TOAR-III Scope and Roadmap for Working Groups and Publications
Authored by the TOAR-III Steering Committee, July 31, 2026

Summary: The third phase of IGAC's Tropospheric Ozone Assessment Report (TOAR-III) was initiated on January 1, 2026 (https://igacproject.org/activities/TOAR/TOAR-III). This document defines the mission, goals, scientific scope and publication framework of TOAR-III. Consistent with previous TOAR phases, TOAR-III research will be guided by the international scientific community. While the mission, goals and scientific scope are defined here, the scientific priorities will evolve during the first year through the Quick Start event, the Kick-off Workshop and the activities of the Focus Working Groups. Together, these activities will identify emerging scientific opportunities, address knowledge gaps highlighted by TOAR-II, and refine the scientific priorities that will guide the TOAR-III Community Special Issue and inform the establishment of the Assessment Working Groups.

TOAR-III will produce two complementary sets of peer-review papers, within a special issue of an open-access journal: (i) contributed papers supporting the preparation of the assessment (TOAR-III Community Special Issue) and (ii) invited papers comprising the assessment report (TOAR-III Core Assessment). Community papers may be developed through TOAR-III-sponsored Focus Working Groups or by other scientists or teams of scientists interested in collaborating with TOAR-III. These papers should contribute to the TOAR-III objectives and, ideally, help prepare the TOAR-III assessment, for example, by providing new data or analytical methods, or by reviewing the state of science on chemical and physical processes affecting the ozone budget. The use of the TOAR-III data resources and the contribution of new datasets is strongly encouraged to strengthen the scientific foundation of the TOAR-III assessment.

The invited Core Assessment papers will be prepared by formally established Assessment Working Groups. These papers will: (1) report key findings and their uncertainties using IPCC calibrated language; (2) use ozone metrics from the TOAR Ozone Database; (3) report global and regional ozone trends and distributions using appropriate statistical methods, with a focus on common time periods; and 4) follow common TOAR-III style guidelines to ensure consistency across the assessment.

Preamble

TOAR Mission (*https://igacproject.org/activities/TOAR*) :

TOAR's mission, developed in 2014, is to provide the research community and decision makers with **an up-to-date scientific assessment of tropospheric ozone's global distribution and trends from the surface to the tropopause and their drivers**. This includes the production of tropospheric ozone assessment reports based on the peer-reviewed literature and new analyses, as well as the provision of easily accessible, documented data on ozone mixing ratios, including exposure and dose metrics at thousands of measurement sites around the world, and links to quality assessed data sources of free tropospheric ozone at the TOAR data portal. All TOAR data are freely accessible for independent research on the global-scale impact of ozone on climate, human health and crop/ecosystem productivity. The first phase of TOAR (TOAR-I) spanned 2014-2019, and was followed by the second phase of TOAR (TOAR-II) which spanned 2020-2025.

TOAR-I Accomplishments, 2014-2019 (*https://igacproject.org/activities/TOAR/TOAR-I*) :

TOAR delivered on its goals of producing the first tropospheric ozone assessment report and building the world's largest database of surface ozone metrics, calculated consistently for over 9000 surface ozone time series worldwide. TOAR's accomplishments were made possible by the collective efforts of the international research community, drawing on the expertise of 230 scientists and air quality specialists from 36 nations, representing research on all seven continents. For details, see TOAR

Accomplishment Report, September 2019, and the TOAR papers published in a Special Feature of Elementa: Science of the Anthropocene.

TOAR-II Accomplishments, 2020-2025 (*https://igacproject.org/activities/TOAR/TOAR-II*) :
The TOAR-II Focus Working Groups collectively advanced a coordinated, community based assessment of tropospheric ozone by integrating observations, models, and emerging analytical approaches across regions and themes. Regional groups evaluated ozone distributions and trends in key regions, including Africa, East Asia, and South Asia. Satellite, ground-based, and chemical reanalysis efforts improved data integration, validation, and coverage in observation-poor regions. Modeling and precursor-focused studies strengthened attribution of ozone variability and change to emissions, chemistry, and transport, while process-oriented groups improved understanding of deposition, oceanic influences, tropical variability, and urban ozone. Additional efforts reported impacts on human health and climate, and advances in statistics and machine learning provided new tools for trend analysis and interpretation. The TOAR-II Community Special Issue, sponsored by Copernicus open access journals (https://acp.copernicus.org/articles/special_issue1256.html), gathered 59 papers from the wider research community although the majority came from the WGs. It served as a basis, alongside TOAR-I, IPCC AR6 and other articles recently published in the broader peer-reviewed literature, for the eight TOAR-II assessment papers prepared for a Philos. Trans. R. Soc. A. Special Issue. It allowed TOAR-II to provide a more comprehensive assessment of how and why tropospheric ozone is changing, and its impacts on climate, health, and vegetation. It has led to topical assessments (vegetation, health, climate, satellite data, Stratosphere-Troposphere Exchange) as well as regional assessments (South America, Ozone over the Oceans and Polar Regions).

