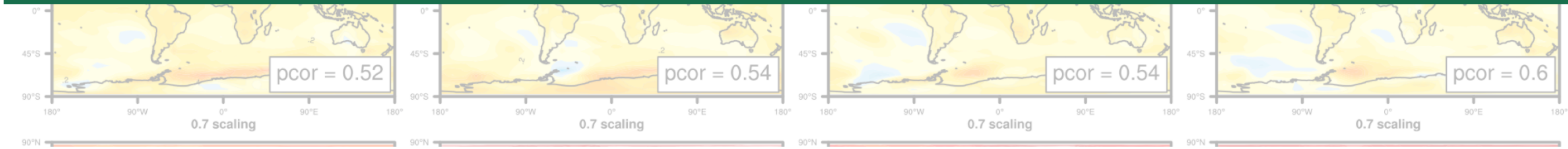
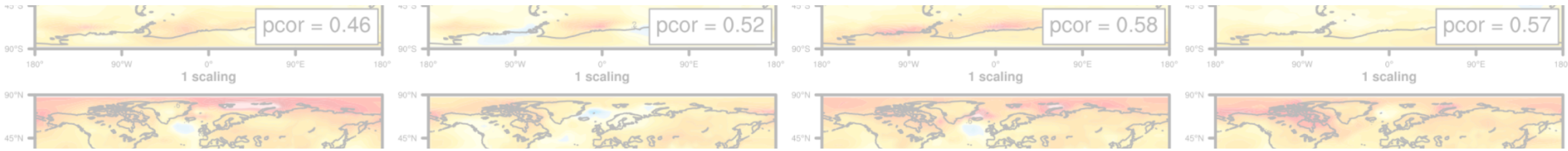
Emergence of the climate change signal and the sensitivity of historical climate simulations to uncertain aerosol forcing



Andrea Dittus, **Ed Hawkins**, Laura Wilcox and Rowan Sutton
Chris Smith and Martin Andrews



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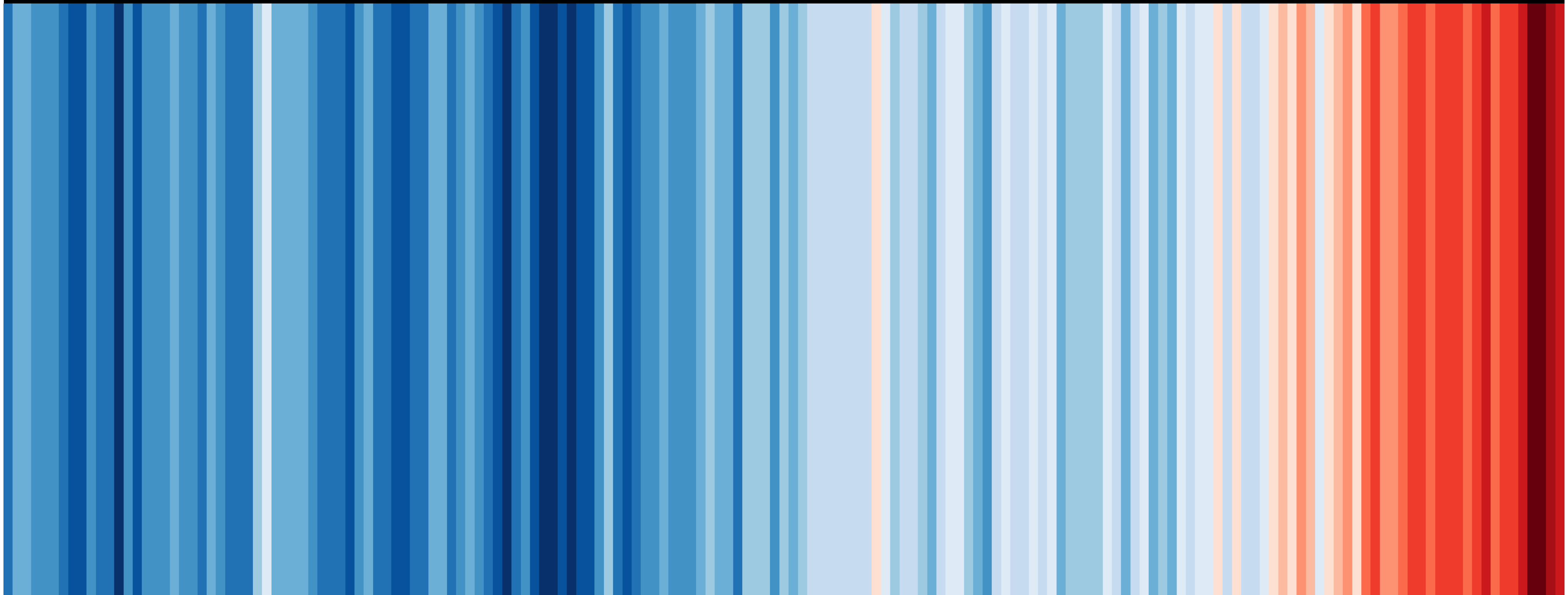
Global annual temperatures (1850-2018)



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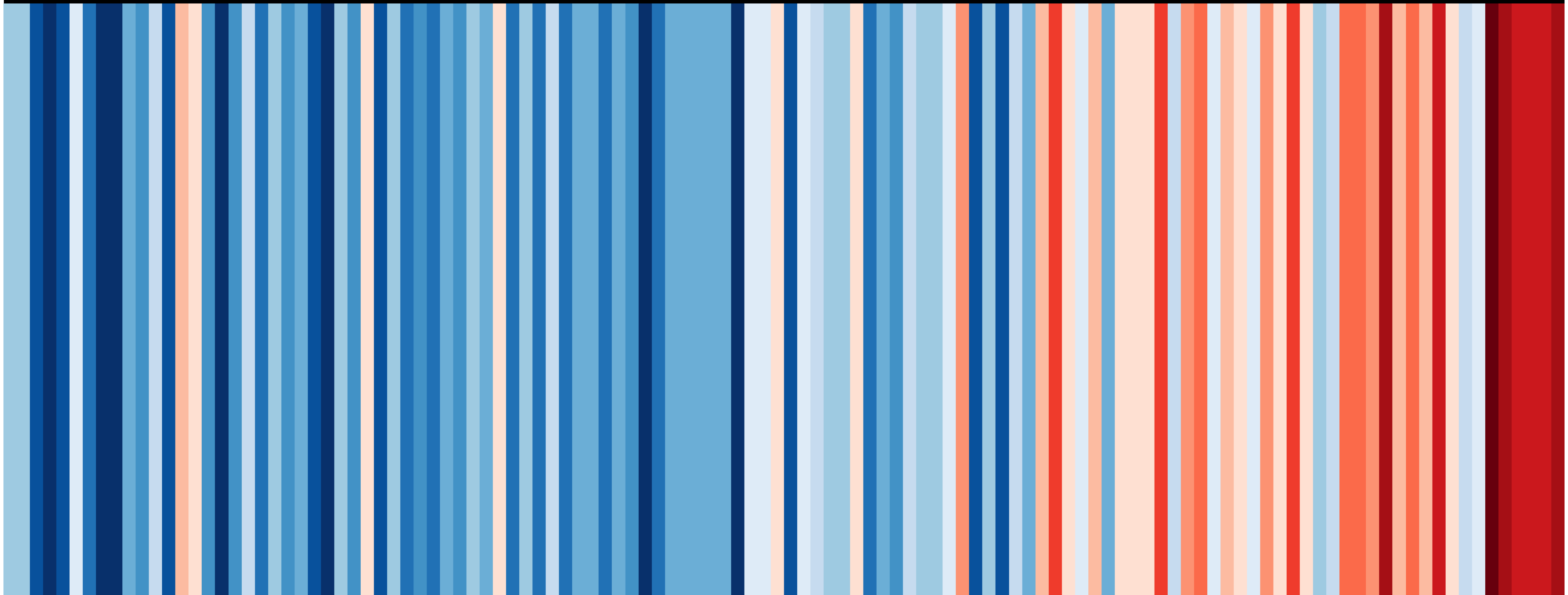
Australia annual temperatures (1901-2018)



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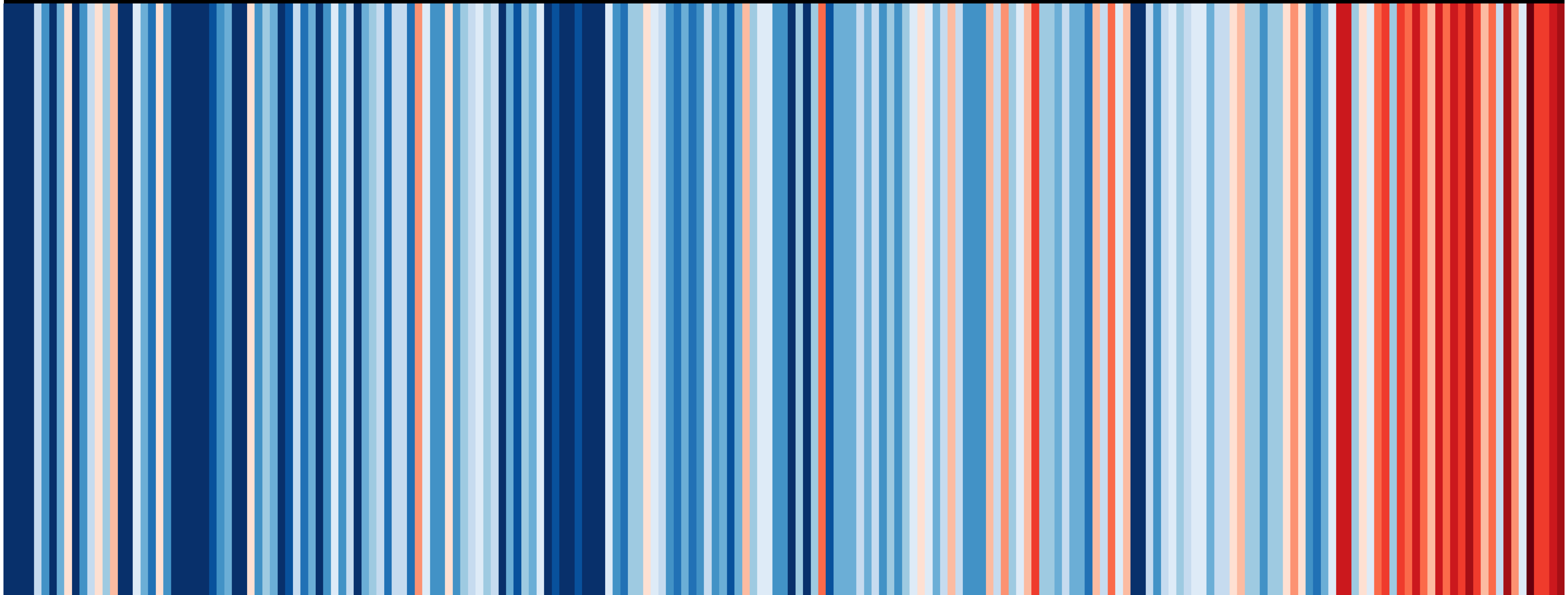
Oxford annual temperatures (1814-2018)



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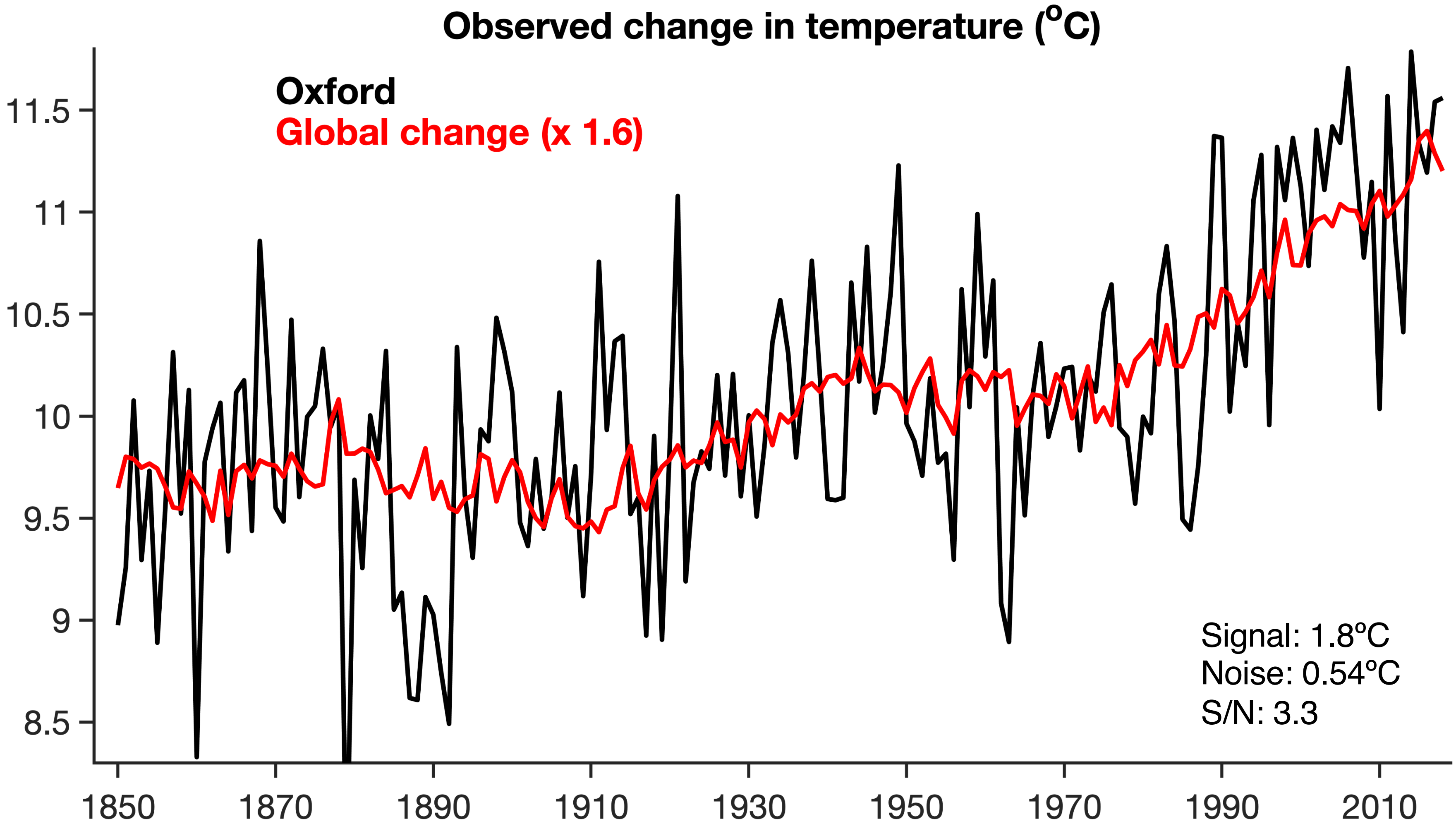
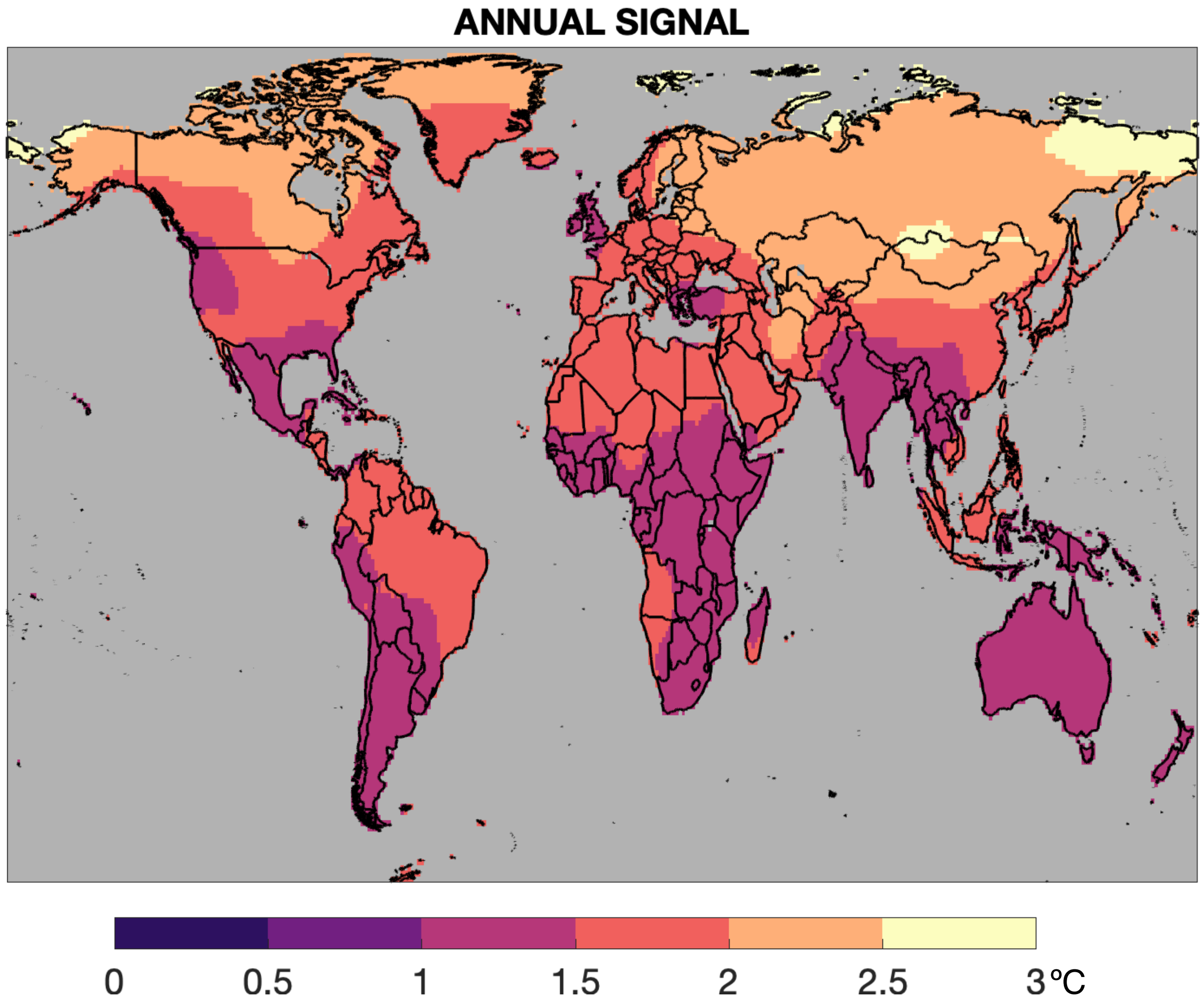


