Study on impact of the water resources management on projected future change of drought

Atmosphere and Ocean Research Institute, The University of Tokyo
Yusuke Satoh and Kei Yoshimura*

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- Summary

HI : **Human Impact** ← includes anthropogenic impact on terrestrial water cycle
(Human Intervention) Irrigation (river and groundwater)・reservoir opera

NAT : **Naturalized** ← natural but **not real any more**!!

To accommodate changing drought

Changing drought under climate change

- Its spatially-temporally large scale impact causes appreciable economic/human damage.
- Seriousness and spatial distribution of drought would be altered due to change in hydrometeorological cycle.

Water resource management (WRM) as adaptation tool

- alleviates impact due to natural variability and aims to stable water supply
- has potential to be a effective measure to avert altered drought

Need strategic preparation for this undesirable change !! It requires…

① Understanding about Change characteristics of drought
② Projection of vulnerable regions
③ Understanding of our adaptation capability
(effectivity of water resource management)

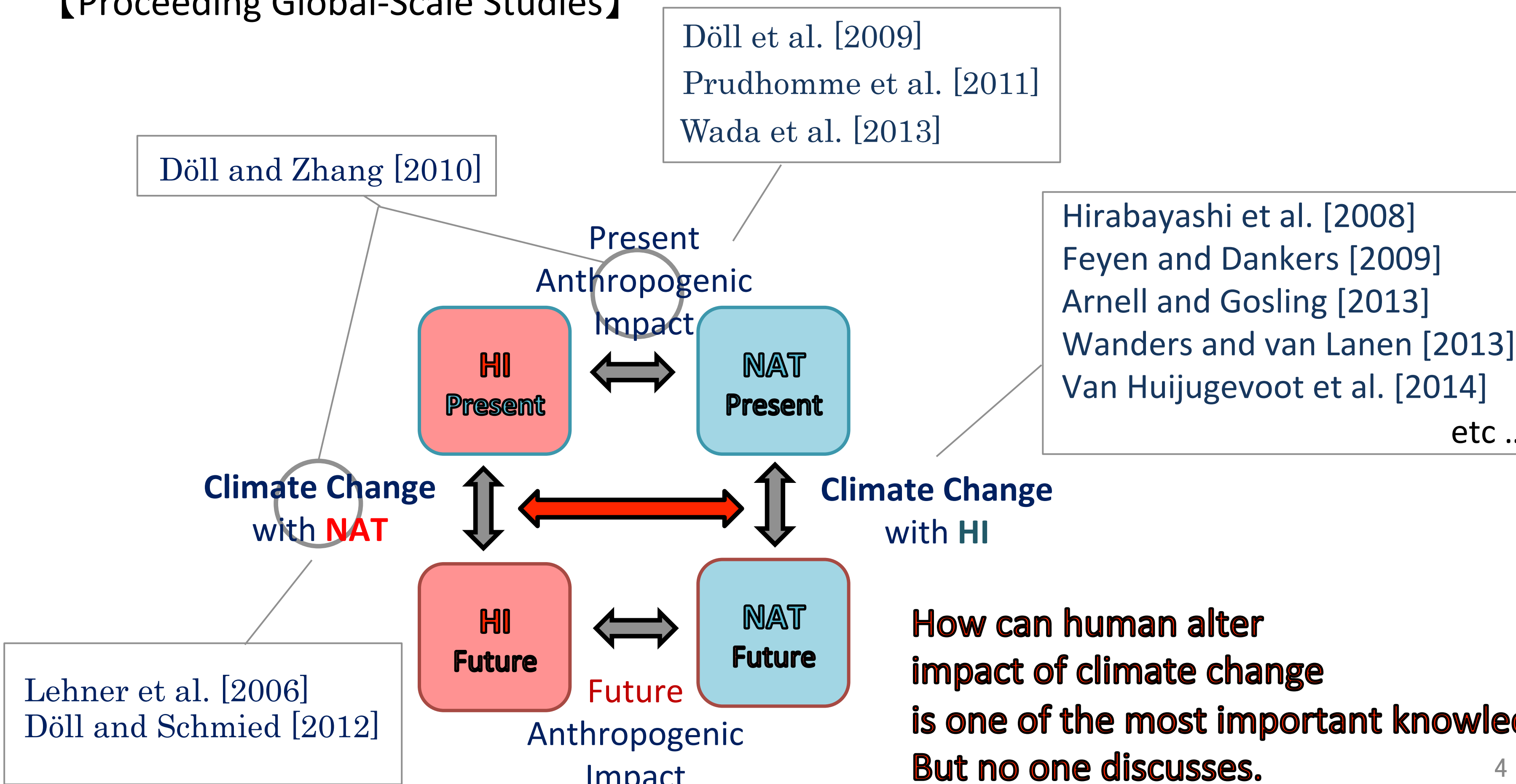
However,

Impact assessment of climate change about drought which considers anthropogenic effect on terrestrial hydrological cycle is still limited!!

Lack of consideration of human impact in drought study

- Impact assessment of climate change, especially about drought (Low flow), considering anthropogenic effect on terrestrial water cycle, is quite limited.

【Proceeding Global-Scale Studies】



How can human alter impact of climate change is one of the most important knowledge!! But no one discusses.

Our Challenges

1. How will the drought be with regards to the climate change?
2. How capable is our society with regards to the drought change?
3. When will the drought change be?

