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Matters arising

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# Autumn cooling paused increased $CO_2$ release in central Eurasia

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Check for updates

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ARISING FROM: R. Tang et al. *Nature Climate Change* https://doi.org/10.1038/s41558-022-01304-w (2022).

In a recent publication in *Nature Climate Change*, Tang et al.[1] reported an increase in net $CO_2$ release under northern autumn cooling from 2004 to 2018, indicating that both autumn warming and cooling result in net $CO_2$ release. Here we show that the conclusion regarding net $CO_2$ release under autumn cooling was impacted by the choice of the autumn period, which resulted in overlooking the appropriate cooling regions. Our analysis of individual months in autumn with empirical upscaling of eddy flux observations (FLUXCOM[2], the same data used by Tang et al.[1]) and atmospheric $CO_2$ measurements from seven towers[3] suggested that the increased net $CO_2$ release paused during the 2004–2018 autumn cooling in central Eurasia.

With 'autumn' defined as a period from September to November, Tang et al.[1] concluded that the widespread autumn cooling for 2004–2018 induced an increasing trend in the net $CO_2$ release. However, this definition of autumn is not ideal for assessing the effect of autumn cooling on $CO_2$ fluxes because three-month averages obscure whether the cooling occurred in months with temperatures above 0 °C. As $CO_2$ fluxes, particularly gross primary production (GPP), become extremely small below 0 °C, it is possible that the autumn cooling barely affected fluxes in regions where cooling occurred in months when temperatures were already below 0 °C. To evaluate this aspect, we used Climate Research Union (CRU) TS4.05 (ref. [4]) data to classify the land north of 25° N into four regions by months when temperatures fall below 0 °C (Fig. 1a): regions with monthly mean temperature (MMT) of all three months below 0 °C (Reg1), regions with MMT of October and November below 0 °C (Reg2), regions with MMT of November below 0 °C (Reg3) and regions with MMT of all three months above 0 °C (Reg4).

As Tang et al.[1] reported, CRU TS4.05 data indicate that the cooling trend for September–October–November (SON) is widespread north of 25° N, and the cooling areas largely overlap with Reg2 and Reg3 of both North America and Eurasia (Fig. 1b). However, for September–October (SO), the spatial extent of the cooling trend reduced northward in North America; consequently, the cooling areas remained in Reg2 and barely overlapped with Reg3 (Fig. 1b). Having these results, caution should be applied while considering whether North America is an appropriate region for evaluating the relationship between autumn cooling and $CO_2$ fluxes. Variations in $CO_2$ fluxes may be small in the cooling area overlapping with Reg2 as only sparse vegetation inhabits that area (Supplementary Fig. 1). Similarly, the cooling area in Reg3 is unlikely to cause a large variation in $CO_2$ fluxes because the cooling in this region occurs in November when MMT is below 0 °C (Fig. 1b). Regional mean temperatures (Fig. 1c–h) indicated that contrary to that of SON (Fig. 1d), SO temperature for Reg3 of North America increased during 2004–2018 (Fig. 1g), suggesting that the apparent cooling trend created by averaging the data for the three months concealed the warming trend.

Contrary to that in North America, the widespread cooling trend in Eurasia remained the same for SON and SO, overlapping the most in Reg3 (Fig. 1b). Regional mean SON and SO temperatures indicated that among all the regions north of 25° N, Reg2–3 of Eurasia largely reflected a transition from autumn warming to cooling around 2004 (Fig. 1c,d,f,g). As the Eurasian cooling area largely overlaps with the distribution of boreal forests, this region probably impacted $CO_2$ fluxes (Supplementary Fig. 1).

Assessment of the contrasting effects of the autumn cooling and warming on $CO_2$ fluxes indicates that monthly GPP and terrestrial ecosystem respiration (TER) from FLUXCOM tended to show positive trends for 2004–2018 in Reg2–3 of North America but a negative trend in Reg2–3 of Eurasia (Fig. 1i,j). This result was consistent with our expectation that, for North America, the warming effect on $CO_2$ fluxes is more profound than the cooling effect and vice versa for Eurasia; thus, trends in $CO_2$ fluxes should be opposite between these regions. In Reg4 of North America and Eurasia, where the autumn warming is profound (Fig. 1e,h), trends in monthly TER were positive whereas those in GPP varied monthly (Fig. 1k). In all the regions, trends in monthly TER tended to be greater than those in monthly GPP, indicating that autumn temperatures influence TER more than GPP (Fig. 1i–k). This result is opposite to the conclusion of Tang et al.[1] that the autumn cooling induced a greater decrease in GPP than in TER.

