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Future changes of photovoltaic power generation on climate change simulated by CORDEX II multi-RCMs over East Asia

(Park and Cha et al., in prep.)

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*Contributions: CORDEX-EA modelling teams in South Korea

Introduction

❖ East Asia is a highly industrialized region with high CO_2 emissions from fossil fuel use.

❖ Therefore, to achieve the goal of the Paris Agreement on CO_2 reduction, an increase in the production of renewable energy such as photovoltaic (PV) is required in this region.

❖ The PV power generation is directly affected by weather and climate.
- Surface down-welling shortwave radiation (RSDS) directly affects solar energy production, and surface air temperature (TAS) and surface wind speed (SFCWIND) affect solar panel efficiency.

❖ To develop an efficient and reliable future solar energy production policy, detailed investigations of the current and future changes in the climate variables affecting solar energy production and PV power potential production (PVpot) are needed.

❖ This study investigated future changes of PVpot and climate variables affecting it using CORDEX-East Asia phase 2 RCMs with 25km horizontal resolution forced by multi-GCMs (HadGEM2-AO and MPI-ESM-LR) over East Asia.

Observation and model datasets

❖ Observation dataset

- ERA5
  - Monthly surface solar radiation downwards, 2m temperature, and 10m wind speed (1981-2005)
  - 0.25° X 0.25° horizontal resolutions covering the Earth

❖ RCM datasets

- Historical experiment: 1981-2005 (25 years)
- RCP8.5 scenario: 2070-2099 (late 21st C, 30 years)
- 6 CORDEX-EA phase II regional climate models (RCMs) in 3 types driven by HadGEM2-AO and MPI-ESM-LR GCMs
  - HadGEM3-RA, SNURCM, and CCLM performed for the CORDEX East Asia project domain
  - 25 km X 25 km horizontal resolutions covering Asian domain
- For comparison with observation,
  - RCMs are interpolated onto 0.5° X 0.5° ERA5 grids.

❖ Analysis domain: East Asia (20°N –50°N and 80°E –150°E)

❖ Analysis season: Spring (March-April-May, MAM), Summer (June-July-August, JJA), Autumn (September-October-November, SON), and Winter (December-January-February, DJF)

❖ Variable

- Monthly Surface down-welling shortwave radiation (RSDS), Near-surface air temperature (TAS), and Near-surface wind speed (SFCWIND)

Methods

❖ PVpot calculation (Jerez et al., 2015, *Nat. Commun.*; Bichet et al., 2019, *Environ. Res. Lett.*)

$$PV_{pot}(t) = P_R(t)\frac{RSDS(t)}{RSDS_{STC}}$$

*** PVpot is dimensionless magnitude**

- $RSDS(t)$: RSDS for t, STC: standard conditions ($RSDS_{STC}$=1,000 W m^{-2}), P_R: performance ratio

$$P_R(t) = 1 + \gamma[T_{cell}(t) - T_{STC}]$$

- T_{cell}: PV cell temperature, $T_{STC} = 25$°C, γ=-0.005℃$^{-1}$, considering the typical response of monocrystalline silicon solar panels.

$$T_{cell}(t) = c_1 + c_2TAS(t) + c_3RSDS(t) + c_4SFCWIND(t)$$

- $c_1 = 4.3$°C, $c_2 = 0.943$, $c_3 = 0.028$°C m^2W^{-1}, $c_4 = -1.528$°Csm^{-1}

❖ TAS- and SFCWIND-induced changes in PVpot

$$\Delta TAS\ induced\ PV_{pot}\ rel(t) = \left(\frac{\alpha_3 RSDS(t)\cdot \Delta TAS}{PV_{pot_{historical}} mean}\right)\cdot 100$$

$$\Delta SFCWIND\ induced\ PV_{pot}\ rel(t) = \left(\frac{\alpha_4 RSDS(t)\cdot \Delta SFCWIND}{PV_{pot_{historical}} mean}\right)\cdot 100$$

- $\alpha_3 = -4.715\ \times 10^{-6} W\ m^{-2}, \alpha_4 = 7.64\ \times 10^{-6} W\ m^{-2} m\ s^{-1}$

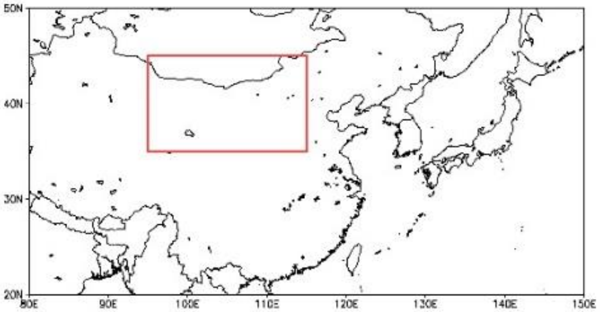
Methods

❖ We analyzed the spatial distributions applying the MME (Multi-Model Ensemble) of 6 RCMs

