

Event attribution of 2013 Korean summer heat wave using multi-model ensemble

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- Background
 - Event Attribution
 - 2013 summer Korean heat wave
- Data: C20C+ and CMIP5
- Methods: Fraction Attributable Ratio (FAR)
- Results
- Sensitivity to FAR
- Conclusions

What is Event Attribution ?

- **Event** – “discrete episodes of **extreme weather or unusual climate conditions**, often associated with deleterious impacts on society or natural systems, defined using some metric to characteristics of the event or the consequent impacts” (Stott et al. 2013)

- **Attribution** – “the process of evaluating the **relative contributions** of multiple causal factors to a change or event with an assignment of **statistical confidence**” (Hegerl et al. 2010)

- **Event attribution assessment** – “**quantify** to what extent anthropogenic or natural influences have altered the probability or magnitude of a particular type of event having occurred” (Stott et al. 2015)

- Allen (2003, Nature) first described a methodology to event attribution assessment.
- Stott et al. (2004, Nature) applied it to the European heat wave in 2003 → at least doubled the risk due to human influence

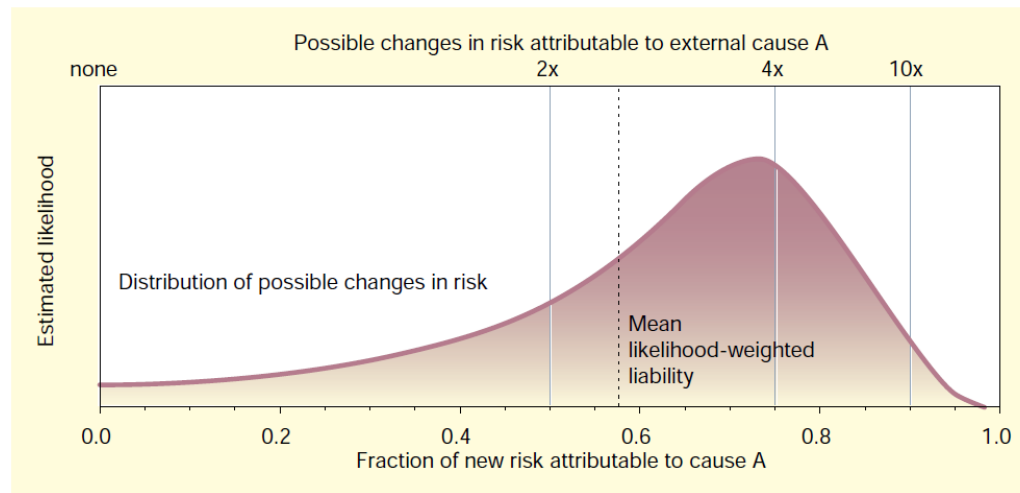


Figure 1 How we might be able to calculate liability for climate change. We will never know exactly how external drivers of this change, such as greenhouse-gas emissions, alter the risk of undesirable events, such as floods, but this does not prevent us working out a 'mean likelihood-weighted liability' by averaging over all possibilities consistent with currently available information.

Allen et al. (2003)

History of Event Attribution Researches

- Emergence with the studies for event attribution surrounding the Russian heat wave in 2010
 - Dole et al. (2011) : A negligible role of anthropogenic influence
 - Rahmstorf and Coumou (2011) : Fivefold increase due to human influence

- Since 2012, BAMS have issued special reports on attributing extreme events of the previous year

EXPLAINING EXTREME EVENTS OF 2011 FROM A CLIMATE PERSPECTIVE

Thomas C. Peterson, Peter A. Stott and Stephen Mearns, Editors

Using a variety of methodologies, six extreme events of the previous year are explained from a climate perspective.

INTRODUCTION

Peter A. Stott, PhD (Oxbridge), British Antarctic Survey, Cambridge, UK; Thomas C. Peterson, Ph.D. (Oxbridge), National Center for Environmental Prediction, NCEP, Silver Spring, MD; Stephen Mearns, Ph.D. (Oxbridge), National Center for Environmental Prediction, NCEP, Silver Spring, MD

Each year, the Bulletin of the American Meteorological Society publishes an annual report on the State of the Climate. This report is a valuable resource for the public and the scientific community. In this report, we provide an overview of the past year and point to the most significant weather and climate events of the year. One of the reasons for this is to provide

insight into the causes of extreme events and to provide a context for the public and the scientific community. In this report, we provide an overview of the past year and point to the most significant weather and climate events of the year. One of the reasons for this is to provide

APPROXIMATE PRICES: NOAA National Climate Data Center, Asheville, North Carolina; \$20.00 (US) (hard copy); \$15.00 (US) (digital copy); \$25.00 (US) (hard copy and digital copy); \$30.00 (US) (hard copy and digital copy); \$35.00 (US) (hard copy and digital copy); \$40.00 (US) (hard copy and digital copy); \$45.00 (US) (hard copy and digital copy); \$50.00 (US) (hard copy and digital copy); \$55.00 (US) (hard copy and digital copy); \$60.00 (US) (hard copy and digital copy); \$65.00 (US) (hard copy and digital copy); \$70.00 (US) (hard copy and digital copy); \$75.00 (US) (hard copy and digital copy); \$80.00 (US) (hard copy and digital copy); \$85.00 (US) (hard copy and digital copy); \$90.00 (US) (hard copy and digital copy); \$95.00 (US) (hard copy and digital copy); \$100.00 (US) (hard copy and digital copy)

AMERICAN METEOROLOGICAL SOCIETY

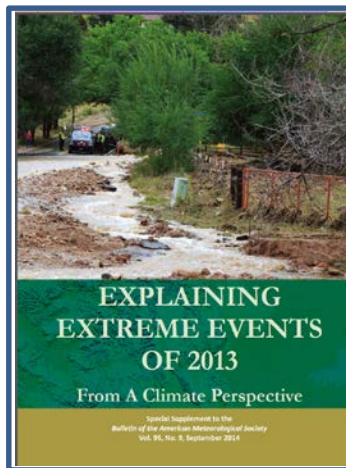
EXPLAINING EXTREME EVENTS OF 2012 FROM A CLIMATE PERSPECTIVE

Editors

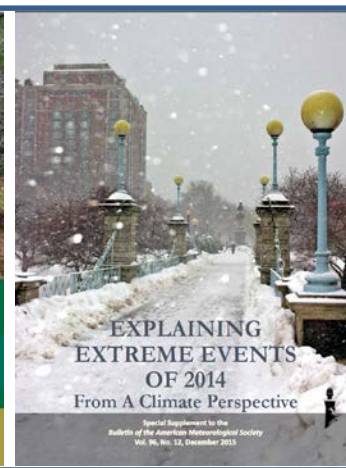
Thomas C. Peterson, Martin F. Hoesung, Peter A. Stott, and Stephen C. Mearns

Special Supplement to the Bulletin of the American Meteorological Society Vol. 94, No. 9, September 2013

