Journal Club

8 Dec 2020

machine learning in climate science

Environ. Res. Lett. **14** (2019) 123006 https://doi.org/10.1088/1748-9326/ab4557

Environmental Research Letters

TOPICAL REVIEW

Causes of climate change over the historical record

Gabriele C Hegerl[1,7], Stefan Brönnimann[2], Tim Cowan[3], Andrew R Friedman[1], Ed Hawkins[4], Carley Iles[5], Wolfgang Müller[6], Andrew Schurer[1] and Sabine Undorf[1]

1 School of Geosciences, University of Edinburgh, Edinburgh, United Kingdom
2 Oeschger Centre for Climate Change Research and Institute of Geography, University of Bern, Bern, Switzerland
3 University of Southern Queensland & Bureau of Meteorology, Melbourne, Australia
4 National Centre for Atmospheric Science, Department of Meteorology, University of Reading, Reading, United Kingdom
5 Laboratoire des Sciences du Climat et de l'Environnement, LSCE/IPSL, CEA-CNRS-UVSQ, Université Paris-Saclay, F-91198 Gif-sur-Yvette, France
6 Max-Planck Institute for Meteorology, Hamburg, Germany
7 Author to whom any correspondence should be addressed.

E-mail: gabi.hegerl@ed.ac.uk

Keywords: climate change, instrumental record, attribution, extreme events, precipitation

- **Review paper**

- **Climate change drivers**
  - Temperature (longer time horizon, ~ 1750 – present)
  - Precipitation (20th century alone)

- **Two main questions:**
  - “When did the response to greenhouse gases emerge on hemispheric and global scales?”
  - “What factors cause decadal and multidecadal deviations from the greenhouse warming trend?”

- **Review paper**

- **Climate change drivers**
  - Temperature (longer time horizon, ~ 1750 – present)
  - Precipitation (20th century alone)

relatively less focus on this

- **Two main questions:**
  - “When did the response to greenhouse gases emerge on hemispheric and global scales?”
  - “What factors cause decadal and multidecadal deviations from the greenhouse warming trend?”

improperly defined

- **Review paper**

- **Climate change drivers**
  - **Temperature (longer time horizon, ~ 1750 – present)**
  - Precipitation (20th century alone)

- **Two main questions:**
  - "When did the response to greenhouse gases emerge on hemispheric and global scales?"
  - **"What factors cause decadal and multidecadal deviations from the greenhouse warming trend?"**

