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Disentangling Regional Climate Change

Assessing the contribution of global– and regional–scale anthropogenic drivers to the observed warming

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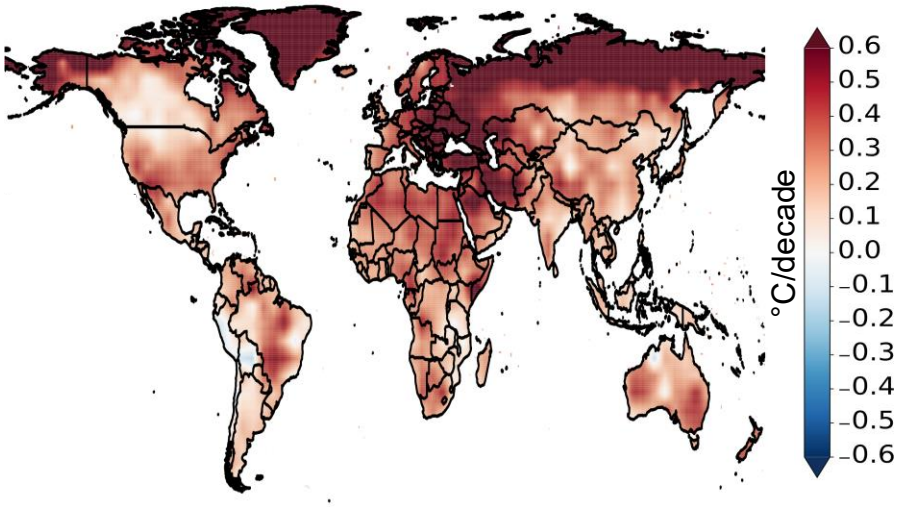
Observed annual temperature trend (HadCRUT4; 1991-2020)



Disentangling regional observed trends

The Earth's climate system evolves over time as a result of two distinct mechanisms:

1) Chaotic/stochastic interactions within the climate system, natural modes of variability PDO, ENSO,…

2) Imbalances in the planet's energy budget due to external factors:

a) Global-scale anthropogenic drivers:
Well-mixed GHG emissions (CO_2,CH_4,..)

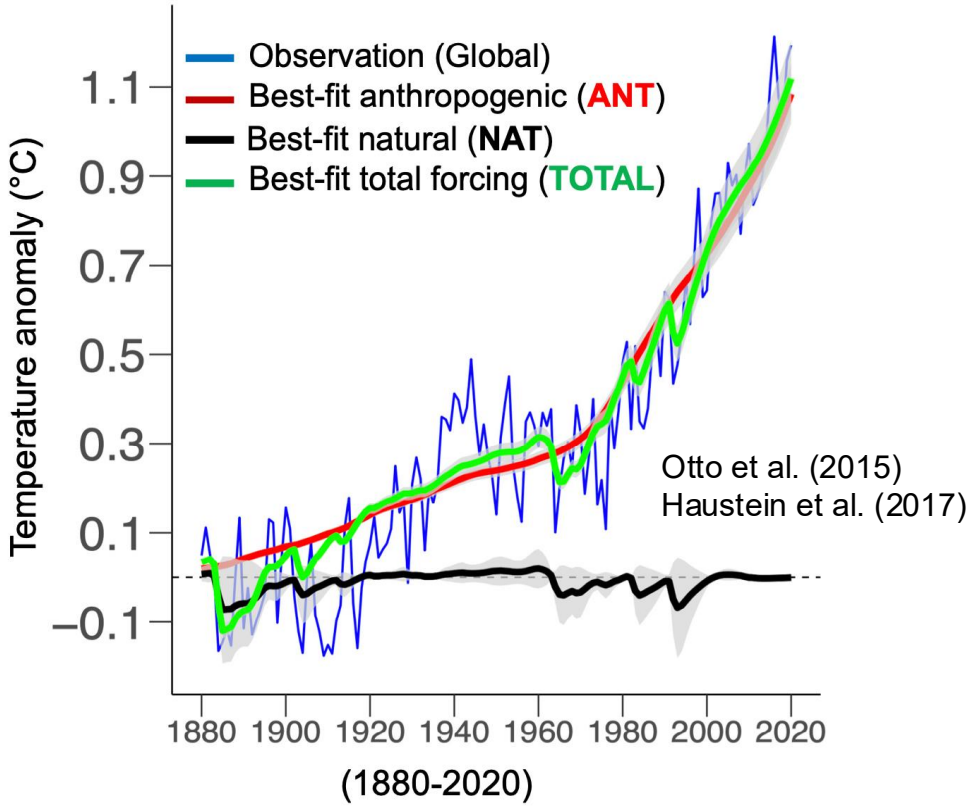
b) Regional-scale anthropogenic drivers:
Industrial aerosols, black carbon aerosols
Land-use/land-cover changes (urbanization, and deforestation)

