The Tropospheric Ozone Assessment Report:
A community-wide effort to quantify tropospheric ozone in a rapidly changing world

Owen R. Cooper, CIRES, U. of Colorado/NOAA Earth System Research Laboratory, Boulder

NASA HAQAST4, July 16-17, 2018

Gordon Dining and Event Center, UW-Madison

TOAR
tropospheric ozone assessment report

Tropospheric Ozone Assessment Report (TOAR)

Global metrics for climate change, human health and crop/ecosystem research

INTERNATIONAL GLOBAL ATMOSPHERIC CHEMISTRY
IGAC

Mission:
To provide the research community with an up-to-date scientific assessment of tropospheric ozone's global distribution and trends from the surface to the tropopause.

Deliverables:

1) The first tropospheric ozone assessment report based on all available surface observations, the peer-reviewed literature and new analyses.
2) A database containing ozone exposure metrics at thousands of measurement sites around the world, freely accessible for research on the global-scale impact of ozone on climate, human health and crop/ecosystem productivity.

http://www.igacproject.org/activities/TOAR

Stakeholders:

WMO | GAW

World Health Organization

NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

LRTAP
Long-range Transboundary Air Pollution

Task Force on Hemispheric Transport of Air Pollution

TOAR members: 230+ scientists from 36 nations, representing research on all 7 continents

TOAR Publications

ELEMENTA Science of the Anthropocene

Schultz, MG, et al 2017 Tropospheric Ozone Assessment Report: Database and metrics data of global surface ozone observations. *Elem Sci Anth,* 5: 58, DOI: https://doi.org/10.1525/elementa.244

RESEARCH ARTICLE

Tropospheric Ozone Assessment Report: Database and metrics data of global surface ozone observations

Martin G. Schultz[1,82], Sabine Schröder[1], Olga Lyapina[1], Owen R. Cooper[2,3], Ian Galbally[4], Irina Petropavlovskikh[2,3], Erika von Schneidemesser[5], Hiroshi Tanimoto[6], Yasin Elshorbany[7,8], Manish Naja[9], Rodrigo J. Seguel[10], Ute Dauert[11], Paul Eckhardt[12], Stefan Feigenspan[11], Markus Fiebig[12], Anne-Gunn Hjellbrekke[12], You-Deog Hong[13], Peter Christian Kjeld[14], Hiroshi Koide[15], Gary Lear[16], David Tarasick[17], Mikio Ueno[15], Markus Wallasch[18], Darrel Baumgardner[19], Ming-Tung Chuang[20], Robert Gillett[4],

ELEMENTA Science of the Anthropocene

Chang, K-L, et al 2017 Regional trend analysis of surface ozone observations from monitoring networks in eastern North America, Europe and East Asia. *Elem Sci Anth,* 5: 50, DOI: https://doi.org/10.1525/elementa.243

RESEARCH ARTICLE

Regional trend analysis of surface ozone observations from monitoring networks in eastern North America, Europe and East Asia

Kai-Lan Chang[*], Irina Petropavlovskikh[*,†], Owen R. Cooper[*,†], Martin G. Schultz[‡] and Tao Wang[§]

Surface ozone is a greenhouse gas and pollutant detrimental to human health and crop and ecosystem productivity. The Tropospheric Ozone Assessment Report (TOAR) is designed to provide the research community with an up-to-date observation-based overview of tropospheric ozone's global distribution and trends. The TOAR Surface Ozone Database contains ozone metrics at thousands of monitoring sites around the world, densely clustered across mid-latitude North America, western Europe and East Asia. Calculating regional ozone trends across these locations is challenging due to the uneven spacing of the monitoring sites across urban and rural areas. To meet this challenge we conducted a spatial and temporal trend analysis of several TOAR ozone metrics across these three regions for summertime (April–September)

ELEMENTA Science of the Anthropocene

Lefohn, AS, et al. 2018 Tropospheric ozone assessment report: Global ozone metrics for climate change, human health, and crop/ecosystem research. *Elem Sci Anth,* 6: 28. DOI: https://doi.org/10.1525/elementa.279

RESEARCH ARTICLE

Tropospheric ozone assessment report: Global ozone metrics for climate change, human health, and crop/ecosystem research

Allen S. Lefohn[*], Christopher S. Malley[†,‡,§], Luther Smith[‖], Benjamin Wells[¶], Milan Hazucha[**], Heather Simon[¶], Vaishali Naik[††], Gina Mills[‡‡], Martin G. Schultz[§§], Elena Paoletti[‖‖], Alessandra De Marco[¶¶], Xiaobin Xu[***], Li Zhang[†††], Tao Wang[†††], Howard S. Neufeld[‡‡‡], Robert C. Musselman[§§§], David Tarasick[‖‖‖], Michael Brauer[¶¶¶], Zhaozhong Feng[****], Haoye Tang[††††], Kazuhiko Kobayashi[‡‡‡‡], Pierre Sicard[§§§§], Sverre Solberg[‖‖‖‖] and Giacomo Gerosa[¶¶¶¶]

ELEMENTA Science of the Anthropocene

Young, PJ, et al. 2018 Tropospheric Ozone Assessment Report: Assessment of global-scale model performance for global and regional ozone distributions, variability, and trends. *Elem Sci Anth,* 6: 10. DOI: https://doi.org/10.1525/elementa.265

REVIEW

Tropospheric Ozone Assessment Report: Assessment of global-scale model performance for global and regional ozone distributions, variability, and trends

P. J. Young[*,†,‡], V. Naik[§], A. M. Fiore[‖,¶], A. Gaudel[**,††], J. Guo[‖], M. Y. Lin[§,‡‡], J. L. Neu[§§], D. D. Parrish[**,††], H. E. Rieder[¶,‖‖], J. L. Schnell[¶¶], S. Tilmes[***], O. Wild[*], L. Zhang[†††], J. Ziemke[‡‡‡,§§§], J. Brandt[‖‖‖], A. Delcloo[¶¶¶], R. M. Doherty[****], C. Geels[‖‖‖], M. I. Hegglin[††††], L. Hu[‡‡‡‡], U. Im[‖‖‖], R. Kumar[§§§§], A. Luhar[‖‖‖‖], L. Murray[¶¶¶¶], D. Plummer[*****], J. Rodriguez[‡‡‡], A. Saiz-Lopez[†††††], M. G. Schultz[‡‡‡‡‡], M. T. Woodhouse[‖‖‖‖] and G. Zeng[§§§§§]

The goal of the Tropospheric Ozone Assessment Report (TOAR) is to provide the research community with an up-to-date scientific assessment of tropospheric ozone, from the surface to the tropopause. While a suite of observations provides significant information on the spatial and temporal distribution of tropospheric ozone, observational gaps make it necessary to use global atmospheric chemistry models to synthesize our understanding of the processes and variables that control tropospheric ozone abundance and its variability. Models facilitate the interpretation of the observations and allow us to make projections of future tropospheric ozone and trace gas distributions for different anthropogenic or natural perturbations. This paper assesses the skill of current-generation global atmospheric chemistry models in simulating the observed present-day tropospheric ozone distribution, variability, and trends. Drawing upon the results of recent international multi-model intercomparisons and using a range of model evaluation techniques, we demonstrate that global chemistry models are broadly skillful in capturing the spatio-temporal variations of tropospheric ozone over the seasonal cycle, for extreme pollution episodes, and changes over interannual to decadal periods. However, models are consistently biased high in the northern hemisphere and biased low in the southern hemisphere, throughout the depth of the troposphere, and are unable to replicate particular metrics that define the longer term trends in tropospheric ozone as derived from some background sites. When the models compare unfavorably against observations, we discuss the potential causes of model biases and propose directions for future developments, including improved evaluations that may be able to better diagnose the root cause of the model-observation disparity. Overall, model results should be approached critically, including determining whether the model performance is acceptable for the problem being addressed, whether biases can be tolerated or corrected, whether the model is appropriately constituted, and whether there is a way to satisfactorily quantify the uncertainty.

ELEMENTA Science of the Anthropocene

Fleming, ZL, et al. 2018 Tropospheric Ozone Assessment Report: Present-day ozone distribution and trends relevant to human health. *Elem Sci Anth,* 6: 12. DOI: https://doi.org/10.1525/elementa.273

RESEARCH ARTICLE

Tropospheric Ozone Assessment Report: Present-day ozone distribution and trends relevant to human health

Zoë L. Fleming[*], Ruth M. Doherty[†], Erika von Schneidemesser[‡], Christopher S. Malley[§,****,††††], Owen R. Cooper[‖,‖‖], Joseph P. Pinto[¶], Augustin Colette[**], Xiaobin Xu[††], David Simpson[‡‡,¶¶¶], Martin G. Schultz[§§,‖‖], Allen S. Lefohn[¶¶], Samera Hamad[***], Raeesa Moolla[†††], Sverre Solberg[‡‡‡] and Zhaozhong Feng[§§§]

This study quantifies the present-day global and regional distributions (2010–2014) and trends (2000–2014) for five ozone metrics relevant for short-term and long-term human exposure. These metrics, calculated by the Tropospheric Ozone Assessment Report, are: 4th highest daily maximum 8-hour ozone (4MDA8); number of days with MDA8 > 70 ppb (NDGT70), SOMO35 (annual Sum of Ozone Means Over 35 ppb) and two seasonally averaged metrics (3MMDA1; AVGMDA8). These metrics were explored at ozone monitoring sites worldwide, which were classified as urban or non-urban based on population and nighttime lights data.