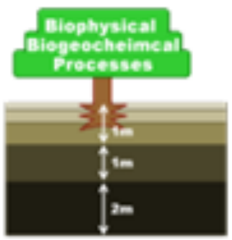
- In this presentation we try to reveal -

- Spatial characteristics of change and uncertainty of prediction
- Trend analysis for regional scale
- Effect of water resource management (WRM) on drought change
- Estimation of time left for preparation for drought change

Land surface model

HiGW-MAT

[Pokhrel et al. 2011]



LSM

MATSIRO

[Takata 2003]

Naturalized hydrological cycle

+

Crop growth & irrigation module

Human water withdrawal module

Reservoir operation module

Environmental flow requirement module

Ground water

Anthropgenic water resource management (WRM)

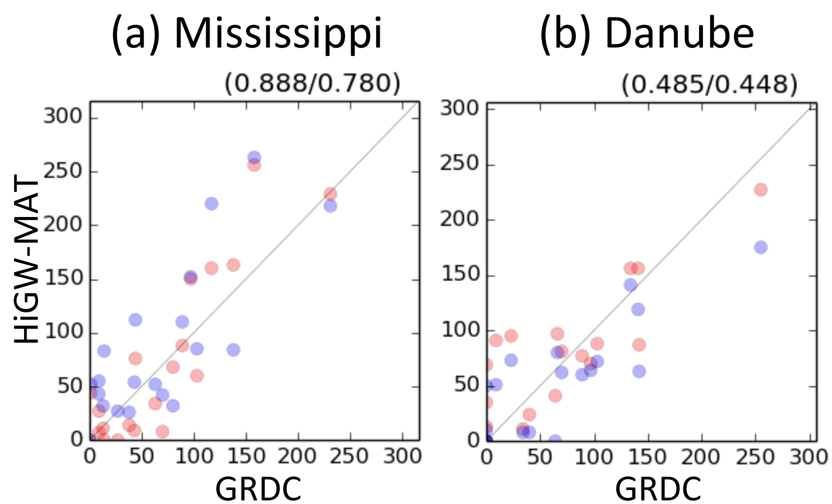
[Hanasaki 2008, 2010]

Effect of WRM on Stream drought

	Effect	
	River	**Crop land**
Withdrawal **(River irrigation, dom, ind)**	Discharge decrease ↓	Get wet, evaporation will increase ↑ runoff may increase ↑ Supply water through river irrigation
Ground water irrigation	Discharge may increase ↑	
Reservoir operation	Mitigate low flow ↑	

(Validation)

The number of drought day per year



Acceptable replodicibility as a large scale model

Hydrological Drought

Definition of "Drought"

- Stream drought
- If daily discharge is less equal than threshold, the day is drought day
  - Remove **shorter** drought event than **7 days**
  - Interpolate shorter interruption than 4 days which is between two drought events, and concatenate them [IT method; Fleig 2006]
- The number of drought days per year (**DDyr**) is analyzed here.

Daily variable threshold method [Stahl et al., 2001]

- Every grid and every day has own threshold by moving window sampling

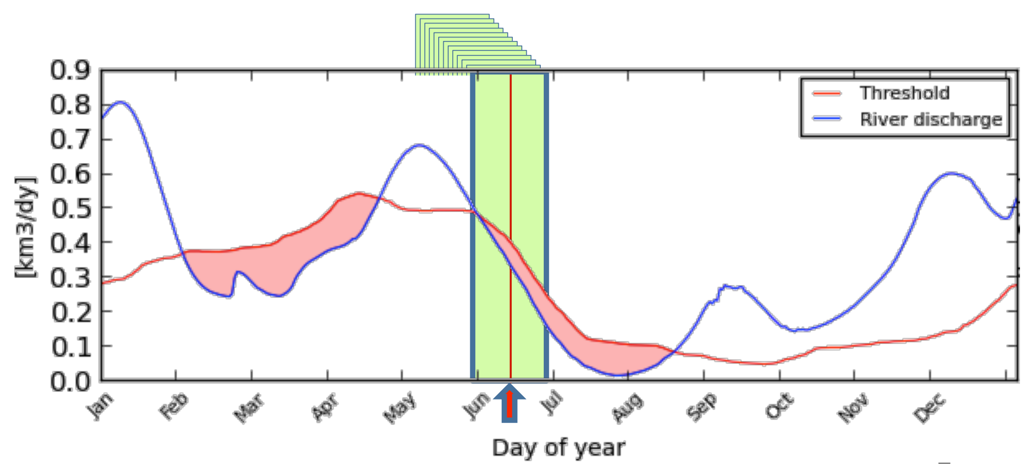
window size : 31day/yr
Period :20yr

▽

620 sample

▽

threshold : low 80 percentile



Simulation setting

Long-term continuous off-line simulation with 5GCMs

- Analysis period : **1980-2099** (120yr) ← Historical 1980-1999 / Future 2000-2099
- Spatail resolution : **0.5° ×0.5°**
- Scenario : **RCP8.5**
- Forcing : **ISI-MIP※1 forcing data** [Hempel et al. 2013]

GCM	Resolution	Nation	Institue
HadGEM2-ES	192 × 145	UK	Met Office Hadley Centre
IPSL-CM5A-LR	96 × 96	France	Institut Pierre-Simon Laplace
GFDL-ESM2M	144 × 90	USA	NOAA Geophysical Fluid Dynamics Laboratory
MIROC-ESM-CHEM	128 × 64	Japan	JAMSTEC, AORI, NIES
NorESM1-M	144 × 96	Norway	Norwegian Climate Centre

