TOAR-II Focus Working Group - Ozone and Precursors in the Tropics (OPT)

Will be active **until 2024** or **until goals of the WG are met**

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I- Context and Motivation of OPT

The tropics constitute 40% of Earth's surface area and contain 36% of Earth's landmass. As of 2014, the region was home to 40% of the world's population, and this figure was then projected to reach 50% by 2050, as populations in the tropics —especially Africa— are growing at a much faster clip than in temperate regions. Tropospheric ozone (O3) has increased in the northern hemisphere during the past two decades even at mid-latitudes despite emissions controls of ozone precursors such as NOx and VOCs (Gaudel et al., 2020). This rise seems to be partly caused by the increase of anthropogenic emissions in the tropics where sunshine is plentiful, ozone production efficiency is high and where deep convection is efficient to recirculate polluted air towards higher latitudes (Zhang et al., 2016; Gaudel et al., 2020). Natural sources (lightning, soil, and biomass burning emissions) in the tropics are also active and participate in ozone budget and ozone production efficiency (Sauvage et al., 2007a; 2007b).

Specific patterns and phenomena in the tropics have been discovered using in situ data, satellite and models, for instance:

1) The ozone maximum above the convergent zone of the Atlantic (lightning, biomass burning) and low ozone above the Pacific (deep convection, Walker circulation) (Thompson et al., 2003; Martin et al., 2007; Sauvage et al., 2006; 2007a,b; Jourdain et al., 2007).

2) The impact of biomass burning on ozone occurring during the dry season (e.g. Ziemke et al., 2009a; Leventidou et al., 2016).

4) The impact of the Madden-Julian Oscillation on ozone (Ziemke et al., 2007, 2015; Stauffer et al., 2018).

However, there are still large gaps in understanding ozone variability and changes throughout the tropical troposphere and the exchange between the tropics and extratropics. In addition, in situ observations are too sparse in terms of their temporal and spatial distribution to fully evaluate satellite products and model output. At the surface, the TOAR-database shows very limited data in the tropical band. Throughout the troposphere, only two profiling networks are available, SHADOZ and IAGOS, and neither fully covers the entire tropical band, especially in the southern hemisphere.

II- Goals of the Ozone and Precursors in the Tropics Focus Working Group (OPT WG) in support of TOAR-II

We articulated five central goals for the OPT WG:

a) Quantify the seasonal and interannual variability of ozone and its precursors across the tropical band.

b) Assess the ozone budget within the tropics, and its main uncertainties related to the main sources, among anthropogenic and natural sources (gas and aerosols), and climate variables (ENSO, MJO, …).

c) Assess the impact of tropical pollution on local and remote tropical regions, as well as subtropical and mid-latitudes regions.

d) Quantify how much the tropical tropospheric ozone increase affects the global ozone burden.

e) Quantify the radiative forcing due to tropospheric ozone increases in the tropics and its contribution to the global radiative effect.

III- Plans for broader community involvement

a) Promote and encourage collaboration and partnerships with scientists and institutes from tropical countries, to collect, analyze data and shape the papers that will emerge from this OPT WG.

b) Model studies:

i) Ozone budget
ii) Radiative forcing
iii) 20+ years of data for trends calculation
iv) Sensitivity tests

The details on the output should be discussed among the members of the working group. It will depend on the available models output shared by the members.

c) Collaboration with the other TOAR WGs

i) Statistics WG (proposal submitted)

We will be using up-to-date statistical methods recommended and developed by the *Statistics Focus Working Group* led by Kai-Lan Chang. We are already building our approach to analyze data based on Kai-Lan Chang's work during TOAR-I and beyond.

ii) HEGIFTOM WG (proposal approved)

As for the SOWG, we will learn from *The Harmonization and Evaluation of Ground Based Instruments for Free Tropospheric Ozone Measurements (HEGIFTOM) Focus Working Group*, led by Roeland Van Malderen and Herman Smit, on how to understand the uncertainties of the data in order to assess accurate tropospheric ozone trends.

