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REVIEW

Tropospheric ozone assessment report: Missions, developments, and outlook

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The Tropospheric Ozone Assessment Report (TOAR), an activity of the International Global Atmospheric Chemistry Project (IGAC), has become a major international framework for assessing tropospheric ozone as an air pollutant, greenhouse gas, and ecosystem stressor from the surface to the tropopause. This contribution summarizes the evolution, scientific achievements, and remaining challenges of TOAR-I and TOAR-II, and outlines priorities for a possible TOAR-III. TOAR-I established the foundation for global ozone assessment by compiling a harmonized surface ozone database and producing standardized metrics for evaluating ozone distributions, trends, and exposure risks relevant to human health, vegetation, and climate. TOAR-II has expanded this foundation through 16 Focus Working Groups and a broad Community Special Issue, with stronger integration of surface observations, satellites, ozonesondes, aircraft, reanalysis products, and models. Its scientific advances include improved characterization of ozone variability and trends, greater emphasis on attribution to emissions, meteorology, transport, and stratosphere-troposphere exchange, and more explicit assessment of climate, health, crop, and ecosystem impacts. Remaining challenges include sparse long-term observations in the Global South, tropics, oceans, polar regions, and rapidly changing megacities; limited vertical profiling and precursor measurements; uncertainties in ozone deposition, radical chemistry, wildfire influences, and hemispheric transport; and inconsistent methods for trend detection, source attribution, and model evaluation. Future TOAR activities should therefore strengthen observational capacity, harmonize multi-platform data products, improve process-level understanding and predictive capability, and better connect ozone exposure with health burdens, crop yield and nutritional quality, forest carbon sequestration, ecosystem responses, and climate forcing.

Keywords: Ozone, Climate, Health, Global, Air pollution

1. Overview of Tropospheric Ozone Assessment Report (TOAR) activities

The Tropospheric Ozone Assessment Report (TOAR) is an activity of the International Global Atmospheric Chemistry Project (IGAC) that aims to assess the current state of knowledge on tropospheric ozone, that is, ozone in the lower part of the atmosphere (surface to about 12 km), and to evaluate the impacts of ozone on human health, ecosystems, and climate. The mission, development and achievements of TOAR are documented at https://igacproject.org/

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activities/TOAR. TOAR has evolved into a flagship initiative of IGAC with highly cited papers and substantial uptake by several global stakeholders such as the Intergovernmental Panel on Climate Change (IPCC), the World Health Organization (WHO), and the Global Burden of Disease (GBD).

The efficient work of TOAR comes from four main components: firstly, its governance structure (chairs and a representative steering committee); secondly, the development and curation of the TOAR data infrastructure at the Jülich Supercomputing Centre (https://toar-data.org) which has over 100 users and has been used in dozens of studies on atmospheric science, climate change, human health, and crop/ecosystem research as well as the development of deep learning models; thirdly, the working groups formed according to themes and regions; fourthly, the active community engagement expressed through the set of assessment and community special issue papers. Collectively, these efforts provide open, well-documented data resources and standardized analytical methods that enable reproducible research and strengthen the scientific basis for ozone–climate–health assessments.

So far, TOAR activities have been conducted in two separate phases, each with a clear strategy and road map. Upon approval by the IGAC Scientific Steering Committee in 2014, the first phase of TOAR was billed as Tropospheric Ozone Assessment Report (TOAR): Global metrics for climate change, human health, and crop/ecosystem research. Now known as TOAR-I, the activity was defined as an international effort aimed at improving our understanding of tropospheric ozone's global distribution and trends, with research activities conducted over a 5-year period (2014–2019). A major achievement of TOAR-I was the compilation of the world's largest open-access database of surface measurements of ozone and related pollutants (Schultz et al., 2017), which created a common observational foundation for global-scale analyses. Building on this resource, TOAR-I provided harmonized assessments of ozone distribution and trends across urban, rural, and background sites, and consistently calculated widely used exposure metrics relevant to climate change, human health, and vegetation, including MDA8, SOMO35, AOT40, and M7 (Fleming et al., 2018; Gaudel et al., 2018; Lefohn et al., 2018; Mills et al., 2018; Tarasick et al., 2019). These standardized products improved cross-study comparability and accessibility worldwide. TOAR-I also included broader assessments of global-scale model performance and long-term changes in the tropospheric ozone burden and budget, while stimulating additional regional analyses of surface ozone trends in eastern North America, Europe, East Asia, and China (Chang et al., 2017; Young et al., 2018; Archibald et al., 2020; Xu et al., 2020). Collectively, the TOAR-I assessment papers (published in Elementa: Science of the Anthropocene, 2020 https://igacproject.org/activities/TOAR/TOAR-I) provided a landmark synthesis of global ozone science and established the scientific and data foundation for TOAR-II. TOAR-I provided the first globally consistent, observation-based framework for assessing tropospheric ozone and its impacts on climate, human health, vegetation, and ecosystem services. Its objectives were to harmonize surface ozone observations, establish robust exposure and trend metrics, and create an open database for model evaluation, impact assessment, and future research. While TOAR-I established the scientific and data foundation for global ozone assessment, it also revealed important limitations in spatial coverage, metadata completeness, vertical information, precursor measurements, trend attribution, and links to impact-relevant diagnostics. These achievements and remaining gaps shaped the scientific priorities of TOAR-II, as summarized in **Table 1**.

Building on these achievements and remaining gaps, TOAR entered its second phase (TOAR-II) in February 2020. TOAR-II was designed to update the global assessment of tropospheric ozone while moving beyond trend detection toward attribution, multi-platform integration, regional synthesis, and impact-oriented diagnostics. These priorities provided the rationale for the TOAR-II Focus Working Groups (Section 2), which were organized to strengthen observations and harmonization, advance process understanding and attribution, expand regional analyses, and improve linkages to climate, health, vegetation, and ecosystem impacts. As of May 2026, TOAR-II was finalizing a new set of assessment papers and was expected to continue until these had been reviewed and accepted. A key focus in TOAR-II is to move beyond trend detection to attribute observed ozone changes to specific drivers such as precursor emissions (e.g., NO_x and VOCs), climate variability, long-range transport, and stratosphere-troposphere exchange (STE). TOAR-II has increased the integration of modeling studies with observations, using chemical transport and Earth-system models alongside satellite, ozonesonde, aircraft, and surface datasets to diagnose source-receptor relationships and attribution. The Community Special Issue publishes papers presenting original research (new datasets, methods, evaluations, regional analyses), whereas the forthcoming Assessment Special Issue synthesizes those results with the wider literature into standardized, non-prescriptive assessments (i.e., providing evidence and metrics without prescribing specific policies). Furthermore, the current phase also prioritizes better integration of observing systems and expanded coverage in under-sampled regions, including the Southern Hemisphere, the tropics, and parts of Africa, South America, China, and South/Southeast Asia, as well as oceanic and polar regions. This is achieved by linking satellite, ozonesonde, aircraft, and surface networks through harmonized QA/QC, common data structures, and joint analyses, while also leveraging newer deployments such as geostationary platforms where available. Maintenance and expansion of the TOAR database with high-resolution, quality-assured data continued throughout TOAR-II.

2. Key summaries of papers in TOAR-II Community Special Issue

2.1. Scientific goals of TOAR-II and structure of the Community Special Issue

Building on the observational and assessment foundation established by TOAR-I, TOAR-II was designed to provide a more integrated, diagnostic, and policy-relevant assessment of tropospheric ozone. Its goals can be grouped into seven areas: (i) updating and expanding the global ozone database; (ii) improving trend detection and attribution;

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Table 1. Summary table of TOAR-I objectives, major achievements, remaining gaps, and implications for TOAR-II

TOAR-I Objective	Major Achievements in TOAR-I	Remaining Gap After TOAR-I	Implication for TOAR-II
Establish a global surface ozone database	Harmonized surface ozone observations with quality control and metadata	Sparse coverage in the Global South, remote regions, and complex terrain	Expand observations and integrate surface, satellite, aircraft, ozonesonde, and reanalysis products
Standardize ozone metrics	Consistently calculated health-, vegetation-, and climate-relevant metrics	Some metrics remained weakly linked to biological uptake and impact endpoints	Refine exposure metrics for health, vegetation, and assessment applications
Assess ozone distributions and trends	Produced coordinated global and regional trend assessments	Trend interpretation limited by site history, metadata gaps, and meteorology	Improve metadata, statistical methods, and uncertainty quantification
Identify drivers of ozone variability	Revealed regionally heterogeneous O_3 changes and changing peak/background O_3 behavior	Limited attribution to emissions, transport, chemistry, and stratosphere-troposphere exchange	Strengthen process-based attribution using observations and models
Support model evaluation	Provided observational benchmarks for global and regional models	Coordinated model intercomparison and process diagnosis remained limited	Develop systematic model evaluation and reanalysis-model-observation comparisons
Link ozone to impacts	Synthesized O_3 effects on health, vegetation, ecosystems, and climate	Exposure-impact links remained incomplete, especially in data-sparse regions	Strengthen health, ecosystem, crop, and climate impact assessments
Establish an assessment community	Created a shared scientific infrastructure for long-term O_3 assessment	Sustained data submission, regional capacity, and cross-platform harmonization remained challenging	Organize TOAR-II Focus Working Groups around data, methods, attribution, and impacts

(iii) strengthening the linkage between observations, models, reanalyzes, and satellite products; (iv) advancing health, vegetation, ecosystem, and climate impact assessments; (v) connecting ozone variability with precursor chemistry, deposition, and photochemical regimes; (vi) developing policy-relevant diagnostics for air-quality management, methane mitigation, crop protection, and transboundary pollution; and (vii) promoting open, reproducible, and community-based assessment. The TOAR-II Community Special Issue was organized around these goals and provides the scientific basis for the forthcoming assessment papers. **Table 2** summarizes how the 58 papers contribute to these goals.