Considering GPP and TER trends, it is not the best approach to group the lands north of 25° N (that is, Reg1–4) to assess the effect of

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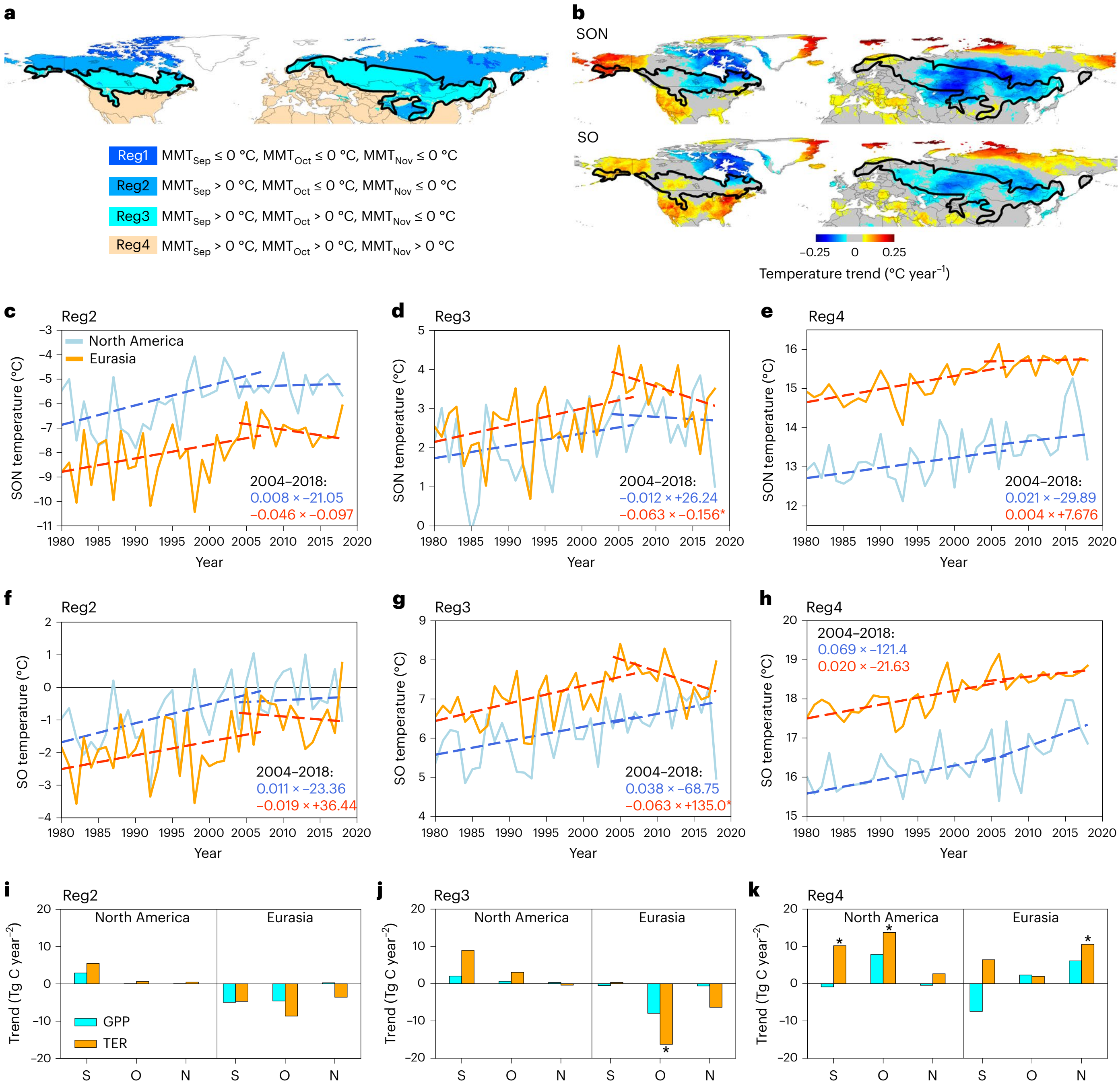


