Benefits to uniformity of atmospheric ozone measurements:

Achievements of the Tropospheric Ozone Assessment Report

Owen R. Cooper
Senior Research Scientist, CIRES, University of Colorado Boulder
NOAA Chemical Sciences Laboratory, Boulder

on behalf of the TOAR-II Steering Committee

BIPM Accurate Monitoring of Surface Ozone Virtual Workshop
October 5-9, 2020

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TOAR-I 2014-2019

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.

Stakeholders: WMO, GAW, World Health Organization, NOAA, LRTAP Long-range Transboundary Air Pollution, Task Force on Hemispheric Transport of Air Pollution

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TOAR-I 2014-2019

Funding and in-kind donations provided by:

IGAC – International Global Atmospheric Chemistry

NOAA – National Oceanic and Atmospheric Administration, U.S. Department of Commerce

JÜLICH Forschungszentrum

WMO

CIRES – Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder

AEMet – Agencia Estatal de Meteorología

Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences

Nanjing University 1902

Environment and Climate Change Canada

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https://igacproject.org/activities/TOAR/TOAR-II

TOAR-I Accomplishments, 2014-2019

Nine highly-cited journal publications in Elementa

A database with easily accessible ozone metrics at 1000s of stations worldwide

A highly motivated community of > 240 scientists from over 35 countries

Uptake of TOAR results by other communities (e.g. WMO, GBD and IPCC)

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https://igacproject.org/activities/TOAR/TOAR-II

TOAR-I publications in Elementa

https://collections.elementascience.org/toar

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.

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, Sabine Schröder, Olga Lyapina, Owen R. Cooper, Ian Galbally, Irina Petropavlovskikh, Erika von Schneidemesser, Hiroshi Tanimoto, Yasin Elshorbany, Manish Naja, Rodrigo J. Seguel, Ute Dauert, Paul Eckhardt, Stefan Feigenspan, Markus Fiebig, Anne-Gunn Hjellbrekke, You-Deog Hong, Peter Christian Kjeld, Hiroshi Koide, Gary Lear, David Tarasick, Mikio Ueno, Markus Wallasch, Darrel Baumgardner, Ming-Tung Chuang, Robert Gillett, Meehye Lee, Suzie Molloy, Raeesa Moolla, Tao Wang, Katrina Sharps, Jose A. Adame, Gerard Ancellet, Francesco Apadula, Paulo Artaxo, Maria E. Barlasina, Magdalena Bogucka, Paolo Bonasoni, Limseok Chang, Aurelie Colomb, Emilio Cuevas-Agulló, Manuel Cupeiro, Anna Degorska, Aijun Ding, Marina Fröhlich, Marina Frolova, Harish Gadhavi, Francois Gheusi, Stefan Gilge, Margarita Y. Gonzalez, Valerie Gros, Samera H. Hamad, Detlev Helmig, Diamantino Henriques, Ove Hermansen, Robert Holla, Jacques Hueber, Ulas Im, Daniel A. Jaffe, Ninong Komala, Dagmar Kubistin, Ka-Se Lam, Tuomas Laurila, Haeyoung Lee, Ilan Levy, Claudio Mazzoleni, Lynn R. Mazzoleni, Audra McClure-Begley, Maznorizan Mohamad, Marijana Murovec, Monica Navarro-Comas, Florin Nicodim, David Parrish, Katie A. Read, Nick Reid, Ludwig Ries, Pallavi Saxena, James J. Schwab, Yvonne Scorgie, Irina Senik, Peter Simmonds, Vinayak Sinha, Andrey I. Skorokhod, Gerard Spain, Wolfgang Spangl, Ronald Spoor, Stephen R. Springston, Kelvyn Steer, Martin Steinbacher, Eka Suharguniyawan, Paul Torre, Thomas Trickl, Lin Weili, Rolf Weller, Xu Xiaobin, Likun Xue and Ma Zhiqiang

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

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, O. R. Cooper, G. Ancellet, B. Barret, A. Boynard, J. P. Burrows, C. Clerbaux, P.-F. Coheur, J. Cuesta, E. Cuevas, S. Doniki, G. Dufour, F. Ebojie, G. Foret, O. Garcia, M. J. Granados-Muñoz, J. W. Hannigan, F. Hase, B. Hassler, G. Huang, D. Hurtmans, D. Jaffe, N. Jones, P. Kalabokas, B. Kerridge, S. Kulawik, B. Latter, T. Leblanc, E. Le Flochmoën, W. Lin, J. Liu, X. Liu, E. Mahieu, A. McClure-Begley, J. L. Neu, M. Osman, M. Palm, H. Petetin, I. Petropavlovskikh, R. Querel, N. Rahpoe, A. Rozanov, M. G. Schultz, J. Schwab, R. Siddans, D. Smale, M. Steinbacher, H. Tanimoto, D. W. Tarasick, V. Thouret, A. M. Thompson, T. Trickl, E. Weatherhead, C. Wespes, H. M. Worden, C. Vigouroux, X. Xu, G. Zeng, J. Ziemke

ELEMENTA Science of the Anthropocene

Tarasick, D, et al. 2019. Tropospheric Ozone Assessment Report: Tropospheric ozone from 1877 to 2016, observed levels, trends and uncertainties. Elem Sci Anth, 7: 39. DOI: https://doi.org/10.1525/elementa.376

REVIEW

Tropospheric Ozone Assessment Report: Tropospheric ozone from 1877 to 2016, observed levels, trends and uncertainties

