Assessing natural climate variability and long-term trend of surface temperature by climate models in a global and regional scale

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Background

- As global temperatures continue to rise in the coming years, the contribution of global warming to this increase is expected to become even more significant.
- The 2018 peak summer heat wave in South Korea as an important example:
  - The 2018 summer temperature distribution is similar to a 3 ºC global warming temperature scenario (Im et al 2019).
  - The 2018 summer experienced a more than fourfold increase in heat wave duration due to global warming (Min et al 2020).
  - However, atmospheric circulation patterns also played a significant role in 2018 summer (Ha et al 2020).
- In summary, global warming and natural climate variability both significantly contributed to the Korean peak summer heat wave.
- Finally, we estimate the Time of Emergence, when global warming surpasses natural climate variability.

Research Question

1) **When is the Time of Emergence (TOE) of the Korean peak summer temperature?**
2) **Trust in TOE requires confidence in natural climate variability and warming trends, but could we trust the regional outputs of climate models?**

Data and Method

Data

Variable		Dataset	Period
Temperature	Reanalysis	KMA, JRA55, ERA5, CRU, 20CRV3, NCEP R1	1959-2014
	Model	CMIP6 (42), MIROC6 (50), CanESM5 (25)	1959-2100
		CESM2-LE (50), EC-Earth3 (22)	1959-2014
CO_2 concentration		Mauna Lore observatory	1959-2014

- CMIP6, MIROC6, CanESM5: historical, SSP245, SSP585
- CESM2-LE, EC-Earth3: historical

Method

$e = t_c n_t \sigma \gamma(n_t, r_1) g(n_t)$ (Eq.1) $T = aT_{detrend} + bCO_2conc.$ (Eq.2)

- The TOE is calculated based on a single threshold method.
- Natural climate variability:
  - $\sigma(T_{detrend})$
  - e (from Eq.1, According to Thompson et al., 2015.)
- Long-term trend:
  - Linear projection of SSP scenarios.
  - $bCO_2conc.$ (from Eq.2)

Result and Discussion

1. Estimation of TOE during the Korean peak summer

- The TOE predictions range from the 2010s to the early 2030s in the SSP 585.
  - When assessing the multi-model and multi-ensemble individually, the TOE range further expands from the early 2000s to the 2070s.
- The TOE is also delayed in the case of the SSP245 compared to that of the SSP585.
- When the long-term trends is approximated with the CO_2 concentrations
  - The TOE is pushed back from approximately 35 to 70 years beyond one based on the linear future trend.
- When incorporating natural climate variability with observational and reanalysis data
  - The TOE appears to be even further delayed in comparison to the projections from CMIP6.

