



中国科学院大气物理研究所

Institute of Atmospheric Physics, Chinese Academy of Sciences

《巴黎协定》温升目标下的全球季风变化

周天军

致谢：张文霞、陈晓龙、Shingi Nangombe、李东欢、邹立维

第五届区域气候变化监测与检测学术研讨会

2018年8月27-28日 银川

The Goal of Paris Climate Agreement

“Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C , recognizing that this would significantly reduce the risks and impacts of climate change”.



In the Sixth assessment cycle of IPCC, a special report on the impacts of global warming of 1.5°C is developed.

Special Report on Global Warming of 1.5°C



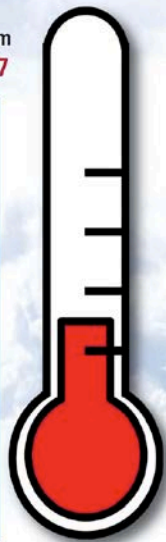
Participate in the First Order Draft Expert Review

Expert Review will take place from
31 July to 24 September 2017

The expert review of the First Order Draft is a key element of the IPCC assessment process. The purpose of this expert review is to help ensure that the report provides a balanced and comprehensive assessment of the latest scientific findings.

The IPCC Procedures state that the expert review process will be objective, open and transparent, involving as many independent experts as possible, seeking a range of views, expertise, and geographical representation.

"The quality of the IPCC assessment strongly depends on the contribution made by expert reviewers from all over the world", says Valérie Masson-Delmotte, Co-Chair of Working Group I. "We solicit experts to join us in this review effort, including early career scientists, as an opportunity to participate in the IPCC process and contribute directly to the process of the special report."



Registration from 17 July 2017 on

<https://www.ipcc.ch/apps/comments/sr15/fod/register.php>

Need information?

- Check the IPCC website: <http://www.ipcc.ch/>
- Contact Working Group I Technical Support Unit: tsu@ipcc-wg1.universite-paris-saclay.fr



Our ref.: 5261-17/IPCC/SR15

To the Executive Heads of
International and other Organizations

Geneva, 17 July 2017

Subject: *IPCC Special Report on Global Warming of 1.5°C*

Sir/Madam,

I have the honour of addressing you on the matter of the Expert Review of the IPCC "Special Report on Global Warming of 1.5°C, an IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty".

You may recall that at the twenty-first session of the Conference of Parties (COP-21) to the United Nations Framework Convention on Climate Change (UNFCCC) in its decision on the adoption of the Paris Agreement, explicitly invited the IPCC to provide a Special Report in 2018 on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways. At the 43rd Session of the IPCC (11 to 13 April 2016, Nairobi, Kenya), the Panel accepted the UNFCCC's invitation to provide the Special Report on 1.5°C in 2018 in the context of strengthening the global response to the threat of climate change, sustainable development and efforts to eradicate poverty. Following a Scoping Meeting in Geneva, Switzerland, in August 2016, the outline of the Special Report on Global Warming of 1.5°C was approved at the 44th Session of the IPCC in Bangkok, Thailand, in October 2016.

Following an IPCC call for nominations in October 2016 to member governments and observer organizations for experts to participate in the Special Report on Global Warming of 1.5°C, Coordinating Lead Authors, Lead Authors and Review Editors were selected by the Working Group I, II and III Bureau in February 2017 from the large number of nominations received. The authors are now working on a first draft report (First Order Draft (FOD)) of the Special Report on Global Warming of 1.5°C, which will be available for expert review from **31 July 2017 to 24 September 2017 midnight (GMT+1)**.

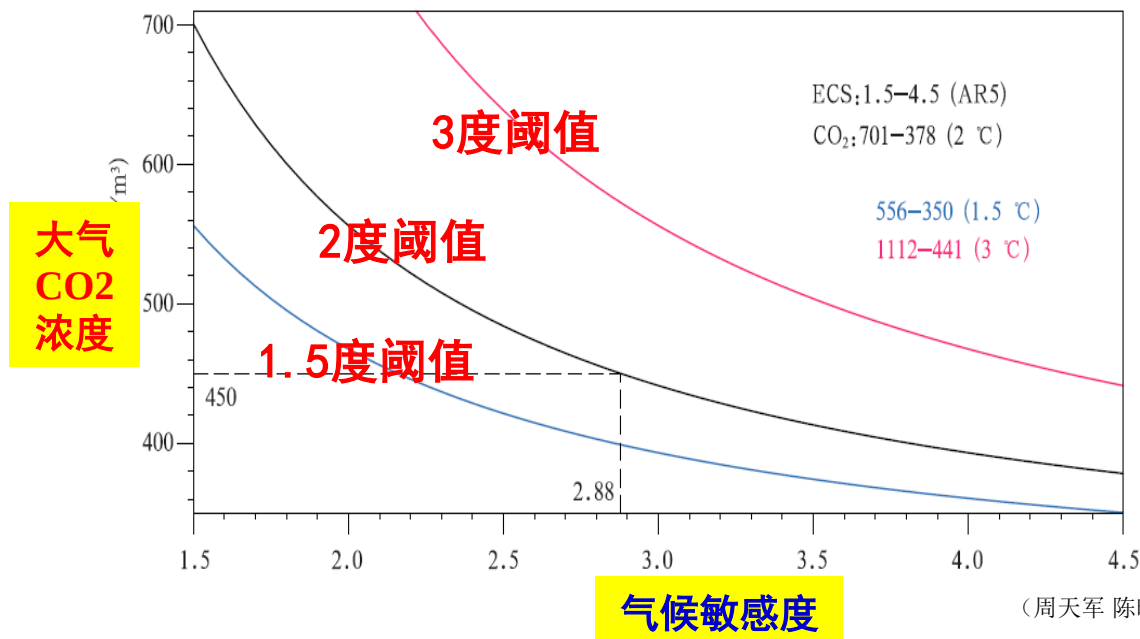
The expert review of the FOD is a key element of the IPCC assessment process. The purpose of this expert review is to help ensure that the report provides a balanced and comprehensive assessment of the latest scientific findings. The IPCC Procedures state that the expert review process shall be objective, open and transparent, with a wide circulation that aims to involve as many independent experts as possible in the IPCC process, seeking a range of views, expertise, and geographical representation. In addition, the review shall be undertaken by experts nominated by governments and observer organizations.

IPCC Secretariat

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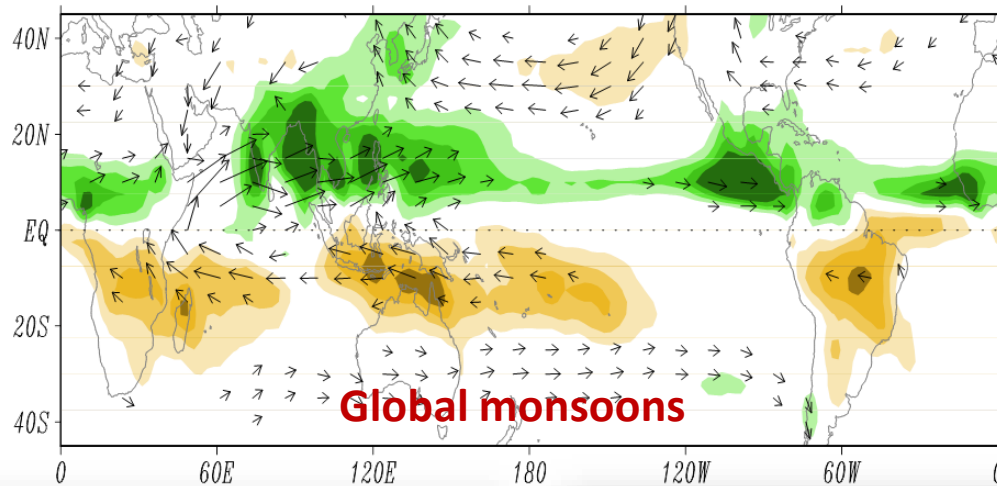


温升阈值、气候敏感度与大气CO₂浓度的关系

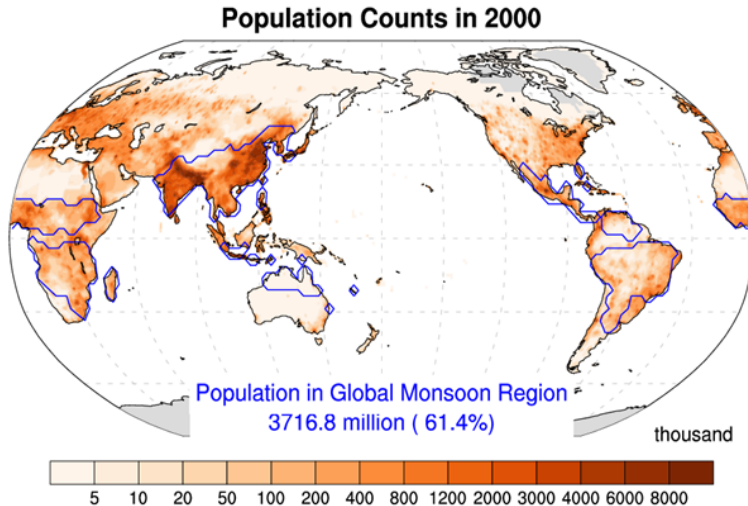


若认为气候敏感度为估计的中间值（约3K），在2度阈值目标下，
大气CO₂浓度不能超过450ppm

Monsoon impacts a large part of the world

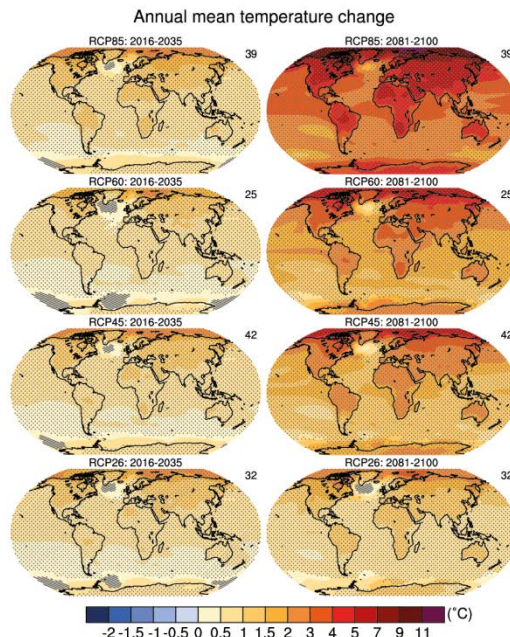
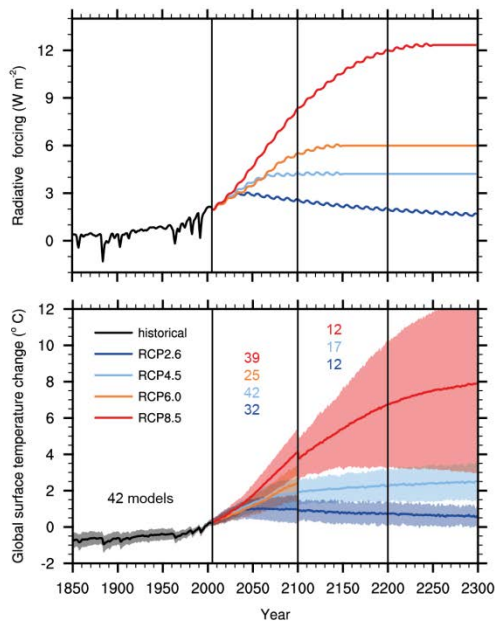


