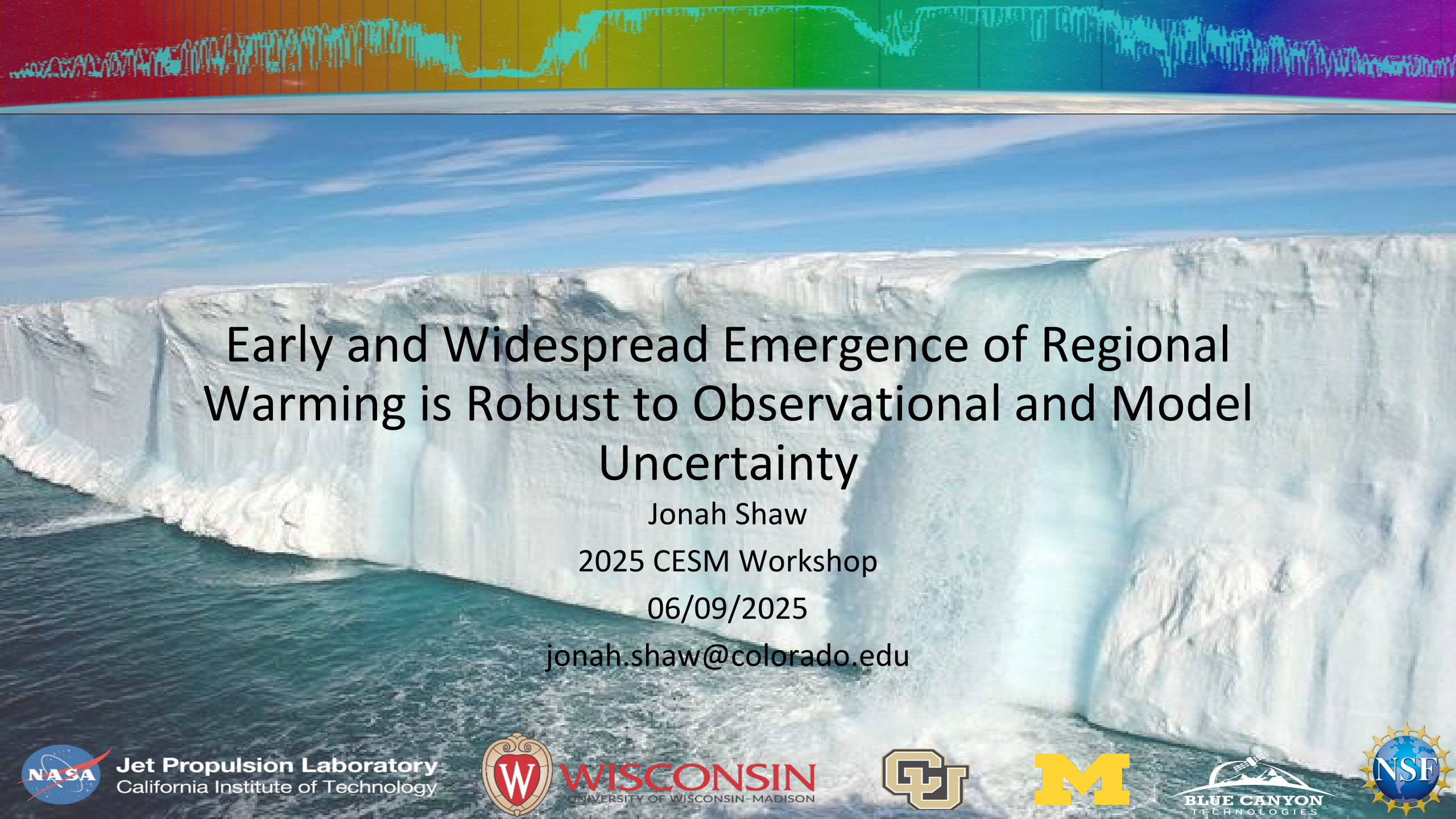

Early and Widespread Emergence of Regional Warming is Robust to Observational and Model Uncertainty

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2025 CESM Workshop

06/09/2025

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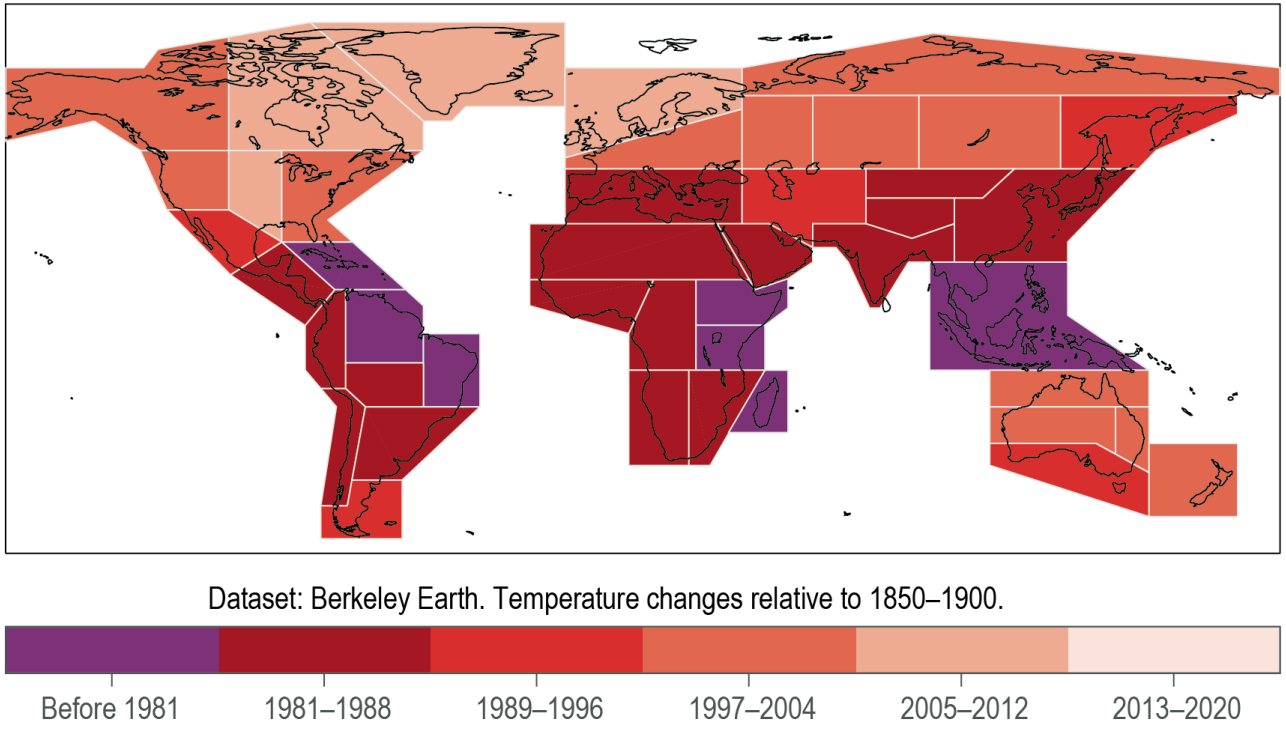
BLUE CANYON TECHNOLOGIES
NSF