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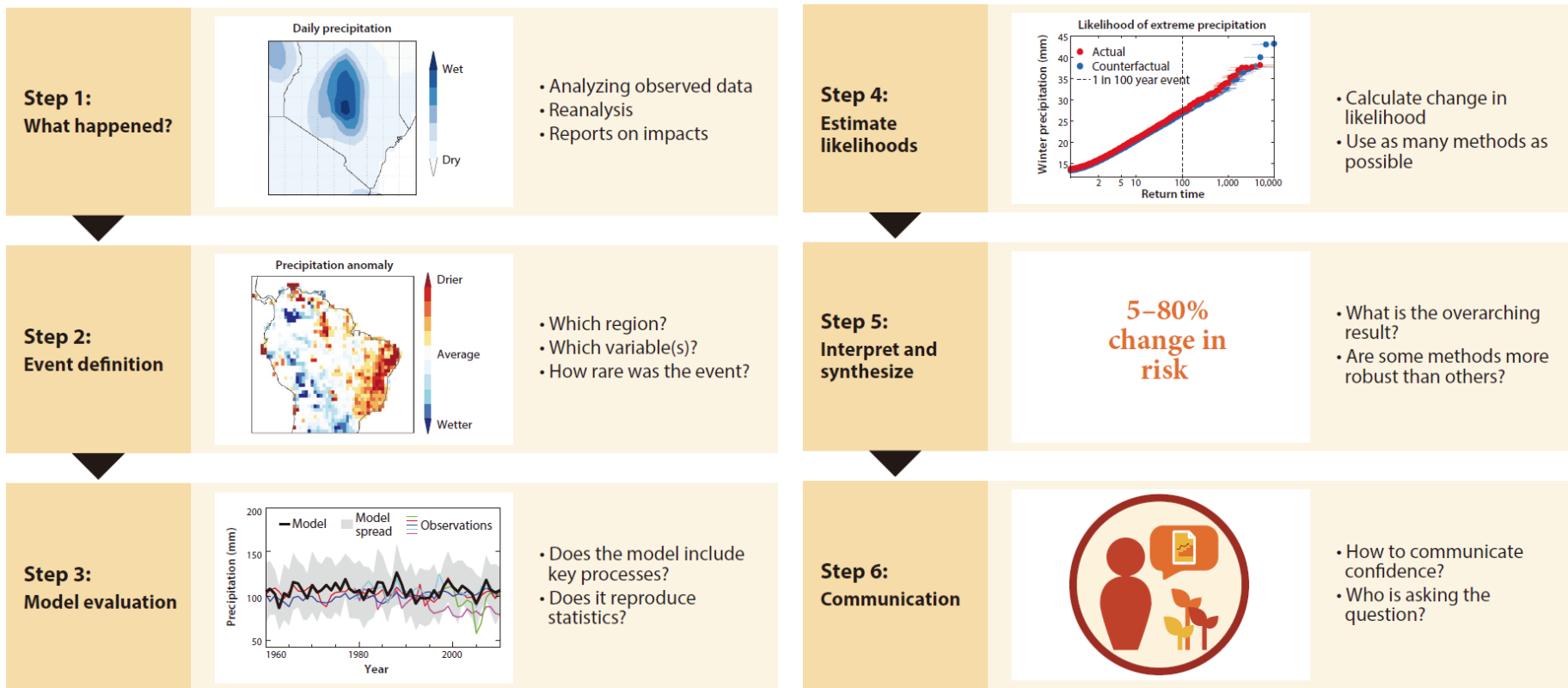
2013 summer heat wave



2014 hot spring & 2014 SST warming

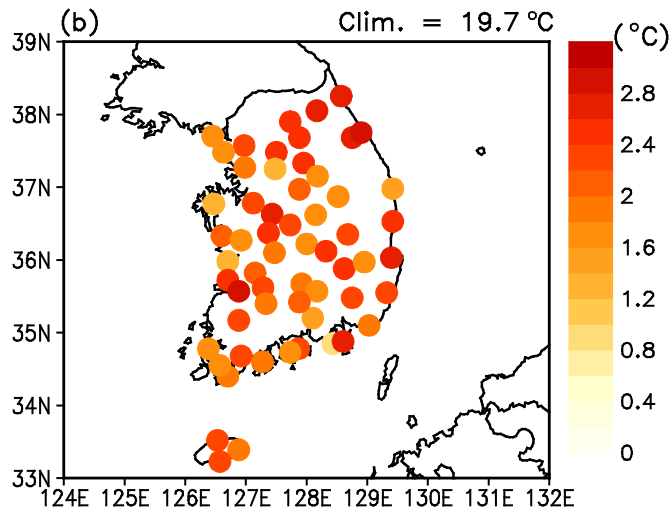


Six steps for event attribution analysis



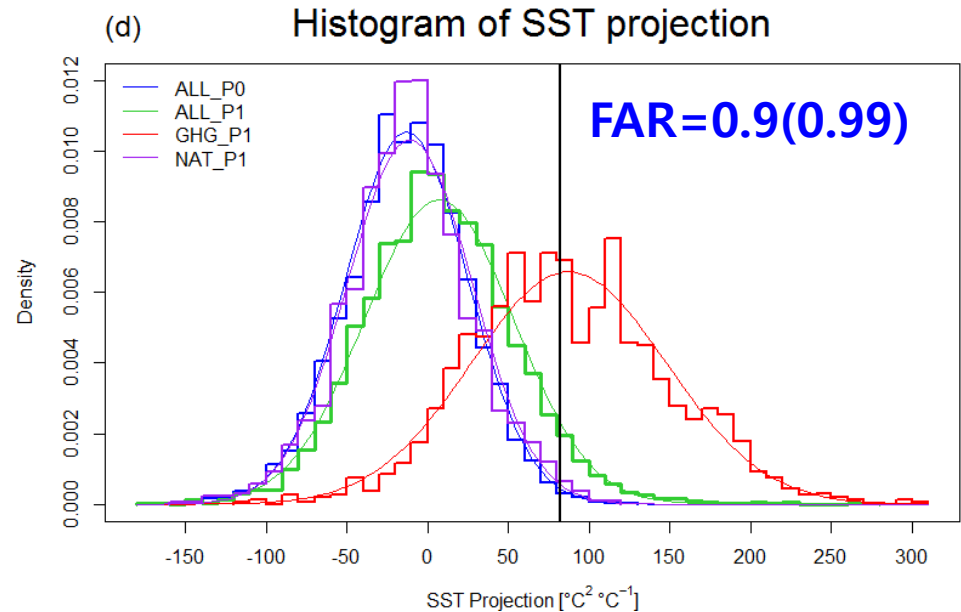
Otto (2017)

Summer mean daily Tmin



Record high in 2013!!

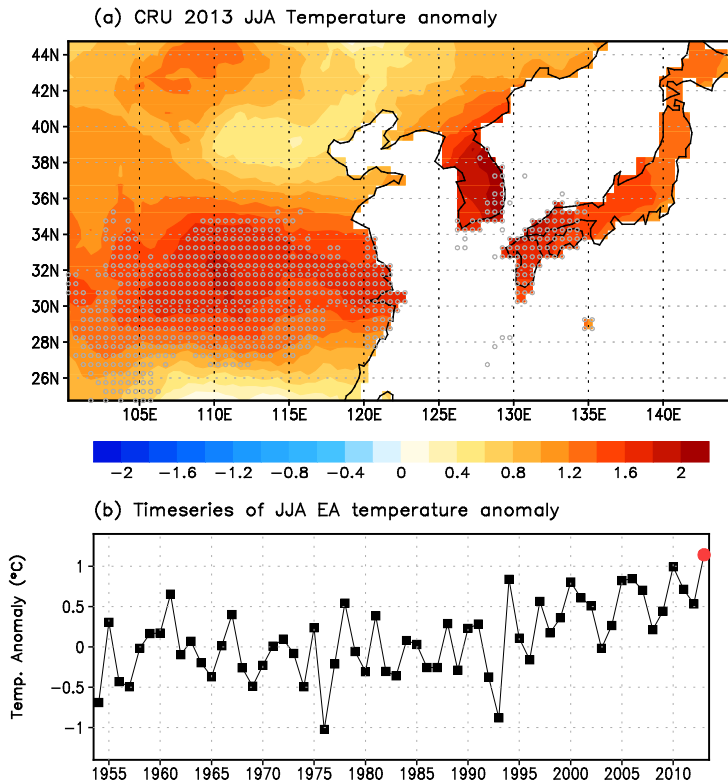
Comparison of PDFs



**Extreme hot summers
10 times more likely
due to human influence**

[Min et al. 2014, BAMS]

2013 summer East Asian heat wave



Reference	Focusing Area	Model & Exp.	FAR & Risk
Zhou <i>et al.</i> (2014)	Central eastern China	CMIP5 (31 models)	FAR=0.58 (2.12 times)
Sun <i>et al.</i> (2014)	Eastern China	CMIP5 (26 models)	> 60 times
Ma <i>et al.</i> (2017)	Central eastern China	CMIP5 (17 models) & 2AGCMs	FAR=0.58 ~0.94 (2~17 times)
Imada <i>et al.</i> (2014)	Japan	MIROC5 (AGCM)	FAR=0.86, 0.96 (7, 20 times)