The open and FAIR (findable, accessible, inter-operable, and reusable) provision of air quality monitoring data, and especially of ozone observations, was the second key objective of TOAR-II alongside the scientific assessment. TOAR-II adopted a free and open data access policy, requiring all data providers to agree that all data that is needed to reproduce the assessment results be shared with a Creative Commons - By Attribution (CC-BY 4.0) license but also give credit in publications to all people and institutions who are involved in the laborious undertaking of atmospheric composition measurements. A simple data portal (https://toar-data.org) facilitates the discovery of tropospheric ozone-related datasets for use in the TOAR context. The TOAR-II assessment would not be possible without an extensive data collection and harmonisation efforts. Note that to ensure high quality and harmonisation of the data in the TOAR database neither the OpenAQ network (https://openaq.org/) nor those from low cost sensor networks have been included in the analyses.
At the centre of many TOAR-II papers is the TOAR database of surface station observations with its associated web services (https://toar-data.fz-juelich.de). Building on the experiences gained with databases in TOAR-I, the TOAR-II database was completely re-designed at the Jülich Supercomputing Centre with maximum usability and performance in mind and the database team obtained a Core Trust Seal certificate in 2023 and applied for a renewal of this certificate in the summer of 2025. TOAR-II has succeeded in creating and documenting the world's most comprehensive collection of datasets relevant for assessing the distribution, burden, and temporal trends of tropospheric ozone.

TOAR-III Implementation Goals, 2026-2030 (https://igacproject.org/activities/TOAR/TOAR-III):
1. TOAR Ozone Data Portal: Update the ozone observations in the TOAR surface ozone database to include all recent observations (since 2024 and up to 2028), and include data from new sites and regions, as well as ozone precursor and meteorological data. Develop methods for including historical data (pre-1975). Link to repositories of free tropospheric observations, in-situ measurements, model

ensembles, remote sensing based datasets (e.g. the link to https://toar-data.org/satellite-data/), reanalysis as well as emission and concentration of ozone precursors. Pursue the efforts to improve existing observational records and to produce multi-instrument datasets on a regular basis.

2. Maximize exploitation of the TOAR Ozone Database by, 1) helping scientists around the world, including those outside the TOAR community, to use it for new analyses, and 2) exploring new data science methods and favoring multi-record multi-species studies to improve the analysis of global ozone trends and their attribution. Extend the statistical toolbox and metrics of the TOAR trend analyses.

3. TOAR publications: Exploit the new observational datasets collected by Goal 1 (with data through 2028) to provide an updated state of the science estimate of ozone's distribution and trends relevant to climate, human health and vegetation at multiple temporal and spatial scales (e.g., daily, monthly, urban, regional, global). These results will be published in the open-access, peer-reviewed literature.

4. Community: TOAR has served as an important international collaborative platform that gathers scientists across continents, research domains and analysis methods. Engage scientists from the atmospheric and Earth System sciences communities, alongside statisticians and scientists focused on broader global change and sustainability issues, to identify and address outstanding science questions regarding tropospheric ozone. The scope of TOAR-II was expanded beyond the original TOAR effort to investigate the impacts of tropospheric ozone on climate, human health and vegetation to include urban-scale issues alongside the regional and global scales. Sustaining and consolidating this comprehensive effort is essential to moving forward.

Gaps and Limitations and opportunities identified in TOAR-II

In drafting the TOAR-II assessment papers, several remaining or newly identified knowledge and data gaps have emerged, as summarized by Lu et al. (accepted) and Worden et al. (accepted). They point toward future research priorities that may form the basis for a TOAR-III continuation. A few are summarized here for inspiration:

Observations/Database

With respect to surface and aircraft observations, several gaps remain, particularly over Africa, Australia/Oceania, South America, and South East Asia. This is due to a lack of observations, as well as weak responsiveness or a lack of agreement among data providers to release their data openly (see Worden et al. 2026 for details). Clearly, a stronger effort, such as onboarding regional scientists as **points of contact** to ensure an optimal **collection of existing data** and better structure the data collection, and promoting the **expansion of monitoring networks** (need for more stations in tropics, Global South, vertical profiles, GEO satellites), will be needed in the future to close the remaining gaps in the TOAR database.