问题一：全球季风区降水的变化



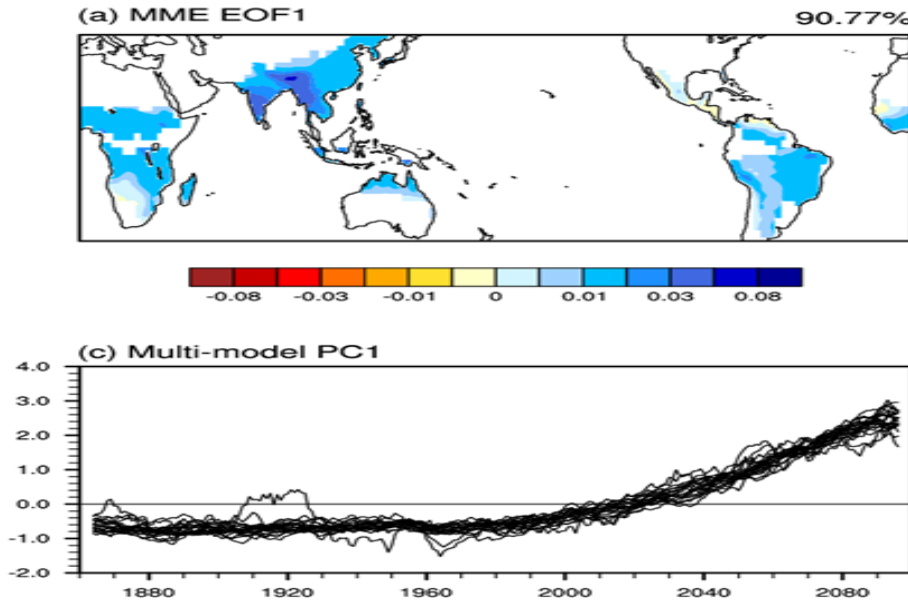
- How much worse would 2 degrees be than 1.5?
- What are the avoided impacts and reduced risks at 1.5 degree warming compared with 2 degree?

不同辐射强迫预估的温度变化



(IPCC AR5)

The leading EOF of RX5day in CMIP5 RCP8.5 Projection



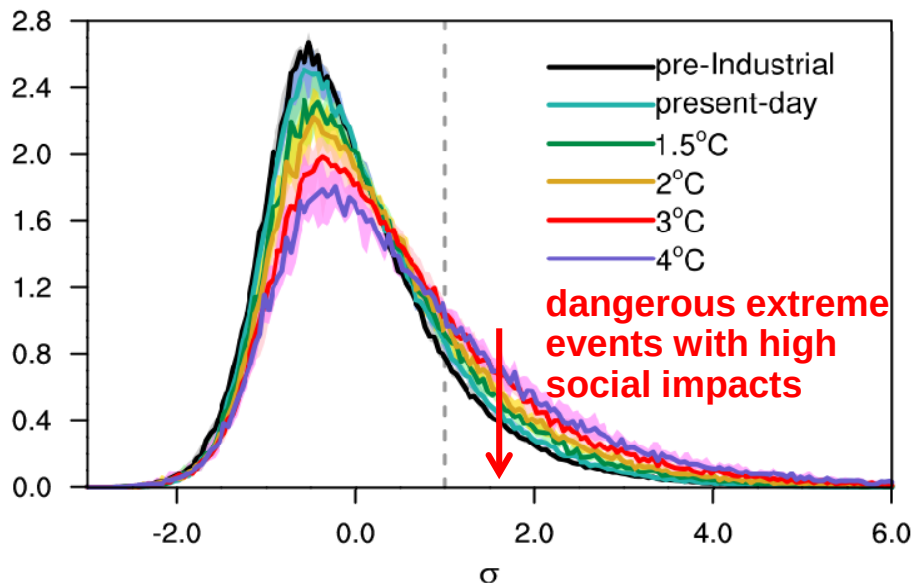
Increasing trend is evident in global monsoon domains except for N. American monsoon

Data: daily precipitation from 27 CMIP5 models: *historical* + *RCP4.5/RCP8.5*

Zhang W., T. Zhou*, L. Zou, L. Zhang, X. Chen, 2018: Reduced exposure to extreme precipitation by 0.5° C less warming for global land monsoon regions . *Nature Communication* 9, Article number: 3153 (2018). doi: 10.1038/s41467-018-05633-3

Response of extreme precipitation to warming in CMIP5 Models

PDF of Rx5day over global land monsoon region



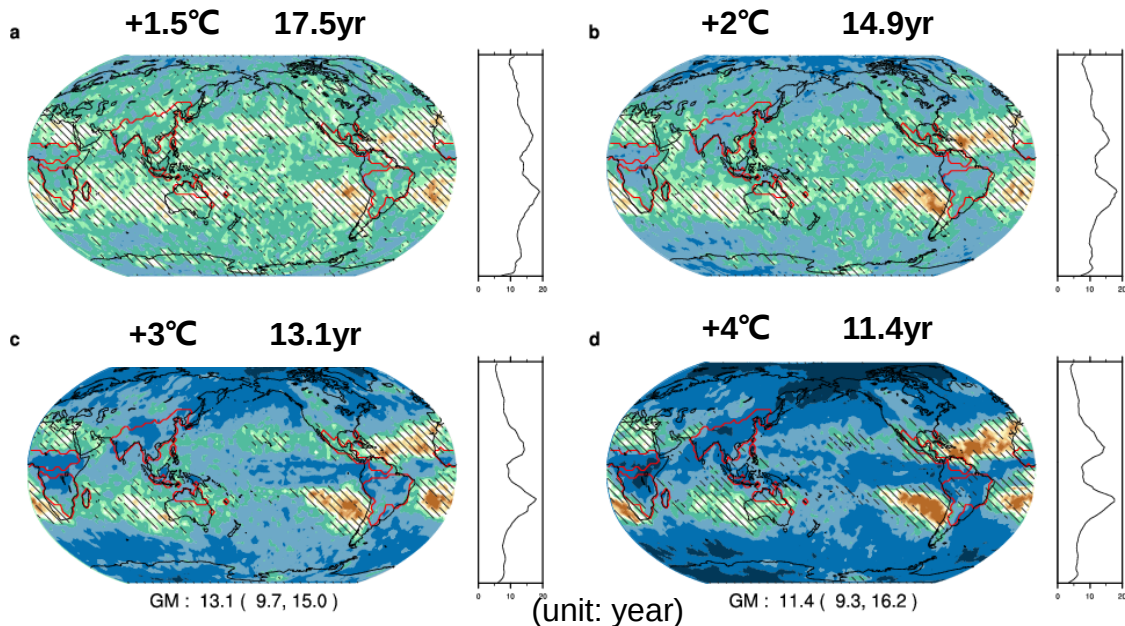
Once-in-10/20-year events
derived from Generalized
Extreme Value (GEV)
distribution

Two-folded response of extreme precipitation

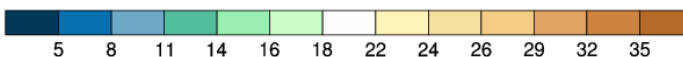
- Increase in mean state (shift of the distribution)
- Increase in variability (widening of the distribution)

