Climate Change and Air Pollution in the Middle East

Jos Lelieveld

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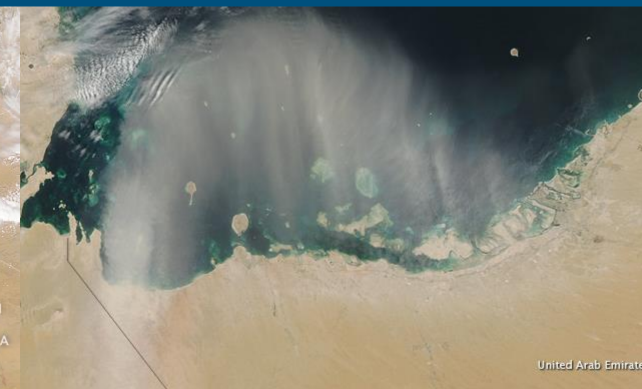

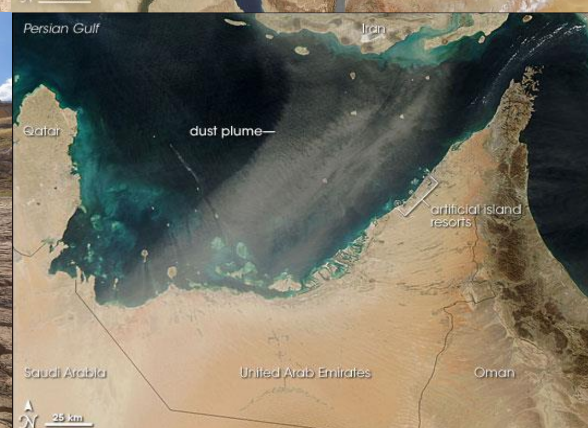

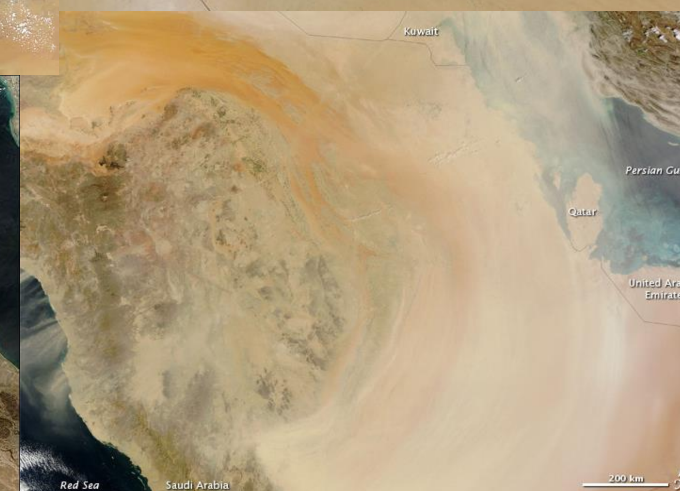

Observed temperature trends in the Eastern Mediterranean – Middle East (EMME)

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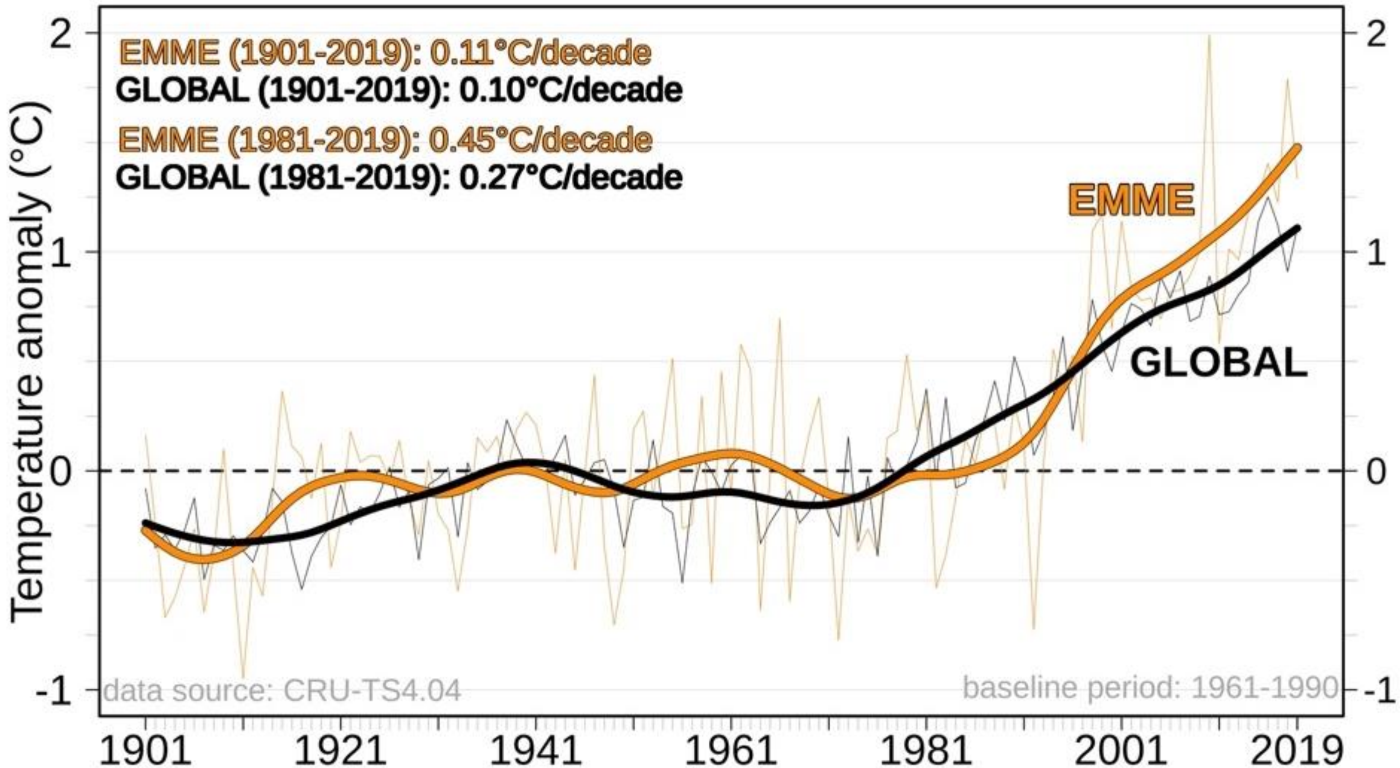

Observed temperature trends compared to other regions

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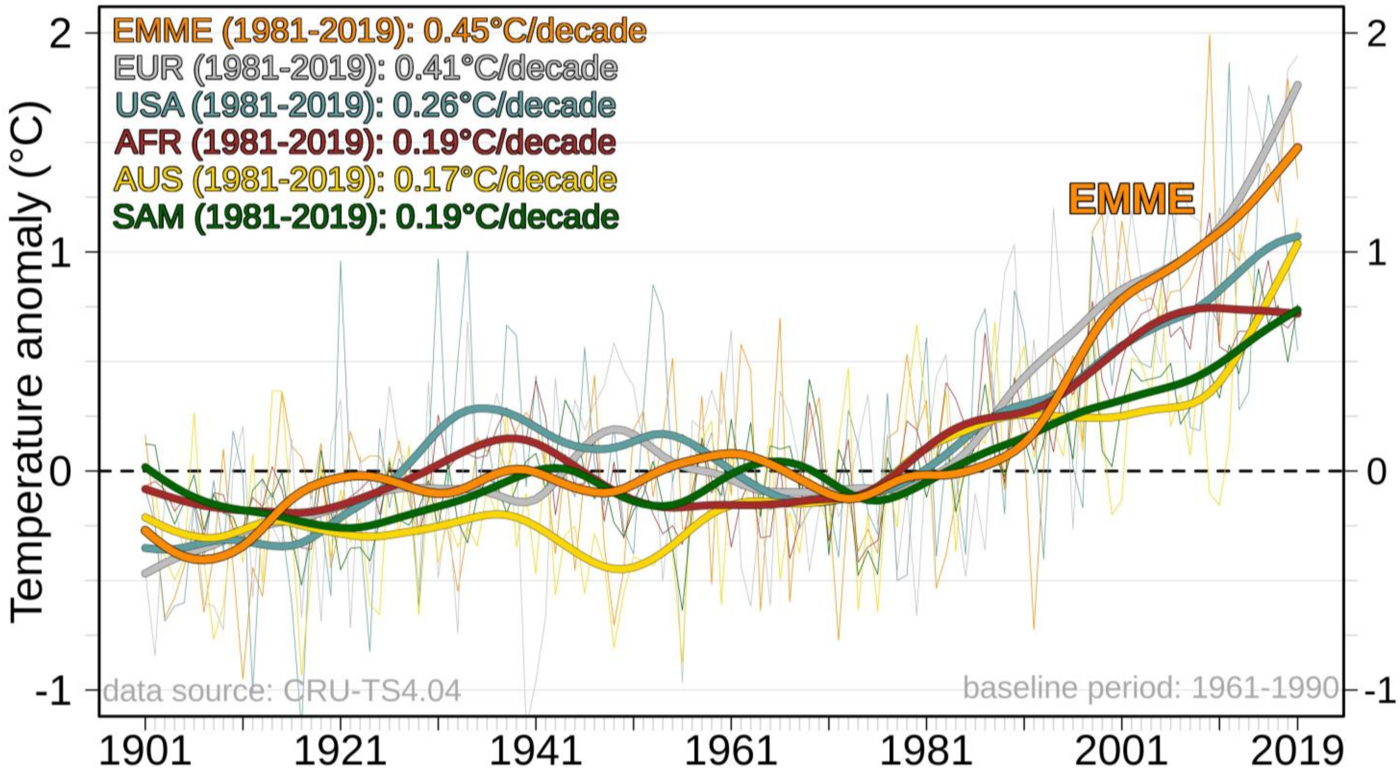

Temperature trends (land only) based on regional climate model ensembles

(relative to pre-industrial times, add another 0.8°C)

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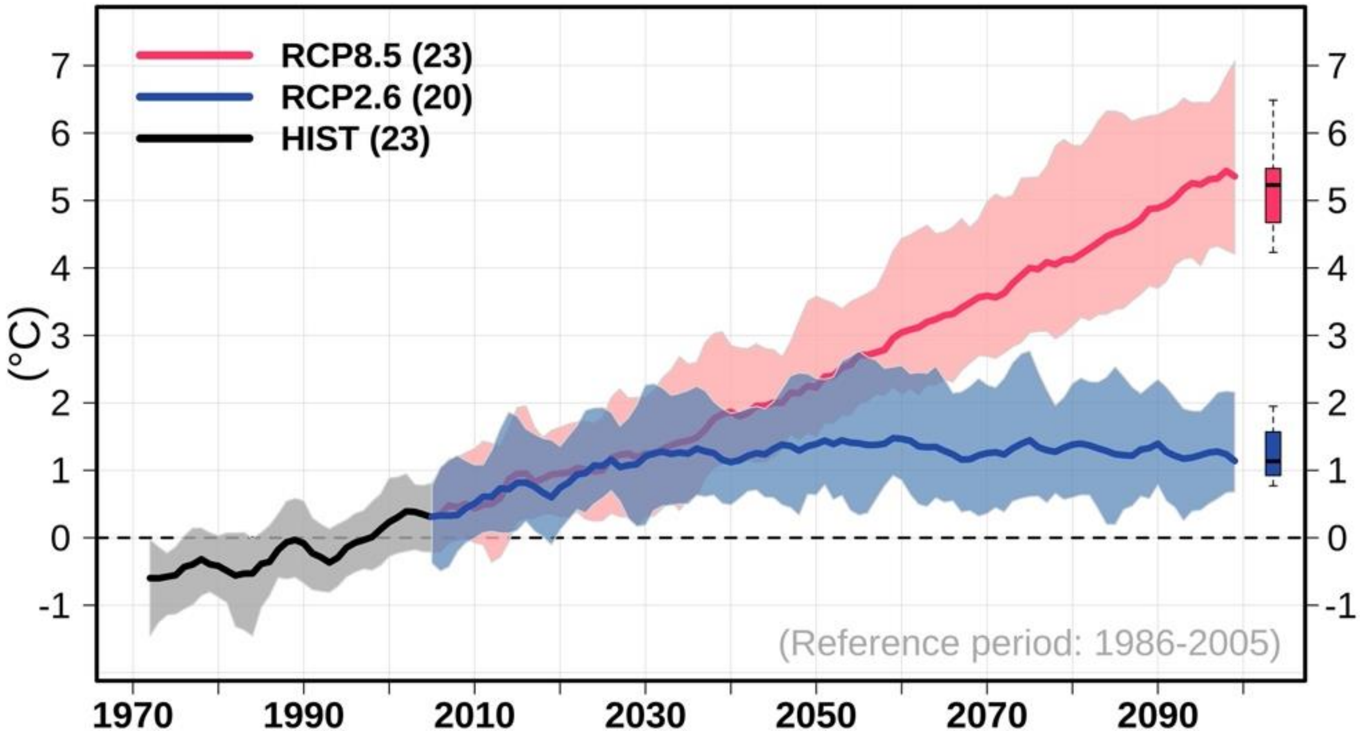