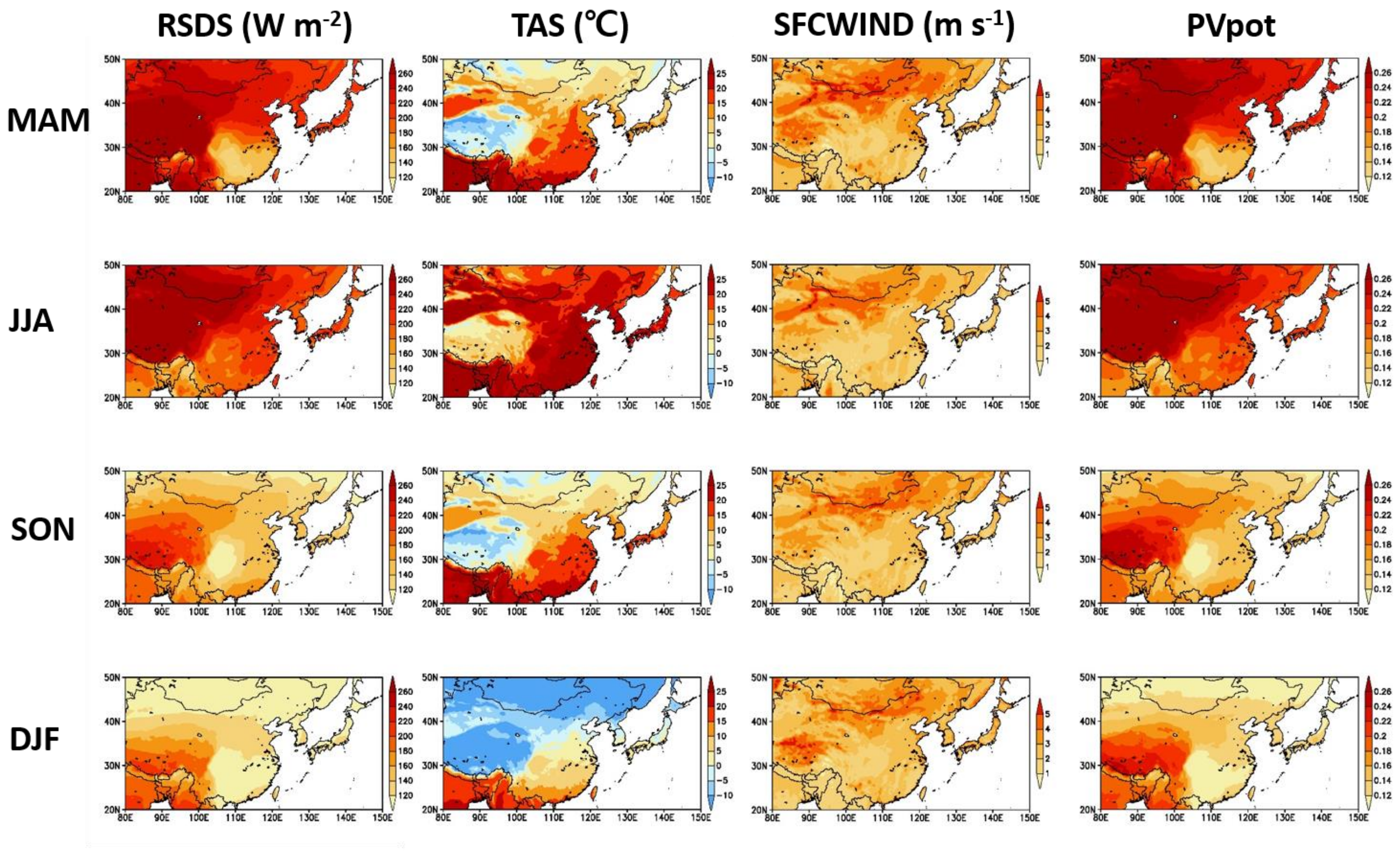
❖ The change in PVpot is expressed as a percentage.

❖ Evaluation the performance of RCM and their MME
- Bias: the difference between model and observation.
- Taylor diagram: the spatial variability and correlation between model and observation

❖ Sub-region analysis of dense areas of solar power complex in northern China (35°N-45°N, 95°N-115°N)
- Tengger Desert Solar Park (37°33′00″N, 105°03′14″E)
- Longyangxia Dam Solar Park (36°10′54″N, 100°34′41″E)
- Jinchuan, Gansu (38°36′26″N, 102°08′59″E)
- Haixi Delingha Solar Park (37°21′26″N, 97°12′52″E)
- Huanghe Hydropower Golmud Solar Park (36°24′00″N, 95°07′30″E)