Changes in return periods under warming conditions

Return periods of historical (1950-2005) **once-in-20-year** Rx5day events



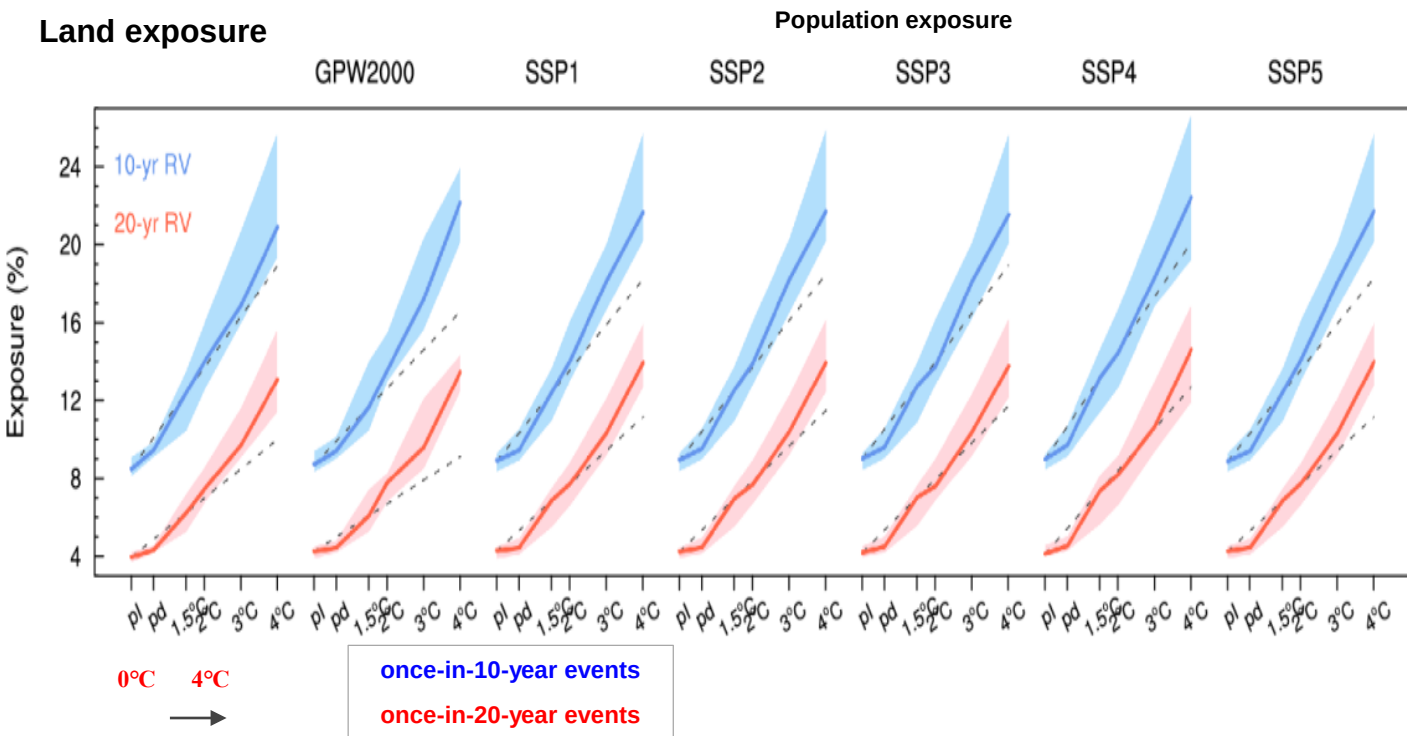
shorter return period



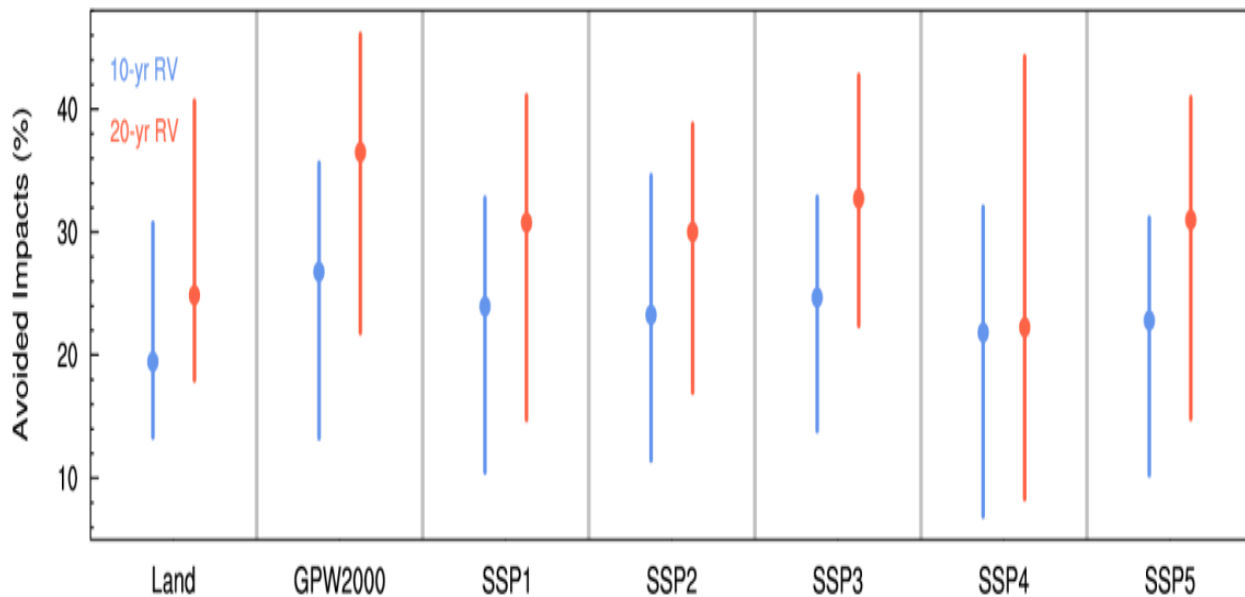
longer return period

Shorter return periods for dangerous extremes are expected under further warming conditions.

Increase in exposure with global warming levels



1.5°C vs. 2°C: avoided impacts for global land monsoon region



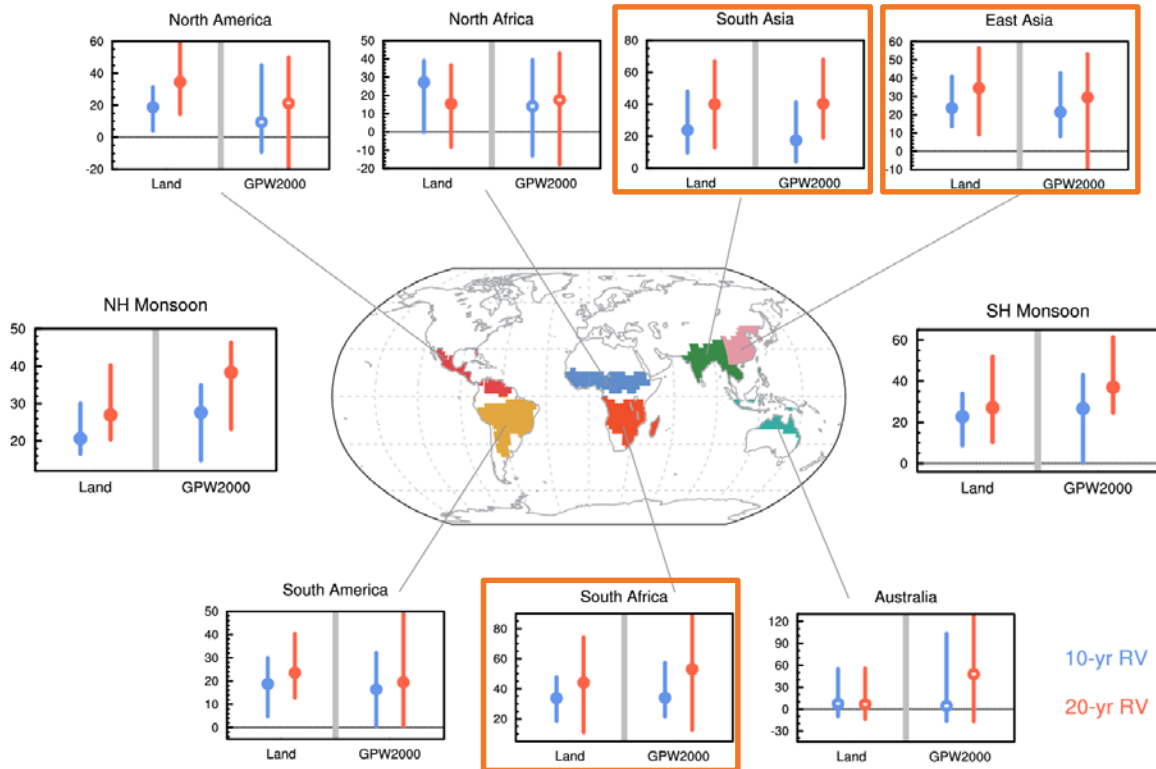
$$\text{Avoided Impact} = \frac{EXP_{2^{\circ}\text{C}} - EXP_{1.5^{\circ}\text{C}}}{EXP_{\text{present-day}}} \times 100\%$$

once-in-10-year events

once-in-20-year events

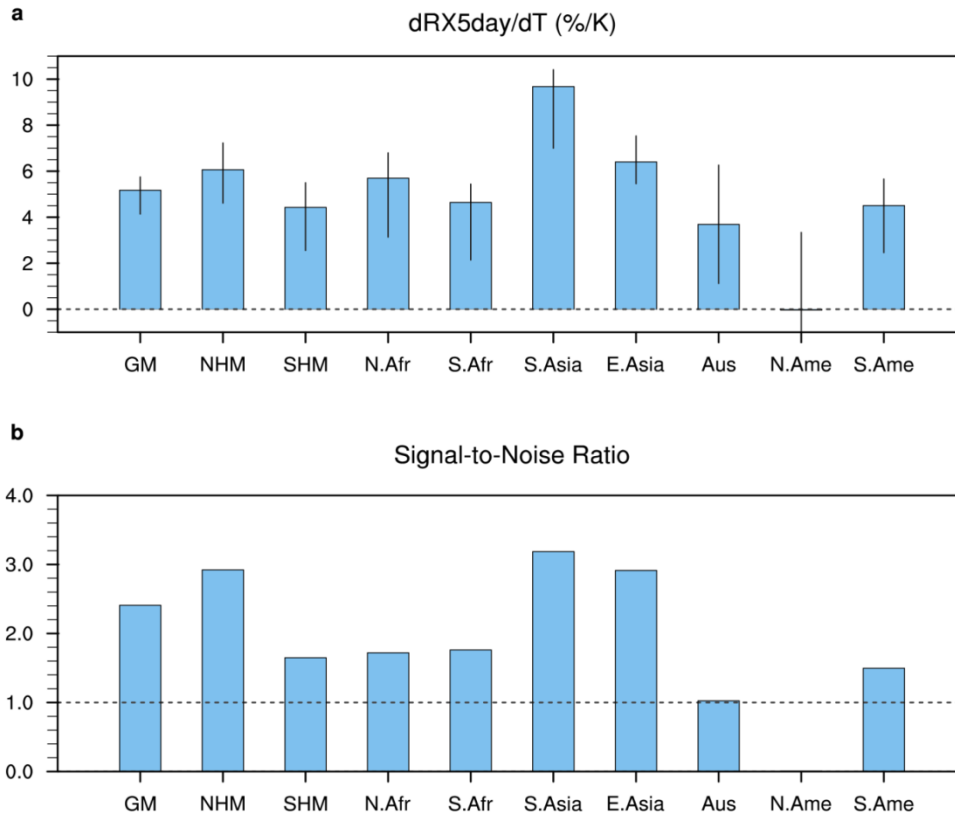
- **Avoided exposure: ~20-40%**

Avoided impacts: regional hotspots



- ◆ **South African, South Asian, and East Asian monsoon regions** would benefit most from the 0.5°C less warming.

Response of RX5day to global warming: Signal-to-Noise ratio



Interim Summary # 1



1. The 0.5° C less warming would reduce areal and population exposures to dangerous *extreme precipitation (once-in-10/20-year) events* by ~20-40%, for the global land monsoon region.
2. South African, South Asian, and East Asian monsoon regions would benefit most from the 1.5° C low warming target, in terms of reduced exposure to dangerous extremes.

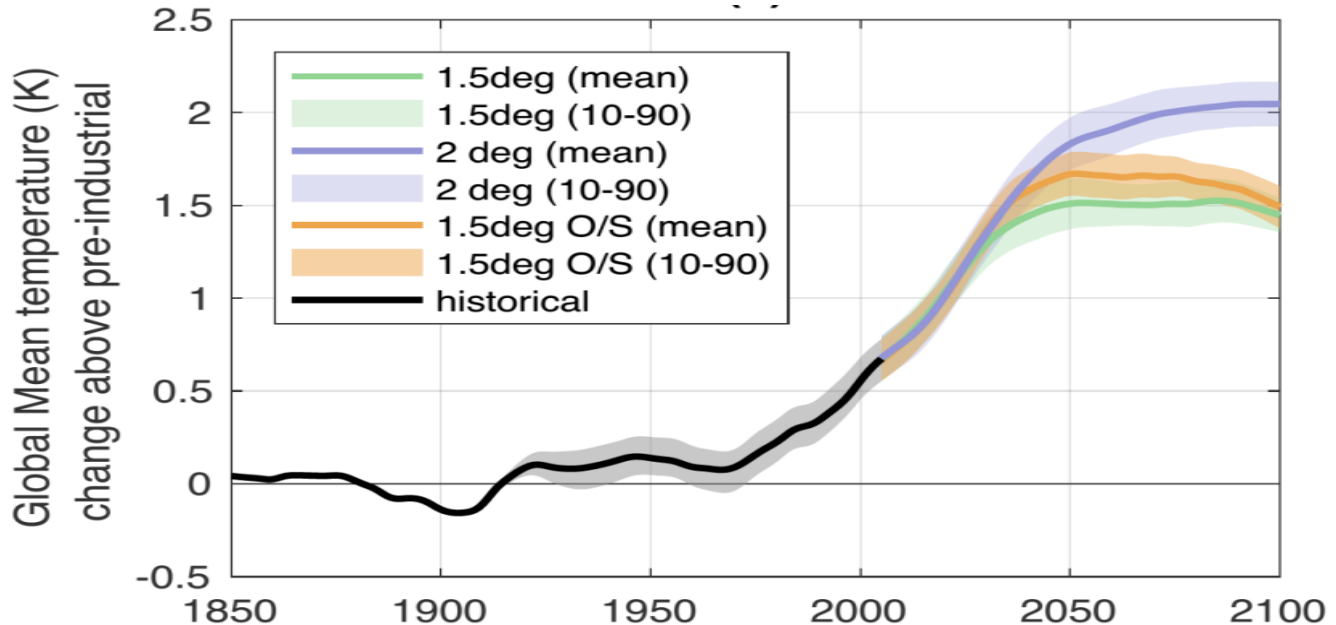
We highlights the benefits of the 1.5° C low warming target in terms of lower exposure to dangerous precipitation extremes for the populous monsoon regions.