Summer mean temperatures in the reference period (1986–2005) (left) and changes based on RCP8.5 climate projections (right)

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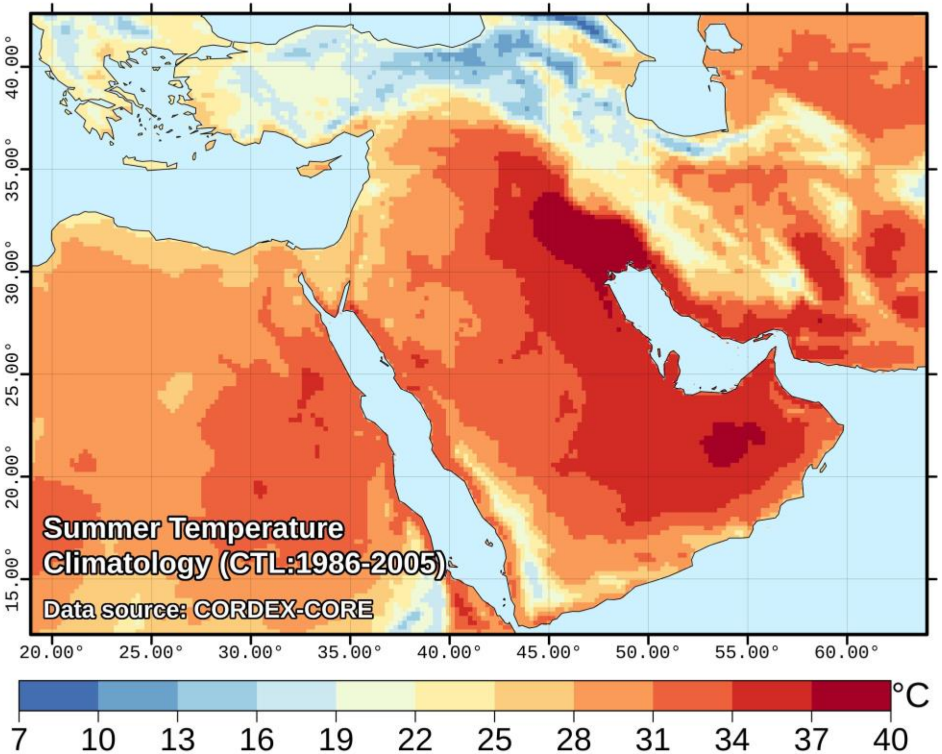

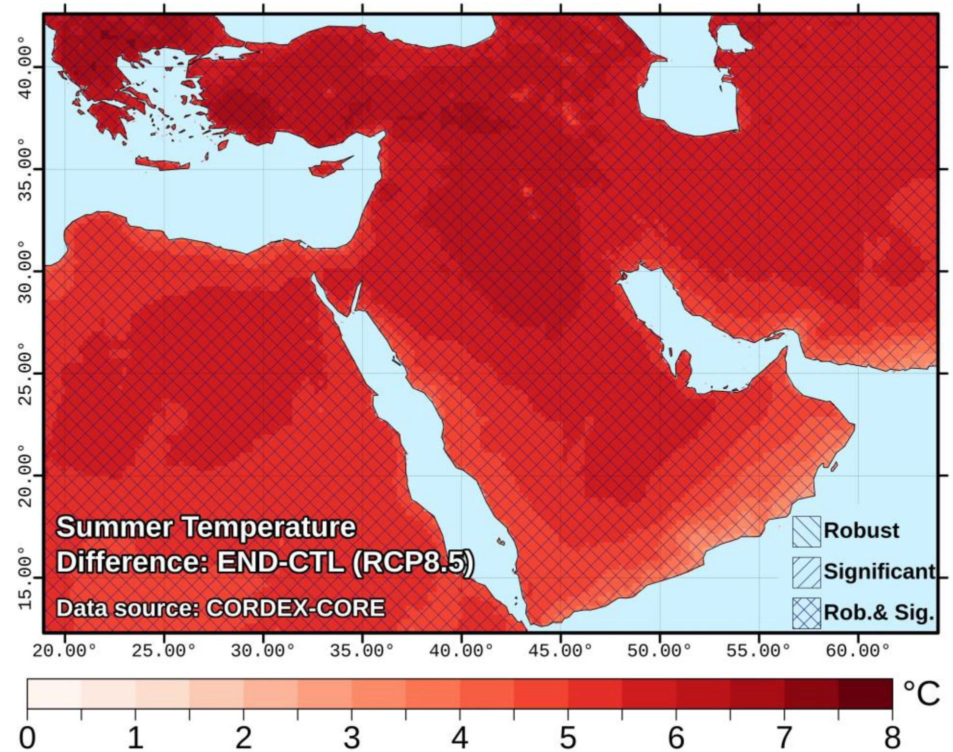

Probability density or relative risk distributions of annual temperature anomalies (relative to the 1986-2005 mean)

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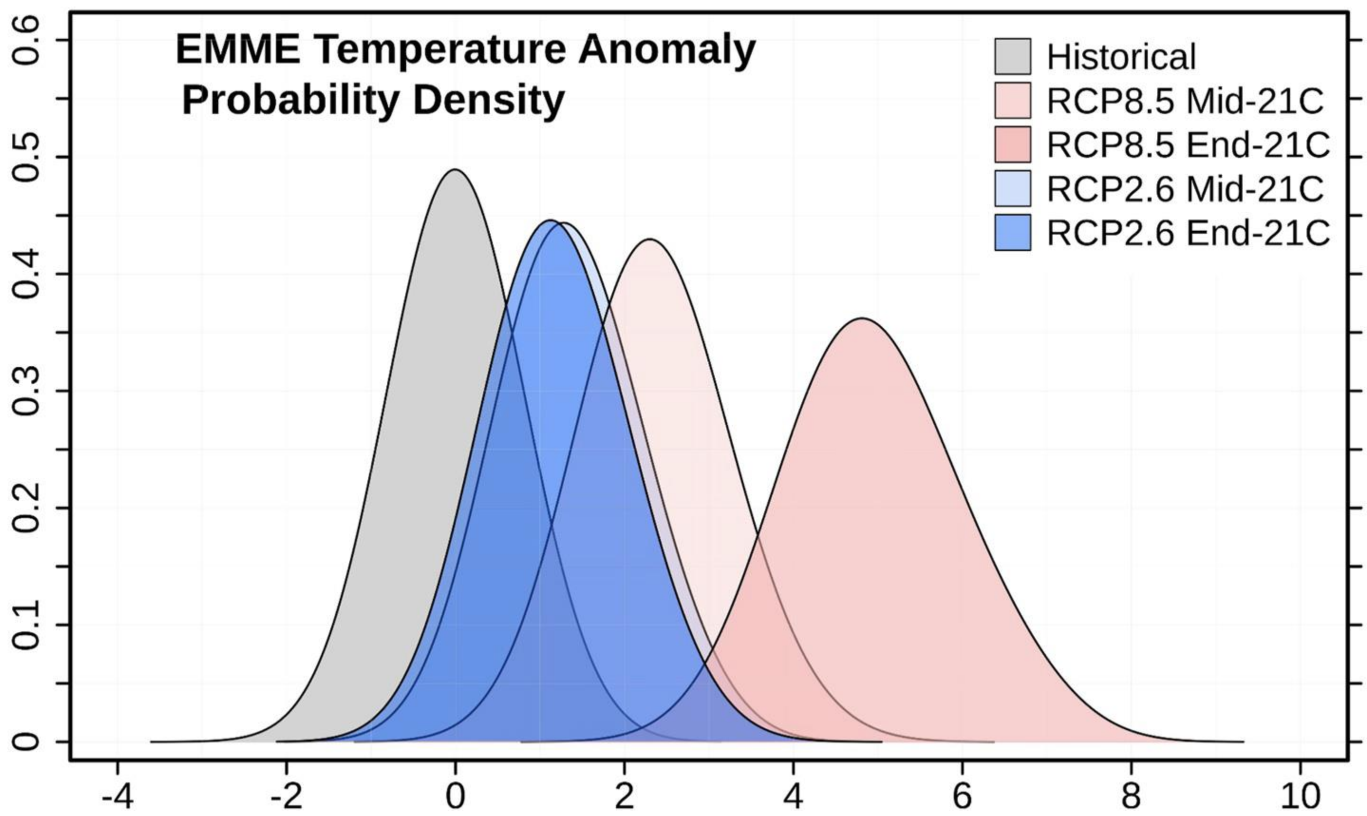

Precipitation trends (land only)

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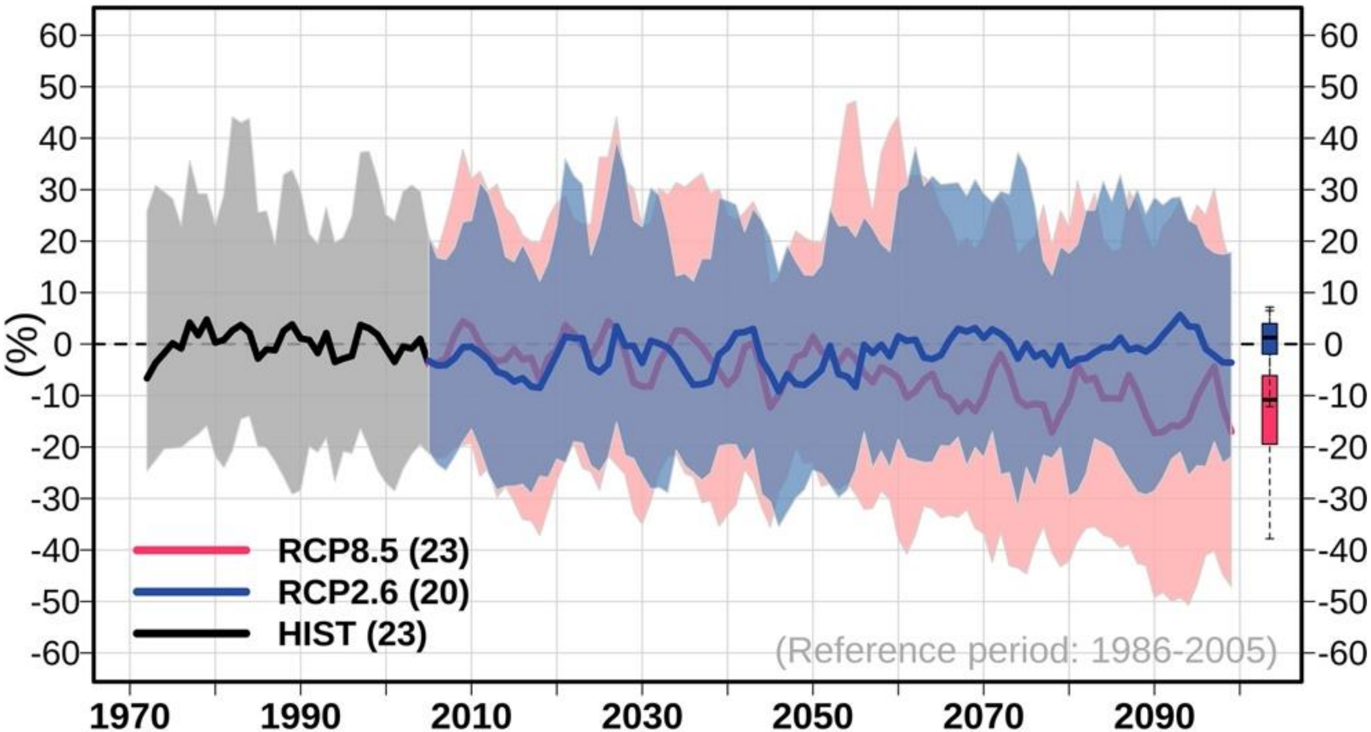

Winter mean precipitation in the reference period (1986–2005) (left) and changes based on RCP8.5 climate projections (right)