$$\mathbf{y} = \mathbf{X}\mathbf{a} + \mathbf{u}$$

y: *n* x 1 vector

X: *n* x *m* matrix

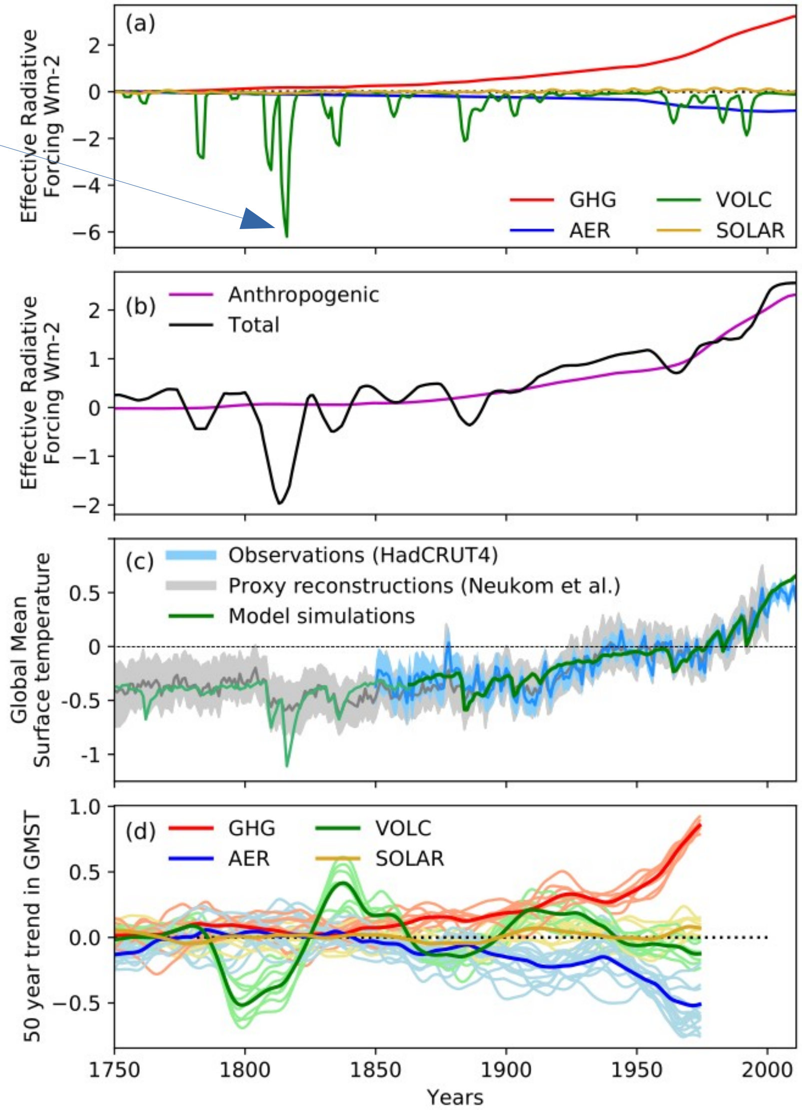
a: *m* x 1 vector

u: *n* x 1 vector

n: number of observations (length of time series)

m: number of ‘**fingerprints**,’ i.e., factors impacting **y**

Mt. Tambora eruption
(Sumbawa, Indonesia)



Year Without a Summer

From Wikipedia, the free encyclopedia

The year 1816 is known as the **Year Without a Summer** (also the **Poverty Year** and **Eighteen Hundred and Froze To Death**)[1] because of severe climate abnormalities that caused average global temperatures to decrease by 0.4–0.7 °C (0.7–1 °F).[2] Summer temperatures in Europe were the coldest on record between the years of 1766–2000.[3] This resulted in major food shortages across the Northern Hemisphere.[4]

Evidence suggests that the anomaly was predominantly a volcanic winter event caused by the massive 1815 eruption of Mount Tambora in April in the Dutch East Indies (known today as Indonesia). This eruption was the largest in at least 1,300 years (after the hypothesized eruption causing the extreme weather events of 535–536), and perhaps exacerbated by the 1814 eruption of Mayon in the Philippines.

Figure 1. External forcing compared to observed global temperature data. (a) Radiative forcing over the industrial period from IPCC AR5 (Myhre *et al* 2013) for individual forcings (smoothed by a 3 year running mean), and (b) decadally smoothed (11 year running mean, followed by a 7 year running mean; natural forcings centred on long-term average, 1750–2011) anthropogenic and combined forcing over the industrial period. (c) Observed (Morice *et al* 2012) and reconstructed global temperature anomalies ([K], Neukom *et al* 2019), as well as multi-model mean simulations which are generated by merging 23 last millennium simulations from 7 models: bcc-csm1-1(×1), CCSM4(×1), CESM1(×10), CSIRO-Mk3l(×3), GISS-E2-R(×3), HadCM3(×4), MPI-ESM-P(×1) with 109 CMIP5 historical simulations from 41 models (see methods), anomalies calculated from a 1961–1990 climatology. (d) Running 50 year trends (trend calculated from timeseries smoothed by a 5 then 3 year running average, plotted against central time point, [K/50 yrs]) that illustrate trends caused by individual forcings in two models (HadCM3 and CESM1) (thicker lines: multi-model mean, thinner lines: individual simulations).