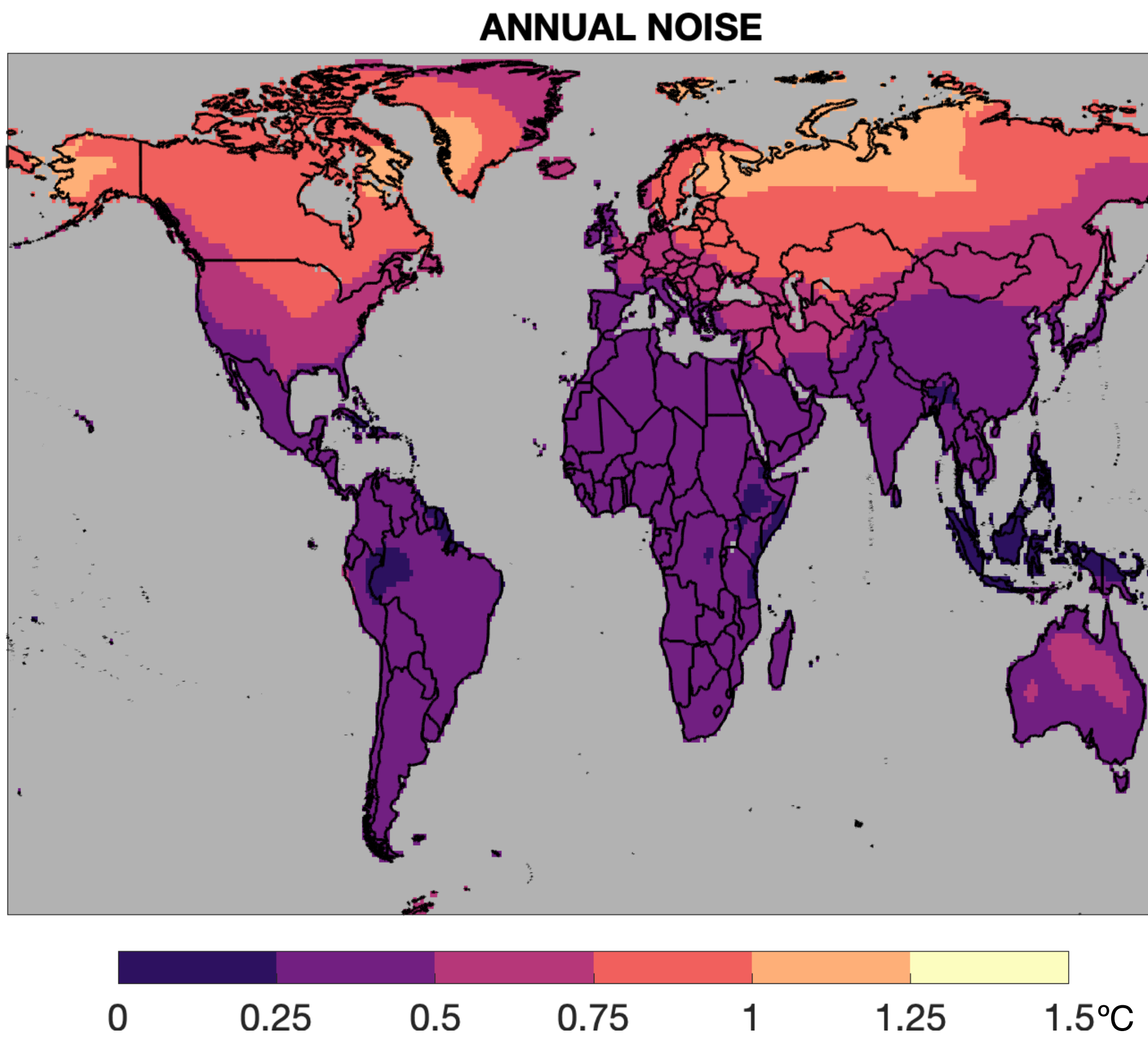
Hawkins et al., in prep



Signal of observed temperature change since the early-industrial period (1850-1900)

Data: Berkeley Earth

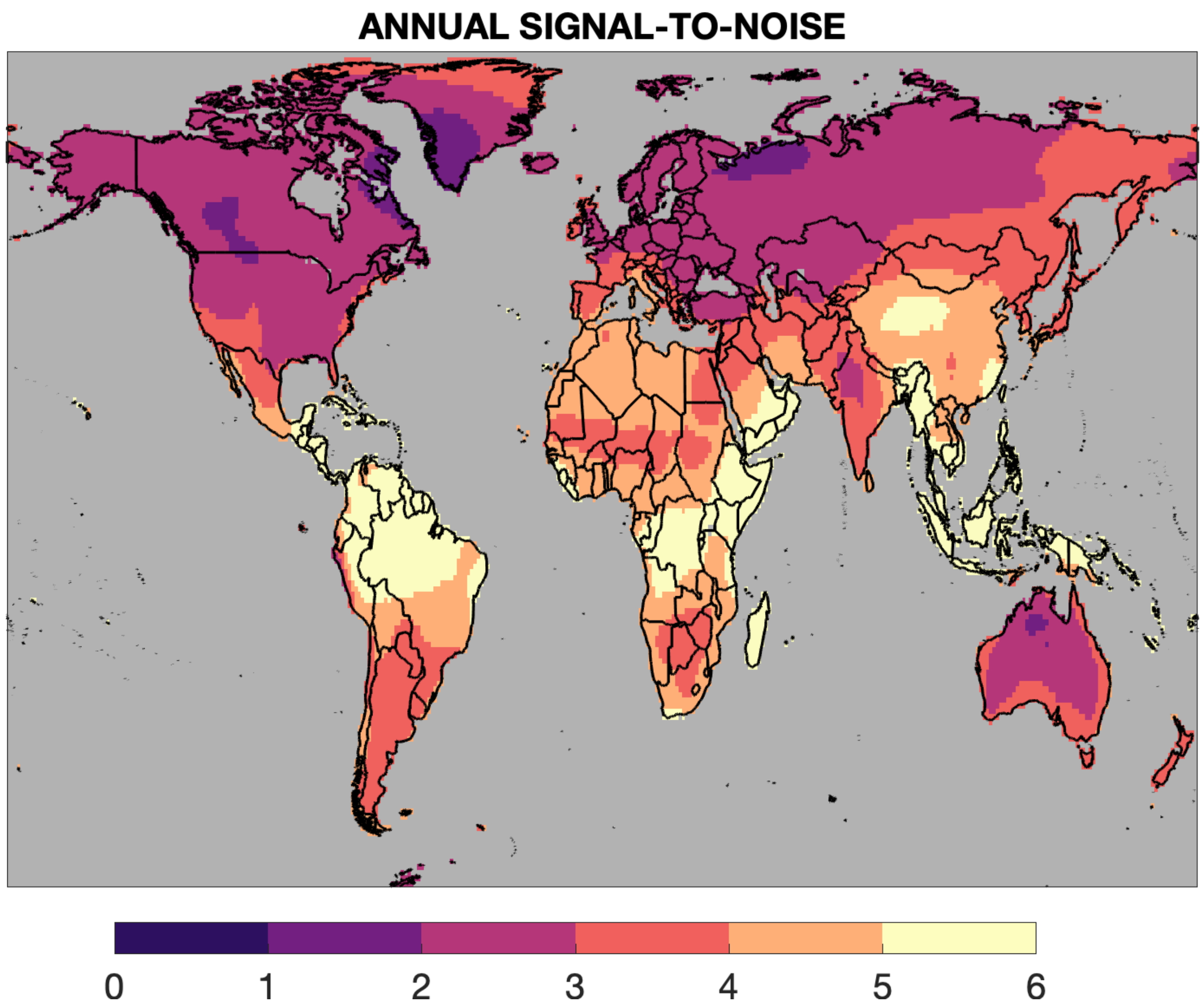
Hawkins et al., in prep



Noise of observed temperature change since the early-industrial period (1850-1900)

Data: Berkeley Earth

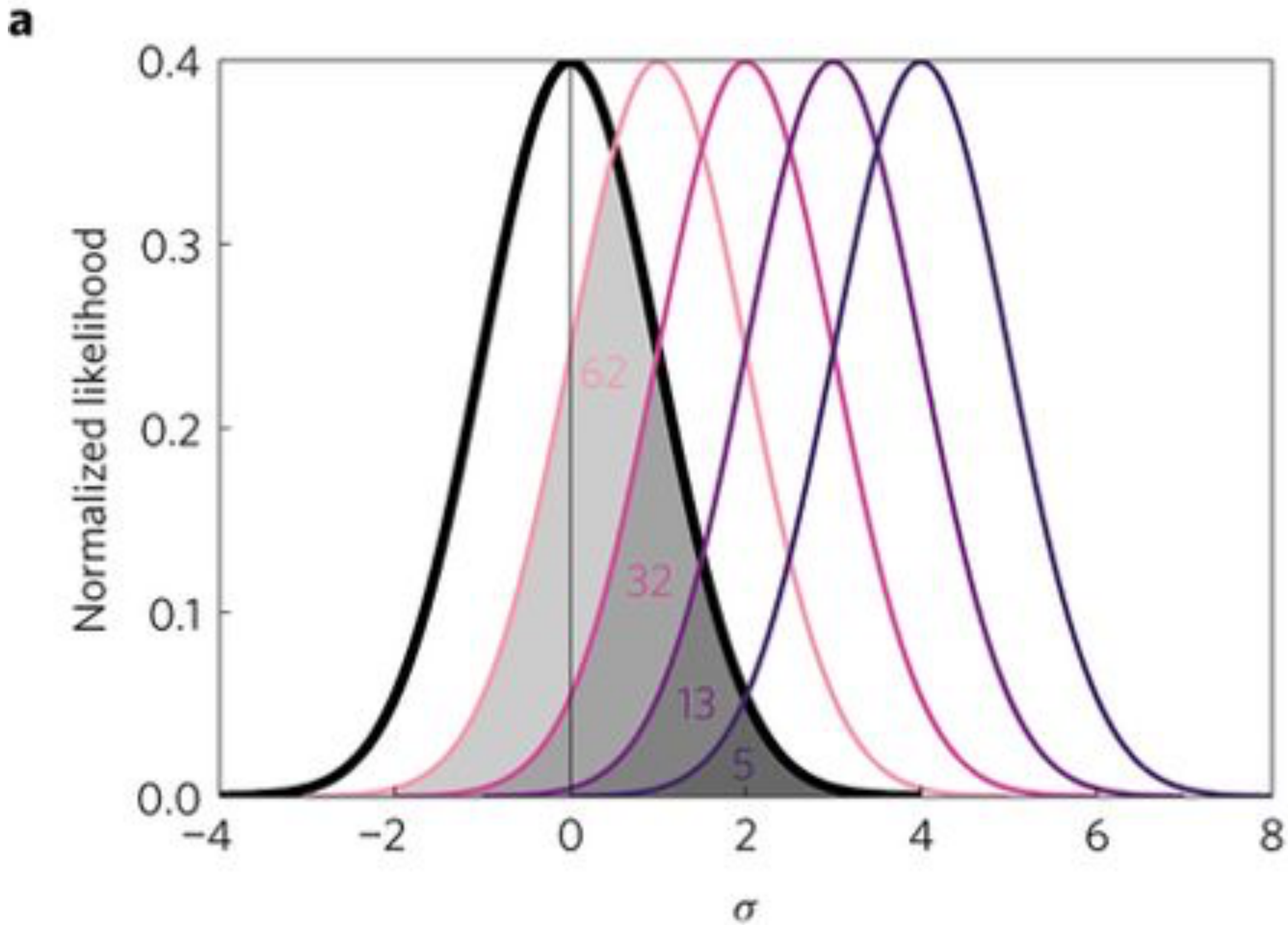
Hawkins et al., in prep



Signal-to-noise ratio of observed temperature change since the early-industrial period (1850-1900)