2.2. Scientific advances from the TOAR-II Community Special Issue

The TOAR-II Community Special Issue is an inter-journal initiative spanning five Copernicus journals (ACP (lead), AMT, GMD, BG, and ESSD) to connect method, data, modeling, and impact studies under a common special-issue umbrella. The goal of this special issue was to collect new information and individual perspectives on relevant factors from tropospheric ozone drivers to impacts. Through this, the TOAR-II steering group wanted to create a rich body of literature on which the actual TOAR-II assessment can now build. Within TOAR-II, 16 Focus Working Groups provided the backbone for this effort. They were established to (i) deliver foundational observations and harmonized data/metrics (e.g., HEGIFTOM, Satellite Ozone, Statistics); (ii) advance process understanding and attribution (e.g., Tropospheric Ozone Precursors (TOP), Ozone Deposition, Radiative Forcing, Chemical Reanalysis, Global and Regional Models, Machine Learning); (iii) produce regional syntheses (East Asia, South Asia, Tropics, Oceans); and (iv) assess impacts and applications (Human Health, Urban Ozone), with ROSTEES linking stratosphere-troposphere exchange to tropospheric burdens. This WG structure is mandated by TOAR-II's mission to update the global distribution, trends, drivers, and impacts of tropospheric ozone from the surface to the tropopause.

As of May 2026, the 58 articles in the TOAR-II Community Special Issue (https://bg.copernicus.org/articles/special_issue10_1256.html) reflect a systematic progression along the tropospheric ozone knowledge chain from the working groups: from foundational observation and data harmonization, through trend attribution and mechanistic evaluation, to impact quantification, machine learning-based innovation, and finally, policy-relevant scenario analysis. This framework ensures not only scientific coherence but also relevance to climate-air quality policy decision-making. Here, we summarize the key scientific advances across five interconnected thematic areas.

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Table 2. Mapping of TOAR-II Community Special Issue publications to TOAR-II scientific goals

TOAR-II Scientific Goal	Community Special Issue Publications Mapped to this Goal	Synthesis of Contributions
Strengthen observations and harmonized data products	Pope et al. (2023); Orfanoz-Cheuquelaf et al. (2024); Pope et al. (2024a); Wang et al. (2024); Zang et al. (2024); Björklund et al. (2024); Satheesan et al. (2024); Iturrate-Garcia et al. (2025); Arosio et al. (2025); Van Malderen et al. (2025a); Pennington et al. (2025); Kanaya et al. (2025); Smit et al. (2025); Coldewey-Egbers et al. (2025); Keppens et al. (2025)	Expanded and harmonized satellite, ozonesonde, aircraft, ground-based, oceanic, polar, and precursor datasets; evaluated retrieval bias, instrument consistency, vertical sensitivity, representativeness, metadata quality, and measurement traceability.
Improve trend detection and attribution	Gaudel et al. (2024); Stauffer et al. (2024); Chang et al. (2024); Seguel et al. (2024); Donnou et al. (2024); Froidevaux et al. (2025); Chang et al. (2025); Lu et al. (2025); Li et al. (2025); Van Malderen et al. (2025b); Pimlott et al. (2025a); Nelson and Drysdale (2025); Ansari et al. (2025); Thompson et al. (2025)	Quantified surface, free-tropospheric, and column O_3 trends across regions; documented heterogeneous changes in tropical, urban, high-elevation, East/Southeast Asian, South American, African, European, and North American O_3; improved statistical treatment of sparse and heterogeneous records.
Link ozone variability with process understanding and precursor chemistry	Li et al. (2024); Mertens et al. (2024); Elshorbany et al. (2024); Lebourgeois et al. (2024); Huang et al. (2025); Souri et al. (2025); Nalam et al. (2025); Fadnavis et al. (2025); Gong et al. (2025); Seguel et al. (2025); Okamoto et al. (2026)	Connected O_3 distributions and variability with precursor emissions, reactive nitrogen, VOCs, transport emissions, biomass burning, Arctic processes, tropical Atlantic variability, O_3 production regimes, and stratosphere-troposphere exchange.
Assess climate forcing and ozone–climate interactions	Pope et al. (2024b); Collins et al. (2025); Sellitto et al. (2025)	Updated estimates of tropospheric O_3 radiative effects and evaluated how precursor emissions, vertical O_3 redistribution, future emission pathways, and metric choice influence ozone–climate forcing assessments.
Quantify health, crop, forest, and ecosystem impacts	Cook et al. (2024); Pande et al. (2025); Cook et al. (2025); Everett et al. (2025); Karlsson et al. (2025); Turnock et al. (2025); Wang et al. (2025)	Linked O_3 exposure with crop phenology, wheat yield, nutritional quality, forest biomass growth, carbon sequestration, health-risk drivers, and uncertainty in health-relevant O_3 exposure datasets.
Develop modeling, reanalysis, statistical, and machine-learning tools	Brown et al. (2024); Sekiya et al. (2025); Miyazaki et al. (2025); Hickman et al. (2025); Jones et al. (2026)	Evaluated Earth-system models and chemical reanalyzes; assessed the value of assimilating satellite O_3 and precursor observations; applied explainable machine learning and reviewed emerging AI applications for ozone research.
Use perturbation events, urban sensitivity analyses, and scenarios for policy-relevant insight	Putero et al. (2023); Pimlott et al. (2025b); Cazorla et al. (2025)	Used COVID-19 emission perturbations, satellite-model analyses, and urban NO_x/VOC sensitivity studies to diagnose O_3 responses under rapid emission changes and to inform air-quality management in data-limited regions.

2.2.1. Ozone observation and data product development

Building on decades of global ozone observations, this theme strengthens the observational backbone by improving accuracy, cross-platform comparability, and precursor data coverage. Several studies provide intercomparisons between satellite (e.g., Ozone Mapping and Profiler Suite (OMPS) and Tropospheric Monitoring Instrument (TROPOMI)), ozonesonde, and aircraft observations (e.g., In-Service Aircraft for a Global Observing System (IAGOS)), revealing systematic differences related to vertical sensitivity (especially near the surface), sampling/representativeness, and retrieval uncertainty; these differences can influence trend detection and highlight where methodological refinement is needed (Pope et al., 2023; Pope et al., 2024a; 2024b; Gaudel et al., 2024; Wang

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et al., 2024). Complementing these are evaluations of chemical reanalysis products, which identify spatial–temporal performance variations and inform targeted improvements (Miyazaki et al., 2025; Jones et al., 2026). A novel strand of this thematic area involves expanding observational networks, especially for ozone precursors such as OVOCs, which are difficult to measure because of their low atmospheric abundance and lack of stable and traceable calibration standards. Beyond well-instrumented regions (e.g., Europe, the USA, and parts of China), significant gaps remain in in situ monitoring of both anthropogenic and biogenic VOCs. Expanding coverage would improve attribution of ozone formation regimes and trend detection. Iturrate-Garcia et al. (2025) emphasize metrological traceability for OVOC measurements, while satellite datasets such as GOP-ECV and OMPS-based (OMPS-NM/OMPS-LP ozone profile and related tropospheric ozone column) products offer enhanced continuity and coverage. More broadly, TOAR surface observations provide an objective reference for evaluating emerging satellite-derived tropospheric ozone products and their ability to inform spatial patterns and trends at the surface, especially where vertical sensitivity is limited (Pope et al., 2023; Gaudel et al., 2024). Collectively, these efforts reinforce the integrity of long-term ozone data for subsequent analysis (Chang et al., 2024).

2.2.2. Ozone distribution and variability

Building on improved data foundations, this thematic area investigates global and regional ozone patterns, their evolution, and underlying causes. Multiple analyses report post-2000 declines in high-percentile surface-ozone metrics across much of North America, along with short-term COVID-period reductions in Europe and western North America; changes are more heterogeneous for other metrics and across site settings (e.g., urban vs. rural/background) (Putero et al., 2023; Gaudel et al., 2024; Pope et al., 2024a; Chang et al., 2025; Pimlott et al., 2025a; 2025b). Complementary TOAR-II syntheses based on harmonized multi-platform observations (e.g., ozonesondes, IAGOS, FTIR, lidar, and Umkehr) quantify free-tropospheric and tropospheric-column ozone trends and provide additional context and constraints for satellite-based trend estimates (Thompson et al., 2025; Van Malderen et al., 2025a; 2025b). Aircraft observations across the stratosphere-troposphere exchange region show a hemispheric contrast with lower, more stratosphere-like ozone in the Southern Hemisphere, and year-to-year variability tied to stratospheric dynamics, exemplified by the 2019 sudden stratospheric warming (Seguel et al., 2025). The improved Trajectory-mapped Ozonesonde dataset for the Stratosphere and Troposphere (TOST) spanning 1970–2021 provides global seasonal and decadal context and indicates stagnant lower-stratospheric ozone since the late 1990s (Zang et al., 2024). Vertical distribution patterns and upper tropospheric anomalies are also scrutinized through IAGOS and satellite composites. Attribution studies further identify the meteorological and anthropogenic drivers of ozone variability, ranging from NO_x/VOC emission trends to STE and biomass burning. Lebourgeois et al. (2024) apply trajectory diagnostics and tagged tracers to isolate source contributions while modeling studies by Sekiya et al. (2025) and Huang et al. (2025) quantify the precursor influences with reanalysis-informed sensitivity frameworks. This integrative approach bridges observation with process understanding, supporting consistent trend attribution across scales from local to global dimensions.