- ✓ Eastern China and Japan also experienced record hot summer in 2013.
- ✓ Large range of anthropogenic influences assessed (**2~60 times increase in risk**), depending on the analysis domain, climate models, and sampling methods.
- ✓ Mostly based on a limited number of coarse resolution GCMs

Motivation and Objective

- **Climate of the 20th Century plus (C20C+) Detection and Attribution project**
 - Produce a **large pool of AGCM simulation data with relatively high resolution**
 - To help understand extreme weather in context of past and current climate change
 - Generation and comparison of two climate scenarios: **ALL** and **NAT**

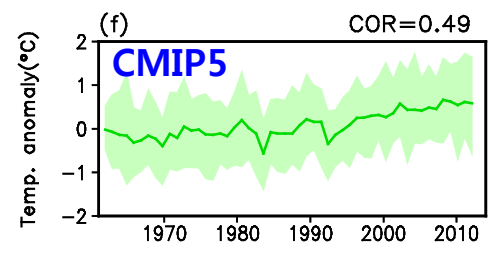
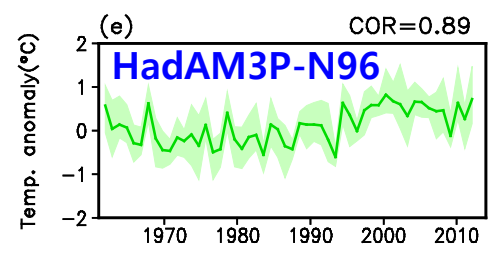
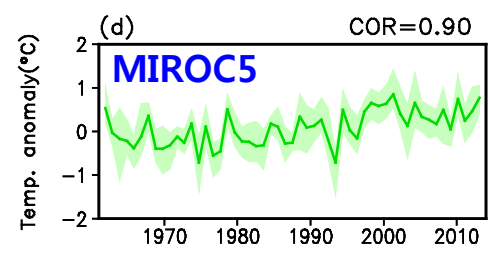
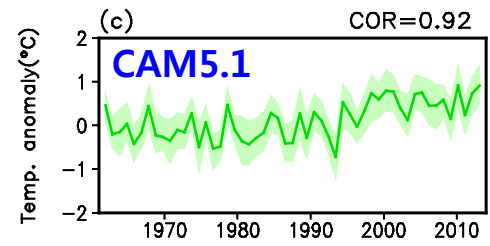
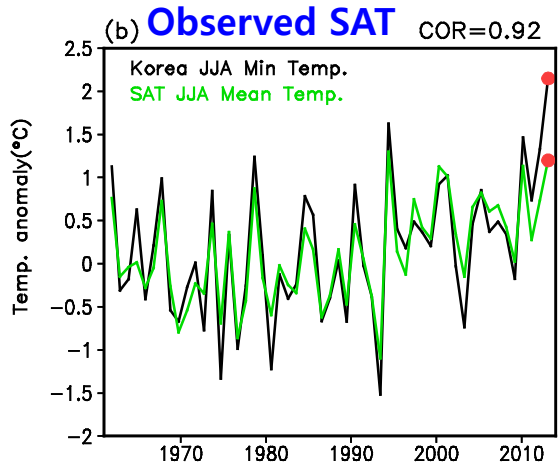
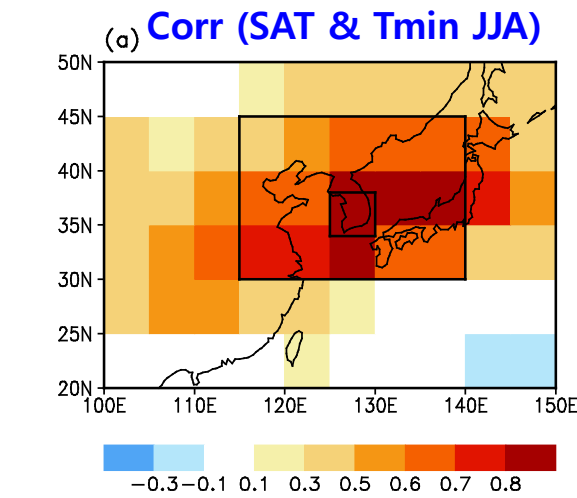
- **Advantage of a large ensemble of single AGCMs**
 - Generation of many simulations to enable robust sampling under different initial conditions
 - Reduction of model uncertainty due to prescribe observed boundary condition

- **This study assesses the event attribution of the 2013 summer heat wave in Korea by comparing the C20C+ D&A models with a CMIP5 multi-model ensemble using a fraction of attributable risk (FAR) approach.**

- **Observation data : Daily minimum temperature** data measured by the 12 KMA weather stations for 1954-2013
- **Surface air temperature (SAT)** data from HadCRUT4 (CRUTEM4-surface air temperature + HadSST3-sea surface temperature)
- **C20C+ AGCMs: 3 models**
 - **ALL** : observed boundary conditions
 - **NAT** : absence of anthropogenic interference (pre-industrial level, 1850)
SST and SIC are prescribed as observed SST minus Hisr45-Nat in CMIP5
- **CMIP5 CGCMs: 10 models**
 - **ALL** : Historical + RCP 4.5 experiment (natural plus anthropogenic forcing)
 - **NAT** : HistoricalNat experiment (natural only forcing)

Model	CAM5.1 v2	MIROC5	HadAM3P-N96	CMIP5
Spatial resolution	1°×1°	1.4°×1.4°	1.875°×1.25°	1°×1°
N. of ENS	100	100	50	10(39)
Analysis period	2007-2013	2007-2013	2007-2012	2007-2012
Boundary condition	HadISST +NOAA OI v2	HadISST	HadISST +NOAA OI v2	
aerosol	Prescribed aerosol burdens	Prescribed aerosol emission	Prescribed aerosol burdens (ALL & NAT)	

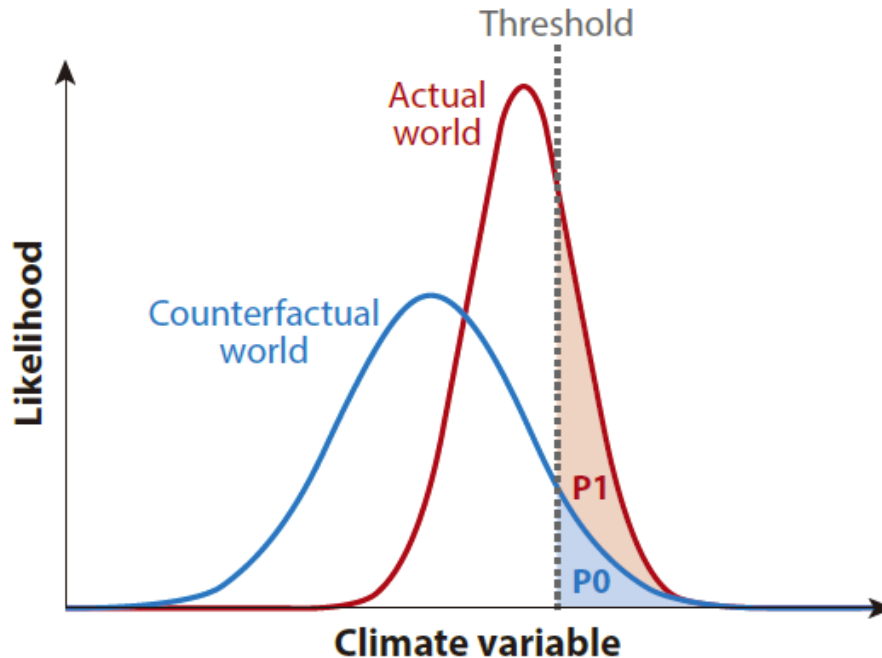
Upscaling Approach



- Find a **large-scale SAT indicator** for Korean summer temperature with strong correlation (>0.6)
 - Calculate area-average SAT anomalies from observation, AGCMs and CMIP5
- AGCMs and CMIP5 well reproduced the inter-annual variability of the SAT anomaly
- SAT anomalies : relative to the 1971-2000 climatology.