【Assumption】

- Future spatial distribution of Land use（Irrigation area，Reservoir）is same as that of year 2000
- Unlimited ground water pumping

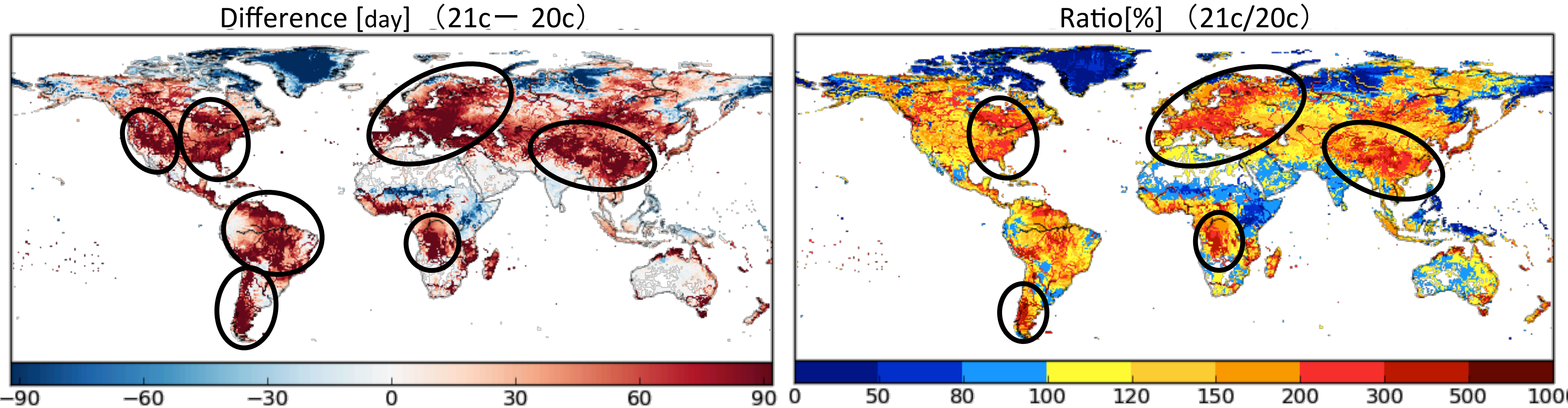
※1：Inter-Sectoral Impact Model Intercomparison Project

Result 1

Change of drought days due to climate change

1980-1999 vs 2080-2099

HI, RCP8.5
Ensemble Mean of 5GCMs



- Drought will increase in **70.4%** in global land area, decrease in 23.9%
  (NAT: increase in 81.6%, decrease in 15.7%)

- Absolute change in increase is larger than that in decrease.

- Increase by more than 90 days in **N. America**, **S. America**, **Central Africa**, **Europe～Asia**

  More than twice (except Western USA)
  Corresponds to highly populated area
  ⇒ **Vulnerable area for drought**

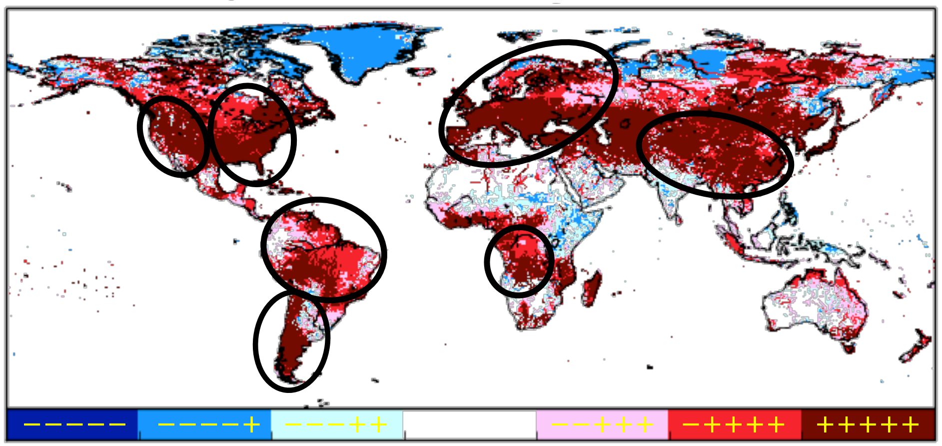
Result 2

Uncertainty evaluation

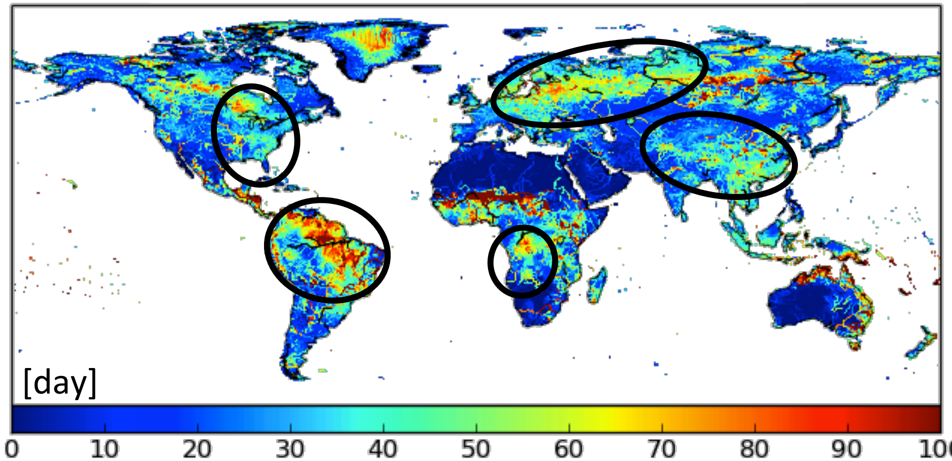
1980-1999 vs 2080-2099

HI, RCP8.5
Ensemble Mean of 5GCMs

Agreement between 5GCMs



Std in change of DDyr between 5GCMs



Agreement of increase-decrease trend between 5 GCMs (Left)