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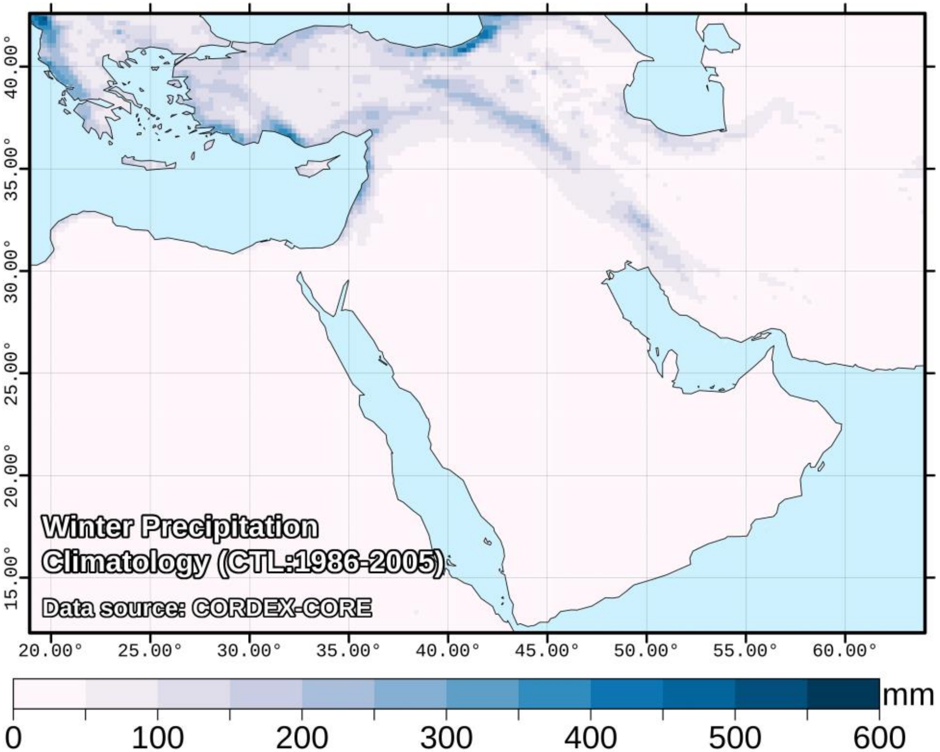

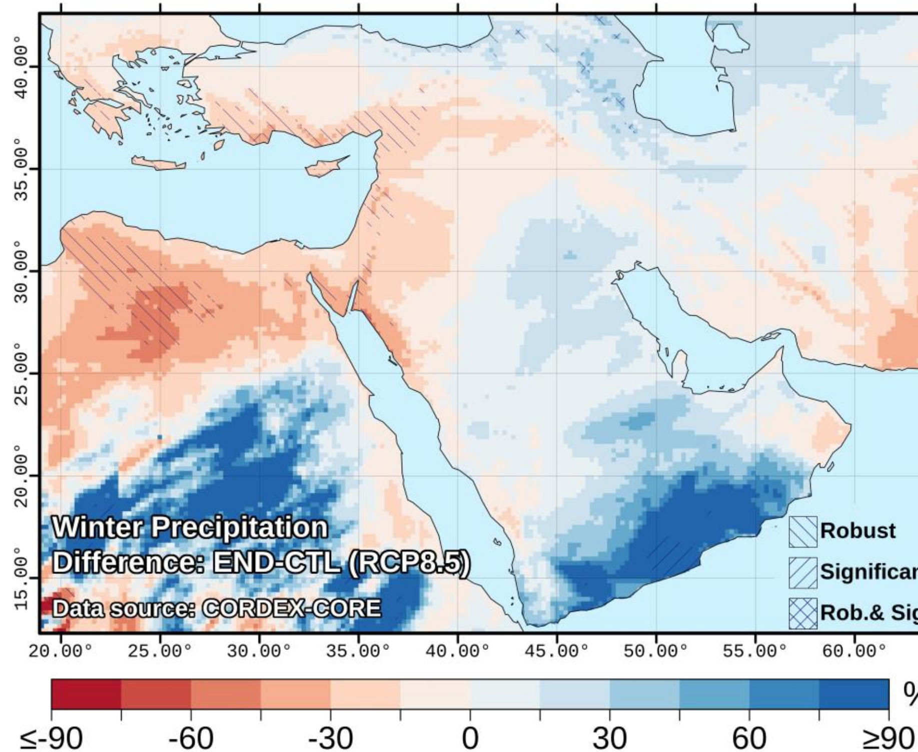

AGU ADVANCING EARTH AND SPACE SCIENCE

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Reviews of Geophysics

REVIEW ARTICLE

10.1029/2021RG000762

Climate Change and Weather Extremes in the Eastern Mediterranean and Middle East

G. Zittis [1], M. Almazroui [2], P. Alpert [3], P. Ciais [1,4], W. Cramer [5], Y. Dahdal [6], M. Fnais [7], D. Francis [8], P. Hadjinicolaou [1], F. Howari [9], A. Jrrar [10], D. G. Kaskaoutis [11,12], M. Kulmala [13], G. Lazoglou [1], N. Mihalopoulos [11,12], X. Lin [4], Y. Rudich [14], J. Sciare [1], G. Stenchikov [15], E. Xoplaki [16,17], and J. Lelieveld [1,18]

[1]Climate and Atmosphere Research Center (CARE-C), The Cyprus Institute, Nicosia, Cyprus, [2]Center of Excellence for Climate Change Research, Department of Meteorology, King Abdulaziz University, Jeddah, Saudi Arabia, [3]Department of Geophysics, Tel Aviv University, Tel Aviv, Israel, [4]Laboratoire des Sciences du Climat et de l'Environnement (LSCE), Institut Pierre Simon Laplace, Paris, France, [5]Institut Méditerranéen de Biodiversité et d'Ecologie marine et continentale (IMBE), Aix Marseille University, CNRS, IRD, Avignon University, Aix-en-Provence, France, [6]Nature Palestine Society, Jerusalem, Palestine, [7]College of Sciences, King Saud University, Riyadh, Saudi Arabia, [8]Environmental and Geophysical Sciences (ENGEOS) Lab, Khalifa University of Science and Technology, Abu Dhabi, UAE, [9]College of Natural and Health Sciences (CNHS), Zayed University, Abu Dhabi, UAE, [10]Computational E-Research Unit, Advanced Research Centre, Royal Scientific Society, Amman, Jordan, [11]Institute for Environmental Research and Sustainable Development, National Observatory of Athens, Athens, Greece, [12]Environmental Chemical Processes Laboratory, Department of Chemistry, University of Crete, Crete, Greece, [13]Institute for Atmospheric and Earth System Research (INAR/Physics), University of Helsinki, Helsinki, Finland, [14]Department of Earth and Planetary Sciences, Weizmann Institute of Science, Rehovot, Israel, [15]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia, [16]Department of Geography, Justus Liebig University Giessen, Giessen, Germany, [17]Center for International Development and Environmental Research, Justus Liebig University Giessen, Giessen, Germany, [18]Max Planck Institute for Chemistry, Mainz, Germany

Key Points:

- The Eastern Mediterranean and Middle East is warming almost two times faster than the global average and other inhabited parts of the world
- Climate projections indicate a future warming, strongest in summers. Precipitation will likely decrease, particularly in the Mediterranean
- Virtually all socio-economic sectors will be critically affected by the projected changes

Supporting Information:

Supporting Information may be found in the online version of this article.

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https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2021RG000762

Observed and modeled mean daytime maximum temperatures in the MENA during the warm season (May–Sept) (left)

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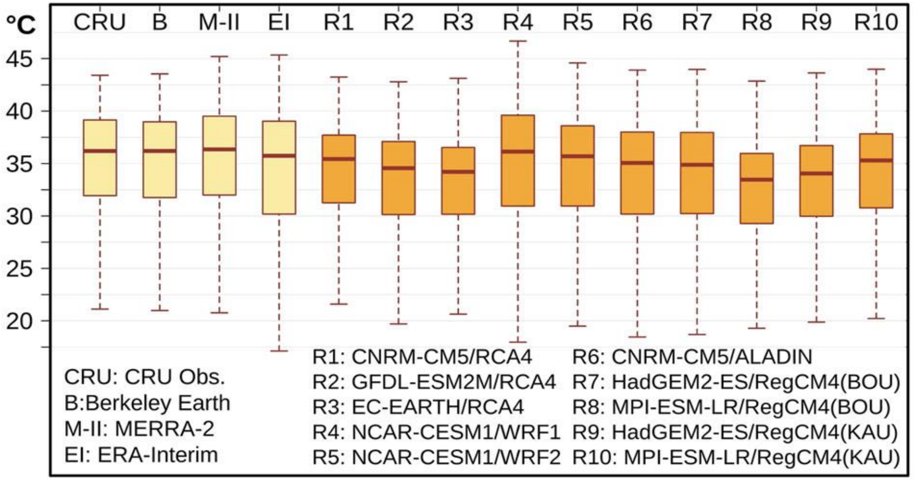
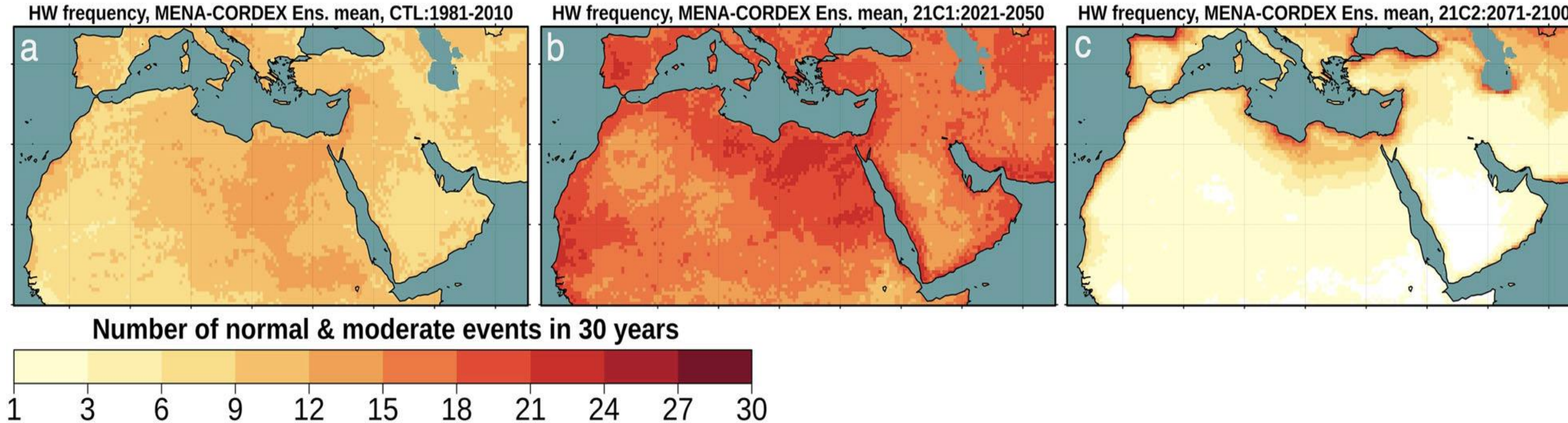
Warm season temperatures (1981-2010): land only