问题二：东亚季风区的热浪变化



CESM Low-warming experiments

Annual global mean temperatures

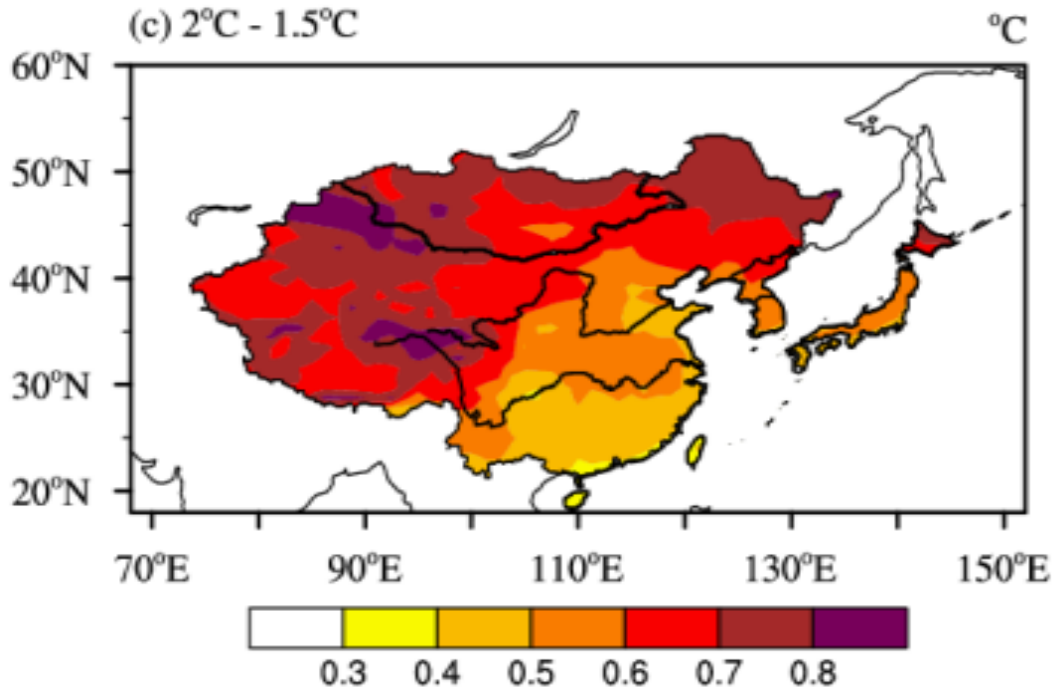


◆ **1.5degNE:** stabilizes in 2050 at 1.5 °C above pre-industrial levels

◆ **2.0degNE:** stabilizes at slightly over 2.1 °C, reaching 2.1 °C by 2090.

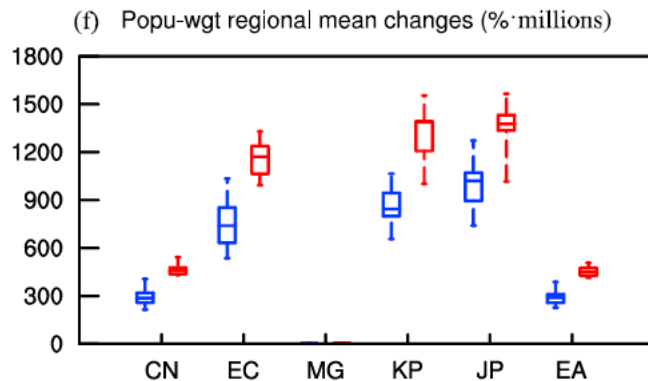
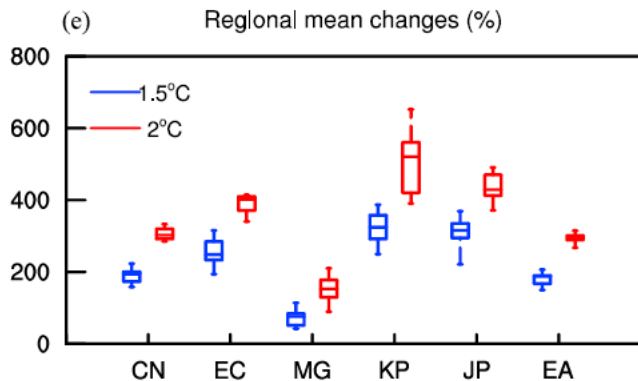
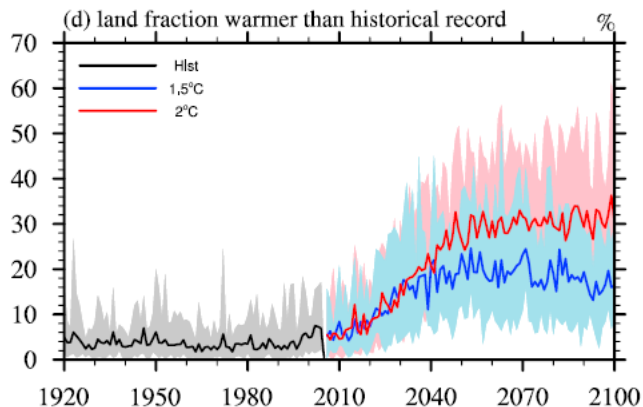
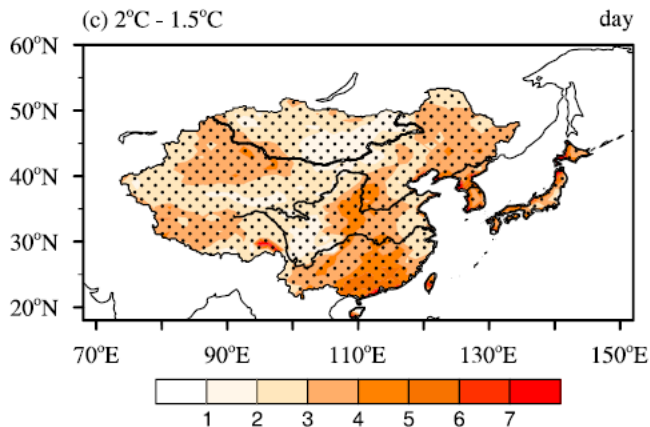
Sanderson et al. (2017)

Changes of surface air temperature over East Asia

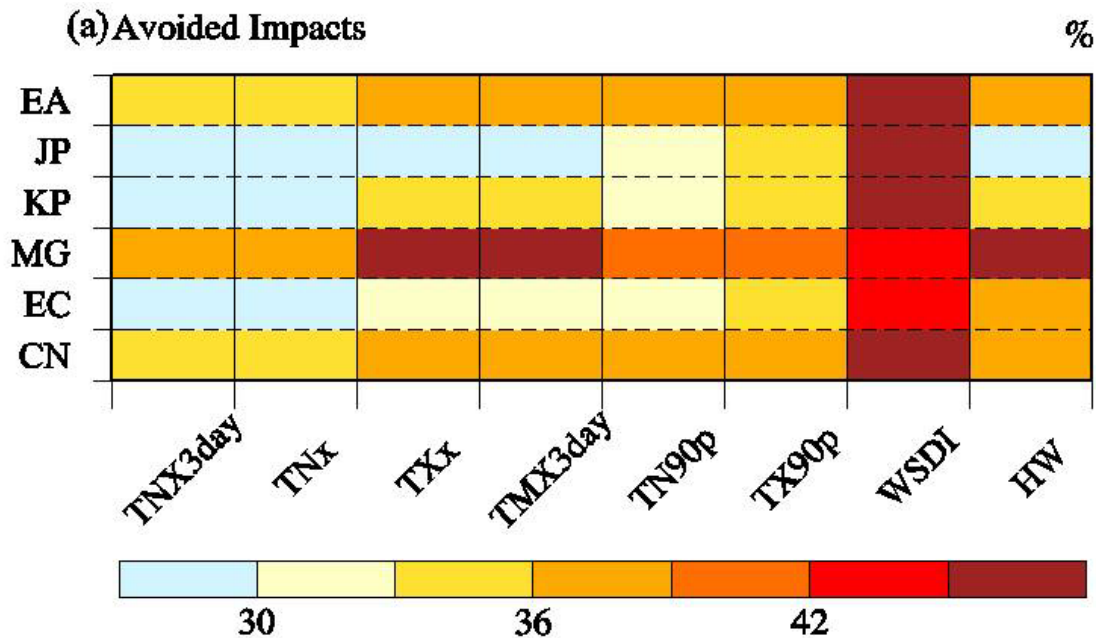


- **Stronger warming:** northwestern China, Mongolia and parts of Korean Peninsula and Japan
- **Weaker Warming:** eastern China

Changes of Heat Wave



相较于2°C温升，1.5°C温升情景下可避免的极端高温事件的增幅（单位：%）



Li, D., T. Zhou, L. Zou, W. Zhang, and L. Zhang (2018), Extreme high-temperature events over East Asia in 1.5°C and 2°C warmer futures: Analysis of NCAR CESM low-warming experiments. *Geophysical Research Letters*, 45. <https://doi.org/10.1002/2017GL076753>.

Interim Summary #2



1. 较之全球平均增温，东亚平均增暖在两个温升情景下都将更强约 0.2°C 。
2. 在人口相对较多的地区，如中国东南部地区、朝鲜半岛以及日本，极端高温事件的强度、频率和持续时间都比其他地区增幅更大。
3. 定量分析表明，与 2°C 温升阈值相比，控制全球增暖在 1.5°C 以内，将令东亚极端高温事件强度、频率和持续时间的增幅减少35%-46%。这意味着对于东亚地区而言，控制 1.5°C 温升是有益的。

Li, D., T. Zhou, L. Zou, W. Zhang, and L. Zhang (2018), Extreme high-temperature events over East Asia in 1.5°C and 2°C warmer futures: Analysis of NCAR CESM low-warming experiments. *Geophysical Research Letters*, 45. <https://doi.org/10.1002/2017GL076753>.

问题三：气候脆弱区的变化--非洲

CLIMATE EXTREMES

Africa and the Paris Agreement

The African continent is one of the most vulnerable regions to future climate change. Research now demonstrates that constraining anthropogenic warming to 1.5 °C instead of 2 °C will significantly lower the risk of heatwaves to inhabitants.

Andries C. Kruger

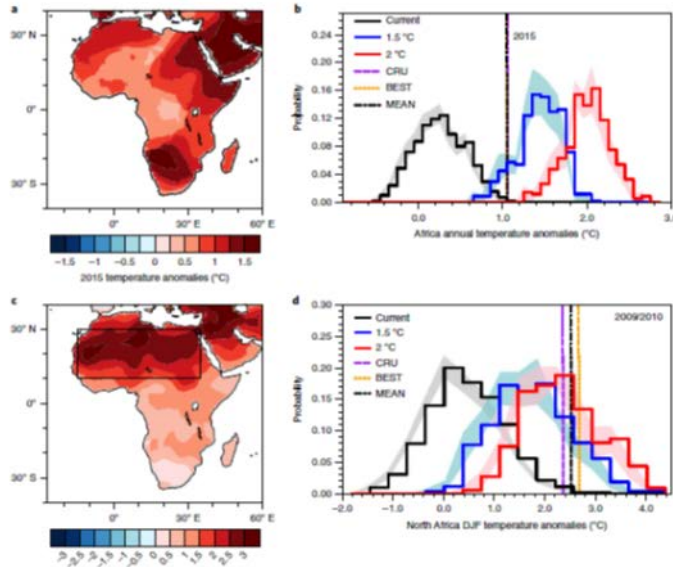
Extreme climatic events have had devastating impacts in Africa, with drought alone killing ~850,000 people since 1900¹. There is a consensus that the continent will also suffer under anthropogenic forcing, both due to its greater vulnerability and the magnitude of projected changes². Reporting in *Nature Climate Change*³, Nangombe Shingirai of the Meteorological Services, Zimbabwe, and colleagues demonstrate that the occurrence of extremes — specifically

those similar to the 1991/1992 southern African drought and 2009/2010 north African heat wave — could be reduced by 20–25% if anthropogenic warming is constrained to 1.5 °C instead of 2 °C above preindustrial levels. Such differences between temperature targets act to further motivate mitigation efforts to minimize the socio-economic impacts of future extreme events across Africa.