David Tarasick, Ian E. Galbally, Owen R. Cooper, Martin G. Schultz, Gerard Ancellet, Thierry Leblanc, Timothy J. Wallington, Jerry Ziemke, Xiong L… Martin Steinbacher, Johannes Staehelin, Corinne Vigouroux, James W. Hanniga… Omaira García, Gilles Foret, Prodromos Zanis, Elizabeth Weatherhead, Irina Petropavlovski… …ohammed Osman, Jane Liu, Kai-Lan Chang, Au… …in, Maria Granados-Muñoz, Anne M. Thompson… Juan Cuesta, Gaelle Dufour, Valerie Thouret, Birgit Hassler, Thomas Trickl and Jessica L. Neu

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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

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

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

ELEMENTA Science of the Anthropocene

Xu, X, et al. 2020. Long-term changes of regional ozone in China: implications for human health and ecosystem impacts. Elem Sci Anth, 8: 13. DOI: https://doi.org/10.1525/elementa.409

RESEARCH ARTICLE

Long-term changes of regional ozone in China: implications for human health and ecosystem impacts

Xiaobin Xu, Weili Lin, Wanyun Xu, Junli Jin, Ying Wang, Gen Zhang, Xiaochun Zhang, Zhiqiang Ma, Yuanzhen Dong, Qianli Ma, Dajiang Yu, Zou Li, Dingding Wang and Huarong Zhao

…OAR …opospheric …one …sessment …port Phase II

TOAR-I publications are highly cited

According to Web of Science

Over 430 citations so far

Current rate is ~250 citations per year

1. Tropospheric Ozone Assessment Report: Present-day distribution and trends of tropospheric ozone relevant to climate and global atmospheric chemistry model evaluation
   By: Gaudel, A.; Cooper, O. R.; Ancellet, G.; et al.
   ELEMENTA-SCIENCE OF THE ANTHROPOCENE Volume: 6 Article Number: 39 Published: MAY 10 2018
   Times Cited: 75 (from All Databases) Highly Cited Paper

2. Tropospheric Ozone Assessment Report: Present-day tropospheric ozone distribution and trends relevant to vegetation
   By: Mills, Gina; Pleijel, Hakan; Malley, Christopher S.; et al.
   ELEMENTA-SCIENCE OF THE ANTHROPOCENE Volume: 6 Article Number: 47 Published: JUN 28 2018
   Times Cited: 64 (from All Databases) Highly Cited Paper

3. Tropospheric Ozone Assessment Report: Database and metrics data of global surface ozone observations
   By: Schultz, Martin G.; Schroder, Sabine; Lyapina, Olga; et al.
   ELEMENTA-SCIENCE OF THE ANTHROPOCENE Volume: 5 Article Number: 58 Published: OCT 18 2017
   Times Cited: 64 (from All Databases)

4. Tropospheric ozone assessment report: Global ozone metrics for climate change, human health, and crop/ecosystem research
   By: Lefohn, Allen S.; Malley, Christopher S.; Smith, Luther; et al.
   ELEMENTA-SCIENCE OF THE ANTHROPOCENE Volume: 6 Article Number: 28 Published: APR 6 2018
   Times Cited: 62 (from All Databases) Highly Cited Paper

5. Tropospheric Ozone Assessment Report: Assessment of global-scale model performance for global and regional ozone distributions, variability, and trends
   By: Young, P. J.; Naik, V.; Fiore, A. M.; et al.
   ELEMENTA-SCIENCE OF THE ANTHROPOCENE Volume: 6 Article Number: 10 Published: JAN 31 2018
   Times Cited: 59 (from All Databases) Highly Cited Paper

6. Regional trend analysis of surface ozone observations from monitoring networks in eastern North America, Europe and East Asia
   By: Chang, Kai-Lan; Petropavlovskikh, Irina; Cooper, Owen R.; et al.
   ELEMENTA-SCIENCE OF THE ANTHROPOCENE Volume: 5 Article Number: 50 Published: SEP 7 2017
   Times Cited: 52 (from All Databases)

7. Tropospheric Ozone Assessment Report: Present-day ozone distribution and trends relevant to human health
   By: Fleming, Zoe L.; Doherty, Ruth M.; von Schneidemesser, Erika; et al.
   ELEMENTA-SCIENCE OF THE ANTHROPOCENE Volume: 6 Article Number: 12 Published: FEB 5 2018
   Times Cited: 48 (from All Databases)

8. Tropospheric Ozone Assessment Report: Tropospheric ozone from 1877 to 2016, observed levels, trends and uncertainties
   By: Tarasick, David; Galbally, Ian E.; Cooper, Owen R.; et al.
   ELEMENTA-SCIENCE OF THE ANTHROPOCENE Volume: 7 Article Number: 39 Published: OCT 11 2019
   Times Cited: 10 (from All Databases)

9. Long-term changes of regional ozone in China: implications for human health and ecosystem impacts
   By: Xu, Xiaobin; Lin, Weili; Xu, Wanyun; et al.
   ELEMENTA-SCIENCE OF THE ANTHROPOCENE Volume: 8 Article Number: 13 Published: MAR 24 2020
   Times Cited: 1 (from All Databases)

