# CEOS Atmospheric Composition Constellation

## Gap Analysis Study

**Final Report**

**Version 1**

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# 1 Introduction

This study was commissioned by NASA, through SSAI, to support work on the CEOS Constellations programme.

A number of constellations were identified as study topics, including the Atmospheric Composition Constellation, which is the scope of this study. The term “constellation” is used in a broad sense and is not limited to the potential of a dedicated set of closely related observation satellites operated in constellation, but extends to the combination of measurement information from different platforms in a more general sense. The concept of the “constellation” is therefore a “virtual” one, which includes the potential of combining different measurement types from a variety of platforms.

## *Study Objective*

The objective of this study is, in the context of monitoring atmospheric composition, to:

- collect and distil information on observational requirements
- summarise the observational capabilities of current and planned satellite missions
- compare the requirements to the identified capabilities
- examine the capability and availability of observations and identify gaps in both

The relevant timescale is from the present, 2008, over the next decade and beyond. The planning horizon used by agencies varies but mission plans in some cases are drafted for the next 20 years. The analysis aims to be quantitative where practical though the amount of detailed information varies widely and a fully quantitative analysis is not possible.

## *Report Structure*

This study report is structured as follows:

**Chapter 1**
This introduction, outlining the scope and purpose of the study, and structure of the report.

**Chapter 2**
Product requirements for atmospheric composition applications are collated from inputs available from agencies. In many cases this is publically available information on the internet. Reference information is given for all inputs.
Requirements and observational capabilities are defined in terms of geophysical products derived directly from measurements, often referred to as level 2 data; in such context level 0 data corresponds to raw telemetry and level 1 as calibrated and geo-located measurement observations.

**Chapter 3**
Missions with instrumentation able to target atmospheric composition are collated. The timescales and capabilities of current and planned missions are summarised.

**Chapter 4**
Analysis of how the missions address the requirements and identification of gaps in measurement coverage and capability.

**Chapter 5**
A summary of the study and comment.

# 2 Assessment of Requirements

## *2.1 Requirement Inputs*

The requirements collected fall into three broad groups covering US, European, and international agencies and programmes. The information has been drawn together in consultation with scientists and programme managers and discussed and enhanced at Atmospheric Composition Constellation (ACC) workshops in 2007 and 2008. Requirements are cast as basic geophysical products derived directly from satellite measurements and may be described as “level 2” requirements.

A list of documents and other material that were considered in producing the distilled set of requirements is provided in the following sections, with brief descriptions, drawing out relevance to atmospheric composition. References are provided.

**US Programmes**

For the US the primary relevant input is the NRC Decadal Survey published in 2007:

- ***NRC Decadal Survey 2007***
  Committee on Earth Science and Applications from Space, 2007: National Imperatives for the Next Decade and Beyond, National Research Council, Washington DC. http://www.nap.edu/catalog/11820.html

This document focuses on Earth observation in the period 2005-2015 and directions beyond. It includes requirements and mission concepts for the period 2010-2020 for 7 themes:

1. Earth-science applications and societal needs.
2. Land-use change, ecosystem dynamics, and biodiversity.
3. Weather, including space weather and chemical weather.
4. Climate variability and change.
5. Water resources and the global hydrologic cycle.
6. Human health and security.
7. Solid-Earth hazards, resources, and dynamics.

The themes of relevance to atmospheric composition particularly are 3, 4 and 6, covering air pollution, climate and ozone; themes 2 and 5 include carbon budget and water vapour related requirements with atmospheric composition aspects.

The NASA Science Plan provides a context for its missions planned over the next decade with Earth Science as one of the science areas covered.

- ***Science Plan for NASA's Science Mission Directorate 2007-2016***
  http://nasascience.nasa.gov/about-us/science-strategy/Science_Plan_07.pdf

## European Programmes

European programmes come under the responsibility of two organisations, the European Space Agency, ESA, and the European Organisation for the Exploitation of Meteorological Satellites, EUMETSAT.

Information is available from study and programme development reports, and mission requirement documents.

### *European Space Agency (ESA)*

- ***CAPACITY Final Report***
  CAPACITY – 'Composition of the Atmosphere: Progress to Applications in the user CommuITY', Operational Atmospheric Chemistry Monitoring Missions, Final Report, ESA contract no. 17237/03/NL/GS, October 2005

- ***GMES Requirements***
  GMES Service Element PROMOTE
  U5 Core User Needs Dossier, Version 12, Paliouras, E. et al., 23 May 2006
  Also see http://www.gse-promote.org/

- ***Sentinel 4 & 5 Mission Requirements Document***
  GMES Sentinels 4 and 5 Mission Requirements Document (Initial Version)
  2 April 2007, Issue 1, Revision 0
  J. Langen, ESA

### *EUMETSAT*

- ***MTG Mission Requirements***
  MTG Mission Requirements Document
  EUM/MTG/SPE/06/0011, Issue : v2B, Date : 6 October 2006
  http://www.eumetsat.int/Home/Main/What_We_Do/Satellites/Future_Satellites/Meteosat_Third_Generation/SP_1124972380654?l=en

- ***Post-EPS Atmospheric Chemistry Position Paper***
  Position Paper on Post-EPS Atmospheric Chemistry Data User Requirements for Operational Atmospheric Chemistry Monitoring in the Post-EPS Time Frame beyond 2020, H. Kelder, KNMI, the Netherlands, B. Kerridge, Rutherford Appleton Laboratory, U.K., I. Isaksen, University of Oslo, Norway, B. Carli IFAC, CNR, Italy, N. Harris University of Cambridge, U.K., E. Hilsenrath University of Maryland, U.S.A
  6 March 2006, Issue 0 Draft H