iii) Satellite Ozone WG (proposal approved)

We will learn from the *Satellite Ozone Focus Working Group* (SOWG) effort, led by Jessica New and Paul Palmer, on how to better analyze the available satellite products, especially for tropospheric ozone trends calculation. We will encourage satellite product development with improved vertical sensitivity that will open new applications such as in air quality (PBL) and climate (UT, UTLS).

iv) Radiative forcing WG (proposal under development)

We will be using the most up-to-date techniques to calculate the radiative forcing due to ozone using observations, which will be developed by the *Radiative Forcing Focus Working Group* led by Pasquale Sellitto.

IV- Data and Methods

To achieve the five goals of the OPT WG, we will be using different data sets from observations and from model output of ozone and its precursors such as CO, NO2 and HCHO.

1) In situ data sets

Data set	**Species**	**Period**	**Groups / PI**
IAGOS	O3	1994-present	U.Toulouse (V.Thouret & B. Sauvage)
IAGOS	CO	2002-present	U.Toulouse (V.Thouret & B. Sauvage)
SHADOZ	O3	1996-present	NASA/GSFC (A.Thompson & R. Stauffer)
ATom	O3/CO2/ CH4/BC	2016-2018	NASA / S. Wofsy
Previous in situ campaigns (See figure 4)	O3	Since 1983	NASA/NOAA European institutes

Table 1: In situ tropical data overview

a) IAGOS

Commercial aircraft observations from the IAGOS (In-Service Aircraft for a Global Observing System) European Research Infrastructure provided a better understanding of ozone variability and changes above 5 regions in the tropics (India, Southeast Asia, Northern South America, Gulf of Guinea and Malaysia/Indonesia) with more than 7500 profiles between 1994 and 2016 (Figure 1).

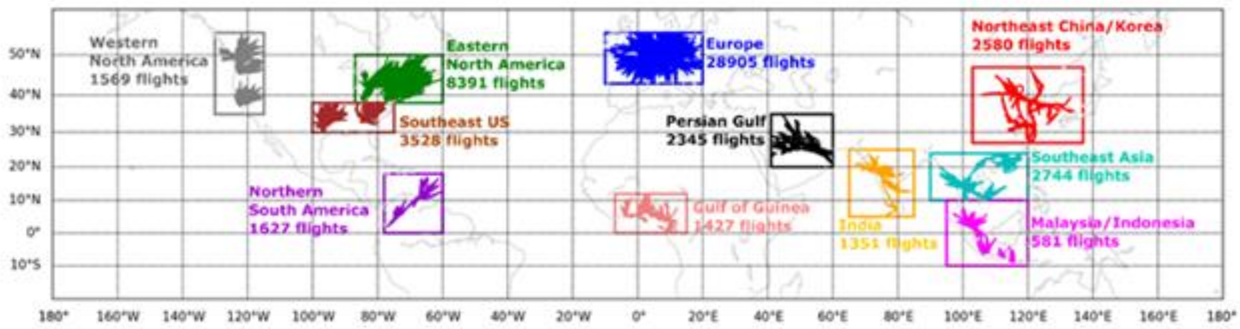

***Figure 1*. *Map of the eleven study regions sampled by IAGOS commercial aircraft*.** *The flight tracks are also indicated in the boxes with Western North America in grey, Eastern North America in green, Europe in blue, Northeast China / Korea in red, Southeast US in brown, Northern South America in purple, Gulf of Guinea in salmon, the Persian Gulf in black, India in orange, Southeast Asia in cyan and Malaysia/Indonesia in magenta. [Figure from Gaudel et al., 2020]*

b) SHADOZ ozonesonde network

The SHADOZ ozonesonde network provides ozone measurement above 10 tropical sites (Figure 2) with 3 or 4 profiles a month from the late 1990's to the present.