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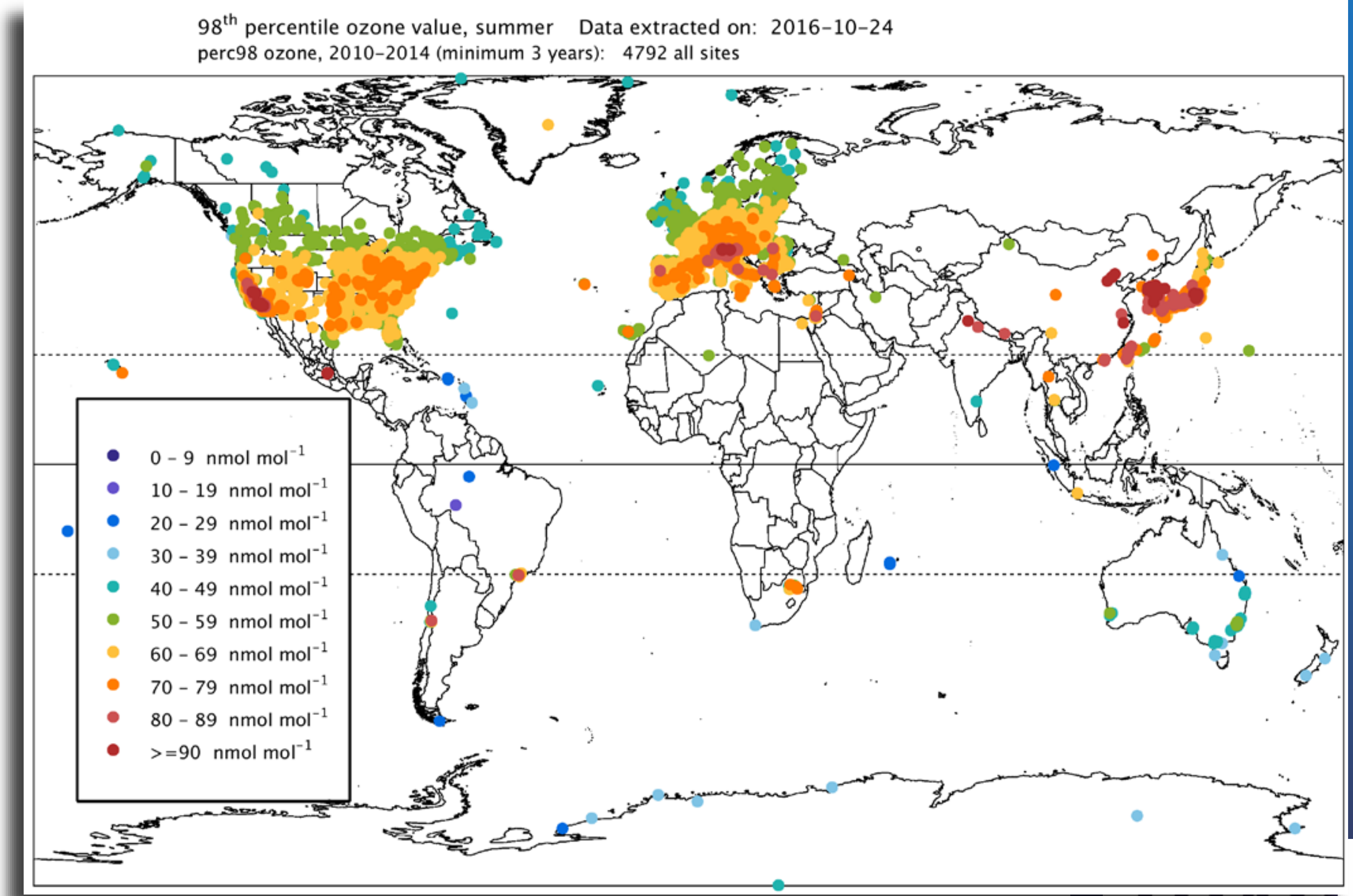
TOAR-I key results



The first global-scale view of all available surface ozone observations

98th percentile

5-year average (2010-2014)

summertime months: *April-Sept. in the N. Hemisphere, and Oct.-March in the S. Hemisphere*

Data available at:

Schultz et al., Tropospheric Ozone Assessment Report, links to Global surface ozone datasets. PANGAEA, https://doi.org/10.1594/PANGAEA.876108

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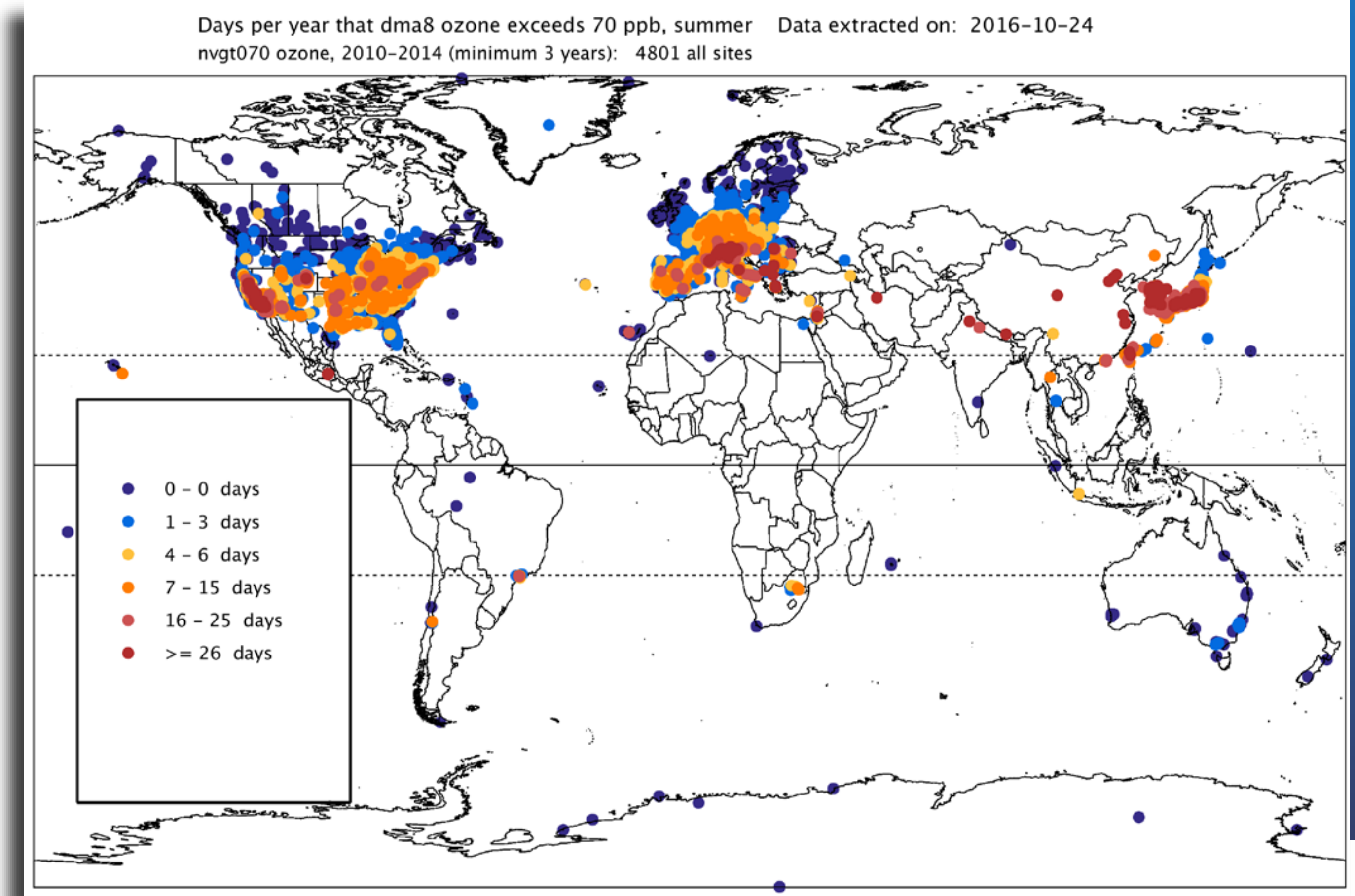
TOAR-I key results