Present-day distributions of 4MDA8 and NDGT70, determined predominantly by peak values, are similar with highest levels in western North America, southern Europe and East Asia. For the other three metrics, distributions are similar with North-South gradients more prominent across Europe and Japan. Between 2000 and 2014, significant negative trends in 4MDA8 and NDGT70 occur at most US and some European sites. In contrast, significant positive trends are found at many sites in South Korea and Hong Kong, with mixed trends across Japan. The other three metrics have similar, negative trends for many non-urban North American and some European and Japanese sites, and positive trends across much of East Asia. Globally, metrics at many sites exhibit non-significant trends. At 59% of all sites there is a common direction and significance in the trend across all five metrics, whilst 4MDA8 and NDGT70 have a common trend at ~80% of all sites. Sensitivity analysis shows AVGMDA8 trends differ with averaging period (warm season or annual). Trends are unchanged at many sites when a 1995–2014 period is used; although fewer sites exhibit non-significant trends. Over the longer period 1970–2014, most Japanese sites exhibit positive 4MDA8/SOMO35 trends. Insufficient data exist to characterize ozone trends for the rest of Asia and other world regions.

ELEMENTA Science of the Anthropocene

Gaudel, A, et al. 2018. Tropospheric Ozone Assessment Report: Present-day distribution and trends of tropospheric ozone relevant to climate and global atmospheric chemistry model evaluation. *Elem Sci Anth,* 6: 39. DOI: https://doi.org/10.1525/elementa.291

RESEARCH ARTICLE

Tropospheric Ozone Assessment Report: Present-day distribution and trends of tropospheric ozone relevant to climate and global atmospheric chemistry model evaluation

A. Gaudel[1,2], O. R. Cooper[1,2], G. Ancellet[3], B. Barret[4], A. Boynard[3,5], J. P. Burrows[6], C. Clerbaux[3], P.-F. Coheur[7], J. Cuesta[8], E. Cuevas[9], S. Doniki[7], G. Dufour[8], F. Ebojie[10], G. Foret[8], O. Garcia[11], M. J. Granados-Muñoz[12,13], J. W. Hannigan[14], F. Hase[15], B. Hassler[1,2,16], G. Huang[17], D. Hurtmans[7], D. Jaffe[18,19], N. Jones[20], P. Kalabokas[21], B. Kerridge[22], S. Kulawik[23,24], B. Latter[22], T. Leblanc[12], E. Le Flochmoën[4], W. Lin[25], J. Liu[26,27], X. Liu[17], E. Mahieu[27], A. McClure-Begley[1,2], J. L. Neu[23], M. Osman[29], M. Palm[6], H. Petetin[4], I. Petropavlovskikh[1,2], R. Querel[28], N. Rahpoe[23], A. Rozanov[23], M. G. Schultz[31,32], J. Schwab[33], R. Siddans[22], D. Smale[20], M. Steinbacher[34], H. Tanimoto[35], D. W. Tarasick[36], V. Thouret[4], A. M. Thompson[37], T. Trickl[38], E. Weatherhead[1,2], C. Wespes[39], H. M. Worden[40], C. Vigouroux[40], X. Xu[41], G. Zeng[30], J. Ziemke[42]

ELEMENTA Science of the Anthropocene

Mills, G, et al. 2018. Tropospheric Ozone Assessment Report: Present-day tropospheric ozone distribution and trends relevant to vegetation. *Elem Sci Anth,* 6: 47. DOI: https://doi.org/10.1525/elementa.302

RESEARCH ARTICLE

Tropospheric Ozone Assessment Report: Present-day tropospheric ozone distribution and trends relevant to vegetation

Gina Mills[*,†], Håkan Pleijel[†], Christopher S. Malley[‡,§,‖], Baerbel Sinha[¶], Owen R. Cooper[**], Martin G. Schultz[††], Howard S. Neufeld[‡‡], David Simpson[§§,‖‖], Katrina Sharps[*], Zhaozhong Feng[¶¶], Giacomo Gerosa[***], Harry Harmens[*], Kazuhiko Kobayashi[†††], Pallavi Saxena[‡‡‡], Elena Paoletti[§§§], Vinayak Sinha[¶] and Xiaobin Xu[‖‖‖]

TOAR
tropospheric ozone assessment report

ELEMENTA Science of the Anthropocene

Schultz, MG, et al 2017 Trop
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5: 58, DOI: https://doi.org/10

Tropospheric Ozone Assessment Repo
metrics data of global surface ozone

Martin G. Schultz[1,82], Sabine Schröder[1], Olga Lyapina[1], Ow
Irina Petropavlovskikh[2,3], Erika von Schneidemesser[5], Hiros
Yasin Elshorbany[7,8], Manish Naja[9], Rodrigo J. Seguel[10], Ute
Stefan Feigenspan[11], Markus Fiebig[12], Anne-Gunn Hjellbrek
Peter Christian Kjeld[14], Hiroshi Koide[15], Gary Lear[16], Davi
Markus Wallasch[18], Darrel Baumgardner[19], Ming-Tung Chua
Meehye Lee[21], Suzie Molloy[4], Raeesa Moolla[22], Tao Wang[23]
Jose A. Adame[25], Gerard Ancellet[26], Francesco Apadula[27]

[1] Institute for Energy and Climate Research (IEK-8), Forschungszentrum Jülich, Jülich, DE
[2] Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO, US
[3] NOAA Earth System Research Laboratory, Boulder, CO, US
[4] CSIRO Climate Science Centre, Aspendale, Victoria, AU
[5] Institute for Advanced Sustainability Studies, Potsdam, DE
[6] National Institute for Environmental Studies, Tsukuba, Ibaraki 305-8506, JP
[7] NASA Goddard Space Flight Center, Greenbelt, MD, US
[8] Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD, US
[9] Aryabhatta Research Institute of Observational Sciences, Nainital, IN
[10] Environmental Department, SAGU, Santiago, CL
[11] Unit II 4.2, Air Quality Assessment, German Environment Agency/Umweltbundesamt, Dessau-Roßlau, DE
[12] Norwegian Institute for Air Research (NILU), Kjeller, NO
[13] Air Quality Research Division, National Institute of Environmental Research, Incheon, Republic of Korea, KR
[14] European Environment Agency, Copenhagen, DK
[15] Japan Meteorological Agency (JMA), Tokyo, JP
[16] Office of Air and Radiation (OAR) – Office of Atmospheric Programs (OAP), U.S. Environmental Protection Agency,

on, Air Quality Research
ch, Environment and
bundesamt, Langen, DE
Universidad Nacional
o City, MX
ering, National Central
ences, Korea University,
d Environmental Stud-
, Johannesburg, ZA
al Engineering, Hong
m, Hong Kong, CN
nvironment Centre
tation Branch,
nology (INTA), Ctra.
lva, ES
MC, Université Versailles
S.p.A., 20134 Milano, IT
o Paulo. Rua do Matao
, BR
nos Aires Main Observa-
Management – National
Maritime Branch,
ring of Hydrosphere

