Multi-model Detection and Attribution of Extreme Temperature Changes

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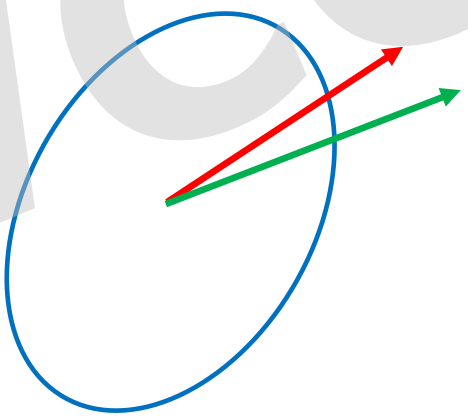
Outline

- Introduction
  - Detection & Attribution (D&A)
  - Extreme temperature changes
- Data: Observations and CMIP3
- Methods: Optimal fingerprinting
- D&A results
  - Global and continental means
  - Sub-continental regions
- Conclusions and discussion

Detection & Attribution (D&A)

- Detection
  - Demonstrating that an **observed change** is significantly different from **natural internal variability**
- Attribution
  - Isolation of **cause(s)** of the detected change
- Possible causes
  - Anthropogenic: Greenhouse gases (GHG), sulphate aerosols, …
  - Natural: Solar and volcanic activities



Human Influence on Climate:

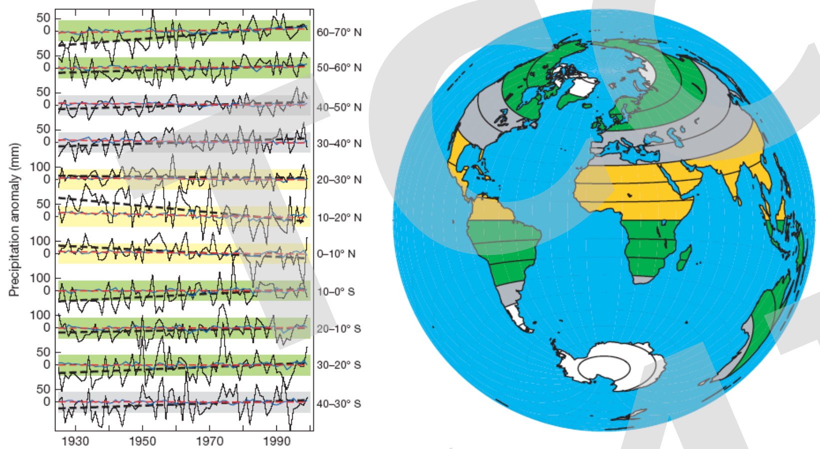
Brief History of D&A Researches

- 1996 Atmospheric thermal structure (Santer et al. *Nature*)
- 1999 Surface air temperature (Tett et al. *Nature*)
- 2000 Surface air temperature (Stott et al. *Science*)
- 2001 Ocean heat content (Barnett et al. *Science*)
- 2003 Sea level pressure (Gillett et al. *Science*)
  North American temperature (Karoly et al. *Science*)
  Tropopause height (Santer et al. *Science*)
- 2004 European heat wave (Stott et al. *Nature*)
- 2006 Tropical sea surface temperature (Santer et al. *PNAS*)

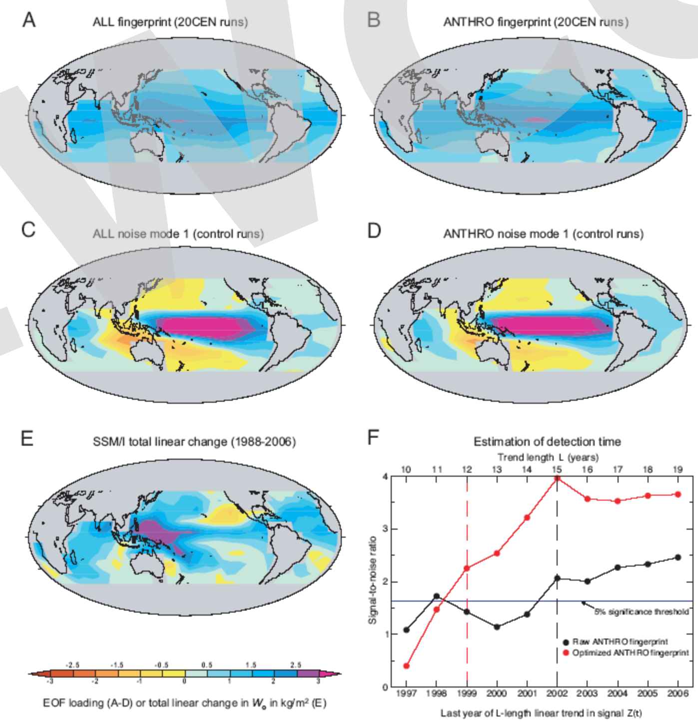
Recent Advances in D&A

Beyond Temperature: Precipitation and Moisture

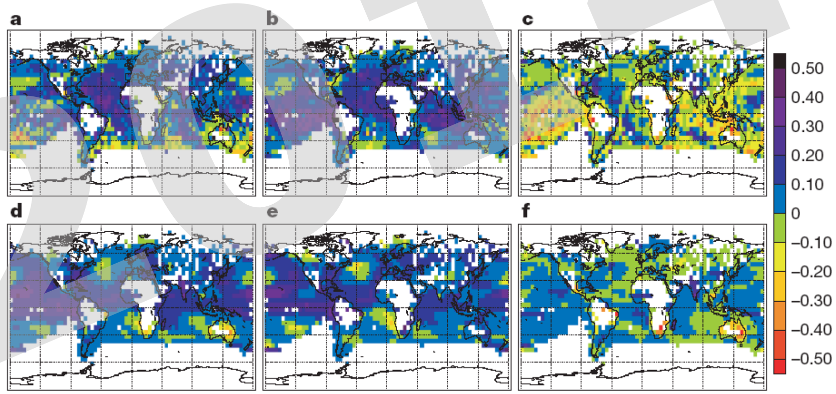
Zonal mean precipitation (Zhang et al. 2007, *Nature*)



Atmospheric Moisture Content (Santer et al. 2007, *PNAS*)