The first global-scale view of all available surface ozone observations

Number of days per year that ozone (max.daily 8-hr avg.) exceeds 70 ppb

5-year average (2010-2014)

summertime months: *April-Sept. in the N. Hemisphere, and Oct.-March in the S. Hemisphere*

See *TOAR-Health* for further details:

Fleming, Z. L., and R. M. Doherty et al. (2018), Tropospheric Ozone Assessment Report: Present-day ozone distribution and trends relevant to human health, Elem Sci Anth, 6(1):12, DOI:https://doi.org/10.1525/elementa.273

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TOAR-I key results

The first global-scale view of all available surface ozone observations

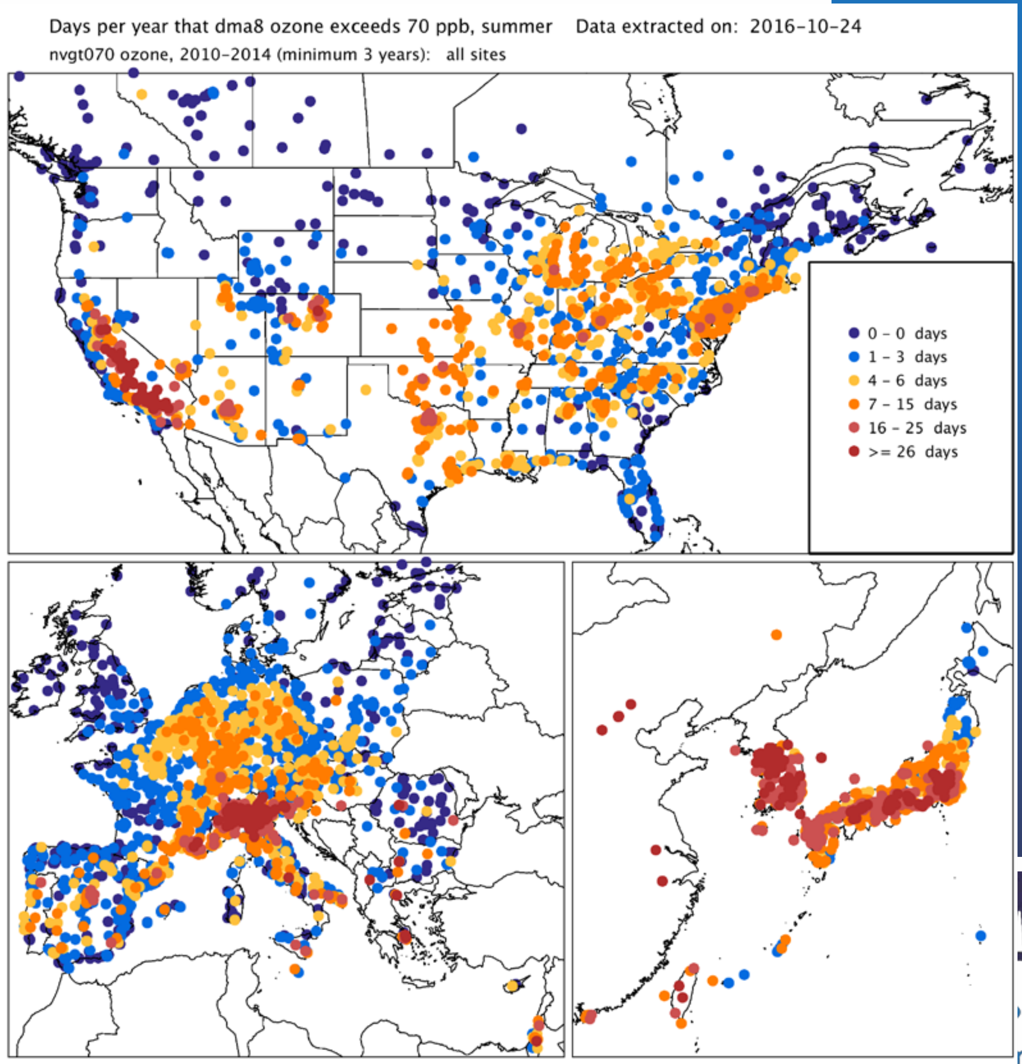
Number of days per year that ozone (max.daily 8-hr avg.) exceeds 70 ppb

