing risk of droughts
- Increasing risk of biodiversity loss
- Increasing risk of forest fires
- Increased competition between different water users
- Increasing water demand for agriculture
- Decrease in crop yields
- Increasing risks for livestock production
- Increase in mortality from heat waves
- Expansion of habitats for southern disease vectors
- Decreasing potential for energy production
- Increase in energy demand for cooling
- Decrease in summer tourism and potential increase in other seasons
- Increase in multiple climatic hazards
- Most economic sectors negatively affected
- High vulnerability to spillover effects of climate change from outside Europe

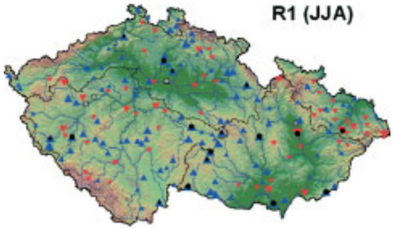


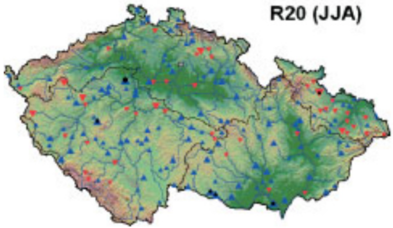
source: EEA (2017) Climate change, impacts and vulnerability in Europe 2016. An indicator-based report. EEA Report 1/2017.

Outline

- Observed and projected climate change impacts on
  - precipitation extremes
  - characterisitics of precipitation events
  - rainfall erosivity
  - hydrological balance
  - characteristics of drought and water availability
- Adaptation options + case studies
  - reduction of direct runoff and increasing infiltration with land use changes
  - reduction of deficit volumes by reservoir storage

PRECIPITATION





Observed data

- likelihood of detection of significant change is low due to rare occurence of extremes
- e.g. trend in 1-day, 20-days precipitation maxima seldom significant
- trends often positive

source: Kyselý, J. (2009) Trends in heavy precipitation in the Czech Republic over 1961–2005. International Journal of Climatology, 29, 1745–1758.

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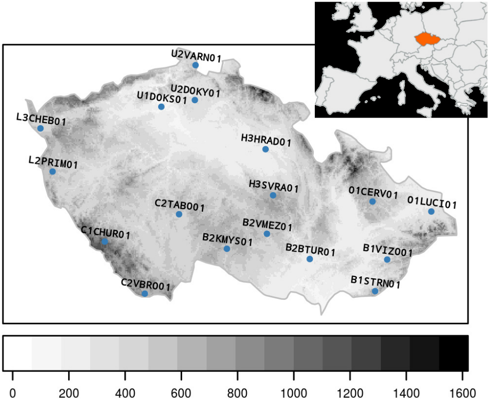
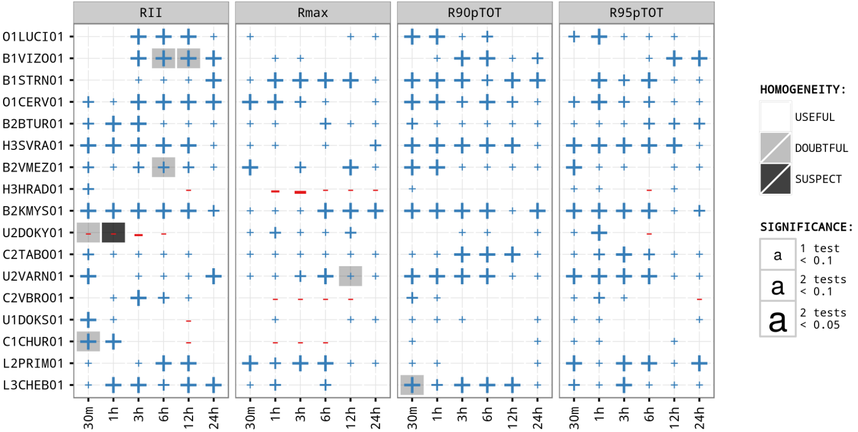
DATA



Observed data

- 17 stations
- 1962-2011
- warm season (April-September)
- 30-min time step
- 30-min, 1h, 3h, 6h, 12h, 24h temporal aggregations
- quality controlled data

Precipitation maxima



- significant increase in fraction of precipitation above 90th and 95th percentile in particular for short durations
- significant increase in rainfall intensity and precipitation maxima at several sites

source: Hanel, M. et al. (2016) Trends in characteristics of sub-daily heavy precipitation and rainfall erosivity in the Czech Republic. International Journal of Climatology, 36, 1833–1845.

Precipitation maxima - projected changes

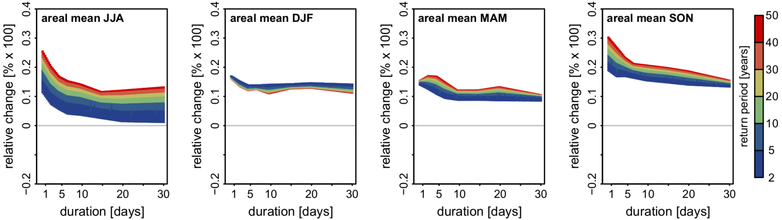
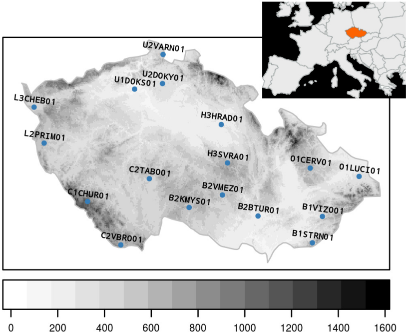


Fig. 7. Ensemble mean relative changes in the quantiles of the distribution of seasonal precipitation extremes between the periods 1961–1990 and 2070–2099. Changes are averaged over the four regions.