- Agreement in increase trend is good (Especially distinct increase show even better agreement)
  → **Projection of large increase tends to be robust.**
- Decrease around low-middle latitude show worse agreement

Standard deviation of change between 5 GCMs (Right)

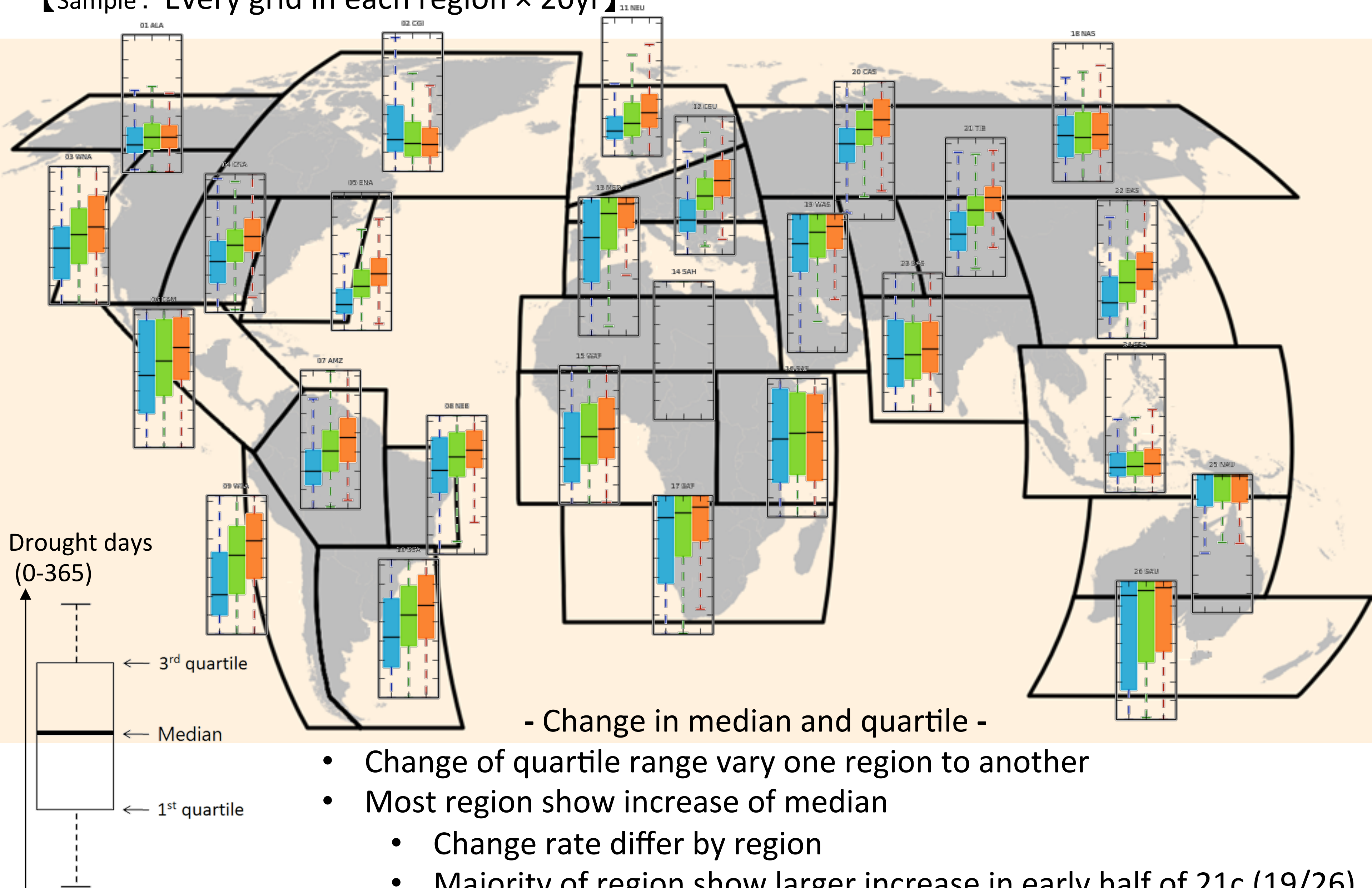
- Change vary much even if all GCM agree (Particularly variability is large in Amazon and Sub-Sahara.)
- Areas where drought will increase due to precipitation decrease have small variability,
  → expressing better robustness.
- Central-Asia where drought increase because of evaporation increase also shows small variability