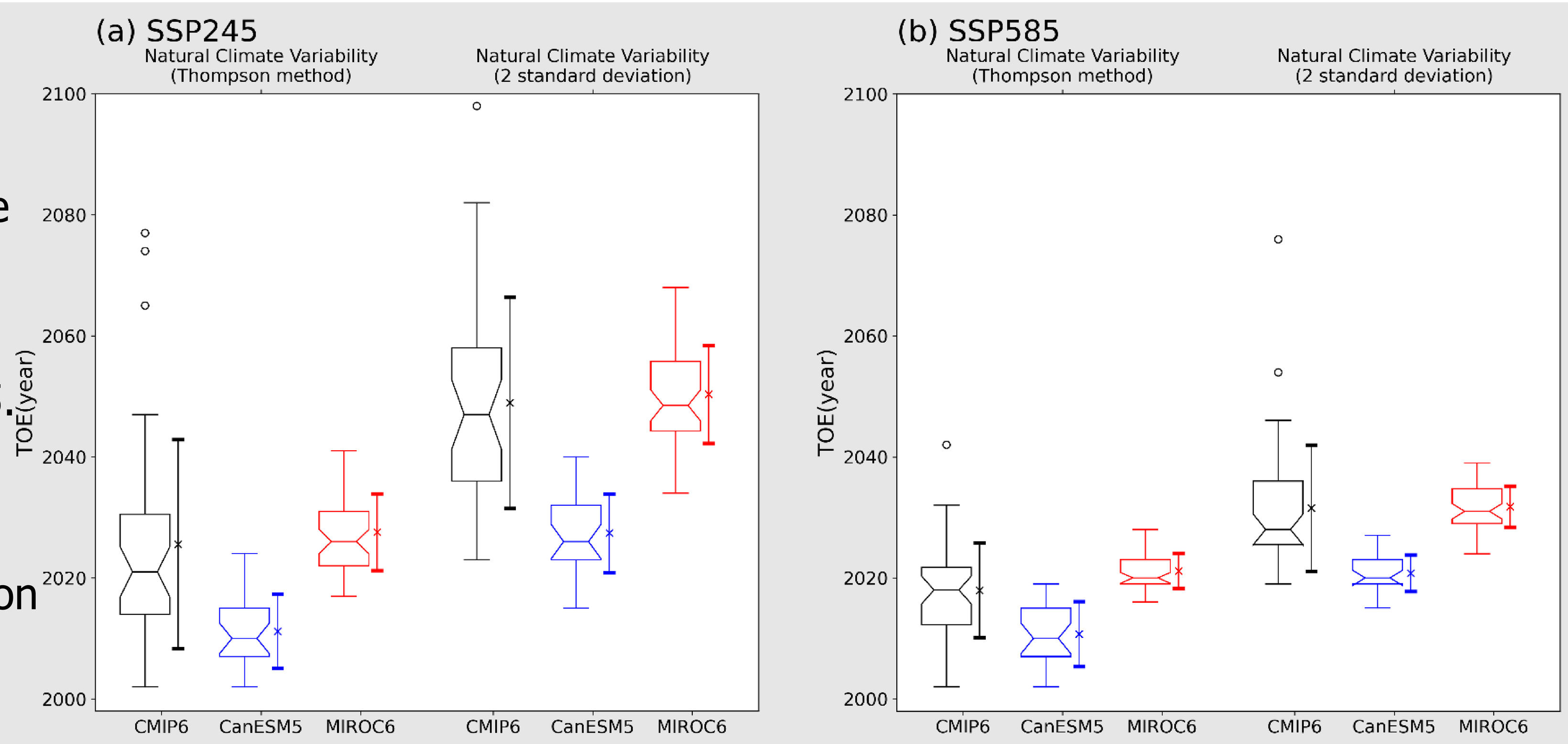

Figure 1. TOE based on Korean peak summer temperature based on SSP245 in (a) and SSP585 in (b). The black, blue, and red boxplots represent CMIP6, CanESM5, and MIROC6, respectively. The three box plots on the left use Thompson's method for natural climate variability and the three box plots on the right use double standard deviation.