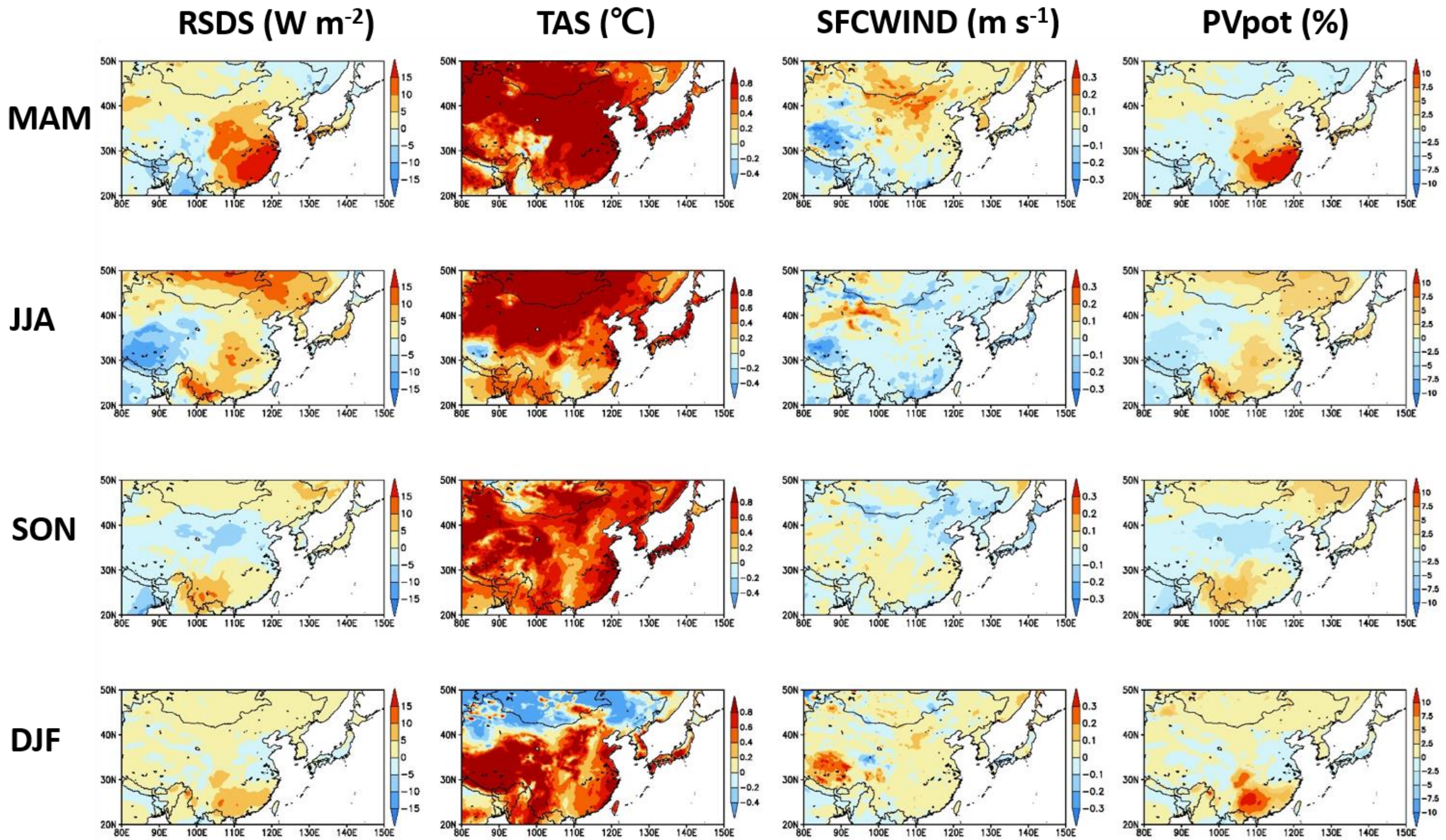


Seasonal distributions of observed climatology for RSDS, TAS, SFCWIND, and PVpot over East Asia (1981-2005)



- The spatial distribution of PVpot in all seasons in East Asia is very similar to that of RSDS.
- The magnitudes of RSDS and Pvpot were the largest in western China.
- PVpots in East Asia had the largest summer and the smallest winter.

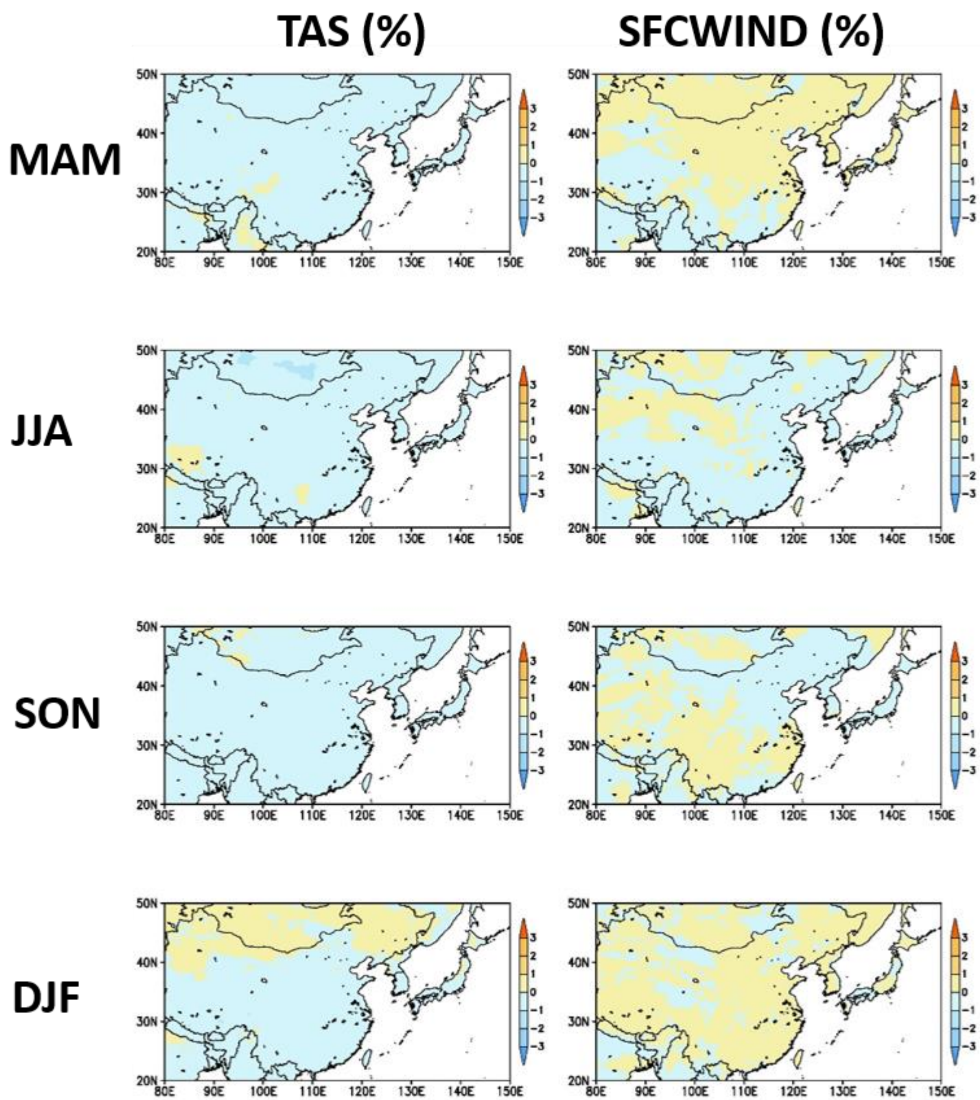
Recent changes of observed seasonal climatology for RSDS, TAS, SFCWIND, and PVpot over East Asia (P2-P1)