Figure 2: SHADOZ ozonesonde sites.

c) ATom

ATom (Atmospheric Tomography Mission) is a recent pole-to-pole aircraft mission conducted above the Atlantic and the Pacific basins between 2016 and 2018 to measure profiles of the atmospheric composition during all four seasons. ATom provides co-located global measurements of ozone and its precursors such as NOx, CO, VOCs. This unique dataset representative of the remote atmosphere will be used to analyze the impact of polluted regions on remote regions in the tropical band.

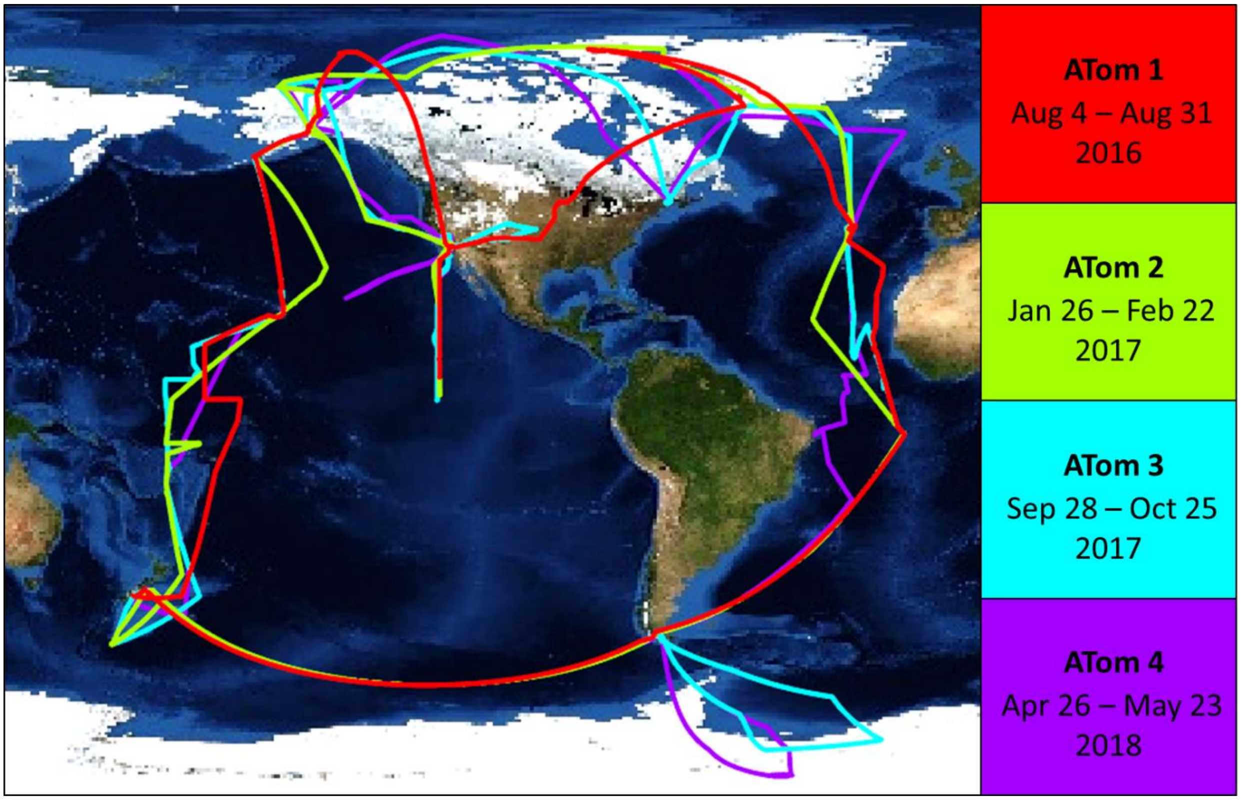

Figure 3. Flight tracks of ATom, a global field mission led by NASA.

d) Previous in situ campaigns

Different international campaigns have been conducted across the tropics, yielding measurements of various species and aerosols above different regions and periods. These data are valuable and have been rarely used together for a comprehensive understanding of the tropics or for model evaluation.