The new generation of **satellite observations based on geostationary platforms** (GEO) are designed to document the diurnal variations in ozone and precursors (NOx and VOCs) over much of the Northern Hemisphere. The exploitation of these data will require **validation using ground-based reference data, harmonization and data fusion of the various retrieval systems** and verification of the continuity with legacy Low Earth Orbit platforms. In parallel, the consequence of losing long-standing sensors needs to be documented.

Small sensor development and deployment offer opportunities to document undersampled locations but pose significant challenges for calibration and data quality. Such opportunities and limitations should be investigated to provide recommendations on how to responsibly incorporate small sensor

data in the database

Process understanding to better attribute trends and extremes

Deeper mechanistic understanding: To analyse the recent change in ozone drivers and project future responses to emissions, climate, and land use changes, we need a better understanding of the natural system dynamics, such as wildfires, stratosphere-troposphere exchange, vegetation, soils, and their influence on the tropospheric ozone budget. This will require specific analysis of multi-parameters observations and ad-hoc multimodel experiments to anticipate future ozone trends associated with climate change. The recent evolution of wildfires in the northern mid and high latitudes is an example of opportunity to investigate the impact of climate change related extreme events on ozone production and loss. The investigation of the links between extreme events, variability and ozone is essential for public health prevention. In parallel, a deeper understanding of the net impact of ozone on climate change is needed.

Improved chemistry in models: Improved understanding of ozone chemical regimes (e.g. organic peroxy radical (RO_2) chemistry, reactive nitrogen chemistry, in-plume chemistry, aerosol interactions) is needed to better understand ozone changes and to assess the potential of pollution controls in the context of rapidly changing regional precursor emissions. This will require new ways to develop and compare chemical mechanisms and to confront them with observations from supersites.

Cross-sector policy evaluation and co-benefit analysis including health records and demographic sensitivity will be needed to better integrate Air-Quality-Climate-Health, in addition to evaluating the **relevance of ozone-associated metrics**.

Integration of diverse observations: Statistical approaches, including data assimilation and data harmonization, have been used to develop integrated ozone datasets from in situ, aircraft, and satellite observations. Further improving these methods and extending them to incorporate a broader range of observing systems could provide a more spatially and temporally consistent understanding of ozone variability.

Integration of models, reanalysis, and emerging statistical machine-learning tools

Standardized **statistical tools** to analyse trends and uncertainties are needed as well as a framework for **model benchmarking** (including process diagnosis). Forthcoming multi-model activities such as AerChemMIP2 (Fiedler et al., 2026), CCMI, HTAP with models advanced to better incorporate interactions between atmospheric chemistry and land and oceanic processes could be leveraged for better attribution of trends and extremes. At the same time, recent advances in artificial intelligence (AI) are beginning to yield promising results for atmospheric composition and air-quality applications. These include ozone model emulation to reduce the computational cost, downscaling to provide finer-scale information relevant to human health, and bias correction to generate more reliable atmospheric states for climate and health assessments. It can be anticipated that these models will mature over the next few years and then provide novel information, particularly for near time forecasts relevant to a new tropospheric ozone assessment.

TOAR-III Scientific Scope

The scientific scope of TOAR-III is an observation-based, up-to-date assessment of tropospheric ozone's distribution and trends on regional, hemispheric and global scales. Observations include in situ measurements using modern quantitative methods, e.g. UV-absorption instruments (surface and airborne), wet chemical ozonesondes, and remote sensing methods from ground- and space-based

platforms (e.g. lidar, UV-absorption, thermal-infrared). Historical tropospheric ozone data (pre-1975) may also be considered, including those inferred from proxy for preindustrial times. The scientific scope of TOAR-III aligns closely with those of the IPCC Working Groups I and II (https://www.ipcc.ch/working-groups/). Paralleling Working Group I (Physical Science Basis), TOAR-III will assess the physical science of tropospheric ozone's global distribution and trends. Mirroring Working Group II (Impacts, Adaptation, and Vulnerability), it will explore and quantify the impacts of tropospheric ozone on human health, crop and ecosystem productivity, and climate change. Conversely, topics related to IPCC Working Group III (Mitigation)—such as methods for reducing or removing greenhouse gases—fall outside the scope of TOAR-III, though TOAR data will remain publicly available to support independent research in these areas. Finally, adhering to IPCC standards, TOAR-III assessments aim to be policy-relevant but strictly not policy-prescriptive.