[31] National Research Council, Institute of Atmospheric Sciences and Climate, Bologna, IT
[32] National Institute of Environmental Research, Incheon, Republic of Korea, KR
[33] Université Clermont Auvergne, CNRS, LaMP, F-63000 Clermont-Ferrand, FR
[34] Izana Atmospheric Research Center, State Meteorological Agency of Spain (AEMET), Santa Cruz de Tenerife, ES
[35] Servicio Meteorológico Nacional, Ushuaia, Tierra del Fuego, AR
[36] Institute of Environmental Protection – National Research Institute, Warsaw, PL
[37] Joint International Research Laboratory of Atmospheric and Earth System Sciences, School of Atmospheric Sciences, Nanjing University, Nanjing, CN
[38] Umweltbundesamt/Federal Environment Agency Austria, Vienna, AT
[39] Latvian Environment Geology and Meteorology Centre, Riga, LV
[40] National Atmospheric Research Laboratory, Gadanki, IN
[41] Laboratoire d'Aérologie, University of Toulouse, CNRS, UPS, Toulouse, FR
[42] Meteorological Observatory Hohenpeissenberg, German Meteorological Service (DWD), Hohenpeissenberg, DE
[43] German Meteorological Service (DWD), Research Center Human Biometeorology, Freiburg, DE
[44] Atmospheric Research and Instrumentation Branch, National Institute for Aerospace Technology (INTA), Madrid, ES
[45] LSCE, Laboratoire des Sciences du Climat et de l'Environnement, CEA-CNRS-UVSQ, IPSL, Gif-sur-Yvette, FR
[46] School of Public Health, University of Maryland, College Park, MD, US
[47] Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, CO, US
[48] Regional Delegation of Azores, Portuguese Institute for Sea and Atmosphere (IPMA), Ponta Delgada, Azores, PT
[49] Department of Environmental Science, Aarhus University, 4000 Roskilde, DK
[50] School of Science, Technology, Engineering and Math, University of Washington-Bothell, Bothell, WA, US
[51] National institute of Aeronautics and Space, Jl., Bandung 40173, ID
[52] Finnish Meteorological Institute, Helsinki, FI
[53] National Institute of Meteorological Sciences, Korea Meteorological Administration, Jeju, Republic of Korea, KR
[54] Air Quality and Climate Change Division, Ministry of Environmental Protection, Jerusalem, IL
[55] Atmospheric Science Program, Michigan Technological University, Houghton, MI, US
[56] Malaysian Meteorological Department, Jalan Sultan, Petaling Jaya, MY
[57] Slovenian Environment Agency, Ljubljana, SI
[58] Administratia Nationala de Meteorologie, Sos Bucuresti-Ploiesti 97, RO

[59] National Centre for Atmospheric Science (NCAS), Department of Chemistry, University of York, Heslington, York, YO10 5DD, UK
[60] Auckland Council, Auckland, NZ
[61] German Environment Agency, GAW Global Observatory Zugspitze/Hohenpeissenberg, Zugspitze, DE
[62] School of Environmental Sciences, Jawaharlal Nehru University, New Delhi – 110067, IN
[63] Atmospheric Sciences Research Center, State University of New York at Albany, Albany, NY, US
[64] Office of Environment and Heritage, Sydney, New South Wales, AU
[65] Kislovodsk High Mountain Scientific Station of A. M. Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences, Moscow, RU
[66] School of Chemistry, University of Bristol, Bristol, GB
[67] Department of Earth and Environmental Sciences, Indian Institute of Science Education and Research (IISER) Mohali, Manauli PO, Punjab, IN
[68] A.M. Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences, Moscow, RU
[69] National University of Ireland Galway, Galway, GB
[70] National Institute of Public Health and the Environment, Bilthoven, NL
[71] Environmental and Climate Sciences Dept., Brookhaven National Laboratory, Upton, NY, US
[72] South Australia Environment Protection Authority, Adelaide, South Australia, AU
[73] Swiss Federal Laboratories for Materials Science and Technology (Empa), Dübendorf, CH
[74] Indonesian Agency for Meteorological Climatological and Geophysics, Jakarta, ID
[75] Environment Protection Authority Victoria, Melbourne, Victoria, AU
[76] Karlsruher Institut für Technologie, Institut für Meteorologie und Klimaforschung, Atmosphärische Umweltforschung (IMK-IFU), Garmisch-Partenkirchen, DE
[77] Meteorological Observation Center, China Meteorological Administration, Beijing, CN
[78] Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, DE
[79] Key Laboratory for Atmospheric Chemistry, Chinese Academy of Meteorological Sciences, China Meteorological Administration, Beijing, CN
[80] Environment Research Institute, Shandong University, Ji'nan, Shandong, CN
[81] Institute of Urban Meteorology, China Meteorological Administration, Beijing, CN
[82] Jülich Supercomputing Centre (JSC), Forschungszentrum Jülich, Jülich, DE

Corresponding author: Martin G. Schultz (m.schultz@fz-juelich.de)

The TOAR Database

As of March 2018:

10989 O_3 data series at 9791 stations

The database is being expanded to include:

NO_2
NO
PM10
CO
Meteorological data, incl. COSMO reanalysis @ 6km
…

TOAR
tropospheric ozone assessment report

JÜLICH
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TOAR Ozone Metrics

The TOAR database contains various ozone metrics at thousands of surface sites around the world. Some key metrics are:

Human Health:

- Maximum daily 8-hour average
- annual number of 8-hour exceedances above 70 ppb

Vegetation:

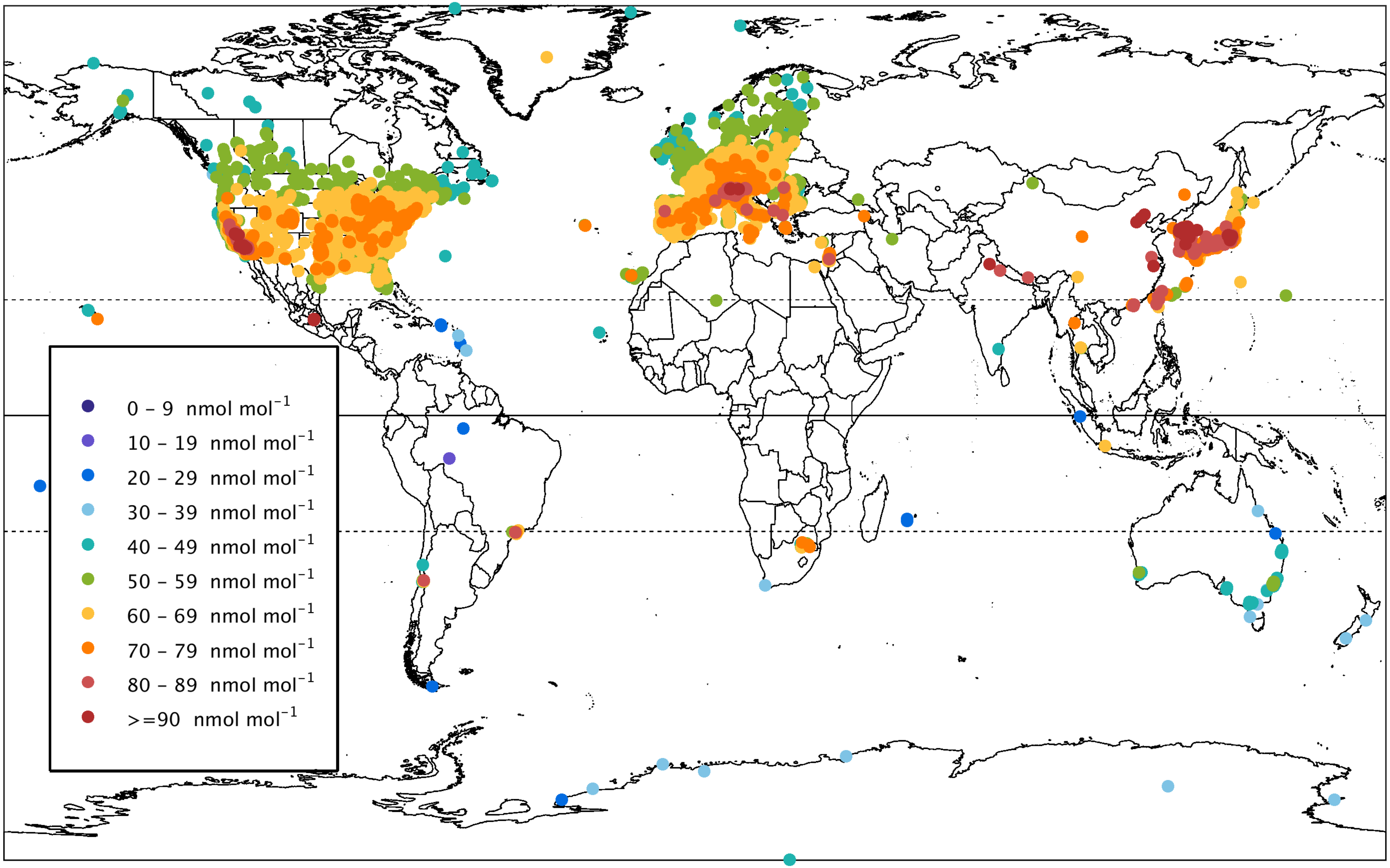
- Cumulative Exposure Index: W126
- Cumulative Exposure Index: AOT40

Climate Change:

- Monthly means, medians and various percentiles
- Monthly and seasonal mean vertical profiles:
  ozonesondes, lidar, MOZAIC/IAGOS commercial aircraft
- tropospheric ozone burden or columns
  OMI/MLS, TES, GOME/GOME2, IASI, ground-based FTIR instruments

98th percentile ozone value, summer   Data extracted on: 2016-10-24

perc98 ozone, 2010-2014 (minimum 3 years): 4792 all sites



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Long-Term Ozone Exposure and Mortality in a Large Prospective Study

Michelle C. Turner[1,2,3,4], Michael Jerrett[5], C. Arden Pope III[6], Daniel Krewski[1,7], Susan M. Gapstur[8], W. Ryan Diver[8], Bernardo S. Beckerman[5], Julian D. Marshall[9], Jason Su[5], Daniel L. Crouse[10], and Richard T. Burnett[11]

[1]McLaughlin Centre for Population Health Risk Assessment and [7]School of Epidemiology, Public Health and Disease Prevention, Faculty of Medicine, University of Ottawa, Ottawa, Ontario, Canada; [2]Centre for Research in Environmental Epidemiology, Barcelona, Spain; [3]Universitat Pompeu Fabra, Barcelona, Spain; [4]CIBER Epidemiología y Salud Pública, Madrid, Spain; [5]Division of Environmental Health Sciences, School of Public Health, University of California, Berkeley, Berkeley, California; [6]Department of Economics, Brigham Young University, Provo, Utah; [8]Epidemiology Research Program, American Cancer Society, Atlanta, Georgia; [9]Department of Civil and Environmental Engineering, University of Washington, Seattle, Washington; [10]Department of Sociology, University of New Brunswick, Fredericton, New Brunswick, Canada; and [11]Population Studies Division, Health Canada, Ottawa, Ontario, Canada

Abstract

Rationale: Tropospheric ozone (O_3) is potentially associated with cardiovascular disease risk and premature death. Results from long-term epidemiological studies on O_3 are scarce and inconclusive.