Regional Climate Change: Where Impacts Happen

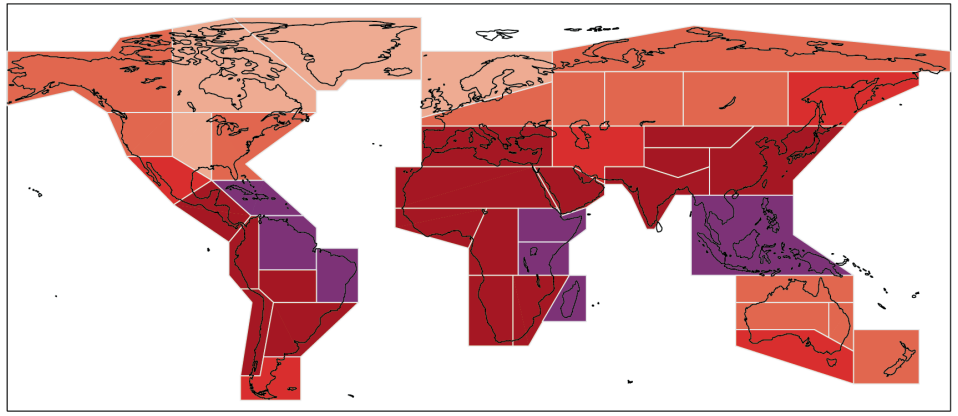


Time of Emergence

IPCC AR6, 2021

Regional Climate Change: Where Impacts Happen

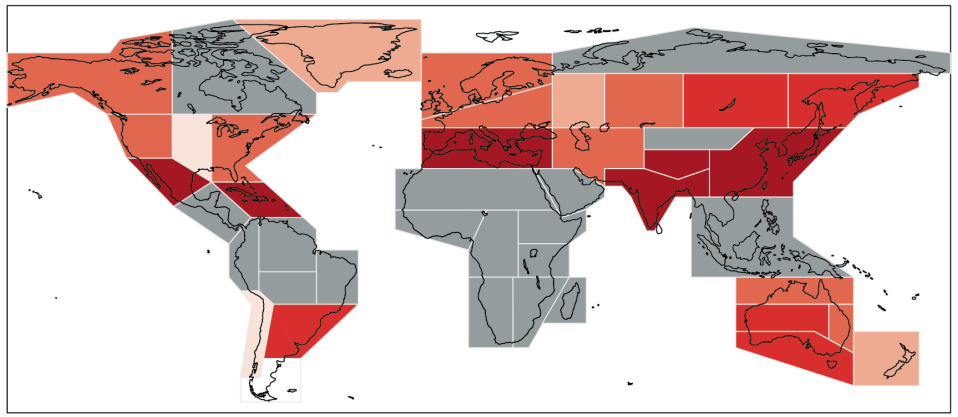
Where are observed changes robustly detectable?



Dataset: Berkeley Earth. Temperature changes relative to 1850–1900.

Before 1981 | 1981–1988 | 1989–1996 | 1997–2004 | 2005–2012 | 2013–2020

Year of significant emergence of changes in temperature over land regions (S/N>2)



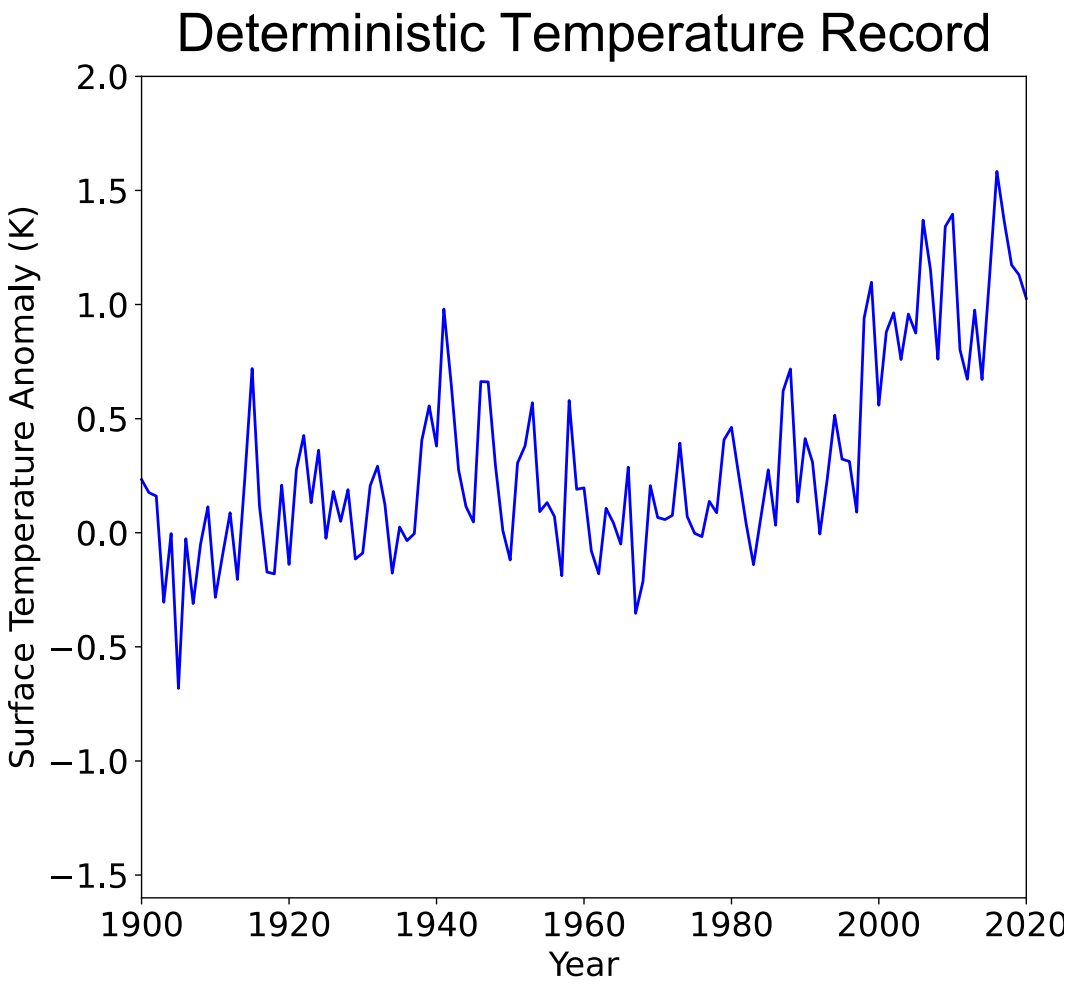
Dataset: CRUTEM5. Temperature changes relative to 1850–1900. Grey: not enough data.

Before 1981 | 1981–1988 | 1989–1996 | 1997–2004 | 2005–2012 | 2013–2020

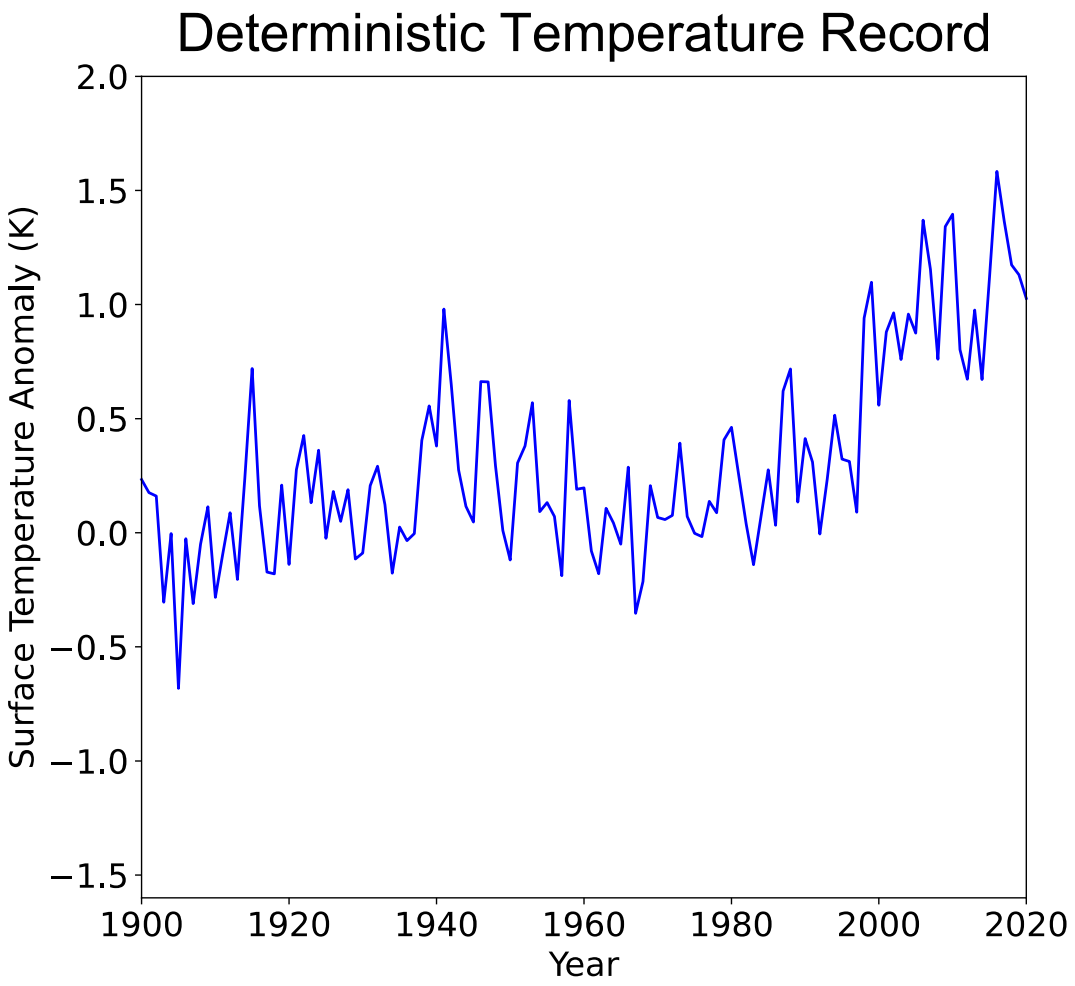
How do observational and model uncertainty influence the detection of regional warming?