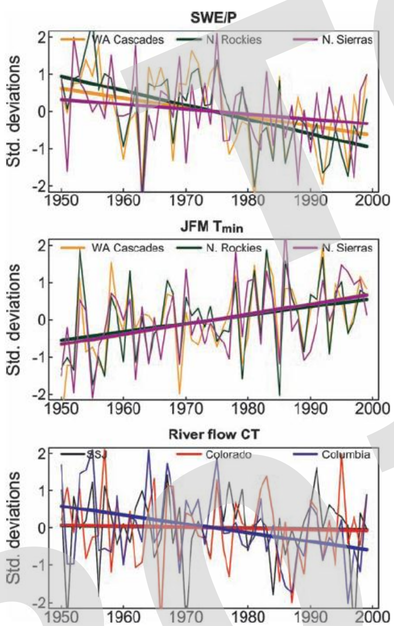
Surface humidity (Willett et al. 2007, *Nature*)



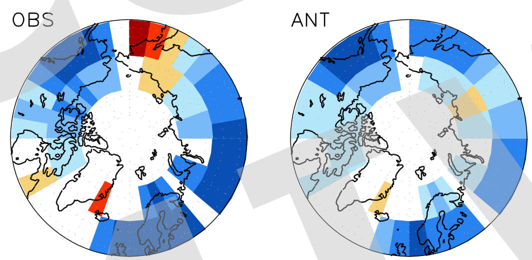
Recent Advances in D&A

Smaller Scales and More Impact-Relevant

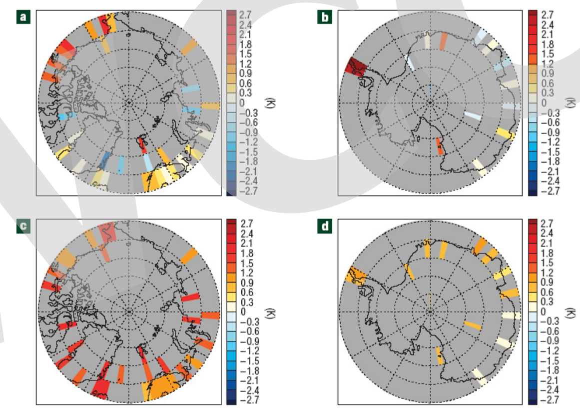
Western US hydrology (Barnett et al. 2008, *Science*)



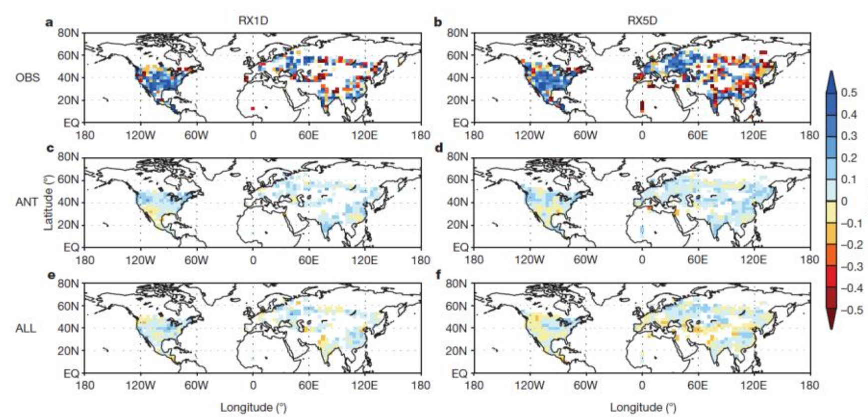
Arctic moistening (Min et al. 2008, *Science*)



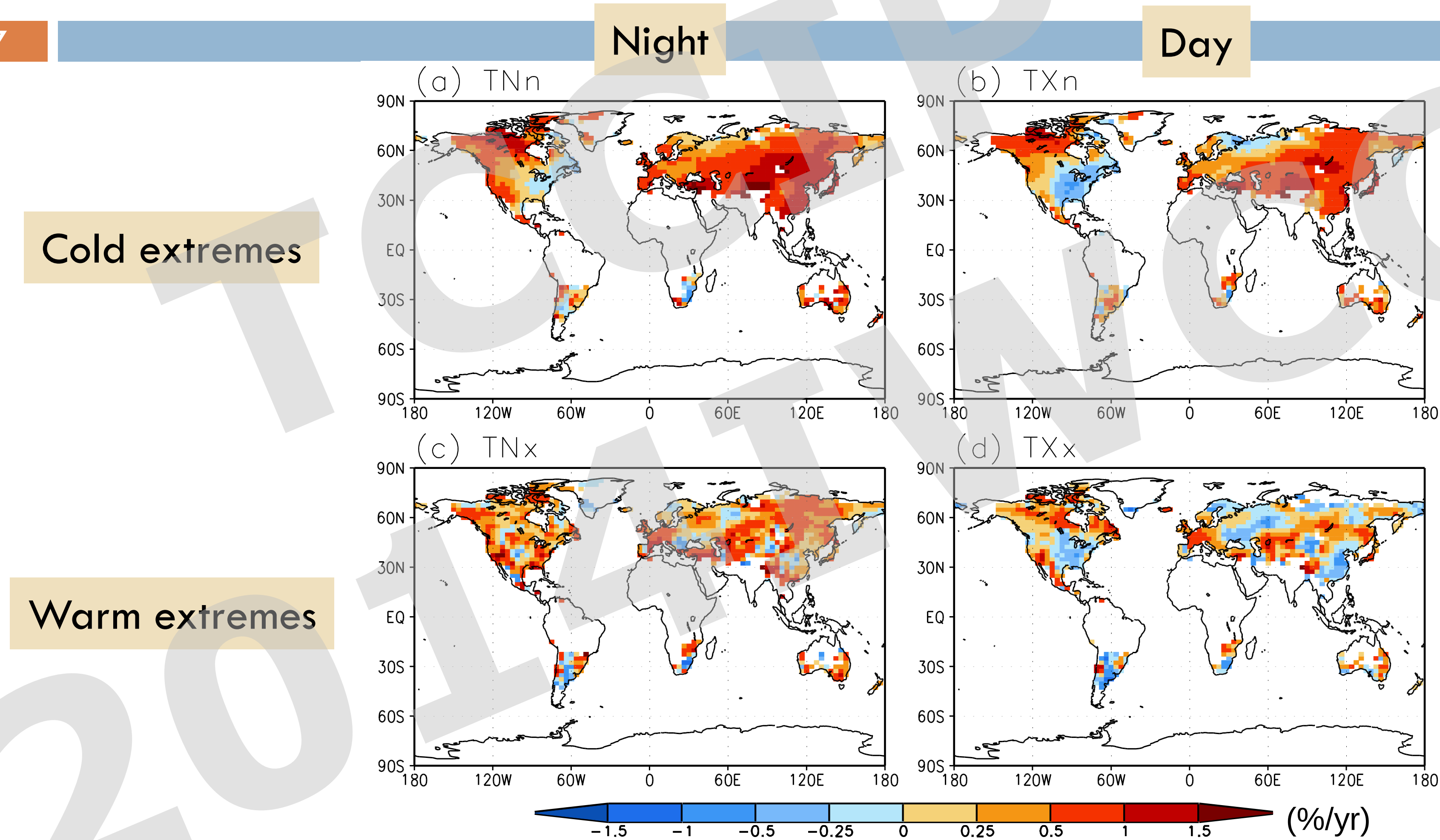
Polar warming (Gillett et al. 2008, *Nature Geo*)