Objectives: In this study, we examined associations between chronic ambient O_3 exposure and all-cause and cause-specific mortality in a large cohort of U.S. adults.

Methods: Cancer Prevention Study II participants were enrolled in 1982. A total of 669,046 participants were analyzed, among whom 237,201 deaths occurred through 2004. We obtained estimates of O_3 concentrations at the participant's residence from a hierarchical Bayesian space–time model. Estimates of fine particulate matter (particulate matter with an aerodynamic diameter of up to 2.5 μm [$PM_{2.5}$]) and NO_2 concentrations were obtained from land use regression. Cox proportional hazards regression models were used to examine mortality associations adjusted for individual- and ecological-level covariates.

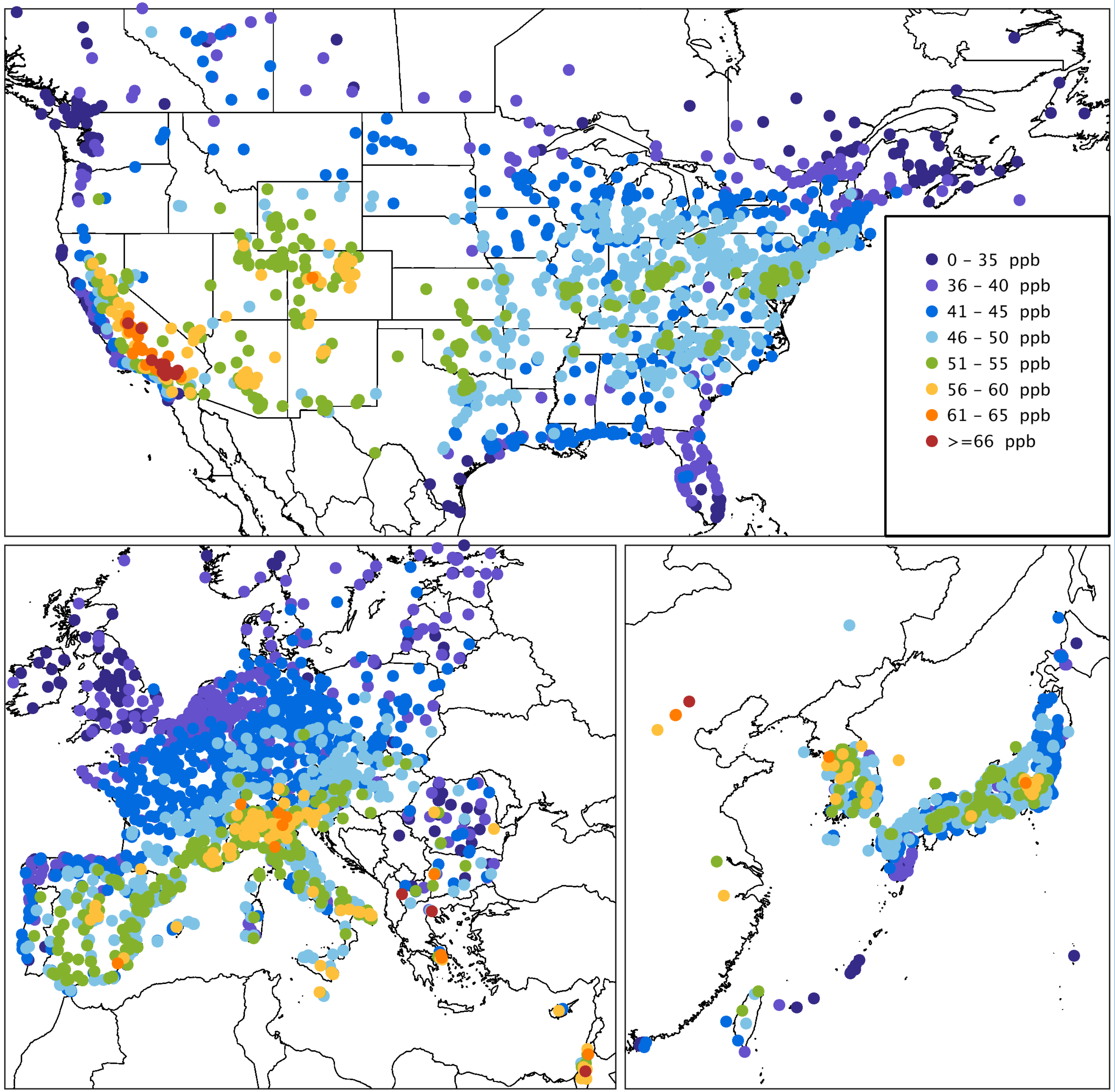
Measurements and Main Results: In single-pollutant models, we observed significant positive associations between O_3, $PM_{2.5}$, and NO_2 concentrations and all-cause and cause-specific mortality. In two-pollutant models adjusted for $PM_{2.5}$, significant positive associations remained between O_3 and all-cause (hazard ratio [HR] per 10 ppb, 1.02; 95% confidence interval [CI], 1.01–1.04), circulatory (HR, 1.03; 95% CI, 1.01–1.05), and respiratory mortality (HR, 1.12; 95% CI, 1.08–1.16) that were unchanged with further adjustment for NO_2. We also observed positive mortality associations with both $PM_{2.5}$ (both near source and regional) and NO_2 in multipollutant models.

Conclusions: Findings derived from this large-scale prospective study suggest that long-term ambient O_3 contributes to risk of respiratory and circulatory mortality. Substantial health and environmental benefits may be achieved by implementing further measures aimed at controlling O_3 concentrations.

Keywords: air pollution; mortality; ozone; prospective study

Average of the daily maximum 8-hr average O_3 values, summer   Data extracted on: 2016-10-24

avgdma8epax ozone, 2010-2014 (minimum 3 years): all sites



A vector indicates the linear trend at a station for the period 2000-2014.

Warm colors indicate increasing ozone while cool colors indicate decreasing ozone.