❖ The distributions of difference between the second half (1999-2018) and the first half (1979-1998) of the recent 40 years (1979-2018).

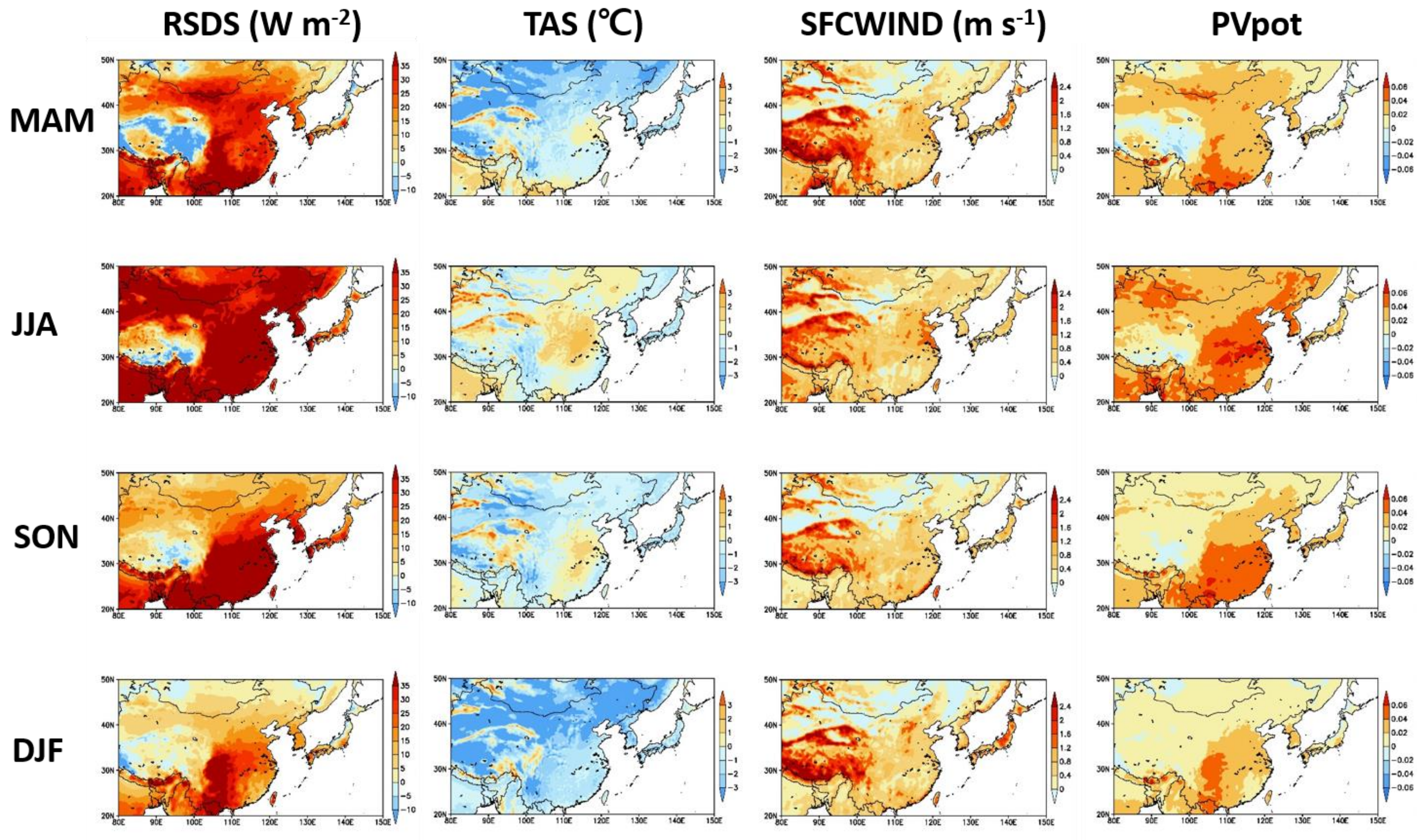
- RSDS and PVpot in East Asia increased in spring, summer, and winter seasons.
- Increases in RSDS and Pvpot were dominant in southern China
- Overall, TAS in East Asia has increased in recent period, but in winter it has decreased in northern China and Mongolia.