Result 3

Trend analysis for regional scale

【Sample： Every grid in each region × 20yr】

Hist : 1980-1999
Mid : 2045-2064
Far : 2080-2099

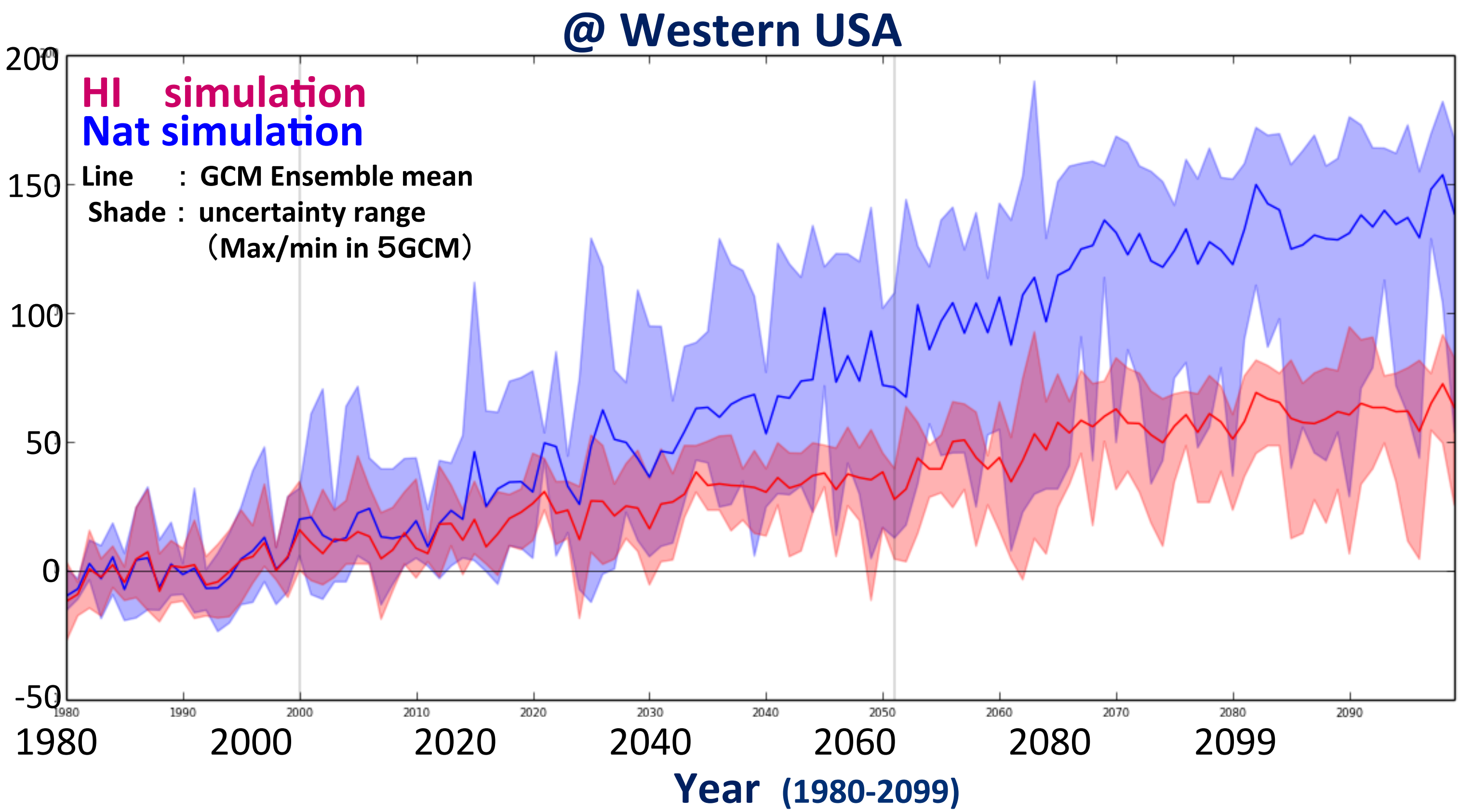


Drought days (0-365)

- Change in median and quartile -

- Change of quartile range vary one region to another
- Most region show increase of median
  - Change rate differ by region
  - Majority of region show larger increase in early half of 21c (19/26)