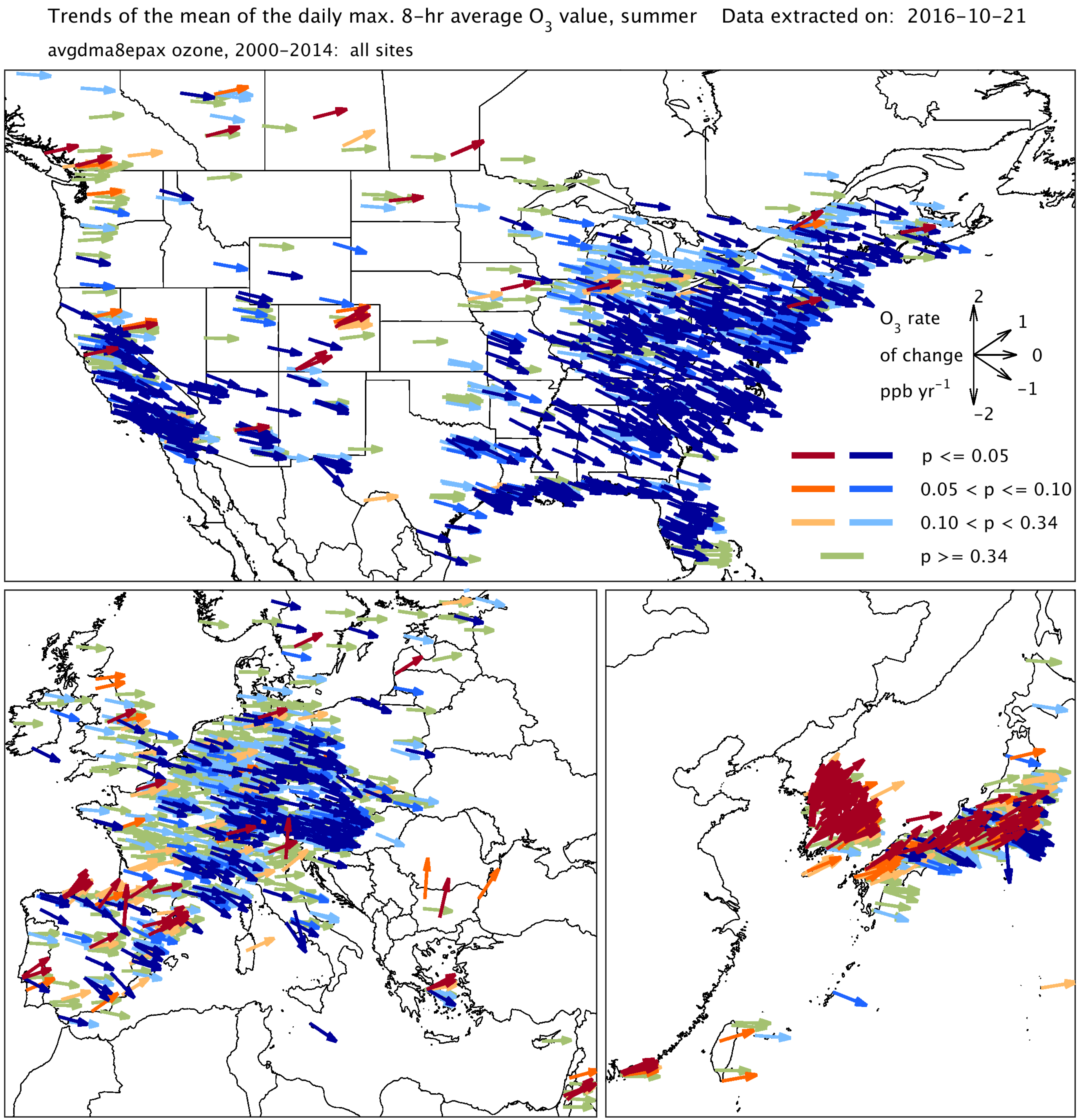
The legend shows the p-Values on the linear trends associated with each vector, as indicated by the shading.

Statistically significant trends at the 95% confidence interval are shown on top in dark red and dark blue.

Medium orange and blue provide an indication of a trend.

Light orange and blue provide a weak indication of change.

Green indicates weak or no change.



In collaboration with Jason West, UNC Chapel Hill, TOAR metrics are supporting NASA HAQAST research.

A new method for combining observations and multiple model output for an improved estimate of the global surface ozone distribution

Kai-Lan Chang[1,2], Owen R. Cooper[2,3], J. Jason West[4], Marc Serre[4], Martin G. Schultz[5], Meiyun Lin[6,7], Virginie Marecal[8], Makoto Deushi[9], Kengo Sudo[10], Junhua Liu[11], and Christoph A. Keller[11,12,13]

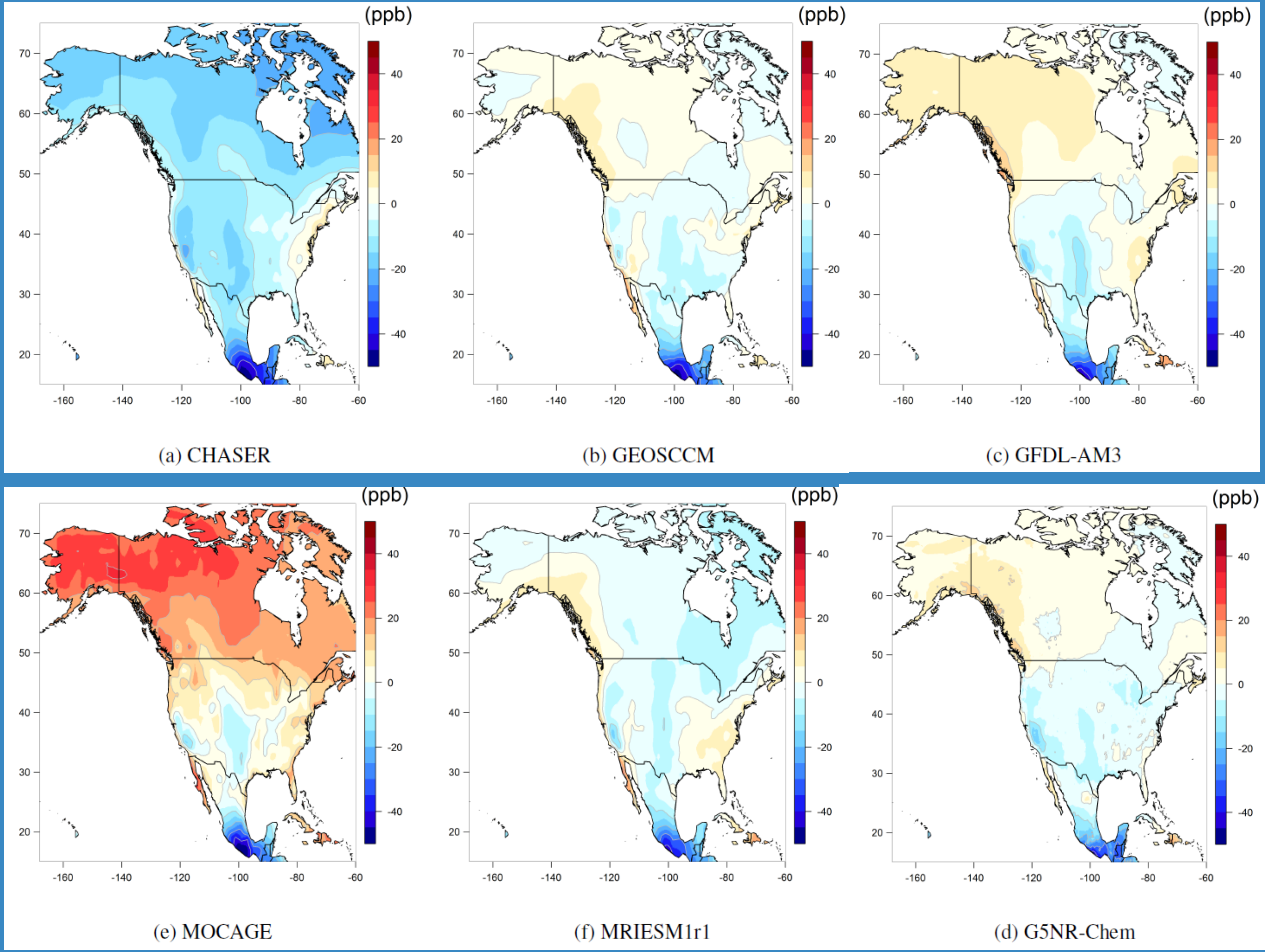
[1]National Research Council Fellow
[2]NOAA Earth System Research Laboratory, Boulder, CO, USA
[3]Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO, USA
[4]Department of Environmental Sciences & Engineering, University of North Carolina, Chapel Hill, NC, USA
[5]Institute for Energy and Climate Research (IEK-8), Forschungszentrum Jülich, Jülich, Germany
[6]NOAA Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA
[7]Program in Atmospheric and Oceanic Sciences, Princeton University, Princeton, NJ, USA
[8]Météo-France, Centre National de Recherches Météorologiques, Toulouse, France
[9]Meteorological Research Institute (MRI), Tsukuba, Japan
[10]Graduate School of Environmental Studies, Nagoya University, Nagoya, Japan
[11]NASA Goddard Space Flight Center, Greenbelt, MD, USA
[12]John A. Paulson School of Engineering and Applied Science, Harvard University, Cambridge, MA, USA
[13]Universities Space Research Association, Columbia, MD, USA