- ensemble of 15 regional climate models; non-stationary regional statistical model used for assessment of changes
- 10-20% increase in precipitation maxim for all seasons
- significant only for large quantiles in summer and all quantiles in winter

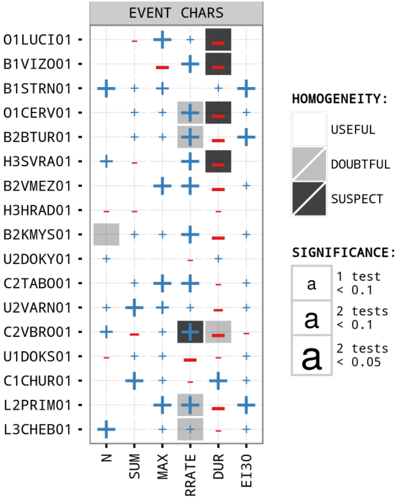
source: Hanel, M. and Buishand (2012) Multi-model analysis of RCM simulated 1-day to 30-day seasonal precipitation extremes in the Czech Republic. Journal of Hydrology, 412-413, 141-150.

Characteristics of precipitation events



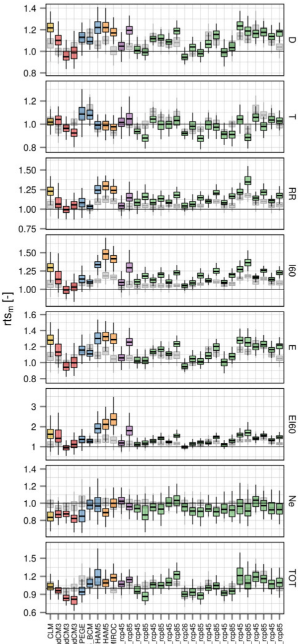
- data for the same 17 stations
- 1962-2011, 30-min time step, warm season (April-September)
- individual precipitation events defined based on USLE
- i.e. 6 hour minimum interevent time, min. 12.7 mm depth or intensity $>$ 6.35 mm/10 min

Characteristics of precipitation events



- consistent increase in event rain rate and decrease in event duration
- indication of increase in event maxima and event erosivity

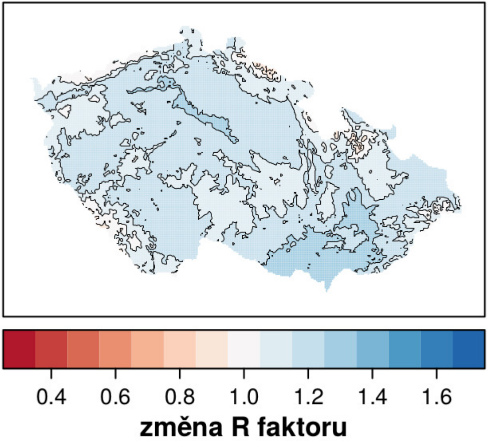
Precipitation maxima



- ensemble of 30 RCMs in hourly time step
- increase in event depth, rain rate, maxima and erosivity
- changes in general lareger for larger quantiles
- seasonal total due to heavy events more or less constant
- decrease in number of events per season

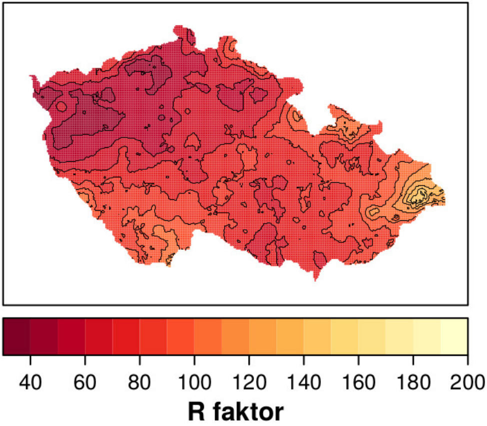
source: Svoboda, V. et al. (2016) Projected changes of rainfall event characteristics for the Czech Republic. Journal of Hydrology and Hydromechanics, 64(4), 415-425.

Rainfall erosivity



- ensemble of 30 RCMs
- statistical model accounting for differences in changes if rainfall erosivity between geographical location and elevation
- 17% average change for 2030-2050

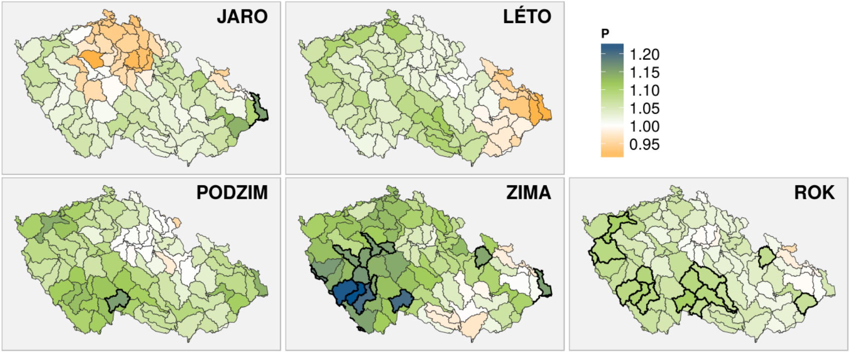
Rainfall erosivity



- ensemble of 30 RCMs
- statistical model accounting for differences in changes if rainfall erosivity between geographical location and elevation
- 17% average change for 2030-2050

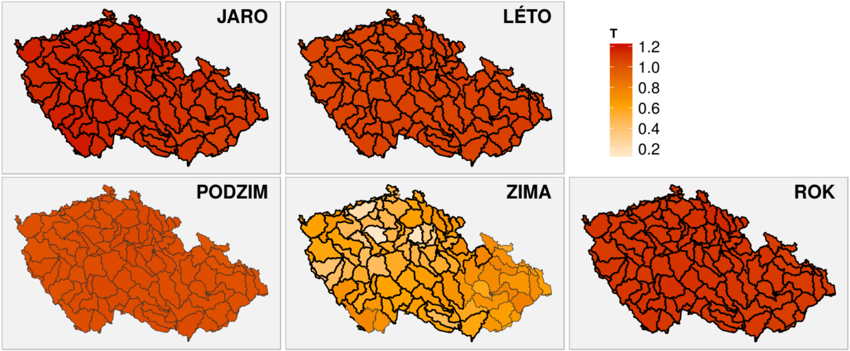
Hydrological balance and drought

Observed changes - Precipitation



- precipitation increases over most of the CR in most of the seasons (usually upto ca 10 %)
- except for ca 5% precipitation decrease in spring (middle and north Bohemia) and summer (north Moravia) season
- statistically significant only in few cases