Extreme Precipitation (Min et al. 2011, *Nature*)



Observed Extreme Temperature Trends 1951-2000



➔ Overall warming trends with stronger amplitudes in cold extremes

This Study…

❖ **Targets**

- Detecting human influence on extreme temperature changes at “regional” scales for 1951-2000
- Using more model and longer samples to reduce uncertainty

Data

❖ HadEX observations

- Global land-based climate extremes datasets: gridded (3.75° lon × 2.5° lat) (Alexander et al. 2006, JGR)

❖ Models - 12 CMIP3 models

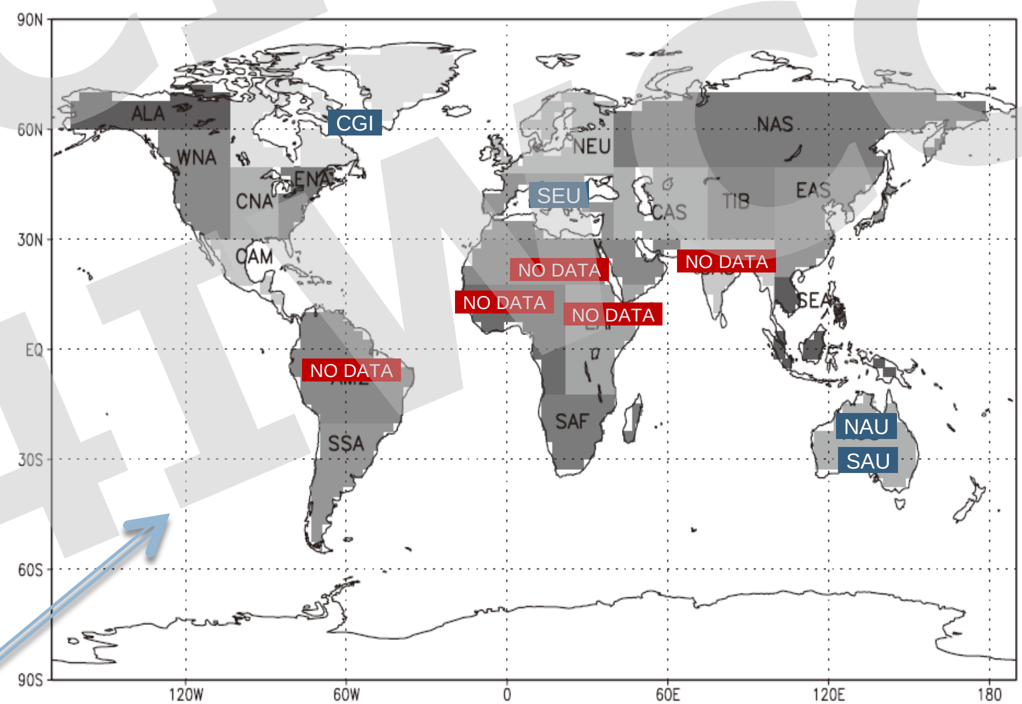
- ANT (anthropogenic, 8 models, 27 runs)
- ALL (natural plus anthropogenic, 8 models, 26 runs)
- CTL (preindustrial control, 10 models, 158 50-yr chunks)

❖ Data processing

- Standardize probability index (PI) on the original grids
- Interpolate PI onto the same HadEX grids (3.75° × 2.5°)
- Apply space-time observational mask