Fraction of Attributable Risk (FAR)

- Quantifying anthropogenic influence on extreme events (Stott et al. 2004, Nature)
- Comparing the probability of extreme events occurring in **a real world (with human influence) with that in a counterfactual world (without human influence)**



$$FAR = 1 - (P_0/P_1)$$

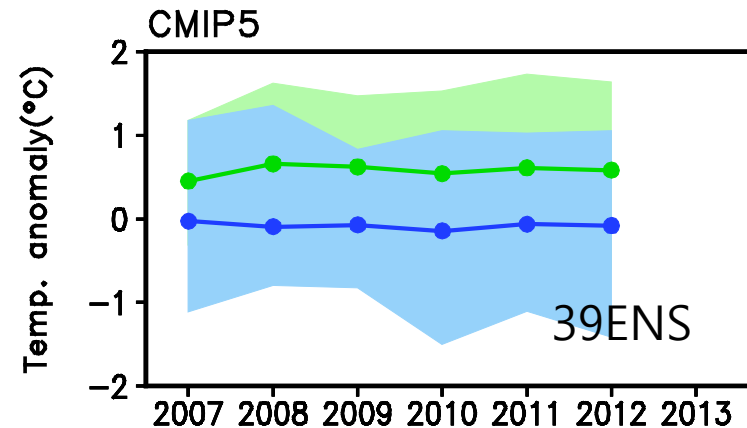
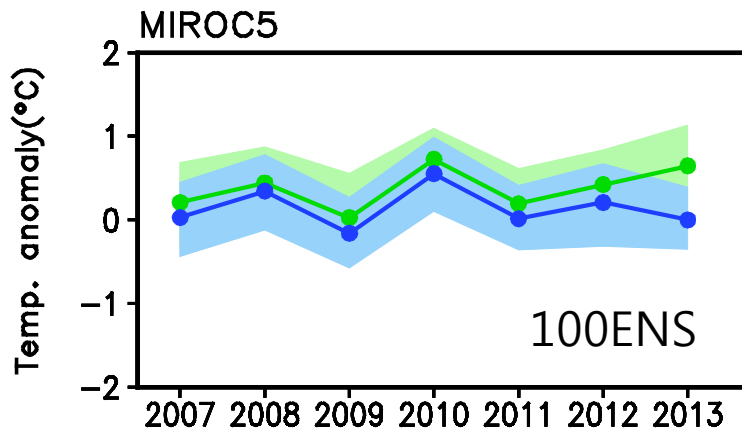
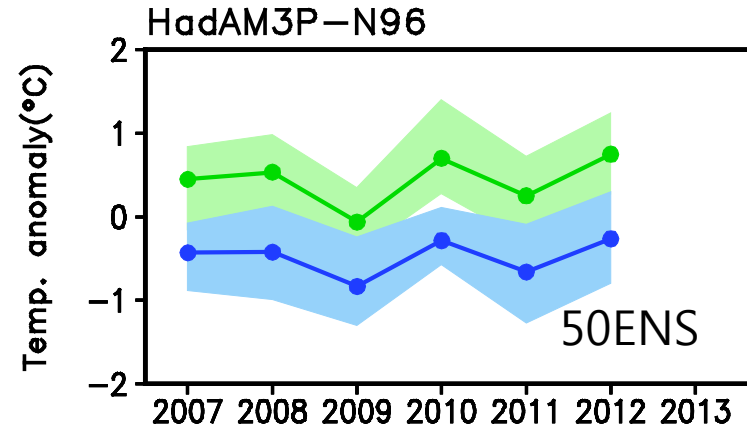
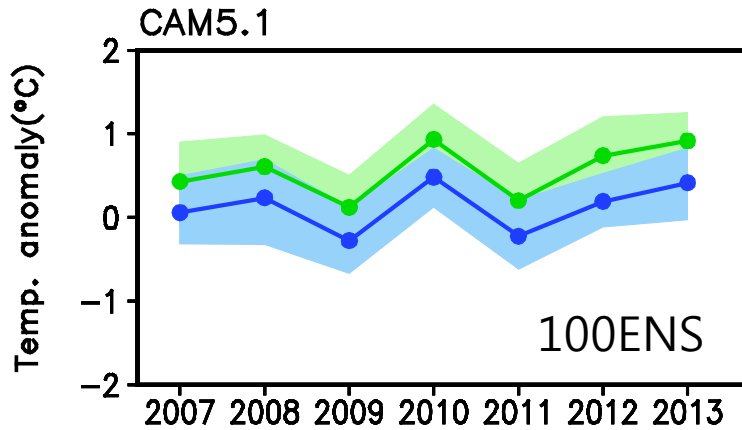
P_0 : Probability that extremes will occur exceeding the observed strength in **natural unforced conditions (NAT)**

P_1 : Probability estimated in **anthropogenic forced conditions (ALL)**

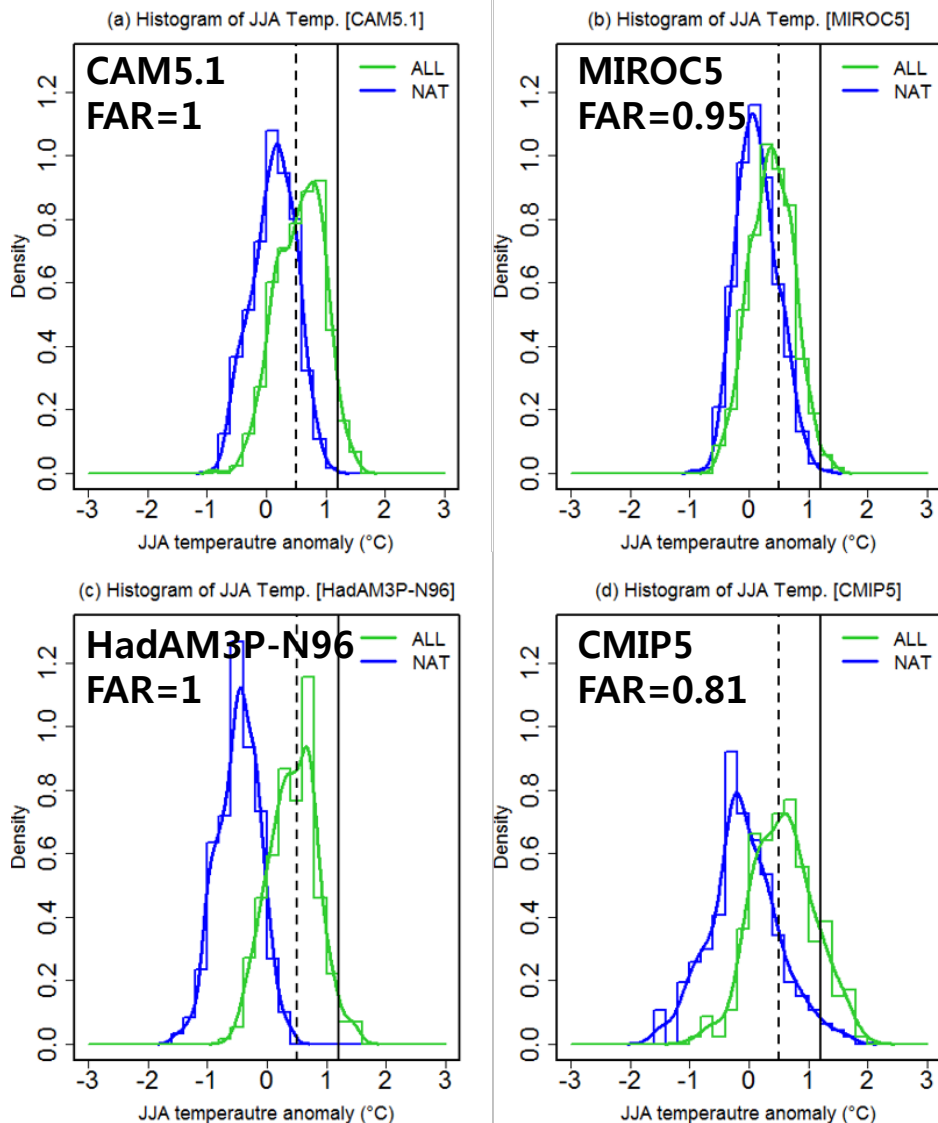
- FAR of 0.5 and 0.67 mean doubled and tripled risk of extreme events respectively.