2.2.3. Evaluation of ozone impacts and drivers

Several papers (Pope et al., 2024b; Collins et al., 2025; Everett et al., 2025; Fadnavis et al., 2025; Sellitto et al., 2025) assess the impacts of ozone in the Earth system, as a short-lived climate forcer, an ecological stressor, and a pollutant that affects human health. From the climate aspect, Pope et al. (2024b) update the tropospheric ozone radiative effect (TO_3RE) for 2008–2017 to 1.21–1.26 W m^{-2} and show a negligible global trend due to offsetting impacts from precursor-emission changes and meteorology; Fadnavis et al. (2025) demonstrate that NO_x emission changes dominate TO_3RE responses (with the largest enhancements over South and East Asia); and Sellitto et al. (2025) use IAGOS-constrained offline radiative modeling to show that RF did not decrease between recent periods because of shifts in the vertical distribution of ozone. These analyses frame ozone within the context of short-lived climate forcers and global warming potential. Concurrently, ecosystem impact assessments quantify ozone-induced crop yield and nutritional quality losses and forest productivity reductions in relation to carbon sequestration. Everett et al. (2025) apply crop models to estimate the effect of ozone on irrigated and rainfed crops under current and future climate simulations in India and find that ozone has the potential to offset some of the benefit to yield offered by irrigation. Cook et al. (Cook et al., 2024; 2025) developed crop modeling methods capable of linking surface ozone exposure to nutritional quality declines and yield penalties, and translating ozone impacts into effects on amino acids and dietary protein requirements for human health. Karlsson et al. (2025) estimate ozone-induced biomass losses in managed European forests, and find that carbon sequestration would increase by 31% under the scenarios considered in the absence of ozone pollution (i.e., exposure to elevated near-surface ozone above natural/background levels). Collectively, these studies underline the societal relevance of tropospheric ozone, especially in food and nutritional security and forest carbon sequestration. Finally, Turnock et al. (2025) additionally show that historical increases in peak-season surface ozone and associated health risk were driven mainly by rising anthropogenic precursor emissions, particularly NO_x and CH_4. For health-relevant exposure metrics, Wang et al. (2025) intercompare multiple global ground-level ozone mapping products and show that differences among datasets are large enough to materially affect estimated population exposure and health impacts.

2.2.4. Technological innovation

Innovation in ozone research is increasingly driven by machine learning (ML) and data integration technologies. This thematic area encompasses novel uses of AI and statistical learning to enhance model interpretation, trend

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attribution, and uncertainty quantification. Miyazaki et al. (2025) employ an explainable machine learning technique to identify bias sources in chemical reanalysis products, while Lu et al. (2025) integrate chemical transport models with neural networks to improve East and Southeast Asian ozone trend attribution. Hickman et al. (2025) provide a comprehensive review of recent advances in ML applications for tropospheric ozone research, highlighting progress in short-term forecasting, chemical mechanism emulation, and remote sensing-based ozone estimation. They identify major barriers such as limited model explainability, generalizability, and the need for benchmark datasets, and propose actionable pathways to strengthen the integration of ML into atmospheric chemistry through interdisciplinary collaboration. These approaches offer scalable tools for ozone monitoring and modeling, promising enhanced performance in both global assessments and regional applications.

2.2.5. Perturbation events and policy-relevant diagnostics

The final thematic area addresses how external shocks to the economy and contextual shifts influence tropospheric ozone levels and related policy responses. Several studies exploit the COVID-19 lockdown as a natural experiment: Putero et al. (2023) and Pimlott et al. (2025b) quantify ozone decreases associated with reduced anthropogenic activities, while Arosio et al. (2025) use the event to validate satellite column measurements under altered emission conditions. Beyond the COVID-19 perturbation, other Community Special Issue papers examine ozone responses to heat waves, biomass-burning influences, and tropical dynamical variability, including climate-oscillation-related changes in convection and transport over equatorial Southeast Asia (Lebourgeois et al., 2024; Stauffer et al., 2024; Chang et al., 2025). These events not only demonstrate the non-linear sensitivity of ozone chemistry to rapid change in precursor emissions, meteorology, and fire-related emissions but also offer insights into resilience and control strategies. Scenario and sensitivity modelling further support policy-relevant diagnostics by quantifying how precursor-emission changes affect ozone production, health-relevant exposure, and climate forcing (Cazorla et al., 2025; Collins et al., 2025; Fadnavis et al., 2025; Turnock et al., 2025).

In summary, the TOAR-II Community Special Issue provides a structured synthesis of the global ozone landscape and advances scientific understanding across many areas. The five thematic areas form a coherent research continuum: from rigorous observational groundwork to impact evaluation and policy-relevant modeling. By addressing observational gaps, refining attribution, and quantifying interactions with health, climate, and ecosystems, these studies deliver an integrated and actionable scientific foundation for the next generation of ozone assessment and management.

2.3. Community participation and geographic coverage

The TOAR-II Community Special Issue reflects a broad international effort, with contributions from research groups across North America, Europe, Asia, South America, Africa, and Oceania. This wide participation is important because tropospheric ozone is shaped by regionally diverse emission patterns, meteorology, chemistry, transport, and exposure settings. At the same time, the authorship and data coverage of the Community Special Issue also illustrate a continuing imbalance in global ozone research capacity. Contributions and long-term observations remain concentrated in Europe, North America, and parts of East Asia, whereas Africa, South America, South and Southeast Asia, the tropics, oceans, and polar regions remain comparatively underrepresented. This imbalance reinforces one of the central conclusions from TOAR-I and TOAR-II: future assessment activities must combine scientific synthesis with sustained capacity building, data rescue, harmonized metadata collection, and stronger engagement with under-sampled regions.

3. TOAR-II assessment papers: Overview and review

Building on the community special issue publications, TOAR-II is now developing several assessment papers focused on climate, health, and vegetation impacts, while extending TOAR-II focus areas beyond TOAR-I to include regional syntheses and an up-to-date assessment of stratosphere-troposphere exchange processes. Thus, the health assessment efforts align with improving assessments of ozone exposure in developing regions where data are sparse, using GBD (Global Burden of Disease), and newly developed models. In terms of Ozone and Ecosystem Impacts, emphasis has been placed on strengthening links between ozone exposure and impacts on crops and forests, as well as applying more biologically relevant metrics that reflect cumulative ozone uptake and damage to vegetation. The climate assessment will focus on analyzing feedback among ozone, climate change, and greenhouse gases, and on quantifying ozone's radiative forcing and its co-benefits/risks in climate mitigation strategies. In line with this, the assessment will support global assessments, such as reports by the IPCC and WMO with updated tropospheric ozone data. The regional assessments are vital because coverage in the Global South remains sparse in both TOAR-I and TOAR-II. Significant gaps persist across Africa, South America, Central and Southeast Asia, and the Pacific and Southern Oceans, which we identify as priority targets for future capacity-building and assessment updates. Most surface ozone data come from Europe, North America, and East Asia, limiting global representativeness. Thus, the TOAR-II assessment papers aim to bridge this gap with a focus on these key geographic regions such as South America, Africa, the oceans, and the polar regions. Methodologically, TOAR-II delivered a clear step forward by standardizing trend and uncertainty methods and harmonizing units and exposure metrics, thereby improving reproducibility and cross-study comparability across the assessment.

Although the TOAR-II Community Special Issue has now been completed, the TOAR-II assessment papers remain in preparation and/or under review. In drafting the assessment papers, several remaining or newly identified knowledge and data gaps have emerged. Some of the key limitations

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of TOAR-II that were discussed at the TOAR Writing Team Meeting in York, UK in July 2025, are listed in **Table 3**. They point toward future research priorities: expanded monitoring networks, improved chemistry in models, harmonized remote sensing techniques, robust statistical frameworks, and deeper mechanistic understanding, which may form the basis for a TOAR-III continuation.

4. TOAR-III in planning

TOAR-III is currently being planned and is intended to address underexplored or emerging areas that were only partially covered in TOAR-I and TOAR-II. The potential focus areas summarized in **Table 4** are motivated by the limitations identified in **Table 3**—for example, strengthening observing capacity and harmonization, improving model chemistry and process representation, and advancing the linkage between in situ data and remote sensing for trend attribution. In particular, **Table 4** priorities can be viewed as three connected thrusts: (i) expanding and harmonizing observations (including in developing regions) to reduce spatial gaps and improve measurement comparability; (ii) improving process understanding, attribution methods, and model representation to better attribute trends and extremes; and (iii) strengthening the translation from ozone exposure metrics to climate, health, and ecosystem-relevant outcomes. These thrusts directly respond to **Table 3** limitations by pairing data needs with methodological advances and by clarifying where new observing strategies, evaluation frameworks, and cross-program coordination can accelerate progress. Stronger links are expected to be pursued with other related international science programs including HTAP (Hemispheric Transport of Air Pollution), CCAC (Climate and Clean Air Coalition), and AQMx (Air Quality Management Exchange Platform) (**Table 4**). To strengthen the focus on developing regions, the TOAR steering committee has already appointed Dr Rodrigo Seguel from Universidad de Chile as the first co-chair to lead TOAR-III.