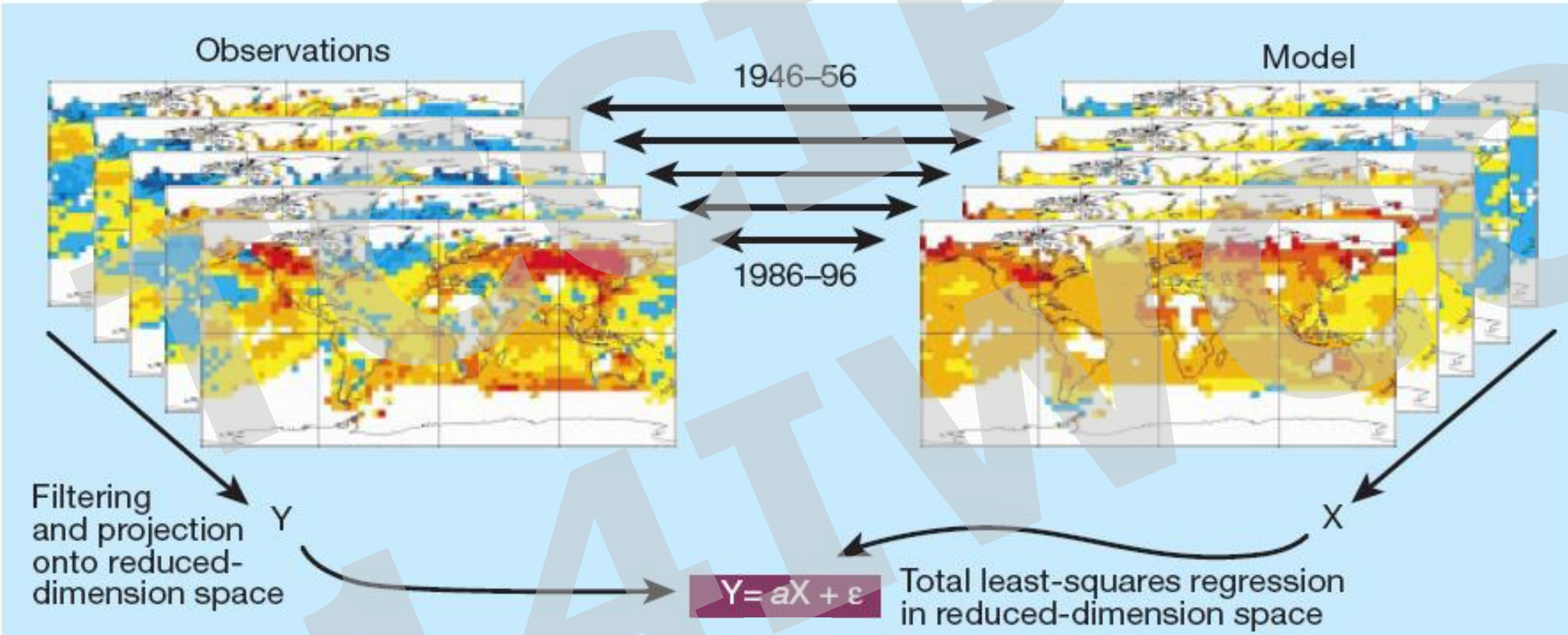
Variables & Domain

- **Analysis variables**
  - Annual extremes of coldest night and day (TNn, TXn), warmest night and day (TNx, TXx) for 1951-2000
- **Spatial domains**
  - Global mean
  - 5 continental mean (N. America, S. America, Europe, Asia, Australia)
  - 16 sub-continents (based on Giorgi's domain)



Based on Giorgi and Francisco (2000)

Optimal Fingerprinting

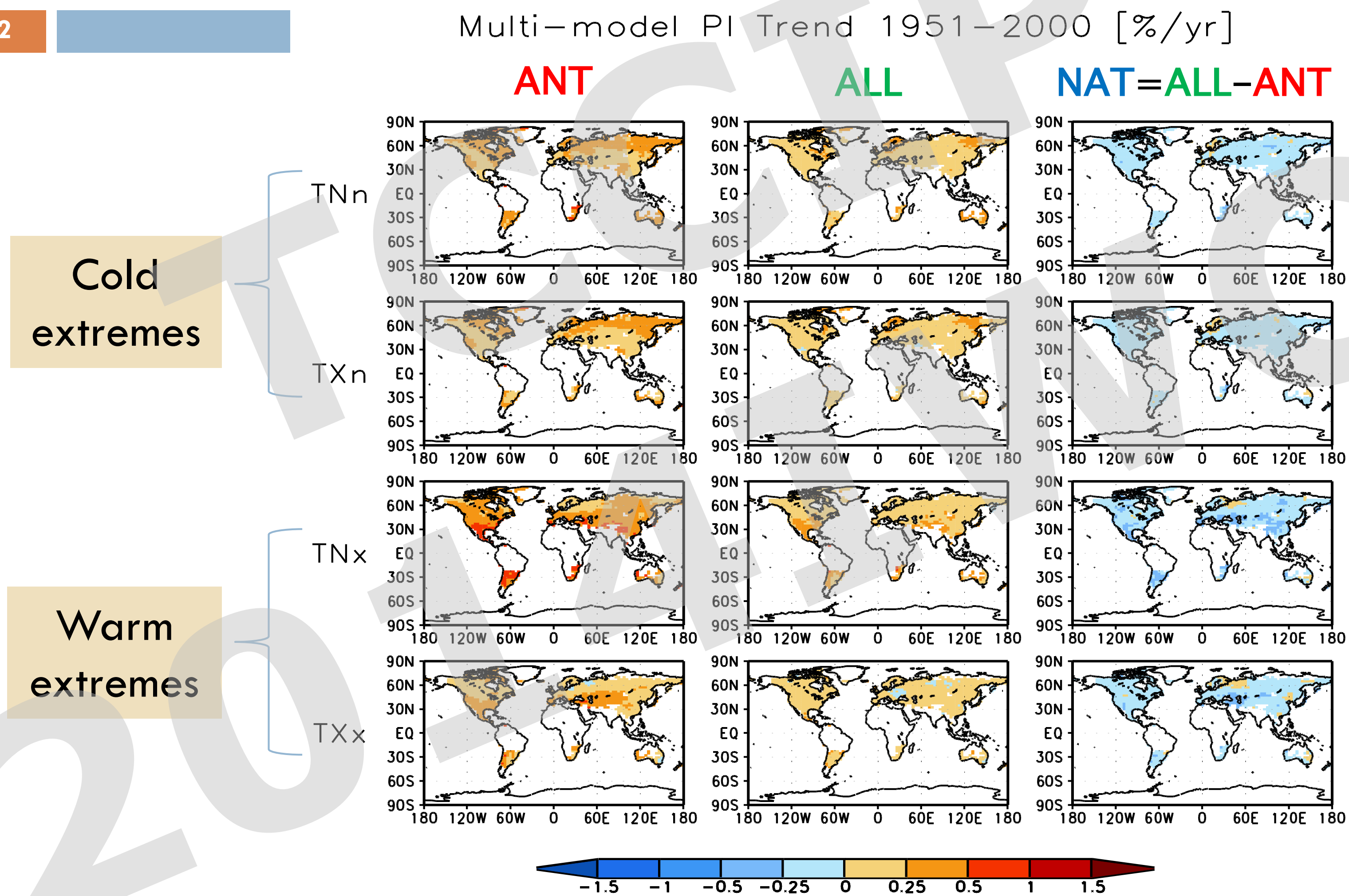


(Weaver & Zwiers 2000)