c) Natural external forcing
Solar forcing, Volcanos

Science Questions:

- To what extent can global-scale anthropogenic drivers, particularly CO_2 emissions, account for regional warming?
- How do regional-scale anthropogenic drivers **quantitatively** contribute to the observed regional warming?

Real-time Global Warming Index



The GWI is based on a least squares method that establishes a correspondence between the observed global average temperatures and the expected responses to global radiative forcing, derived from a two-component impulse response model from global radiative forcing series.

Univariate detection

Internal-variability uncertainty
Pre-industrial 7,000-year control runs derived from CMIP6 GCMs)

Global Warming Index

$$Y_{obs} = \sum_{x=1}^{m} (GWI_x) * \beta_x + u_{obs}$$

2m temperature (HadCRUT4)

Unknown scaling factor

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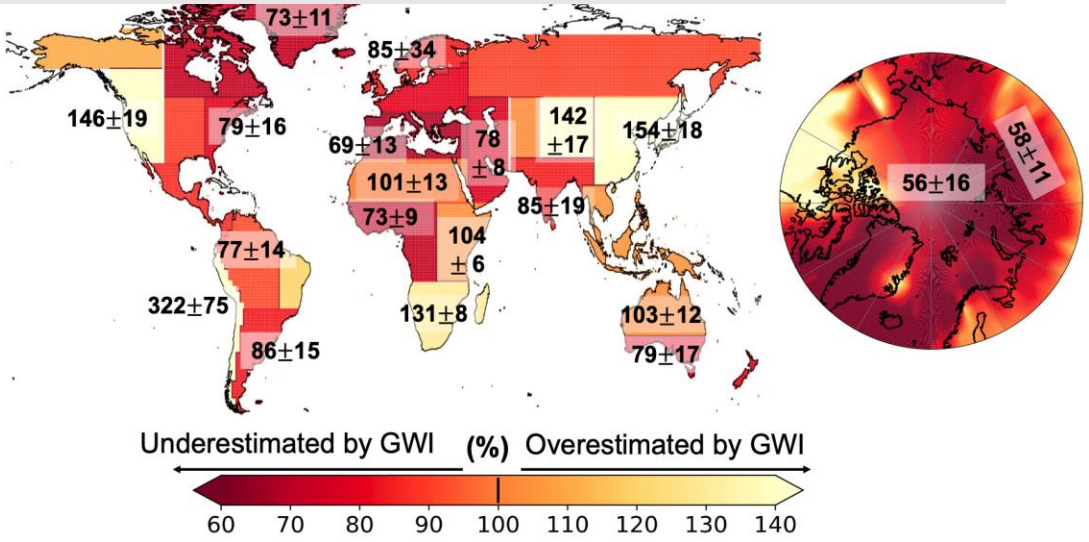
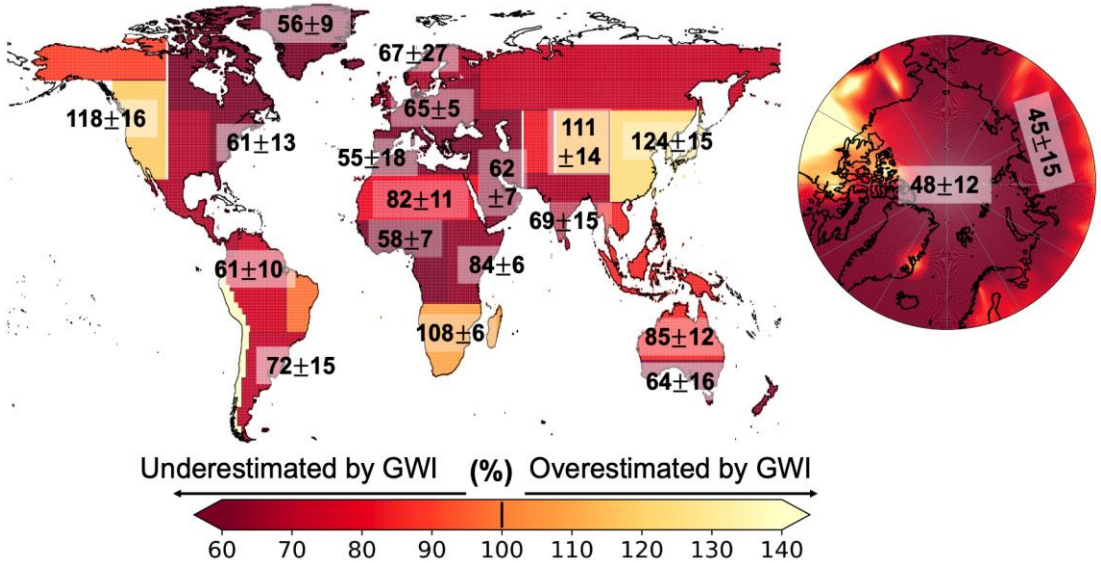
Contribution of **TOTAL (ANT + NAT)** external forcing to the observed temperature trend (1991-2020)