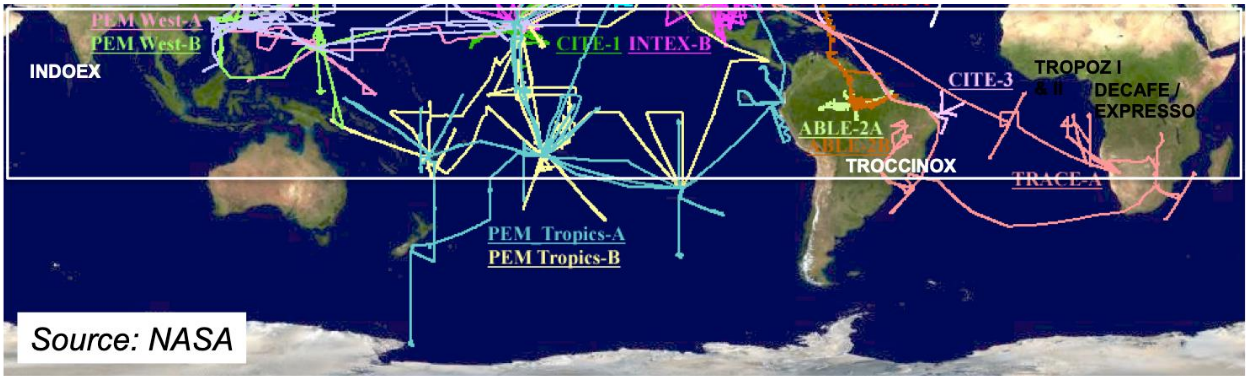

Figure 4. In situ campaigns dedicated to gas and aerosols measurements in the Tropics since 1983 and led by NOAA/NASA and European institutes.

2) Satellite data

Satellite data will give us a broad perspective of ozone variability and trends above the tropical region. We would like to work closely with the Satellite Ozone Working Group dedicated to understanding the discrepancies between the products, especially in assessing the trends of ozone.

Satellite - Instrument	Time period	Groups
Metop A,B,C - IASI Ozone and CO	2008 - present	LATMOS (FORLI retrieval) LISA (KOPRAFIT retrieval) U.Toulouse/CNRS (SOFRID)
Metop A,B,C - GOME-2 Ozone and NO_2	2008 - present	U. Bremen
Metop - IASI/GOME-2	2008 - present	LISA (KOPRAFIT) STFC
Aura - OMI trop. column Ozone and NO_2	2004 - present	NASA/GSFC KNMI
Aura - OMI/MLS	2004 - present	NASA/GSFC

Aura - OMI profile	2004 - present	SAO
Aqua - AIRS/ Aura - OMI	2004 - present	NASA/JPL
TROPOMI - trop. column Ozone and NO_2	2018 - present	KNMI
MOPITT CO	2000 - present	NCAR

Table 2: Satellite observations of trace gases

3) Models

a) Global models

Both chemistry transport models (CTM) and chemistry climate models (CCM) as well as the earth system models (ESM), which are the next generation of CCMs, will be useful in the OPT WG.

CTMs (e.g. MOCAGE, GEOS-Chem, etc) will be useful to have detailed representation of the main processes influencing ozone distributions (sources, detailed chemistry of O3-COV-NOx-aerosols, stratospheric chemistry, etc) to perform a thorough analysis of (1) the main ozone distribution drivers throughout sensitivities back in time, and of (2) the tropical tropospheric ozone budget evaluation. Horizontal resolution should be at least 2x2.5° lat x lon, with monthly or seasonal mean output, over 10 to 30 years simulations.

CCM and ESM (e.g. CESM, CAMS-Chem, CAMS, GEOSCCM, GFDL-AM3, IPSL-CM6, G5NR-Chem, CHASER, MRI-ESM1r1, etc) will be useful to have dynamic/chemistry interaction and provide a detailed estimation of ozone radiative impact and trends in the Tropics. Horizontal resolution should be at least 3x3° lat x lon, with at least seasonal mean output, over 20 to 30 years simulations.

b) Lagrangian modeling

We will use Lagrangian models (e.g. FLEXPART, SOFT-IO, etc) to provide an efficient quantification of source influence distribution on receptor (“footprint”), using in situ data.