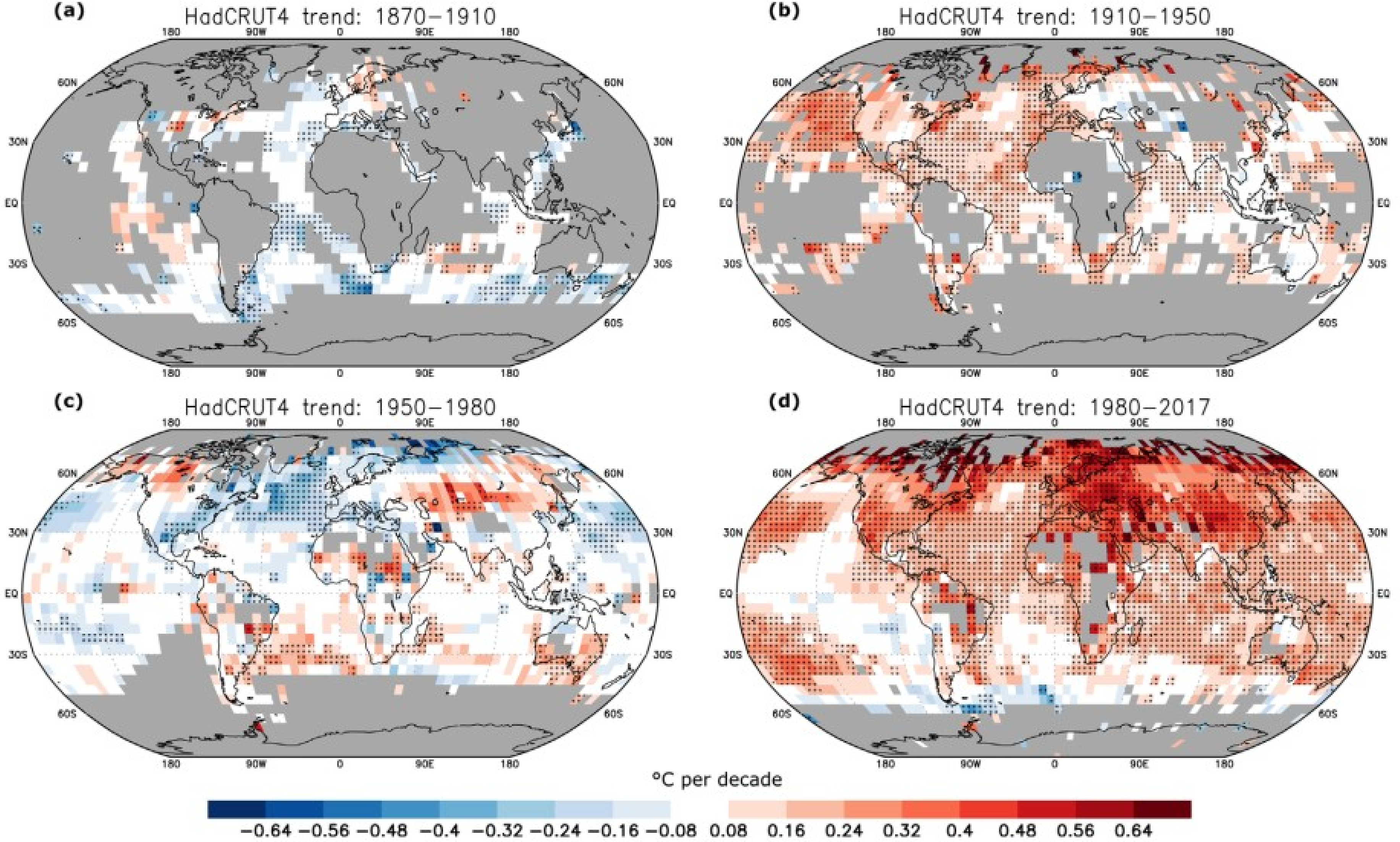

(a)
HadCRUT4 trend: 1870–1910
(b)
HadCRUT4 trend: 1910–1950
(c)
HadCRUT4 trend: 1950–1980
(d)
HadCRUT4 trend: 1980–2017
180
90W
0
90E
60N
30N
EQ
30S
60S
°C per decade
−0.64 −0.56 −0.48 −0.4 −0.32 −0.24 −0.16 −0.08 0.08 0.16 0.24 0.32 0.4 0.48 0.56 0.64

Figure 2. Long-term multi-year trends over the instrumental period [°C per decade]. HadCRUT4 (Morice *et al* 2012) 3 year running mean annual mean (November–October) trends over: (a) 1870–1910, (b) 1910–1950, (c) 1950–1980, and (d) 1980–2017. The 3 year annual means are constructed from averaging November–April and May–October anomalies, each smoothed with a 3 year running mean. Grey areas indicate regions where each overlapping 3 year segment does not contain at least one datapoint from both November–April and May–October. The slopes are stippled where significant at $p < 0.05$ using a 2-tailed t-test, adjusted for autocorrelation induced by the 3 year running mean by increasing the regression standard error by a factor of $\sqrt{3}$, and by using 1 degree of freedom for every 3 years of length.

What caused these spatially diverse long-term trends?