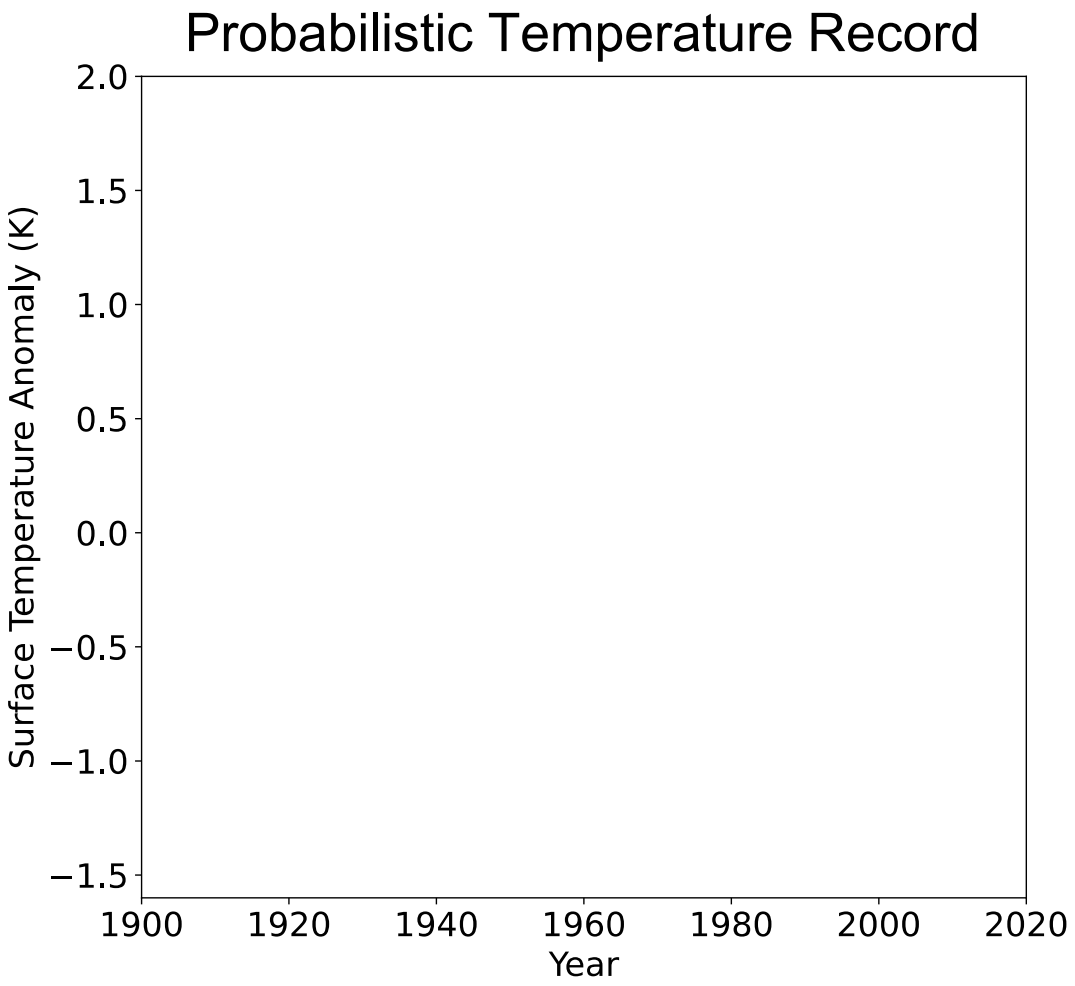
IPCC AR6, 2021

Uncertainty in Historical Surface Temperature Records

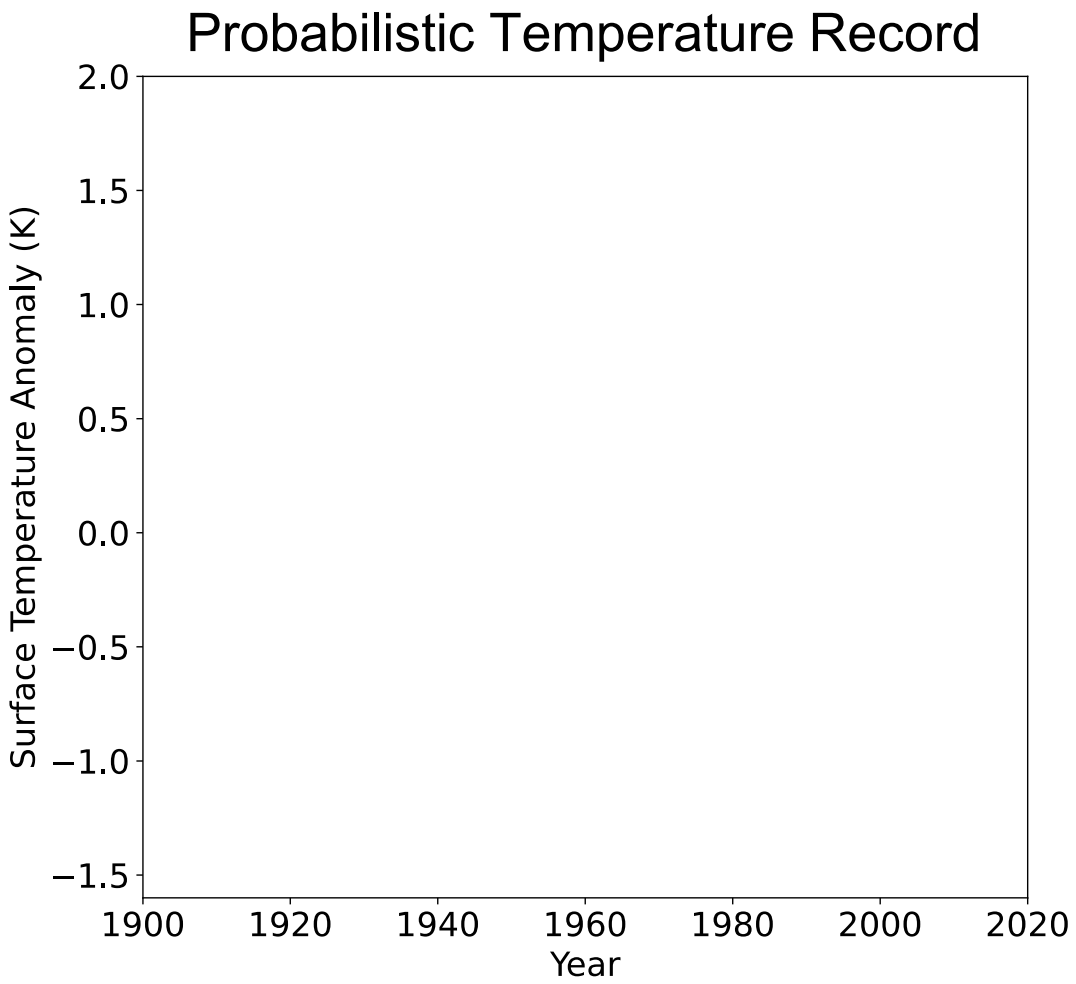


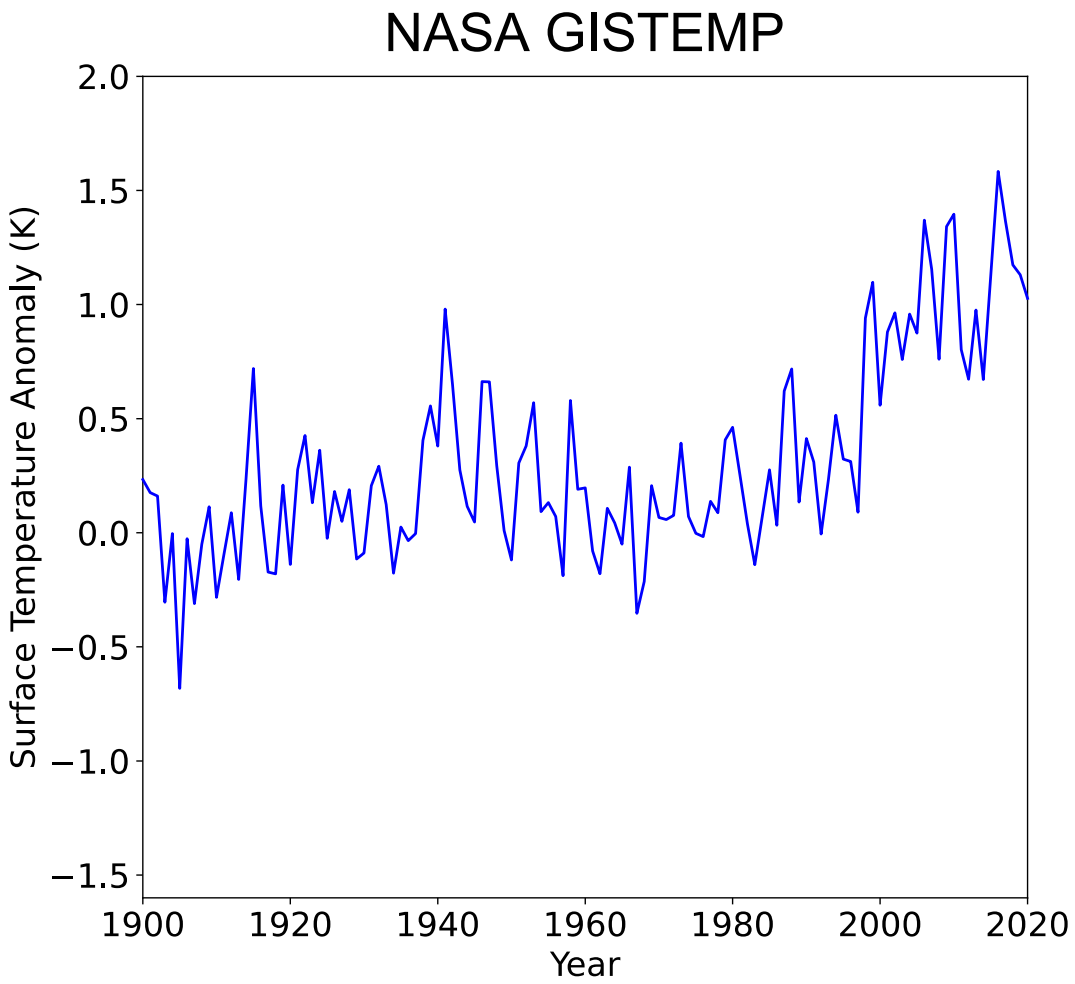
Uncertainty in Historical Surface Temperature Records