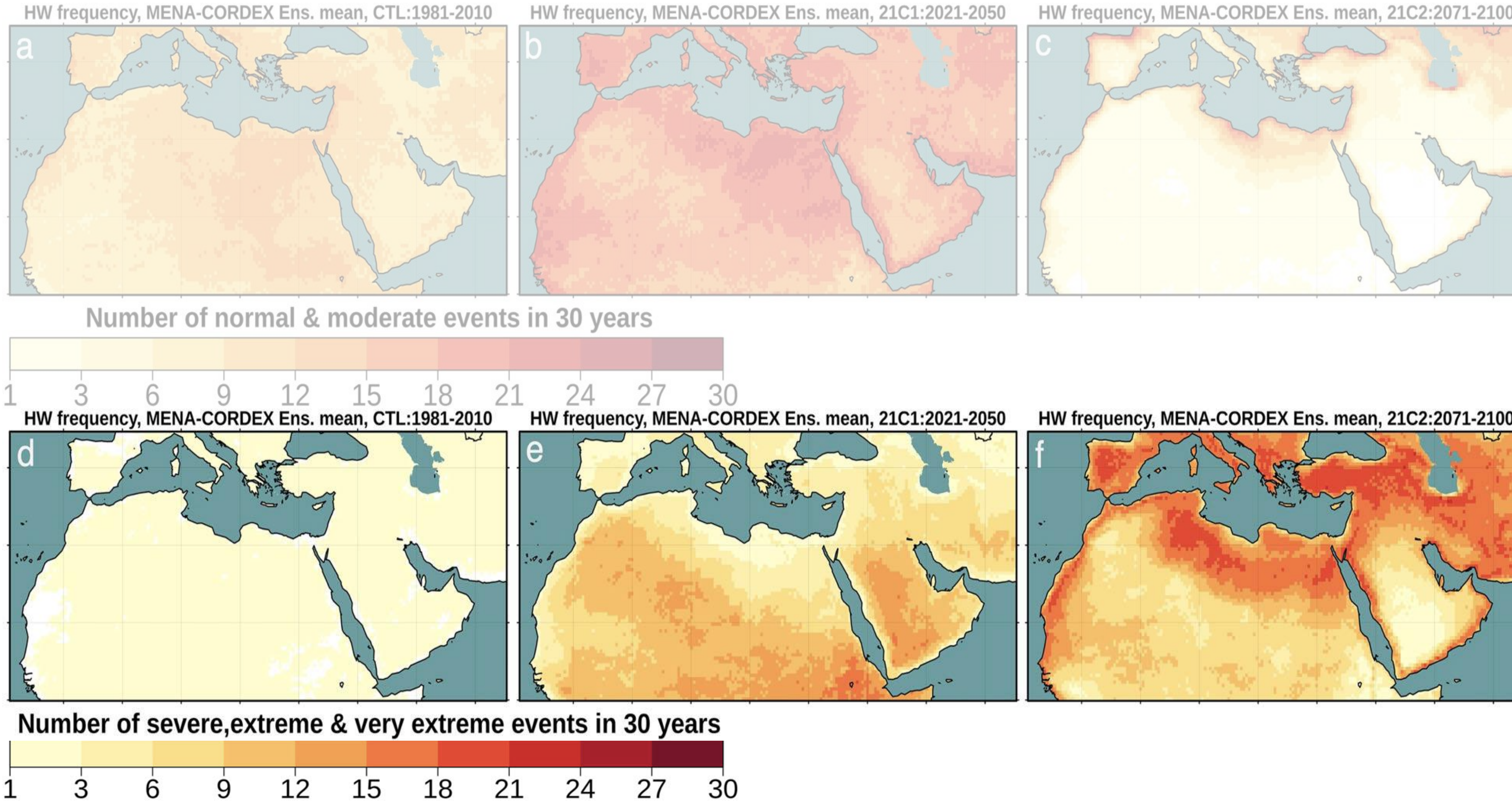


Heatwave magnitude index and heatwave categories that have occurred in the past decades

Year	Location	HWMId	HW category
2010	Russia	71.9	Super extreme
2003	Central Europe	44.7	Very extreme
1972	Finland	38.2	Very extreme
1976	United Kingdom	35.8	Very extreme
1969	Norway	26.5	Extreme
2015	Central Europe	26	Extreme
2007	Greece	22.9	Extreme
1994	Benelux	21.3	Extreme
2014	Scandinavia	21.2	Extreme



HW frequency, MENA-CORDEX Ens. mean, CTL:1981-2010
HW frequency, MENA-CORDEX Ens. mean, 21C1:2021-2050
HW frequency, MENA-CORDEX Ens. mean, 21C2:2071-2100
a
b
c
Number of normal & moderate events in 30 years
1 3 6 9 12 15 18 21 24 27 30



HW frequency, MENA-CORDEX Ens. mean, CTL:1981-2010
HW frequency, MENA-CORDEX Ens. mean, 21C1:2021-2050
HW frequency, MENA-CORDEX Ens. mean, 21C2:2071-2100
a
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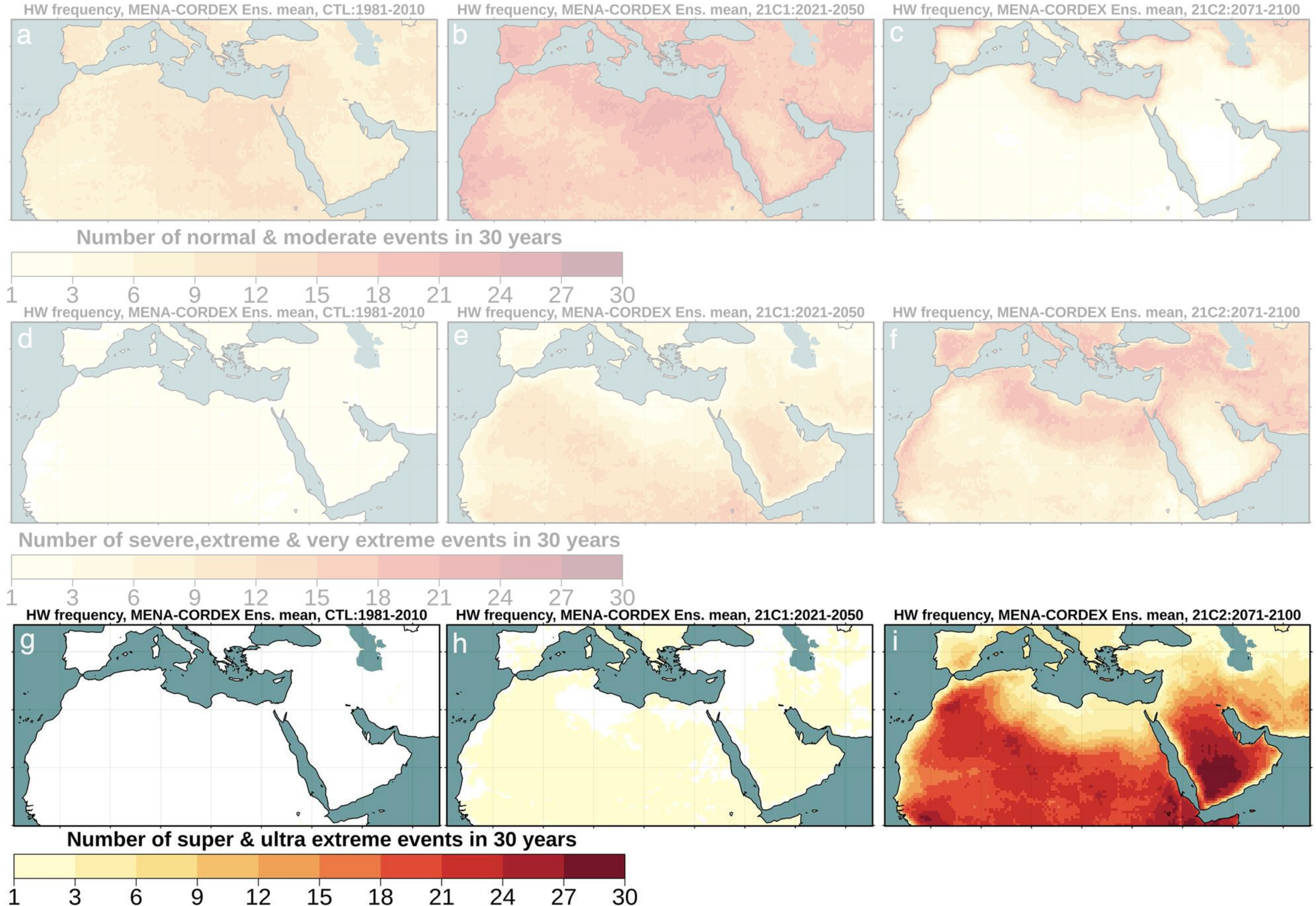
Number of normal & moderate events in 30 years
1 3 6 9 12 15 18 21 24 27 30
HW frequency, MENA-CORDEX Ens. mean, CTL:1981-2010
HW frequency, MENA-CORDEX Ens. mean, 21C1:2021-2050
HW frequency, MENA-CORDEX Ens. mean, 21C2:2071-2100
d
e
f
Number of severe,extreme & very extreme events in 30 years
1 3 6 9 12 15 18 21 24 27 30



HW frequency, MENA-CORDEX Ens. mean, CTL:1981-2010
HW frequency, MENA-CORDEX Ens. mean, 21C1:2021-2050
HW frequency, MENA-CORDEX Ens. mean, 21C2:2071-2100
a
b
c
Number of normal & moderate events in 30 years
1 3 6 9 12 15 18 21 24 27 30
d
e
f
Number of severe,extreme & very extreme events in 30 years
g
h
i
Number of super & ultra extreme events in 30 years

Business-as-usual will lead to super and ultra-extreme heatwaves in the Middle East and North Africa, to which hundreds of millions people will be exposed (up to 90% urban)

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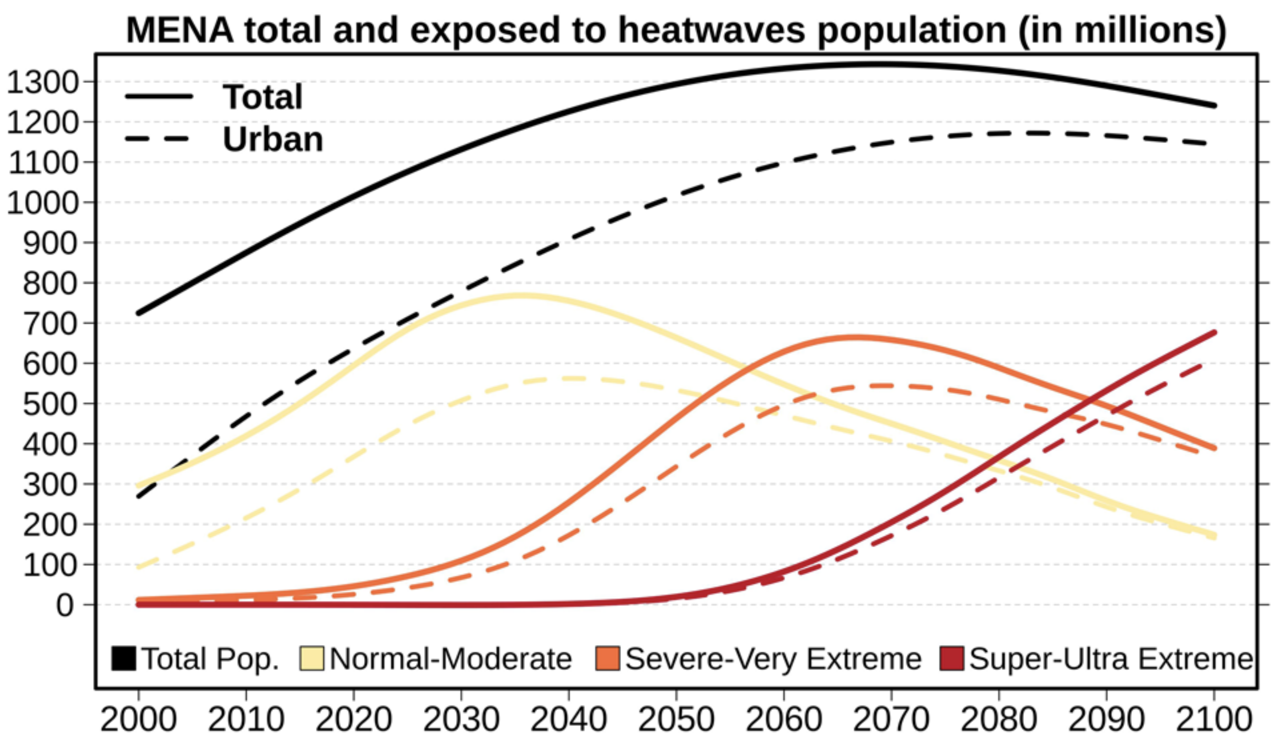

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npj | Climate and Atmospheric Science

www.nature.com/npjclimatsci

ARTICLE OPEN

Check for updates

Business-as-usual will lead to super and ultra-extreme heatwaves in the Middle East and North Africa