Time series variation of regional median



【HI vs NAT】

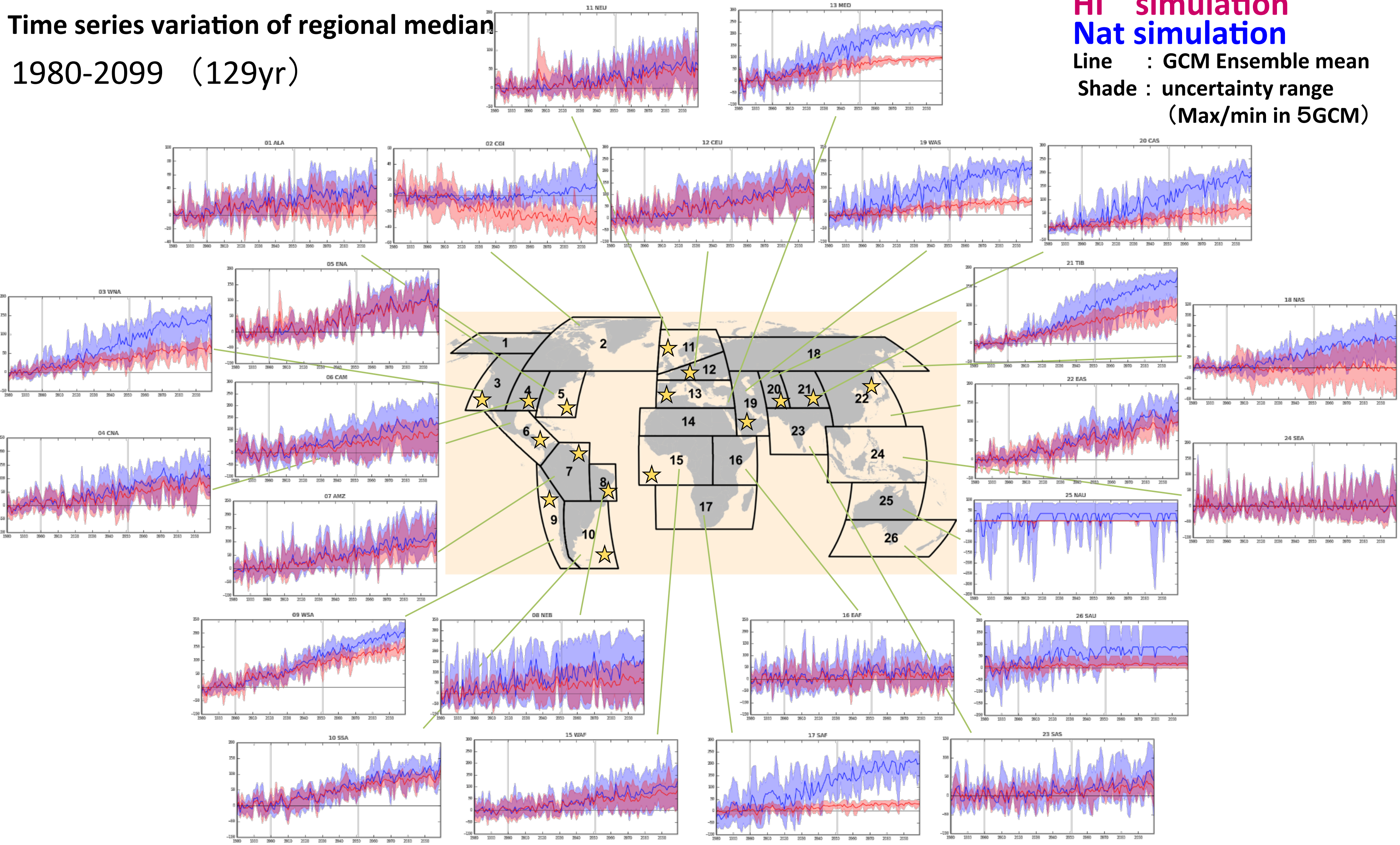
Anthropogenic water resource management can

- Alleviate interannual variation → alleviate uncertainty of projection, too
- Alleviate increase rate → Many proceeding study overestimate ??

Time series variation of regional median

1980-2099　(129yr)

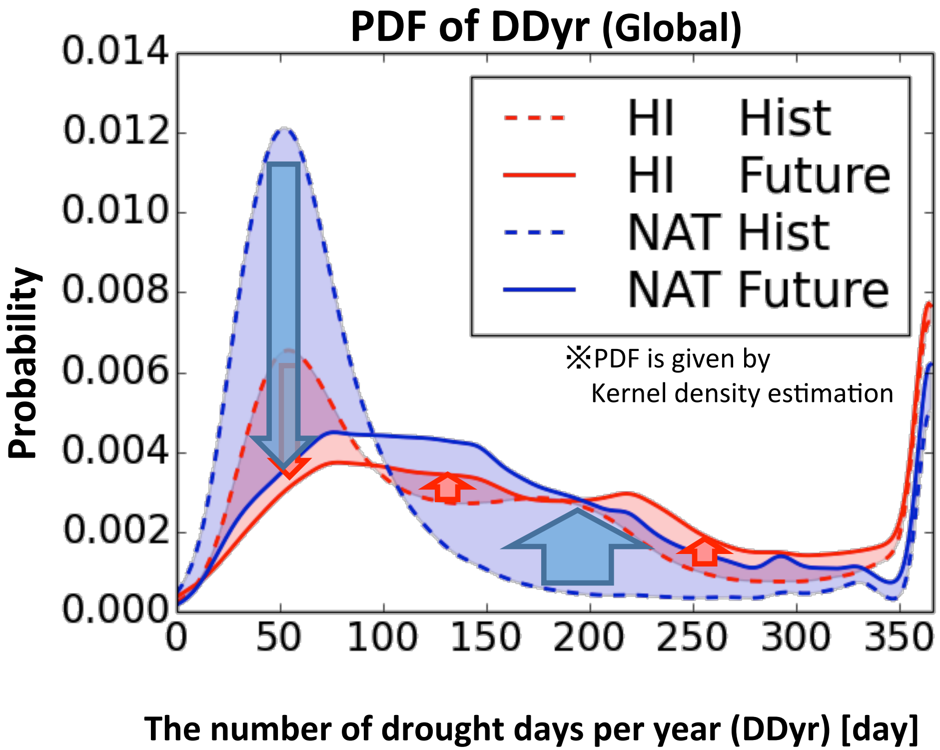
HI　simulation
Nat simulation
Line　: GCM Ensemble mean
Shade : uncertainty range (Max/min in 5GCM)