“*Detection and Attribution*” analyses

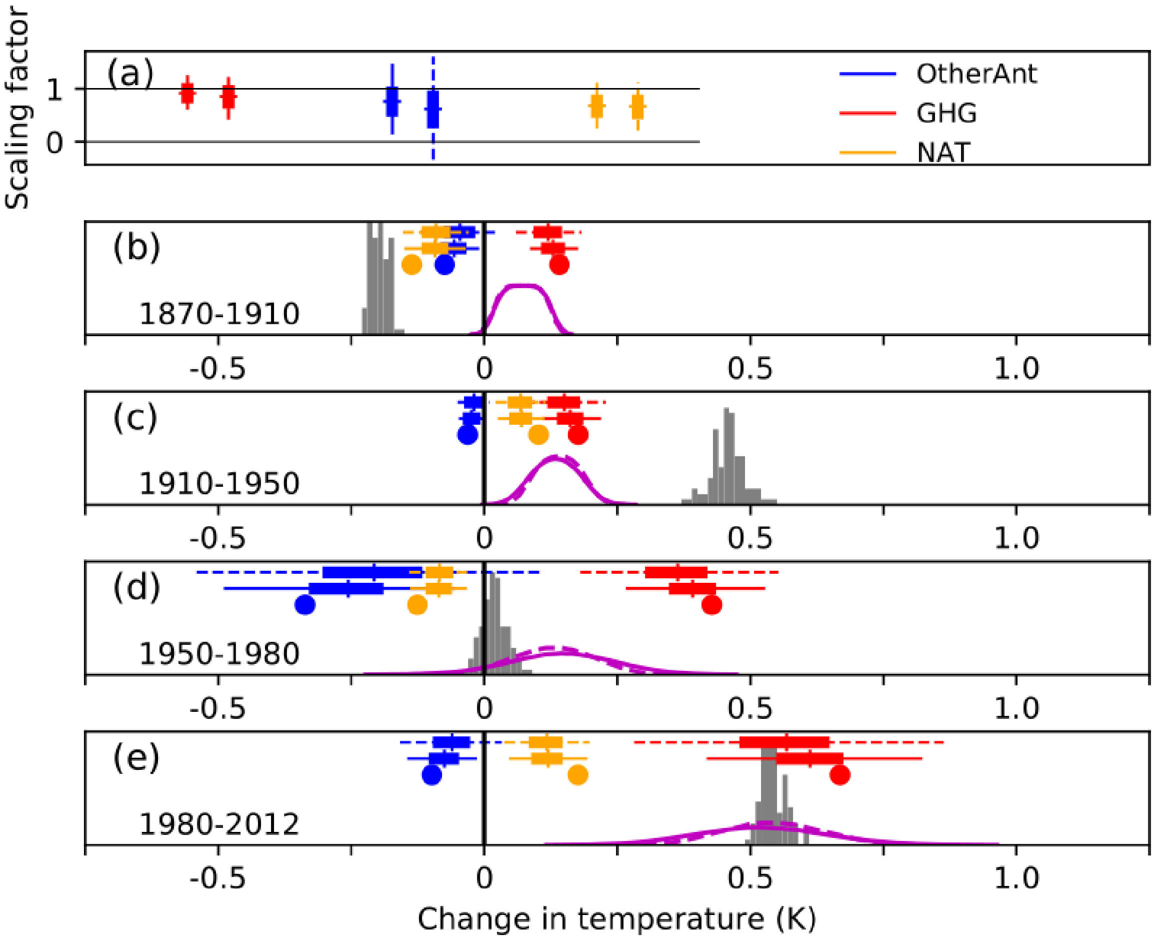
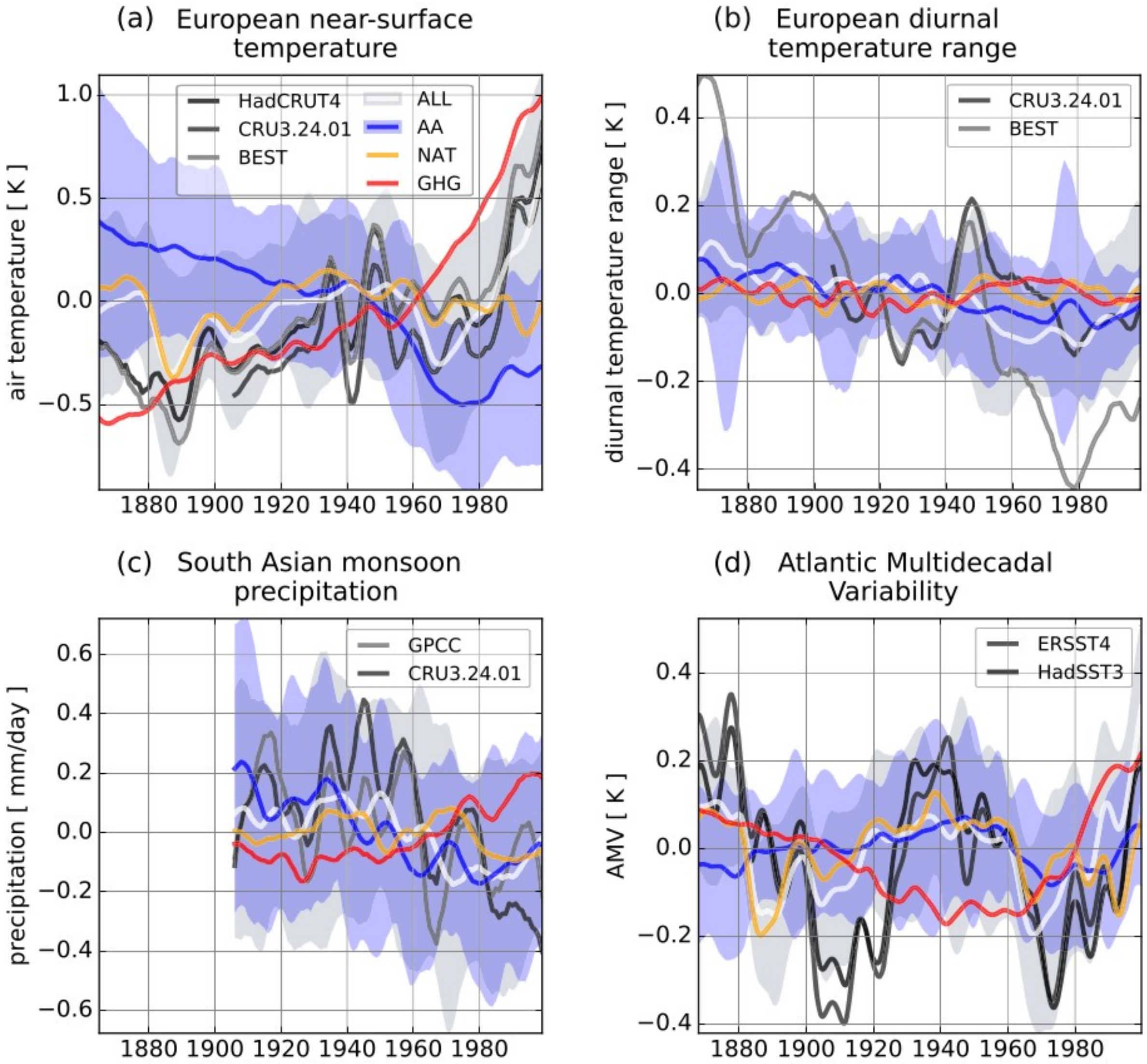