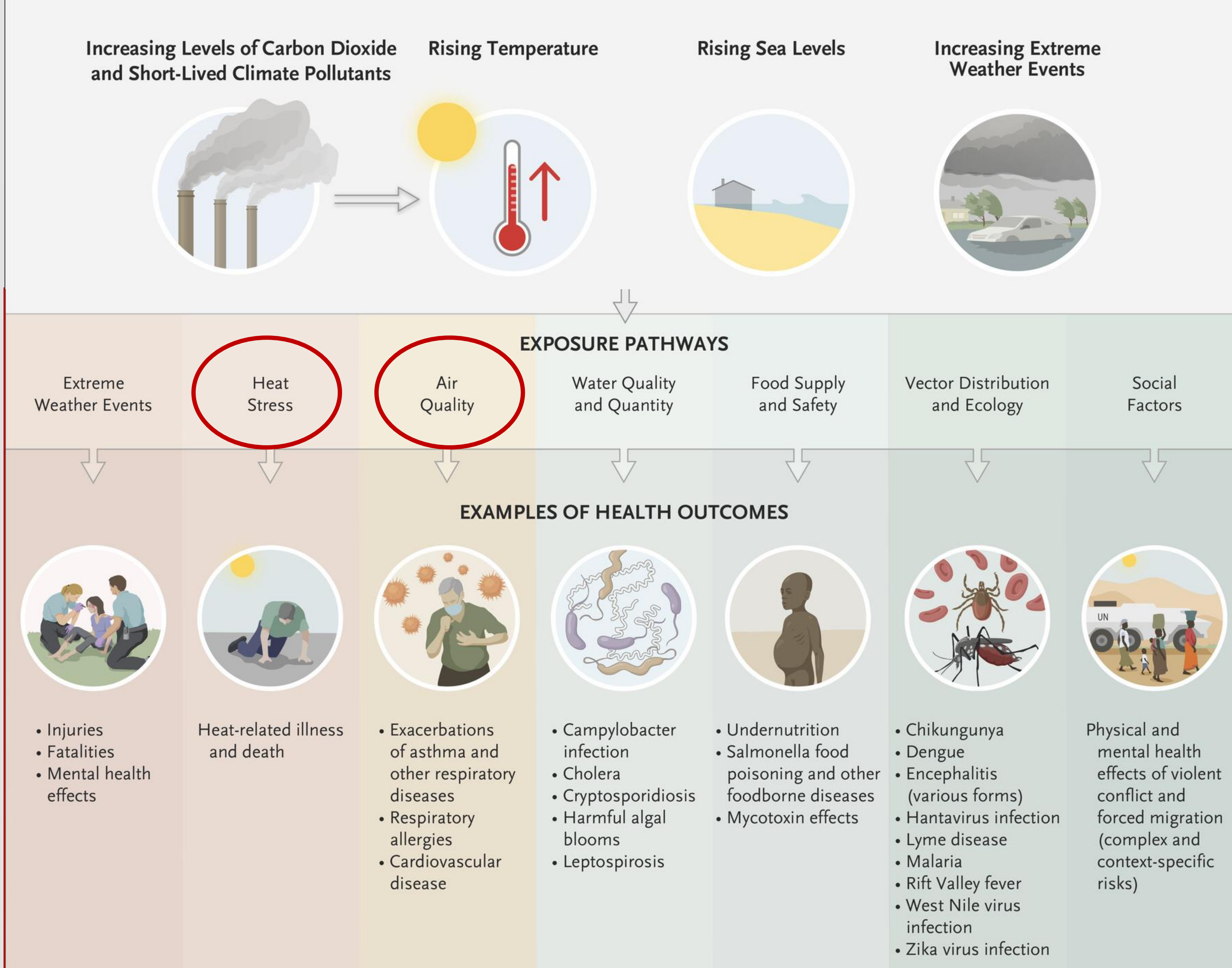
George Zittis[1]✉, Panos Hadjinicolaou[1], Mansour Almazroui[2], Edoardo Bucchignani[3,4], Fatima Driouech[5], Khalid El Rhaz[6], Levent Kurnaz[7,8], Grigory Nikulin[9], Athanasios Ntoumos[1], Tugba Ozturk[10], Yiannis Proestos[1], Georgiy Stenchikov[11], Rashyd Zaaboul[12] and Jos Lelieveld[1,13]

Global climate projections suggest a significant intensification of summer heat extremes in the Middle East and North Africa (MENA). To assess regional impacts, and underpin mitigation and adaptation measures, robust information is required from climate downscaling studies, which has been lacking for the region. Here, we project future hot spells by using the Heat Wave Magnitude Index and a comprehensive ensemble of regional climate projections for MENA. Our results, for a business-as-usual pathway, indicate that in the second half of this century unprecedented super- and ultra-extreme heatwave conditions will emerge. These events involve excessively high temperatures (up to 56 °C and higher) and will be of extended duration (several weeks), being potentially life-threatening for humans. By the end of the century, about half of the MENA population (approximately 600 million) could be exposed to annually recurring super- and ultra-extreme heatwaves. It is expected that the vast majority of the exposed population (>90%) will live in urban centers, who would need to cope with these societally disruptive weather conditions.

npj Climate and Atmospheric Science (2021)4:20 ; https://doi.org/10.1038/s41612-021-00178-7

https://www.nature.com/articles/s41612-021-00178-7

Climate change health impacts



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Health impacts of heat extremes in the MENA

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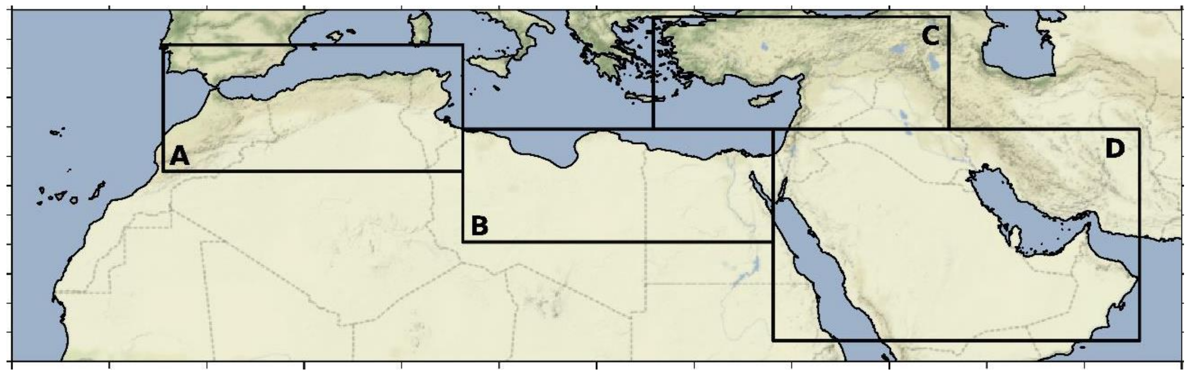
	Total annual heat-related deaths	Annual heat-related mortality rate per 100 000 people
Algeria	262	0·78
Morocco	250	0·93
Tunisia	116	1·14
Egypt	2591	1·68
Libya	98	0·97
Cyprus	26	3·32
Türkiye	1364	2·40
Syria	575	1·59
Iraq	1091	2·34
Iran	1703	11·00
Israel	218	3·74
Jordan	79	1·13
Kuwait	24	0·84
Lebanon	65	2·15
Oman	17	0·66
Qatar	19	0·95
Saudi Arabia	285	1·03
Palestine	43	1·65
United Arab Emirates	78	0·95
Total MENA countries	8904	2·06

MENA=Middle East and North Africa.

Table: **Current annual heat-related deaths, by MENA country**



Optimized relative risk functions for four subdomains within the MENA, accounting for temperature and relative humidity

Health impacts of heat extremes in the MENA

Additional annual heat-related mortality (per 100,000 population) for each country relative to 2001–2020

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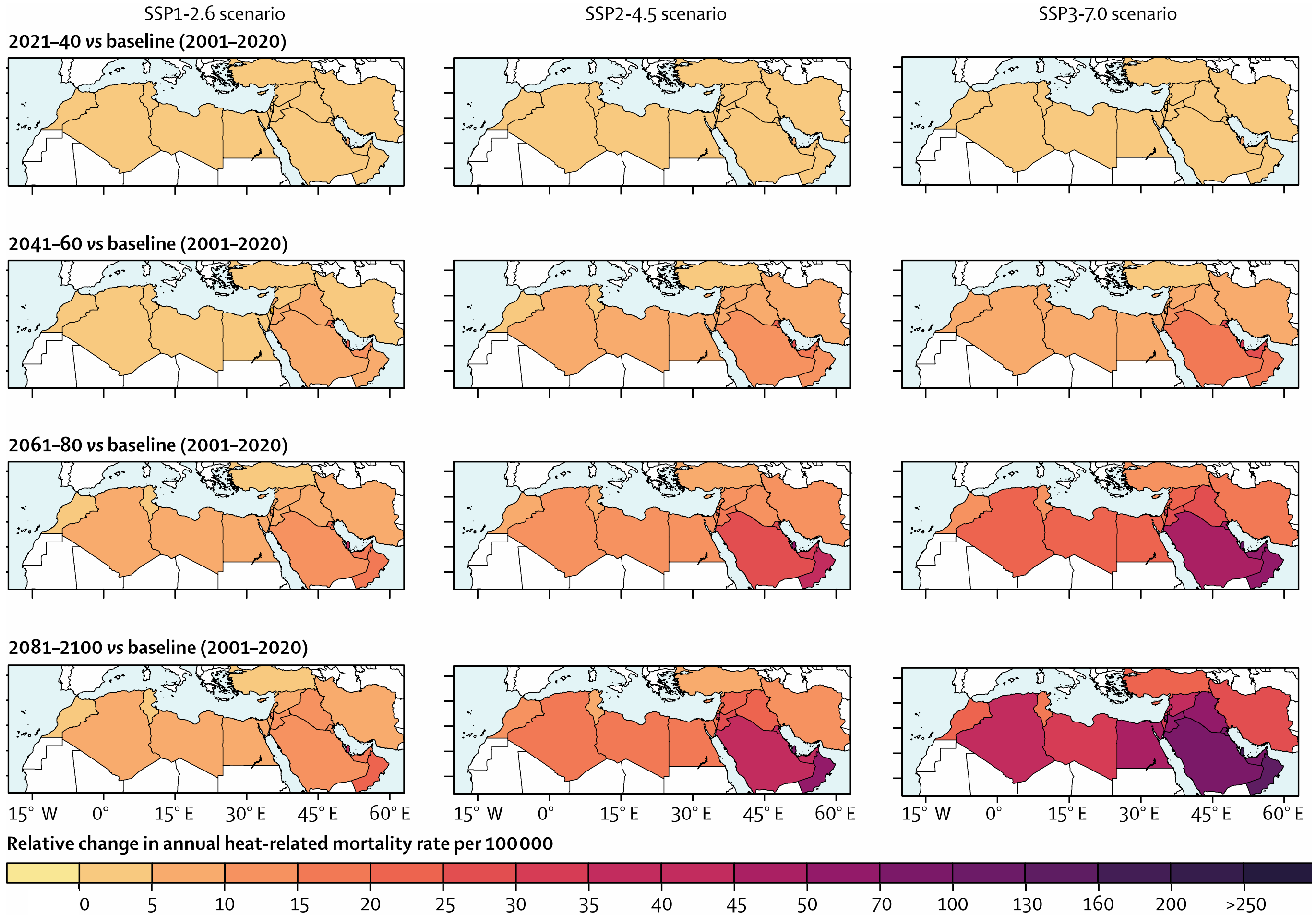

https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(23)00045-1/fulltext

Current and future trends in heat-related mortality in the MENA region: a health impact assessment with bias-adjusted statistically downscaled CMIP6 (SSP-based) data and Bayesian inference

Shakoor Hajat, Yiannis Proestos, Jose-Luis Araya-Lopez, Theo Economou, Jos Lelieveld

Summary

Background The Middle East and North Africa (MENA) is one of the regions that is most vulnerable to the negative effects of climate change, yet the potential public health impacts have been underexplored compared to other regions. We aimed to examine one aspect of these impacts, heat-related mortality, by quantifying the current and future burden in the MENA region and identifying the most vulnerable countries.

Methods We did a health impact assessment using an ensemble of bias-adjusted statistically downscaled Coupled Model Intercomparison Project phase 6 (CMIP6) data based on four Shared Socioeconomic Pathway (SSP) scenarios (SSP1-2·6 [consistent with a 2°C global warming scenario], SSP2-4·5 [medium pathway scenario], SSP3-7·0 [pessimistic scenario], and SSP5-8·5 [high emissions scenario]) and Bayesian inference methods. Assessments were based on apparent temperature–mortality relationships specific to each climate subregion of MENA based on Koppen-Geiger climate type classification, and unique thresholds were characterised for each 50 km grid cell in the region. Future annual heat-related mortality was estimated for the period 2021–2100. Estimates were also presented with population held constant to quantify the contribution of projected demographic changes to the future heat-mortality burden.