5-year average (2010-2014)

summertime months: *April-Sept. in the N. Hemisphere, and Oct.-March in the S. Hemisphere*

See *TOAR-Health* for further details:

Fleming, Z. L., and R. M. Doherty et al. (2018), Tropospheric Ozone Assessment Report: Present-day ozone distribution and trends relevant to human health, Elem Sci Anth, 6(1):12, DOI:https://doi.org/10.1525/elementa.273



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https://igacproject.org/activities/TOAR/TOAR-II

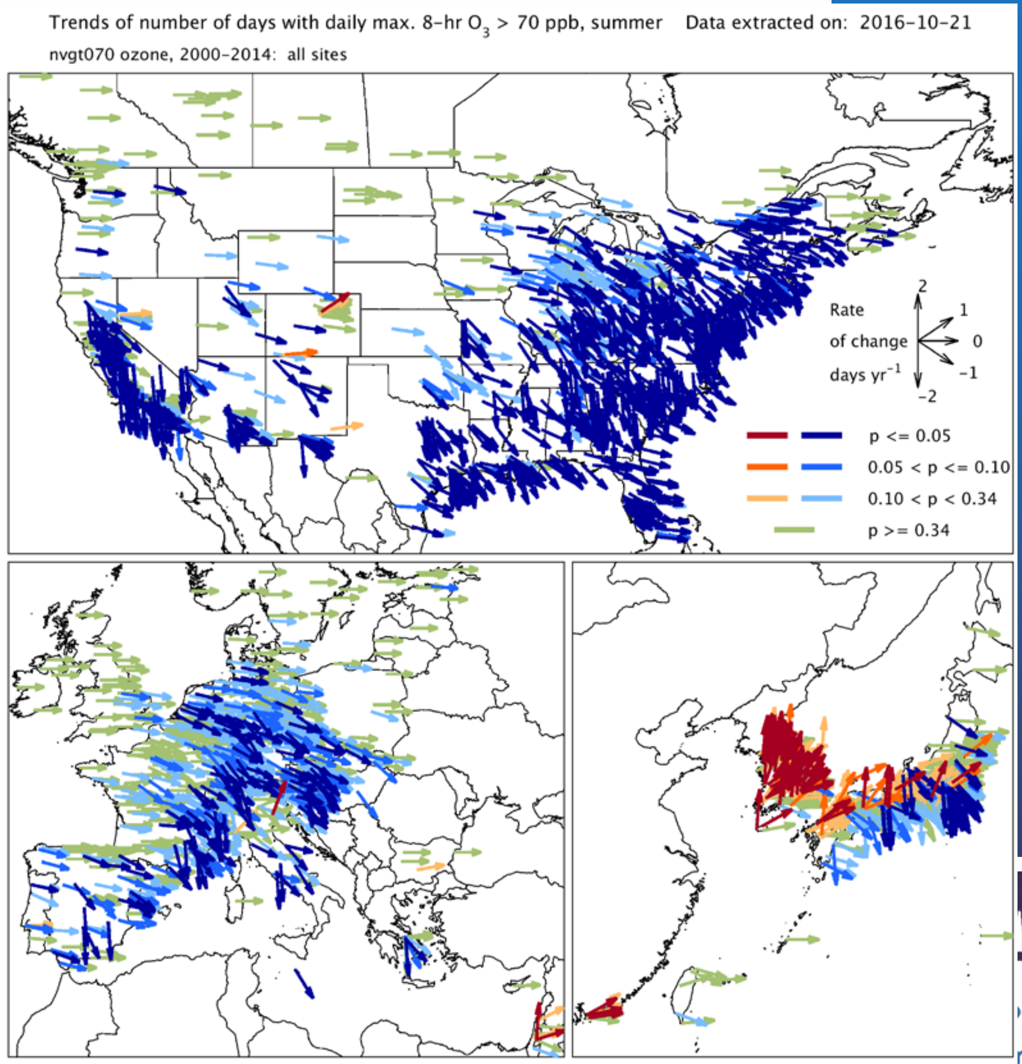
TOAR-I key results

The first global-scale view of all available surface ozone observations

Number of days per year that ozone (max.daily 8-hr avg.) exceeds 70 ppb

Trends: 2000-2014

summertime months: *April-Sept. in the N. Hemisphere, and Oct.-March in the S. Hemisphere*



See *TOAR-Health* for further details:

Fleming, Z. L., and R. M. Doherty et al. (2018), Tropospheric Ozone Assessment Report: Present-day ozone distribution and trends relevant to human health, Elem Sci Anth, 6(1):12, DOI:https://doi.org/10.1525/elementa.273