- Observations **Y** are regressed onto fingerprints **X** as **Y** = **Xβ** + **ε**
- Fitted by total least squares (Allen and Stott, 2003)
- Fingerprints **X** estimated from multi-model mean, internal variability **ε** estimated from control simulations

➔ **Detection: 5-95% range of scaling factor β > 0**

Multi-Model PI Trends



➔ ANT warming offset by NAT cooling

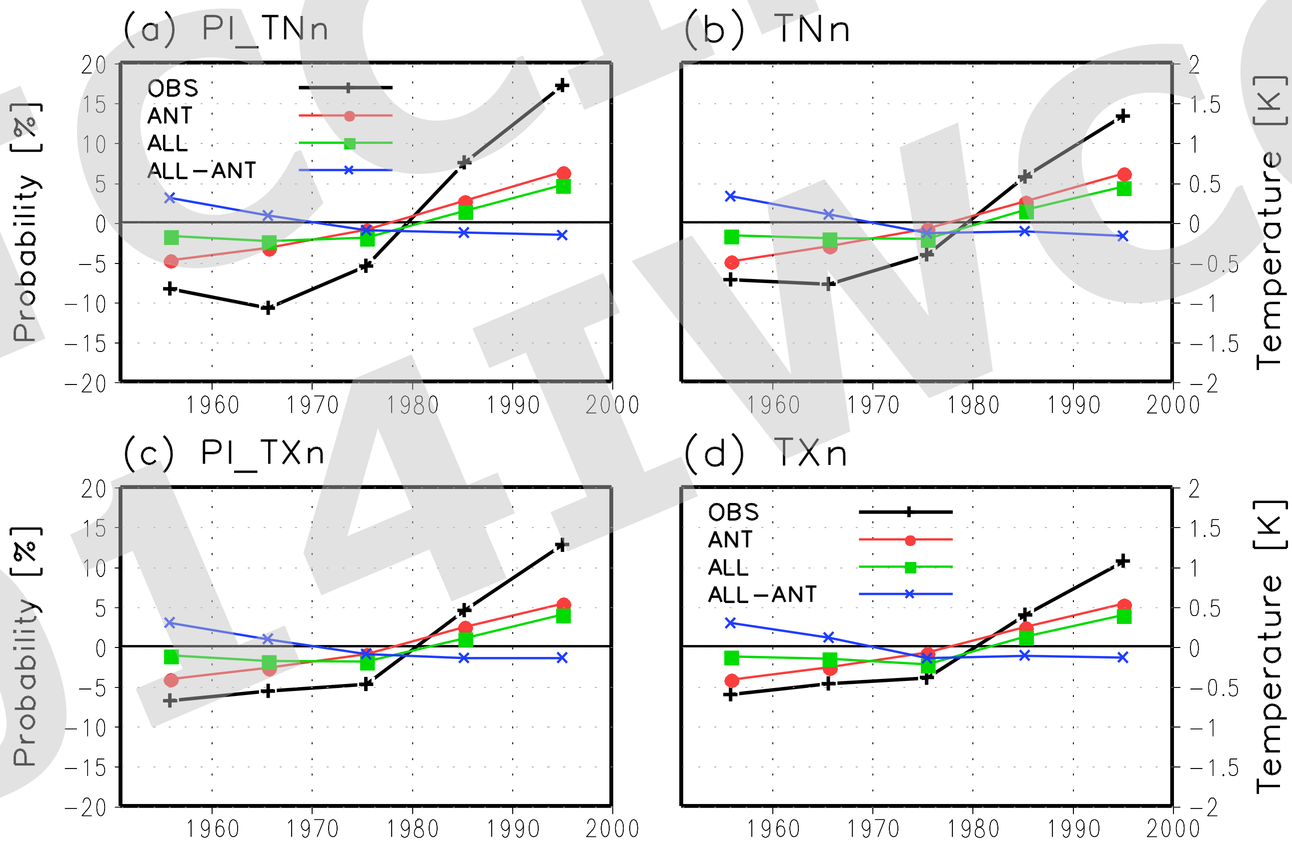
Global Mean Time Series
Cold Extremes

PI (%)

Temperature (K)