Table 3. Key areas of limitation within TOAR-II analysis

Gap Area	Specific Needs
Geographic and Vertical Data	More stations in tropics, Global South, vertical profiles, GEO satellites
Chemical Processes	Organic peroxy radical (RO_2) chemistry, reactive nitrogen chemistry, aerosol interactions
Model/Reanalysis Accuracy	Fix hemispheric biases, replicate trends
Statistical Methods	Standardized trend/uncertainty tools
Attribution Studies	Apportion drivers of ozone trends (emissions, meteorology, STE)
Satellite Retrieval Consistency	Harmonize data from different instruments
Urban and Extreme Events	Cover wildfire, convective influence
Ecosystem Metrics	Evaluation of stomatal uptake-based indicators and associated effects
Model Benchmarking	Deep intercomparison and process diagnosis

Table 4. Potential focus areas for TOAR-III

Underexplored Focus Area	Potential Contribution in TOAR-III
Air-Quality-Climate-Health Integration	Cross-sector policy evaluation and co-benefit analysis, including health records and demographic sensitivity
Climate Effect Management	Improve international accountability and emissions policy, for example, "what reductions in precursor emissions would achieve a 0.1 K reduction from O_3 RF?"
Biosphere Feedback	Link ozone with global carbon–water cycle
Wildfires and Biomass Burning	Impact of wildfires and wildland-urban interface fires on O_3
Real-Time Forecasting	Expanded use of AI
Data Fusion	GEO observations for diurnal observations of ozone and precursors (NO_x and VOCs)
Evolving Satellite Observing System	Leverage new GEO/LEO missions and ensure continuity as legacy platforms phase out; improve cross-sensor harmonization and long-term trend robustness
Supersites and Radical Chemistry	Advance process understanding and modeling

5. Conclusions and outlook

This IGAC anniversary contribution provides a guided overview of TOAR-I and TOAR-II activities and the TOAR-II Community Special Issue, which collectively advance tropospheric ozone science along an observation-to-impact knowledge chain. Key advances include (i) improved harmonization and intercomparison of ozone observations across platforms; (ii) more robust characterization of regional patterns and changes, including improved attribution of drivers; (iii) integration of models, reanalysis, and emerging machine-learning tools to quantify uncertainties and evaluate mechanisms; and (iv) strengthened linkages to climate, health, and ecosystem impacts through standardized exposure metrics. Continued progress will require expanding high-quality observations in under-sampled regions, sustaining open data infrastructures, and further integrating surface observations with profiling and satellite capabilities to support trend attribution and assessment use. The priorities under consideration for TOAR-III (**Table 4**) are designed to address these needs and to strengthen connections to allied international assessment activities.

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Appendix A. List of abbreviations

Abbreviation	Full Term
AOT40	Accumulated ozone exposure over a threshold of 40 ppb
AQMx	Air Quality Management Exchange Platform
CCAC	Climate and Clean Air Coalition
CTM	Chemical transport model
ESM	Earth system model
ESSD	Earth System Science Data
FTIR	Fourier-transform infrared spectroscopy
GBD	Global Burden of Disease
GEO	Geostationary Earth orbit
GMD	Geoscientific Model Development
HEGIFTOM	Harmonization and Evaluation of Ground-based Instruments for Free Tropospheric Ozone Measurements
HTAP	Hemispheric Transport of Air Pollution
IAGOS	In-service Aircraft for a Global Observing System
IGAC	International Global Atmospheric Chemistry Project
IPCC	Intergovernmental Panel on Climate Change
LEO	Low Earth orbit
M7	Mean daytime 7 h ozone mixing ratio
MDA8	Maximum daily 8 h average
ML	Machine learning
NO_x	Nitrogen oxides
OMPS	Ozone Mapping and Profiler Suite
OVOC	Oxygenated volatile organic compound
QA/QC	Quality assurance and quality control
RF	Radiative forcing
ROSTEES	Role of Stratosphere-Troposphere Exchange in the Earth System
RO_2	Organic peroxy radical
SOMO35	Sum of ozone means over 35 ppb
STE	Stratosphere-troposphere exchange
TO3RE	Tropospheric ozone radiative effect
TOAR	Tropospheric Ozone Assessment Report
TOAR-I	First phase of the Tropospheric Ozone Assessment Report
TOAR-II	Second phase of the Tropospheric Ozone Assessment Report
TOAR-III	Planned third phase of the Tropospheric Ozone Assessment Report
TROPOMI	Tropospheric Monitoring Instrument
TOST	Trajectory-mapped Ozonesonde dataset for the Stratosphere and Troposphere
VOC	Volatile organic compound
WMO	World Meteorological Organization
WHO	World Health Organization

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Competing interests

The authors declare no competing interests.

Author contributions

KL, HW, and MS conceptualized this work. KL and RM drafted this manuscript. All authors commented on drafting and revision of this manuscript during both the in situ and online TOAR workshops.

References

Arosio, C, **Sofieva, V**, **Orfanoz-Cheuquelaf, A**, **Rozanov, A**, **Heue, K-P**, **Loyola, D**, **Malina, E**, **Stauffer, RM**, **Tarasick, D**, **Van Malderen, R**, **Ziemke, JR**, **Weber, M**. 2025. Intercomparison of tropospheric ozone column datasets from combined nadir and limb satellite observations. *Atmospheric Measurement Techniques* **18**(14): 3247–3265.

Archibald, AT, **Neu, JL**, **Elshorbany, Y**, **Cooper, OR**, **Young, PJ**, **Akiyoshi, H**, **Cox, RA**, **Coyle, M**, **Derwent, R**, **Deushi, M**, **Finco, A**, **Frost, GJ**, **Galbally, IE**, **Gerosa, G**, **Granier, C**, **Griffiths, PT**, **Hossaini, R**, **Hu, L**, **Jöckel, P**, **Josse, B**, **Lin, MY**, **Mertens, M**, **Morgenstern, O**, **Naja, M**, **Naik, V**, **Oltmans, S**, **Plummer, DA**, **Revell, LE**, **Saiz-Lopez, A**, **Saxena, P**, **Shin, YM**, **Shaahid, I**, **Shallcross, D**, **Tilmes, S**, **Trickl, T**, **Wallington, TJ**, **Wang, T**, **Worden, HM**, **Zeng, G**. 2020. Tropospheric ozone assessment report: A critical review of changes in the tropospheric ozone burden and budget from 1850 to 2100. *Elementa: Science of the Anthropocene* **8**(1): 034.

Ansari, T, **Nalam, A**, **Lupaşcu, A**, **Hinz, C**, **Grasse, S**, **Butler, T**. 2025. Explaining trends and changing seasonal cycles of surface ozone in North America and Europe over the 2000–2018 period: A global modelling study with NO_x and VOC tagging. *Atmospheric Chemistry and Physics* **25**: 16833–16876. DOI: https://doi.org/10.5194/acp-25-16833-2025.

Björklund, R, **Vigouroux, C**, **Effertz, P**, **García, OE**, **Geddes, A**, **Hannigan, J**, **Miyagawa, K**, **Kotkamp, M**, **Langerock, B**, **Nedoluha, G**, **Ortega, I**, **Petropavlovskikh, I**, **Poyraz, D**, **Querel, R**, **Robinson, J**, **Shiona, H**, **Smale, D**, **Smale, P**, **Van Malderen, R**, **De Mazière, M**. 2024. Intercomparison of long-

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term ground-based measurements of total, tropospheric, and stratospheric ozone at Lauder, New Zealand. *Atmospheric Measurement Techniques* **17**: 6819–6849. DOI: https://doi.org/10.5194/amt-17-6819-2024.

Brown, F, **Folberth, G**, **Sitch, S**, **Artaxo, P**, **Bauters, M**, **Boeckx, P**, **Cheesman, AW**, **Detto, M**, **Komala, N**, **Rizzo, L**, **Rojas, N**, **dos Santos Vieira, I**, **Turnock, S**, **Verbeeck, H**, **Zambrano, A**. 2024. Performance evaluation of UKESM1 for surface ozone across the pan-tropics. *Atmospheric Chemistry and Physics* **24**: 12537–12555. DOI: https://doi.org/10.5194/acp-24-12537-2024.

Cazorla, M, **Trujillo, M**, **Seguel, R**, **Gallardo, L.** 2025. Comparative ozone production sensitivity to NOx and VOCs in Quito, Ecuador, and Santiago, Chile. *Atmospheric Chemistry and Physics* **25**: 7087–7109. DOI: https://doi.org/10.5194/acp-25-7087-2025.

Chang, K-L, **Cooper, OR**, **Gaudel, A**, **Petropavlovskikh, I**, **Effertz, P**, **Morris, G**, **McDonald, BC**. 2024. Technical note: Challenges in detecting free tropospheric ozone trends in a sparsely sampled environment. *Atmospheric Chemistry and Physics* **24**: 6197–6218.

Chang, K-L, **Petropavlovskikh, I**, **Cooper, OR**, **Schultz, MG**, **Wang, T**. 2017. Regional trend analysis of surface ozone observations from monitoring networks in eastern North America, Europe and East Asia. *Elementa: Science of the Anthropocene* **5**: 50.

Chang, K-L, **McDonald, BC**, **Harkins, C**, **Cooper, OR.** 2025. Surface ozone trend variability across the United States and the impact of heat waves (1990–2023). *Atmospheric Chemistry and Physics* **25**: 5101–5132. DOI: https://doi.org/10.5194/acp-25-5101-2025.