Scaling factor
(a)
1
0
OtherAnt
GHG
NAT
(b)
1870-1910
(c)
1910-1950
(d)
1950-1980
(e)
1980-2012
-0.5
0
0.5
1.0
Change in temperature (K)

Figure 3. Estimated contribution by forcing to observed changes across the instrumental record. This is based on HadCRUT4 surface temperature data with histograms reflecting uncertainty (Morice *et al* 2012). (a) Estimated magnitude of the response to forcing by greenhouse gases (GHG, red), other anthropogenic forcing (OtherAnt, blue) and natural forcing (solar and volcanic, NAT, yellow). Results are based on a Bayesian approach over the full period (1863–2012) using the multimodel mean response (Schurer *et al* 2018); using global mean and hemispheric difference as spatial components, and decadally averaged timeseries. Values in the bottom four panels are calculated by scaling the linear trend by the best fit of the model fingerprint to observations over the entire record. The purple line is the combined anthropogenic contribution to the change in that period, the grey histogram is the range of observational values. The thick line indicates the 33–66th percentile, the thin line 5%–95% of the uncertainty, and the continuous line is an estimate using prior information that favours scaling near one and avoids unphysical negative scaling, while the dashed line shows results for a flat prior between −1 and 3. Circles in each of the bottom panels indicate the multi-model mean estimate of the forced contribution without scaling. Note that the prior information makes little difference to the estimate of the total anthropogenic contribution, but does affect the estimate of individual forcings.