Observed changes - Temperature



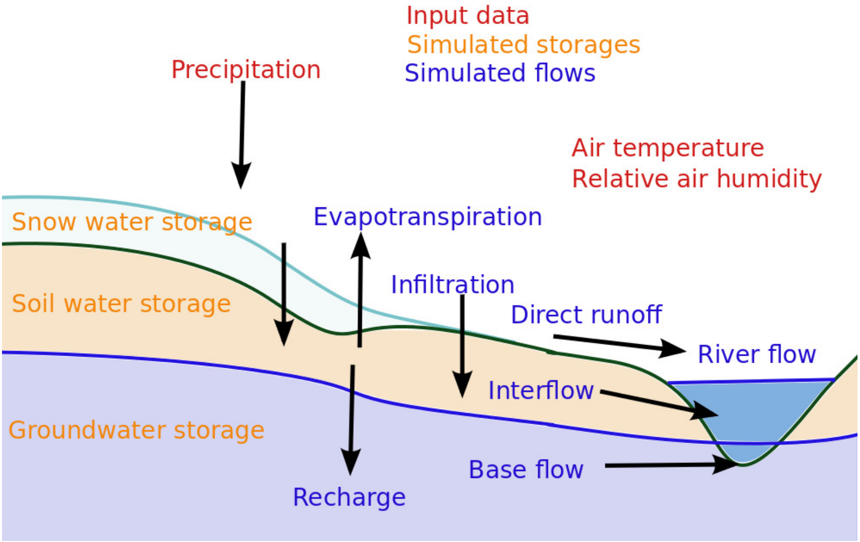
- increase over the whole area in all seasons
- in spring, summer and on annual average ca 1°C, autumn ca 0.6°C, winter 0.2 - 0.5°C
- often statistically significant

Evaluation of changes in components of hydrological cycle

- for precipitation and temperature sufficient (long, homogeneous and with good spatial coverage) exist
- long records but with lower spatial coverage exist for runoff, however, the trend detection is complicated due to water use
- other components of hydrological balance are difficult to assess at regional scale / limited data availability / short records

$\Longrightarrow$ therefore hydrological model Bilan used for assessing changes in hydrological balance

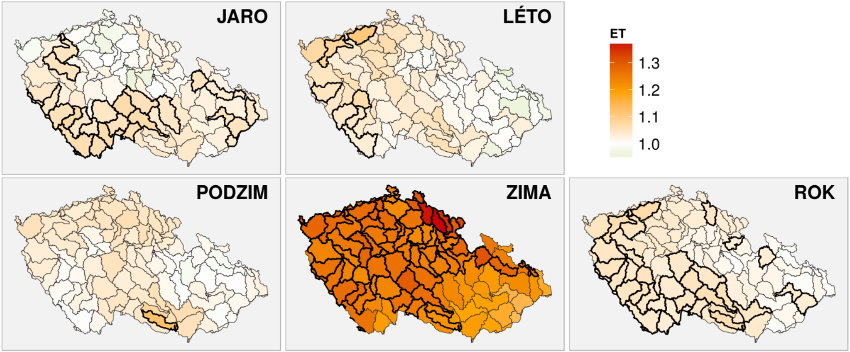
Bilan - Hydrological balance model



DATA

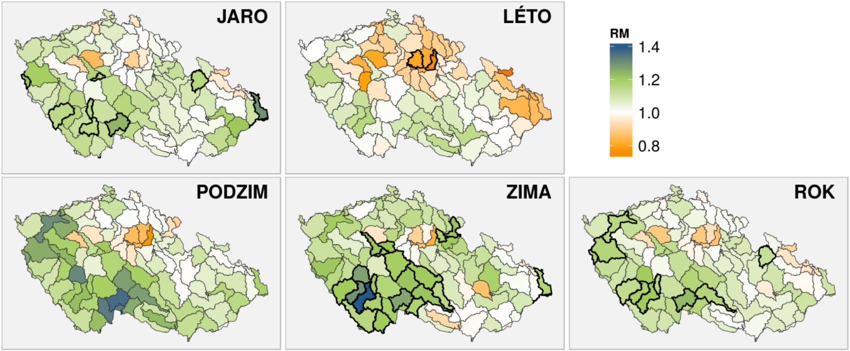
- 130 catchments covering ČR
- area ca 500 - 1000 km^2
- 1961-2015
- precipitation and temperature interpolated for catchments from gridded time series (resolution 25 km)

Evaluation of changes - Evapotranspiration



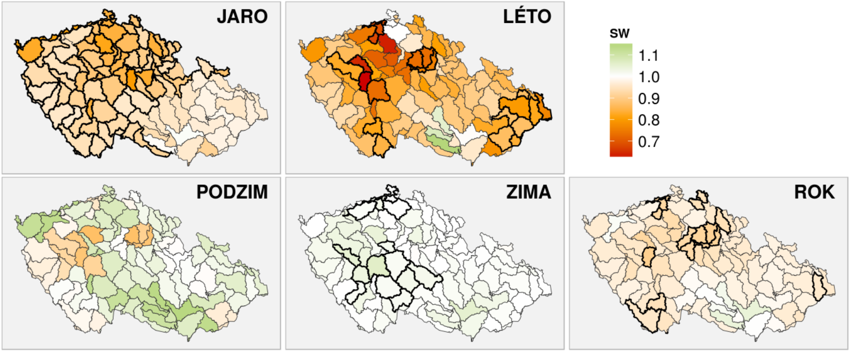
- dominant change is increase in potential and actual evapotranspiration in winter
- related to good water availability in winter

Evaluation of changes - Total runoff



- total annual runoff stable or slightly increasing
- decrease in summer runoff for most of the ČR
- statistically significant only in individual cases