**Fig. 1 | Regional patterns of 2004–2018 autumn cooling and associated GPP and TER trends for the land north of 25° N. a**, Spatial patterns of four regions (Reg1–4) classified by MMT for 2004–2018 based on CRU TS4.05. **b**, Spatial patterns of trends in SON and SO temperatures during 2004–2018. Thick black lines in **a**,**b** represent a border of Reg3. **c**–**h**, Interannual variability in regional mean SON temperatures for Reg2 (**c**), Reg3 (**d**) and Reg4 (**e**) of North America and Eurasia, and in regional mean SO temperatures for Reg2 (**f**), Reg3 (**g**) and Reg4 (**h**) of North America and Eurasia. Linear regressions are shown for the periods 1980–2006 and 2004–2018 for North America (blue dashed lines) and Eurasia (red dashed lines), respectively, and statistics of linear regression for the period 2004–2018 are shown for North America (blue letters) and Eurasia (red letters). **i**–**k**, Trends of GPP and TER from FLUXCOM for Reg2 (**i**), Reg3 (**j**) and Reg4 (**k**) of North America and Eurasia for the period 2004–2018. * indicates that $P < 0.05$ for all results. S, September; O, October; N, November.

autumn cooling on net ecosystem exchange (NEE). Even with Reg4 excluded from the estimate, the autumn (defined as SON) NEE from FLUXCOM did not show a decreasing trend during 2004–2018 for all the lands north of 25° N (Fig. 2a; corresponding to Fig. 2a by Tang et al.[1]). Focusing on the individual continent, autumn NEE for North America continuously increased in Reg1–3 since 1980 and including Reg4 enhanced the increasing trend for 2004–2018 (Fig. 2b). However, irrespective of whether Reg4 was included, autumn NEE for Eurasia indicated a transition from an increasing to a decreasing trend around 2004 with a notable anomalous decrease between 2011 and 2016 (Fig. 2c). This is consistent with the pattern of temperatures (Fig. 1d,g).

Multi-site $CO_2$ measurements in central Eurasia, where significant autumn cooling occurred around the towers (Supplementary Figs. 2 and 3 and Supplementary Table 1), also showed a decrease in atmospheric $CO_2$ between 2011 and 2016 in response to the SO temperature, regardless