Data: Berkeley Earth

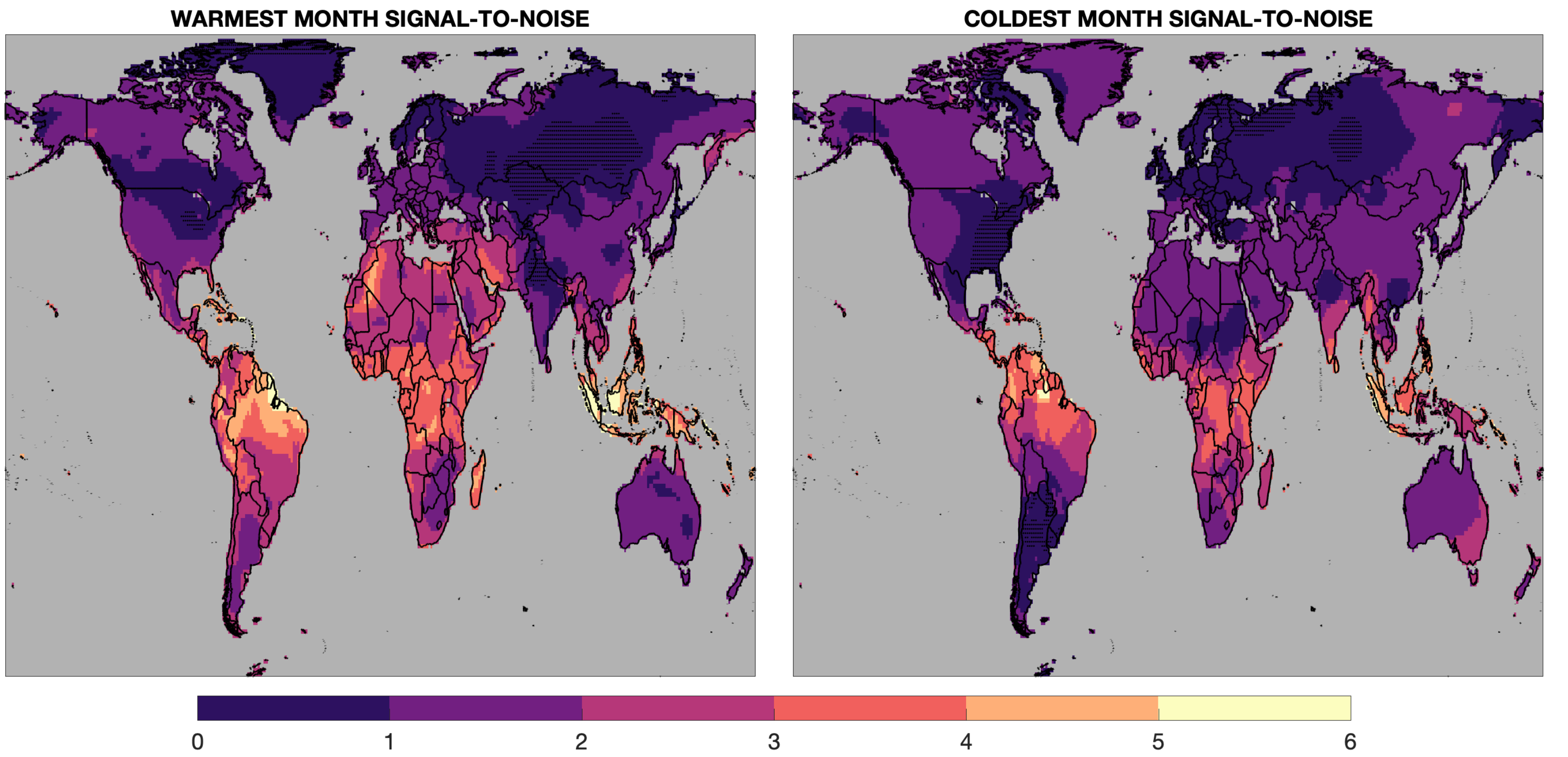
Hawkins et al., in prep



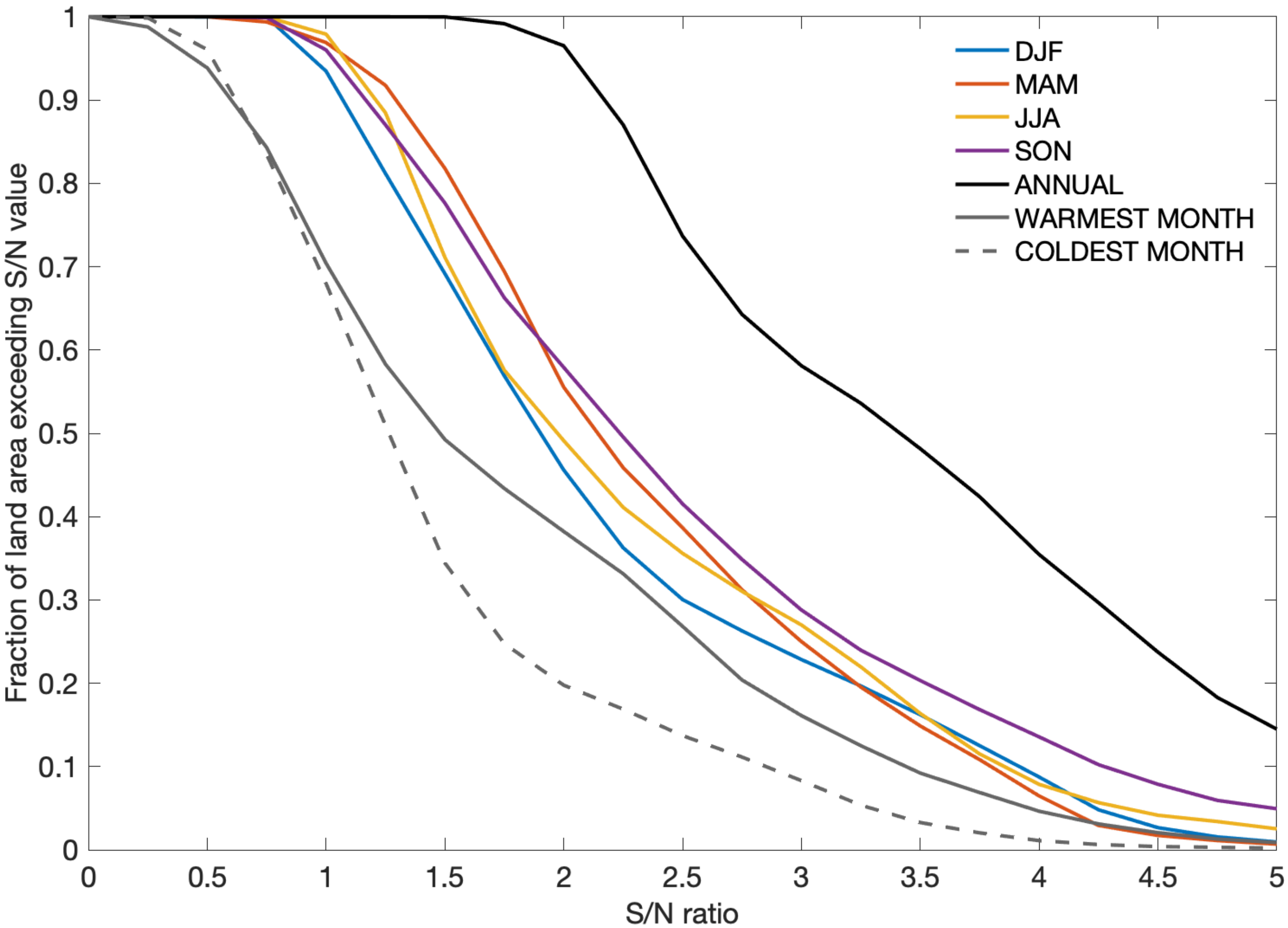
S/N>1: Unusual
S/N>2: Unfamiliar
S/N>3: Unknown

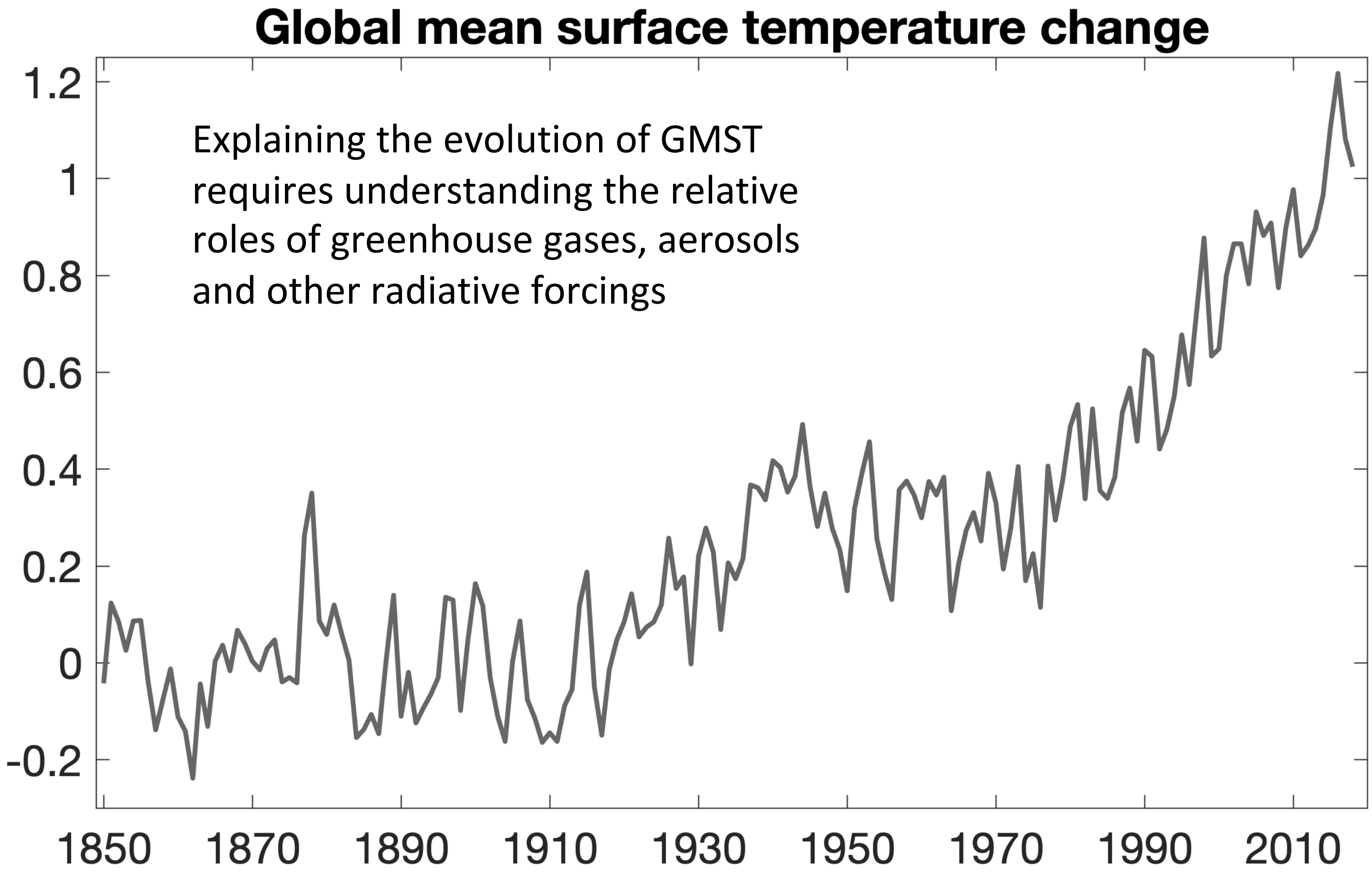
Frame et al, 2017

Signal-to-noise ratio of observed temperature change since the early-industrial period (1850-1900)

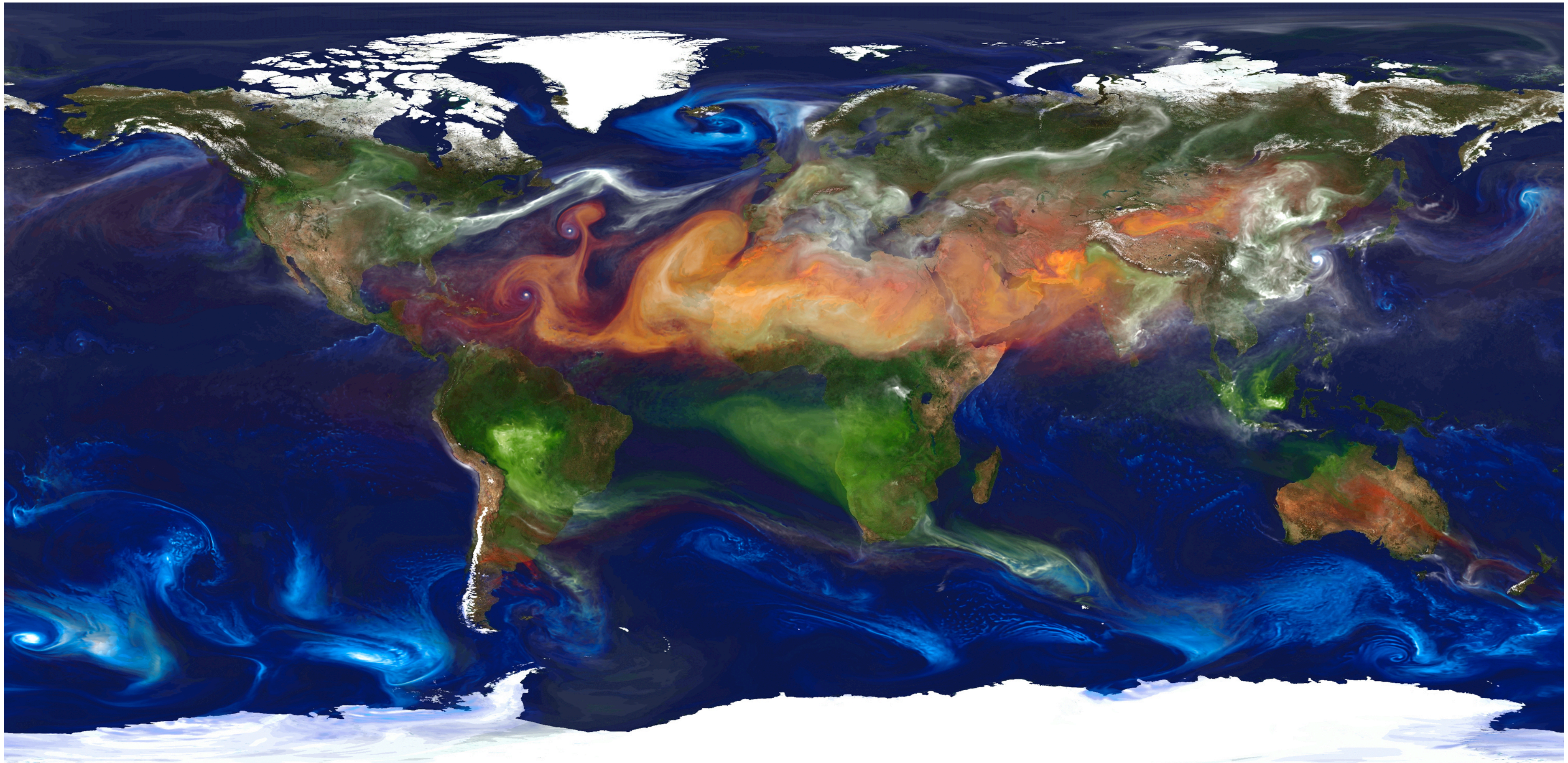


Hawkins et al., in prep


DJF
MAM
JJA
SON
ANNUAL
WARMEST MONTH
COLDEST MONTH
Fraction of land area exceeding S/N value
S/N ratio
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


Global mean surface temperature change
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
1850
1870
1890
1910
1930
1950
1970
1990
2010
Explaining the evolution of GMST requires understanding the relative roles of greenhouse gases, aerosols and other radiative forcings