Collins, WJ, **O'Connor, FM**, **Byrom, RE**, **Hodnebrog, Ø**, **Jöckel, P**, **Mertens, M**, **Myhre, G**, **Nützel, M**, **Olivié, D**, **Bieltvedt Skeie, R**, **Stecher, L**, **Horowitz, LW**, **Naik, V**, **Faluvegi, G**, **Im, U**, **Murray, LT**, **Shindell, D**, **Tsigaridis, K**, **Abraham, NL**, **Keeble, J.** 2025. Climate forcing due to future ozone changes: An intercomparison of metrics and methods. *Atmospheric Chemistry and Physics* **25**: 9031–9060. DOI: https://doi.org/10.5194/acp-25-9031-2025.

Cook, J, **Brewster, C**, **Hayes, F**, **Booth, N**, **Bland, S**, **Pande, P**, **Thankappan, S**, **Pleijel, H**, **Emberson, L**. 2024. New ozone-nitrogen model shows early senescence onset is the primary cause of ozone-induced reduction in grain quality of wheat. *Biogeosciences* **21**: 4809–4835.

Cook, J, **Yadav, DS**, **Hayes, F**, **Booth, N**, **Bland, S**, **Pande, P**, **Thankappan, S**, **Emberson, L**. 2025. Modelling ozone-induced changes in wheat amino acids and protein quality using a process-based crop model. *Biogeosciences* **22**: 1035–1056.

Coldewey-Egbers, M, **Loyola R, DG**, **Latter, B**, **Siddans, R**, **Kerridge, B**, **Hubert, D**, **van Roozendael, M**, **Eisinger, M**. 2025. The novel GOME-type Ozone Profile Essential Climate Variable (GOP-ECV) data record covering the past 26 years. *Atmospheric Measurement Techniques* **18**: 5485–5505. DOI: https://doi.org/10.5194/amt-18-5485-2025.

Donnou, HEV, **Akpo, AB**, **Ossohou, M**, **Delon, C**, **Yoboué, V**, **Laouali, D**, **Ouafo-Leumbe, M**, **Van Zyl, PG**, **Ndiaye, O**, **Gardrat, E**, **Dias-Alves, M**, **Galy-Lacaux, C.** 2024. Measurement report: Long-term measurements of surface ozone and trends in semi-natural sub-Saharan African ecosystems. *Atmospheric Chemistry and Physics* **24**: 13151–13182. DOI: https://doi.org/10.5194/acp-24-13151-2024.

Everett, G, **Hodnebrog, Ø**, **Agrawal, M**, **Yadav, DS**, **O'Neill, C**, **Jamir, C**, **Cook, J**, **Pande, P**, **Bland, S**, **Emberson, L.** 2025. Ozone pollution may limit the benefits of irrigation to wheat productivity in India. *Biogeosciences* **22**(16): 4203–4219.

Elshorbany, Y, **Ziemke, JR**, **Strode, S**, **Petetin, H**, **Miyazaki, K**, **De Smedt, I**, **Pickering, K**, **Seguel, RJ**, **Worden, H**, **Emmerichs, T**, **Taraborrelli, D**, **Cazorla, M**, **Fadnavis, S**, **Buchholz, RR**, **Gaubert, B**, **Rojas, NY**, **Nogueira, T**, **Salameh, T**, **Huang, M**. 2024. Tropospheric ozone precursors: Global and regional distributions, trends, and variability. *Atmospheric Chemistry and Physics* **24**: 12225–12257. DOI: https://doi.org/10.5194/acp-24-12225-2024.

Fleming, ZL, **Doherty, RM**, **von Schneidemesser, E**, **Malley, CS**, **Cooper, OR**, **Pinto, JP**, **Colette, A**, **Xu, X**, **Simpson, D**, **Schultz, MG**, **Lefohn, AS**, **Hamad, S**, **Moolla, R**, **Solberg, S**, **Feng, Z.** 2018. Tropospheric Ozone Assessment Report: Present-day ozone distribution and trends relevant to human health. *Elementa: Science of the Anthropocene* **6**(1): 12. DOI: https://doi.org/10.1525/elementa.273.

Fadnavis, S, **Elshorbany, Y**, **Ziemke, J**, **Barret, B**, **Rap, A**, **Satheesh Chandran, PR**, **Pope, RJ**, **Sagar, V**, **Taraborrelli, D**, **Le Flochmoen, E**, **Cuesta, J**, **Wespes, C**, **Boersma, F**, **Glissenaar, I**, **De Smedt, I**, **Van Roozendael, M**, **Petetin, H**, **Anglou, I**. 2025. Influence of nitrogen oxides and volatile organic compounds emission changes on tropospheric ozone variability, trends and radiative effect. *Atmospheric Chemistry and Physics* **25**: 8229–8254. DOI: https://doi.org/10.5194/acp-25-8229-2025.

Froidevaux, L, **Kinnison, DE**, **Gaubert, B**, **Schwartz, MJ**, **Livesey, NJ**, **Read, WG**, **Bardeen, CG**, **Ziemke, JR**, **Fuller, RA**. 2025. Tropical upper-tropospheric trends in ozone and carbon monoxide (2005–2020): Observational and model results. *Atmospheric Chemistry and Physics* **25**: 597–624. DOI: https://doi.org/10.5194/acp-25-597-2025.

Gaudel, A, **Bourgeois, I**, **Li, M**, **Chang, K-L**, **Ziemke, J**, **Sauvage, B**, **Stauffer, RM**, **Thompson, AM**, **Kollonige, DE**, **Smith, N**, **Hubert, D**, **Keppens, A**, **Cuesta, J**, **Heue, K-P**, **Veefkind, P**, **Aikin, K**, **Peischl, J**, **Thompson, CR**, **Ryerson, TB**, **Frost, GJ**, **McDonald, BC**, **Cooper, OR.** 2024. Tropical tropospheric ozone distribution and trends from in situ and satellite data. *Atmospheric Chemistry and Physics* **24**: 9975–10000.

Gaudel, A, **Cooper, OR**, **Ancellet, G**, **Barret, B**, **Boynard, A**, **Burrows, JP**, **Clerbaux, C**, **Coheur, P-F**, **Cuesta, J**, **Cuevas, E**, **Doniki, S**, **Dufour, G**, **Ebojie, F**, **Foret, G**, **Garcia, O**, **Granados-Muñoz, MJ**, **Hannigan, JW**,

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Hase, F, **Hassler, B**, **Huang, G**, **Hurtmans, D**, **Jaffe, D**, **Jones, N**, **Kalabokas, P**, **Kerridge, B**, **Kulawik, S**, **Latter, B**, **Leblanc, T**, **Le Flochmoën, E**, **Lin, W**, **Liu, J**, **Liu, X**, **Mahieu, E**, **McClure-Begley, A**, **Neu, JL**, **Osman, M**, **Palm, M**, **Petetin, H**, **Petropavlovskikh, I**, **Querel, R**, **Rahpoe, N**, **Rozanov, A**, **Schultz, MG**, **Schwab, J**, **Siddans, R**, **Smale, D**, **Steinbacher, M**, **Tanimoto, H**, **Tarasick, DW**, **Thouret, V**, **Thompson, AM**, **Trickl, T**, **Weatherhead, E**, **Wespes, C**, **Worden, HM**, **Vigouroux, C**, **Xu, X**, **Zeng, G**, **Ziemke, J**. 2018. Tropospheric Ozone Assessment Report: Present-day distribution and trends of tropospheric ozone relevant to climate and global atmospheric chemistry model evaluation. *Elementa: Science of the Anthropocene* **6**: 39. DOI: https://doi.org/10.1525/elementa.291.

Gong, W, **Beagley, SR**, **Toyota, K**, **Skov, H**, **Christensen, JH**, **Lupu, A**, **Pendlebury, D**, **Zhang, J**, **Im, U**, **Kanaya, Y**, **Saiz-Lopez, A**, **Sommariva, R**, **Effertz, P**, **Halfacre, JW**, **Jepsen, N**, **Kivi, R**, **Koenig, TK**, **Müller, K**, **Nordstrøm, C**, **Petropavlovskikh, I**, **Shepson, PB**, **Simpson, WR**, **Solberg, S**, **Staebler, RM**, **Tarasick, DW**, **Van Malderen, R**, **Vestenius, M**. 2025. Modelling Arctic lower-tropospheric ozone: Processes controlling seasonal variations. *Atmospheric Chemistry and Physics* **25**: 8355–8405. DOI: https://doi.org/10.5194/acp-25-8355-2025.

Hickman, SHM, **Kelp, MM**, **Griffiths, PT**, **Doerksen, K**, **Miyazaki, K**, **Pennington, EA**, **Koren, G**, **Iglesias-Suarez, F**, **Schultz, MG**, **Chang, K-L**, **Cooper, OR**, **Archibald, A**, **Sommariva, R**, **Carlson, D**, **Wang, H**, **West, JJ**, **Liu, Z**. 2025. Applications of machine learning and artificial intelligence in Tropospheric Ozone Research. *Geoscientific Model Development* **18**: 8777–8800. DOI: https://doi.org/10.5194/gmd-18-8777-2025.

Huang, M, **Carmichael, GR**, **Bowman, KW**, **De Smedt, I**, **Colliander, A**, **Cosh, MH**, **Kumar, SV**, **Guenther, AB**, **Janz, SJ**, **Stauffer, RM**, **Thompson, AM**, **Fedkin, NM**, **Swap, RJ**, **Bolten, JD**, **Joseph, AT**. 2025. Reactive nitrogen in and around the northeastern and mid-Atlantic US: Sources, sinks, and connections with ozone. *Atmospheric Chemistry and Physics* **25**: 1449–1476.