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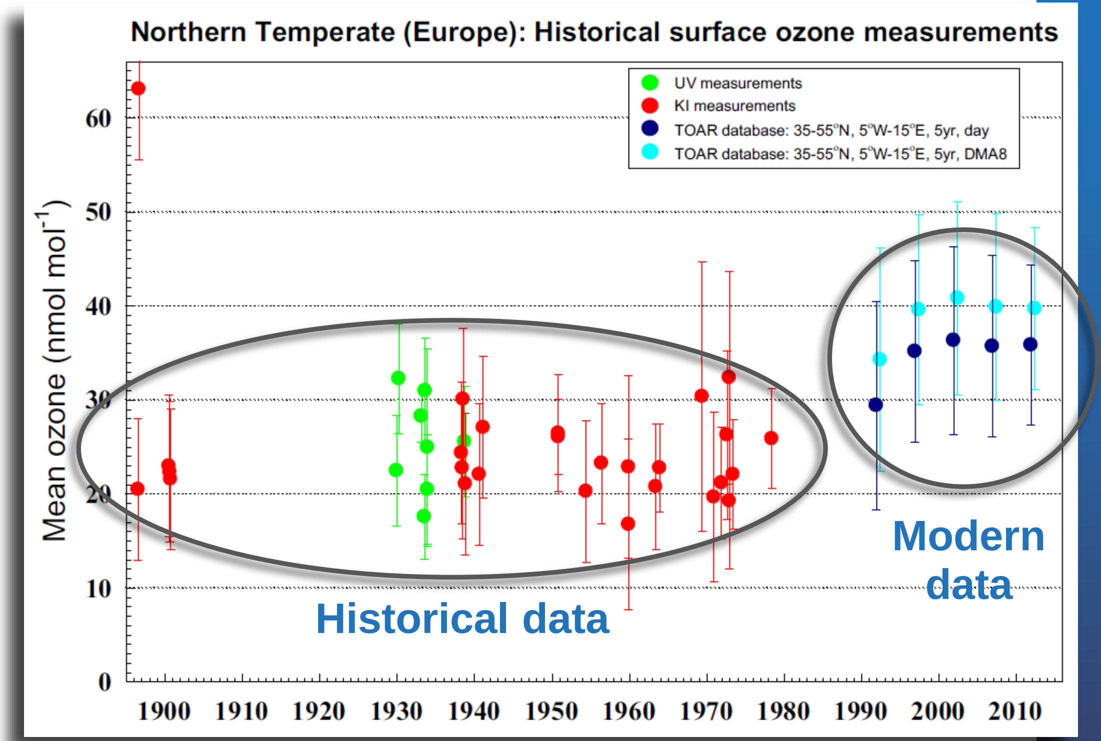
TOAR-I key results

The most extensive evaluation of historical (pre-1975) ozone observations

Ozone has increased at northern mid-latitudes since the mid-20th century, in the range 30-70 %



See *TOAR-Observations* for further details:

Tarasick and Galbally et al. (2019), Tropospheric Ozone Assessment Report: Tropospheric ozone from 1877 to 2016, observed levels, trends and uncertainties. Elem Sci Anth, 7(1)
DOI: http://doi.org/10.1525/elementa.376

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TOAR-I Anticipating the change in ozone cross-section

"The numerical value of the ozone absorption cross-section is currently under review (Hodges et al., 2019; Orphal et al. 2016), with a recommendation that the value should be decreased by approximately 1.23% (Hodges et al., 2019). If accepted by the appropriate agencies (BIPM,WMO, ISO), this change will require all tropospheric ozone measurements on the current UV standard scale to be increased by 1.23%. This will not affect trends, but it will have a small effect on estimates that depend on the absolute ozone amount, such as calculations of ozone radiative forcing. This change will also improve agreement of the UV scale with gas phase titration (GPT) and the potassium iodide (KI) ECC ozonesondes."

Tarasick, D, et al. 2019. Tropospheric Ozone Assessment Report: Tropospheric ozone from 1877 to 2016, observed levels, trends and uncertainties. Elem Sci Anth, 7: 39. DOI: https://doi.org/10.1525/elementa.376

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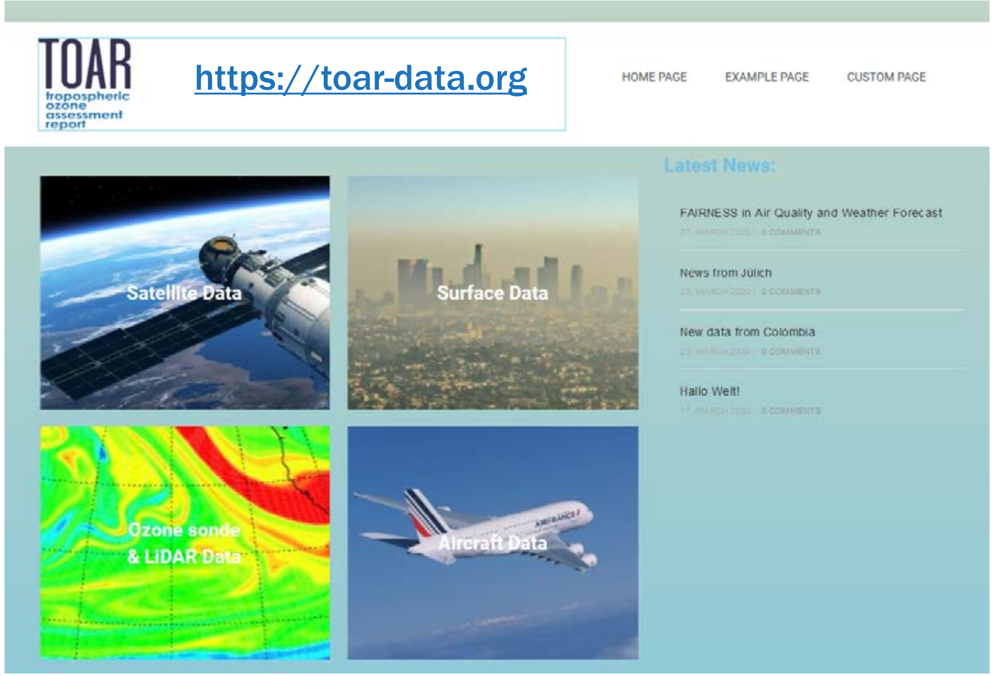
TOAR-II Goals for 2020-2024

TOAR Ozone Data Portal: Update the TOAR Surface Ozone Database with all recent ozone observations (through 2020); new sites and regions; ozone precursors and meteorological data. Develop methods for including historical data (pre-1975) and create links to repositories of free tropospheric observations.