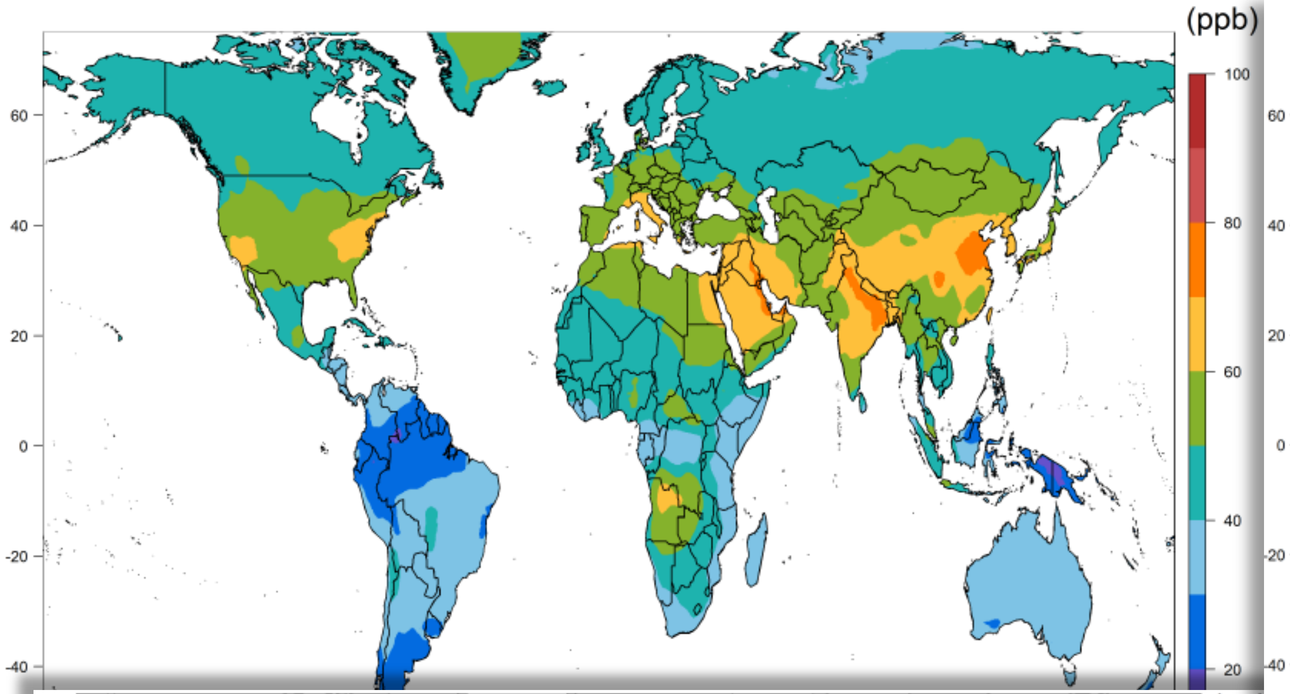
a manuscript to be submitted to Global Model Development

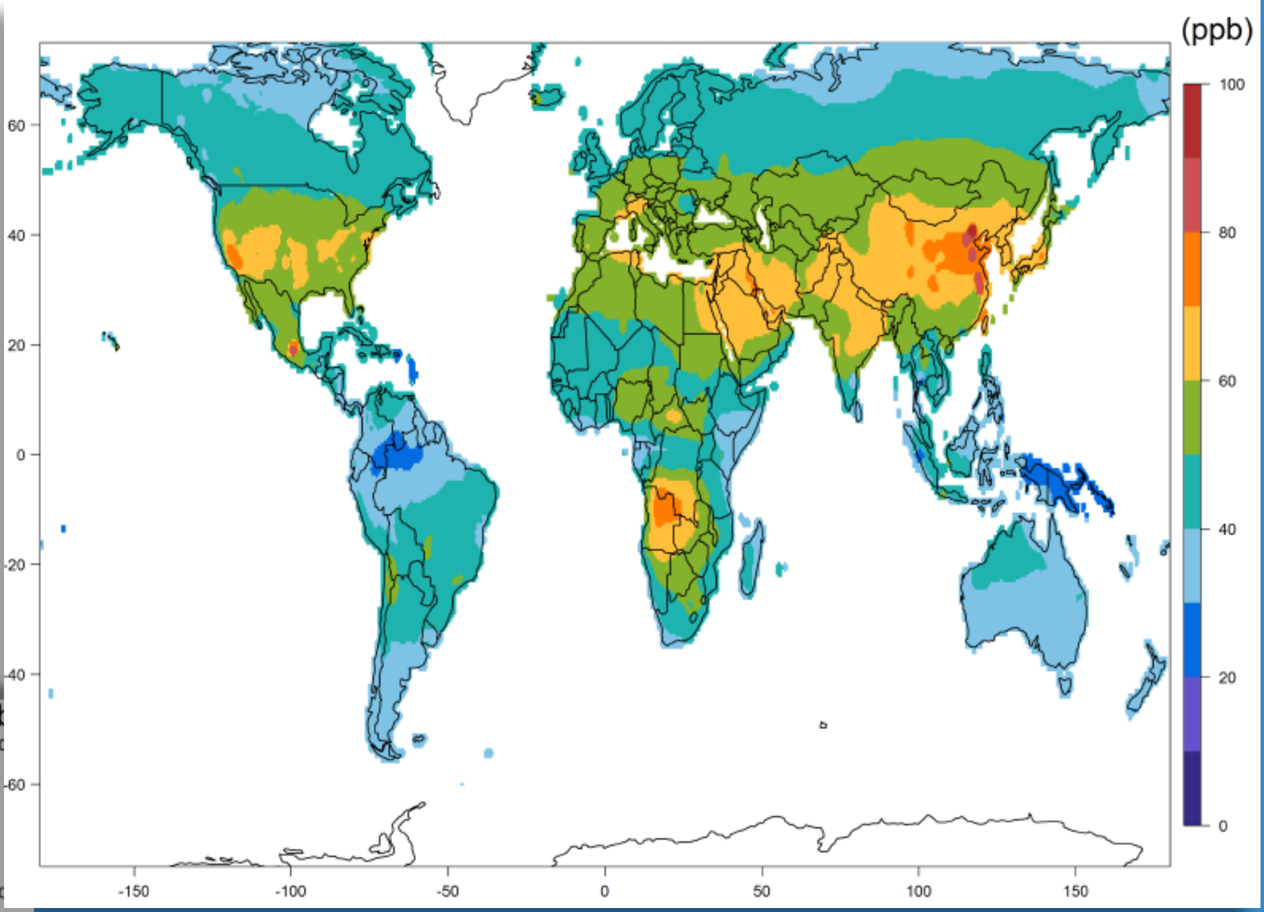
When simulating surface ozone, 6 different chemistry-climate models differ in their abilities to reproduce the observations from the TOAR database.

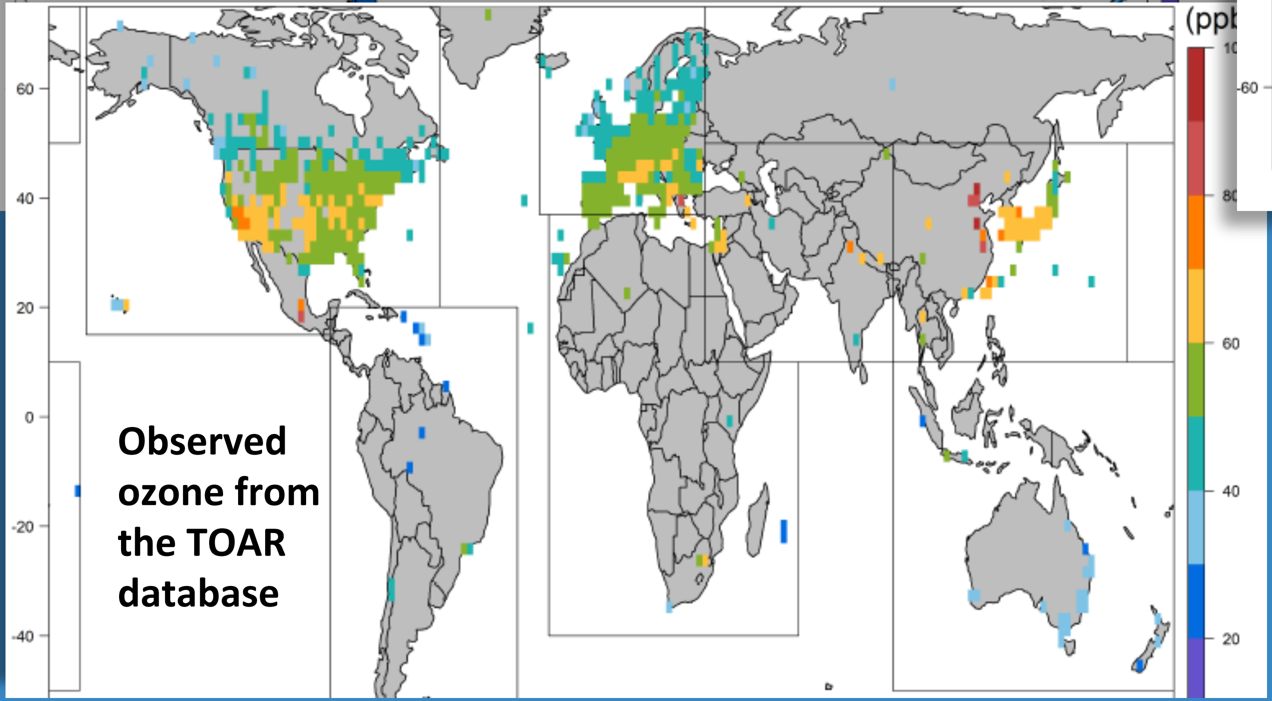
Ozone metric: annual peak of the 6-month mean of the maximum daily 8-hour average.

This metric aligns with the ozone metric used by *Turner et al*. 2016.