Time series of SAT for 2007-2013(2012)

Construction of PDFs

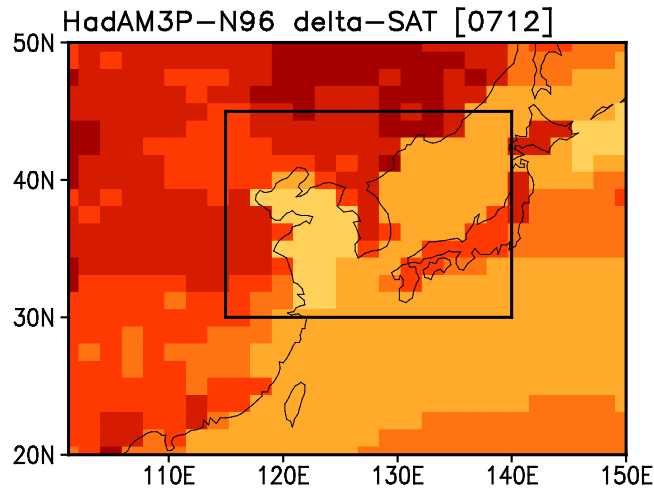
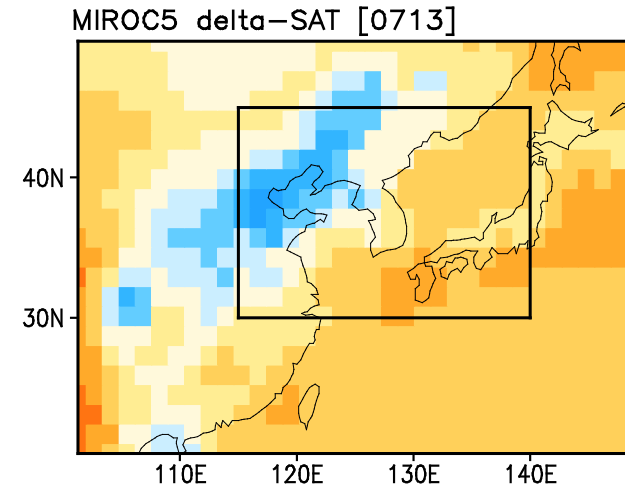
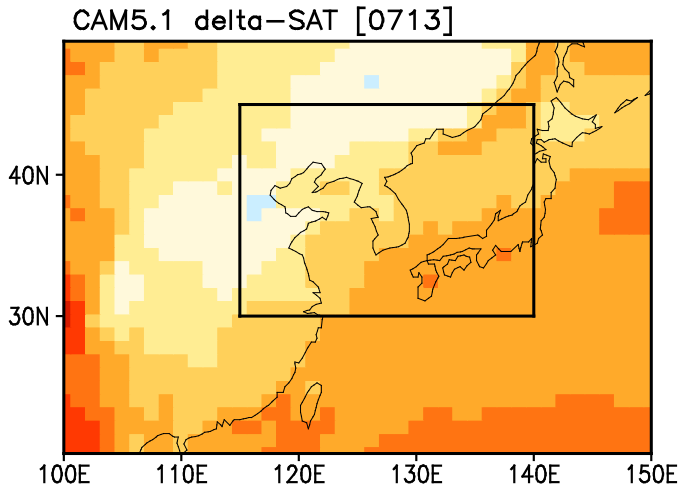


Histogram & FAR of SAT anomaly

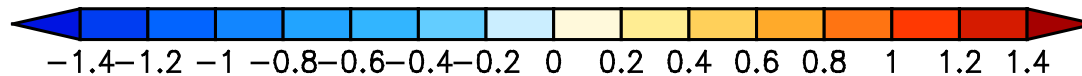


- **CAM5.1 & HadAM3P-N96** : FAR=1
 → dominant anthropogenic impacts
- **MIROC5** : 20 times increase in risk due to anthropogenic forcing
- **CMIP5** : 5 times increase in risk
- **Possible causes of different FARs**
 - ✓ **Delta-SAT (ALL minus NAT)**
 HadAM3P > CAM5.1 > MIROC5
 - ✓ **Internal variability (spread of distribution)**
 CAM5.1 > HadAM3P > MIROC5
 - ✓ **Model sensitivity to GHG forcing (TCR)**
 CAM5.1 > HadAM3P > MIROC5

Delta-SAT Pattern



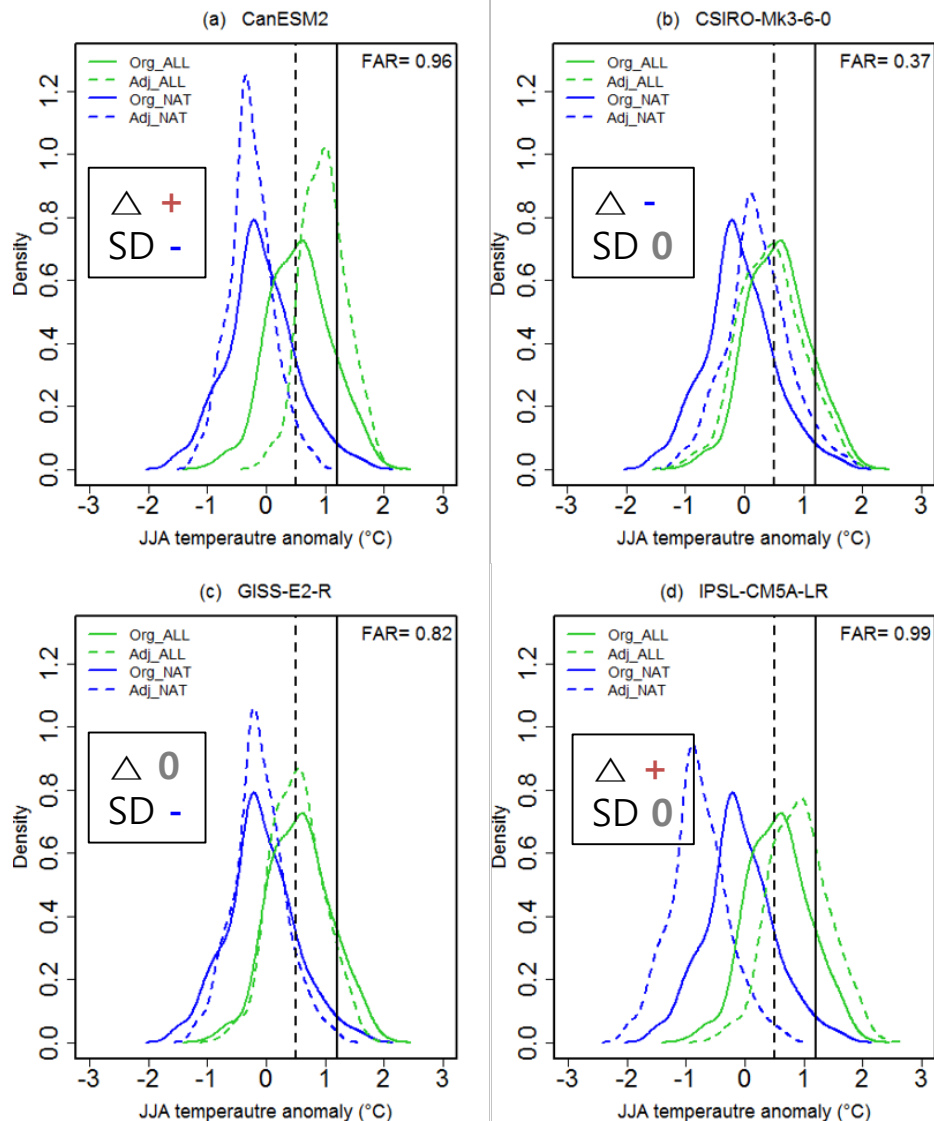
- MIROC5 shows a negative delta-SAT over the land area → influenced by aerosol cooling feedback
- HadAM3P-N96 exhibits larger positive SAT → zero aerosol forcing