As in other regions of the world⁴, the African continent has experienced a range

of weather and climate extremes in recent decades. In several instances, these have been record-breaking, and ultimately had dire socio-economic impacts. In 1991/1992, for example, extreme drought occurred across southern Africa, devastating agricultural production, and placing an estimated 16 million people at risk of starvation; many countries throughout southern Africa consequently had to import large quantities of food to meet consumption needs, adding considerable financial stresses. On the

Likelihood of extreme events over Africa



2015 extremely high temperature over Africa

1.5°C: 91% (88%-93%)
2°C: 100% (100%-100%),

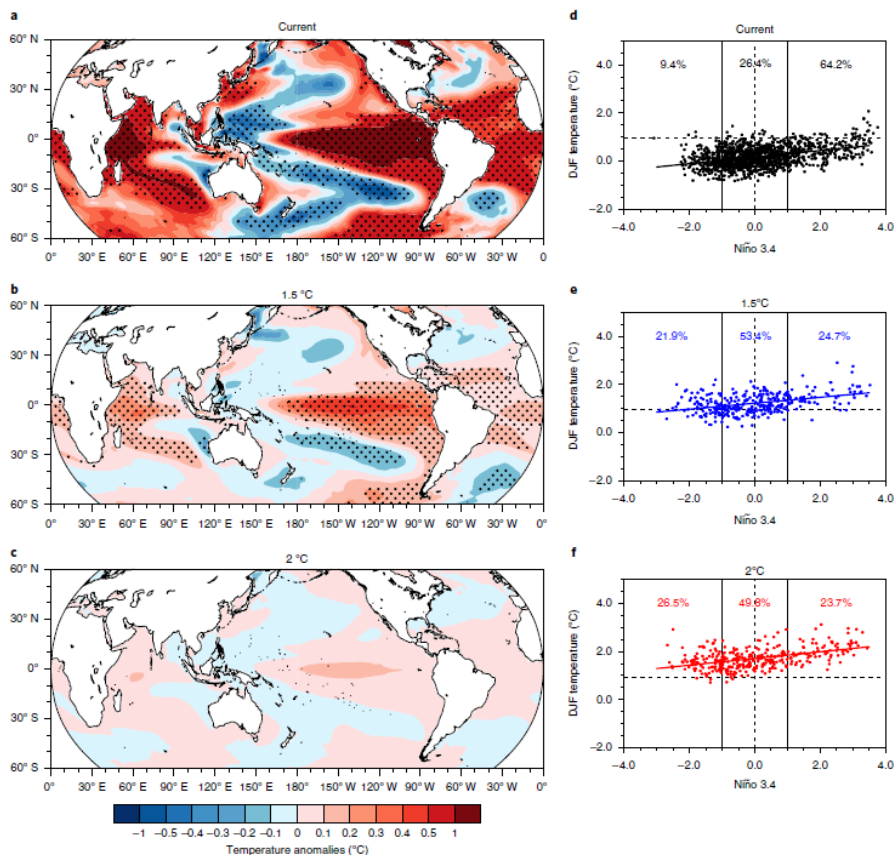
2009/2010 DJF extremely high temperature over North Africa

1.5°C: 11% (9%-14%)
2°C: 30% (28%-34%)

Shadings show 10%-90% confidence intervals derived from bootstrap

Nangombe S., T. Zhou*, W. Zhang, B. Wu, S. Hu, L. Zou & D.Li: Record-breaking climate extremes in Africa under stabilized 1.5 °C and 2 °C global warming scenarios. *Nature Climate Change* (2018) doi:10.1038/s41558-018-0145-6

Hot events much stronger than that in **DJF of 1991/1992**, over southern Africa, are more likely to occur under El Nino conditions in warmer climate scenarios



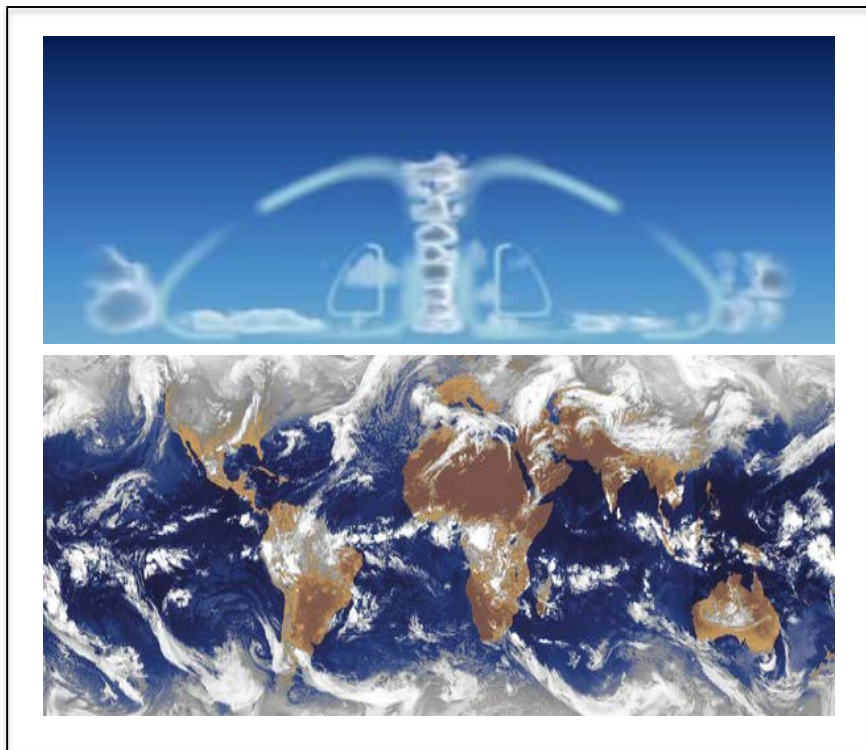
Nangombe S., T. Zhou*, W. Zhang, B. Wu, S. Hu, L. Zou & D.Li: Record-breaking climate extremes in Africa under stabilized 1.5 °C and 2 °C global warming scenarios. *Nature Climate Change* (2018) doi:10.1038/s41558-018-0145-6

Interim Summary # 3



1. 在1.5和2.0温升背景下，非洲地区的温升将高于全球平均值，极端热浪事件的发生频率将明显升高。
2. 如果把相对于工业革命前的未来全球温升目标控制在1.5° C而不是2° C，则类似2009/2010年发生在北部非洲、2015年横扫整个非洲的极端热浪的发生概率将分别减少20%和10%；而类似1991/1992年伴随南部非洲大旱出现的极端热浪发生概率将减少25%。
3. 与预估的极端高温事件发生风险随温升幅度而增加不同，破记录的极端降水事件未来的发生风险在两种温升阈值下的变化差异不显著。
4. 在暖的气候背景下，厄尔尼诺现象对非洲极端气候事件的影响将加剧，在厄尔尼诺年发生比历史上1991/1992年更强的热浪事件的风险显著增加。

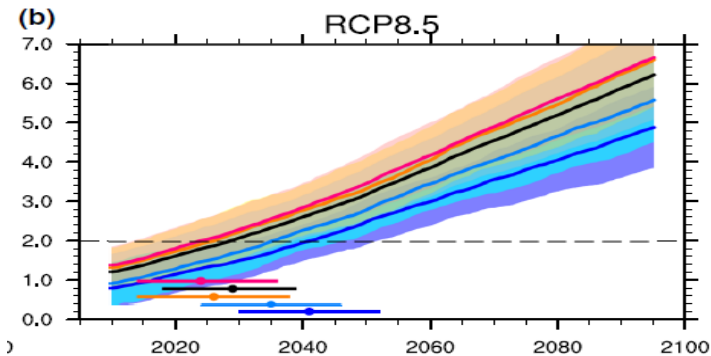
问题四：气候敏感度对预估结果的影响



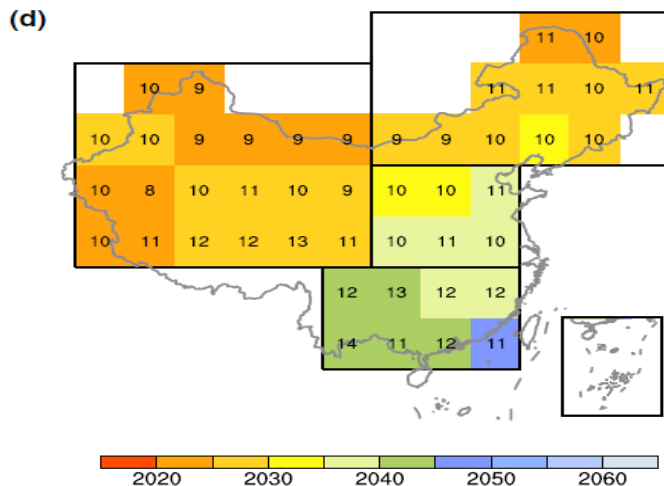
气候敏感度度：
大气中CO₂-e加倍时地球气候系统的平衡态升温幅度（ECS）



WCRP大科学挑战计划：云、环流和气候敏感度



预估的中国区域温度变化
(上图)、
达到2C温升阈值的时间和模
式离差 (下图)



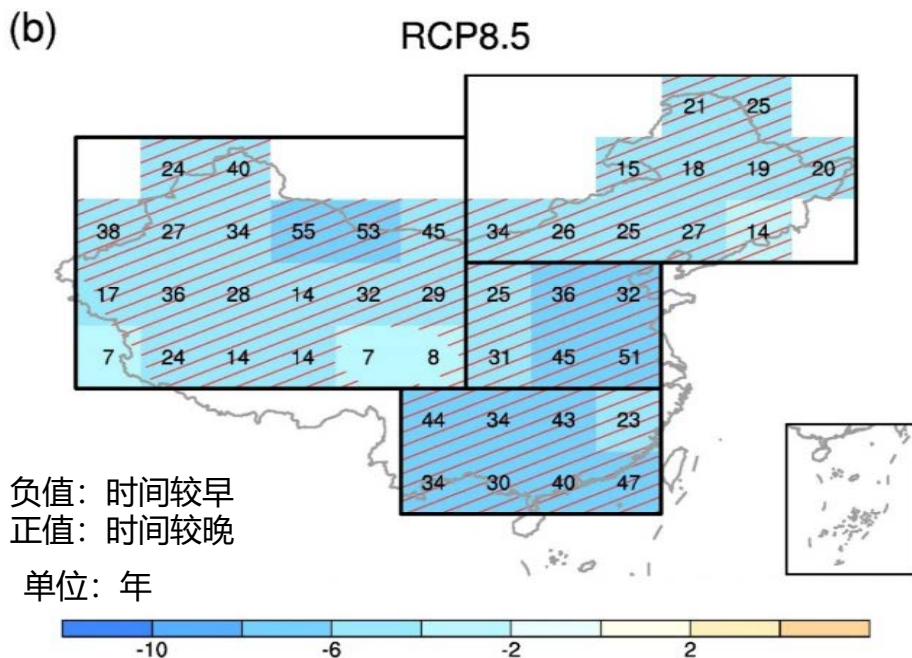
填色：多模式平均预估的2C到达时间

数字：模式间标准差，数值越大表示不确定性越大

Chen Xiaolong, Tianjun Zhou, 2016: Uncertainty in crossing time of 2C warming threshold over China,