Effects of TAS and SFCWIND on the recent changes of seasonal Pvpots over East Asia (%)



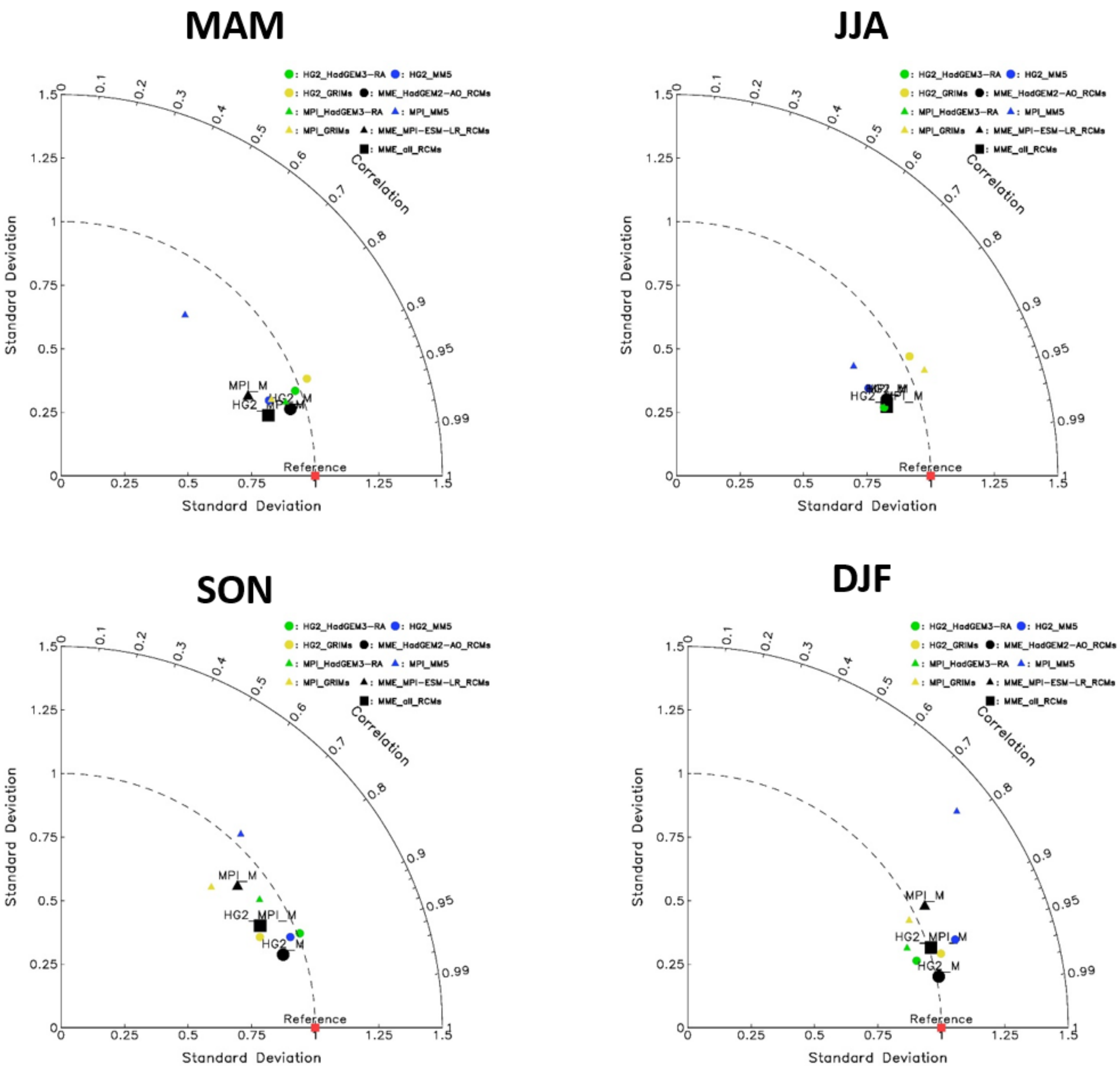
- The effect of TAS and SFCWIND on PVpot change is less than ±1 %, which is not large magnitudes.
- As the global warming affecting solar panel performance, the increase in TAS over East Asia has the negative effect on the recent changes of PVpot in all season.

Seasonal distributions of biases of MMEs of RCMs for RSDS, TAS, SFCWIND, and PVpot from historical experiment