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TOAR-I Anticipating the change in ozone cross-section

- All ozone observations uploaded to TOAR-II Database must be flagged according to the ozone cross-section applied when the data were reported:

  For example, 1 for the new cross-section, 0 for the former cross-section

- Once the new cross-section is adopted any ozone metric output by the database will be adjusted so that it reflects the new cross-section

- This protocol will ensure that time series are consistent and that calculated trends are reliable

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TOAR-II Status and roadmap

2020

- Selection of new steering committee
- Planning of objectives and roadmap
- Development of enhanced data infrastructure

2021

- First TOAR-II workshops
- Formation of working groups (WGs)
- Beginning of new data collection
- Bring data infrastructure online

2022

- WGs: Preparation of analyses and planning of manuscripts
- Develop new metrics and populate database

2023

- Finalize data
- Perform new and updated analyses
- Draft manuscripts, submit by Sept. 1

2024

- Publication of TOAR-II

Owen Cooper on behalf of the TOAR-II Steering Committee
TOAR-II Quickstart Event, September 16, 2020

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https://igacproject.org/activities/TOAR/TOAR-II

TOAR tropospheric ozone assessment report Phase II

Detailed information on TOAR-II scope and procedures can be found on the TOAR-II webpage:

https://igacproject.org/activities/TOAR/TOAR-II

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The WMO Global Atmosphere Watch (GAW) Programme focuses on:

- building a single coordinated global understanding of atmospheric composition and its change
- helps to improve the understanding of interactions between the atmosphere, the oceans and the biosphere.

Ozone is presently monitored at over 100 GAW stations worldwide (primarily in remote or rural settings).

Data provided to the GAW Programme by WMO Members and contributing networks are submitted to the World Data Centre for Reactive Gases (WDCRG), hosted by the Norwegian Institute for Air Research (NILU). https://www.gaw-wdcrg.org

GAW stations are described in the GAW Station Information System (GAWSIS), supported by MeteoSwiss: https://gawsis.meteoswiss.ch

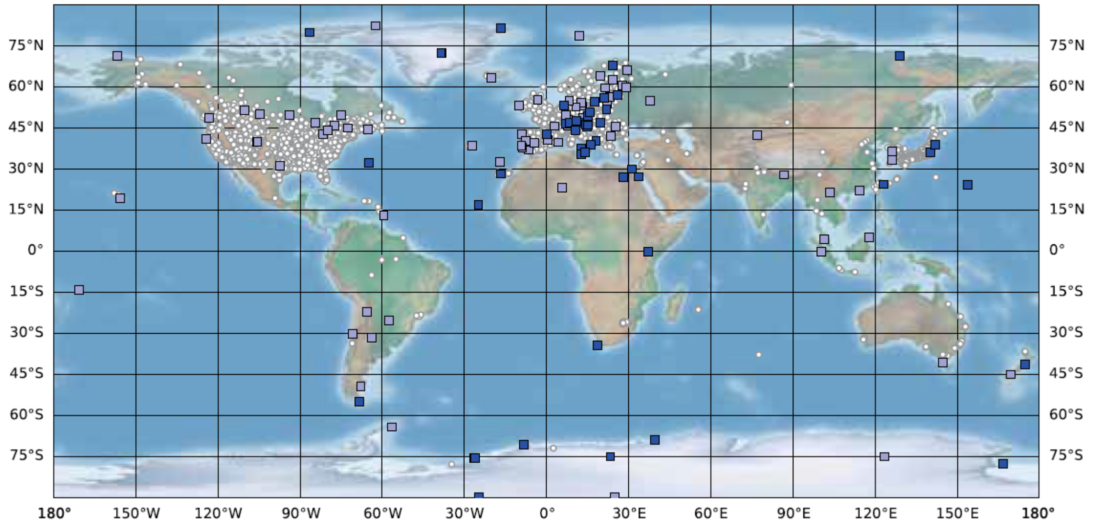


Figure 2. Global coverage of surface ozone observing stations. Dark squares (data recently updated in the World Data Centre for Reactive Gases) and light-blue squares denote stations from the GAW network; small white circles show stations from other networks included in the TOAR database.

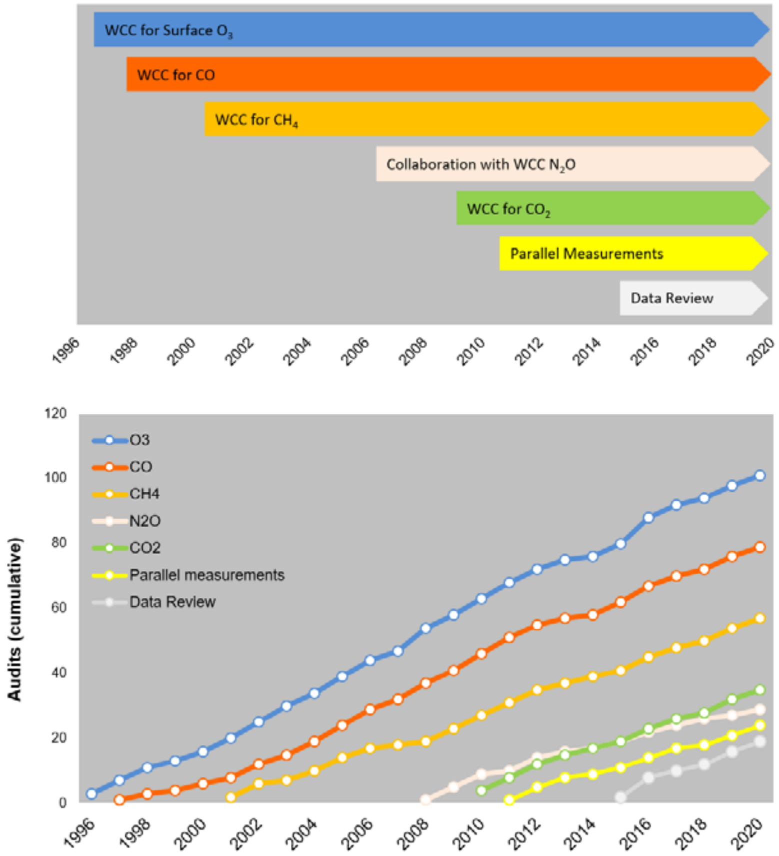
Schultz, M.G., et al. (2015), The Global Atmosphere Watch reactive gases measurement network. Elem Sci Anth, 3, p.000067. DOI: http://doi.org/10.12952/journal.elementa.000067