Procedures for TOAR-III manuscript development

TOAR-III findings will be disseminated through the peer-reviewed literature. The papers will be organized in two TOAR-III Special Issues of a yet to be determined peer-reviewed, open-access host journal under two categories: (i) a set of papers contributing to the TOAR-III Community Special Issue which support the preparation of the assessment, and (ii) an invited set of core papers comprising the assessment report. Supporting papers to be contributed to the TOAR-III Community Special Issue can be developed through TOAR-III-sponsored Focus Working Groups (see the Working Group Guidelines document on the TOAR-III website), or by other scientists or teams of scientists interested in collaborating with TOAR-III. These papers should contribute to TOAR-III objectives and ideally help the preparation of the TOAR-III assessment, for example by contributing new data or analysis methods, or through reviewing the impact of specific ozone formation and loss processes. We specifically encourage the use of the TOAR-III data resources and/or contribution of new data to these resources in order to further improve the foundation of the TOAR-II assessment. Uptake of these papers in the TOAR-III assessment is facilitated if new findings are presented in relation to an extensive literature review, with detailed comparisons to previous work, and if these studies conclude with concise summary statements that provide the broader context of new findings, along with uncertainty estimates. While the authors are free to use statistical methods of their choosing, ozone distributions and trends should also be reported using common TOAR methods and/or TOAR time periods to enable comparisons across studies. We encourage contributing author teams to share their ideas for papers with the TOAR-III Steering Committee in the early stages of paper development, to identify ways that the papers can be most supportive of the assessment report, and thereby maximizing their impact. Papers contributing to the TOAR-III Community Special Issue must be submitted by September 1, 2028, so that their results can be included in the core assessment report papers. Once papers are submitted to the Special Issue they will proceed through the normal peer-review process and will be subject to the scope of the host journal. Assessment Working Groups, which are established using a clear protocol and which are governed through documented principles established by the TOAR-III Steering Committee (see the Working Group Guidelines document on the TOAR-III website), will produce the invited peer-reviewed core papers comprising the assessment report. These papers will: 1) report key findings and their uncertainties using IPCC calibrated language (described below); 2) use ozone metrics from the TOAR Surface Ozone Database; 3) report global and regional ozone trends and distributions using appropriate statistical methods, with a focus on common time periods; and 4) produce figures and tables following TOAR-II style guidelines to ensure a common look and feel to the papers. As of this writing, the list of assessment report core papers consists of updates to TOAR-Health, TOAR Vegetation and TOAR-Climate. Additional core papers will be identified by the TOAR-III Steering Committee at a later date, based on input from the

TOAR-III community. Each TOAR-III assessment paper must include an SC member as a co-author and each paper must be approved by the SC prior to submission.

TOAR-III Timetable

01/2026 TOAR-III initiated
09/2026 TOAR-III Quickstart (on Sept 10 at the IGAC conference in Heraklion, Greece) +
11/03/2026 Online Information meeting - working group proposals will be solicited
04/2027 First TOAR-III Kick-off Workshop, held in hybrid format
2027 Continuous update of the ozone database, collection of new data, development of new ozone metrics
01/2028 begin preparation of papers for the Community Special issue
09/2028 deadline for submission of papers to Community Special Issue
12/2028 begin preparation of the core assessment papers
10/2029 Community review of the core assessment papers
12/2029 Submission of core assessment papers
12/2030 End of TOAR-III

Calibrated Language

The IPCC Fifth Assessment Report developed a method for the consistent treatment of uncertainties across all three IPCC Working Groups. Mastrandrea et al. (2010), "define a common approach and calibrated language that can be used broadly for developing expert judgments and for evaluating and communicating the degree of certainty in findings of the assessment process." This method has been adopted for the subsequent IPCC Assessment Reports and will also be used by TOAR-III. The method relies on two metrics for communicating the degree of certainty in key findings: 1) Confidence in the validity of a finding, based on the type, amount, quality, and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgment) and the degree of agreement. Confidence is expressed qualitatively. 2) Quantified measures of uncertainty in a finding expressed probabilistically (based on statistical analysis of observations or model results, or expert judgment). Further details are provided by Mastrandrea et al. (2010).

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