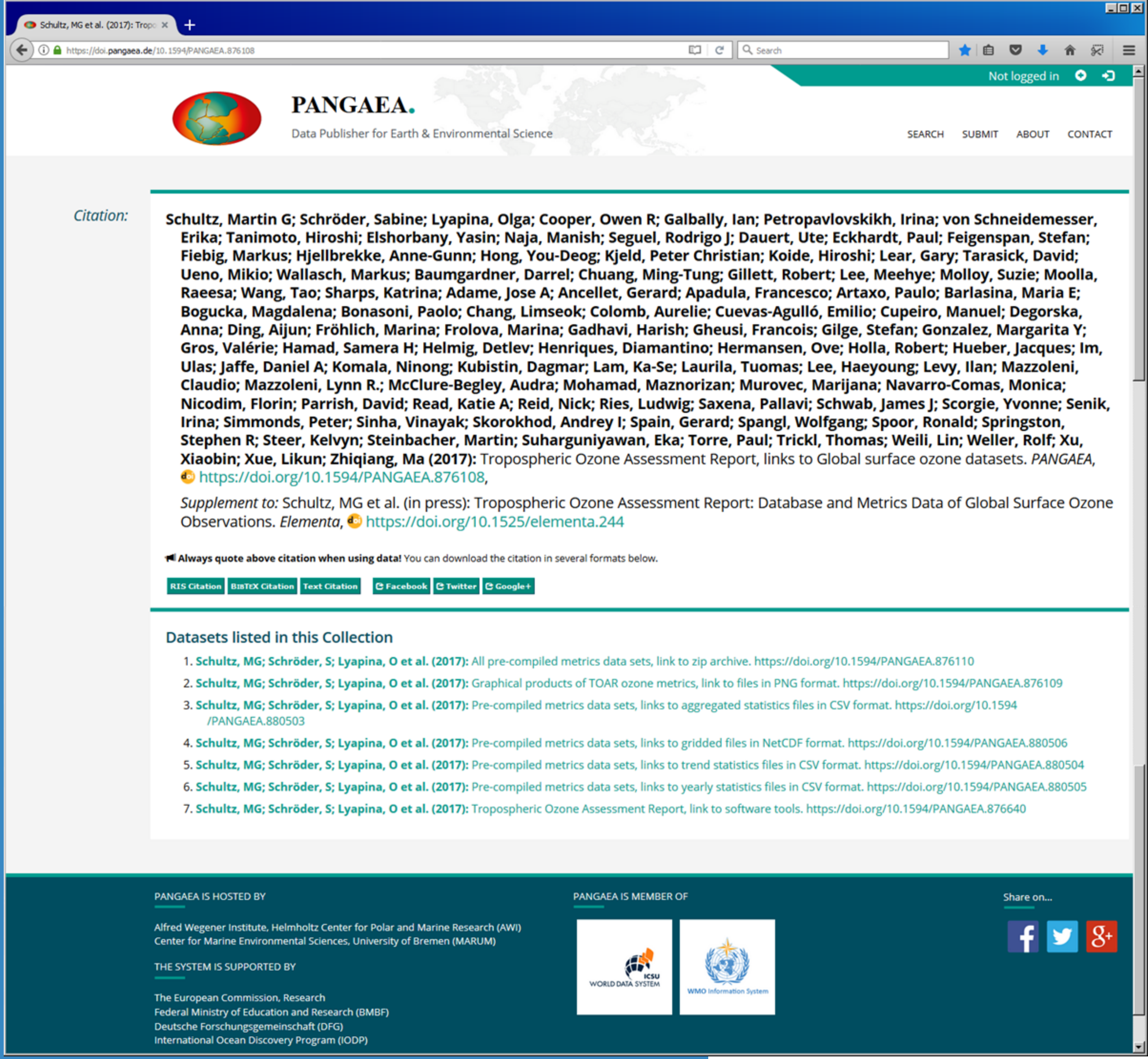
Fusing the observations with the most accurate models in 8 regions of the globe produces a new ozone field with greater accuracy than any individual model.

Next steps:

1) Finish the two remaining papers and submit them to *Elementa (TOAR-Observations and TOAR-Ozone Budget)*

2) The database of ozone metrics has been released to the general public

3) Encourage human health, ecosystem and climate researchers to utilize the database for their impact studies.



All metrics and figures can be downloaded from:
https://doi.pangaea.de/10.1594/PANGAEA.876108

New review of O_3 pollution in China

Led by Tao Wang

Hong Kong Polytechnic

Presently, ozone production in Chinese urban areas is VOC limited.

So far, recent NO_x reductions at power plants have had no observable impact on ozone pollution.

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Ozone pollution in China: A review of concentrations, meteorological influences, chemical precursors, and effects

CrossMark

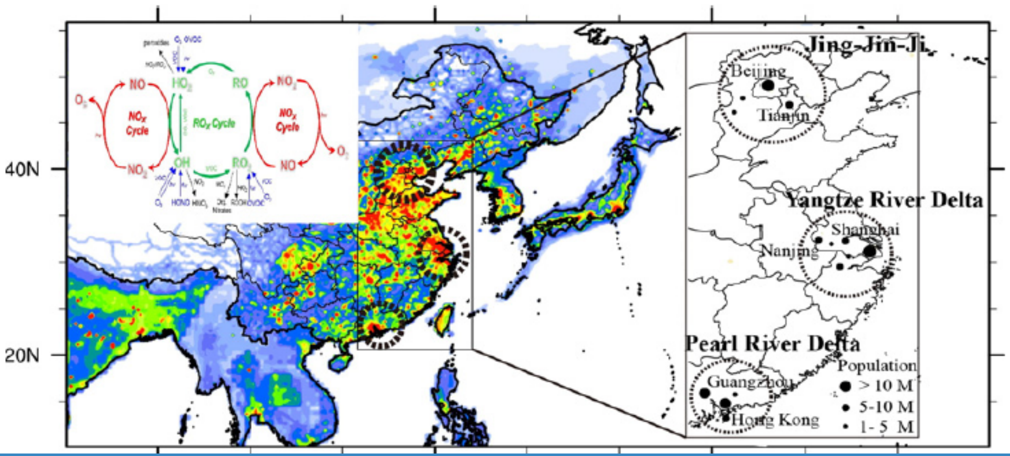
Tao Wang [a,*], Likun Xue [b], Peter Brimblecombe [c], Yun Fat Lam [c], Li Li [d], Li Zhang [a]

[a] Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong
[b] Environment Research Institute, Shandong University, Ji'nan, Shandong, China
[c] School of Energy and Environment, City University of Hong Kong, Hong Kong
[d] Shanghai Academy of Environmental Sciences, Shanghai, China

HIGHLIGHTS

- Studies of atmospheric ozone in urban and rural areas of China are reviewed.
- Topics include abundance, chemical and meteorological processes, and effects.
- Available data reveals serious and worsening ozone pollution in major areas of China.
- Data from national network are needed to get a full picture of ozone pollution and to evaluate its impact.
- Strategies for control ozone precursors need to be developed.

GRAPHICAL ABSTRACT



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Atmospheric Chemistry and Physics Open Access EGU

Significant increase of summertime ozone at Mount Tai in Central Eastern China

Lei Sun[1], Likun Xue[1], Tao Wang[2,1], Jian Gao[3], Aijun Ding[4], Owen R. Cooper[5,6], Meiyun Lin[7,8], Pengju Xu[9], Zhe Wang[2], Xinfeng Wang[1], Liang Wen[1], Yanhong Zhu[1], Tianshu Chen[1], Lingxiao Yang[1,10], Yan Wang[10], Jianmin Chen[1,10], and Wenxing Wang[1]

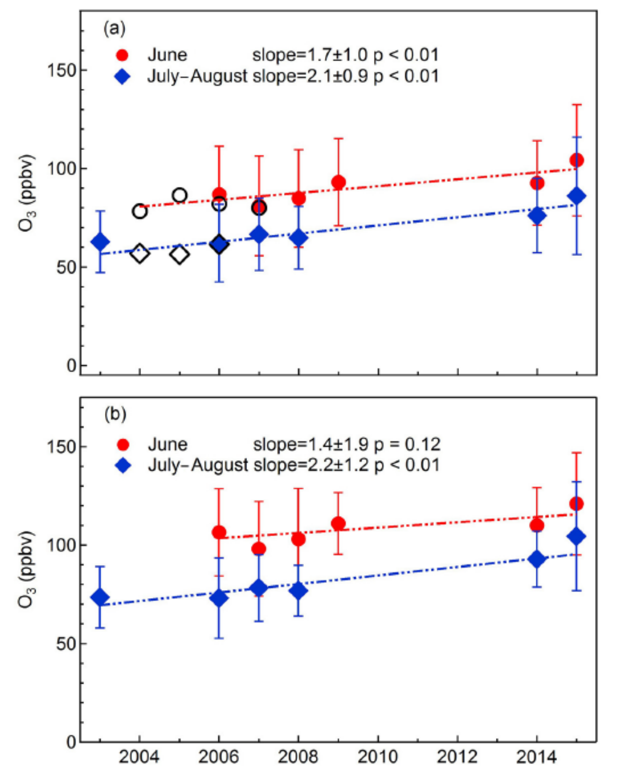

Figure 6. Monthly averaged (a) 1-hour and (b) MDA8 O_3 mixing ratios at Mt. Tai in June and July–August over 2003–2015. Error bars indicate the standard deviation of the mean. The black open circles and squares represent the data taken from Kanaya et al. (2013). The fitted lines are derived from the least square linear regression analysis with the slopes (±95 % confidence intervals) and p values annotated.