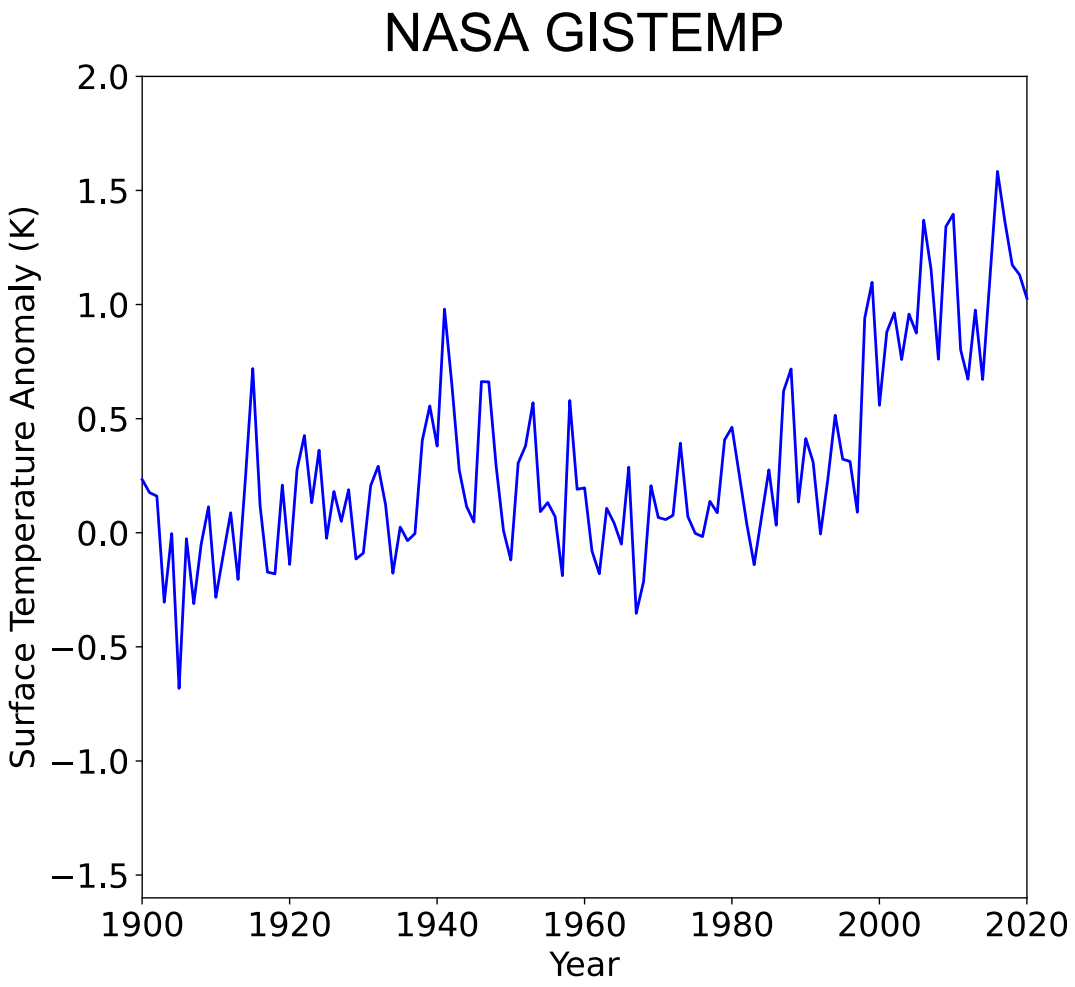


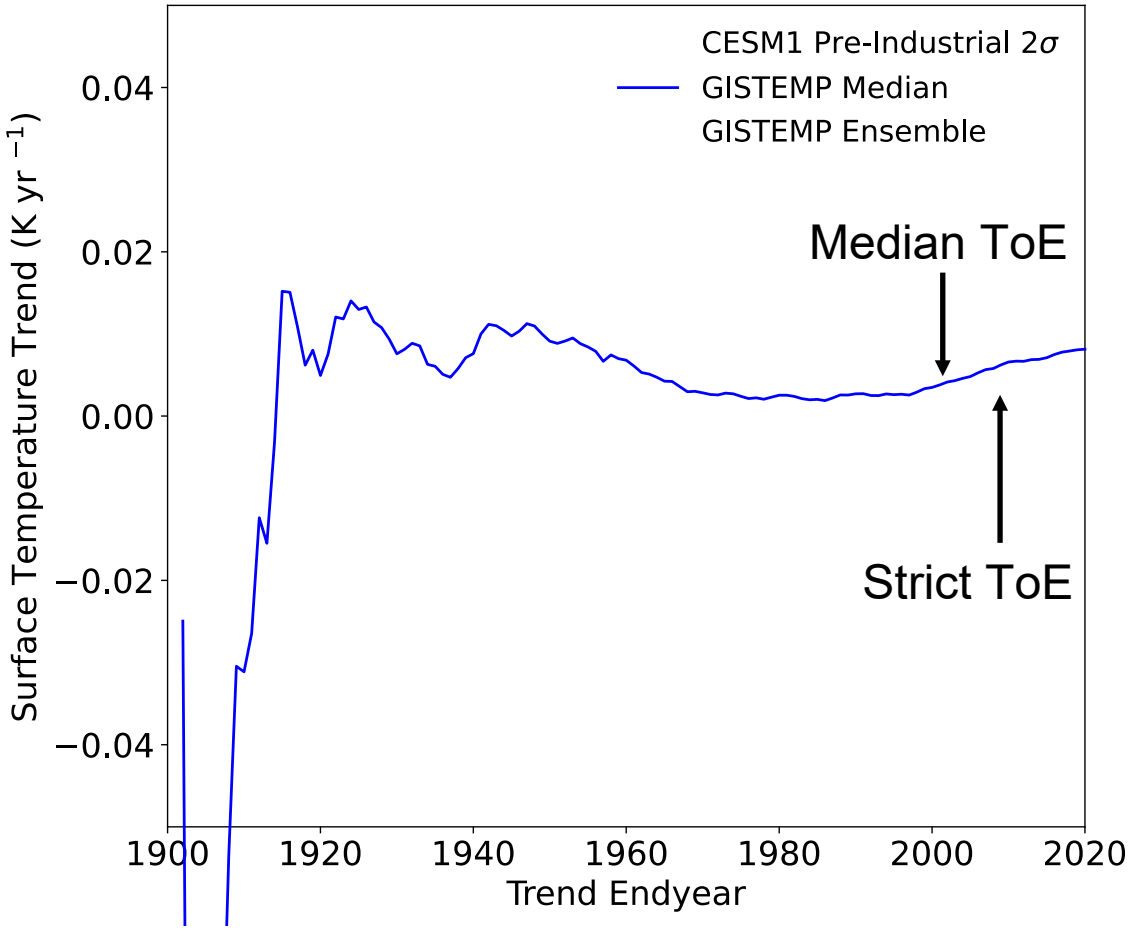
Uncertainty in Historical Surface Temperature Records





Uncertainty in Historical Surface Temperature Records



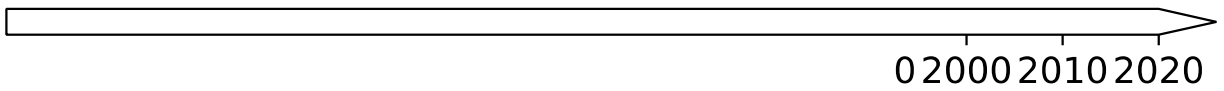


Regional Time of Emergence with Observational Uncertainty

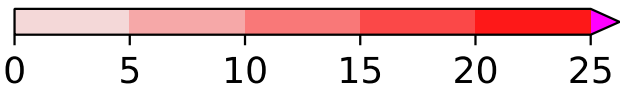
Regional Time of Emergence with Observational Uncertainty

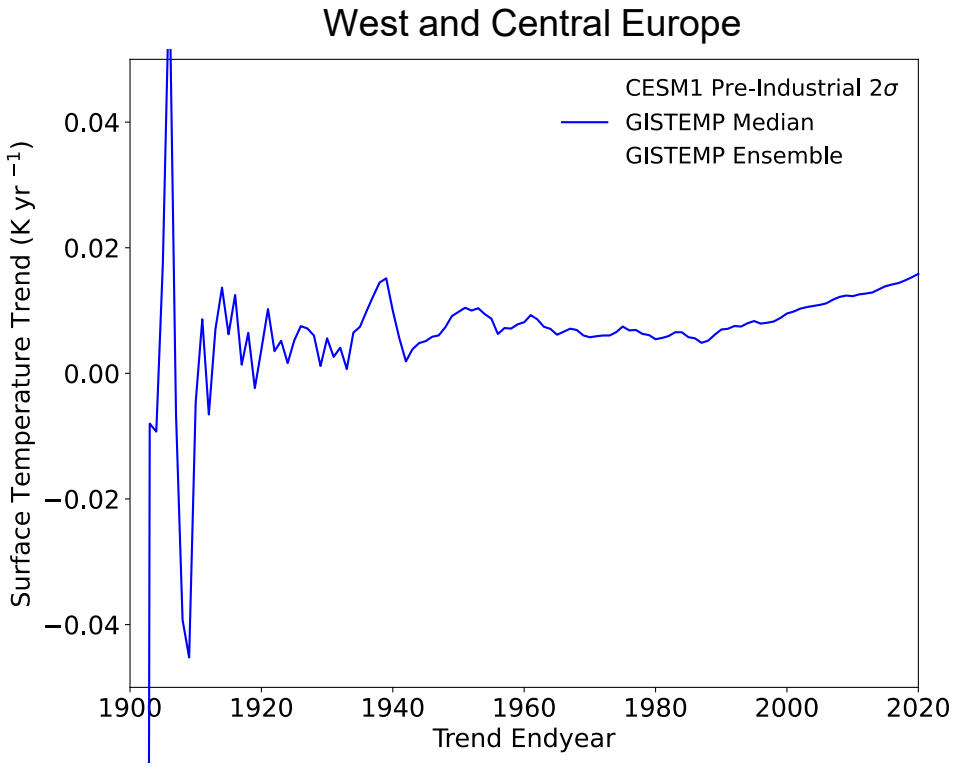
a.

b.

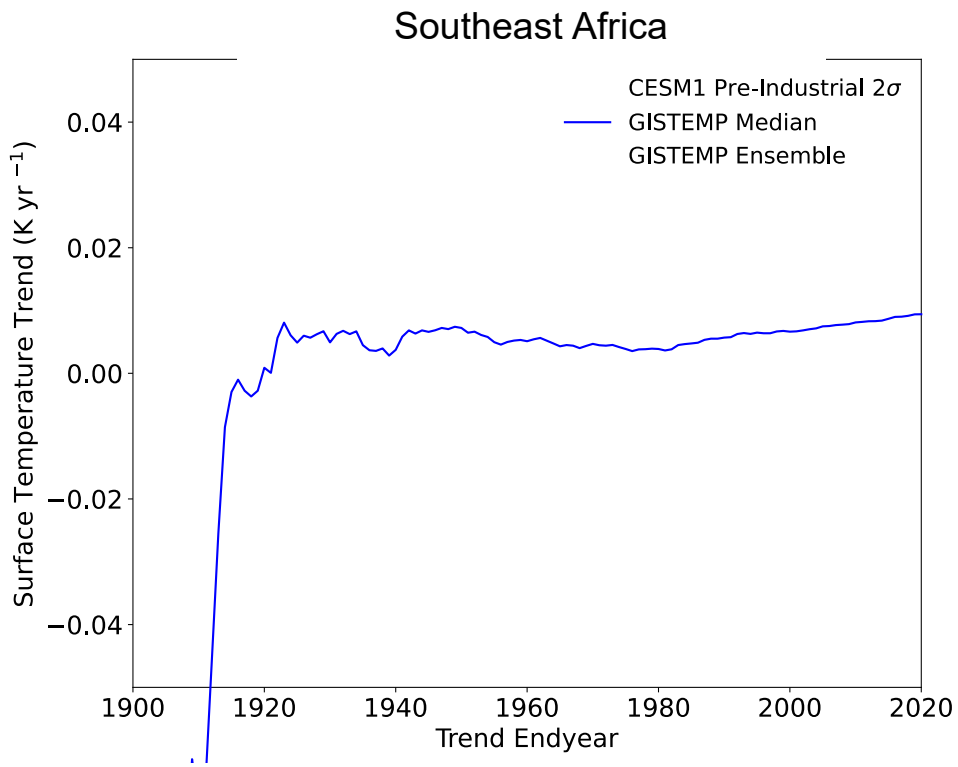


c.





Low Uncertainty,
Monotonic Trends



Moderate Uncertainty,
Non-monotonic Trends

Non-monotonic warming trends and low observation quality cause the greatest delays in Time of Emergence.