Findings The average annual heat-related death rate across all MENA countries is currently 2·1 per 100 000 people. Under the two high emissions scenarios (SSP3-7·0 and SSP5-8·5), most of the MENA region will have experienced substantial warming by the 2060s. Annual heat-related deaths of 123·4 per 100 000 people are projected for MENA by 2100 under a high emissions scenario (SSP5-8·5), although this rate would be reduced by more than 80% (to 20·3 heat-related deaths per 100 000 people per year) if global warming could be limited to 2°C (ie, under the SSP1-2·6 scenario). Large increases are also expected by 2100 under the SSP3-7·0 scenario (89·8 heat-related deaths per 100 000 people per year) due to the high population growth projected under this pathway. Projections in MENA are far higher than previously observed in other regions, with Iran expected to be the most vulnerable country.

Interpretation Stronger climate change mitigation and adaptation policies are needed to avoid these heat-related mortality impacts. Since much of this increase will be driven by population changes, demographic policies and healthy ageing will also be key to successful adaptation.

Lancet Planet Health 2023; 7: e282–90

Centre on Climate Change and Planetary Health, London School of Hygiene & Tropical Medicine, London, UK (Prof S Hajat PhD); **Environmental Predictions Department, Climate and Atmosphere Research Centre, The Cyprus Institute, Nicosia, Cyprus** (Y Proestos PhD; J-L Araya-Lopez PhD, T Economou PhD, Prof J Lelieveld PhD); **Max Planck Institute for Chemistry, Mainz, Germany** (Prof J Lelieveld)

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Climate change impacts

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Since 1980s the region has been warming faster than other inhabited parts of the world

GHG emissions are growing rapidly and contribute significantly to climate change (currently, the Middle East more than the EU)

Climate projections indicate the strongest warming in summer, with unprecedented heat extremes

Total precipitation will likely decrease in many regions, mainly in the eastern Mediterranean, and may increase in low latitudes

Sea level rise follows global mean (BaU ~0.5–1m, more not excluded)

Socio-economic sectors can be critically affected (e.g., public health)

A10 | Thursday, September 15, 2022 THE WALL STREET JOURNAL.

WORLD NEWS

NASSER NASSER/ASSOCIATED PRESS

A juice vendor prepares a drink in the West Bank, where temperatures have regularly topped 100 degrees Fahrenheit oflate.

Intensifying Heat Plagues Mideast

Air quality: which sources and processes can cause hazardous air pollution? What are the health impacts?

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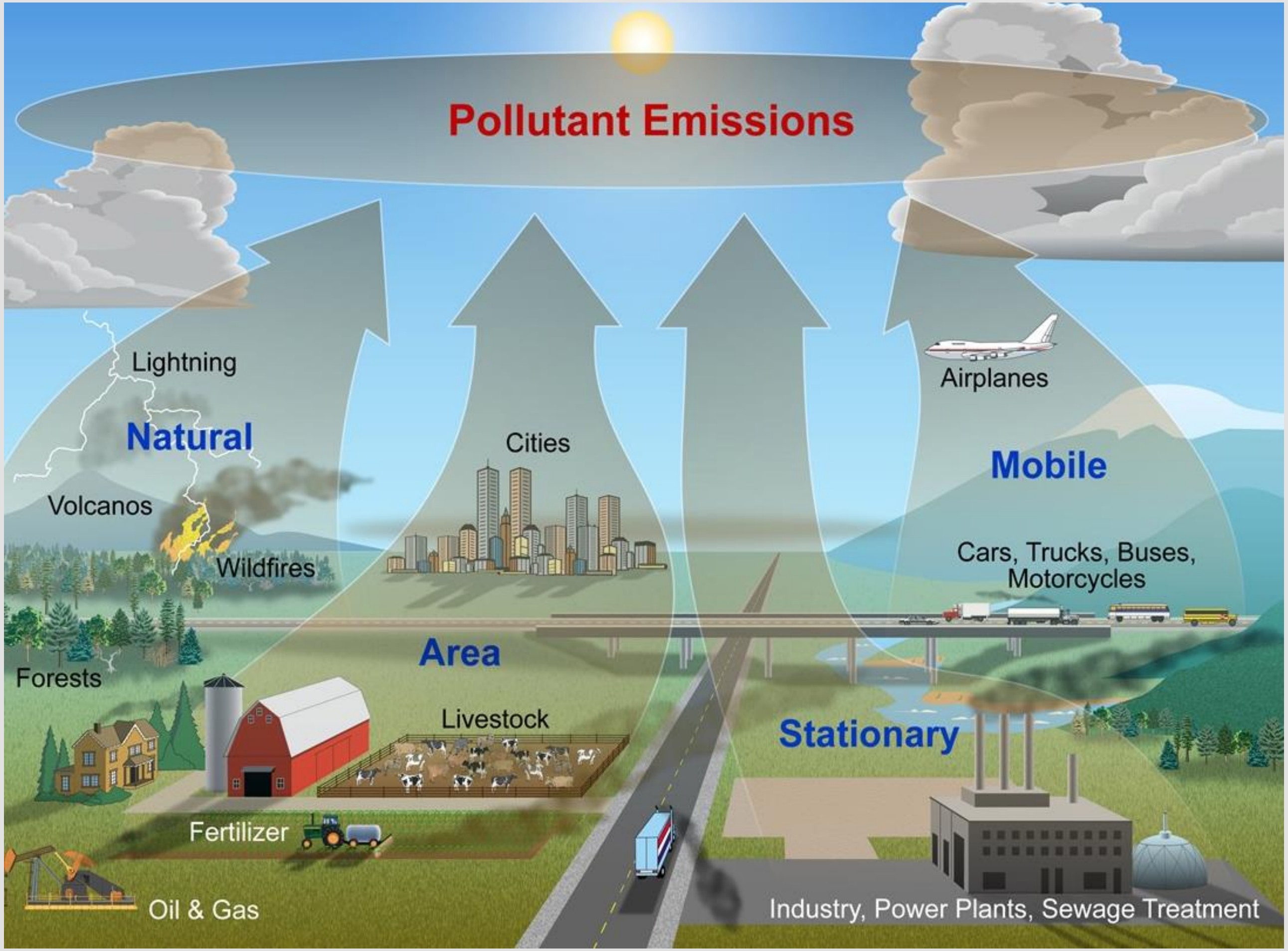

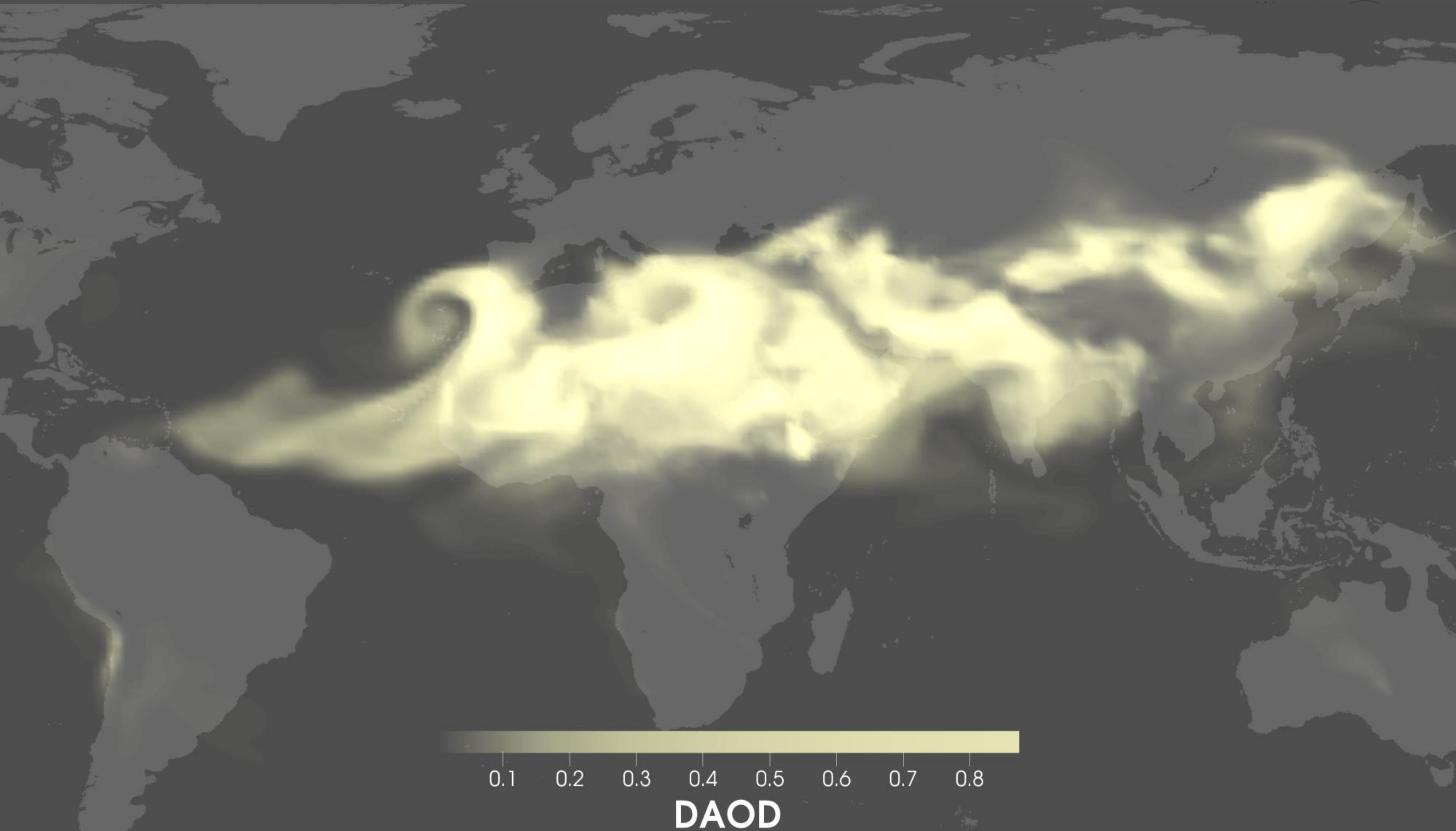
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
DAOD

Annual mean fine particulate matter concentrations ($PM_{2.5}$)

Note: WHO guideline is 5 µg/m³, previously 10 µg/m³

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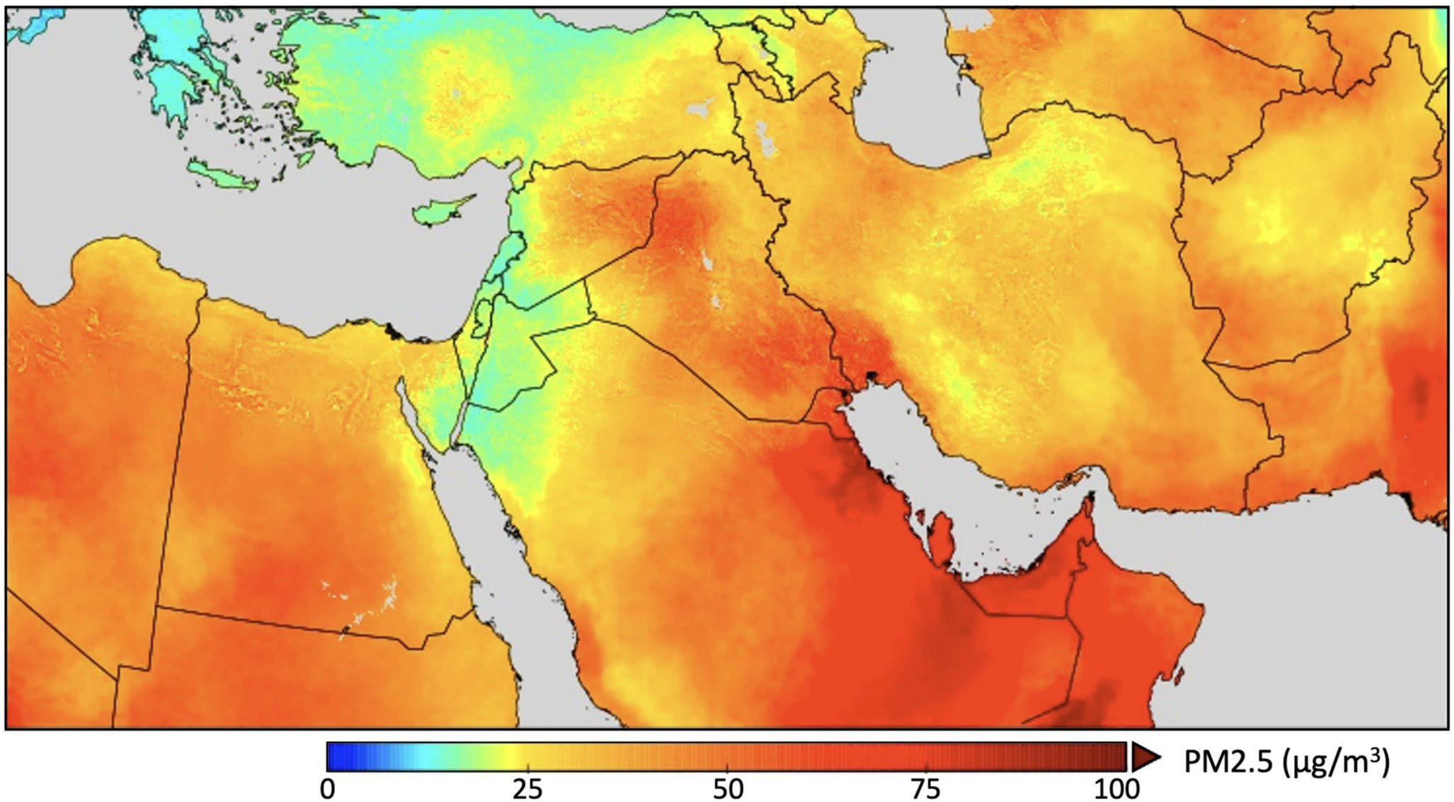