Evaluation of changes - Soil water storage



- decrease in soil water storage in spring and summer (up to 30 %)
- decrease is statistically significant in Bohemia for spring and east Moravia in summer
- the changes are marginal in the rest of the year (though eventually statistically significant due to low variability in soil water storage in autumn and winter)

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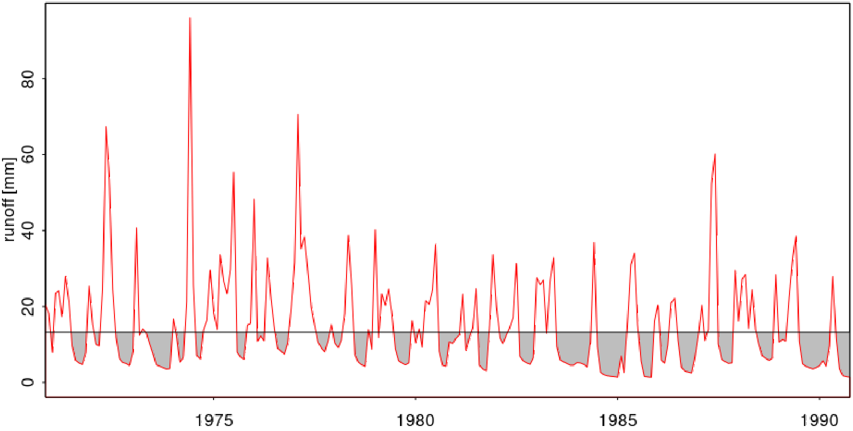
Deficit volumes



- detection of significant changes even more difficult (drought does not occur every year)

Deficit volumes

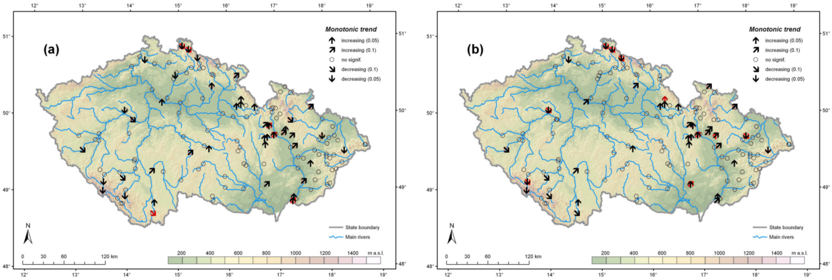


Figure 3. Spatial distribution of trends in annual deficit volumes V_{355} **(a)** and trends in annual numbers of days with discharge under the quantile Q_{355d} **(b)** in Czechia during the period 1961–2005 (black symbols – ABBS–MK test, red symbols – BHMLLESS–MK test).

- detection of significant changes even more difficult (drought does not occur every year)
- increasing deficit volumes in the easetern ČR, decreasing trends in the western ČR

source: Ledvinka, O. (2015) Evolution of low flows in Czechia revisited. Proc. IAHS, 369, 87–95.

Climate change impact assessment

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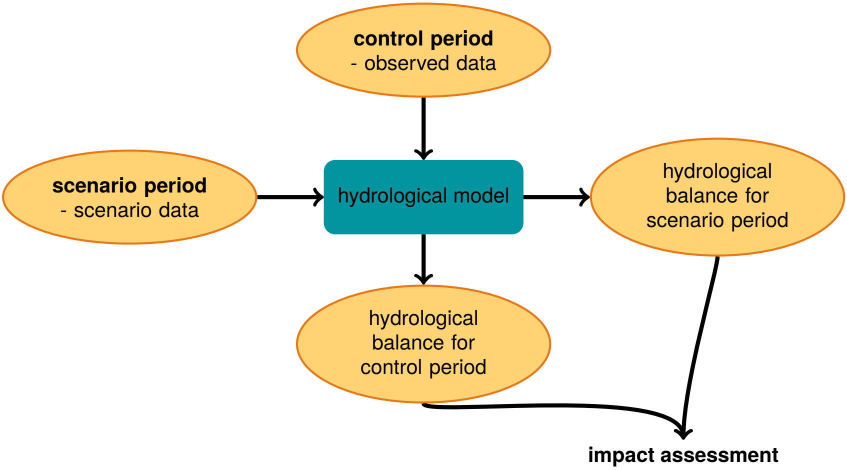
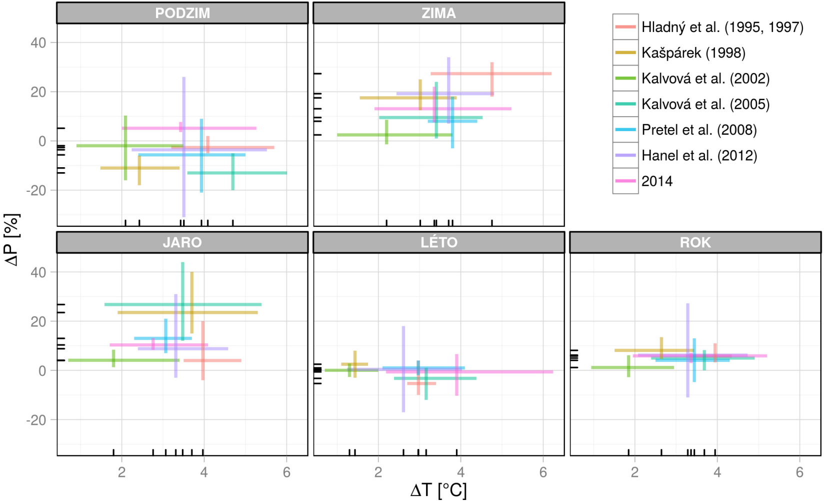
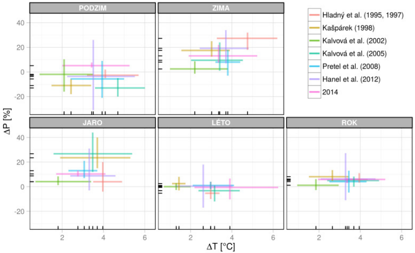


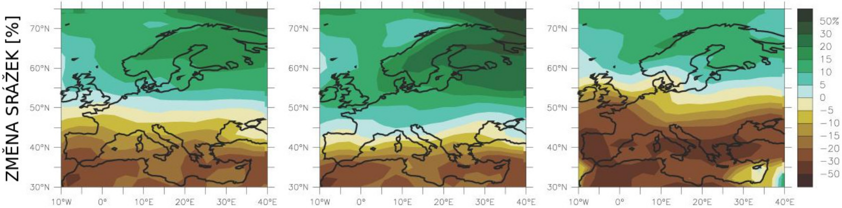
Climate change scenarios for ČR





What is the difference?