4) Methods

The general methodology is based on multiple in situ and remote-sensed data compiling as well as model output. In situ measurements within the tropics are sparse (spatially and temporally, especially in the southern hemisphere). Therefore, new methodology to interpret, analyze data from observations and models will be explored and discussed with the statistics WG (e.g. Kai-Lan Chang methodology for trends and for model evaluation).

a) Data analysis

The monthly mean will be used to study tropospheric ozone variability throughout the troposphere. At the surface, the monthly mean will be limited to daytime hours in the goal of evaluating models output, because models have issues with nighttime deposition.

For in situ data, we might cluster sites to make sure the monthly mean is statistically robust above regions with low temporal resolution.

For satellite data, we will be mostly using tropospheric column ozone and boundary layer ozone if accessible.

Trends calculation will be done over the 1990-2020 time period using Kai-Lan Chang's methodology (Chang et al., 2017; Cooper et al., 2020; Gaudel et al., 2020).

b) Model evaluations with in situ and satellite data

Chemistry and transport models (CTM), climate (CCM) and earth system (ESM) models will be used to have a broader understanding of the tropics. Gas and aerosols data along with Lagrangian modeling (FLEXPART, SOFT-IO) and emission inventories analysis will be used to evaluate 3D models with complete chemistry (gases and aerosols).

A general framework will be defined for coherent simulations using different models: CTM, CCM, ESM after discussion with the models community. Should model's teams join the OPT WG, we will be already asking at least the following simulations characteristics:

i) Global simulations
ii) Full O3-NOx-COVs-aerosols tropospheric chemistry
iii) Monthly output
iv) Tropospheric column
v) Boundary layer column
vi) Simulations for a 30 years period (1990-2020)

The model output will be compared with in situ and satellite data. The kriging of surface data developed by Kai-Lan Chang (lead of the statistic WG; Chang et al., 2019), will be explored and potentially extended using vertical profiles.

We would like to realize intercomparison exercises with specific sensitivity tests. The sensitivity tests can cover the following characteristics:

vii) Stratospheric source (stratospheric chemistry? Global annual flux…)
viii) Anthropogenic source (same inventory, different inventory)
ix) Lightning emissions (fixed or not annual source)
x) Biomass burning emissions (GFAS, GFED4 …)
xi) Ozone radiative impact (TOA)
xii) Enlargement of the tropical band?

V- Three identified publications

1) Present-day tropical ozone variability

The goals of this paper will be to assess the ozone variability by latitude and longitude throughout the tropical band for these five-ten past years, and to assess the impact of polluted regions (continental) on remote regions (oceanic) in terms of ozone and its main precursors.

2) Tropical ozone trends

The goal of this paper is to focus on ozone trends in key areas of the tropics (ozone maximas) in the boundary layer, the free troposphere, and the tropospheric column, over 30 years, and to understand the main drivers of these trends

3) Impact of tropical ozone changes on global ozone

The scope of this paper will depend on the accessibility to models output and the results from the models evaluation. The goal of this paper is to assess a series of impacts due to the rapid changes of tropical ozone and its precursors: regional and global scales, radiative forcing.

VI- Tentative timeline

SON 2020: Solicit participation in working group and set up virtual meetings [scientists from the tropical regions, data providers, modelers]

DJF 2020: Collect observations

MAM 2021: Start data analysis to assess tropospheric ozone distribution and trends in the tropics

JJA 2021: Collect model output and shape the framework for model evaluation

SON 2021: Model evaluation and use to assess impact of ozone increase in the tropics on global ozone and mid-latitude regions

JJA 2022: Write up the results of our analysis

August 2023: submit for publication in the TOAR-II Community Special Issue.

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