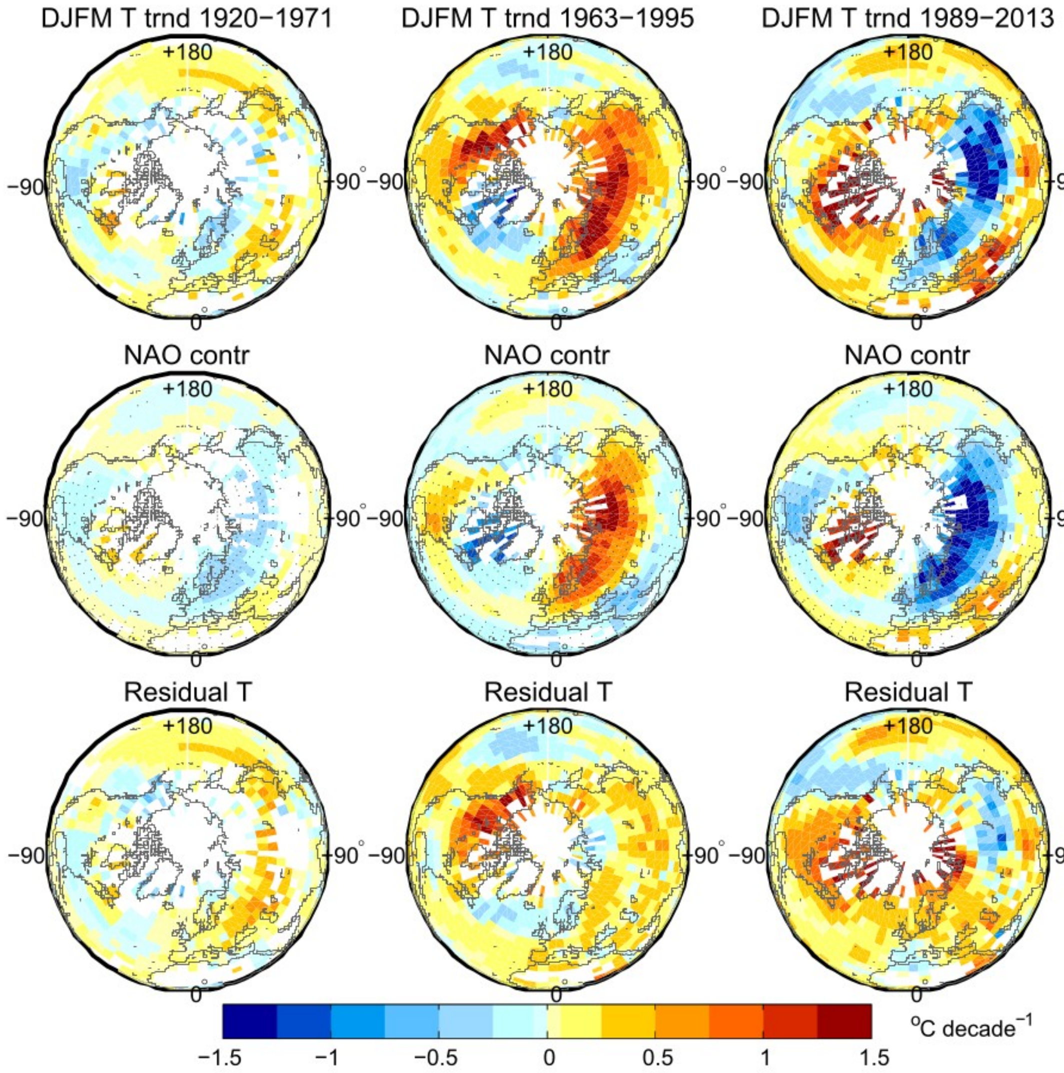
(a) European near-surface temperature
air temperature [K]
HadCRUT4
CRU3.24.01
BEST
ALL
AA
NAT
GHG
1.0
0.5
0.0
−0.5
1880 1900 1920 1940 1960 1980
(b) European diurnal temperature range
diurnal temperature range [K]
CRU3.24.01
BEST
0.4
0.2
0.0
−0.2
−0.4
1880 1900 1920 1940 1960 1980
(c) South Asian monsoon precipitation
precipitation [mm/day]
GPCC
CRU3.24.01
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
1880 1900 1920 1940 1960 1980
(d) Atlantic Multidecadal Variability
AMV [K]
ERSST4
HadSST3
0.4
0.2
0.0
−0.2
−0.4
1880 1900 1920 1940 1960 1980