Coldest night

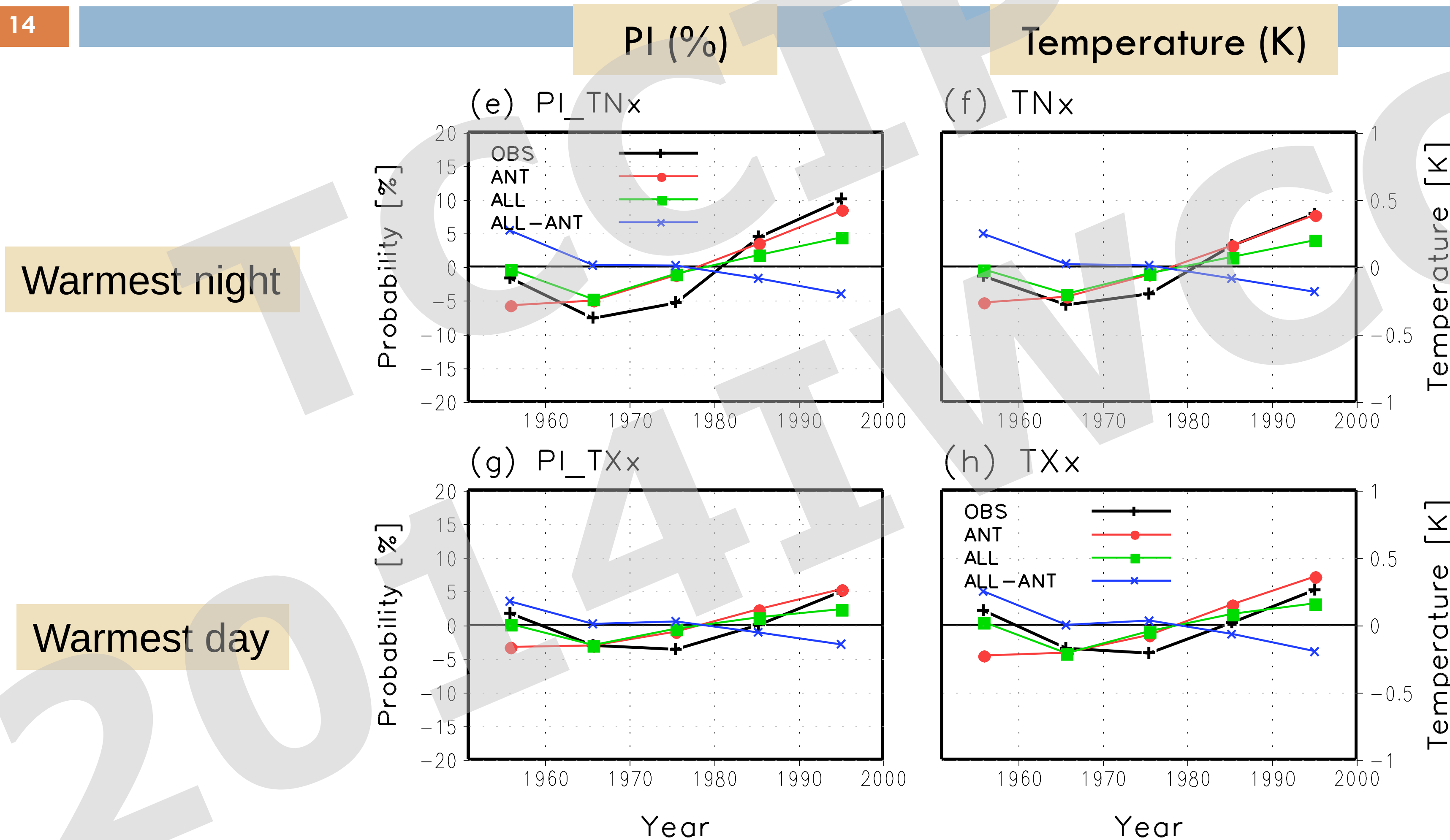
Coldest day



ANT: warming, NAT: cooling, ALL capture observed pattern

➔ Model under-simulate observed warming of cold extremes

Global Mean Time Series
Warm Extremes



ANT: warming, NAT: (stronger) cooling (in summer)

➔ ALL reproduces observed changes with similar amplitude

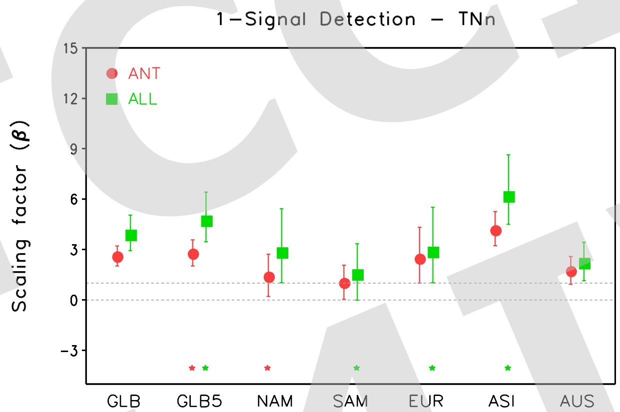
D&A Results for Global/Continental Means: Cold Extremes