- spatial resolution (1 scenario for the whole ČR vs. 50/25/11 km grid)
- ensemble size (4 - several hundreds)
- temporal resolution



source: IPCC AR4 (2007)

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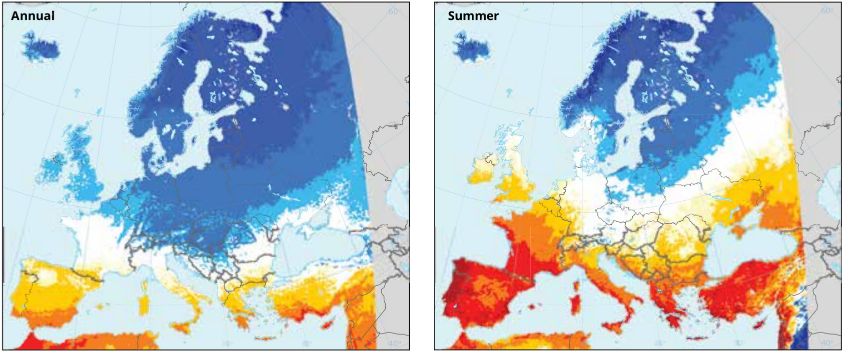
Map 3.8 **Projected change in annual and summer precipitation**



Projected change in annual (left) and summer (right) precipitation

% – 40 – 30 – 20 – 10 – 5 5 10 20 30

Outside coverage

0 500 1 000 1 500 km

Note: This map shows projected changes in annual (left) and summer (right) precipitation (%) in the period 2071–2100 compared with the baseline period 1971–2000 for the forcing scenario RCP8.5. Model simulations are based on the multi-model ensemble average of many different RCM simulations from the EURO-CORDEX initiative.

Source: EURO-CORDEX (Jacob et al., 2014).

source: EEA (2017) Climate change, impacts and vulnerability in Europe 2016. An indicator-based report. EEA Report 1/2017.

Projected changes (2071-2100 / 1980-2010) - Total runoff

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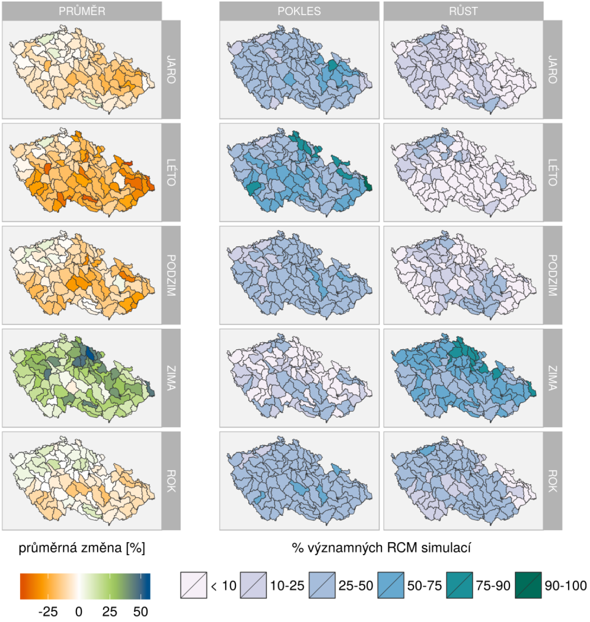
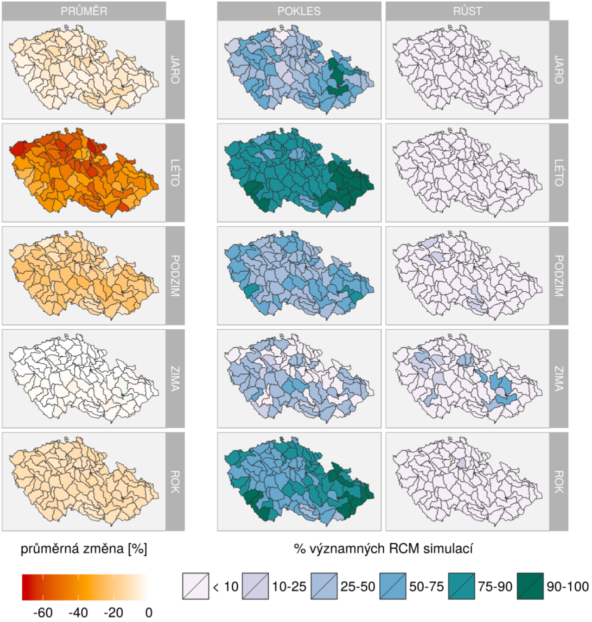


Change in total runoff

- clear changes only in winter and partly in spring
- annual changes rather uncertain

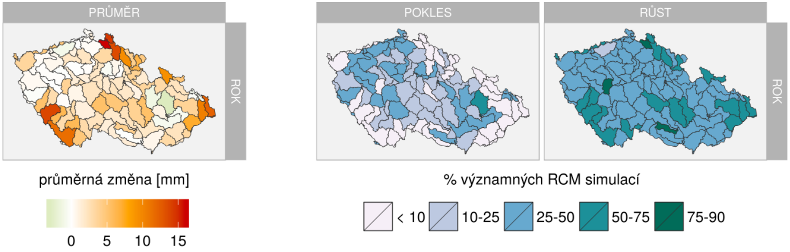
Projected changes (2071-2100 / 1980-2010) - Soil water storage