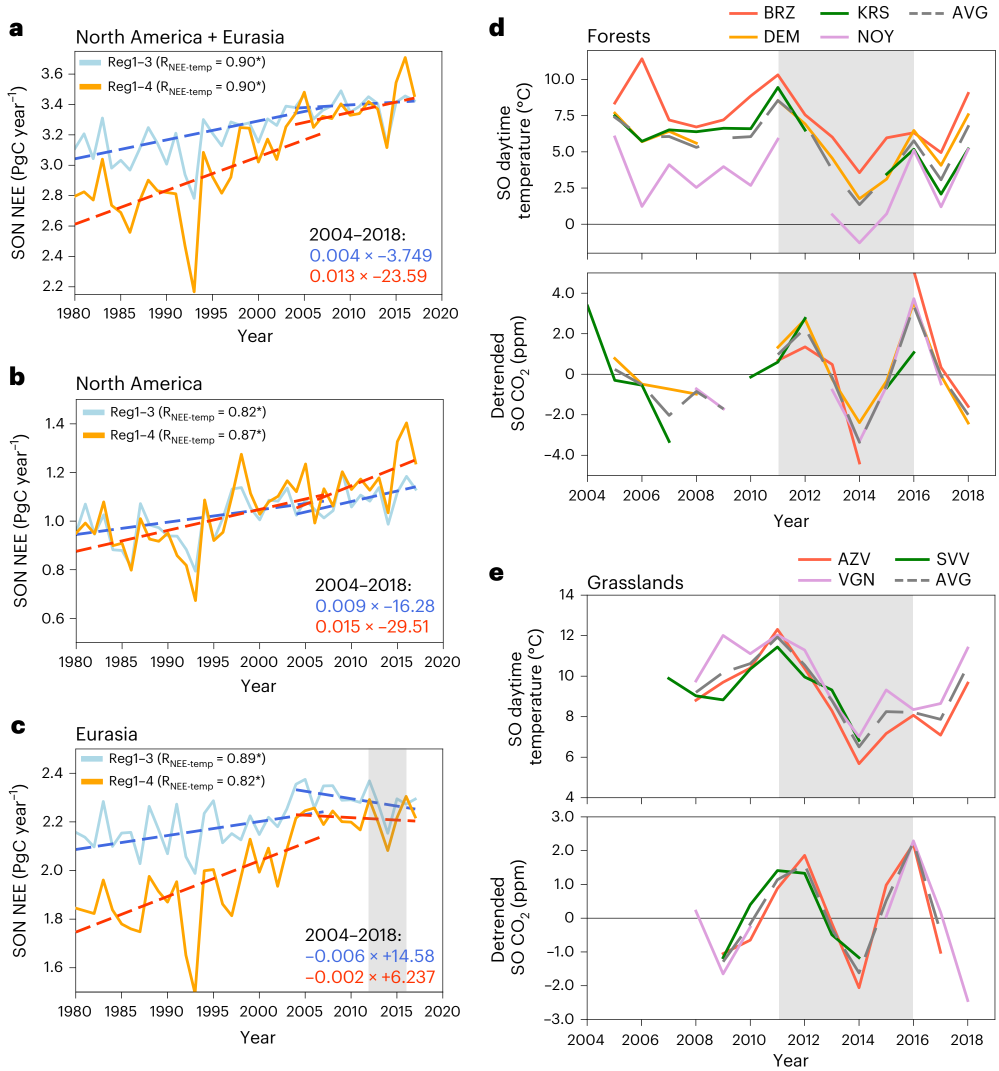


**Fig. 2 | Interannual variability of autumn NEE and $CO_2$. a–c**, Interannual variability in SON NEE from FLUXCOM for the lands north of 25° N (including North America and Eurasia) (**a**), North America (**b**) and Eurasia (**c**). Results are shown for the sums of Reg1–3 and Reg1–4 along with Pearson correlations between FLUXCOM NEE and CRU TS4.05 temperature (* indicates that $P < 0.05$ for all results). Linear regressions are shown for the periods 1980–2006 and 2004–2018 for Reg1–3 (blue dashed lines) and Reg1–4 (red dashed lines), respectively, and statistics of linear regression for the period 2004–2018 are shown for Reg1–3 (blue letters) and Reg1–4 (red letters). Interannual variability in daytime temperature (12:00–18:00) and detrended $CO_2$ (corresponding to the same daytime) averaged for SO. **d**–**e**, Results are shown for towers surrounded by forests, Berezorechka (BRZ), Demyanskoe (DEM), Karasevoe (KRS) and Noyabrsk (NOY), and average (AVG) of the four site data (**d**) and grasslands, Azovo (AZV), Savvushka (SVV) and Vaganovo (VGN), and average (AVG) of the three site data (**e**) (Supplementary Table 1). Grey shading in **c**–**e** represents the period in which anomalous decreases in temperature and NEE were found.

of the surrounding ecosystem types: forests or grasslands (Fig. 2d,e). Tang et al.[1] used atmospheric $CO_2$ measurements at Point Barrow as observational support for increasing $CO_2$ release under autumn cooling, but this is misleading because Point Barrow is targeted to measure the background concentration in the northern 'high' latitudes[5], where the autumn warming is more profound (for example, Alaska and north-eastern Siberia; Fig. 1b). Further, even if Point Barrow reflects changes in atmospheric $CO_2$ in northern middle latitudes, it is unlikely to detect the autumn cooling effect from its measurements as the warming effect in North America overwhelms the cooling effect in Eurasia (Fig. 2a–c).

In summary, the conclusion drawn by Tang et al.[1] could be attributed to overlooking the appropriate autumn period and cooling region. As we have demonstrated, a three-month average resulted in misidentifying the regions where the autumn cooling or warming affected $CO_2$ fluxes, thus leading to the biased NEE–temperature relationship. A detailed evaluation of individual months is recommended for studies to evaluate relationships between seasonal climate and $CO_2$ fluxes.

## Online content

Any methods, additional references, Nature Portfolio reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41558-023-01625-4.

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## Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

## Data availability

CRU TS4.05, FLUXCOM and atmospheric $CO_2$ measurements data used in this study are available respectively from the Climatic Research Unit at the University of East Anglia (https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_4.05/), the data portal of the Max Planck Institute for Biogeochemistry (https://www.bgc-jena.mpg.de/geodb/projects/Home.php) and the Global Environmental Dataset of the Center for Global Environmental Research at the National Institute for Environmental Studies, Japan (https://db.cger.nies.go.jp/portal/geds/atmosphericAndOceanicMonitoring?lang=eng).

## Code availability

The codes used for the analyses are available from the corresponding author.

## Acknowledgements

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## Author contributions

M.K. designed the study, conducted the analysis and wrote the paper. All authors contributed to the discussion and manuscript writing.

## Competing interests

The authors declare no competing interests.

## Additional information

**Supplementary information** The online version contains supplementary material available at https://doi.org/10.1038/s41558-023-01625-4.

**Correspondence and requests for materials** should be addressed to Masayuki Kondo.

**Peer review information** *Nature Climate Change* thanks Minkyu Moon and the other, anonymous, reviewer(s) for their contribution to the peer review of this work.