Contribution of **global-scale anthropogenic** drivers to the observed temperature trend (1991-2020)



- ✓ In the Russian Arctic, 58% ± 11% of the 3 °C warming observed from 1991 to 2020 is attributable to external forcing, with CO_2 alone accounting for 45% ± 10%.
- ✓ In Central Europe, 80% ± 4% of the 1.7 °C warming is driven by TOTAL external forcing, with global anthropogenic drivers accounting for 65% ± 5% of the warming.
- ✓ A contribution from TOTAL external drivers of less than 100% is also noted in West Africa (73% ± 9%), West Asia (78% ± 8%), and the Mediterranean (69% ± 13%), pointing to **local warming influences** not captured by global-scale drivers.
- ✓ In regions like East Asia, Western North America, the GWI overestimates observed warming trends. In East Asia, external forcing accounts for 154% ± 18% of the observed 0.6 °C warming, with 124% ± 15% from global anthropogenic drivers, pointing to **local cooling influences** not captured by global-scale drivers.

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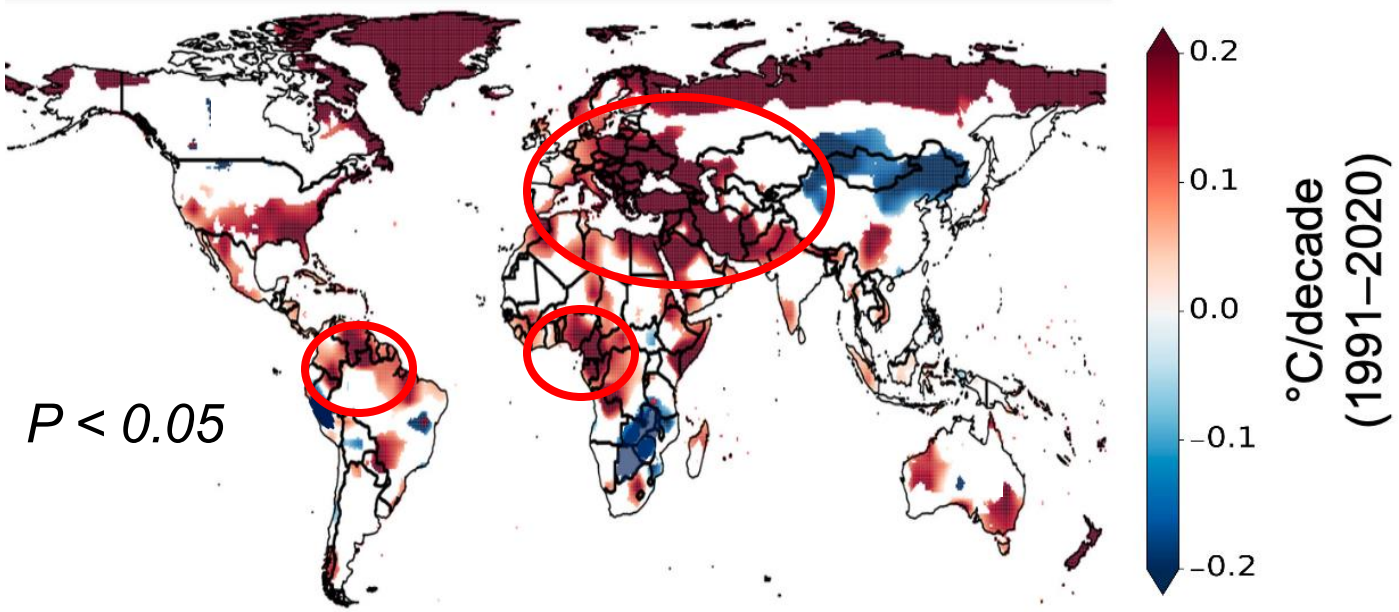
Is this attribution complete?