Sci. Bull., 61(18), 1451-1459, DOI 10.1007/s11434-016-1166-z

气候敏感度差异对2C升温到达时间的影响



结 语

- ◆ 《巴黎协定》1.5C和2C温升目标下的极端事件变化与温升幅度呈现出非线性特征
- ◆ 全球季风区极端降水、东亚季风区极端温度事件、非洲气候脆弱区破记录热浪事件等，在1.5C阈值下发生风险明显降低
- ◆ 亟待研究的科学问题：
 - ✓ 极端事件的变化机制问题
 - ✓ 气候敏感度对预估结果的影响
 - ✓ 温升阈值与碳排放空间问题

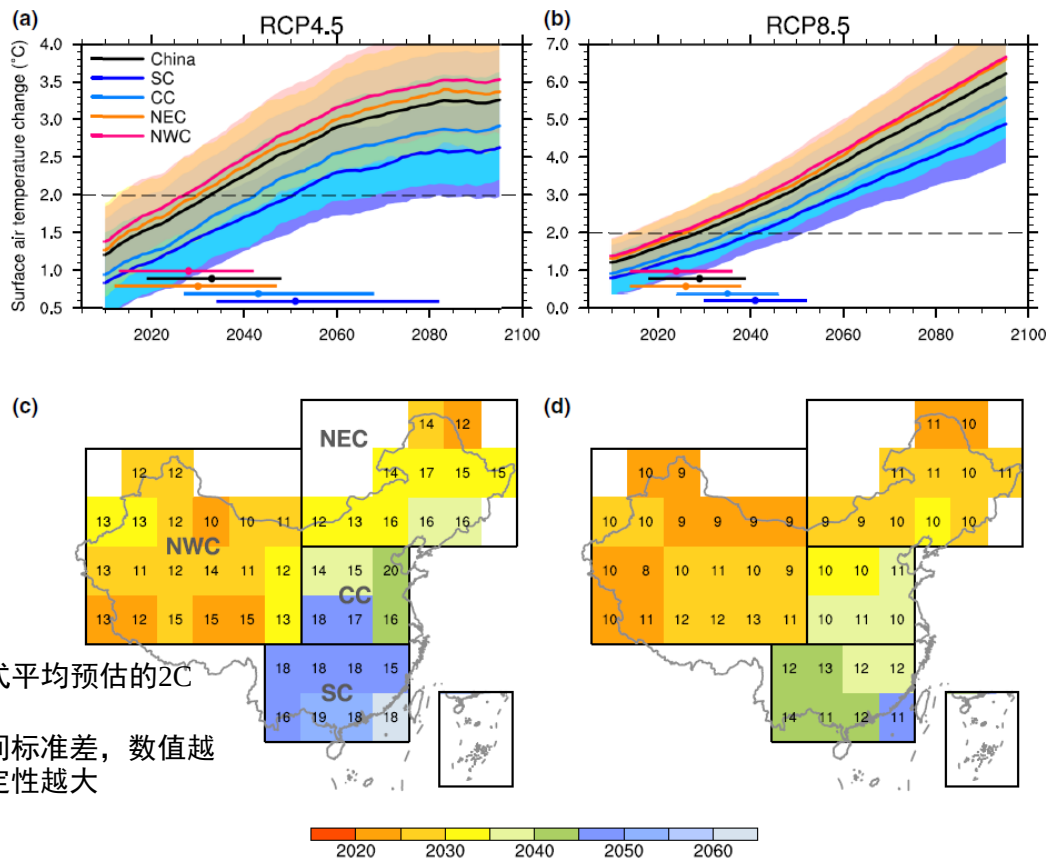


Relevant paper list



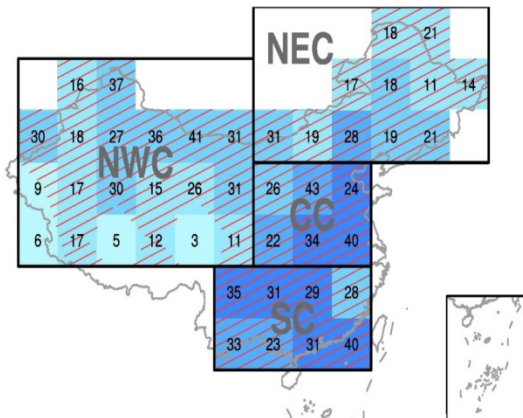
1. Nangombe Shingirai, Tianjun Zhou*, Wenxia Zhang, Bo Wu, Shuai Hu, Liwei Zou & Donghuan Li: Record-breaking climate extremes in Africa under stabilized 1.5 ° C and 2 ° C global warming scenarios. *Nature Climate Change* (2018) doi:10.1038/s41558-018-0145-6
2. Zhang Wenxia, Tianjun Zhou*, Liwei Zou, Lixia Zhang, and Xiaolong Chen: Reduced exposure to extreme precipitation from 0.5C less warming in global land monsoon regions. *Nature Communications*. 9, Article number: 3153 (2018). doi:10.1038/s41467-018-05633-3
3. Li, D., T. Zhou, L. Zou, W. Zhang, and L. Zhang (2018), Extreme high-temperature events over East Asia in 1.5° C and 2° C warmer futures: Analysis of NCAR CESM low-warming experiments. *Geophysical Research Letters*, 45. <https://doi.org/10.1002/2017GL076753>.
4. Zhou T., L. Ren, H. Liu, J. Lu, Impact of 1.5° C and 2.0° C Global Warming on Aircraft Takeoff Performance in China, *Science Bulletin* (2018), doi: <https://doi.org/10.1016/j.scib.2018.03.018>
5. Zhou, T.-J., N. Sun, W.-X. Zhang, et al. 2018: "When and how will the Millennium Silk Road witness 1.5° C and 2° C warmer worlds?" *Atmospheric and Oceanic Science letters* 11. <https://www.tandfonline.com/doi/full/10.1080/16742834.2018.1440134>.
6. Chen Xiaolong, Tianjun Zhou, 2016: Uncertainty in crossing time of 2C warming threshold over China, *Sci. Bull.*, 61(18), 1451-1459, DOI 10.1007/s11434-016-1166-z
7. 陈晓龙,周天军. 2017: 使用订正的“空间型标度”法预估1.5 °C温升阈值下地表气温变化. *地球科学进展*. 32(4): 435-445
8. 李东欢,邹立维,周天军. 2017: 全球1.5 °C温升背景下中国极端事件变化的区域模式预估. *地球科学进展*, 32(4): 446-457
9. 周天军,陈晓龙, 2015: 气候敏感度、气候反馈过程与2度增温阈值的不确定性问题. *气象学报*, 73(4), 624-634

预估的中国区域温度变化（上图）、达到2C温升的时间和模式离差（下图）



(a)

RCP4.5



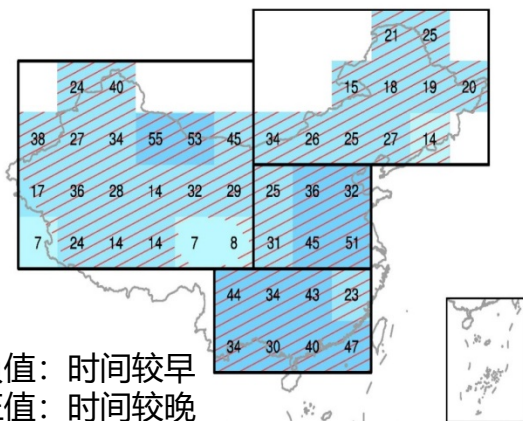
全球平均温度响应的模式间差异对2C升温到达时间的影响



- ✓ 全球平均温度响应的大小代表了模式对温室气体的气候敏感度。
- ✓ 当气候敏感度越高，整个中国区域2C阈值到达时间提前（负值）；同时存在区域差异。
- ✓ 数字表示全球平均温度对2C到达时间不确定性的解释方差。
- ✓ 解释方差在中部南部最高，表明这一区域的增温与气候敏感度的联系最为密切。

(b)

RCP8.5



负值：时间较早
正值：时间较晚



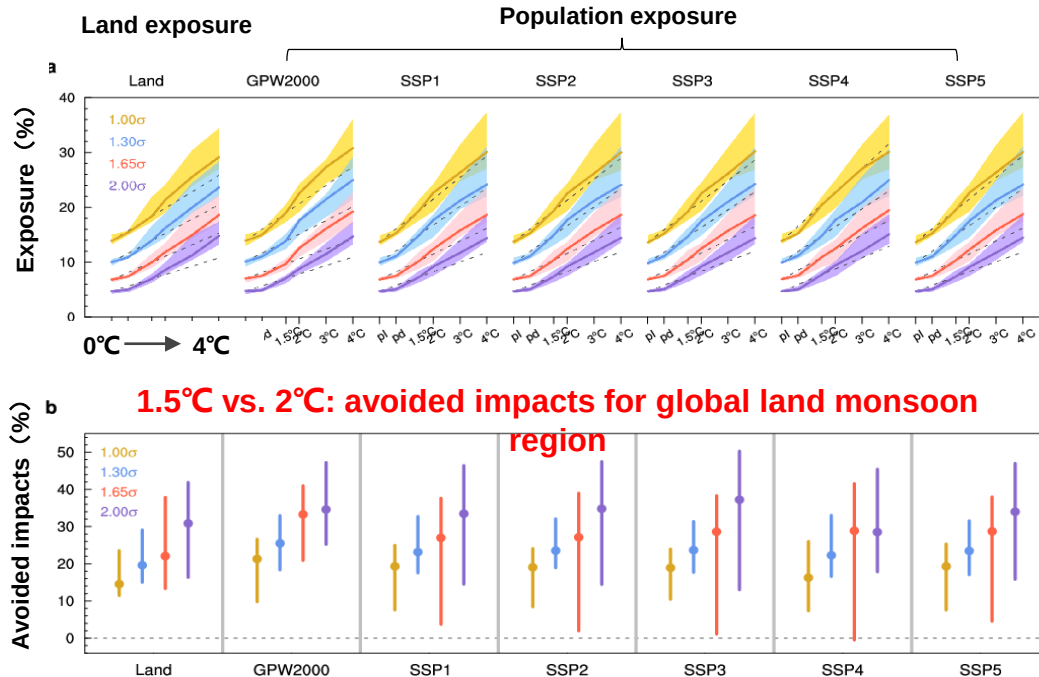
单位：年

彩色背景：气候敏感度若高1C时达到2C升温阈值提前的年数。

数字：气候敏感度所能揭示的模式离差百分比

Chen Xiaolong, Tianjun Zhou, 2016: **Uncertainty in crossing time of 2C warming threshold over China**, *Sci. Bull.*, 61(18), 1451-1459, DOI 10.1007/s11434-016-1166-z