List of CMIP5 model

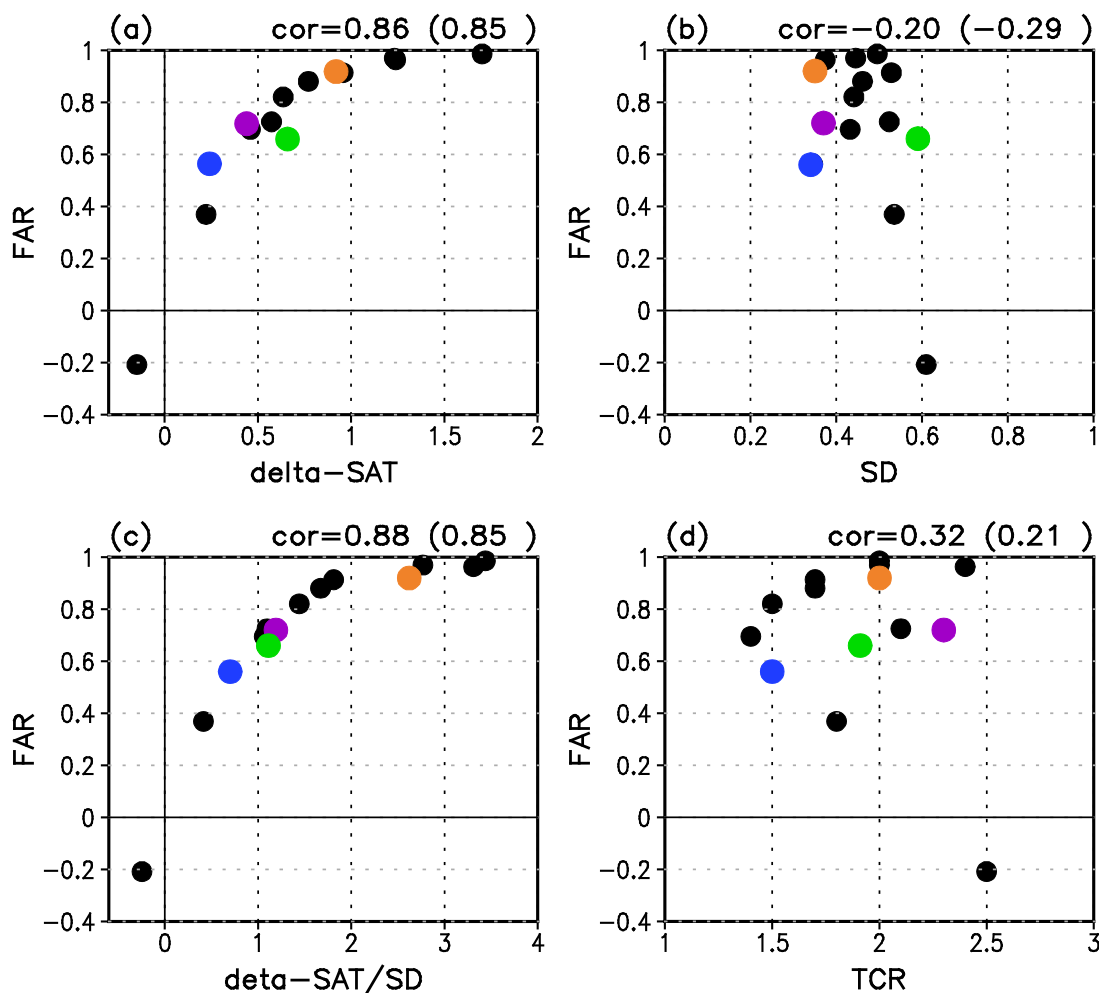
	ALL and NAT (# of runs)	piCTL (years)	TCR (°C)	AER (°C)	delta-SAT (°C)	SD (°C)
bcc-csm1-1	1	500	1.7	-0.21	0.96	0.53
<i>CanESM2</i>	<i>5</i>	<i>996</i>	<i>2.4</i>	<i>-0.24</i>	<i>1.24</i>	<i>0.37</i>
CNRM-CM5	1	850	2.1	-0.45	0.58	0.52
<i>CSIRO-Mk3-6-0</i>	<i>5</i>	<i>500</i>	<i>1.8</i>	<i>-1.43</i>	<i>0.22</i>	<i>0.54</i>
GISS-E2-H	10	780	1.7	-0.71	0.77	0.46
<i>GISS-E2-R</i>	<i>10</i>	<i>850</i>	<i>1.5</i>	<i>-1.00</i>	<i>0.64</i>	<i>0.44</i>
HadGEM2-ES	4	576	2.5	-2.60	-0.15	0.61
IPSL-CM5A-MR	1	300	2.0	-	1.24	0.45
<i>IPSL-CM5A-LR</i>	<i>1</i>	<i>1000</i>	<i>2.0</i>	<i>0.16</i>	<i>1.71</i>	<i>0.50</i>
NorESM1-M	1	501	1.4	-1.31	0.46	0.43
MME			1.9	-0.87	0.66	0.53/0.59

Adjusting CMIP5 MME



- **Assumption** : Distribution of CMIP5 individual model and CMIP5 MME has same shape
- **Adjustment of CMIP5 MME**
 - **Mean** estimated from the ALL and NAT simulations of the individual models during the 2007-2012
 - **SD** estimated from the piCTL of individual models
- **FAR** of CMIP5 MME = **0.71**
- Important role of delta-SAT in determining FAR

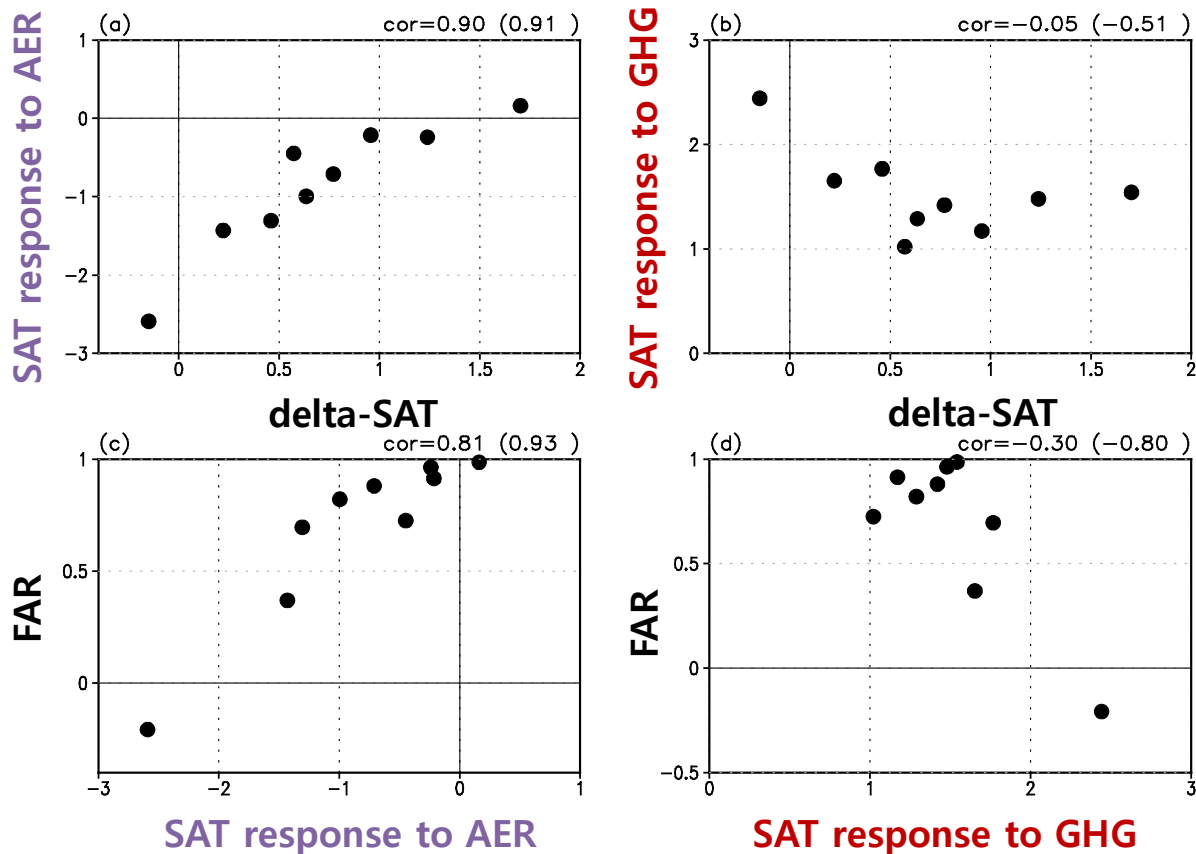
Sensitivity test for FAR



- FAR and delta-SAT is highly correlated across model ($r=0.86$)
 - Internal variability (SD) does not affect FAR much across model
 - FAR-TCR relation is positive but insignificant
- delta-SAT plays a dominant role in the event attribution of Korean heat wave