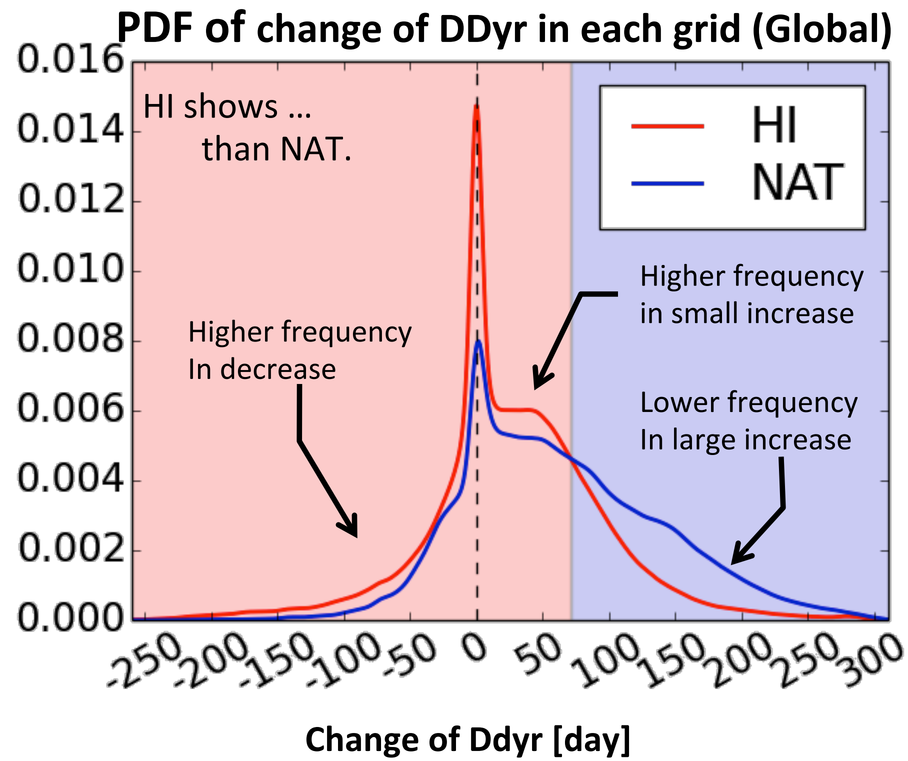


- Almost linear increase in many region.　(Except region 14,16,18,23,24,26. Decrease in region 2)
- Water resource management alleviate short-term variation and long-term change .

⇨ Change rate, besides absolute change, is very important in terms of adaptation.

HI vs NAT in probability distribution





【HI vs NAT about change due to climate change】

- Higher frequency of more DDyr in HI in historical period.
- Small increase of frequency in larger (100~250day) DDyr in HI (Left)
- Alleviate increase of frequency in larger change of DDyr in HI (Right)

➡ **Change due to climate change is more moderate and practically it's easier to adapt in world with water resource management than naturalized world.**

How long is the time left for us to prepare for the change?

Back ground

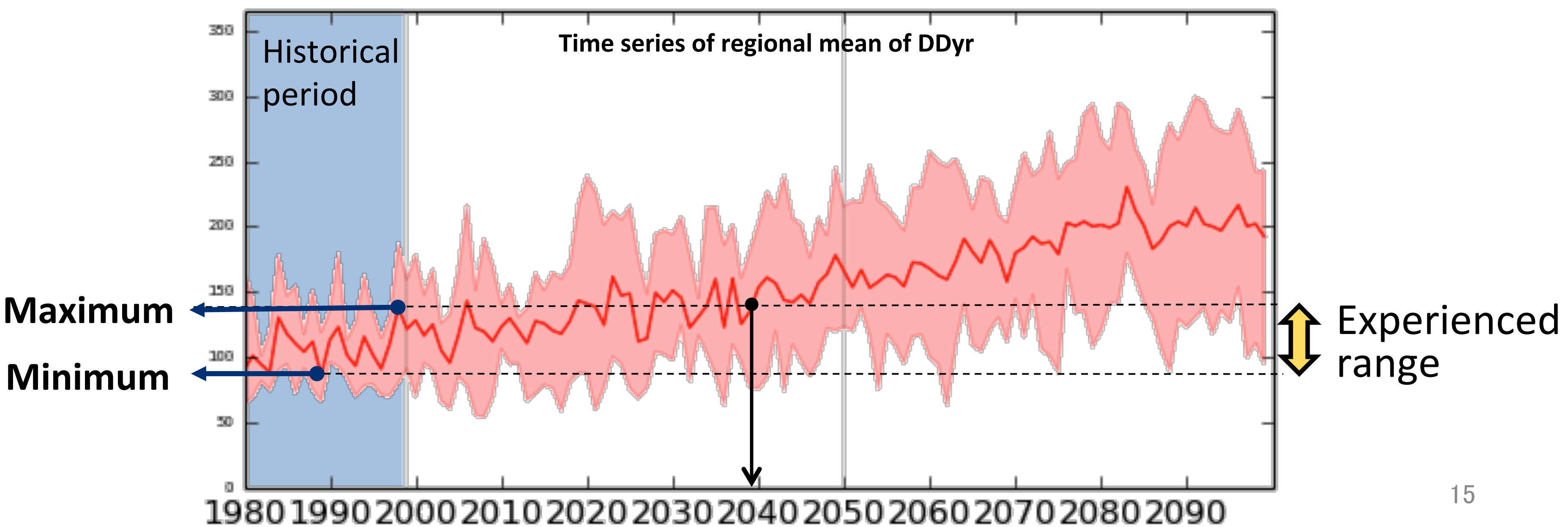
- Existing infrastructures are planed empirically/statistically based on historical data
- If statistical characteristics will get different from historical one, new countermeasure would be required

Timing of perception change for drought (TPCD)

When will drought sift into unprecedented phase?

