Climate change impacts on water availability, dry spells and hydrological droughts in Japan: Dynamic and thermodynamic contributions

Masamichi Ohba (CRIEPI, Japan) [oba-m@criepi.denken.or.jp], R. Arai, T. Sato, M. Imamura, Y. Toyoda Weather and Climate Extremes, 38, 100523 (2022)

Science direct

1. Introduction

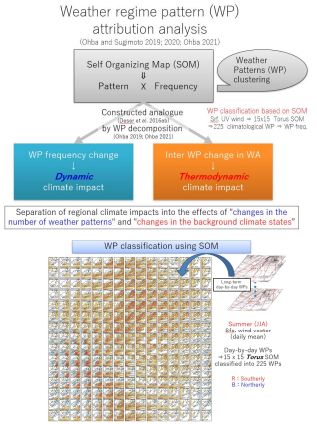
- ✓In recent years, there are concerns that global warming will lead to problems such as increases and decreases in river flows due to changes in precipitation properties and changes in the seasonal progression of snowmelt due to earlier snowmelt.
- ✓It is necessary to consider adaptation to climate change risk from various perspectives, such as reviewing dam reservoir operations and replacing facilities.
- ✓Under such circumstances, large ensemble global warming projection data within high spatiotemporal resolution have begun to be developed in Japan and are now available for use in global warming impact assessment.
- ✓Long-term projections of future river discharge show declining future snow water resources, which may reduce available water resources during summer periods in the future ⇨ Concerns about increased risk of summer drought
- ✓However, few studies have provided detailed analysis of future changes in available water resources and precipitation-free water in the Japanese region.

This study evaluates the areal impact of global warming on the amount of available water resources and the number of days without precipitation, and the hydrological droughts using the latest climate projection data and analyzes its meteorological factors.

2. Data and method

Data: d4PDF climate simulations (Mizuta et al. 2017; Ishii and Mori 2020)
(by MRI climate model：GCM/60km, RCM/20km)
Large number of ensemble simulations for probabilistic impact assessment of climate effects

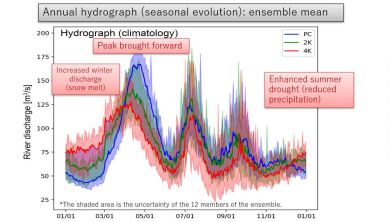
- ✓Historical present climate simulations (PC): 1951 - 2010 (60-years x 30-ensemble members: 1800 years)
- ✓Global warming experiment (4K warming climate): (60-years x 30-ensemble members: 1800 years)
- ➢ For summer: June ~ August
- ➢ (Fresh) Water availability (WA): Precipitation minus evapotranspiration (P-ET: mm)
- ➢ Continuous dry days (CDDs): Number of consecutive days with daily precipitation less than 1 mm/day



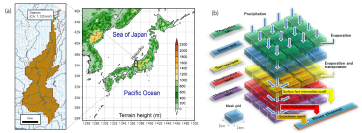
3.3 Hydrological droughts

- ✓ **River discharge simulation:** We used a hydrological model "HYDREEMS" to simulate river discharge. This is a distributed hydrological runoff model that analyzes river flow. Six long-term simulations of streamflow were conducted under each of the climates.
- ✓ **Atmospheric data:** Simulated climate taken from "d4PDF" that was dynamically downscaled for the Japanese region to **5-km RCM (31-years x 12-ensemble members: 372 years, downscaled from d4PDF 20km RCM)**.
- ✓ **Target region:** We evaluated the impact of climate change on snowmelt discharge within the Shogawa River (Class A river) basin in mountainous central Japan. Most of the basin is designated as a "**special heavy snowfall area**".

*Precipitation: statistical bias correction method (Watanabe et al. 2020) applied based on observed values (1-hour AMeDAS station obs.) with snowfall capture rate correction (Masuda et al. 2019).



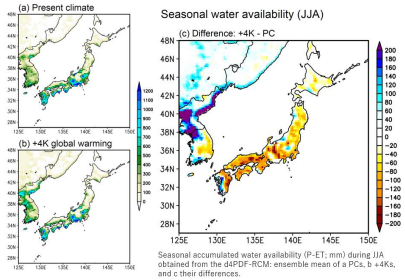
✓ Significant changes in hydrologic statistics due to climate change
✓ Change in the timing of snowmelt runoff from spring to winter with decrease in peak flows
✓ An increase in the occurrence of annual maximum flows in winter



(a) Topographic map of Japan and location of the Daimon River basin study area. (b) Schematic diagram of HYDREEMS.

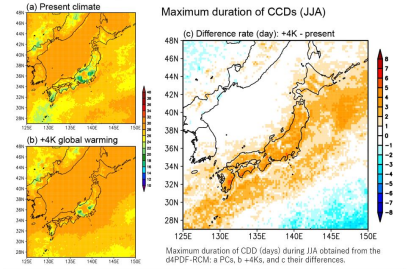
3. RESULTS

3.1 Future discharge changes in water availability and dry spells



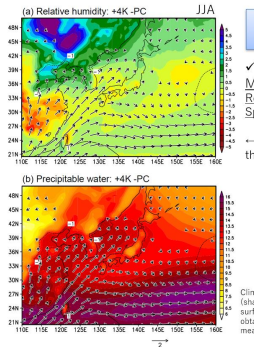
Seasonal accumulated water availability (P-ET; mm) during JJA obtained from the d4PDF-RCM: ensemble mean of a PCs, b +4Ks, and c their differences.

➢ Accumulated freshwater availability are projected to decline in many regions in the future.



Maximum duration of CDD (days) during JJA obtained from the d4PDF-RCM: a PCs, b +4Ks, and c their differences.