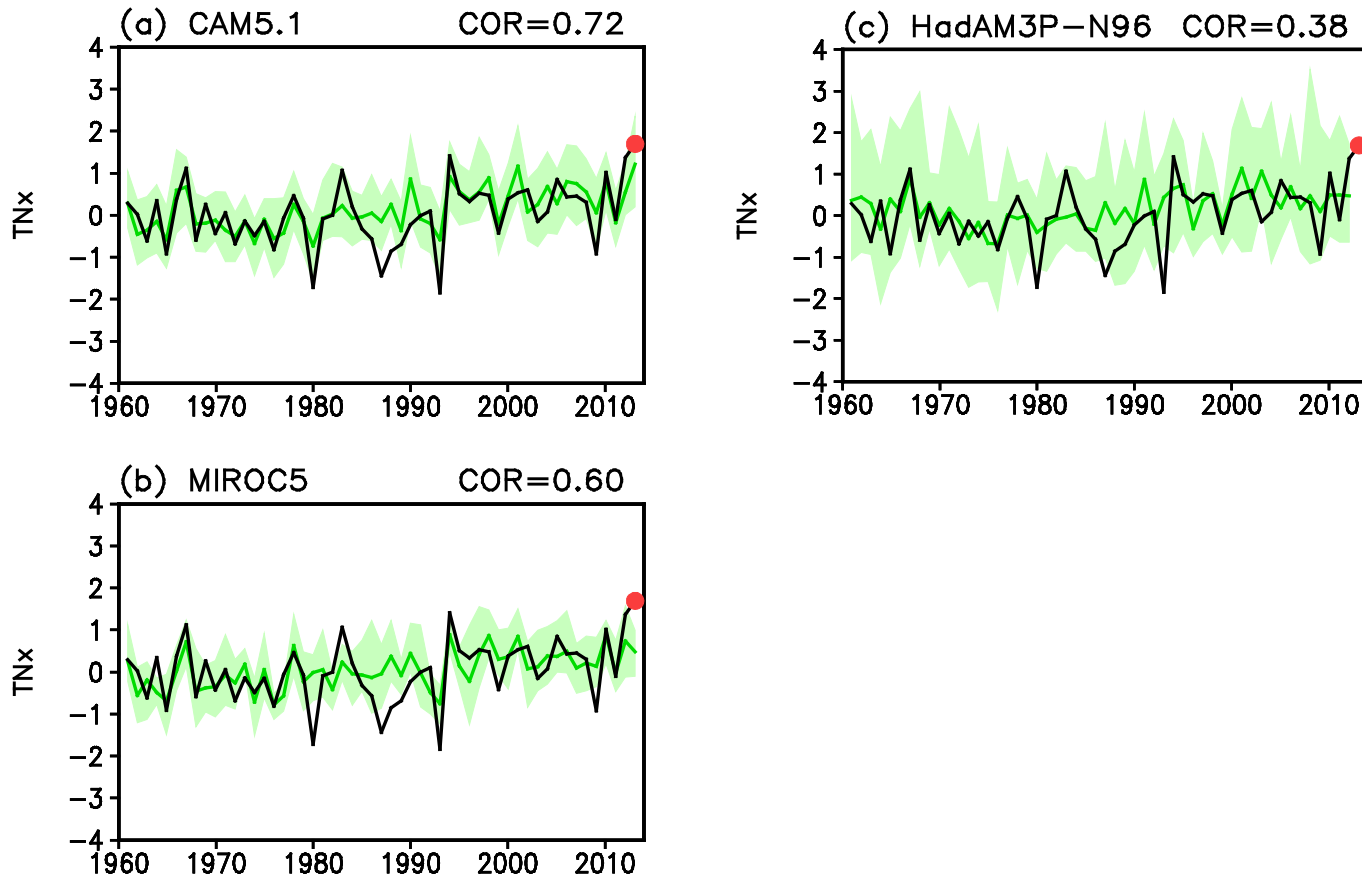
CAM5.1 MIROC5 HadAM3P-N96 CMIP5

What determines delta-SAT?



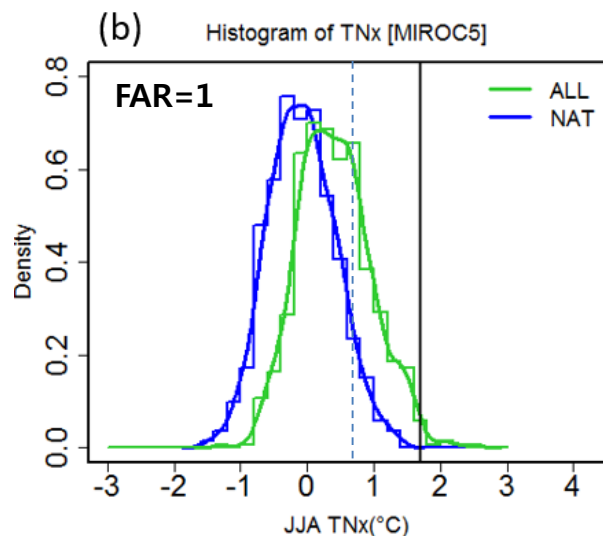
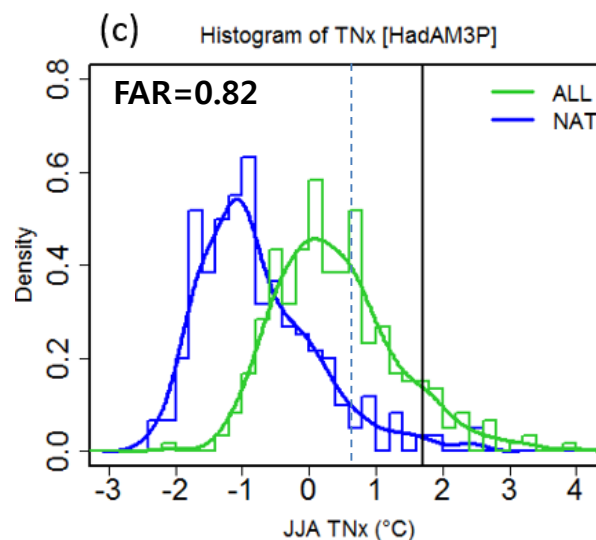
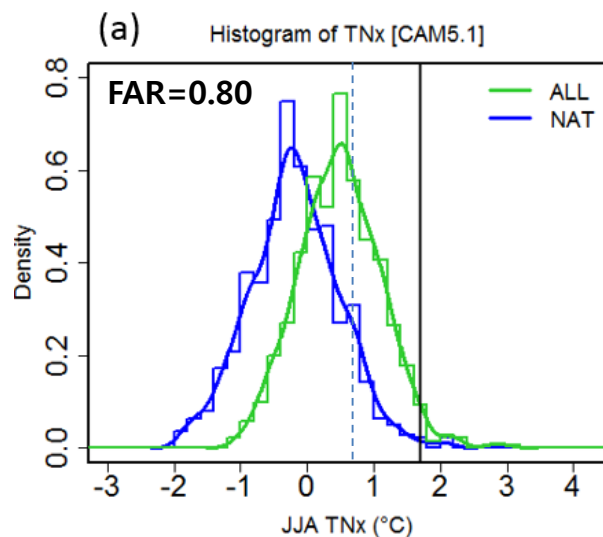
- **SAT response to GHG** : SAT anomalies from GHG experiment during 2007-2012
- **SAT response to AER** : **ALL** - (**GHG**+**NAT**)
- **Inter-model spread in delta-SAT (and FAR) is largely explained by model's response to aerosol forcing ($r=0.90$)**
- Delta-SAT (and FAR) is not related to model's sensitivity to GHG forcing