Change in soil water storage

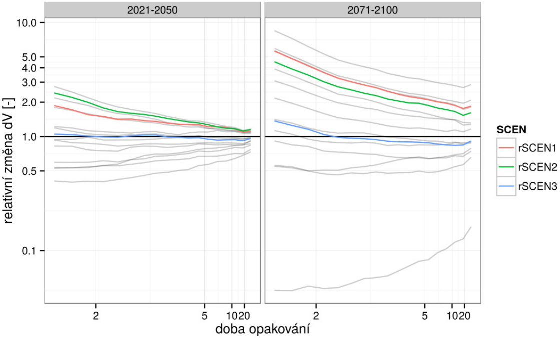
- clear decrease, esp. in summer

Projected changes (2071-2100 / 1980-2010) - Deficit volumes



- significant increase over most of the area projected by most of the climate models

Projected changes (2071-2100 / 1980-2010) - Deficit volumes



- larger increase of smaller deficit volumes at relative scale
- large uncertainty in the actual value of the change

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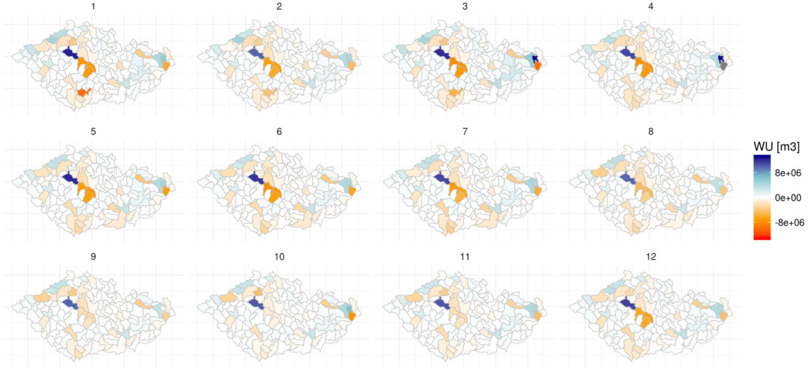
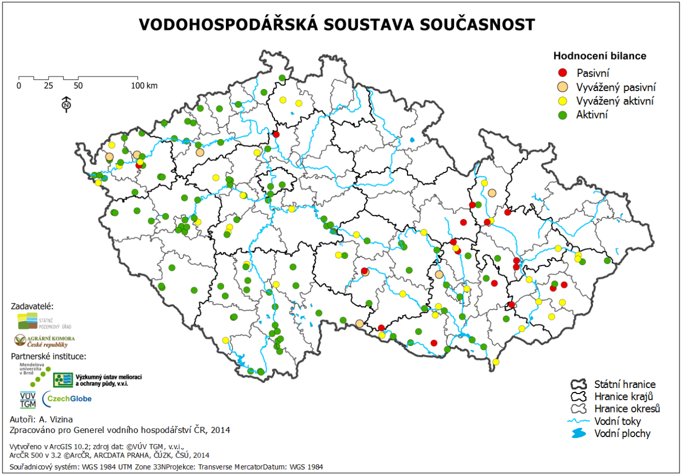
- taking into account water use

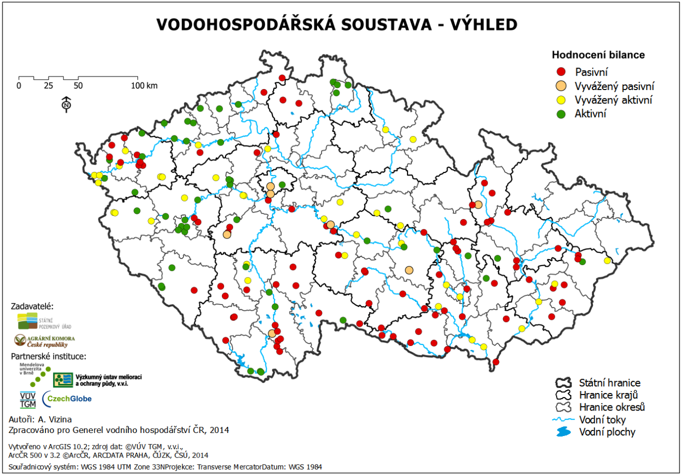


Assessment of water balance



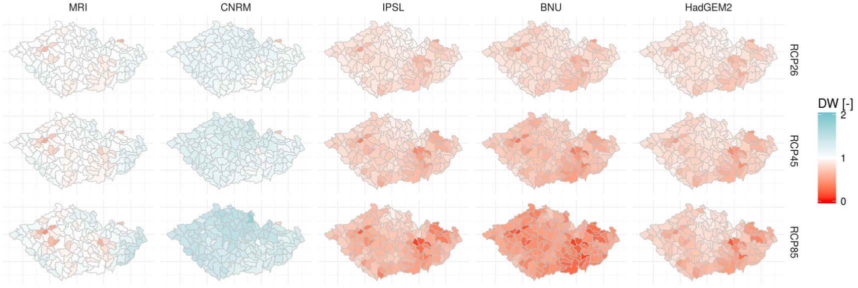
- already for current conditions there are catchments with passive water balance

Assessment of water balance



- already for current conditions there are catchments with passive water balance
- number is increasing in the future

Assessment of water balance



- 3 of 5 GCM project decrease in water availability in the period 2070-2100
- 1 GCM project increase in available water resources