Figure 4. Aerosol influences on European climate, South Asian monsoon and Atlantic Multidecadal Variability. Anomalies of (a) annual-mean near-surface temperature and diurnal temperature range, (b) over Europe (35°–65°N, 15°W-30°E, land only, area-weighted) similar to Undorf *et al* (2018b), (c) summer (JJAS)-mean monsoon precipitation over South Asia (area definition as in Undorf *et al* 2018c), and (d) the annual Atlantic Multidecadal Variability (AMV) index for (black, grays) observations and simulations with (red) greenhouse gas (GHG) forcing, (blue) anthropogenic aerosol (AA), and (yellow) natural (NAT) forcing only, and (white) all forcings together (ALL). Shown are the ensemble means (lines) and the 1.66σ range (shading) of each multi-model ensemble, smoothed by applying (a)–(c) 7-and 5-point and (d) 11-and 7-point filters consecutively. The shadings for GHG and NAT are omitted for clarity. (d) Sea surface temperatures (SSTs) are not available for all models, so surface temperatures over sea areas are used instead and compared with SST observations. The AMV is derived as in Undorf *et al* (2018a). The models and the respective number of ensemble members used are CanESM2 [×5], CESM1-CAM5 [×1], CSIRO-Mk-3-6-0 [×5], GFDL-CM3 [×3], GISS-E2-R [×5], HadGEM2-ES [×4] (only in (a) and (c)), IPSL-CM5A-LR [×1], and NorESM1-M [×1].

Role of (internal) climate forces in effecting global temperature change

- the atmosphere: NAO

- the ocean: heat flux



DJFM T trnd 1920−1971
DJFM T trnd 1963−1995
DJFM T trnd 1989−2013
NAO contr
NAO contr
NAO contr
Residual T
Residual T
Residual T
+180
−90
+90°
0
−1.5
−1
−0.5
0
0.5
1
1.5
°C decade^{-1}

Figure 6. Influence of North Atlantic Oscillation (NAO) variability on Northern Hemisphere winter temperature trends. Reproduced from Iles and Hegerl (2017) © The Author(s). Published by IOP Publishing Ltd. CC BY 3.0. Top row shows raw observed trend patterns [°C/decade], middle row estimated contribution by the NAO from interannual regression analysis (stippling indicates grid cells with a significant ($p < 0.05$) interannual relationship between the NAO and temperature), bottom row: trend pattern after linearly removing the contribution by the NAO; note that the residual results for the three periods are far more similar to each other and to the expected pattern in response to anthropogenic forcing than they were initially. Note that oceanic responses to trends in the NAO may enhance the long-term response over the North Atlantic and Arctic ocean basins.