Iturrate-Garcia, M, **Salameh, T**, **Schlauri, P**, **Baldan, A**, **Vollmer, MK**, **Stratigou, E**, **Dusanter, S**, **Li, J**, **Persijn, S**, **Claude, A**, **Holzinger, R**, **Sutour, C**, **Macé, T**, **Elshorbany, Y**, **Ackermann, A**, **Pascale, C**, **Reimann, S**. 2025. Towards a high-quality in situ observation network for oxygenated volatile organic compounds (OVOCs) in Europe: Transferring metrological traceability to the field. *Atmospheric Measurement Techniques* **18**: 371–403.

Jones, DBA, **Prates, L**, **Qu, Z**, **Cheng, WYY**, **Miyazaki, K**, **Sekiya, T**, **Inness, A**, **Kumar, R**, **Tang, X**, **Worden, H**, **Koren, G**, **Huijnen, V**. 2026. Assessment of regional and interannual variations in tropospheric ozone in chemical reanalyses. *Atmospheric Chemistry and Physics* **26**: 6655–6682. DOI: https://doi.org/10.5194/acp-26-6655-2026.

Karlsson, PE, **Büker, P**, **Bland, S**, **Simpson, D**, **Sharps, K**, **Hayes, F**, **Emberson, LD.** 2025. Ozone causes substantial reductions in the carbon sequestration of managed European forests. *Biogeosciences* **22**: 3563–3582. DOI: https://doi.org/10.5194/bg-22-3563-2025.

Kanaya, Y, **Sommariva, R**, **Saiz-Lopez, A**, **Mazzeo, A**, **Koenig, TK**, **Kawana, K**, **Johnson, JE**, **Colomb, A**, **Tulet, P**, **Molloy, S**, **Galbally, IE**, **Volkamer, R**, **Mahajan, A**, **Halfacre, JW**, **Shepson, PB**, **Schmale, J**, **Angot, H**, **Blomquist, B**, **Shupe, MD**, **Helmig, D**, **Gil, J**, **Lee, M**, **Coburn, SC**, **Ortega, I**, **Chen, G**, **Lee, J**, **Aikin, KC**, **Parrish, DD**, **Holloway, JS**, **Ryerson, TB**, **Pollack, IB**, **Williams, EJ**, **Lerner, BM**, **Weinheimer, AJ**, **Campos, T**, **Flocke, FM**, **Spackman, JR**, **Bourgeois, I**, **Peischl, J**, **Thompson, CR**, **Staebler, RM**, **Aliabadi, AA**, **Gong, W**, **Van Malderen, R**, **Thompson, AM**, **Stauffer, RM**, **Kollonige, DE**, **Gómez Martin, JC**, **Fujiwara, M**, **Read, K**, **Rowlinson, M**, **Sato, K**, **Kurokawa, J**, **Iwamoto, Y**, **Taketani, F**, **Takashima, H**, **Navarro-Comas, M**, **Panagi, M**, **Schultz, MG**. 2025. Observational ozone datasets over the global oceans and polar regions (version 2024). *Earth System Science Data* **17**: 4901–4932. DOI: https://doi.org/10.5194/essd-17-4901-2025.

Keppens, A, **Hubert, D**, **Granville, J**, **Nath, O**, **Lambert, J-C**, **Wespes, C**, **Coheur, P-F**, **Clerbaux, C**, **Boynard, A**, **Siddans, R**, **Latter, B**, **Kerridge, B**, **Di Pede, S**, **Veefkind, P**, **Cuesta, J**, **Dufour, G**, **Heue, K-P**, **Coldewey-Egbers, M**, **Loyola, D**, **Orfanoz-Cheuquelaf, A**, **Satheesan, SM**, **Eichmann, K-U**, **Rozanov, A**, **Sofieva, VF**, **Ziemke, JR**, **Inness, A**, **Van Malderen, R**, **Hoffmann, L**. 2025. Harmonisation of sixteen tropospheric ozone satellite data records. *Atmospheric Measurement Techniques* **18**: 6893–6916. DOI: https://doi.org/10.5194/amt-18-6893-2025.

Lefohn, AS, **Malley, CS**, **Smith, L**, **Wells, B**, **Hazucha, M**, **Simon, H**, **Naik, V**, **Mills, G**, **Schultz, MG**, **Paoletti, E**, **De Marco, A**, **Xu, X**, **Zhang, L**, **Wang, T**, **Neufeld, HS**, **Musselman, RC**, **Tarasick, D**, **Brauer, M**, **Feng, Z**, **Tang, H**, **Kobayashi, K**, **Sicard, P**, **Solberg, S**, **Gerosa, G**. 2018. Tropospheric ozone assessment report: Global ozone metrics for climate change, human health, and crop/ecosystem research. *Elementa: Science of the Anthropocene* **6**: 27. DOI: https://doi.org/10.1525/elementa.279.

Lebourgeois, T, **Sauvage, B**, **Wolff, P**, **Josse, B**, **Marécal, V**, **Bennouna, Y**, **Blot, R**, **Boulanger, D**, **Clark, H**, **Cousin, J-M**, **Nedelec, P**, **Thouret, V**. 2024. Seasonal, regional, and vertical characteristics of high-carbon-monoxide plumes along with their associated ozone anomalies, as seen by IAGOS between 2002 and 2019. *Atmospheric Chemistry and Physics* **24**: 13975–14004.

Li, K, **Tan, R**, **Qiao, W**, **Lee, T**, **Wang, Y**, **Zhang, D**, **Tang, M**, **Zhao, W**, **Gu, Y**, **Fan, S**, **Zhang, J**, **Lyu, X**, **Xue, L**, **Xu, J**, **Ma, Z**, **Latif, MT**, **Amnuaylojaroen, T**, **Gil, J**, **Lee, M-H**, **Bak, J**, **Kim, J**, **Liao, H**, **Kanaya, Y**, **Lu, X**, **Nagashima, T**, **Koo, J-H**. 2025. Surface and

Downloaded from online.ucpress.edu/elementa/article-pdf/14/1/00101/949453/elementa.2025.00101.pdf by guest on 03 November 2026

tropospheric ozone over East Asia and Southeast Asia from observations: Distributions, trends, and variability. *Atmospheric Chemistry and Physics* **25**: 11575–11596. DOI: https://doi.org/10.5194/acp-25-11575-2025.

Li, M, **Kurokawa, J**, **Zhang, Q**, **Woo, J-H**, **Morikawa, T**, **Chatani, S**, **Lu, Z**, **Song, Y**, **Geng, G**, **Hu, H**, **Kim, J**, **Cooper, OR**, **McDonald, BC**. 2024. MIXv2: A long-term mosaic emission inventory for Asia (2010–2017). *Atmospheric Chemistry and Physics* **24**: 3925–3952. DOI: https://doi.org/10.5194/acp-24-3925-2024.

Lu, X, **Liu, Y**, **Su, J**, **Weng, X**, **Ansari, T**, **Zhang, Y**, **He, G**, **Zhu, Y**, **Wang, H**, **Zeng, G**, **Li, J**, **He, C**, **Li, S**, **Amnuaylojaroen, T**, **Butler, T**, **Fan, Q**, **Fan, S**, **Forster, GL**, **Gao, M**, **Hu, J**, **Kanaya, Y**, **Latif, MT**, **Lu, K**, **Nédélec, P**, **Nowack, P**, **Sauvage, B**, **Xu, X**, **Zhang, L**, **Li, K**, **Koo, J-H**, **Nagashima, T**. 2025. Tropospheric ozone trends and attributions over East and Southeast Asia in 1995–2019: An integrated assessment using statistical methods, machine learning models, and multiple chemical transport models. *Atmospheric Chemistry and Physics* **25**: 7991–8028. DOI: https://doi.org/10.5194/acp-25-7991-2025.

Satheesan, SM, **Eichmann, K-U**, **Burrows, JP**, **Weber, M**, **Stauffer, R**, **Thompson, AM**, **Kollonige, D.** 2024. Improved convective cloud differential (CCD) tropospheric ozone from S5P-TROPOMI satellite data using local cloud fields. *Atmospheric Measurement Techniques* **17**: 6459–6484. DOI: https://doi.org/10.5194/amt-17-6459-2024.

Mertens, M, **Brinkop, S**, **Graf, P**, **Grewe, V**, **Hendricks, J**, **Jöckel, P**, **Lanteri, A**, **Matthes, S**, **Rieger, VS**, **Righi, M**, **Thor, RN**. 2024. The contribution of transport emissions to ozone mixing ratios and methane lifetime in 2015 and 2050 in the Shared Socioeconomic Pathways (SSPs). *Atmospheric Chemistry and Physics* **24**: 12079–12106. DOI: https://doi.org/10.5194/acp-24-12079-2024.

Mills, G, **Pleijel, H**, **Malley, CS**, **Sinha, B**, **Cooper, OR**, **Schultz, MG**, **Neufeld, HS**, **Simpson, D**, **Sharps, K**, **Feng, Z**, **Gerosa, G**, **Harmens, H**, **Kobayashi, K**, **Saxena, P**, **Paoletti, E**, **Sinha, V**, **Xu, X.** 2018. Tropospheric Ozone Assessment Report: Present-day tropospheric ozone distribution and trends relevant to vegetation. *Elementa: Science of the Anthropocene* **6**(1): 47. DOI: https://doi.org/10.1525/elementa.302.

Miyazaki, K, **Marchetti, Y**, **Montgomery, J**, **Lu, S**, **Bowman, K.** 2025. Identifying drivers of surface ozone bias in global chemical reanalysis with explainable machine learning. *Atmospheric Chemistry and Physics* **25**: 8507–8532. DOI: https://doi.org/10.5194/acp-25-8507-2025.