2. Assess natural climate variability and long-term trends of global and regional temperature

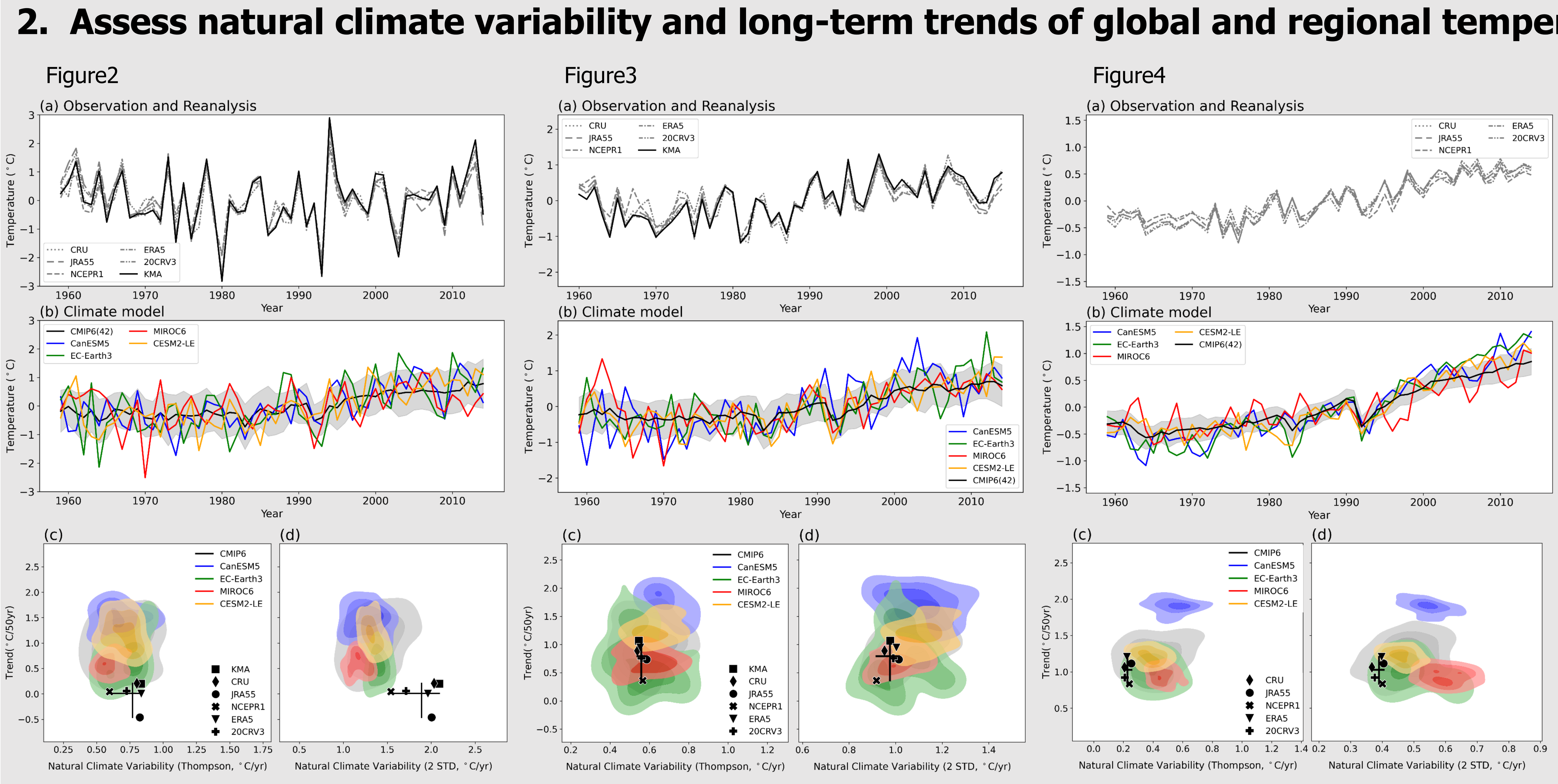

Figure 2-4. Time series and KDE plots of surface air temperature from 1959 to 2014: (a) Time series of five reanalysis datasets, (b) Time series of model data. The KDE plots illustrating natural climate variability and long-term trends of Korean peak summer surface air temperature are presented in (c) and (d), respectively. In the KDE plots, the intensity of shading corresponds to the density of the ensemble. (c) is Thompson's method and (d) is 2 standard deviations. Figures 2-4 are the Korean peak summer, Korean annual mean, and global annual mean, respectively.

- Our focus then narrows to the natural climate variability and long-term trend, as a result of the extensively distributed TOE.
- Fig2: peak summer temperatures in Korea
  - Underestimate natural climate variability
  - Overestimate the long-term trend
- Fig3: the annual mean temperature in Korea
  - Overestimate natural climate variability
  - Well-simulate the long-term trend
- Fig4: the global mean annual temperature
  - Overestimate both natural climate variability and long-term trends.

Conclusion

1. The **TOE for Korean peak summer** varies significantly from **the early 2010s to the early 2030s based on the SSP585 scenario,** indicating the TOE has already passed or is imminent.
2. Earlier estimated TOE could be attributed to the biases that climate models tend to **underestimate natural climate variability** and **overestimate the long-term trend** during the peak summer months of July and August in Korea.
3. The **low-emission scenario highlights a significant delay in the TOE** when compared to the high-emission scenario, emphasizing the crucial role of reducing greenhouse gas emissions in addressing the impacts of climate change.

Reference

- Im E S, Thanh N X, Kim Y H and Ahn J B 2019 2018 summer extreme temperatures in South Korea and their intensification under 3 C global warming Environ. Res. Lett. 14
- Min S-K, Kim Y-H, Lee S-M, Sparrow S, Li S, Lott F and Stott P 2020 Quantifying Human Impact on the 2018 Summer Longest Heat Wave in South Korea Bull. Am. Meteorol. Soc. 101 S103–8.
- Ha K J, Yeo J H, Seo Y W, Chung E S, Moon J Y, Feng X, Lee Y W and Ho C H 2020 What caused the extraordinarily hot 2018 summer in Korea? J. Meteorol. Soc. Japan 98 153–67
- Thompson D W J, Barnes E A, Deser C, Foust W E and Phillips A S 2015 Quantifying the role of internal climate variability in future climate trends J. Clim. 28 6443–56.