AQABA campaign ship track

AQABA is Air Quality and climate change in the Arabian Basin

Kommandor Iona
research and exploration vessel

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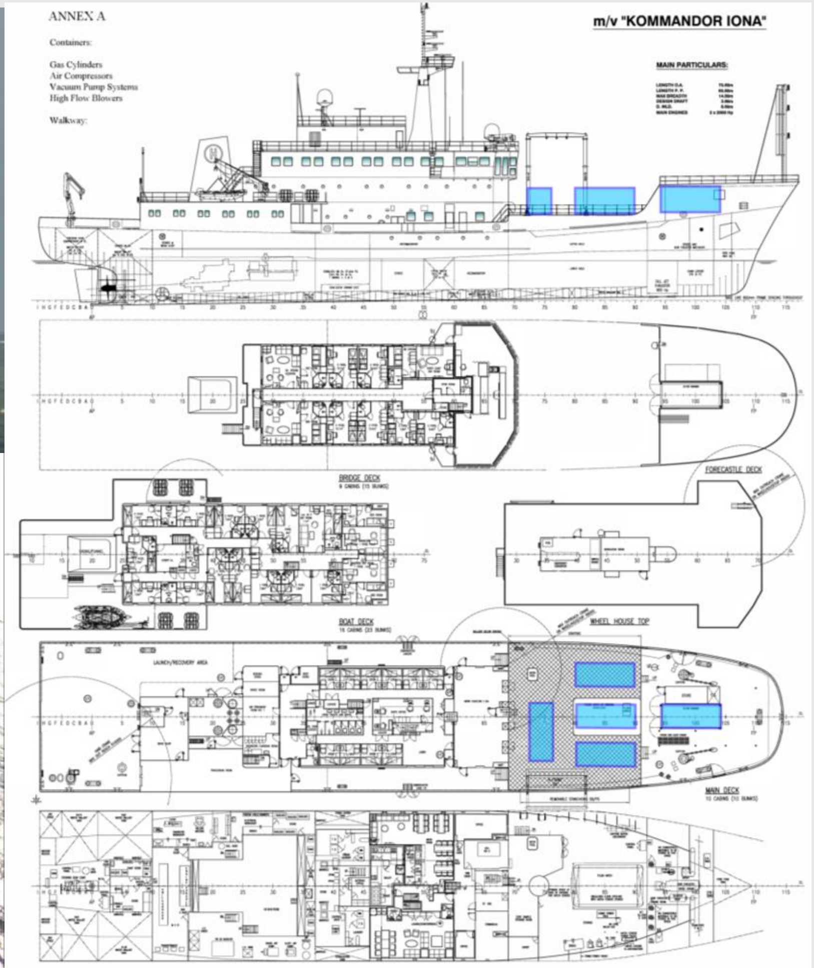




Fine aerosol particle composition during AQABA campaign
(PM_1 <1 µm, finest particles penetrate deepest into lungs)

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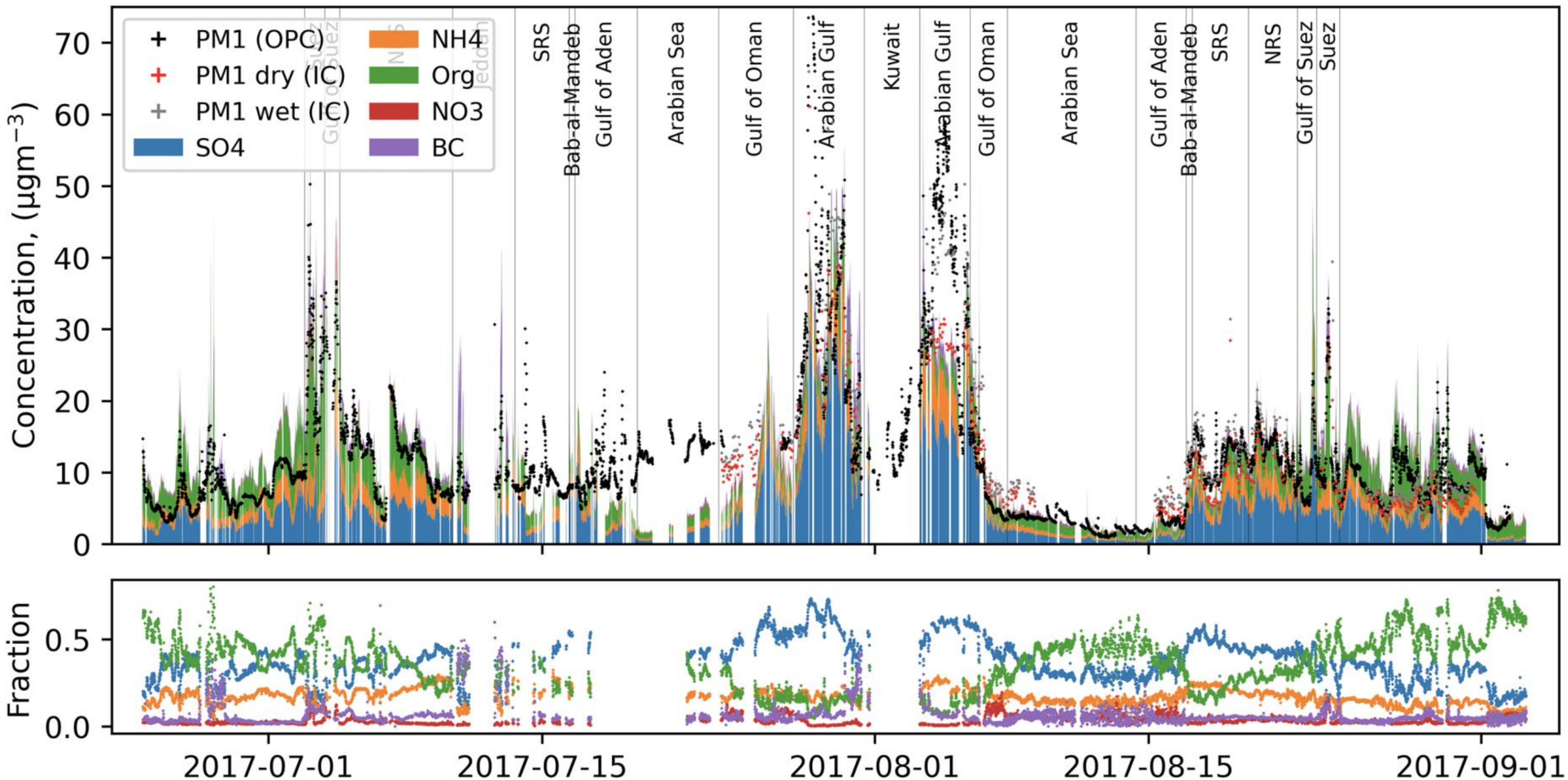
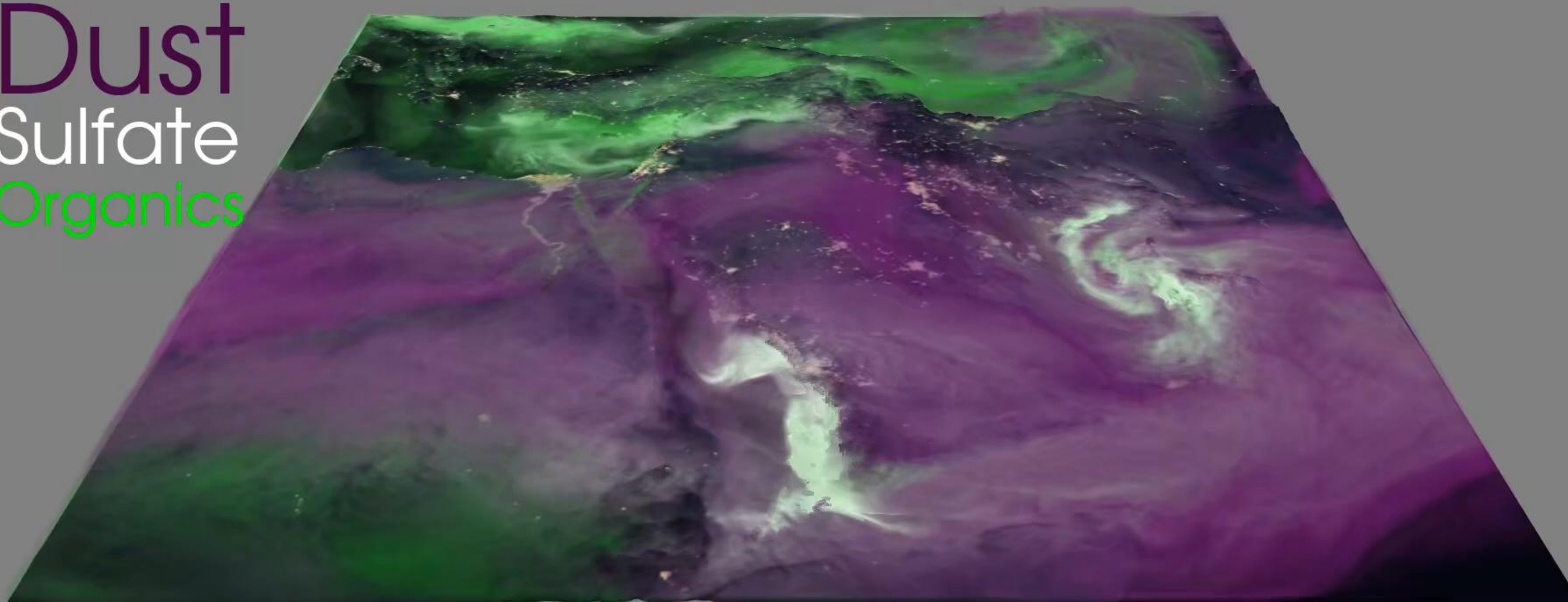


"Arabic" smog

2017-06-22 00:00:00
WRF-Chem (10 km) MADE/VBS
Sergey.Osipov@mpic.de

Dust
Sulfate
Organics



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communications
earth & environment

ARTICLE

https://doi.org/10.1038/s43247-022-00514-6 OPEN

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Severe atmospheric pollution in the Middle East is attributable to anthropogenic sources

Sergey Osipov[1], Sourangsu Chowdhury[1], John N. Crowley[1], Ivan Tadic[1], Frank Drewnick[2], Stephan Borrmann[2], Philipp Eger[1], Friederike Fachinger[2], Horst Fischer[1], Evgeniya Predybaylo[1], Mohammed Fnais[3], Hartwig Harder[1], Michael Pikridas[4], Panos Vouterakos[4], Andrea Pozzer[1], Jean Sciare[4], Alexander Ukhov[5], Georgiy L. Stenchikov[5], Jonathan Williams[1] & Jos Lelieveld[1,4]✉

[1]Atmospheric Chemistry Department, Max Planck Institute for Chemistry, 55128 Mainz, Germany. [2]Particle Chemistry Department, Max Planck Institute for Chemistry, Mainz, Germany. [3]King Saud University, College of Science, Riyadh 11451, Saudi Arabia. [4]Atmosphere and Climate Research Center, The Cyprus Institute, 2121 Aglantzia, Cyprus. [5]King Abdullah University of Science and Technology, Thuwal 23955-6900, Saudi Arabia. ✉email: jos.lelieveld@mpic.de

https://www.nature.com/articles/s43247-022-00514-6

Size of particles matters: fine particles penetrate deeply into the respiratory tract, and the smallest ones can translocate into the bloodstream and affect other organs