Nalam, A, **Lupaşcu, A**, **Ansari, T**, **Butler, T.** 2025. Regional and sectoral contributions of NOx and reactive carbon emission sources to global trends in tropospheric ozone during the 2000–2018 period. *Atmospheric Chemistry and Physics* **25**: 5287–5311. DOI: https://doi.org/10.5194/acp-25-5287-2025.

Nelson, BS, **Drysdale, WS.** 2025. Urban ozone trends in Europe and the USA (2000–2021). *Atmospheric Chemistry and Physics* **25**: 16009–16026. DOI: https://doi.org/10.5194/acp-25-16009-2025.

Okamoto, S, **Cuesta, J**, **Dufour, G**, **Eremenko, M**, **Miyazaki, K**, **Boonne, C**, **Tanimoto, H**, **Peischl, J**, **Thompson, C.** 2026. Natural and anthropogenic influence on tropospheric ozone variability over the Tropical Atlantic unveiled by satellite, reanalyses and in situ observations. *Atmospheric Chemistry and Physics* **26**: 4685–4709. DOI: https://doi.org/10.5194/acp-26-4685-2026.

Orfanoz-Cheuquelaf, A, **Arosio, C**, **Rozanov, A**, **Weber, M**, **Ladstätter-Weißenmayer, A**, **Burrows, JP**, **Thompson, AM**, **Stauffer, RM**, **Kollonige, DE**. 2024. Tropospheric ozone column dataset from OMPS-LP/OMPS-NM limb–nadir matching. *Atmospheric Measurement Techniques* **17**: 1791–1809. DOI: https://doi.org/10.5194/amt-17-1791-2024.

Pande, P, **Bland, S**, **Booth, N**, **Cook, J**, **Feng, Z**, **Emberson, L.** 2025. Development of the DO3SE-Crop model to assess ozone effects on crop phenology, biomass, and yield. *Biogeosciences* **22**: 181–212. DOI: https://doi.org/10.5194/bg-22-181-2025.

Pennington, EA, **Osterman, GB**, **Payne, VH**, **Miyazaki, K**, **Bowman, KW**, **Neu, JL.** 2025. Quantifying biases in TROPESS AIRS, CrIS, and joint AIRS+OMI tropospheric ozone products using ozonesondes. *Atmospheric Chemistry and Physics* **25**: 8533–8552. DOI: https://doi.org/10.5194/acp-25-8533-2025.

Pimlott, MA, **Pope, RJ**, **Kerridge, BJ**, **Siddans, R**, **Latter, BG**, **Feng, W**, **Chipperfield, MP.** 2025a. Long-term satellite trends of European lower-tropospheric ozone from 1996–2017. *Atmospheric Chemistry and Physics* **25**: 15991–16007. DOI: https://doi.org/10.5194/acp-25-15991-2025.

Pimlott, MA, **Pope, RJ**, **Kerridge, BJ**, **Siddans, R**, **Latter, BG**, **Ventress, LJ**, **Feng, W**, **Chipperfield, MP**. 2025b. Large reductions in satellite-derived and modelled European lower-tropospheric ozone during and after the COVID-19 pandemic (2020–2022). *Atmospheric Chemistry and Physics* **25**: 4391–4401.

Pope, RJ, **Kerridge, BJ**, **Siddans, R**, **Latter, BG**, **Chipperfield, MP**, **Feng, W**, **Pimlott, MA**, **Dhomse, SS**, **Retscher, C**, **Rigby, R.** 2023. Investigation of spatial and temporal variability in lower tropospheric ozone from RAL Space UV–Vis satellite products. *Atmospheric Chemistry and Physics* **23**: 14933–14947.

Pope, RJ, **O'Connor, FM**, **Dalvi, M**, **Kerridge, BJ**, **Siddans, R**, **Latter, BG**, **Barret, B**, **Le Flochmoen, E**, **Boynard, A**, **Chipperfield, MP**, **Feng, W**, **Pimlott, MA**, **Dhomse, SS**, **Retscher, C**, **Wespes, C**, **Rigby, R**. 2024a. Investigation of the impact of satellite vertical sensitivity on long-term retrieved lower-tropospheric ozone trends. *Atmospheric Chemistry and Physics* **24**: 9177–9195.

Pope, RJ, **Rap, A**, **Pimlott, MA**, **Barret, B**, **Le Flochmoen, E**, **Kerridge, BJ**, **Siddans, R**, **Latter, BG**, **Ventress, LJ**, **Boynard, A**, **Retscher, C**, **Feng, W**, **Rigby, R**, **Dhomse, SS**, **Wespes, C**, **Chipperfield, MP**. 2024b.

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Quantifying the tropospheric ozone radiative effect and its temporal evolution in the satellite era. *Atmospheric Chemistry and Physics* **24**: 3613–3626.

Putero, D, **Cristofanelli, P**, **Chang, K-L**, **Dufour, G**, **Beachley, G**, **Couret, C**, **Effertz, P**, **Jaffe, DA**, **Kubistin, D**, **Lynch, J**, **Petropavlovskikh, I**, **Puchalski, M**, **Sharac, T**, **Sive, BC**, **Steinbacher, M**, **Torres, C**, **Cooper, OR**. 2023. Fingerprints of the COVID-19 economic downturn and recovery on ozone anomalies at high-elevation sites in North America and western Europe. *Atmospheric Chemistry and Physics* **23**: 15693–15709.

Schultz, MG, **Schröder, S**, **Lyapina, O**, **Cooper, OR**, **Galbally, I**, **Petropavlovskikh, I**, **von Schneidemesser, E**, **Tanimoto, H**, **Elshorbany, Y**, **Naja, M**, **Seguel, RJ**, **Dauert, U**, **Eckhardt, P**, **Feigenspan, S**, **Fiebig, M**, **Hjellbrekke, A-G**, **Hong, Y-D**, **Kjeld, PC**, **Koide, H**, **Lear, G**, **Tarasick, D**, **Ueno, M**, **Wallasch, M**, **Baumgardner, D**, **Chuang, M-T**, **Gillett, R**, **Lee, M**, **Molloy, S**, **Moolla, R**, **Wang, T**, **Sharps, K**, **Adame, JA**, **Ancellet, G**, **Apadula, F**, **Artaxo, P**, **Barlasina, ME**, **Bogucka, M**, **Bonasoni, P**, **Chang, L**, **Colomb, A**, **Cuevas-Agulló, E**, **Cupeiro, M**, **Degorska, A**, **Ding, A**, **Fröhlich, M**, **Frolova, M**, **Gadhavi, H**, **Gheusi, F**, **Gilge, S**, **Gonzalez, MY**, **Gros, V**, **Hamad, SH**, **Helmig, D**, **Henriques, D**, **Hermansen, O**, **Holla, R**, **Hueber, J**, **Im, U**, **Jaffe, DA**, **Komala, N**, **Kubistin, D**, **Lam, K-S**, **Laurila, T**, **Lee, H**, **Levy, I**, **Mazzoleni, C**, **Mazzoleni, LR**, **McClure-Begley, A**, **Mohamad, M**, **Murovec, M**, **Navarro-Comas, M**, **Nicodim, F**, **Parrish, D**, **Read, KA**, **Reid, N**, **Ries, L**, **Saxena, P**, **Schwab, JJ**, **Scorgie, Y**, **Senik, I**, **Simmonds, P**, **Sinha, V**, **Skorokhod, AI**, **Spain, G**, **Spangl, W**, **Spoor, R**, **Springston, SR**, **Steer, K**, **Steinbacher, M**, **Suharguniyawan, E**, **Torre, P**, **Trickl, T**, **Weili, L**, **Weller, R**, **Xu, X**, **Xue, L**, **Ma, Z**. 2017. Tropospheric Ozone Assessment Report: Database and metrics data of global surface ozone observations. *Elementa: Science of the Anthropocene* **5**: 58.

Sekiya, T, **Emili, E**, **Miyazaki, K**, **Inness, A**, **Qu, Z**, **Pierce, RB**, **Jones, D**, **Worden, H**, **Cheng, WYY**, **Huijnen, V**, **Koren, G**. 2025. Assessing the relative impacts of satellite ozone and its precursor observations to improve global tropospheric ozone analysis using multiple chemical reanalysis systems. *Atmospheric Chemistry and Physics* **25**: 2243–2268.

Sellitto, P, **Gaudel, A**, **Sauvage, B.** 2025. Decadal tropospheric ozone radiative forcing estimations with offline radiative modelling and IAGOS aircraft observations. *Atmospheric Chemistry and Physics* **25**: 13299–13309. DOI: https://doi.org/10.5194/acp-25-13299-2025.

Seguel, RJ, **Castillo, L**, **Opazo, C**, **Rojas, NY**, **Nogueira, T**, **Cazorla, M**, **Gavidia-Calderón, M**, **Gallardo, L**, **Garreaud, R**, **Carrasco-Escaff, T**, **Elshorbany, Y**. 2024. Changes in South American surface ozone trends: Exploring the influences of precursors and extreme events. *Atmospheric Chemistry and Physics* **24**: 8225–8242. DOI: https://doi.org/10.5194/acp-24-8225-2024.

Seguel, RJ, **Opazo, C**, **Cohen, Y**, **Cooper, OR**, **Gallardo, L**, **Sinnhuber, B-M**, **Obersteiner, F**, **Zahn, A**, **Hoor, P**, **Rohs, S**, **Marsing, A.** 2025. Hemispheric differences in ozone across the stratosphere–troposphere exchange region. *Atmospheric Chemistry and Physics* **25**: 8553–8573. DOI: https://doi.org/10.5194/acp-25-8553-2025.