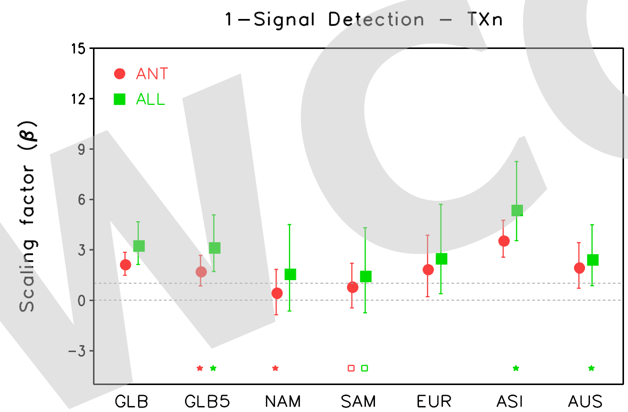
Coldest night

Coldest day

One-Signal

OBS is regressed onto ANT and ALL separately

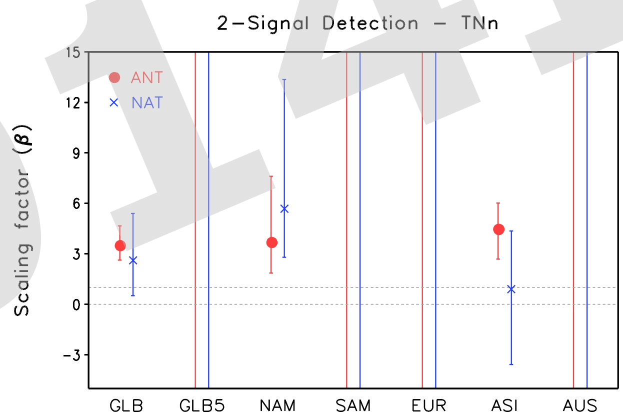


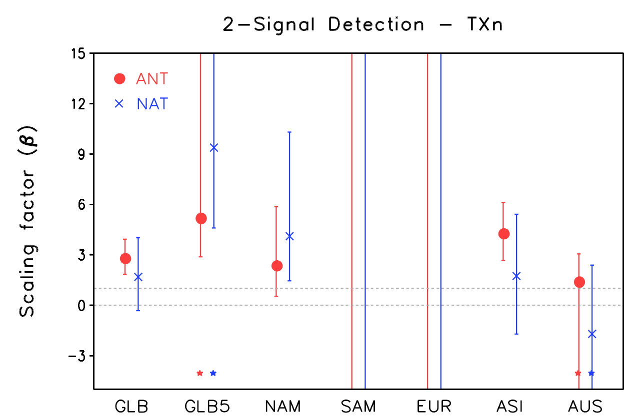


ANT
ALL

Two-Signal

OBS is regressed onto ANT and NAT simultaneously





ANT
NAT

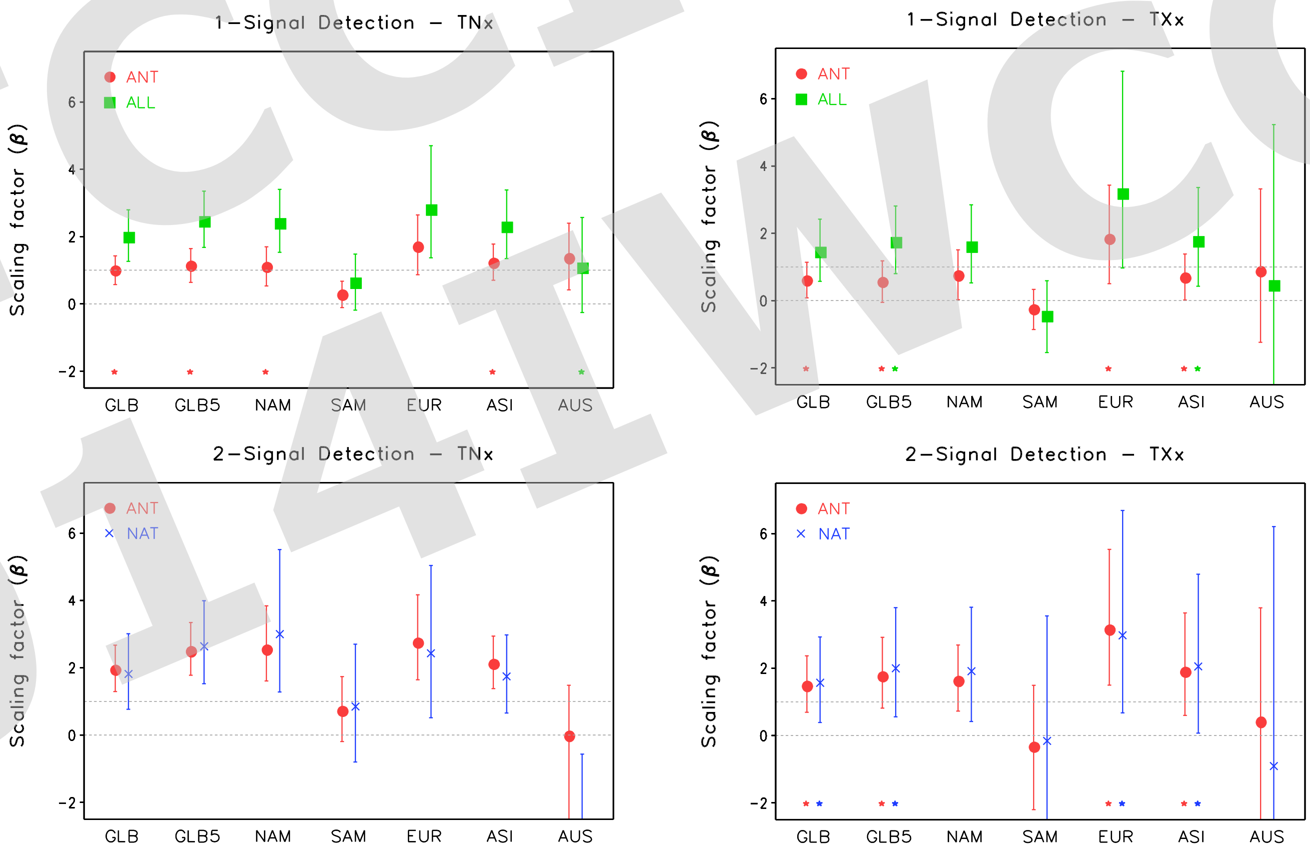
Scaling factors **β**: Best estimate (mark), 5-95% uncertainty range (error bars)

D&A Results for Global/Continental Means: Warm Extremes

Warmest night | Warmest day

One-Signal

Two-Signal



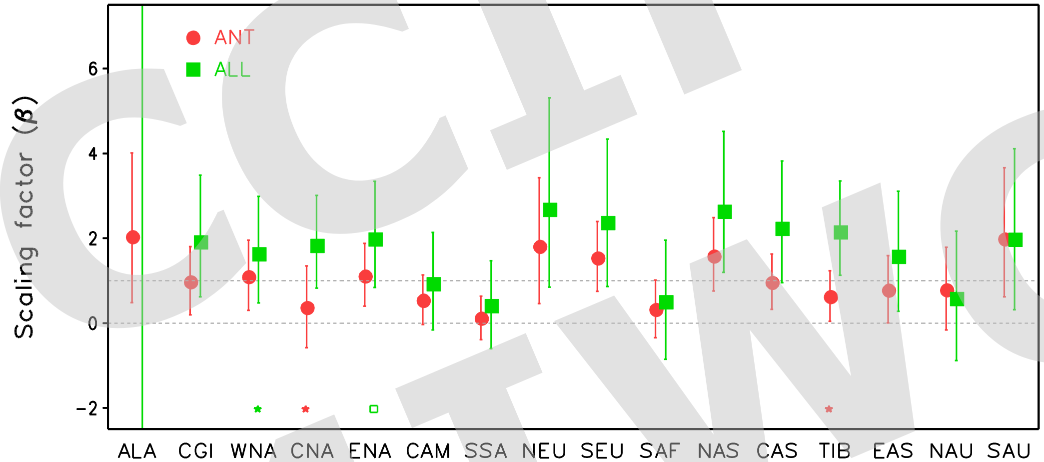
ANT
ALL

ANT
NAT

Scaling factors **β**: Best estimate (mark), 5-95% uncertainty range (error bars)

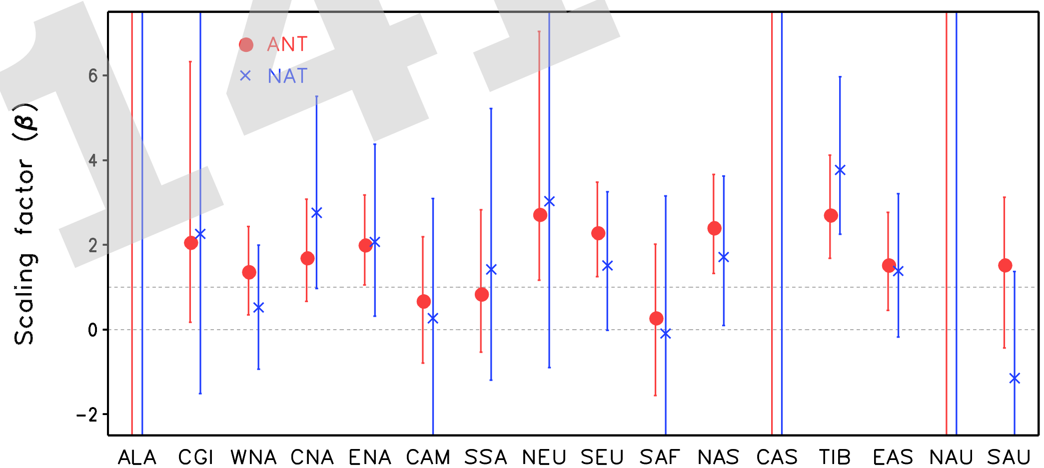
Regional-Scale D&A Results:
Warmest Night (TNx)