World Calibration Centre WCC-Empa

Empa
Materials Science and Technology

- Supports global research and policies since 1996
- More than 100 station audits at mainly global GAW stations
- Covers four important greenhouse and reactive gases
- Collaborates with other calibration centres to improve traceability
- Assesses the performance of stations also with parallel measurements
- Audit procedure includes data and metadata review

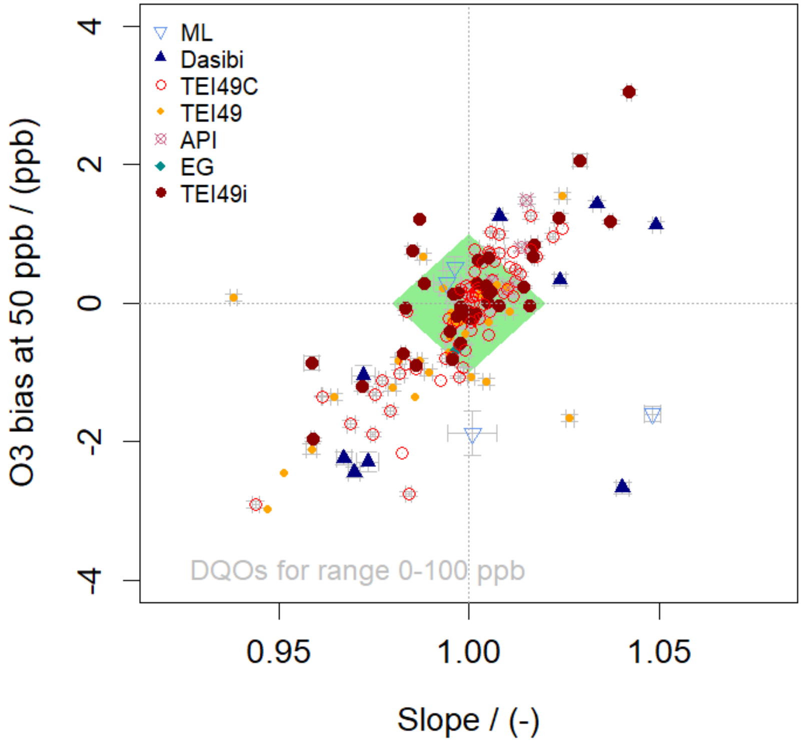
Audited stations by WCC-Empa since 1996 (red triangles); multiple audits at many stations

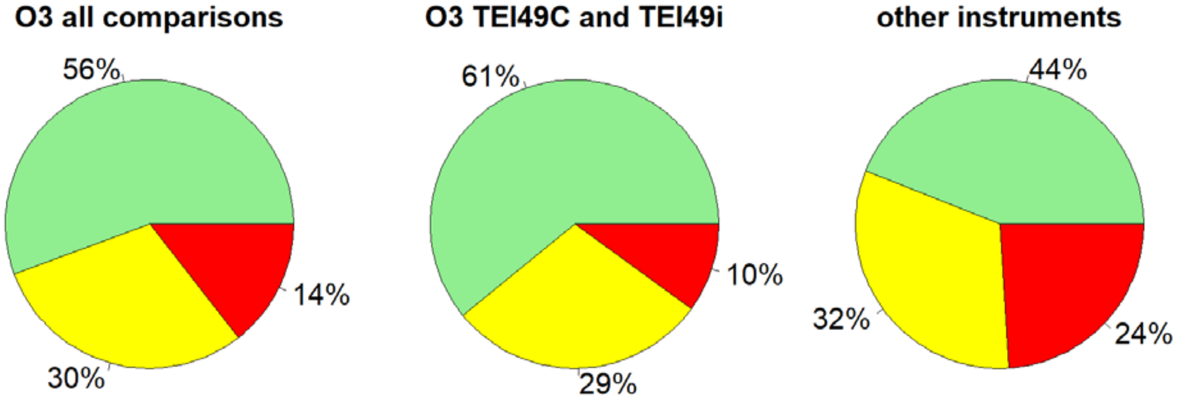


Scope (top) and cumulative number (bottom) of WCC-Empa audits

Ozone comparisons at GAW stations

~100 ozone audits at GAW stations during the past 25 years





Maximum deviation of the instrument in the range 0-100 ppb

Green: < 1 ppb

Yellow: 1 - 5 ppb.

Red: > 5 ppb

GAW is aware of the implications for a new ozone cross section.

This issue will be considered by the GAW *Expert Team on Atmospheric Composition Measurement Quality*

Members of this Expert Team include:

Herman Smit, *Forschungszentrum Jülich, Germany*

Christoph Zellweger, *Empa, Switzerland*

Joëlle Viallon, *BIPM, France*