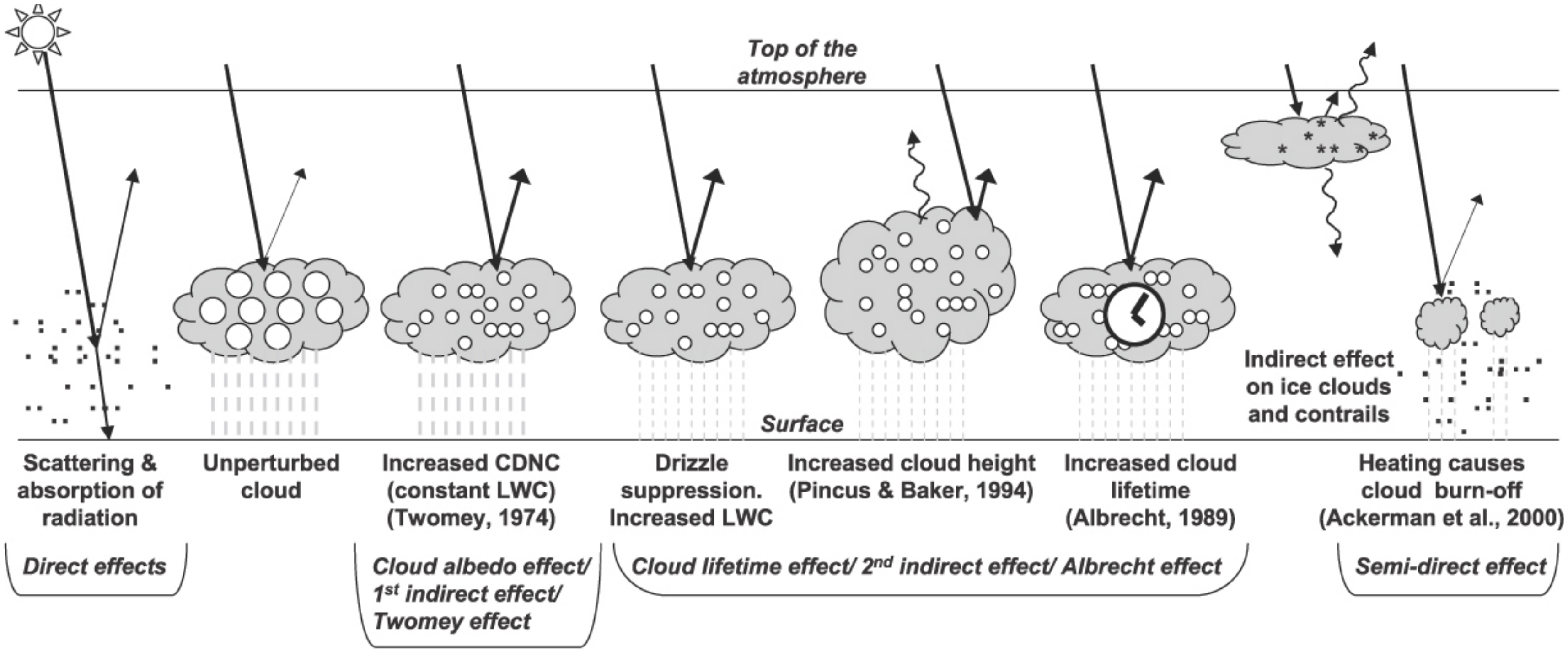
Global aerosol



Red: Dust Blue: Sea salt Green: Smoke White: Sulphate

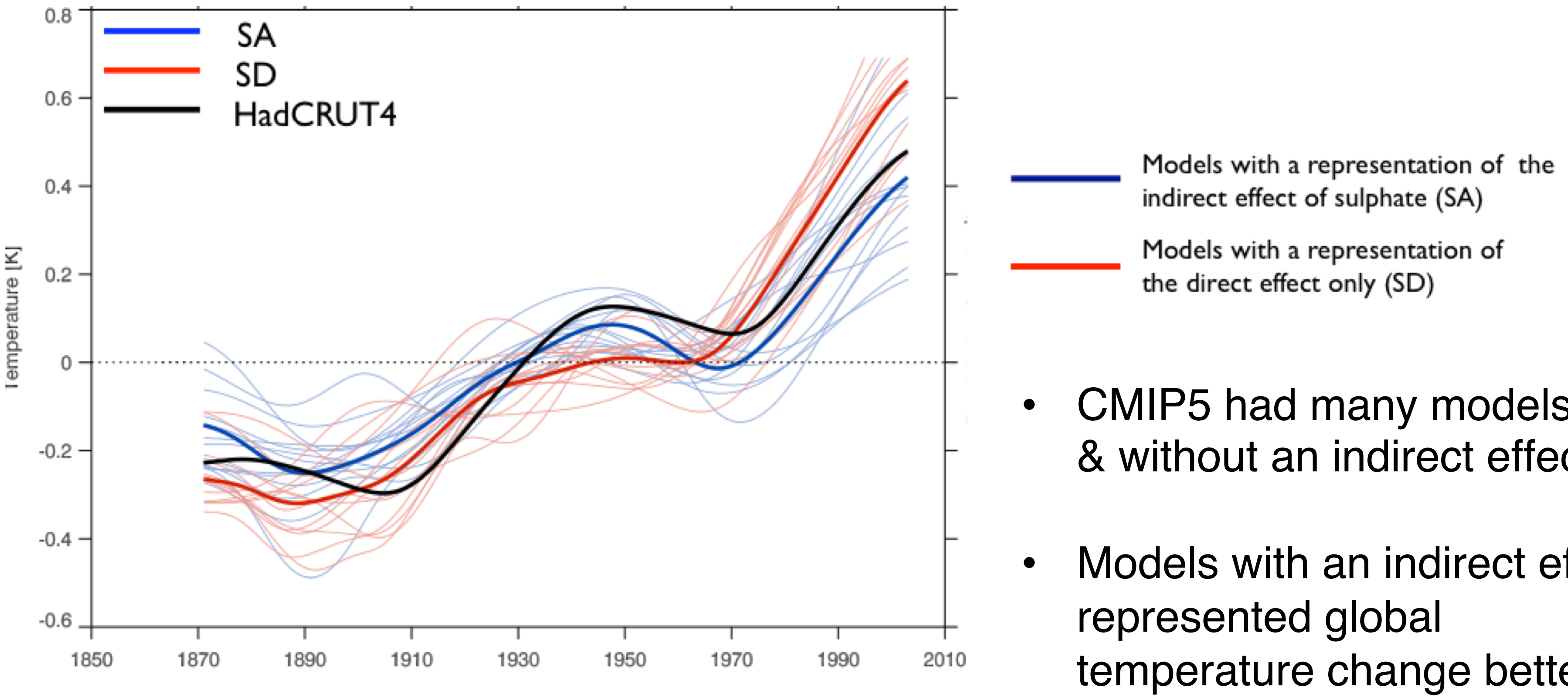
NASA GEOS

Aerosol effects on climate



IPCC (2007)

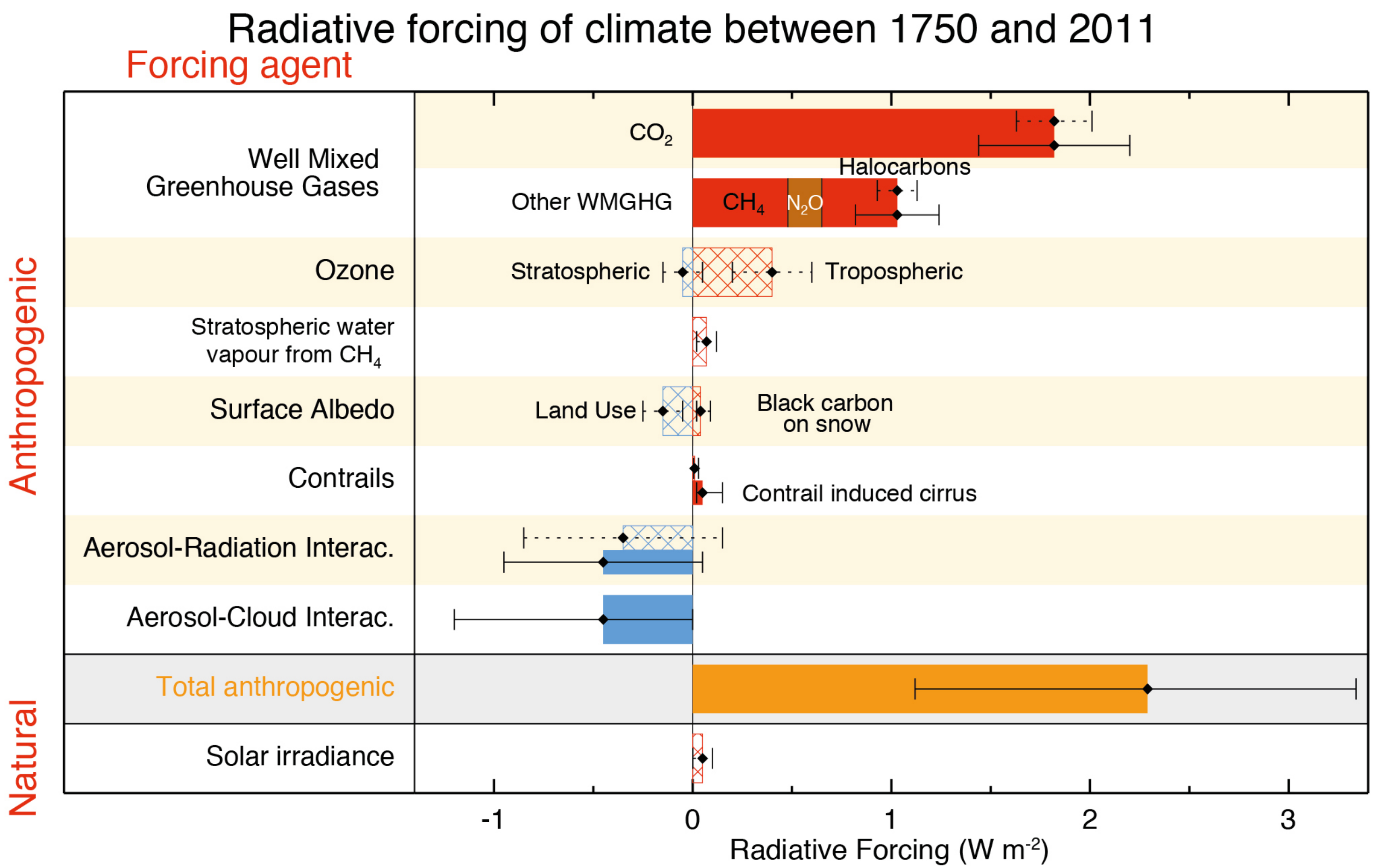
Global temperature variability



Wilcox et al., 2013 (ERL)

- CMIP5 had many models with & without an indirect effect
- Models with an indirect effect represented global temperature change better than models without

Aerosol radiative forcing uncertainty is large

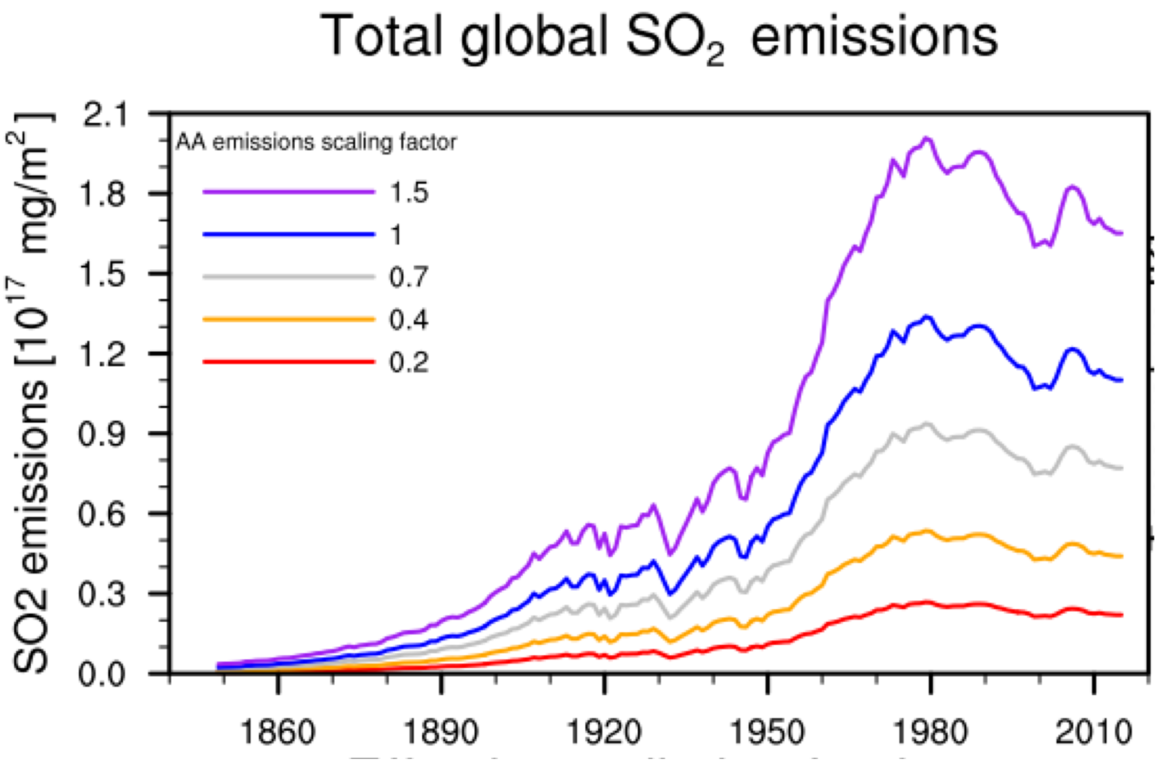


IPCC (2013)

An ‘intermediate’ size historical ensemble with HadGEM3-GC3.1

- 20 historical simulations 1850-2014
- HadGEM3-GC3.1 (CMIP6 version), N96 (135 km in mid-latitudes), 1 degree resolution in ocean
- Forcing: historical CMIP6 forcing with modified anthropogenic aerosol emissions
- **Anthropogenic aerosol emissions are scaled: 0.2x, 0.4x, 0.7x, 1.0x and 1.5x**
- 4 runs per scaling starting from different ocean initial conditions

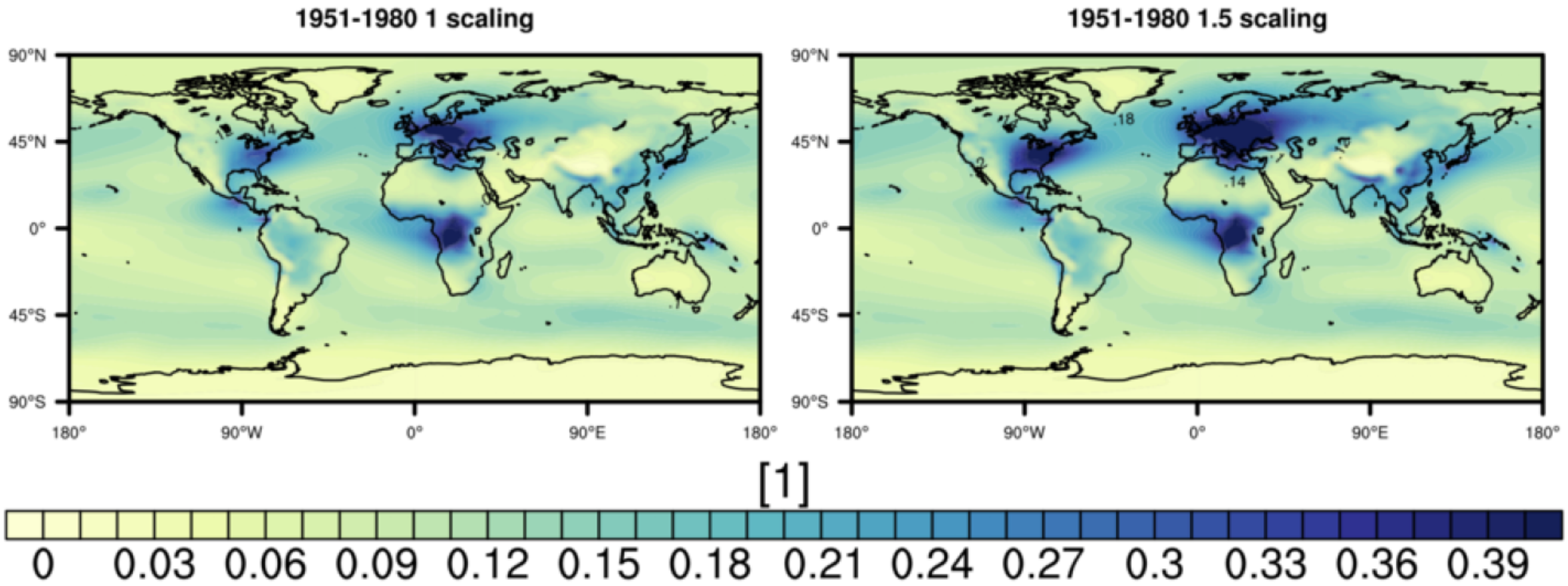
Experimental design: sulphate emissions



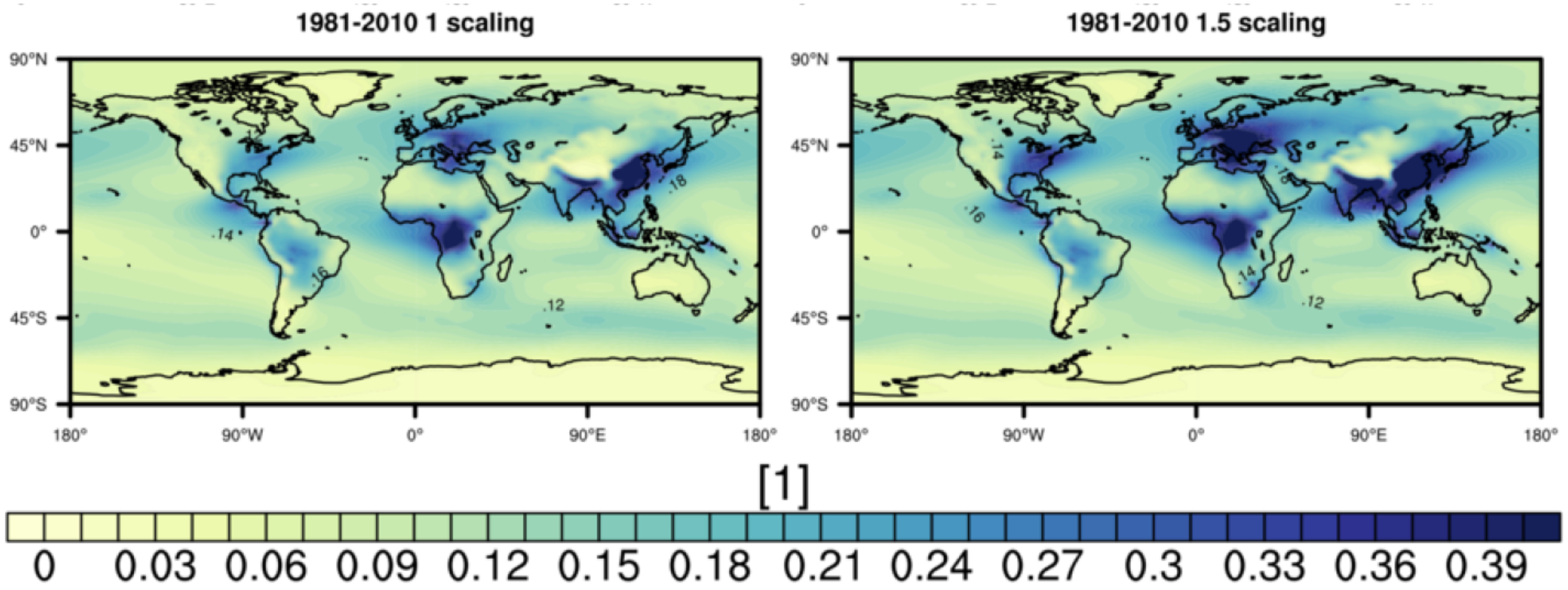
Present-day aerosol forcing:

- 0.2x scaling: -0.35 W/m^2
- 0.4x scaling: -0.63 W/m^2
- 0.7x scaling: -1.0 W/m^2
- 1.0x scaling: -1.3 W/m^2
- 1.5x scaling: -1.6 W/m^2

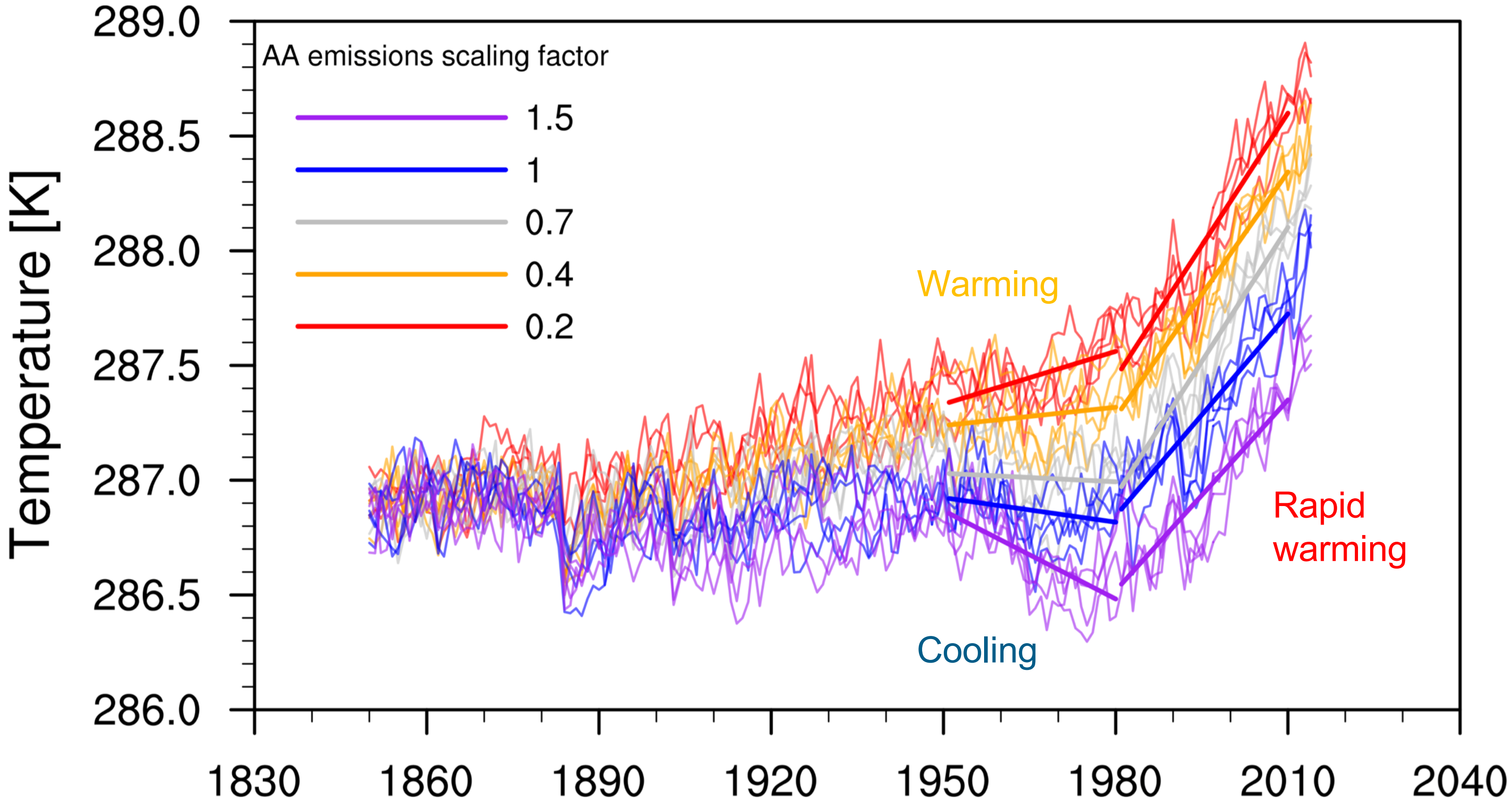
Experimental design: sulphate optical depth



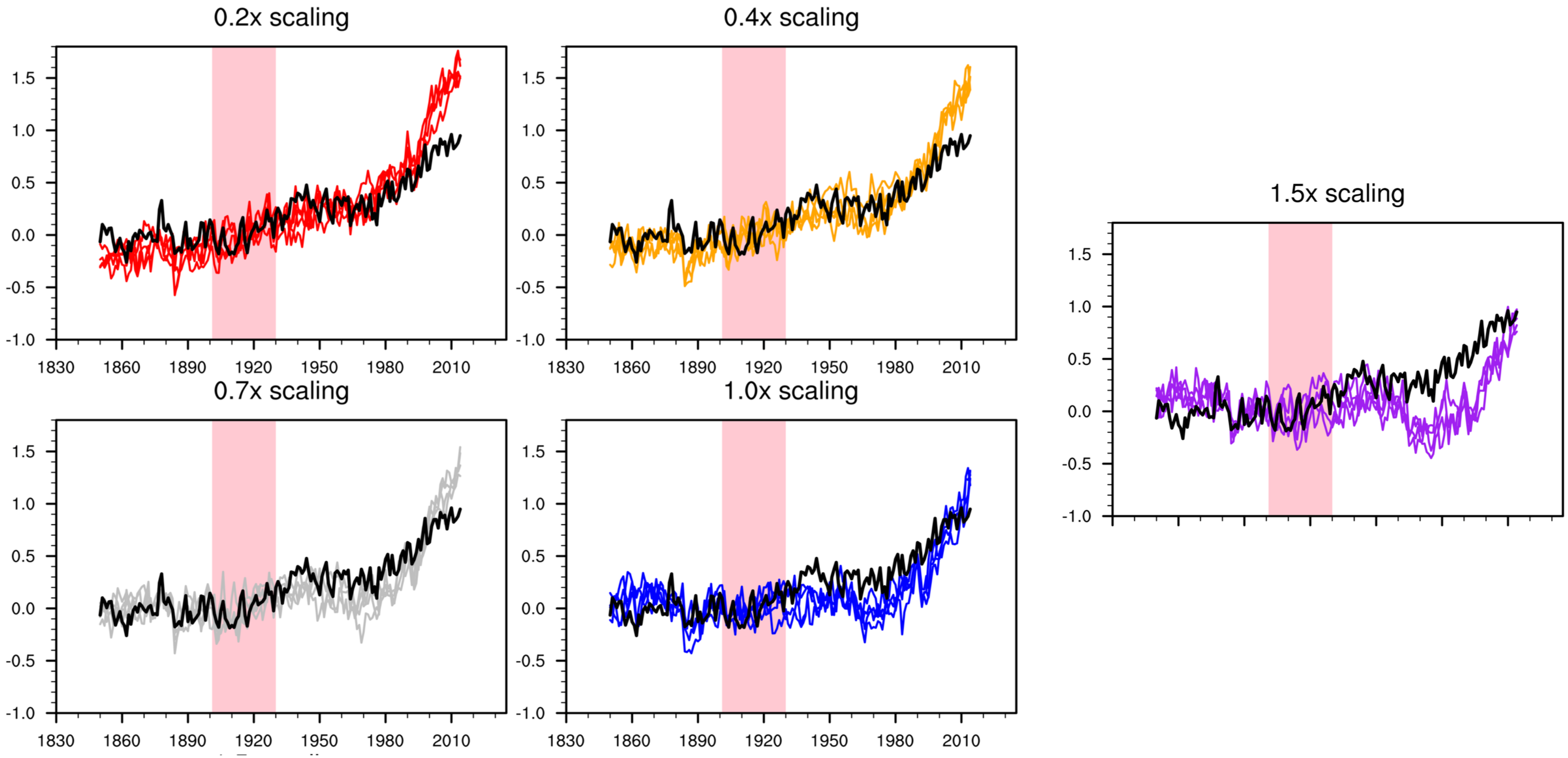
Experimental design: sulphate optical depth



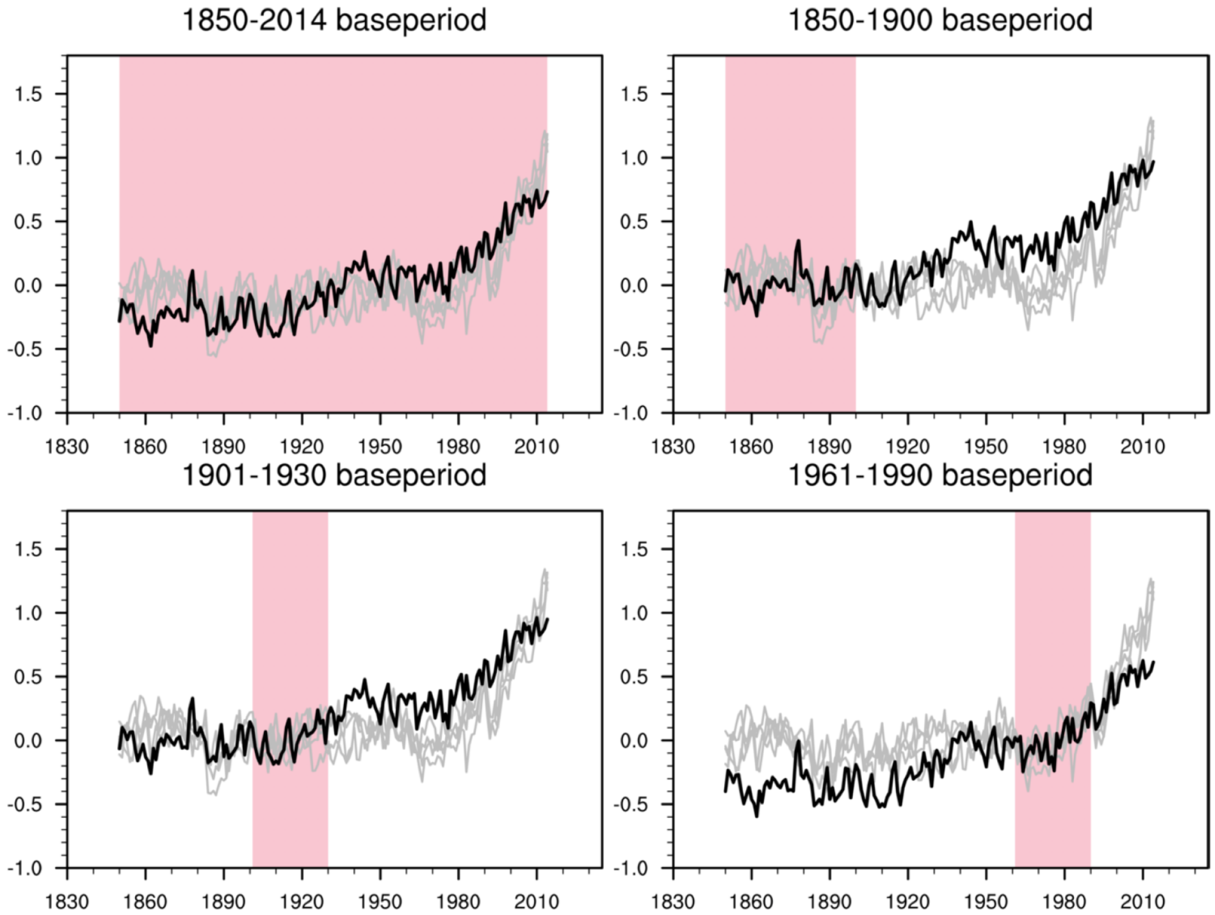
Global mean surface temperature evolution



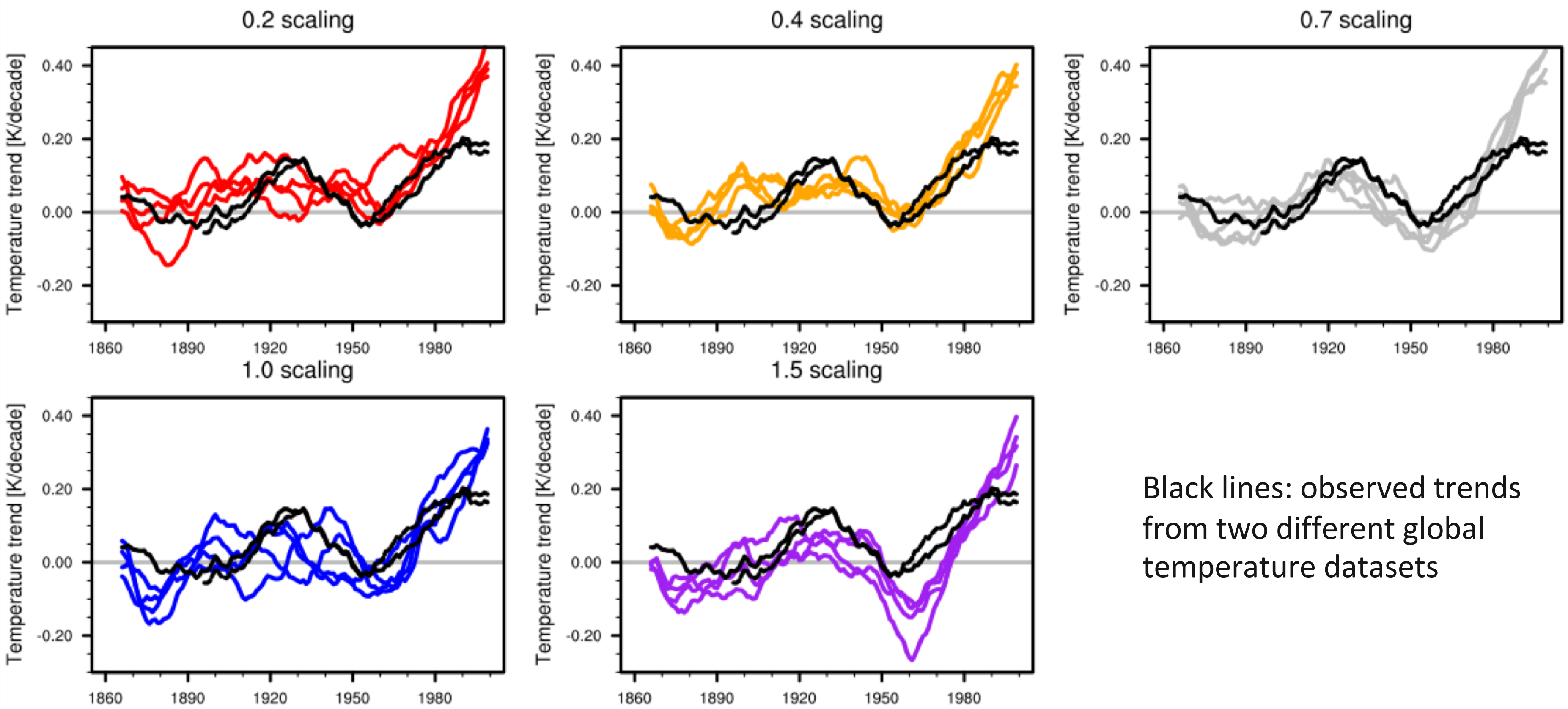
Global mean surface temperature evolution