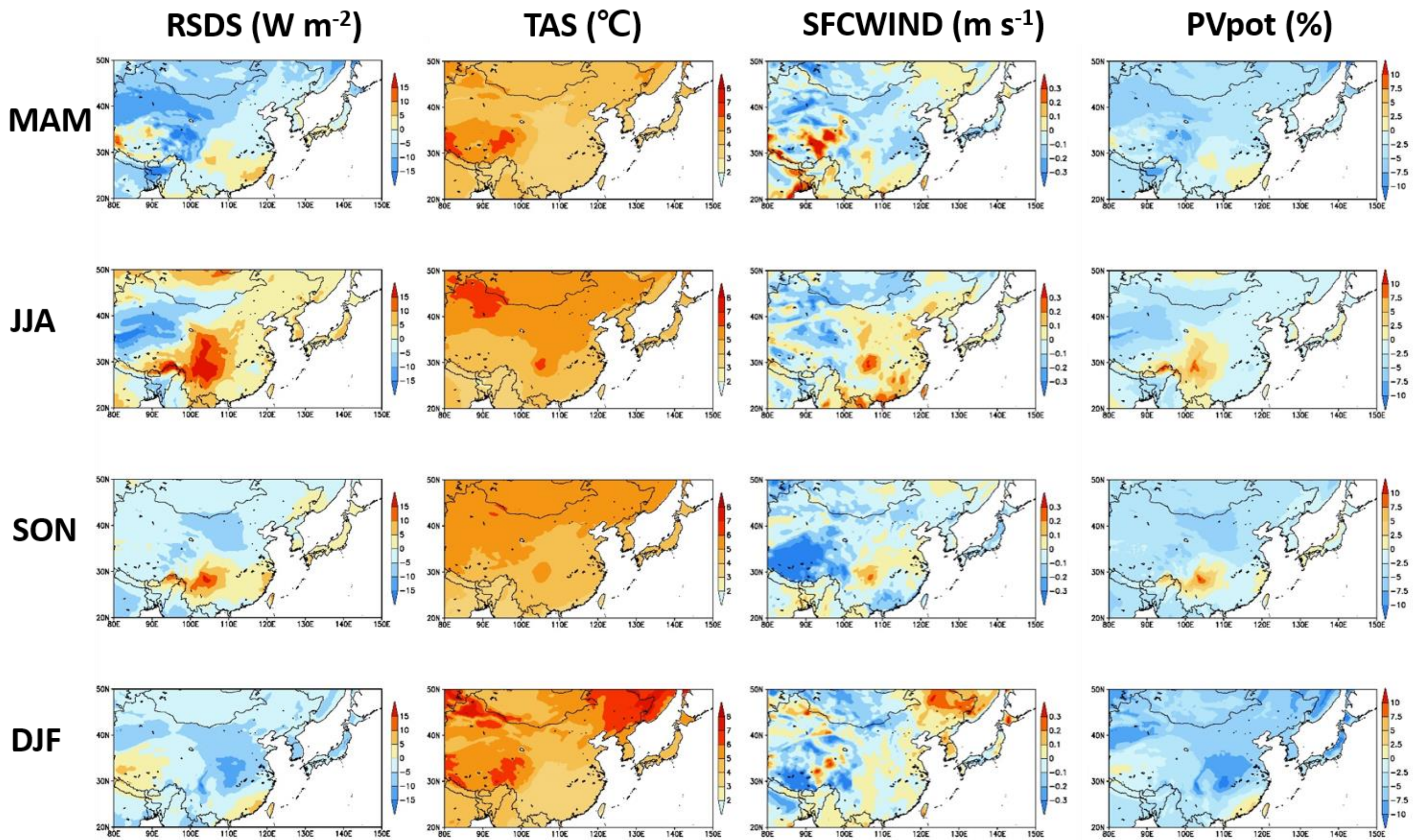
- ❖ MME of 6 RCMs for historical experiment represents positive biases in RSDS, SFCWIND, and Pvpot and negative bias in TAS.
- ❖ In RSDS and PVpot, positive biases are dominant in southern China and negative biases show in western China region.

Taylor diagrams of seasonal PVpots for RCMs and MMEs of historical experiment over East Asia



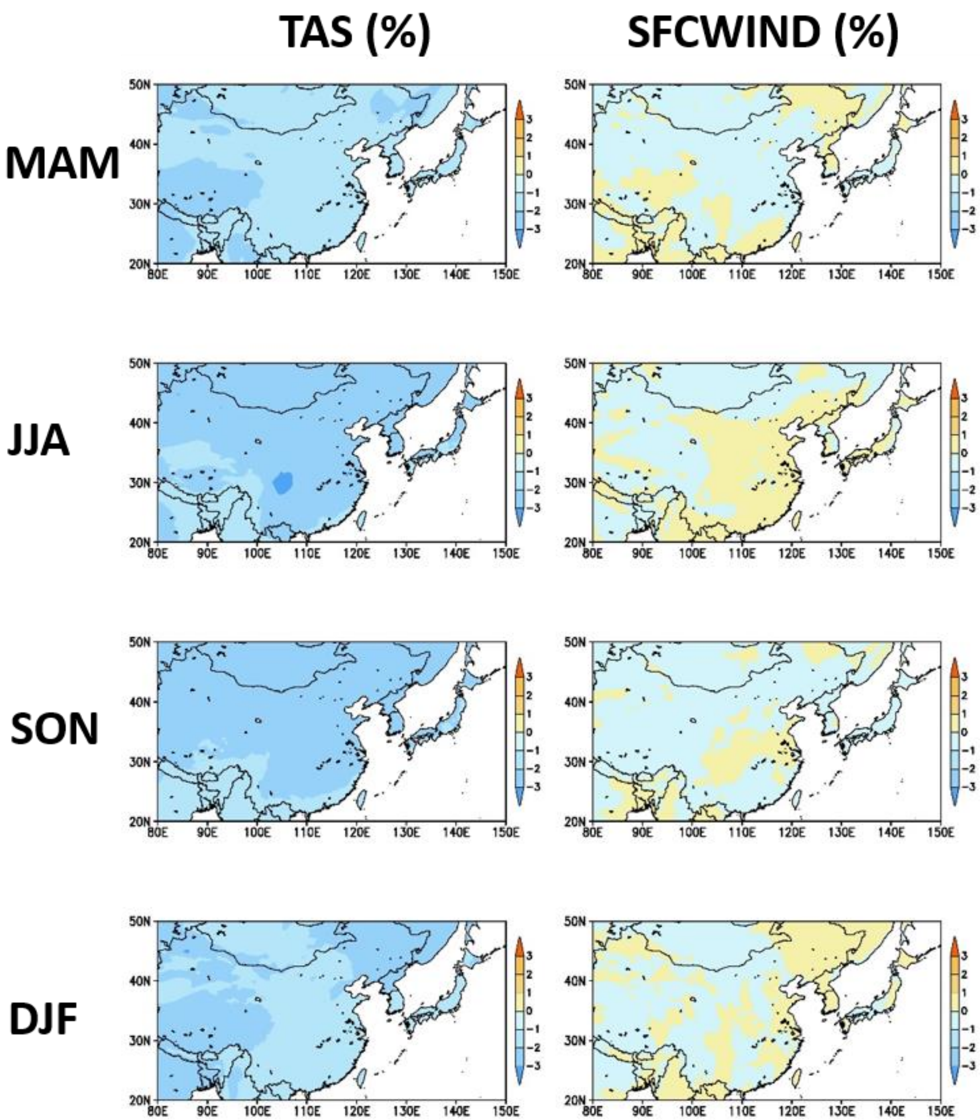
- ❖ Overall, the model's performance is good because the correlation coefficient with the observation exceeds more 0.9 more and the standard deviation is close to 1.
- ❖ In spring and summer seasons, models and MMEs have better performances than in autumn and winter.
- ❖ MMEs driven by HadGEM2-AO perform better than MMEs driven by MPI-ESM-LR.