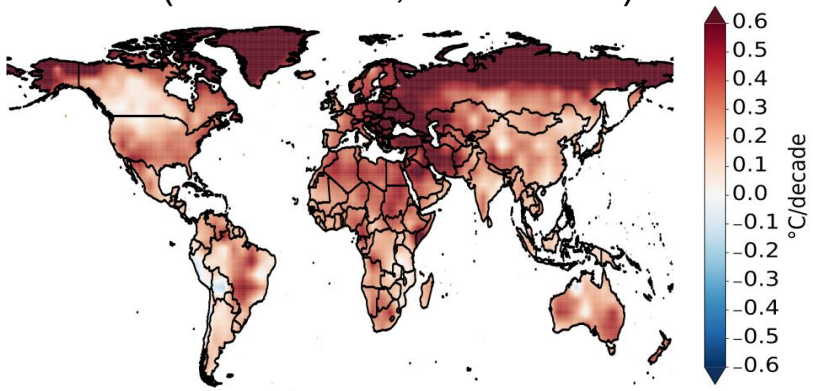
Residuals (unexplained changes)

Detectable forced changes in observed record
post TOTAL (anthropogenic + natural) forcing removal



Regions were systematically forced changes in observed record are still detectable after removing the portion of change attributable to the TOTAL external drivers.

Observed annual temperature trend
(HadCRUT4; 1991-2020)