Sensitivity to choice of baseline period for 1.0x scaling simulations

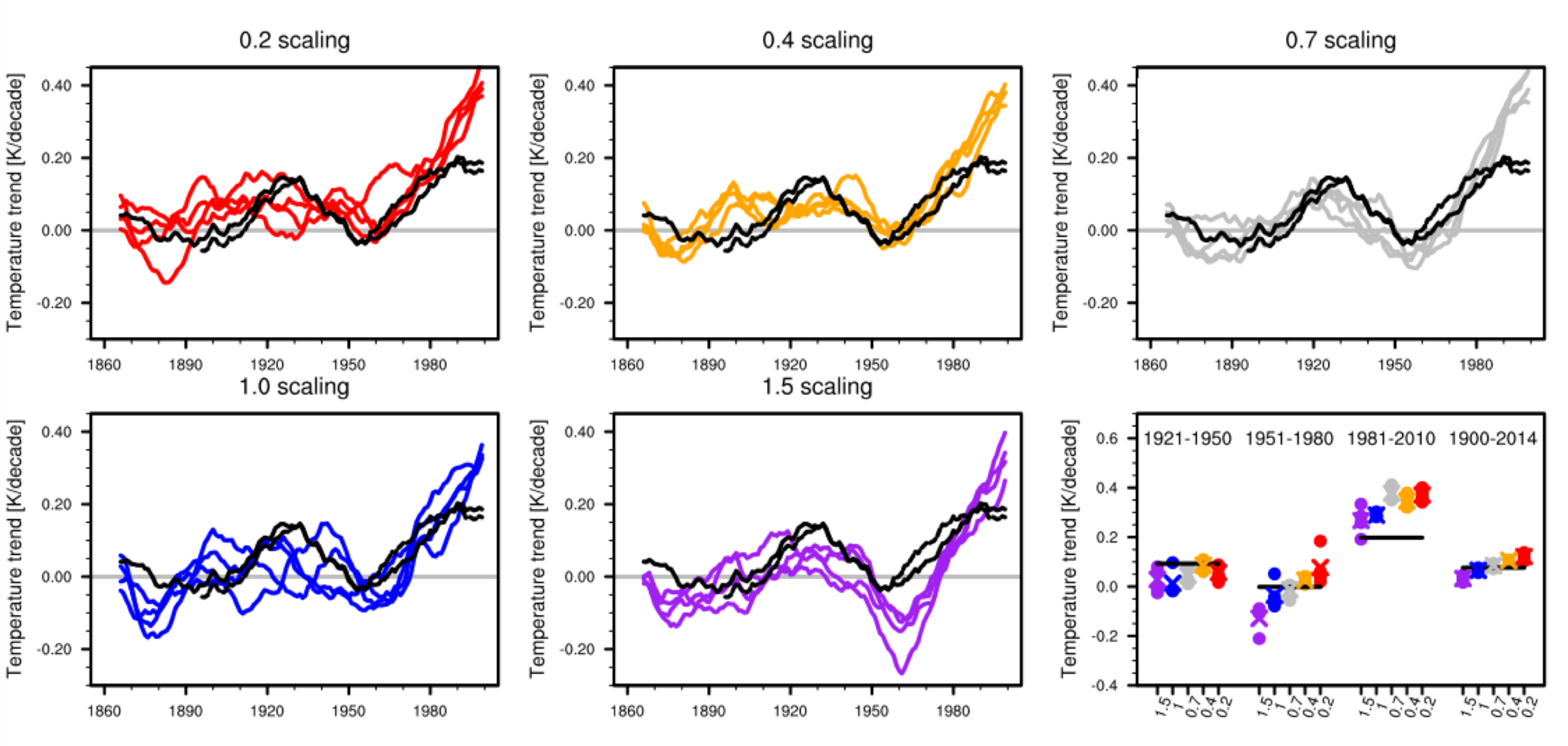


31-year running trends

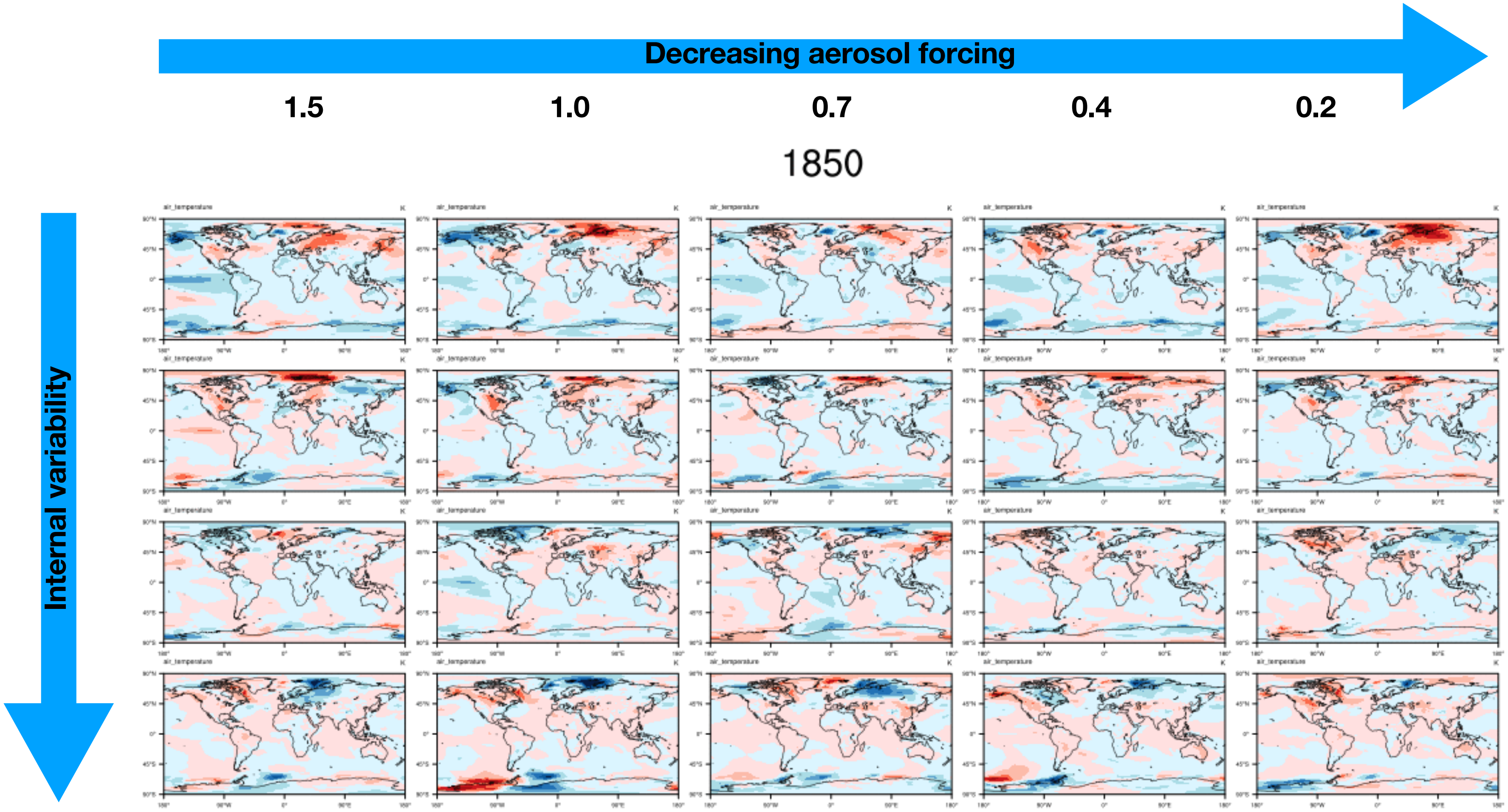


Black lines: observed trends from two different global temperature datasets

31-year running trends

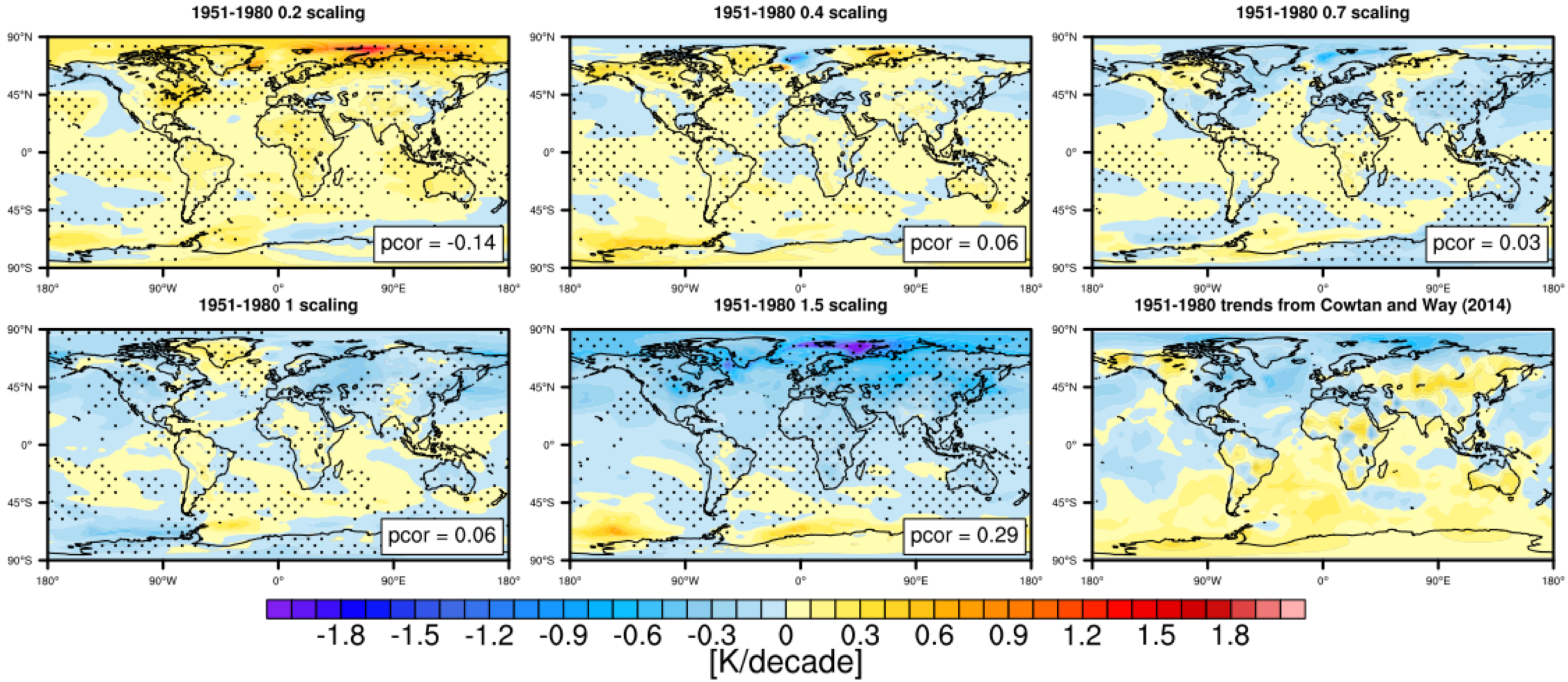


Type to enter a caption.



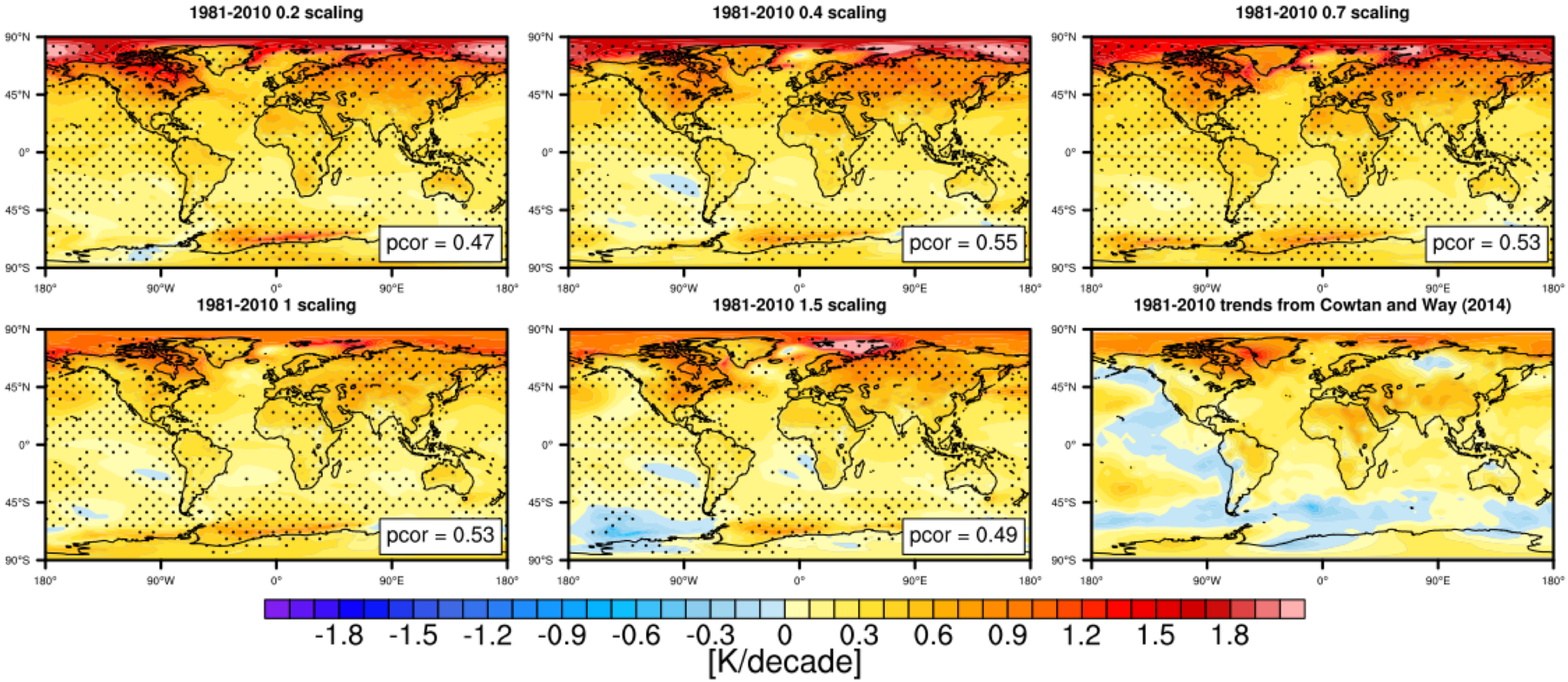
Decreasing aerosol forcing
1.5
1.0
0.7
0.4
0.2
1850
Internal variability

Spatial pattern of temperature trends 1951-1980



Type to enter a caption.