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Corresponding author(s): Masayuki Kondo
Last updated by author(s): 2023-02-01

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| ☐ | ☒ | A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly |
| ☐ | ☒ | The statistical test(s) used AND whether they are one- or two-sided<br>*Only common tests should be described solely by name; describe more complex techniques in the Methods section.* |
| ☒ | ☐ | A description of all covariates tested |
| ☒ | ☐ | A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons |
| ☐ | ☒ | A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals) |
| ☒ | ☐ | For null hypothesis testing, the test statistic (e.g. *F*, *t*, *r*) with confidence intervals, effect sizes, degrees of freedom and *P* value noted<br>*Give P values as exact values whenever suitable.* |
| ☒ | ☐ | For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings |
| ☒ | ☐ | For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes |
| ☒ | ☐ | Estimates of effect sizes (e.g. Cohen's *d*, Pearson's *r*), indicating how they were calculated |

*Our web collection on statistics for biologists contains articles on many of the points above.*

## Software and code

Policy information about availability of computer code

| | |
|---|---|
| Data collection | No software was used to collect data |
| Data analysis | ENVI was used to creat spatial maps in Figure 1, and the rest of figures was created with Matplotlib. |

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio guidelines for submitting code & software for further information.

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All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

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- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

All data used in the analysis are publicly available. The data and code availability statement is presented in the manuscript.


March 2021

## Human research participants

Policy information about studies involving human research participants and Sex and Gender in Research.

| | |
|---|---|
| Reporting on sex and gender | N/A |
| Population characteristics | N/A |
| Recruitment | N/A |
| Ethics oversight | N/A |

Note that full information on the approval of the study protocol must also be provided in the manuscript.

# Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☐ Behavioural & social sciences ☒ Ecological, evolutionary & environmental sciences

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# Life sciences study design

All studies must disclose on these points even when the disclosure is negative.

| | |
|---|---|
| Sample size | N/A |
| Data exclusions | N/A |
| Replication | N/A |
| Randomization | N/A |
| Blinding | N/A |

# Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

| | |
|---|---|
| Study description | N/A |
| Research sample | N/A |
| Sampling strategy | N/A |

| | |
|---|---|
| Data collection | N/A |
| Timing | N/A |
| Data exclusions | N/A |
| Non-participation | N/A |
| Randomization | N/A |

## Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

| | |
|---|---|
| Study description | By analysis of climate data, an empirical estimate of $CO_2$ fluxes, and $CO_2$ observations, this study offers a conclusion opposite to a previous paper published in Nature Climate Change about the impact of autumn cooling on carbon flux. |
| Research sample | The study was based on climate data (CRU-TS 4.05), empirical upscaling of eddy covariance data (FLUXCOM), and $CO_2$ observations taken by seven towers in central Eurasia. |
| Sampling strategy | The analysis focused on the north of 25° north. The region was further classified into four regions by months when temperatures fall below 0 ˚C. |
| Data collection | All data were obtained online. All the URL information is stated in the main text. |
| Timing and spatial scale | The analysis and the data used were on a monthly scale, covering the period from 1980 to 2018. |
| Data exclusions | We did not exlucde any data that we obtained. |
| Reproducibility | Our analysis was based on publicly available data. Every part of our analysis can be reproduced. |
| Randomization | Randomization is not applicable to this study. |
| Blinding | Blinding is not applicable to this study as we only used existing data. |

Did the study involve field work? ☐ Yes ☒ No

## Field work, collection and transport

| | |
|---|---|
| Field conditions | N/A |
| Location | N/A |
| Access & import/export | N/A |
| Disturbance | N/A |

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## Materials & experimental systems

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| --- | --- |
| ☒ | ☐ Antibodies |
| ☒ | ☐ Eukaryotic cell lines |
| ☒ | ☐ Palaeontology and archaeology |
| ☒ | ☐ Animals and other organisms |
| ☒ | ☐ Clinical data |
| ☒ | ☐ Dual use research of concern |

## Methods

| n/a | Involved in the study |
| --- | --- |
| ☒ | ☐ ChIP-seq |
| ☒ | ☐ Flow cytometry |
| ☒ | ☐ MRI-based neuroimaging |

## Antibodies

| | |
| --- | --- |
| Antibodies used | N/A |
| Validation | N/A |

## Eukaryotic cell lines

Policy information about cell lines and Sex and Gender in Research

| | |
| --- | --- |
| Cell line source(s) | N/A |
| Authentication | N/A |
| Mycoplasma contamination | N/A |
| Commonly misidentified lines (See ICLAC register) | N/A |

## Palaeontology and Archaeology

| | |
| --- | --- |
| Specimen provenance | N/A |
| Specimen deposition | N/A |
| Dating methods | N/A |

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| | |
| --- | --- |
| Ethics oversight | N/A |

Note that full information on the approval of the study protocol must also be provided in the manuscript.