Seasonal distributions of future (late 21st C) changes of RSDS, TAS, SFCWIND, and PVpot over East Asia



- ❖ TAS will increase in all areas, and SFCWIND is expected to have large regional variabilities.
- ❖ RSDS is predicted to decrease in spring, autumn and winter, and increase in summer.
- ❖ PVpot, which are considerably affected by RSDS, is similar to the pattern of changes in RSDS, but is expected to decrease in summer. This did not lead to an increase in PVpot as a result of the negative effects of TAS and SFCWIND in regions where the RSDS increase was relatively small.

Effects of TAS and SFCWIND on the future changes of seasonal Pvpots over East Asia (%)

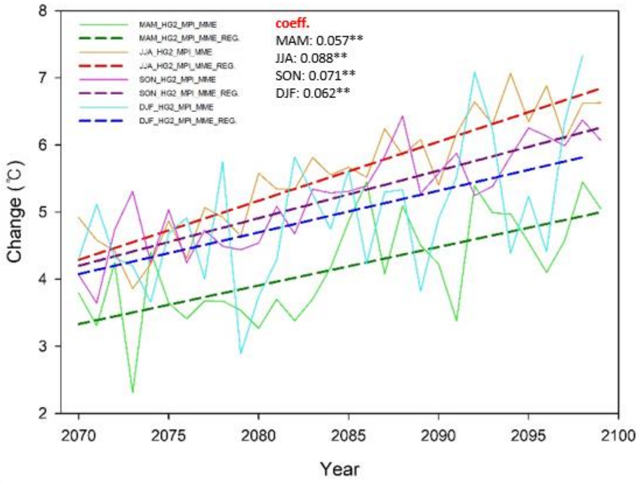


- ❖ The future changes of TAS in all season is expected to reduce PVpot over East Asia
- ❖ In future summer, the negative effect of TAS on PVpot will have the largest of all seasons, on maximum by 4%.
- ❖ The future changes of SFCWIND on PVpot change in all seasons is less than ±1 %, which is not large magnitudes.

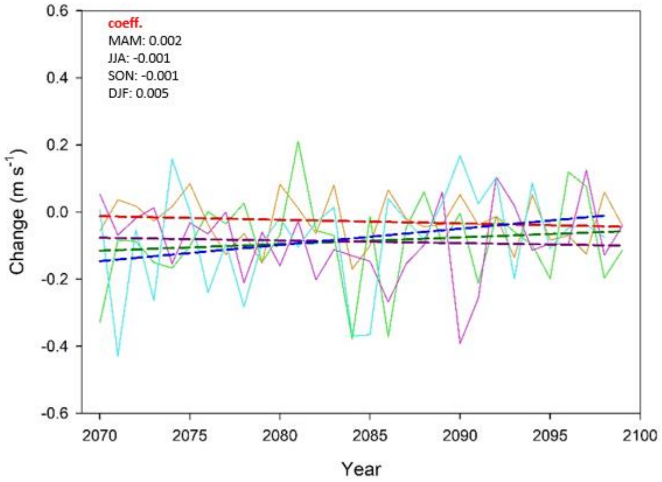
Sub-region analysis of dense areas of solar power complex in northern China (35°N-45°N, 95°N-115°N)