Smit, HGJ, **Galle, T**, **Blot, R**, **Obersteiner, F**, **Nédélec, P**, **Zahn, A**, **Cousin, J-M**, **Bundke, U**, **Petzold, A**, **Thouret, V**, **Clark, H**. 2025. Intercomparison of IAGOS-CORE, IAGOS-CARIBIC and WMO/GAW-WCCOS Ozone Instruments at the Environmental Simulation Facility at Jülich, Germany. *Atmospheric Measurement Techniques* **18**: 4985–5001. DOI: https://doi.org/10.5194/amt-18-4985-2025.

Souri, AH, **González Abad, G**, **Wolfe, GM**, **Verhoelst, T**, **Vigouroux, C**, **Pinardi, G**, **Compernolle, S**, **Langerock, B**, **Duncan, BN**, **Johnson, MS.** 2025. Feasibility of robust estimates of ozone production rates using a synergy of satellite observations, ground-based remote sensing, and models. *Atmospheric Chemistry and Physics* **25**: 2061–2086. DOI: https://doi.org/10.5194/acp-25-2061-2025.

Stauffer, RM, **Thompson, AM**, **Kollonige, DE**, **Komala, N**, **Al-Ghazali, HK**, **Risdianto, DY**, **Dindang, A**, **Jamaluddin, AFB**, **Sammathuria, MK**, **Zakaria, NB**, **Johnson, BJ**, **Cullis, PD**. 2024. Dynamical drivers of free-tropospheric ozone increases over equatorial Southeast Asia. *Atmospheric Chemistry and Physics* **24**: 5221–5234. DOI: https://doi.org/10.5194/acp-24-5221-2024.

Tarasick, D, **Galbally, IE**, **Cooper, OR**, **Schultz, MG**, **Ancellet, G**, **Leblanc, T**, **Wallington, TJ**, **Ziemke, J**, **Liu, X**, **Steinbacher, M**, **Staehelin, J**, **Vigouroux, C**, **Hannigan, JW**, **García, O**, **Foret, G**, **Zanis, P**, **Weatherhead, E**, **Petropavlovskikh, I**, **Worden, H**, **Osman, M**, **Liu, J**, **Chang, K-L**, **Gaudel, A**, **Lin, M**, **Granados-Muñoz, M**, **Thompson, AM**, **Oltmans, SJ**, **Cuesta, J**, **Dufour, G**, **Thouret, V**, **Hassler, B**, **Trickl, T**, **Neu, JL**. 2019. Tropospheric Ozone Assessment Report: Tropospheric ozone from 1877 to 2016, observed levels, trends and uncertainties. *Elementa: Science of the Anthropocene* **7**: 39. DOI: https://doi.org/10.1525/elementa.376.

Turnock, ST, **Akritidis, D**, **Horowitz, L**, **Mertens, M**, **Pozzer, A**, **Reddington, CL**, **Wang, H**, **Zhou, P**, **O'Connor, F**. 2025. Drivers of change in peak-season surface ozone concentrations and impacts on human health over the historical period (1850–2014). *Atmospheric Chemistry and Physics* **25**: 7111–7136.

Thompson, AM, **Stauffer, RM**, **Kollonige, DE**, **Ziemke, JR**, **Johnson, BJ**, **Morris, GA**, **Cullis, P**, **Cazorla, M**, **Diaz, JA**, **Piters, A**, **Nedeljkovic, I**, **Warsodikromo, T**, **Silva, FR**, **Northam, ET**, **Benjamin, P**, **Mkololo, T**, **Machinini, T**, **Félix, C**, **Romanens, G**, **Nyadida, S**, **Brioude, J**, **Evan, S**, **Metzger, J-M**, **Dindang, A**, **Mahat, YB**, **Sammathuria, MK**, **Zakaria, NB**, **Komala, N**, **Ogino, S-Y**, **Quyen, NT**, **Mani, FS**, **Vuiyasawa, M**, **Nardini, D**, **Martinsen, M**,

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Kuniyuki, DT, **Müller, K**, **Wolff, P**, **Sauvage, B**. 2025. Tropical tropospheric ozone trends (1998 to 2023): New perspectives from SHADOZ, IAGOS and OMI/MLS observations. *Atmospheric Chemistry and Physics* **25**: 18475–18507.

Van Malderen, R, **Thompson, AM**, **Kollonige, DE**, **Stauffer, RM**, **Smit, HGJ**, **Barras, EM**, **Vigouroux, C**, **Petropavlovskikh, I**, **Leblanc, T**, **Thouret, V**, **Wolff, P**, **Effertz, P**, **Tarasick, DW**, **Poyraz, D**, **Ancellet, G**, **De Backer, M-R**, **Evan, S**, **Flood, V**, **Frey, MM**, **Hannigan, JW**, **Hernandez, JL**, **Iarlori, M**, **Johnson, BJ**, **Jones, N**, **Kivi, R**, **Mahieu, E**, **McConville, G**, **Müller, K**, **Nagahama, T**, **Notholt, J**, **Piters, A**, **Prats, N**, **Querel, R**, **Smale, D**, **Steinbrecht, W**, **Strong, K**, **Sussmann, R**. 2025a. Global ground-based tropospheric ozone measurements: Reference data and individual site trends (2000–2022) from the TOAR-II/HEGIFTOM project. *Atmospheric Chemistry and Physics* **25**: 7187–7225.

Van Malderen, R, **Zang, Z**, **Chang, K-L**, **Björklund, R**, **Cooper, OR**, **Liu, J**, **Barras, EM**, **Vigouroux, C**, **Petropavlovskikh, I**, **Leblanc, T**, **Thouret, V**, **Wolff, P**, **Effertz, P**, **Gaudel, A**, **Tarasick, DW**, **Smit, HGJ**, **Thompson, AM**, **Stauffer, RM**, **Kollonige, DE**, **Poyraz, D**, **Ancellet, G**, **De Backer, M-R**, **Frey, MM**, **Hannigan, JW**, **Hernandez, JL**, **Johnson, BJ**, **Jones, N**, **Kivi, R**, **Mahieu, E**, **Morino, I**, **McConville, G**, **Müller, K**, **Murata, I**, **Notholt, J**, **Piters, A**, **Prignon, M**, **Querel, R**, **Rizi, V**, **Smale, D**, **Steinbrecht, W**, **Strong, K**, **Sussmann, R**. 2025b. Ground-based tropospheric ozone measurements: Regional tropospheric ozone column trends from the TOAR-II/HEGIFTOM homogenized datasets. *Atmospheric Chemistry and Physics* **25**: 9905–9935.

Wang, H, **Tarasick, DW**, **Liu, J**, **Smit, HGJ**, **Van Malderen, R**, **Shen, L**, **Blot, R**, **Zhao, T**. 2024. Consistency evaluation of tropospheric ozone from ozonesonde and IAGOS (In-service Aircraft for a Global Observing System) observations: Vertical distribution, ozonesonde types, and station–airport distance. *Atmospheric Chemistry and Physics* **24**: 11927–11942.

Wang, H, **Miyazaki, K**, **Sun, HZ**, **Qu, Z**, **Liu, X**, **Inness, A**, **Schultz, M**, **Schröder, S**, **Serre, M**, **West, JJ**. 2025. Intercomparison of global ground-level ozone datasets for health-relevant metrics. *Atmospheric Chemistry and Physics* **25**: 15969–15990.

Xu, X, **Lin, W**, **Xu, W**, **Jin, J**, **Wang, Y**, **Zhang, G**, **Zhang, X**, **Ma, Z**, **Dong, Y**, **Ma, Q**, **Yu, D**, **Li, Z**, **Wang, D**, **Zhao, H**. 2020. Long-term changes of regional ozone in China: Implications for human health and ecosystem impacts. *Elementa: Science of the Anthropocene* **8**: 13. DOI: https://doi.org/10.1525/elementa.409.

Young, PJ, **Naik, V**, **Fiore, AM**, **Gaudel, A**, **Guo, J**, **Lin, MY**, **Neu, JL**, **Parrish, DD**, **Rieder, HE**, **Schnell, JL**, **Tilmes, S**, **Wild, O**, **Zhang, L**, **Ziemke, J**, **Brandt, J**, **Delcloo, A**, **Doherty, RM**, **Geels, C**, **Hegglin, MI**, **Hu, L**, **Im, U**, **Kumar, R**, **Luhar, A**, **Murray, L**, **Plummer, D**, **Rodriguez, J**, **Saiz-Lopez, A**, **Schultz, MG**, **Woodhouse, MT**, **Zeng, G**. 2018. Tropospheric Ozone Assessment Report: Assessment of global-scale model performance for global and regional ozone distributions, variability, and trends. *Elementa: Science of the Anthropocene* **6**: 10. DOI: https://doi.org/10.1525/elementa.265.

Zang, Z, **Liu, J**, **Tarasick, D**, **Moeini, O**, **Bian, J**, **Zhang, J**, **Thompson, AM**, **Van Malderen, R**, **Smit, HGJ**, **Stauffer, RM**, **Johnson, BJ**, **Kollonige, DE**. 2024. The improved Trajectory-mapped Ozonesonde dataset for the Stratosphere and Troposphere (TOST): Update, validation and applications. *Atmospheric Chemistry and Physics* **24**: 13889–13912. DOI: https://doi.org/10.5194/acp-24-13889-2024.

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