## Animals and other research organisms

Policy information about studies involving animals; ARRIVE guidelines recommended for reporting animal research, and Sex and Gender in Research

| | |
| --- | --- |
| Laboratory animals | N/A |

| | |
|---|---|
| Wild animals | N/A |
| Reporting on sex | N/A |
| Field-collected samples | N/A |
| Ethics oversight | N/A |

Note that full information on the approval of the study protocol must also be provided in the manuscript.

## Clinical data

Policy information about clinical studies

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| | |
|---|---|
| Clinical trial registration | N/A |
| Study protocol | N/A |
| Data collection | N/A |
| Outcomes | N/A |

## Dual use research of concern

Policy information about dual use research of concern

### Hazards

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|---|---|---|
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|---|---|---|
| ☒ | ☐ | Demonstrate how to render a vaccine ineffective |
| ☒ | ☐ | Confer resistance to therapeutically useful antibiotics or antiviral agents |
| ☒ | ☐ | Enhance the virulence of a pathogen or render a nonpathogen virulent |
| ☒ | ☐ | Increase transmissibility of a pathogen |
| ☒ | ☐ | Alter the host range of a pathogen |
| ☒ | ☐ | Enable evasion of diagnostic/detection modalities |
| ☒ | ☐ | Enable the weaponization of a biological agent or toxin |
| ☒ | ☐ | Any other potentially harmful combination of experiments and agents |

# ChIP-seq

## Data deposition

☐ Confirm that both raw and final processed data have been deposited in a public database such as GEO.

☐ Confirm that you have deposited or provided access to graph files (e.g. BED files) for the called peaks.

| | |
|---|---|
| Data access links<br>*May remain private before publication.* | N/A |
| Files in database submission | N/A |
| Genome browser session<br>(e.g. UCSC) | N/A |

## Methodology

| | |
|---|---|
| Replicates | N/A |
| Sequencing depth | N/A |
| Antibodies | N/A |
| Peak calling parameters | N/A |
| Data quality | N/A |
| Software | N/A |

# Flow Cytometry

## Plots

Confirm that:

☐ The axis labels state the marker and fluorochrome used (e.g. CD4-FITC).

☐ The axis scales are clearly visible. Include numbers along axes only for bottom left plot of group (a 'group' is an analysis of identical markers).

☐ All plots are contour plots with outliers or pseudocolor plots.

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## Methodology

| | |
|---|---|
| Sample preparation | N/A |
| Instrument | N/A |
| Software | N/A |
| Cell population abundance | N/A |
| Gating strategy | N/A |

☐ Tick this box to confirm that a figure exemplifying the gating strategy is provided in the Supplementary Information.

# Magnetic resonance imaging

## Experimental design

| | |
|---|---|
| Design type | N/A |

| | |
|---|---|
| Design specifications | N/A |
| Behavioral performance measures | N/A |

## Acquisition

| | |
|---|---|
| Imaging type(s) | N/A |
| Field strength | N/A |
| Sequence & imaging parameters | N/A |
| Area of acquisition | N/A |

Diffusion MRI ☐ Used ☐ Not used

## Preprocessing

| | |
|---|---|
| Preprocessing software | N/A |
| Normalization | N/A |
| Normalization template | N/A |
| Noise and artifact removal | N/A |
| Volume censoring | N/A |

## Statistical modeling & inference

| | |
|---|---|
| Model type and settings | N/A |
| Effect(s) tested | N/A |

Specify type of analysis: ☐ Whole brain ☐ ROI-based ☐ Both

| | |
|---|---|
| Statistic type for inference (See Eklund et al. 2016) | N/A |
| Correction | N/A |

## Models & analysis

| n/a | Involved in the study |
|---|---|
| ☒ | ☐ Functional and/or effective connectivity |
| ☒ | ☐ Graph analysis |
| ☒ | ☐ Multivariate modeling or predictive analysis |

| | |
|---|---|
| Functional and/or effective connectivity | N/A |
| Graph analysis | N/A |
| Multivariate modeling and predictive analysis | N/A |