Daily extreme temperature in 2013



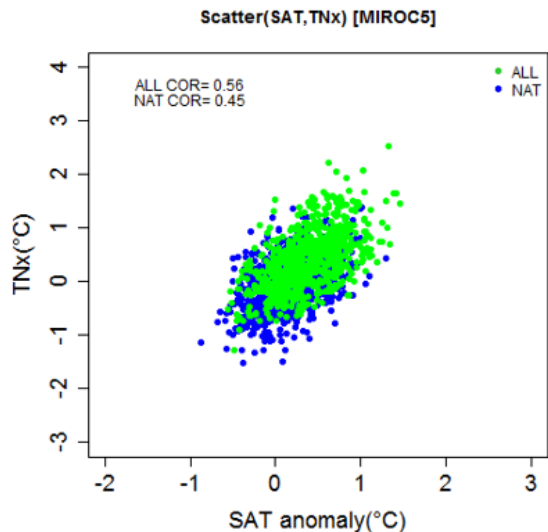
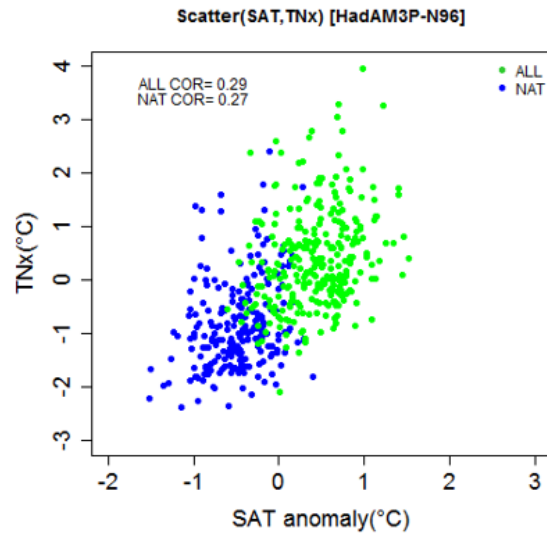
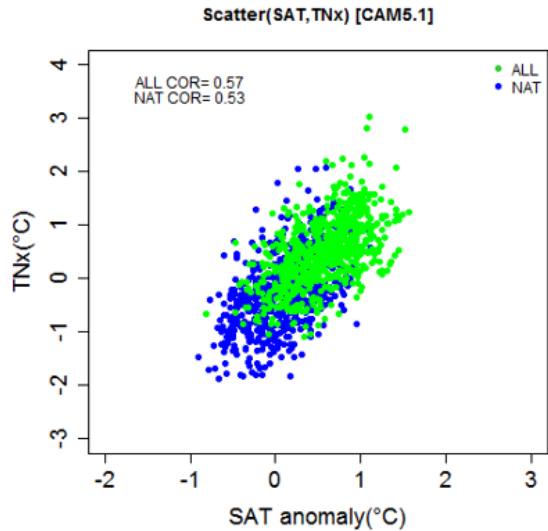
- During the 2013 summer, Korea experienced a **record-breaking seasonal maximum of daily minimum temperature (TNx)**
- Three AGCMs well explained observed fluctuations

FAR for extreme daily temperature



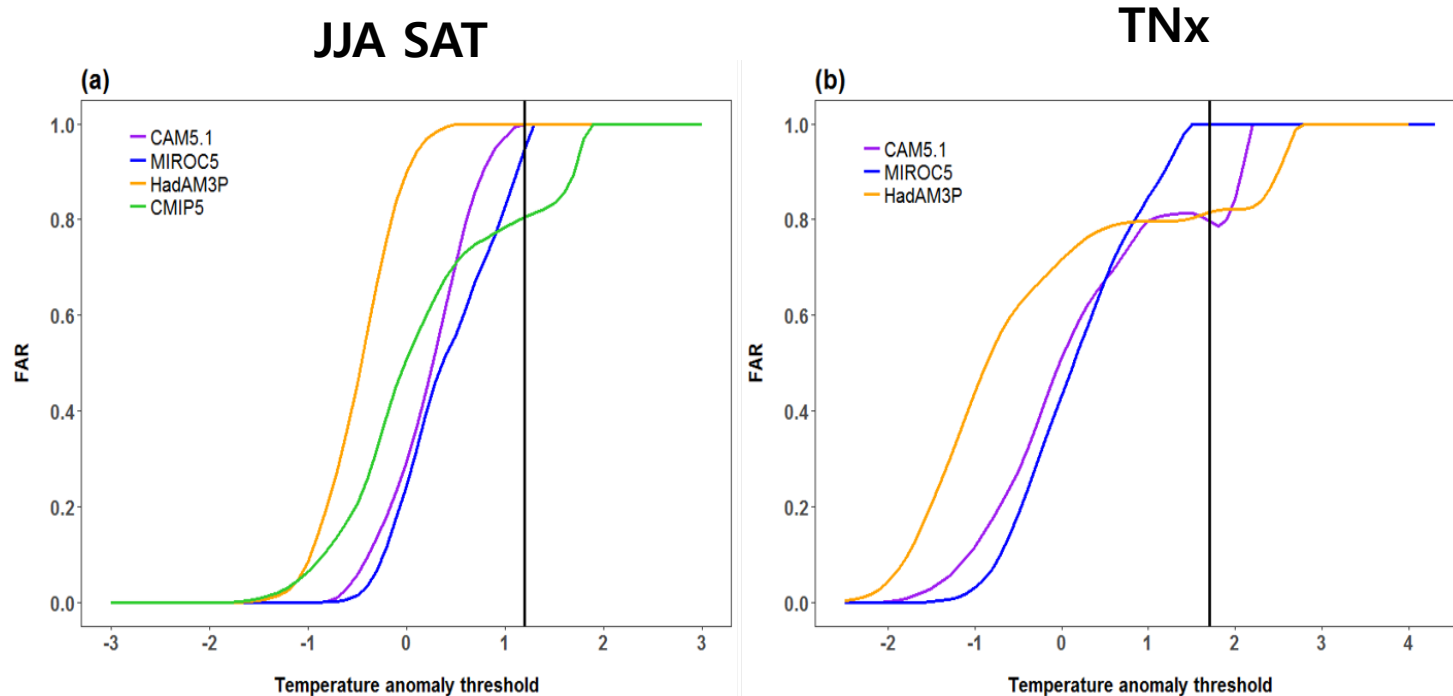
- CAM 5.1 and HadAM3P-N96 : 5-times and 5-6 times increase in likelihood due to anthropogenic influence
- MIROC5 : negligible of human influence
- FAR for 1SD : 0.68(CAM5.1) / 0.76(MIROC5) / 0.79(HadAM3P-N96)

Relationship (SAT & TNx)



- ALL distributions shift from NAT distributions to the upper right direction
- Warming of both seasonal mean and seasonal extreme temperature during 2013 summer

FAR sensitivity to the threshold



- summer SAT : FAR curve of HadAM3P-N96 reached 1 the earliest among the three AGCMs
- TNx : FAR curve of MIROC5 reached 1 the fastest, HadAM3P-N96 reached 1 last

- Event attribution of the 2013 summer Korean heat wave by comparing a large ensemble of 3 AGCMs and 10 CMIP5 CGCMs.
- Both AGCM and CGCM results for 2013 summer mean temperature overall support previous findings that the **extreme heat event in Korea is attributable to the anthropogenic forcing due to greenhouse gas increase**, but with large inter-model difference (large spread in FAR).
- We find that **inter-model uncertainty in event attribution** results is largely explained by **inter-model difference in the delta-SAT**, which is closely related to **model's response to the aerosol forcing**.
- Similar results are obtained from extreme "daily" heat events with at least 5~6 times increase in risk for the 2013-like event.

Thanks for your attention !!