➢ Extreme CDD events will also be intensified in the most of region
→Water resources will become more important (especially for late spring-early summer dams)



Climatology of monthly-mean (June–August) a relative humidity (shade; %) and b precipitable water (shade; kg m²) with horizontal surface wind (vector; m/s) for differences between +4Ks and PCs, obtained from the d4PDF-GCM. The Black contour represents the mean sea level pressure (hPa).

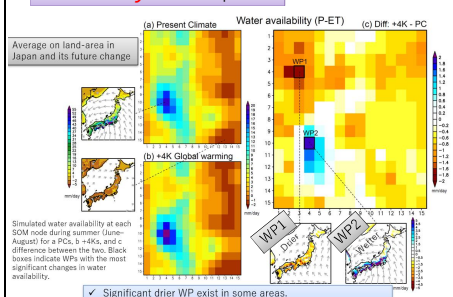
Difference in large-scale environmental filed

✓ Future change
Mid-latitudes around Japan:
Relative humidity decreased in western Japan
Specific humidity increased

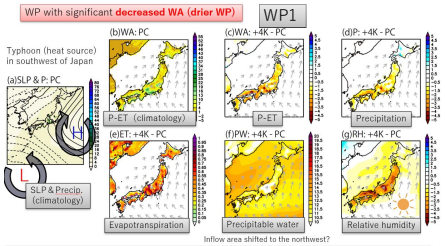
←Drier conditions are seen from the south of the continent to Pacific High.

3.2 Weather patterns leading to changes

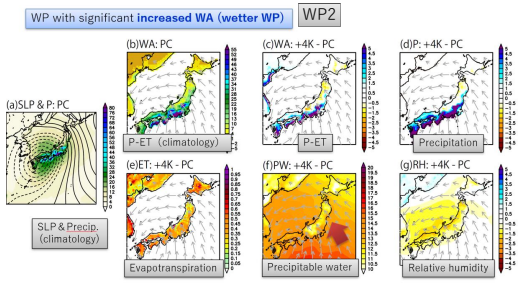
***Thermodynamic* impact**



✓ Significant drier WP exist in some areas.
✓ Conversely, wetter WP also exist.
⇨WWDD (wet-get-wetter, dry-get-drier) occurs even among WP
⇨They cancel out each other in total.



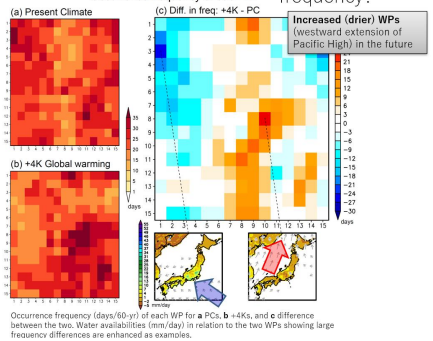
- Drying is significant under WPs in which the Pacific high east of Japan strengthens-extends westward due to the meridional teleconnection caused by typhoon southwest of Japan.
- Under future climate, the relative humidity is reduced, and the water vapor inflow is small.
⇨ Significant decrease in WA (negative surface water balance) during the relevant WP.



- Precipitation associated with typhoons will increase.
- The increases in evapotranspiration are weaker than in other WP.
- Air inflow from areas with large water vapor increase
⇨ Humidity decrease is small, and WA increases due to high water vapor inflow.

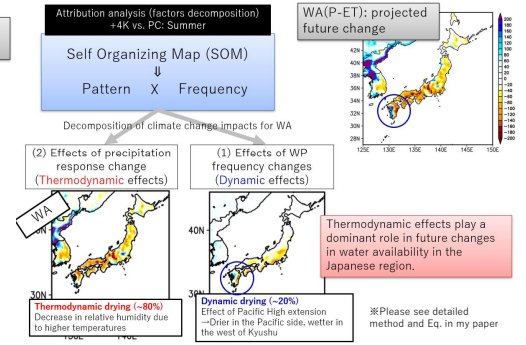
***Dynamic* impact**

How about the WP frequency?



Occurrence frequency (days/60-yr) of each WP for **a** PCs, **b** +4Ks, and **c** difference between the two. Water availabilities (mm/day) in relation to the two WPs showing large frequency differences are enhanced as examples.

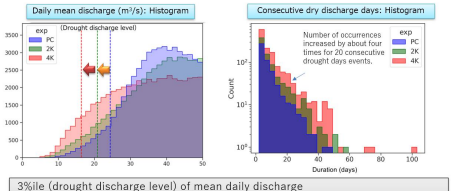
Contribution of Thermodynamic/Dynamic



Thermodynamic effects play a dominant role in future changes in water availability in the Japanese region.

※Please see detailed method and Eq. in my paper

Future changes in hydrological droughts



3%ile (drought discharge level) of mean daily discharge
⇨ **15/33% reduction at +2K/+4K**

Number of consecutive days below the 3%ile value of discharge in PC (drought discharge)
Both the number of occurrences and maximum duration are projected to more than double in +4K (in 372-years run)

- ✓ The climate projections exhibited a reduced WA in the majority of Japan, consistent with increases in both frequency and duration of dry spells.
- ✓ The impacts of climate change on water availability vary by WP, with a significant increase in dry conditions under WPs with intensified climatological Pacific high over eastern Japan.
- ✓ The decompositions of climate change impacts by WP analogs revealed that thermodynamic and dynamic effects account for approximately 80 and 20% of WA change, respectively.
- ✓ Additional hydrological model simulations show that the drought discharge decreased by 33 (15) % under the +4-K (+2-K) warming climate, and the number of consecutive hydrological drought days increased significantly unprecedent level.