ADAPTATION MEASURES

Adaptační opatření			Dopady v krajině					Dopady na průtoky				Dopady na odběry	Dopady na kvalitu vod	
			sucho			přívalové srážky		sucho			příval. povodně			
			vegetace		půda	obce	půda							
			Zhoršení mikroklimatu	Stres stávajících společenstev	Zvětšení větrné eroze	Zvětšení přímého odtoku	Zvětšení vodní eroze	Pokles průměru	Pokles minimálních průtoků	Zánik průtoků	Zvětšení maxim			*
Krajina	Organizační	Pozemkové úpravy	+	0	+	+	+	0	0	0	+	0	0	1
		Využití pozemků	+	0	+	+	+	0(-)	0(-)	0(-)	+	0	+	2
	Agrotechnická		0	+	+	+	+	0	0	0	+	0	+	3
	Biotechnická		0	0	+	+	+	0	0	0	+	0	+	4
	Rozšíření mokřadů		+	0	0	0	+	0	0	0	+	0	0	5
Toky a niva	Revitalizace toků		0	0	0	0	0	0	(+)	0	+	0	+	6
	Uvolnění nivy pro rozlivy		0	0	0	0	0	0	(+)	0	+	0	0	7
Urbanizovaná území	Zvětšení infiltrace srážkové vod		0	0	0	+	+	0	0	0	+	0	0	8
	Využití srážkových vod		0	+	0	+	0	0	0	0	+	+	0	9
Obnova a zřízení vodních nádrží	Jen zásobní		+	+	0	0	0	+	+	+	0	+	+	10
	Jen retenční		0	0	0	0	0	0	0	0	+	0	0	11
	Zásobní i retenční		+		0	0	0	+	+	+	+	+	+	12
Hospodaření s vodními zdroji	Převody vody mezi povodími a vodárenskými soustavami		0	0	0	0	0	+	+	+	+	+	+	13
	Zpětné převody vody uvnitř povodí		0	0	0	0	0	+	+	+	0	0	0	14
	Dočasné využití statických zásob podzemní vody		0	0	0	0	0	0	+	+	0	+	+	15
	Umělé infiltrace		0	0	0	0	0	0	0	0	0	+	0	16
	Řízené vícenásobné využití vody		0	0	0	0	0	0	+	+	0	+	0	17
	Zhodnocení a přerozdělení kapacit		0	0	0	0	0	0	0	+	0	+	0	18
Zmenšování spotřeby vody	Minimalizace ztrát vody ve vodárenských soustavách		0	0	0	0	0	0	0		0	+	0	19
	Využití ekonomických nástrojů		0	0	0	0	0	0	0	0	0	+	0	20
	Inovace závlahových systémů		0	0	0	0	0	0	0		0	+	0	21
Legislativní opatření	Racionalizace systému povolování odběrů vody		0	0	0	0	0	0	+	+	0	+	0	22
	Racionalizace stanovení min. průtoků		0	0	0	0	0	0	+	+	0	+	0	23
	Stanovení priorit pro kritické situace nedostatku vody		0	0	0	0	0	0	+	+	0	+	0	24
Dokonalejší čištění odpadních vod			0	0	0	0	0	0	0	0	0	0	+	25
		*	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	

source: Hanel, M. et al. (2011) Odhad dopadů klimatické změny na hydrologickou bilanci v ČR a možná adaptační opatření. VÚV T.G.Masaryka, 108 p.

CASE STUDY 1

Assessment of reduction of direct runoff and improving infiltration by land use changes (L. Kašpárek et al.)

- CN method
- assessment of land use changes

LULC change	retention increase [%]	rnf reduction [%] 100 mm precip	rnf reduction [%] 50 mm precip
meadow - wood	22.7	30.6	76.4
grassland - wood	82.1	58.7	93.6
agri - wood	121.1	65.9	95.7
agri - meadow	80.2	50.7	82.0

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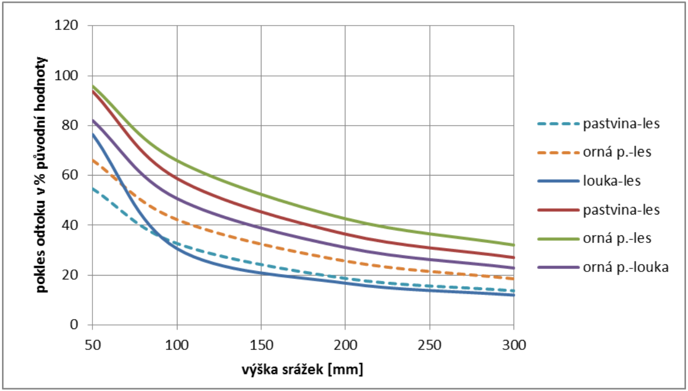

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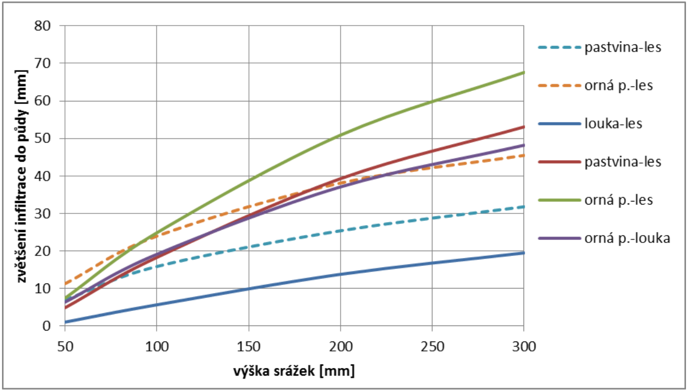
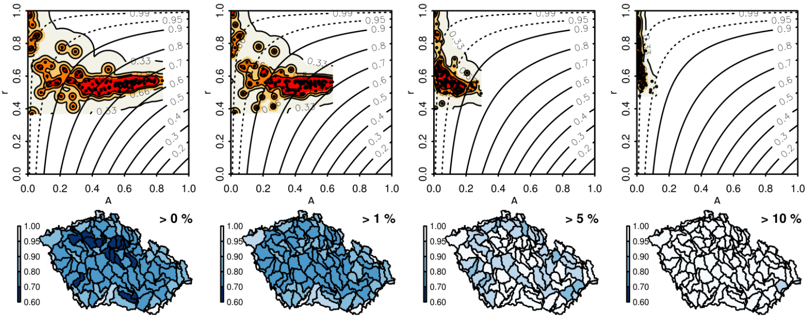
- assessment of land use changes



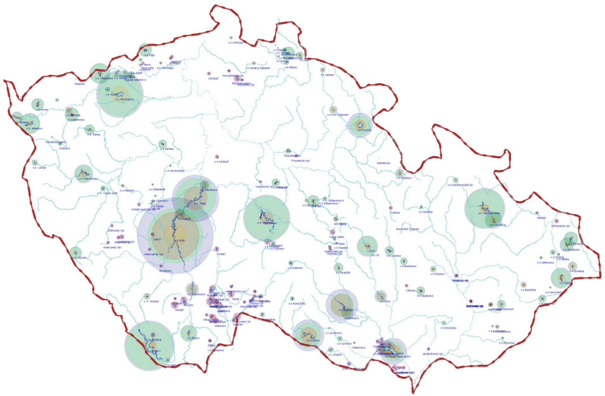
Assessment of reduction of direct runoff and improving infiltration by land use changes (L. Kašpárek et al.)