What about other sources of uncertainty?

- Model uncertainty
- Observational product uncertainty

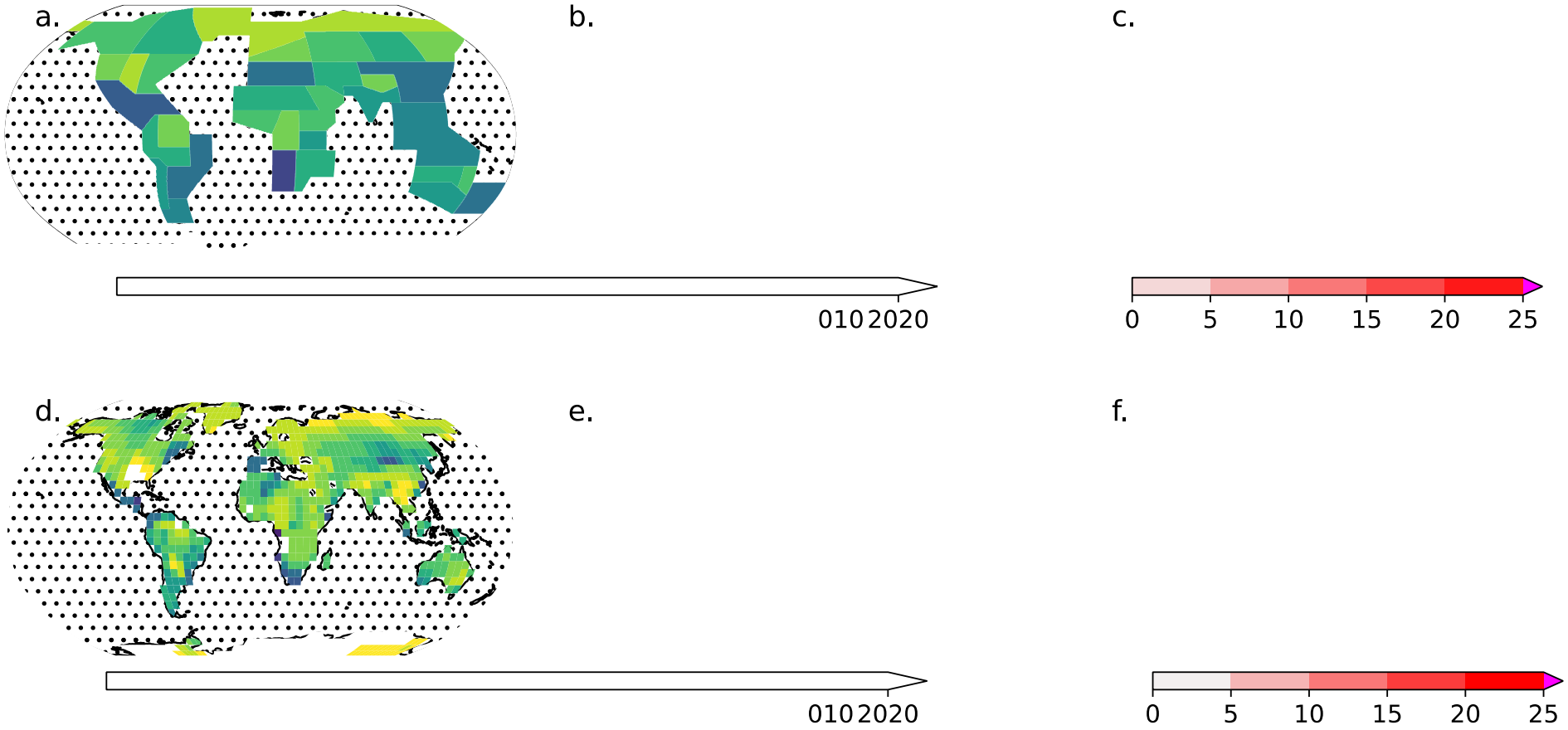
4 Earth System Models

2 Observational Uncertainty Products

200 ensemble members

1600 estimates of Time of Emergence

Regional Time of Emergence with Total Uncertainty

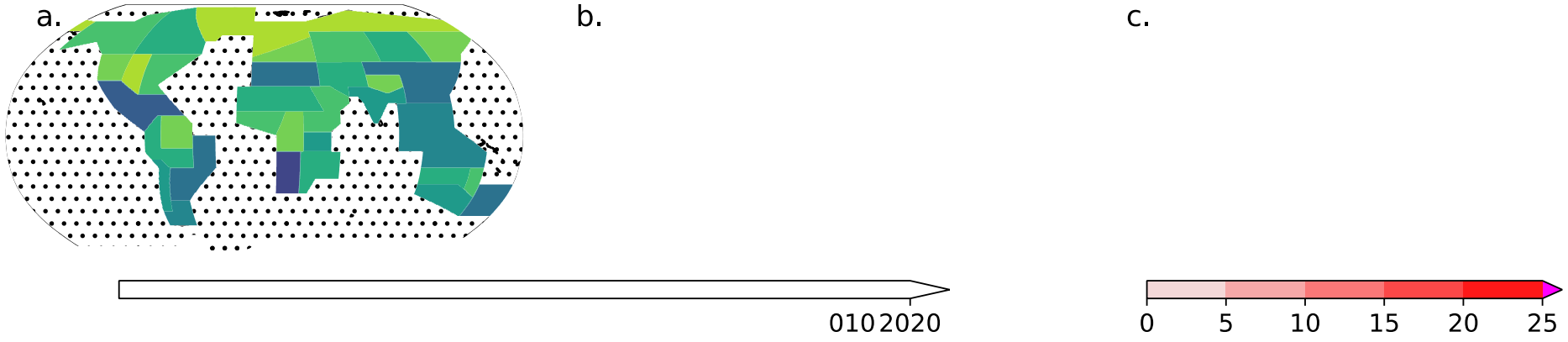


Trend emergence is later and less confident at finer spatial scales.

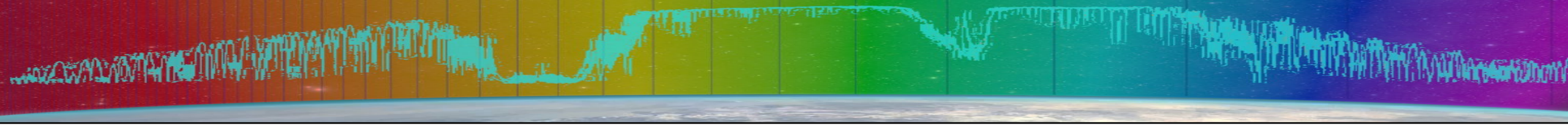
Takeaways: Emergence of Regional Warming is Robust

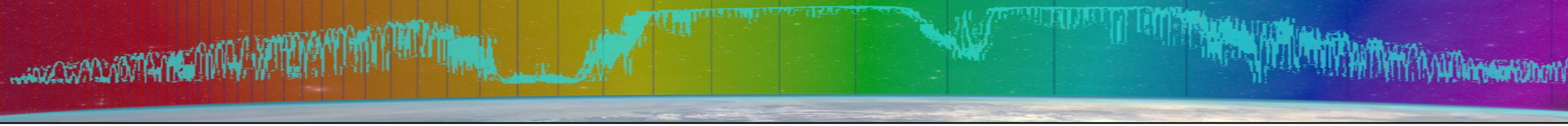
- Warming trends are robustly detectable over the entire non-Antarctic land surface.
- More than 50% of the land surface had emerged by 2000.
- Combined observational and model uncertainty delays trend emergence by 20+ years over more than 35% of the land surface.