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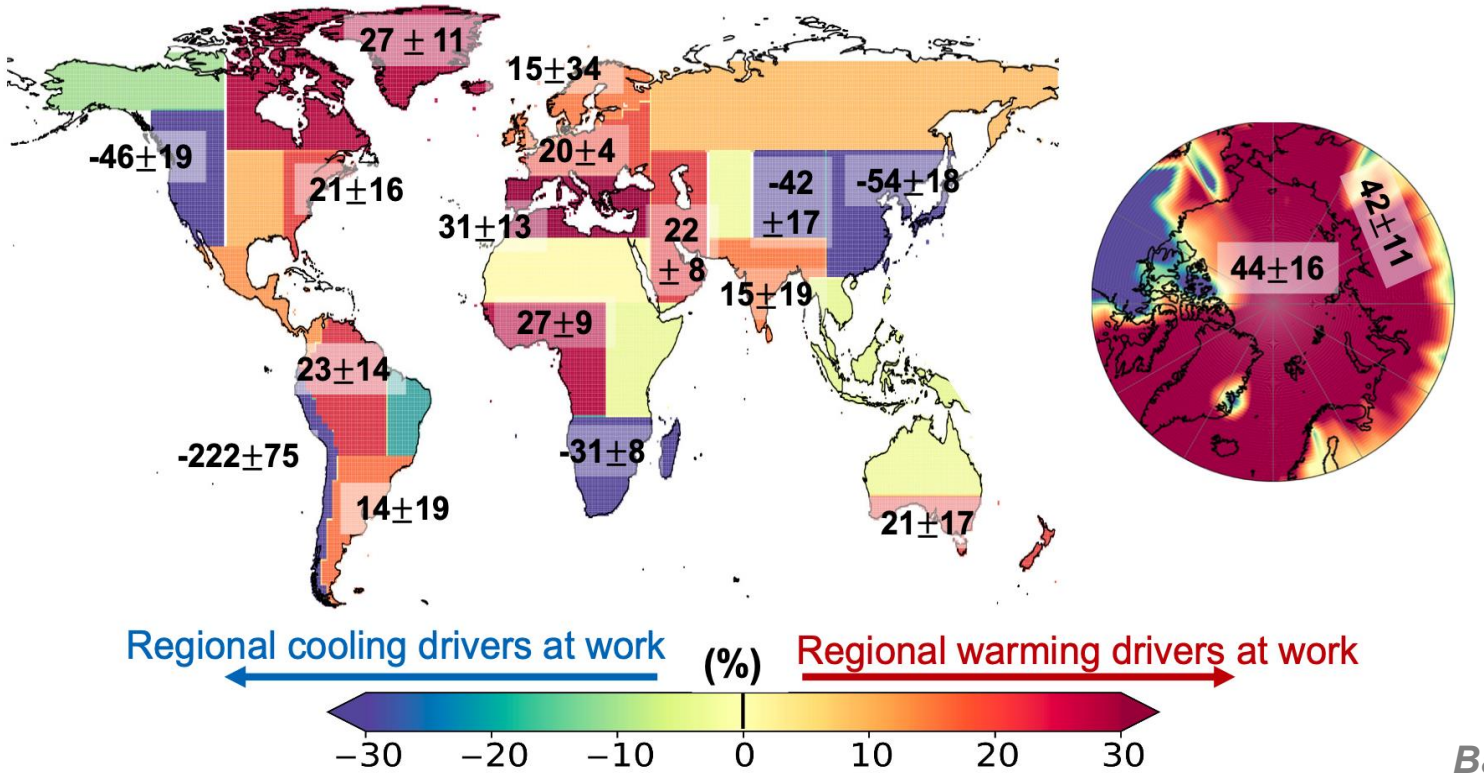
Contribution of regional anthropogenic drivers to the observed regional temperature change (1991-2020)



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- Regional mechanisms significantly amplify warming in key areas:
  - **Russian Arctic**: 42% ± 11% regional contribution amplifying 3 °C warming.
  - **Mediterranean**: 31% ± 13% warming from regional drivers (e.g., land use, aerosols).
  - **Congo and Amazon basins:** 27 ± 9% and 23 ± 14% of the observed warming is from regional drivers further amplifying the warming attributed to global climate change.
  - **East Asia and Tibetan Plateau**: Cooling drivers dominate, especially -42% ± 17% in the Tibetan Plateau.

Conclusion – Breaking down the contributions of climate drivers into global and regional-scale components.

- Global CO_2 forcing explains much, but not all:
  Many regions show substantial residual warming or cooling after accounting for global uniformly-distributed well-mixed GHG forcing.

- Regional mechanisms significantly amplify warming in key areas:
  - **Russian Arctic:** 42% ± 11% regional contribution amplifying 3 °C warming.
  - **Mediterranean:** 31% ± 13% warming from regional drivers (e.g., land use, aerosols).
  - **West Africa & West Asia:** Over 20% of warming is driven by local factors.
  - **Eastern N. America:** 21% ± 16% warming from regional drivers
  - **Congo and Amazon basins:** 27 ± 9% and 23 ± 14% of the observed warming is from regional drivers further amplifying the warming attributed to global climate change.

- Regional cooling drivers are at work in some regions:
  - **East Asia and Tibetan Plateau**: Cooling drivers dominate, especially -42% ± 17% in the Tibetan Plateau.

- This approach reveals how global and regional drivers shape local warming—enabling more effective, localized mitigation strategies that complement global efforts to address climate change.

Published!

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