Robustness of the conclusion: Do not rely on definitions of dangerous events



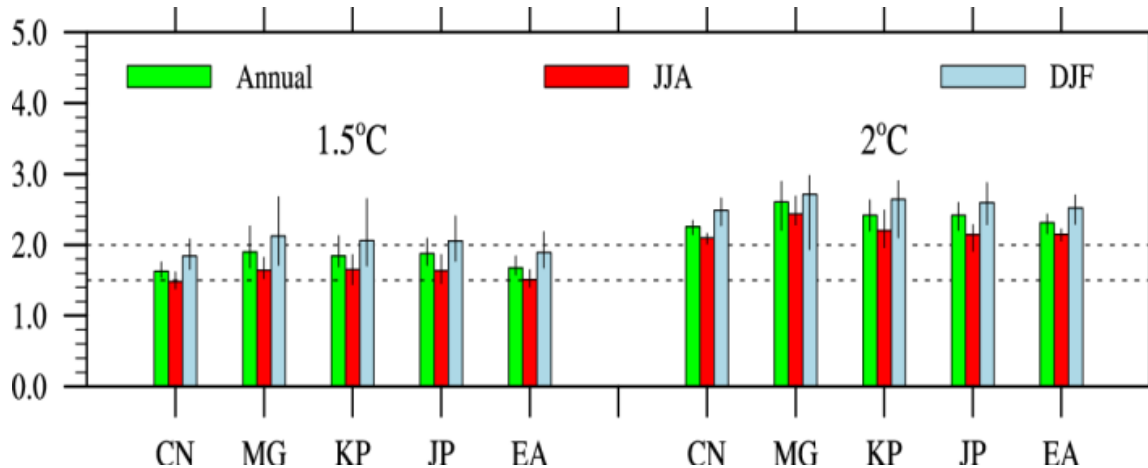
**σ -exceedance
matrix:**

normalization with
respect to 1950-2005

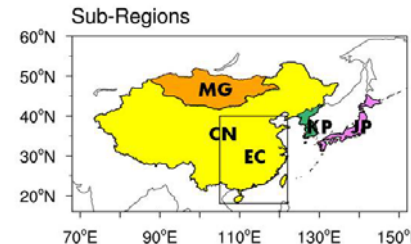
1.00 σ —once-in-6-yr
1.30 σ —once-in-10-yr
1.65 σ —once-in-20-yr
2.00 σ —once-in-44-yr

- ◆ Results based on the σ -exceedance *matrix* quantitatively support those based on the GEV *Return Values*, adding fidelity to the conclusion that the **0.5°C lower warming target** benefits the **populous monsoon regions**.

Changes of surface air temperature over East Asia

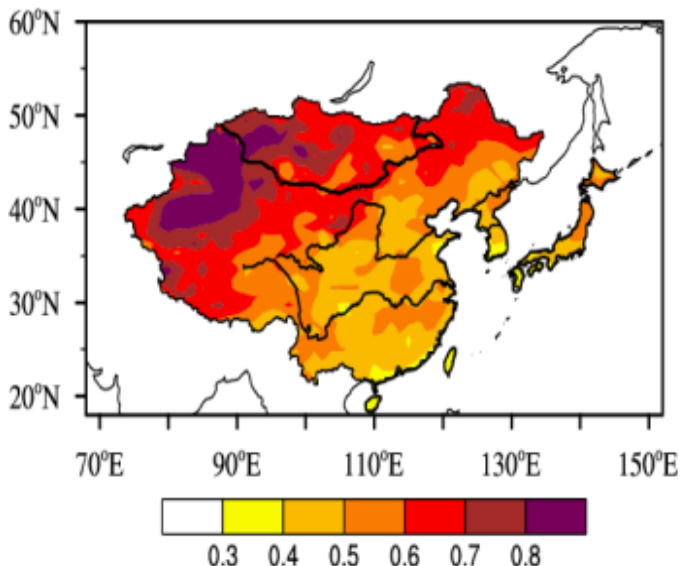


Li, D., T. Zhou, L. Zou, W. Zhang, and L. Zhang (2018), Extreme high-temperature events over East Asia in 1.5°C and 2°C warmer futures: Analysis of NCAR CESM low-warming experiments. *Geophysical Research Letters*, 45. <https://doi.org/10.1002/2017GL076753>.

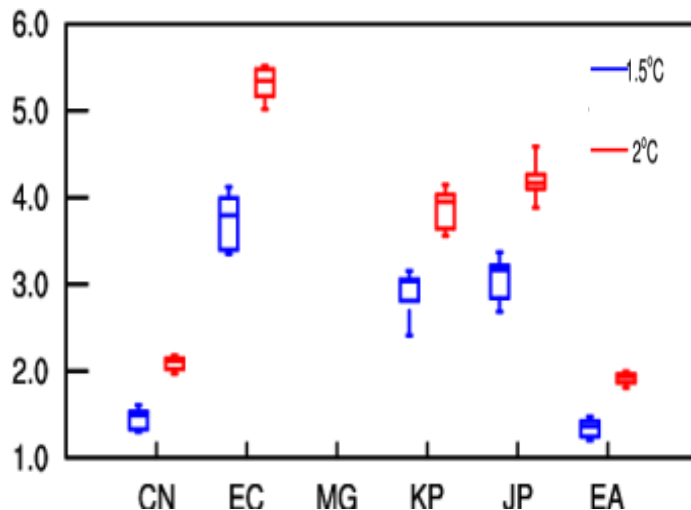


Changes of TNX3day

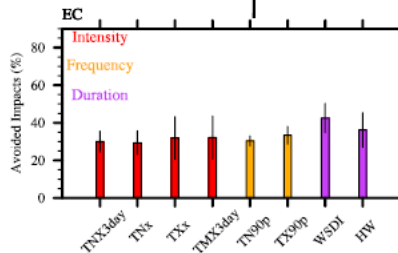
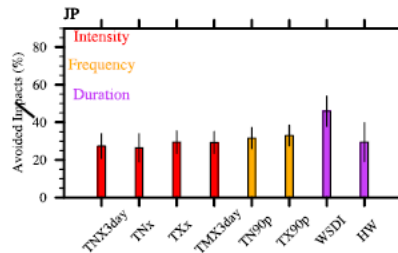
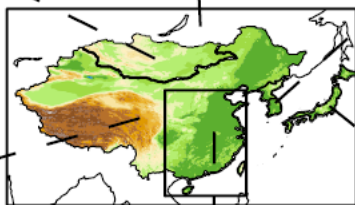
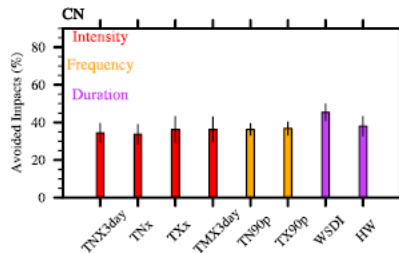
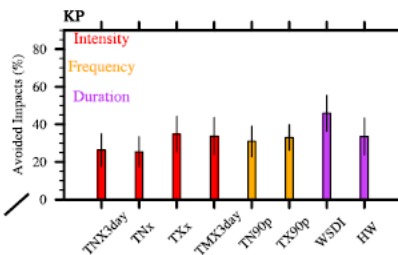
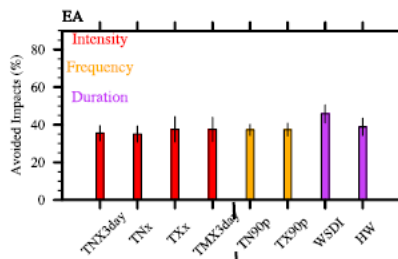
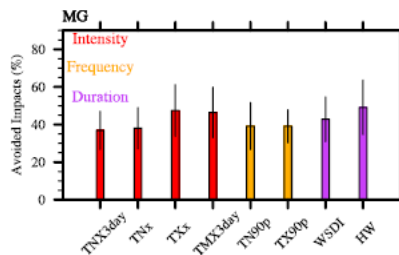
2°C-1.5°C



Population-weighted Regional mean changes



- Take population density into consideration, changes of TNX3day will have much larger impact on eastern China, Korean Peninsula and Japan than other regions.



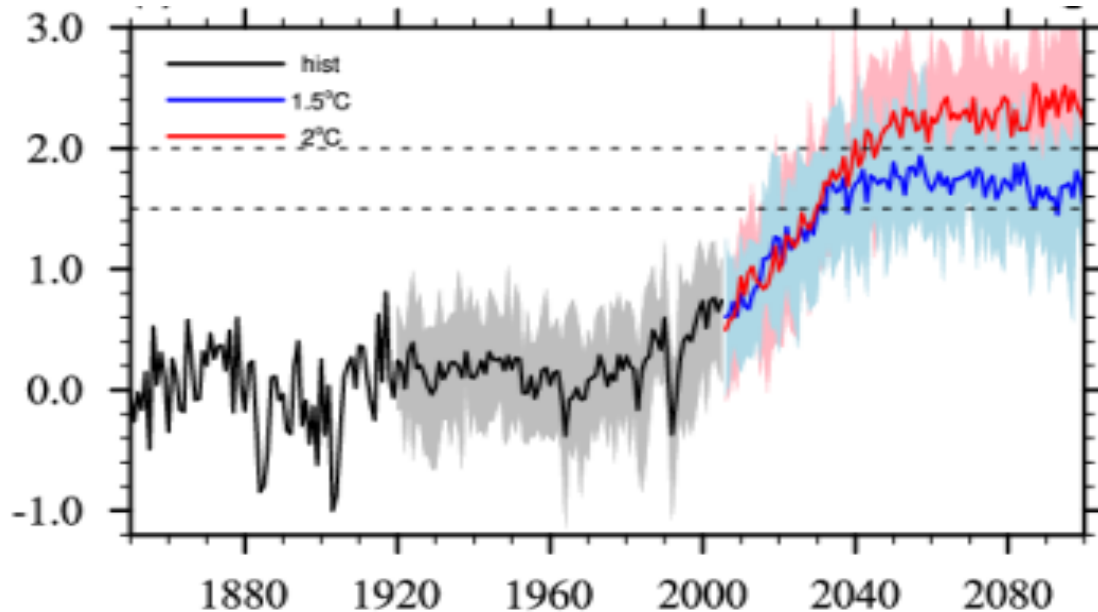
“TNX3day”为每年最大连续3天日最低气温，“TNx”为每年最大日最低气温，“TXx”为每年最大日最高气温，“TMX3day”为每年最大连续3天日最高气温，“TN90p”为暖夜天数，“TX90p”为暖昼天数，“WSDI”和“HW”为暖事件持续时间

Extreme high temperature indices

- **TNX3day:** highest 3-day mean daily minimum temperature in a year
- **HW:** defined as the longest period in a year satisfies these conditions
 - (1) The daily maximum temperature must be above T1 for at least 3 consecutive days
 - (2) The average daily maximum temperature must be above T1 for the whole period
 - (3) the daily maximum temperature must be above T2 for every day of the entire period.
- T1: 95th percentile of the distribution of local summer maximum temperature in the simulated present day climate
- T2: 80th percentile

- ✓ Baseline period of 1976 -2005 is referred to as the present day.
- ✓ The pre-industrial period in this study is 1850-1920.
- ✓ A period of 2071-2100 represents for the 1.5°C and 2°C warming period relative to pre-industrial levels.