Spatial pattern of temperature trends 1981-2010

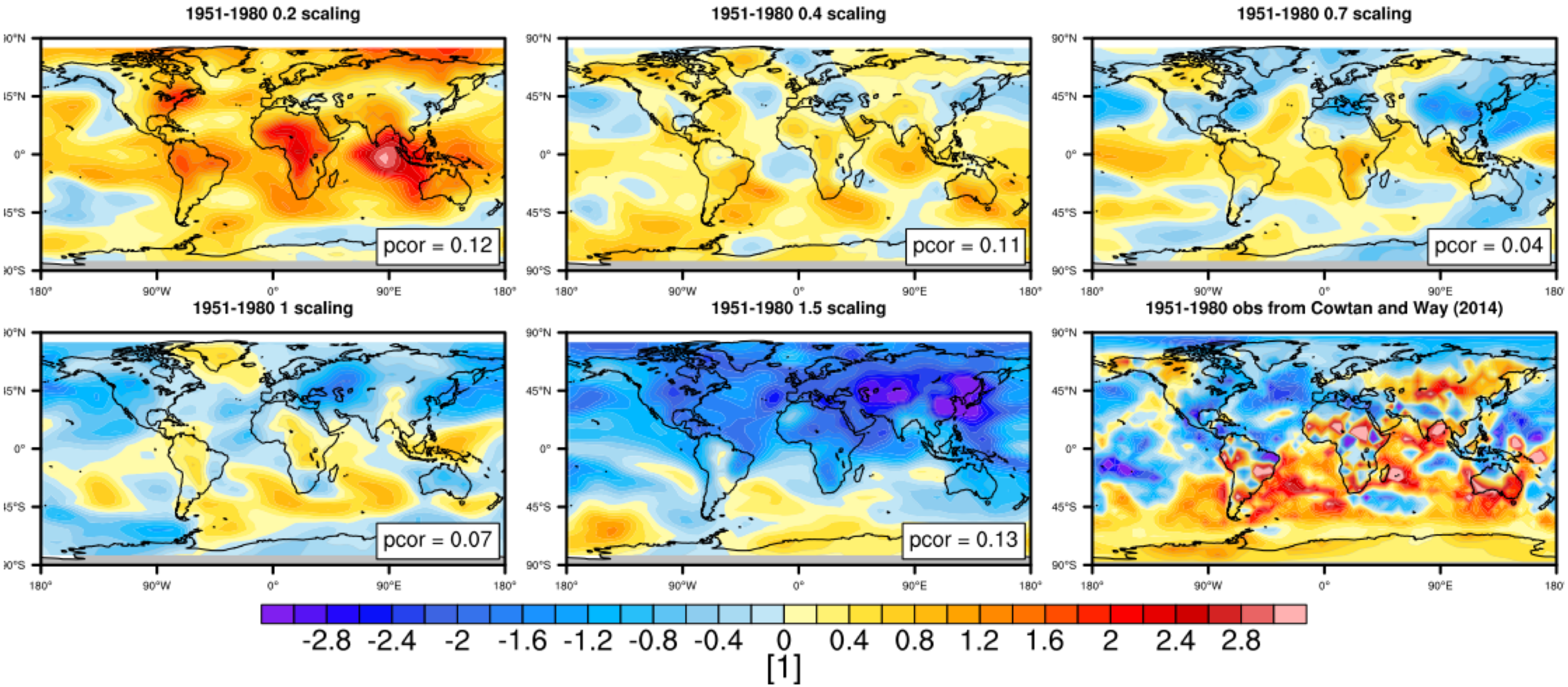


 Type to enter a caption.

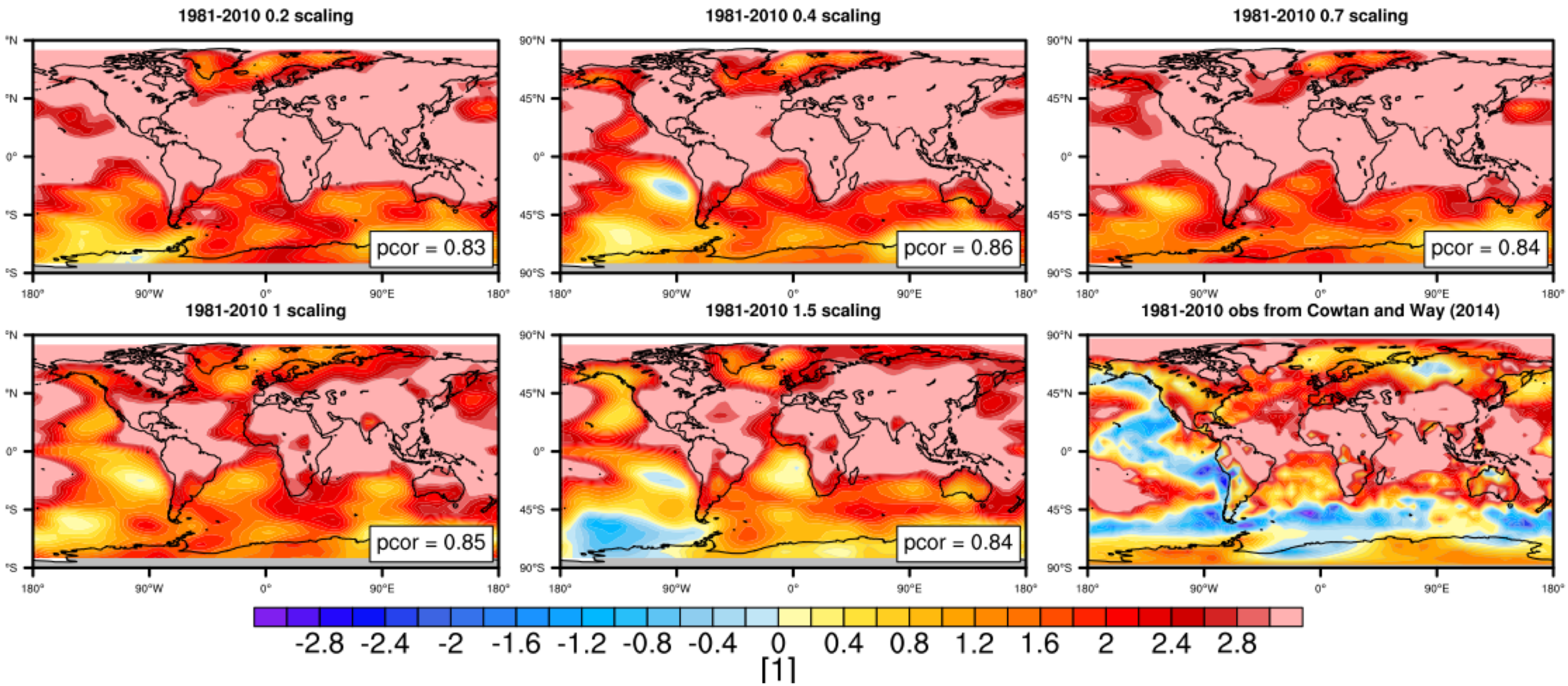
Signal-to-noise ratio 1951-1980

$$S/N_{scaling} = \frac{\overline{Trend_{IC_{1,..,4}}}}{\sigma(trend)_{control\,run}}$$