◆ Future seasonal timeseries of RSDS, TAS, SFCWIND, and PVpot

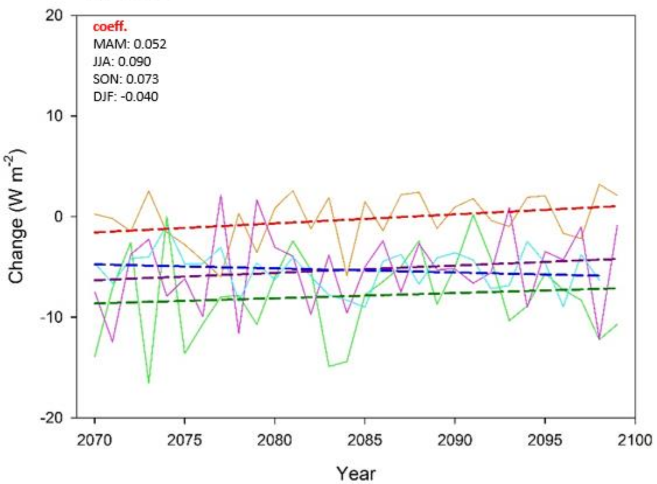
TAS



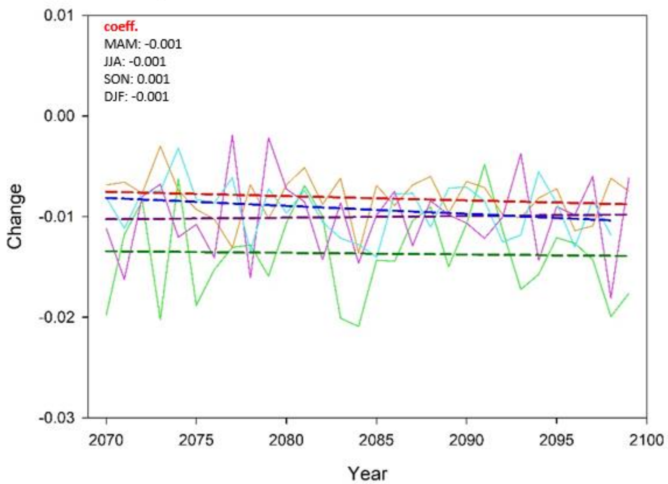
SFCWIND



RSDS



PVpot

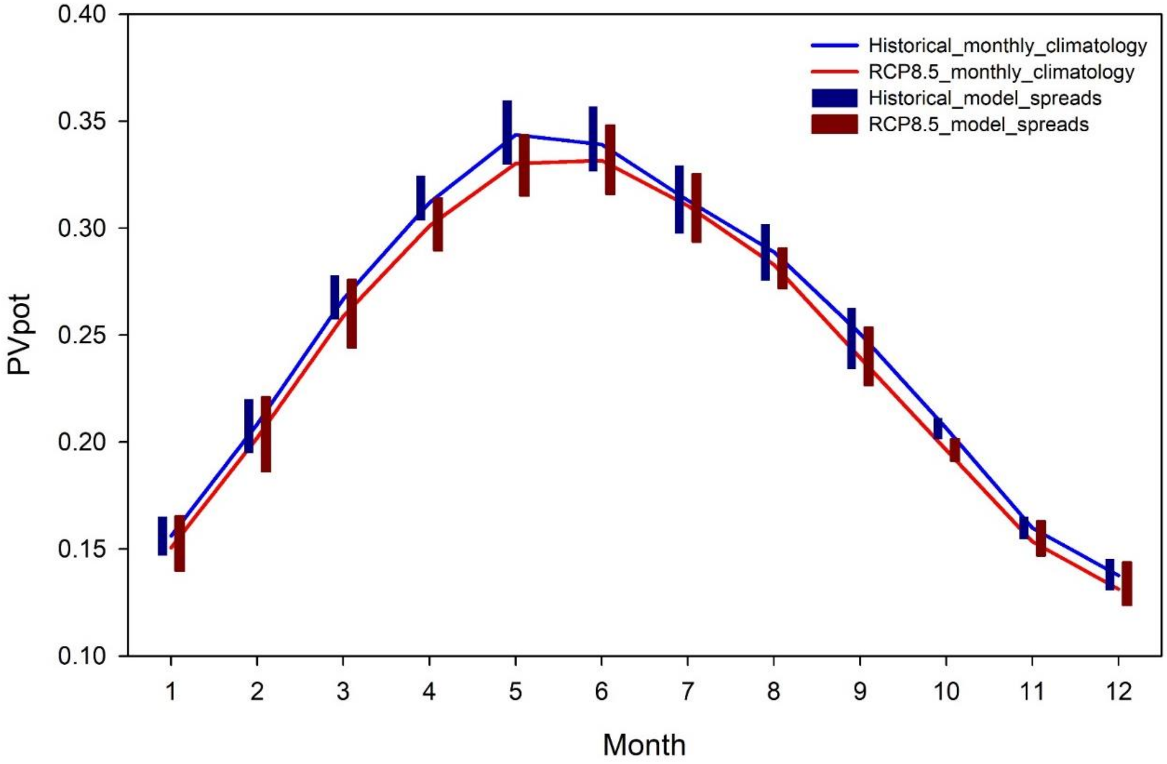


❖ The future timeseries of TAS will expected to increase statistically significantly in all seasons, with the largest increase in summer.

❖ SFCWIND, RSDS, and PVpot were expected to show rarely trend of change in all seasons.

Sub-region analysis of dense areas of solar power complex in northern China (35°N-45°N, 95°N-115°N)

◆ **Variations of monthly climatology of RSDS, TAS, SFCWIND, and PVpot for historical and RCP8.5**



❖ In all month, PVpot is simulated larger in historical experiment than in RCP8.5 scenario.

❖ The maximum month of PVpot shifts from May to June in the late 21st century.

❖ Model spreads show larger in RCP8.5 scenario than in historical experiment.

→ Uncertainty: RCP8.5 > historical

Summary and conclusion

- From the observed climatology, The magnitudes of RSDS and Pvpot were the largest in western China and PVpots in East Asia had the largest summer and the smallest winter.
- In recent changes, RSDS and Pvpot represented the largest increase in southern China over entire East Asia.
- The performance of the six RCMs were evaluated at a fairly good level from the results of the correlation coefficient with the observation and the standard deviation.
- RSDS is predicted to decrease in spring, autumn and winter, and increase in summer. In the project of future changes, PVpot, which are considerably affected by RSDS, is similar to the pattern of changes in RSDS, but is expected to decrease in summer.
  → This did not lead to an increase in PVpot as a result of the negative effects of TAS and SFCWIND in regions where the RSDS increase was relatively small.
- From sub-region analysis of northern China, the maximum month of PVpot shifts from May to June in the late 21st century.
- This study is meaningful as the first study to analyze the future PVpot over East Asia using high-resolution Multi-RCMs forced by Multi-GCMs.
- The results of this study will help to develop policies for efficient future production of renewable energy over East Asia by presenting the projection of future photovoltaic power generation on a detailed regional scale.

Thank you.