One-Signal



ANT
ALL

Two-Signal



ANT
NAT

16 sub-continental regions

Conclusions

- **Statistical comparison between observed and simulated extreme temperature changes**
  - Four annual extreme indices - coldest night and day (TNn and TXn) and warmest night and day (TNx and TXx) for 1951-2000
  - Using an optimal fingerprinting technique
- **Anthropogenic signal (ANT) detected for global and northern continental means**
  - For all four indices, albeit less robustly for TXx
  - Supporting previous studies based on different methods and models
  - ANT separable from natural forcing (NAT) influence at the global scale and to a lesser extent at continental scales

Conclusions (continued)

- **ANT detected at sub-continental scales**
  - less frequent detection due to increased noise
  - ANT detected more in TNx and TNn in many subregions
  - ANT separable from NAT over several subregions for TNx
- **Combined detection analysis**
  - daytime (TX) and night-time (TN) temperature extremes
  - Some improvement in detectability => potential applicability to a multi-variable assessment

Discussion

- **Observation-model discrepancy** - warming of cold extremes (TNn and TXn) is underestimated by the models on global to sub-continental scales in a systematic manner
- **Large uncertainties in the regional detection**
  - Possible influences from **missing processes** such as land cover changes (Portmann et al. 2009; Avila et al. 2012)
  - **Influence of natural climate variability (AO, ENSO, PDO…)** on depending on regions and seasons seasons (Brown et al. 2008; Kenyon and Hegerl 2008; Alexander et al. 2009)
- **Updated analysis is ongoing** - using new observations (HadEX2) and CMIP5 multi-model datasets

Thank You!

Min, S.-K. and Co-authors (2013) Multi-model detection and attribution of extreme temperature changes, *J. Climate*, 26, 7430-7451.

Multi-Model Data: CMIP3

Model name	ANT	ALL	CTL [# of 50-yr chunks]
CCSM3	3	1	-
CGCM3(t47)	5	-	20
CGCM3(t63)	1	-	10
CSIRO-Mk3.0	1	-	6
CSIRO-Mk3.5	2	-	12
ECHAM5/MPI-OM	3	3	10
ECHO-G	3	3	6
GFDL CM2.0	-	3	10
GFDL CM2.1	-	3	10
MIROC3.2(med)	10	10	72
MIROC3.2(hi)	-	1	2
PCM	-	2	-
Total	8 models 27 runs	8 models 26 runs	10 models 158 chunks

Probability-based Index (PI)

- Convert time series (1951-2000) of annual temperature extremes (T) into probability-based index (PI) ranging from 0-1

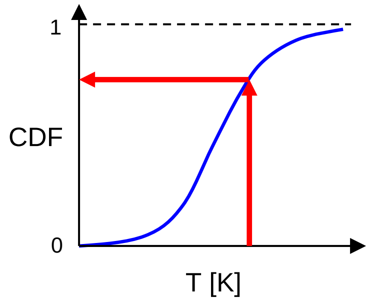
(1) Fit generalized extreme value (GEV) distribution to 50 samples of annual extremes using maximum likelihood method (Kharin and Zwiers, 2005)

CDF

$$F(x;\mu,\sigma,\xi)=\begin{cases}\exp\left[-\exp\left\{-\dfrac{x-\mu}{\sigma}\right\}\right], & \xi=0\\ \exp\left[-\left\{1+\xi\dfrac{x-\mu}{\sigma}\right\}^{-\xi^{-1}}\right], & \xi\neq 0,\quad 1+\xi\dfrac{x-\mu}{\sigma}>0.\end{cases}$$

μ, σ, and ξ : location, scale, and shape parameters (fixed with time)

(2) Each annual extremes T is converted to PI by evaluating the corresponding fitted CDF at the value of that annual extremes (Min et al. 2011)



➔ at grid-point base

Regional Detection Results: 1-Signal

ANT

ALL

Continent	Region	TNn		TXn		TNn+TXn		TNx		TXx		TNx+TXx	
North America	ALA	D	D	D		D		A		A		A	
	CGI		A					A	A	A	A	A	A
	WNA		D			A	D	A				A	A
	CNA								A				A
	ENA							A	A				A
South America	CAM		D		D		D				A	A	A
	SSA												
Europe	NEU	A	A					A	A		A	A	A
	SEU			D				A	A	A		A	A
Africa	SAF												
Asia	NAS	D	D	D	D	D	D	A	D			A	A
	CAS				D			A	A			A	A
	TIB	D	D	D		D			D				D
	EAS	D		D		D		A	A				
Australia	NAU	A	A	A		D	D						
	SAU	A	D	A		A	D	A	A				
Counts (total 16)		7	9	7	3	7	5	10	10	3	3	8	10

D: Detection
A: Attribution

Combined detection (TN+TX)

Regional Detection Results: 2-Signal

ANT

NAT

Continents	Region	TNn		TXn		TNn+TXn		TNx		TXx		TNx+TXx	
North America	ALA	D		A		D							
	CGI	A	A			A	A	A					
	WNA							A				A	
	CNA							A	A				A
	ENA				A			A	A		A	A	A
South America	CAM									A			
	SSA												
Europe	NEU	A				A		D				D	
	SEU							D	A			A	
Africa	SAF												
Asia	NAS	D		D				D	A			A	
	CAS												
	TIB							D	D			D	D
	EAS	A						A					
Australia	NAU					A							
	SAU												
Counts (total 16)		5	1	2	1	4	1	9	5	1	1	6	3

D: Detection
A: Attribution

Combined detection (TN+TX)