- CN method
- assessment of land use changes
- considerable local effects, however, expects transformation of all land of given category - real effects rather small from regional point of view



CASE STUDY 2

Protected localities for accumulation of surface water

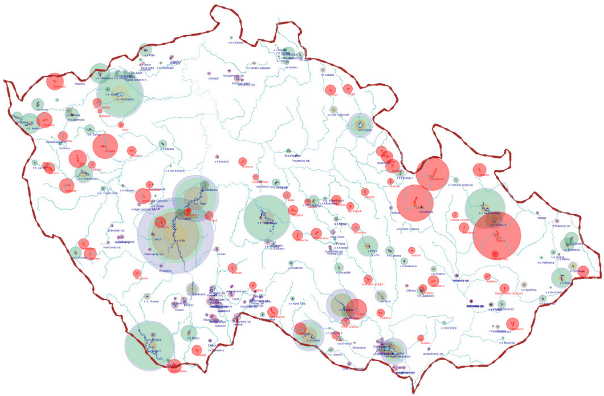


year	# number of localities
before 1988	> 400
1988	210
2005	186
2011	69
2013	65

?

- will be needed?
- will their function be secured?
- can they help considerably to improve the water balance?

Protected localities for accumulation of surface water



year	# number of localities
before 1988	> 400
1988	210
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2011	69
2013	65

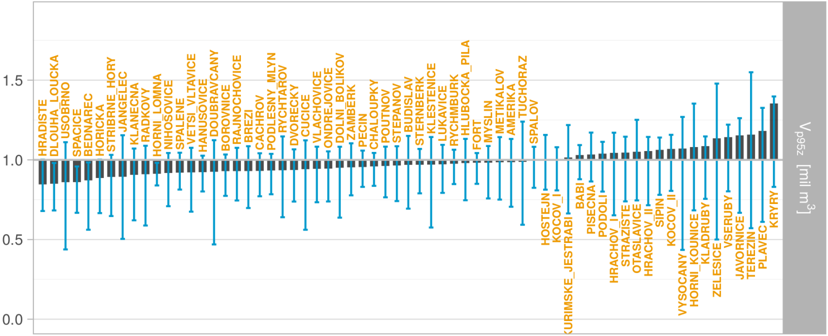
?

- will be needed?
- will their function be secured?
- can they help considerably to improve the water balance?

Will be needed?

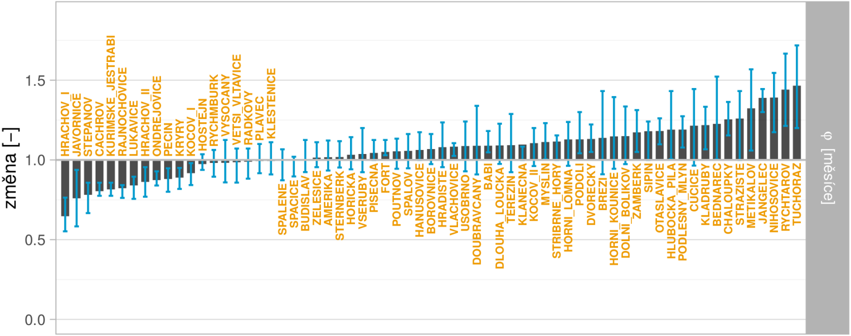
- partly answered by decreasing water availability and increasing risk of drought
- ? but are we able to secure enough water (or decrease demand) with other measures ?

Will their function be secured?



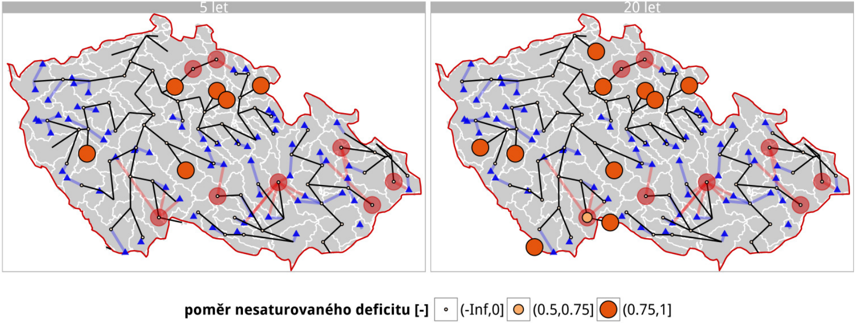
- changes in yield (secured with 95% reliability) are uncertain
- significant increase/decrease in length of the deficit periods

Will their function be secured?



- changes in yield (secured with 95% reliability) are uncertain
- significant increase/decrease in length of the deficit periods

Can they help considerably to improve the water balance?



- preliminary results indicate that deficit volume can be saturated at most of the catchments, provided there is a connection

Conclusions

- observed changes often insignificant although consistent with climate model projections
- climate model projections indicate increase in precipitation maxima, rainfall erosivity, drought occurence and drought severity
- changes in annual water balance not clear
- landscape resilience (reduction of soil erosion impacts and increase in soil water storage) can be improved with biotechnical measures. At the same time, these measures often lead to reduction of runoff and water resources availability
- river runoff and general water availability can be improved by water reservoirs at appropriate locations

- identification of appropriate combination of adaptation measures taking into account different purposes (human, ecosystem, environmental and landscape protection etc.) is a complex optimization problem
- complex evaluation of connected systems of measures has to be performed
- sound quantification of costs and benefits is necessary

Thank you for attention

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