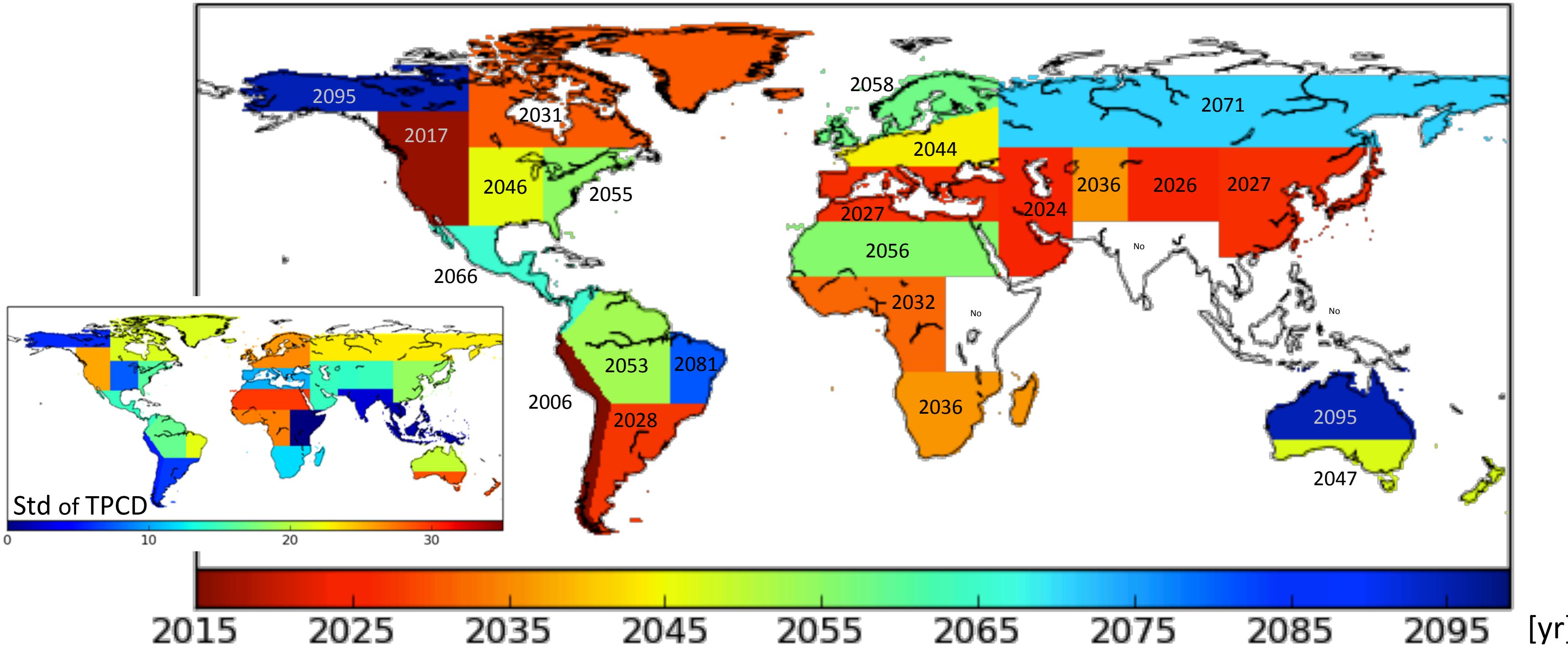
- Timing at which drought deviate from experienced range and never return the range
- Analyzed time series of regional mean

[Mora et al. 2013]



Result 6

TPCD : When will drought sift into unprecedented phase?



- Especially early TPCD are projected around **Chile**(2006), **Western USA** (2017), **The mediterranean region** (2027), **Middle East**(2024), **China**(2026,2027), **Central Asia**(2036),
- The analysis indicates that 13 out of 26 regions show significant signal until 2050's even considering the spread of ensemble GCM projections and will experience unprecedented drought condition.

➡ **Remaining time for some region to prepare for the change are short. we need strategic plan and prompt action.**

Summary

1. **How will drought in global change under climate change?**
    - Drought will increase in 70.4% in global land area
    - Increase by more than 90 days in N. America, S. America, Central Africa, Europe～Asia
    - Projection of large increase tends to be robust.
    - Majority of region show larger increase in early half of 21c
2. **How and how much is current our society's adaptive capacity against expected drought-increase?**
    - Water withdrawal accelerates low flow and lead drought
    - Water resource management alleviate short-term variation and long-term change .
3. **How long is the remaining time for us to prepare for the change?**
    - 13 out of 26 regions show significant signal until 2050's even considering the spread of ensemble GCM projections
    - we need strategic plan and prompt action

Remarks

- Regarding “change trend ”and “strong signal”, we can discuss in a experimental framework with existent large-scale model.
  - → Strategic plan is indispensable for drought management because it takes long time and cost huge sums of money.
  - → To understand climate change as a global problem, we need both small and large scale information.

- In order to plan practical adaptation strategy, we have to provide more information. Good quantitative information. 「How much and what do we need to prepare??」
  - → Besides reproducibility of forcing data, due to special resolution, it is difficult to explain projection of large-scale LSM quantitatively.
  - → With high resolution in mind, improvement of model is necessary.

- Balance between demand and supply is key in next step
  - Stream drought here is just natural phenomenon, and it may not be disaster.
    - strong signal of increase in stream drought indicate less terrestrial water, suggesting the possibility of increase in risk of drought as disaster.
  - More direct way to project change in drought risk is need.
    - Estimation of demand is the biggest charange

Thank you for listening.
Any question or suggestion??

- Summary -

1. **How will drought in global change under climate change?**
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   - we need strategic plan and prompt action