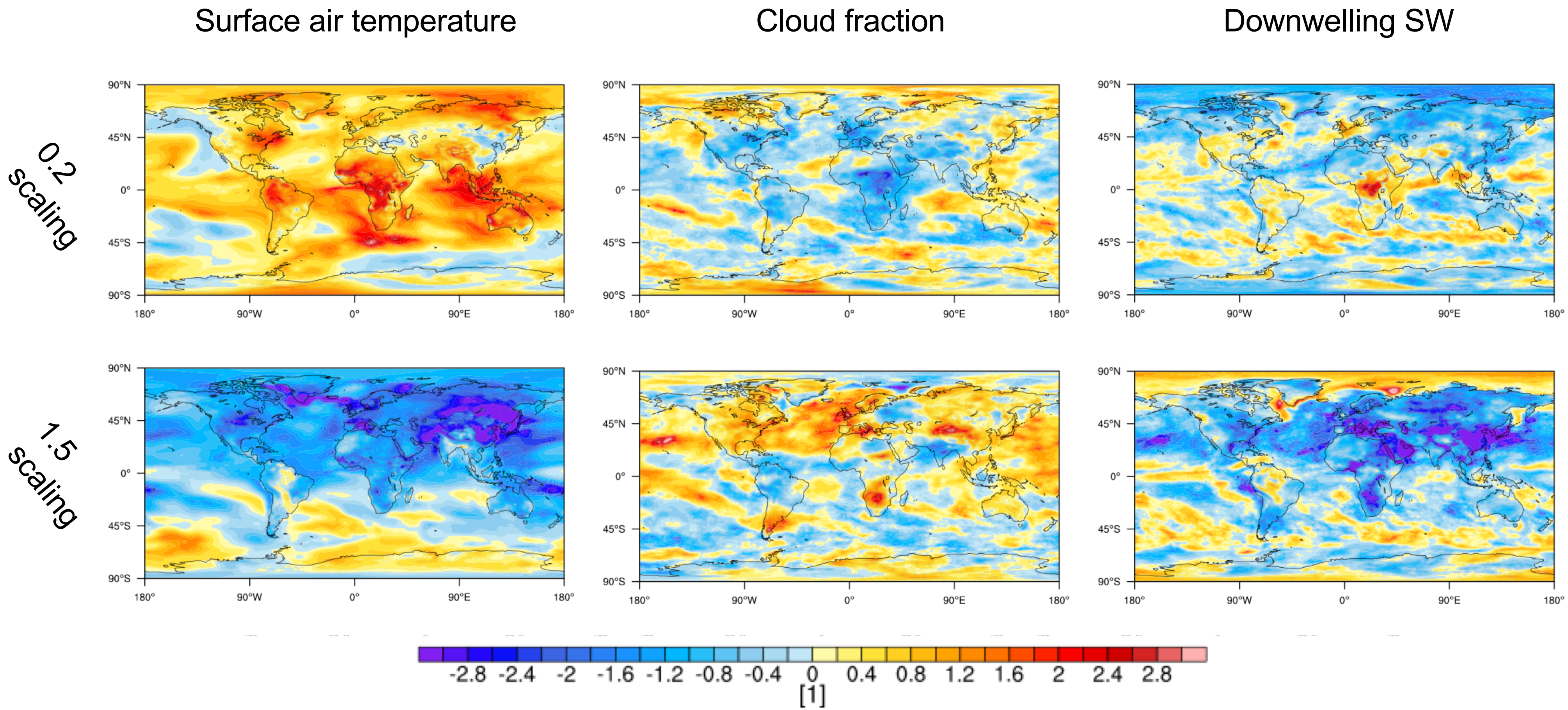
Comparison with observations 1951-1980



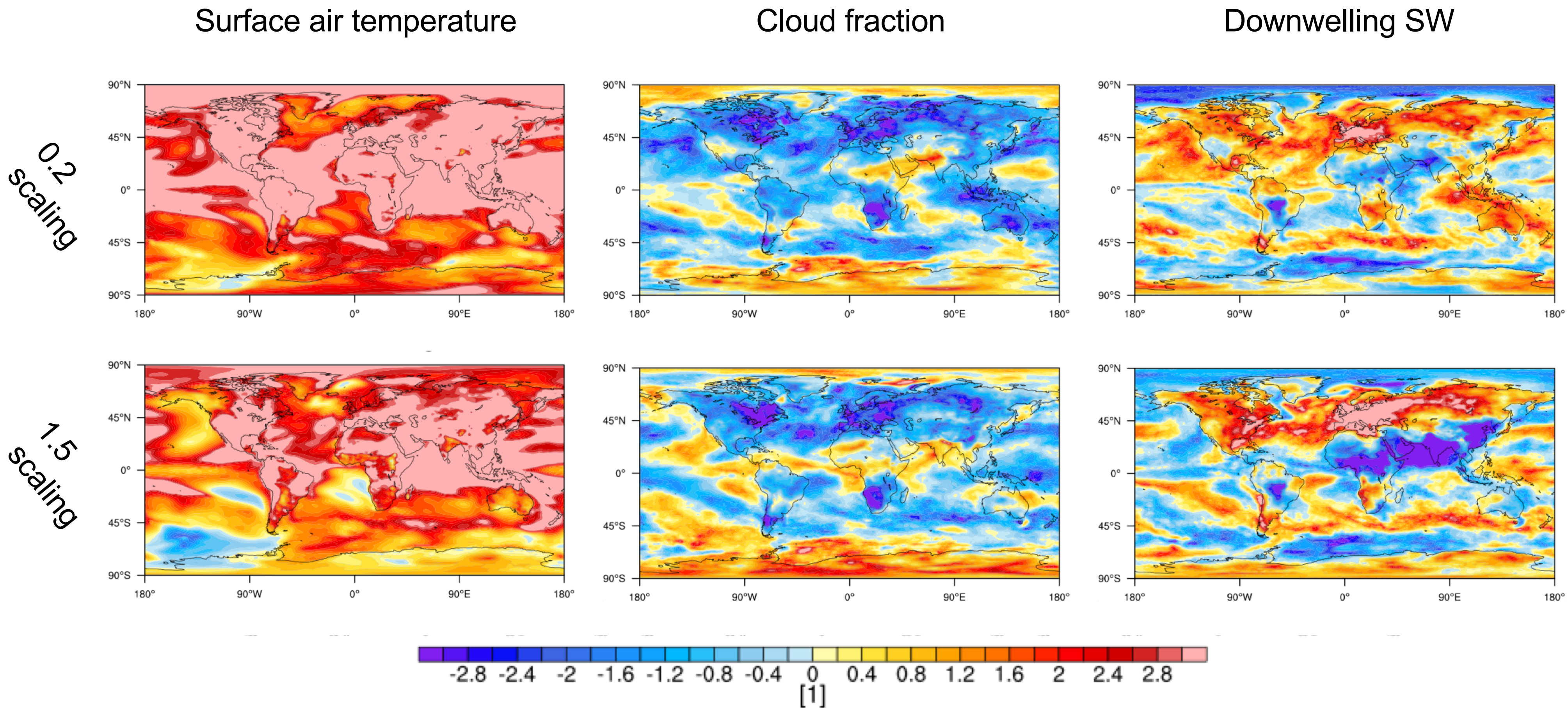
Comparison to observations 1981 - 2010



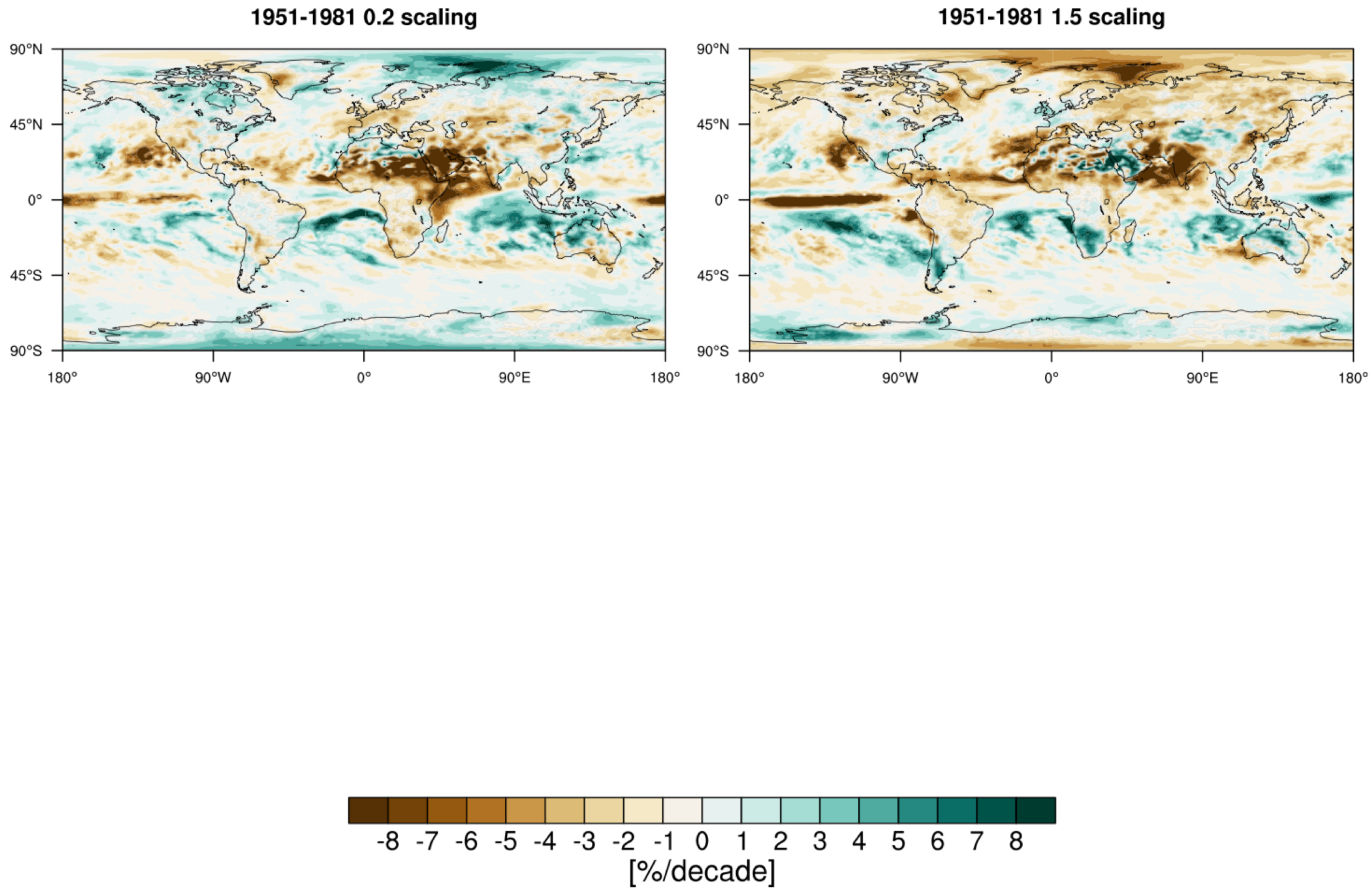
Signal-to-noise ratio 1951-1980



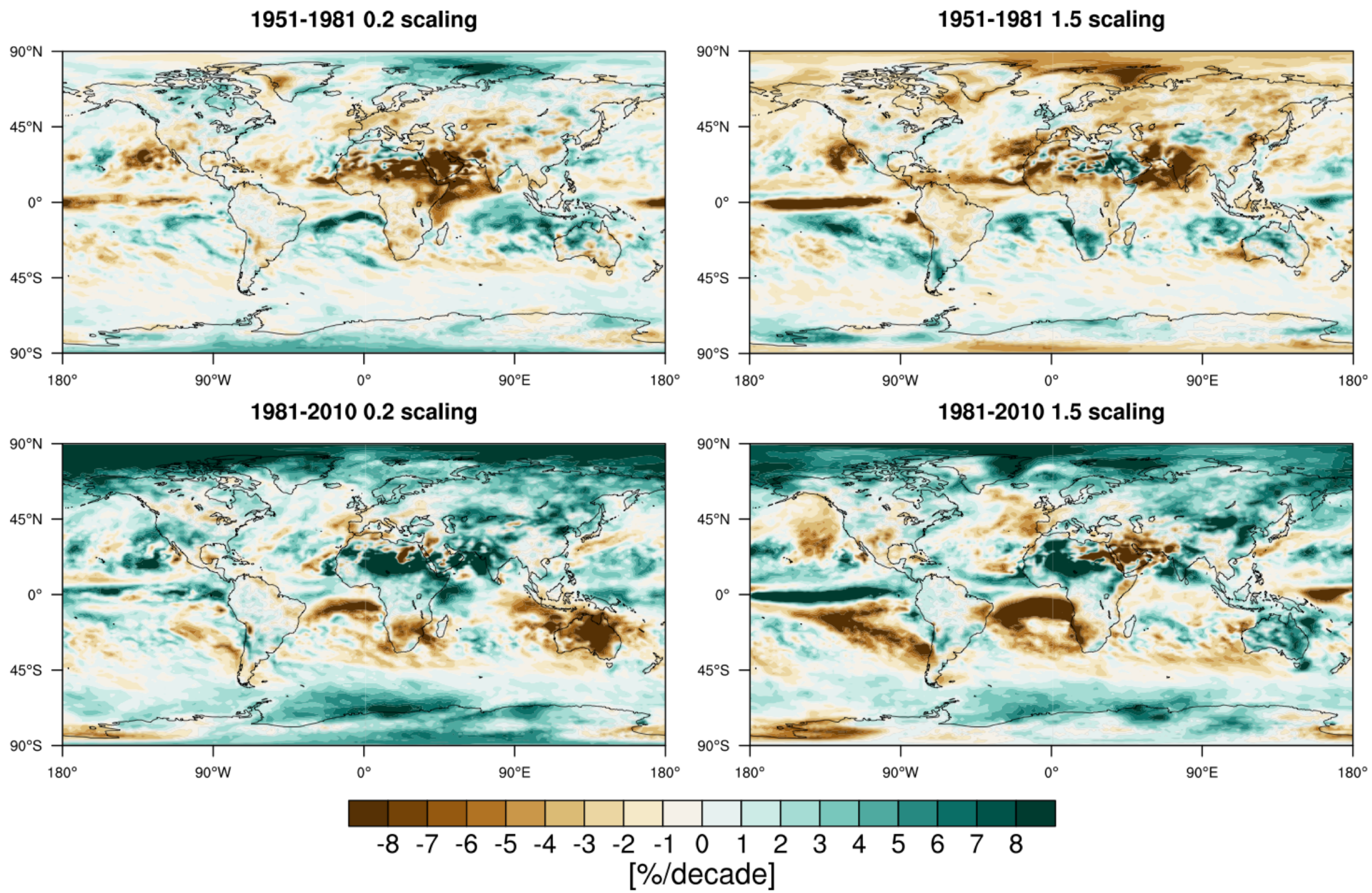
Signal-to-noise ratio 1981- 2010



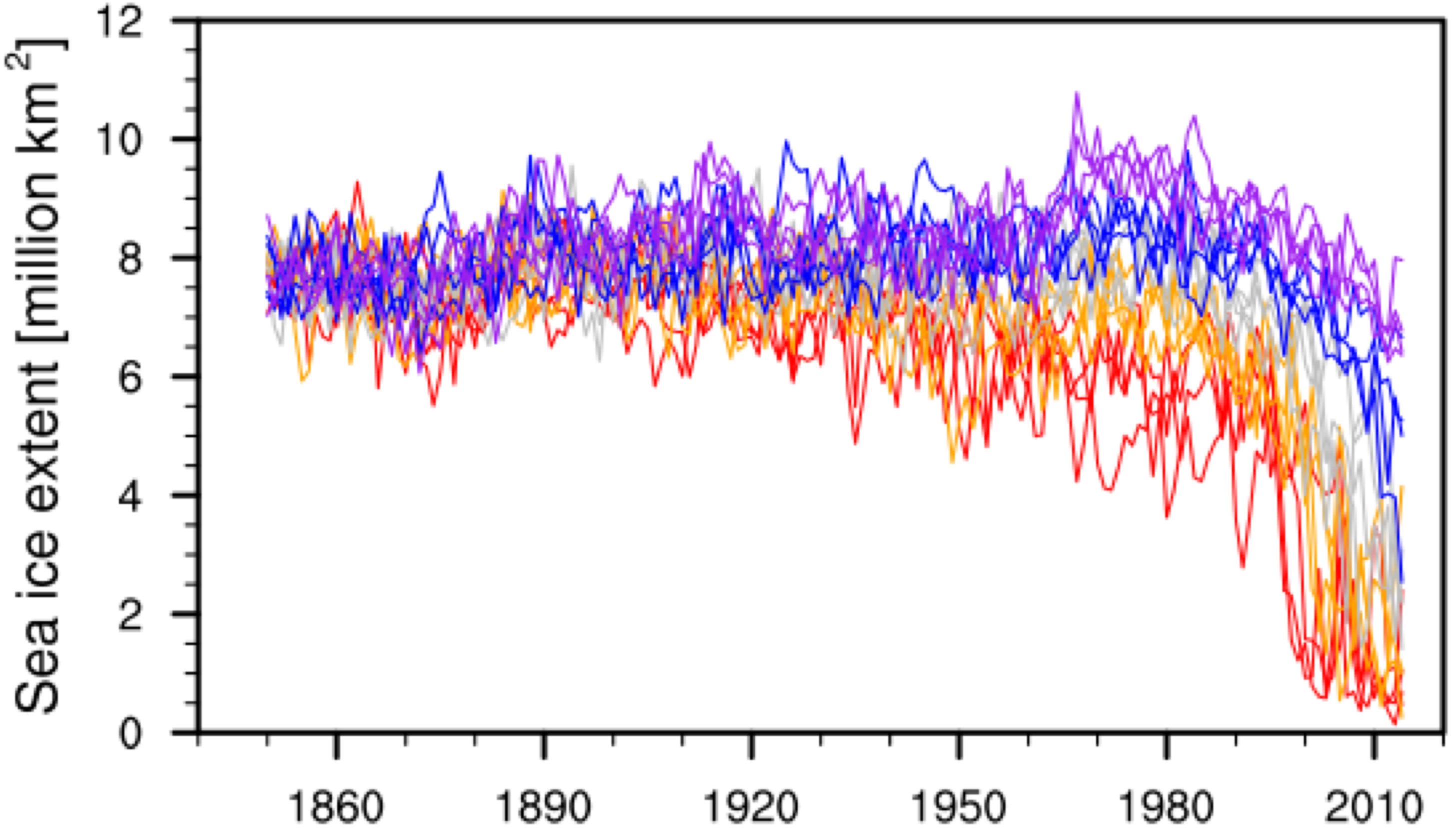
Spatial pattern of precipitation trends



Spatial pattern of precipitation trends



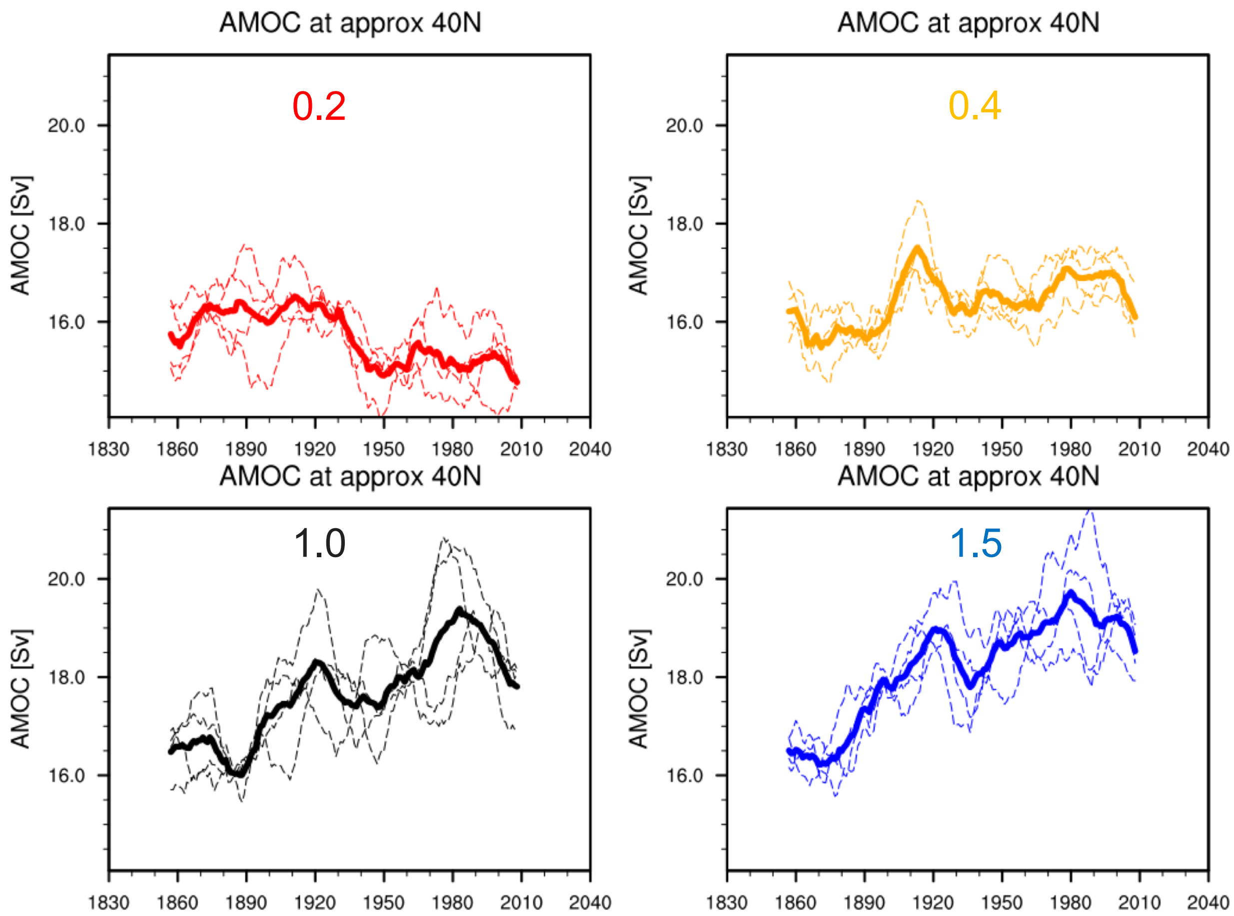
September Arctic sea-ice extent



Conclusions

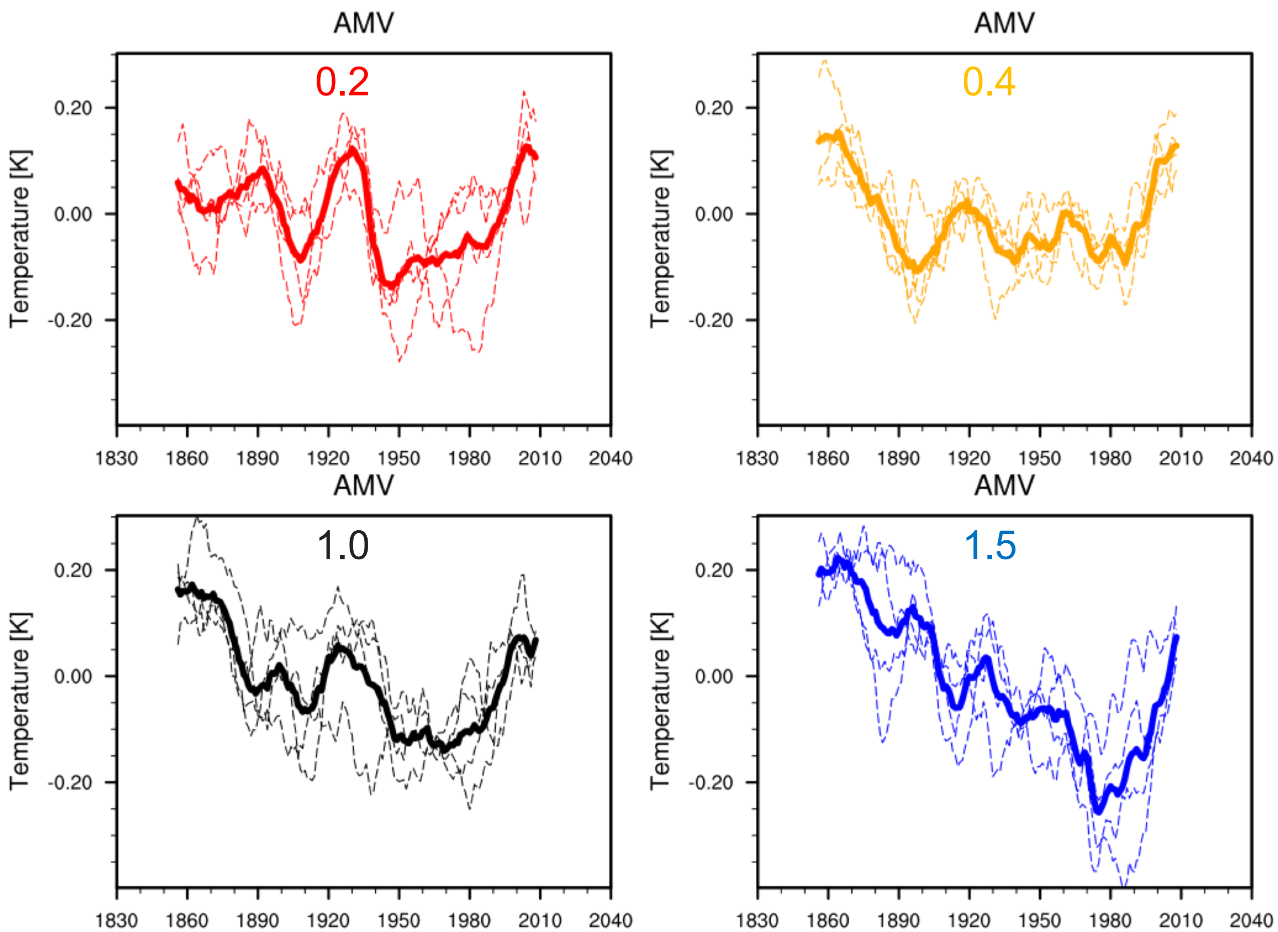
- The signal of climate change is clearly emerging at the local spatial scale and for shorter timescales, especially in regions with larger vulnerability.
- A novel large ensemble of simulations samples the uncertainty in historical aerosol emissions to examine the causes of past changes in climate. Data can be made available.
- Temperature trends from 1951-1980 highly sensitive to magnitude of aerosol forcing. 1981-2010 trends are more similar and primarily GHG driven, regardless of scaling.
- The observed patterns are best matched by 1.5 scaling ensemble for both time periods discussed, but pattern agreement low overall in 1951-1980s
- Analysis of signal-to-noise in trends highlights elements from both GHG and AA forcing over 1951-1980 period

Atlantic Meridional Overturning Circulation (AMOC)



- AMOC increases in high aerosol simulations
- AMOC decline in 1920s common to several sub-ensembles
- GHG driven AMOC decline since 1980

Atlantic Multi-decadal Variability index (AMV)



AMV: defined as Atlantic mean SSTs – global mean excluding Atlantic following Sutton and Dong, 2012 *Nature Geosci*