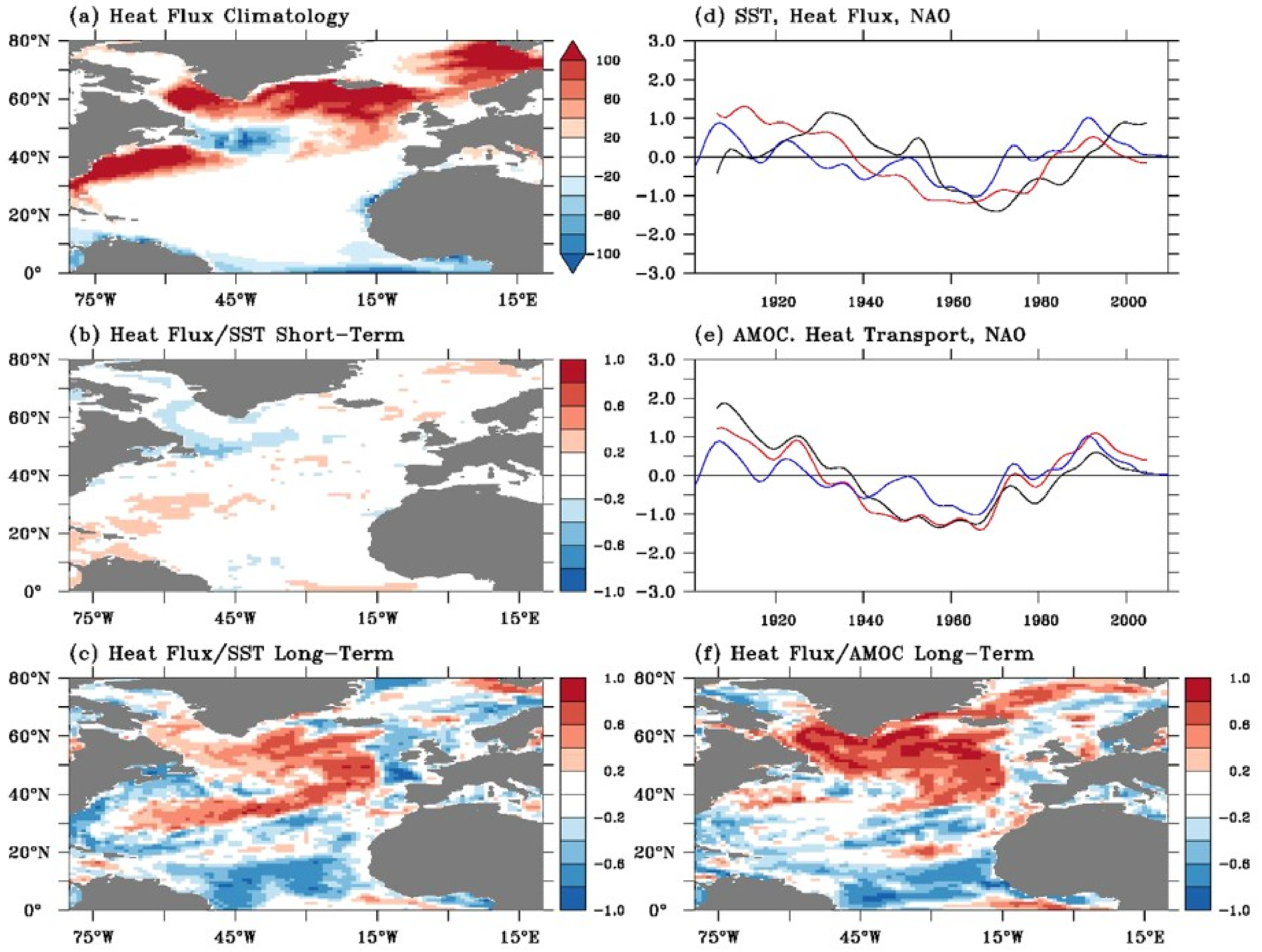

(a) Heat Flux Climatology
(b) Heat Flux/SST Short-Term
(c) Heat Flux/SST Long-Term
(d) SST, Heat Flux, NAO
(e) AMOC. Heat Transport, NAO
(f) Heat Flux/AMOC Long-Term
80°N
60°N
40°N
20°N
0°
75°W
45°W
15°W
15°E
100
60
20
−20
−60
−100
1.0
0.6
0.2
−0.2
−0.6
−1.0
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
1920
1940
1960
1980
2000

Figure 7. Relationship between the North Atlantic Oscillation and multidecadal ocean variations over 1901–2015. Multi-decadal variations in North Atlantic climate illustrated by the Max-Planck Institute ocean model (MPIOM) (Jungclaus *et al* 2013) forced with century-long reanalysis ERA20C (Poli *et al* 2016) (see text; figure adapted after Müller *et al* 2015). Shown are (a) yearly mean surface heat flux climatology (sensible + latent, W m^{-2}), and correlation of averaged yearly mean SST (80°W–0°, 35°–50°N) with surface heat flux for (b) short-term variations (1–10 year; high-pass filtered) and (c) long-term variations (>10 years; low-pass filtered). Positive values indicate heat release into atmosphere. (d) Standardized time series of 10-yearly mean SST (black, 80°W–0°, 35°—50° N), surface heat flux (red, 80°W–0°, 40°–60°N), and winter (JFM) NAO index based on Hurrell station index (blue). SST and surface heat fluxes are taken from the MPIOM. (e) 10 year running mean of AMOC (black, 26°N and 1000 m depth), integrated northern heat transport (red, 26°N) and the JFM NAO index (blue). All time series are standardized. (f) Correlations of yearly mean AMOC 26°N with surface heat flux for long-term variations (>10 years).

Take Home Messages

(official)

- Greenhouse gases play an important role in global temperature change
  - But also aerosols and natural variability
- Our knowledge about impact of aerosols has high uncertainty
- Natural modes of variability like the NAO play an important role
- Extent of natural variability induced by solar forcing is unknown

Take Home Messages

(personal)

- Spatial heterogneity in temperature change is due to reional differences in ‘absorbing’ the forcings
- Aerosols (volcanic and man made) can offset GHG impacts in a complicated way
- Atlantic bias?
  - What is the role of the ENSO?
- Northern Hemisphere bias?
  - What is the role of the Southern Ocean?