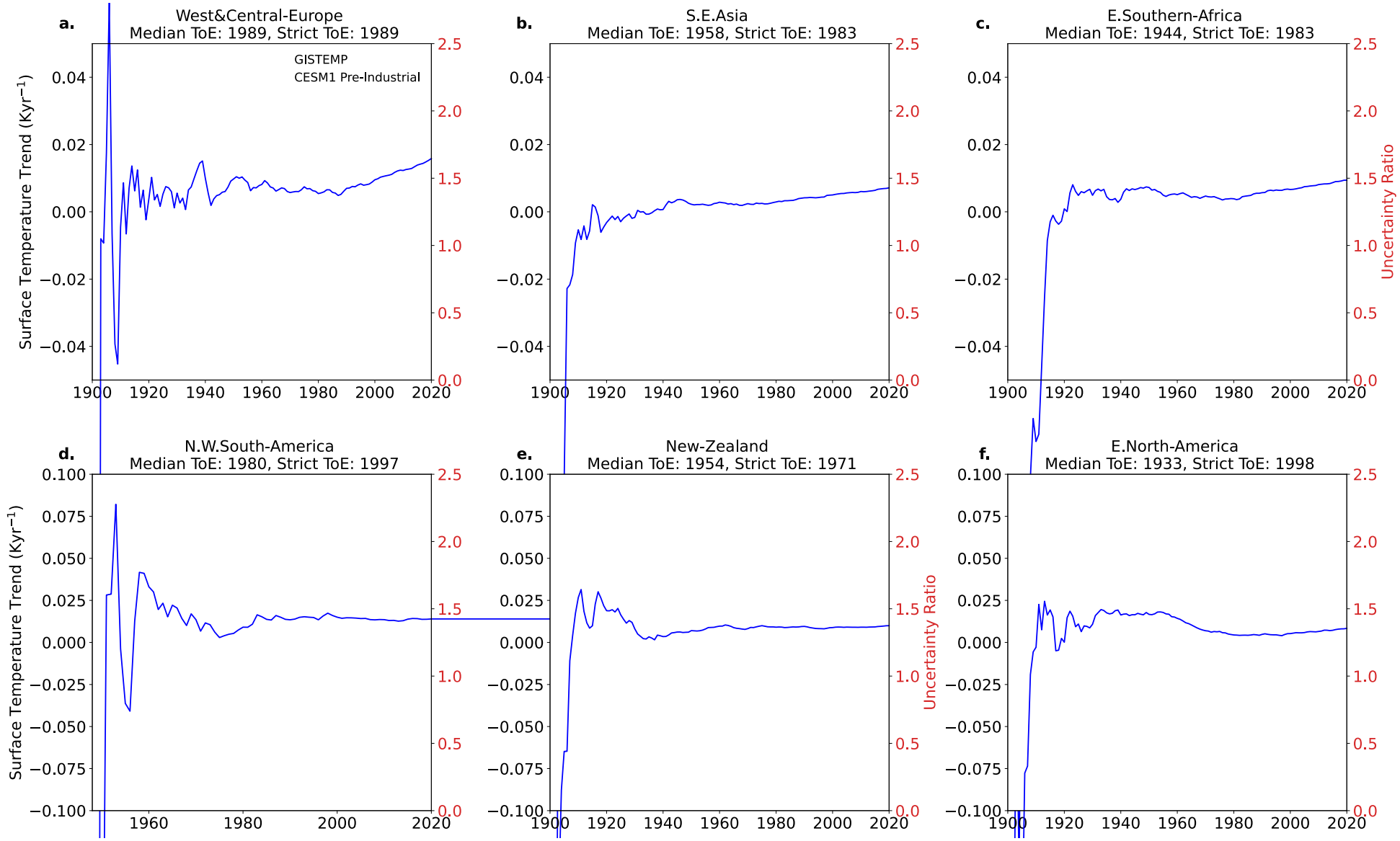
Preprint:

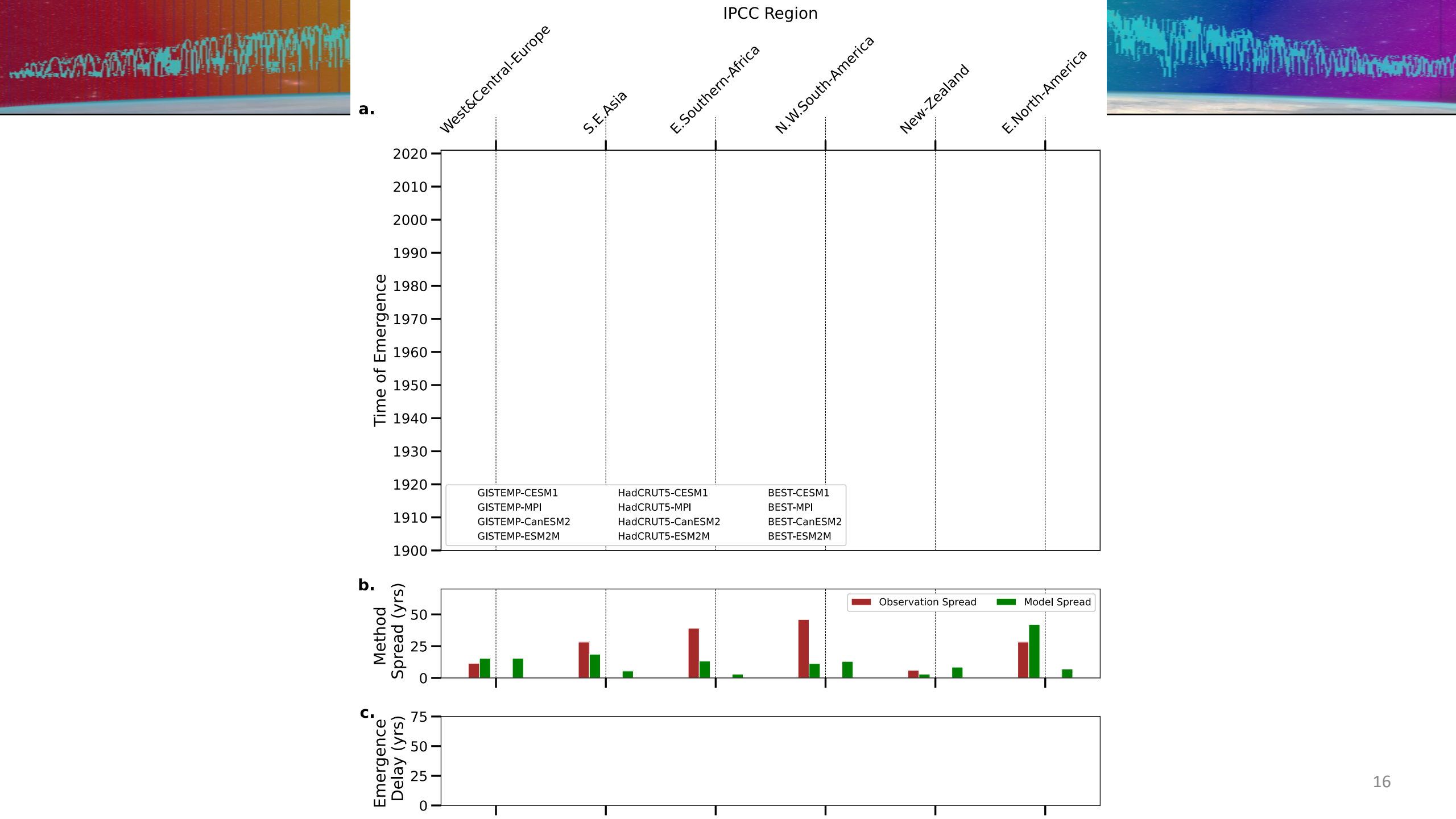


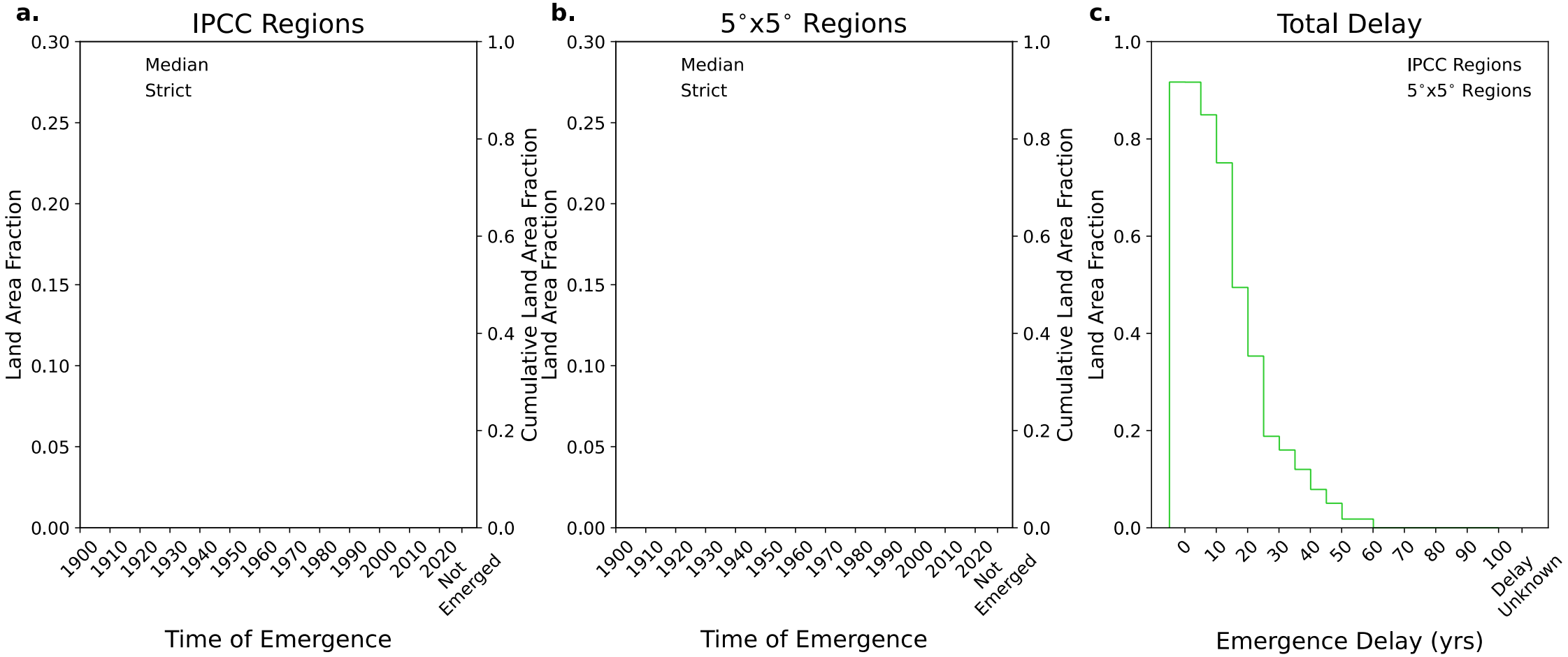
Shaw, J.K., and Lenssen, N., *Early and Widespread Emergence of Regional Warming is Robust to Observational and Model Uncertainty*, Environmental Research Letters [in revision.]

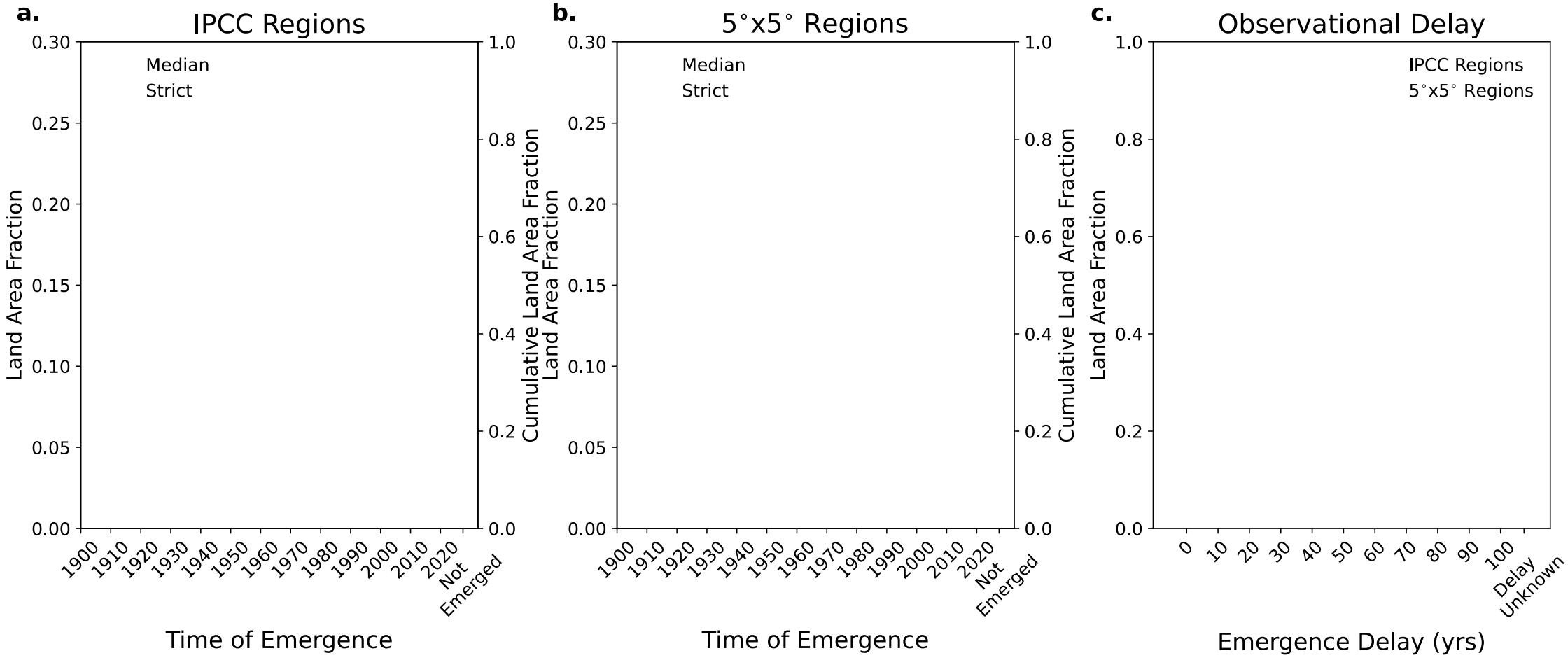





a.
West&Central-Europe
Median ToE: 1989, Strict ToE: 1989
GISTEMP
CESM1 Pre-Industrial
b.
S.E.Asia
Median ToE: 1958, Strict ToE: 1983
c.
E.Southern-Africa
Median ToE: 1944, Strict ToE: 1983
d.
N.W.South-America
Median ToE: 1980, Strict ToE: 1997
e.
New-Zealand
Median ToE: 1954, Strict ToE: 1971
f.
E.North-America
Median ToE: 1933, Strict ToE: 1998
Surface Temperature Trend (Kyr^{-1})
Uncertainty Ratio


IPCC Region
West&Central-Europe
S.E.Asia
E.Southern-Africa
N.W.South-America
New-Zealand
E.North-America
a.
Time of Emergence
2020
2010
2000
1990
1980
1970
1960
1950
1940
1930
1920
1910
1900
GISTEMP-CESM1
GISTEMP-MPI
GISTEMP-CanESM2
GISTEMP-ESM2M
HadCRUT5-CESM1
HadCRUT5-MPI
HadCRUT5-CanESM2
HadCRUT5-ESM2M
BEST-CESM1
BEST-MPI
BEST-CanESM2
BEST-ESM2M
b.
Method Spread (yrs)
50
25
0
Observation Spread
Model Spread
c.
Emergence Delay (yrs)
75
50
25
0


a.
IPCC Regions
Median
Strict
Land Area Fraction
Cumulative Land Area Fraction
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1.0
0.8
0.6
0.4
0.2
0.0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Not Emerged
Time of Emergence
b.
5°x5° Regions
Median
Strict
Land Area Fraction
Cumulative Land Area Fraction
Time of Emergence
c.
Total Delay
IPCC Regions
5°x5° Regions
Land Area Fraction
0
10
20
30
40
50
60
70
80
90
100
Delay Unknown
Emergence Delay (yrs)


a.
IPCC Regions
Median
Strict
Land Area Fraction
Cumulative Land Area Fraction
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1.0
0.8
0.6
0.4
0.2
0.0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Not Emerged
Time of Emergence
b.
5°x5° Regions
Median
Strict
Land Area Fraction
Cumulative Land Area Fraction
Time of Emergence
c.
Observational Delay
IPCC Regions
5°x5° Regions
Land Area Fraction
0
10
20
30
40
50
60
70
80
90
100
Delay Unknown
Emergence Delay (yrs)