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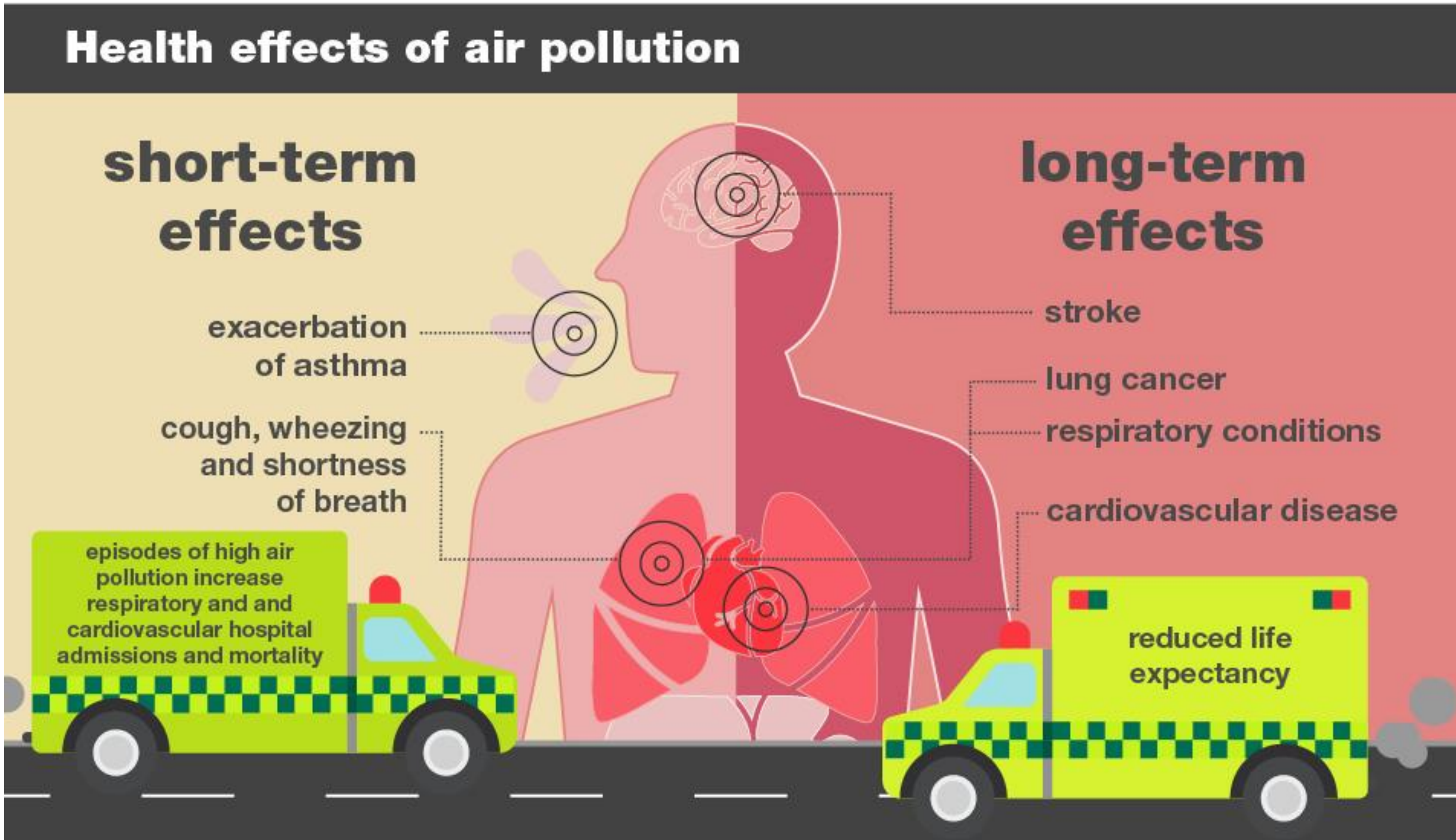

Leading risks 2000

Leading risks 2000	Percentage of total DALYs
1 Particulate matter pollution	10·6 (8·5 to 12·3)
2 Child growth failure	9·3 (6·4 to 11·1)
3 Low birthweight and short gestation	8·9 (8·3 to 9·6)
4 High systolic blood pressure	6·3 (5·2 to 7·4)
5 Smoking	5·6 (4·7 to 6·5)
6 Unsafe water source	4·0 (2·3 to 5·2)
7 Unsafe sanitation	3·3 (2·7 to 3·9)
8 High fasting plasma glucose	3·1 (2·8 to 3·5)
9 High LDL cholesterol	2·6 (1·6 to 3·6)
10 Unsafe sex	2·6 (2·1 to 3·2)
11 High body–mass index	2·5 (1·1 to 3·9)
12 High alcohol use	2·4 (1·9 to 3·1)
13 No access to handwashing facility	2·3 (–0·5 to 4·9)
14 Kidney dysfunction	2·2 (1·9 to 2·4)
15 Occupational injuries	1·6 (1·5 to 1·7)
16 Secondhand smoke	1·6 (0·8 to 2·4)
17 Diet low in fruits	1·3 (0·5 to 2·0)
18 Iron deficiency	1·3 (0·9 to 1·7)
19 Diet high in sodium	1·2 (0·3 to 2·7)
20 Suboptimal breastfeeding	1·2 (0·9 to 1·5)
21 Diet low in whole grains	1·2 (0·5 to 1·8)
22 Lead exposure	1·0 (0·0 to 2·0)
23 Low temperature	0·9 (0·7 to 1·0)
24 Drug use	0·8 (0·7 to 0·9)
25 Diet low in vegetables	0·6 (0·4 to 0·9)
29 Diet low in omega–6 unsaturated fatty acids	0·5 (–1·7 to 1·9)

Leading risks 2021

Leading risks 2021	95% UI	Percentage of total DALYs
1 Particulate matter pollution	(1 to 2)	8·0 (6·7 to 9·4)
2 High systolic blood pressure	(1 to 2)	7·8 (6·4 to 9·2)
3 Smoking	(3 to 6)	5·7 (4·7 to 6·8)
4 Low birthweight and short gestation	(3 to 6)	5·6 (4·8 to 6·3)
5 High fasting plasma glucose	(3 to 6)	5·4 (4·8 to 6·0)
6 High body–mass index	(3 to 10)	4·5 (1·9 to 6·8)
7 High LDL cholesterol	(7 to 10)	3·0 (1·9 to 4·2)
8 Kidney dysfunction	(6 to 10)	3·0 (2·6 to 3·4)
9 Child growth failure	(6 to 14)	2·6 (1·4 to 3·5)
10 High alcohol use	(7 to 11)	2·5 (2·1 to 3·1)
11 Unsafe sex	(11 to 17)	1·5 (1·4 to 1·7)
12 Diet low in fruits	(11 to 22)	1·5 (0·6 to 2·3)
13 Unsafe water source	(11 to 24)	1·5 (0·8 to 2·0)
14 Diet high in sodium	(8 to 36)	1·4 (0·3 to 3·2)
15 Diet low in whole grains	(12 to 23)	1·4 (0·6 to 2·1)
16 Secondhand smoke	(11 to 26)	1·2 (0·6 to 1·8)
17 Iron deficiency	(12 to 23)	1·2 (0·9 to 1·6)
18 Lead exposure	(10 to 52)	1·2 (0·0 to 2·4)
19 Unsafe sanitation	(14 to 23)	1·1 (0·9 to 1·4)
20 Occupational injuries	(15 to 21)	1·1 (1·0 to 1·2)
21 Drug use	(17 to 24)	1·0 (0·8 to 1·1)
22 Low temperature	(19 to 26)	0·9 (0·8 to 1·0)
23 No access to handwashing facility	(11 to 53)	0·8 (–0·2 to 1·8)
24 Diet low in vegetables	(20 to 29)	0·7 (0·4 to 1·0)
25 Diet low in omega–6 unsaturated fatty acids	(11 to 53)	0·6 (–2·0 to 2·3)
36 Suboptimal breastfeeding	(30 to 40)	0·3 (0·2 to 0·4)

Environmental and occupational risks
Behavioural risks
Metabolic risks

https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(24)00933-4/fulltext

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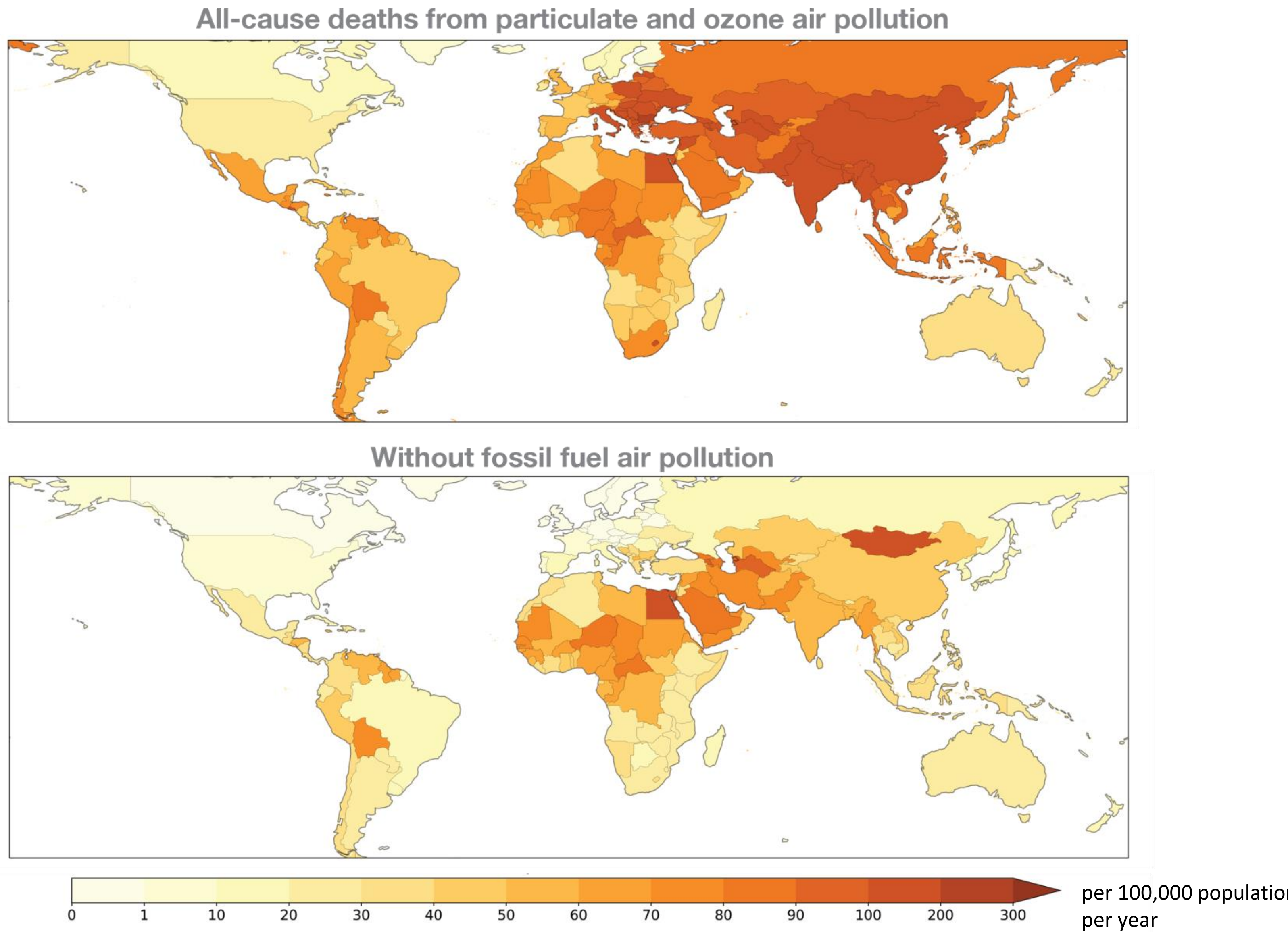
All-cause deaths from particulate and ozone air pollution
Without fossil fuel air pollution
0
1
10
20
30
40
50
60
70
80
90
100
200
300
per 100,000 population
per year

Air quality impacts

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In the Middle East, air pollution levels are in permanent violation of public health guidelines

Hazardous fine particulate matter is mainly anthropogenic (>90%), and distinct from the less harmful, larger desert dust particles

Air pollution is of greater importance than other leading health risk factors, like tobacco smoking

In the Middle East, anthropogenic air pollution is a leading health risk and an important climatic factor

Reducing fossil fuel-related emissions has important co-benefits for air quality (health) and climate

Thank you