Atmos. Chem. Phys., 16, 6191–6205, 2016
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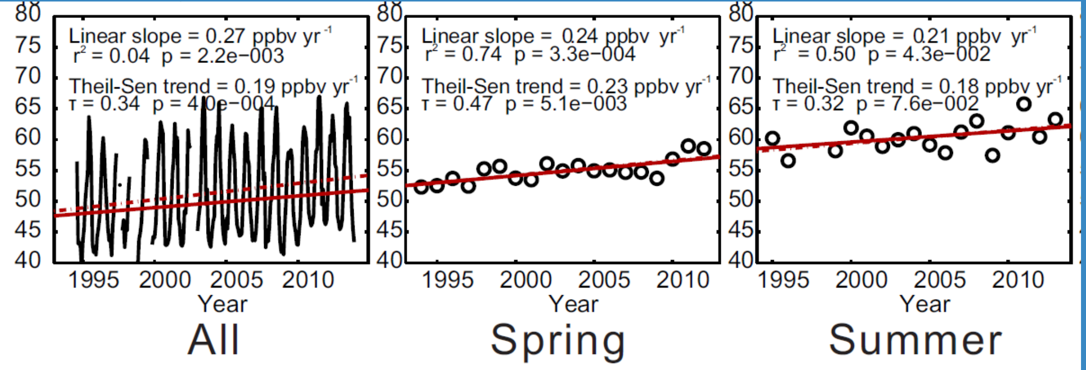
Long-term trends of surface ozone and its influencing factors at the Mt Waliguan GAW station, China – Part 1: Overall trends and characteristics

Wanyun Xu[1], Weili Lin[2], Xiaobin Xu[1], Jie Tang[2], Jianqing Huang[3], Hao Wu[3], and Xiaochun Zhang[2]



Atmos. Chem. Phys., 16, 3969–3977, 2016
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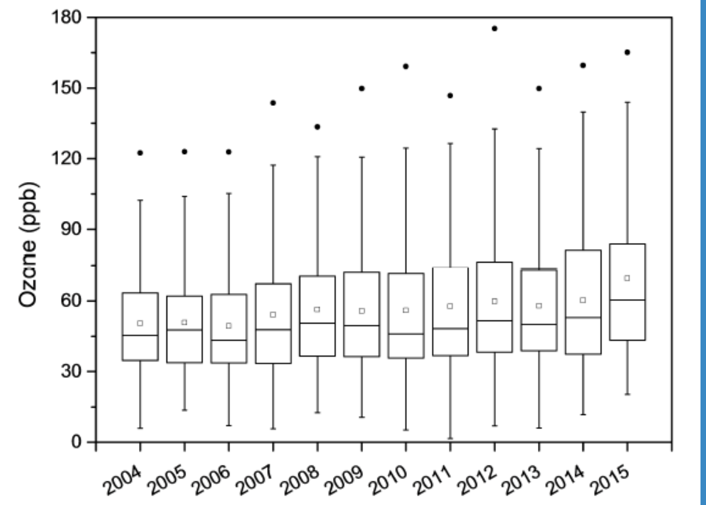
Significant increase of surface ozone at a rural site, north of eastern China - *Shangdianzi*

Zhiqiang Ma[1,2], Jing Xu[1,2], Weijun Quan[2], Ziyin Zhang[2], Weili Lin[3], and Xiaobin Xu[4]



Yearly distributions of MDA8 ozone at Shangdianzi

Severe surface ozone pollution in China: a global perspective

Xiao Lu, Jiayun Hong, Lin Zhang, Owen R. Cooper, Martin G. Schultz, Xiaobin Xu, Tao Wang, Meng Gao, Yuanhong Zhao, Yuanhang Zhang

Manuscript in-review with ES&T Letters

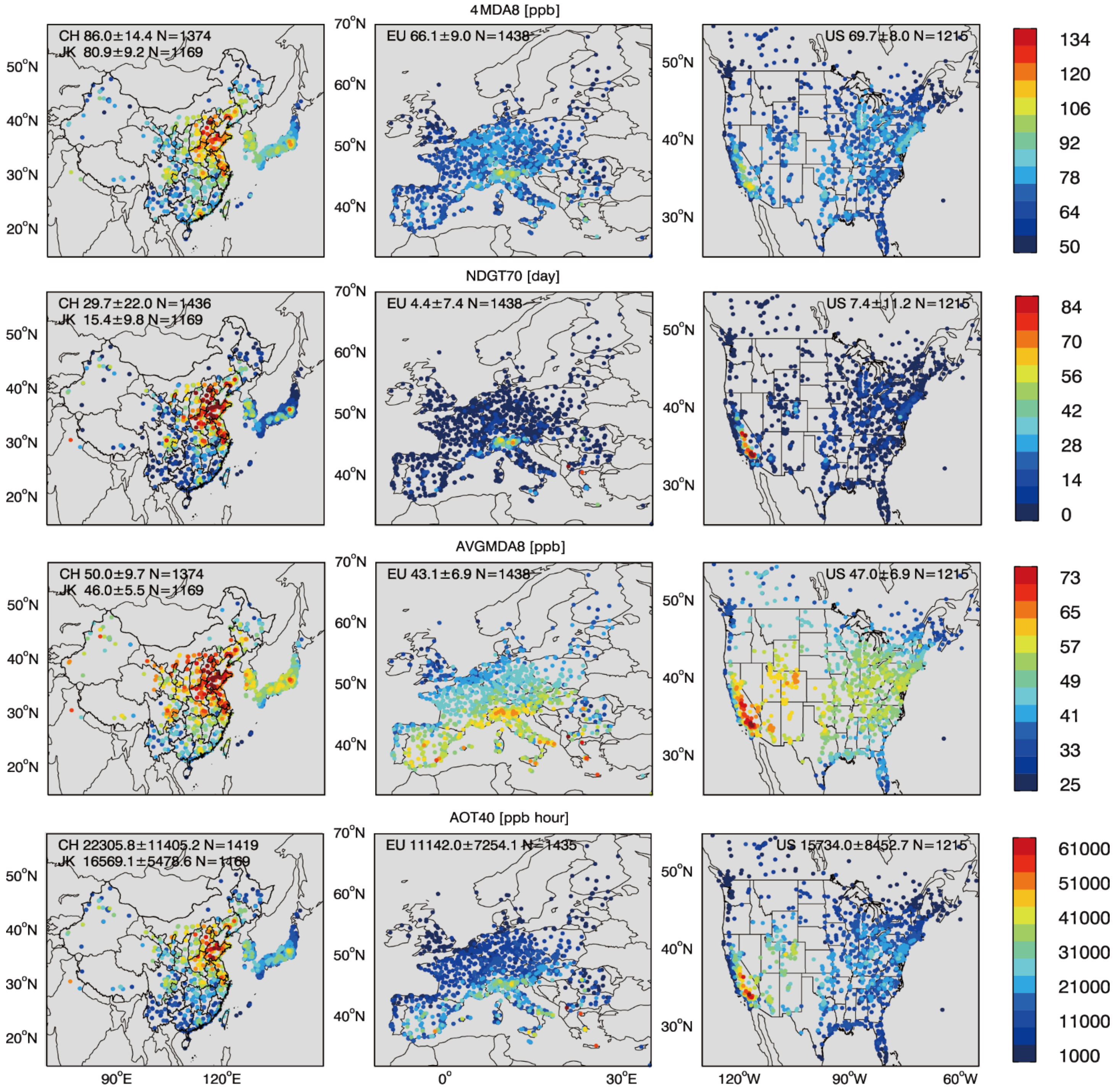


Figure 2. Comparison of April-September ozone metrics (4MDA8, NDGT70, AVGMDA8, AOT40) between China and the industrialized regions of Japan and Korea, Europe, and the US.

Only sites with at least 3-years of measurements are included.

Values inset are regional mean and standard deviation averaged over the N sites.

Figure 3 from *Lu et al., 2018*

Evolution of urban surface ozone pollution in China (red), Japan (purple), Europe (orange), and US (blue) from 1980 to 2017.

Also shown are the ozone time series in Beijing (red) and Los Angeles (blue).

Number of available sites is shown in the parentheses.