Changes of surface air temperature over East Asia



- Regional mean SAT over East Asia will increase **0.2°C larger than global mean** by the end of 21st century: **1.7°C at 1.5°C warming level; 2.3°C at 2°C warming level**

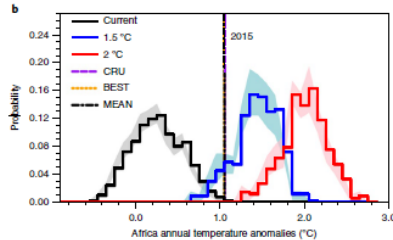
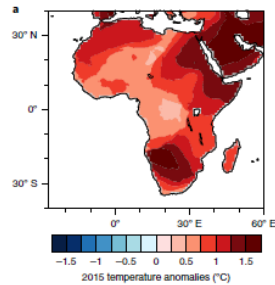
Record-breaking climate extremes in Africa under stabilized 1.5 °C and 2 °C global warming scenarios

Shingirai Nangombe^{1,2,3}, Tianjun Zhou^{1,2*}, Wenxia Zhang^{1,2}, Bo Wu¹, Shuai Hu^{1,2}, Liwei Zou¹ and Donghuan Li^{1,2}

- **Model data:** CESM low warming experiments monthly data
- **Extreme events:** historical record-breaking climate events examined are:
 - (1) Extremely hot 2015 over Africa
 - (2) Extremely hot DJF 2009/2010 in North Africa
 - (3) Extremely high February 2000 precipitation over southeast Africa
 - (4) Severe drought of 1991/92 over southern Africa

- ✓ Baseline period of 1976 -2005 is referred to as the present day.
- ✓ The pre-industrial period in this study is 1850-1920.
- ✓ A period of 2071-2100 represents for the 1.5°C and 2°C warming period relative to pre-industrial levels.

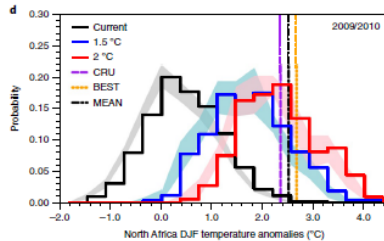
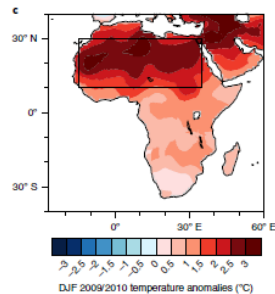
Likelihood of extreme events over Africa



2015 extremely high temperature over Africa

1.5°C: 91% (88%-93%)

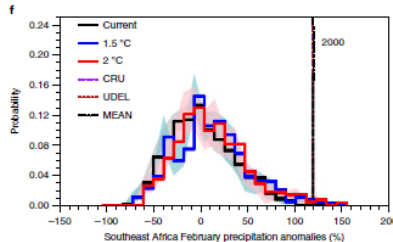
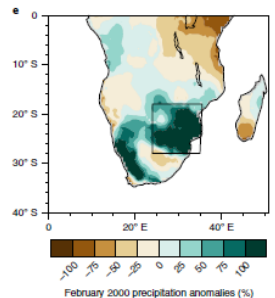
2°C: 100% (100%-100%),



2009/2010 DJF extremely high temperature over North Africa

1.5°C: 11% (9%-14%)

2°C: 30% (28%-34%)

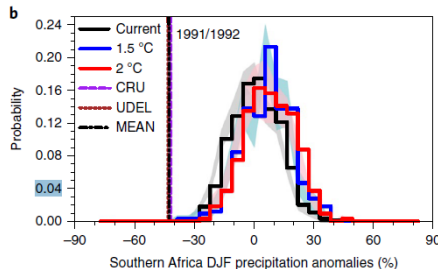
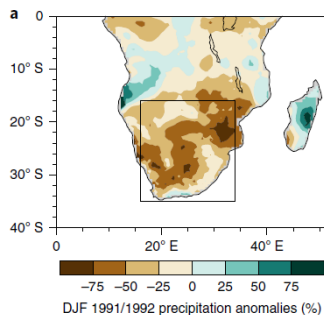


February 2000 extremely high rainfall over S.E Africa

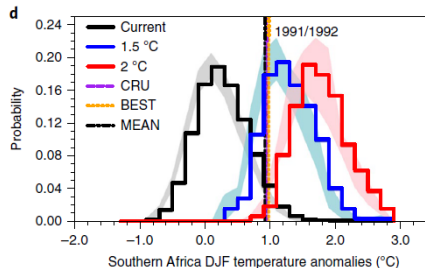
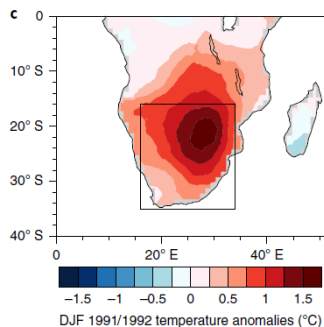
indistinguishable differences between the 1.5°C and 2°C levels

Shadings show 10%-90% confidence intervals derived from bootstrap

1991/92 Southern Africa drought

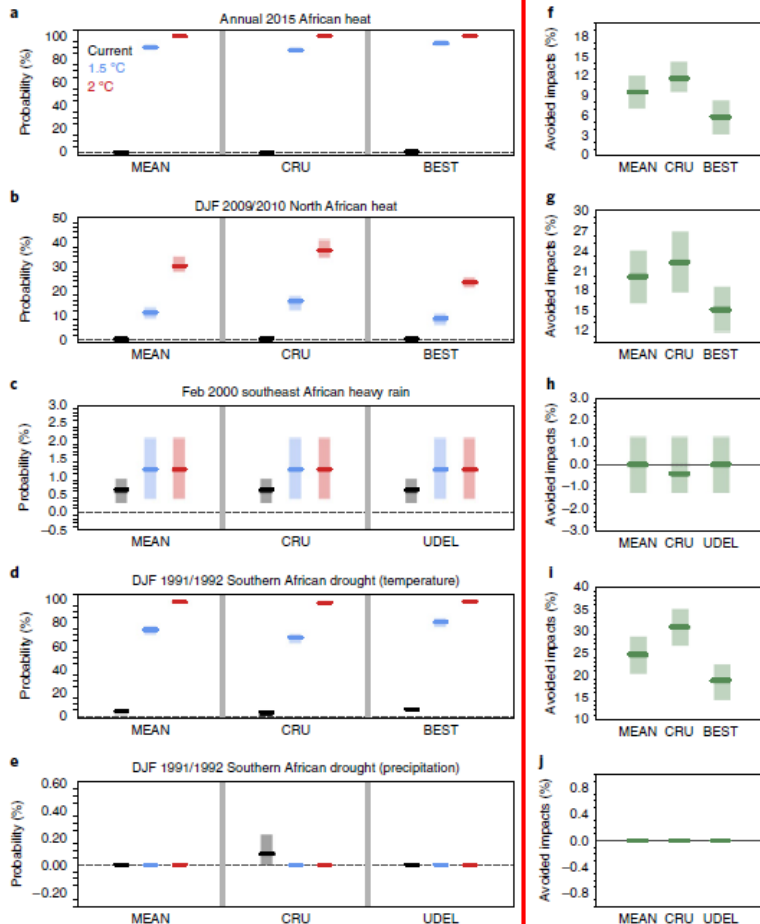


- Ts and Pr used as proxies for drought
- **1991/92 DJF extreme low precipitation over southern Africa**
 - projected to be rare in future scenarios
 - Consistent with the multi-model projections in CMIP5 over same area



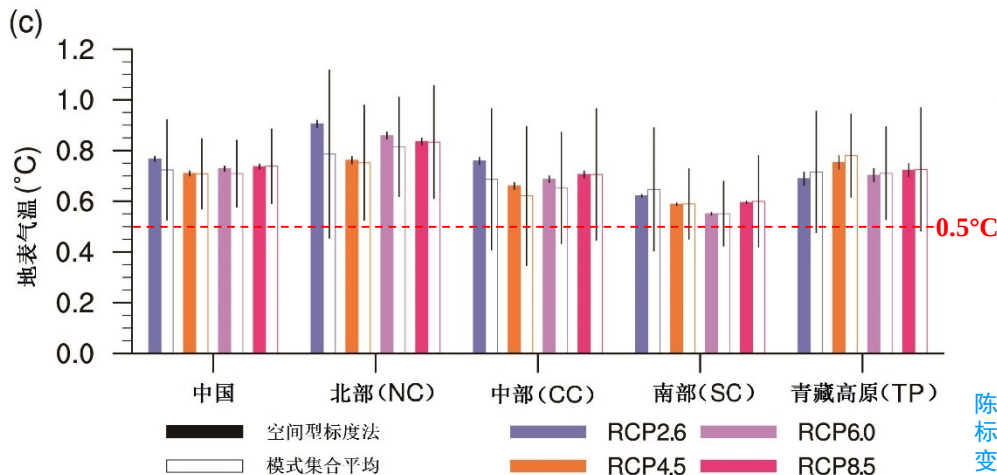
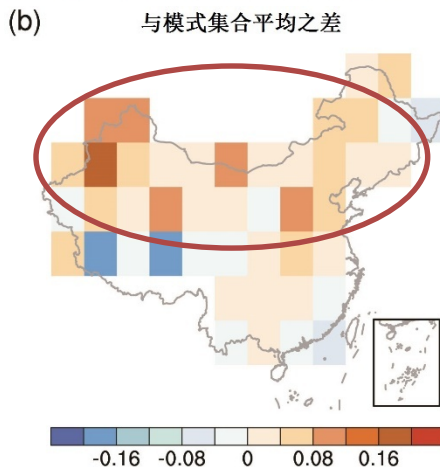
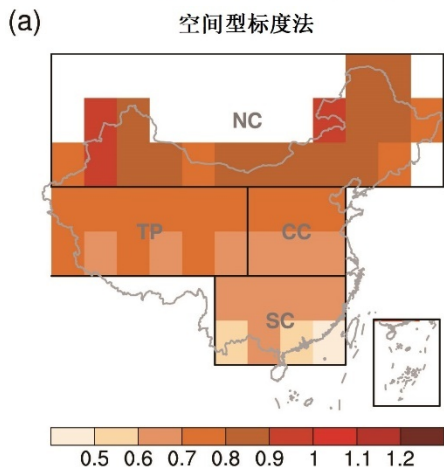
- **1991/92 DJF extreme high temperature over southern Africa**
 - 1.5°C: 74% (70%-78%)
 - 2°C: 98% (97%-100%)

Therefore, regardless of the insignificant precipitation change projected, excessive warming alone might increase the probability of similar droughts occurring in warmer worlds



- Limiting warming to 1.5°C instead of 2°C is projected to reduce the probability of heat event occurrences by:
 - 10% (7%-12%) for events similar to that of 2015 in Africa
 - 20% (16%-24%) for events similar to that of DJF 2009/2010 in northern Africa
 - 25% (20%-29%) for high temperatures with magnitudes similar to that during 1991/1992 southern African drought

1.5° C相对增温1° C的中国区域温度变化



四种情景的平均

- 基于观测的空间型标度法预估结果比模式预估有更大的升温
- 不确定性更小

陈晓龙,周天军. 2017: 使用订正的“空间型标度”法预估1.5 °C温升阈值下地表气温变化. 地球科学进展. 32(4): 435-445