- ***Post-EPS Mission Requirements Document***
  Post-EPS Mission Requirements Document (Initial Version)
  10 January 2007, Issue v1J Draft
  P. Schlüssel, P. Phillips, C. Accadia, R. Munro, S. Banfi, J. Wilson

The atmospheric composition monitoring requirements formulated in Europe have evolved from the international IGACO report, through the CAPACITY study, to the Post-EPS Atmospheric Chemistry position paper (EPS is the current EUMETSAT Polar System). There is some cross-over between and ESA and EUMETSAT approaches and there appears to be a level of convergence on both the requirements and the observational implementation. The requirements used in this study are those available in 2007 provided through the assistance of Dr. R. Munro at EUMETSAT and Dr. J. Langen at ESA.

## International Programmes

In terms of international context, input is available from the Global Climate Observing System (GCOS) programme and the formal response by CEOS, as well as the IGACO report produced by the Integrated Global Observing Strategy (IGOS) partnership:

- ***GCOS Requirements***
  Systematic observation requirements for satellite-based products for climate Supplemental details to the satellite-based component of the implementation plan for the global observing system for climate in support of the UNFCCC, September 2006, (WMO/TD No.1338)
  http://www.wmo.int/pages/prog/gcos/Publications/gcos-107.pdf

- ***CEOS Response to GCOS***
  Satellite Observation of the Climate System
  The Committee on Earth Observation Satellites (CEOS) Response to the Global Climate Observing System (GCOS) Implementation Plan (IP)
  http://www.ceos.org/pages/CEOSResponse_1010A.pdf

- ***IGACO Theme Report***
  The Changing Atmosphere, An Integrated Global Atmospheric Chemistry Observation Theme for the IGOS Partnership, Report of the Integrated Global Atmospheric Chemistry Observation Theme Team, September 2004, ESA SP-1282, September 2004, Report GAW No. 159 (WMO TD No. 1235)
  http://ioc.unesco.org/igospartners/Atmosphere.htm

GCOS is co-sponsored by the World Meteorological Organization, the Intergovernmental Oceanographic Commission of UNESCO, the United Nations Environment Programme and the International Council for Science. Its remit is *"to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users"*. It has established requirements for climate and identifies so-called Essential Climate Variables (ECVs) for atmospheric, oceanic and terrestrial observations.

IGOS is an international partnership of many participants including CEOS and various groups of the WMO and UNESCO. The IGACO report was produced by a panel of scientists convened by WMO and ESA.

## 2.2 Distilled Requirements

This study follows an approach developed over the last decade or so, and taken forward in the CAPACITY study and the Post-EPS Atmospheric Chemistry position paper, by distinguishing 3 application areas that cover atmospheric composition monitoring, namely:

1. Ozone layer and surface UV monitoring and forecasting
2. Composition-climate interaction
3. Air quality monitoring and forecasting

All observational requirements are put into one of these general categories. They have been collected for identified atmospheric species and are shown in table form at the end of this chapter, in section 2.4, one for each product, with quantitative values for particular requirements where available. Typically, these cover any of the following: horizontal and vertical resolution, accuracy, sampling, coverage, stability. The source and driver for the requirements are also noted to ensure traceability. An identifier for the potential programme that is dealing with particular requirements is given and covers NASA, GMES and GCOS.

Measurement requirements generally vary with height and the following height domains are used and indicated in the tables:

| Domain Name | Abbreviation | Typical Altitude |
|---|---|---|
| Troposphere | T | 0 – 12 km |
| Planetary Boundary Layer | PBL | 0 – 2 km |
| Free Troposphere | FT | 2 – 12 km |
| Upper Troposphere | UT | 8 – 12 km |
| Stratosphere | S | 12 – 50 km |
| Lower Stratosphere | LS | 12 – 25 km |
| Middle Stratosphere | MS | 20 – 35 km |
| Upper Stratosphere | US | 25 – 50 km |
| Mesosphere | M | 50 – 80 km |

**Table 2-1:** Standard Altitude Domains

The altitude assignment should be taken as relaxed and varying with latitude, with typical mid-latitude values given in Table 2-1. Other terms used to define a combination of altitude range and vertical resolution are *Total*, *Tropospheric* and *Stratospheric Column* (abbreviated to *Tot, Trop and Strat Col* respectively) which indicates that a value related to the total amount of the target product in the given height range is required.

In producing the distilled tables some simplification and rationalisation has been attempted. The requirements are, by their nature, estimates so may be interpreted with some flexibility. For horizontal resolution, for example, the Post-EPS Atmospheric Chemistry position paper states that the requirement is only specified for one direction and that it is relaxed in other aspects, e.g. for a polar orbiting sounder the along-track sampling interval should satisfy the requirement but some relaxation could be accommodated across track.

One important simplification is that only minimum requirements, also referred to as "threshold" in some contexts, are taken, with the philosophy that this is the level at which measurement is considered useful. The origin of the requirement is indicated in the tables so that for any particular purpose the source documents should be referred to and considered.

There are a large number of different requirements for aerosol and cloud, ranging from detection of polar stratospheric clouds to identification of particle size in the troposphere. These varied requirements are all presented in a single table covering the "Aerosol & Cloud" product. The other products treated as a group are "Volatile Organic Compounds", VOCs, which in some source documents have generic requirements but include specific requirements for ethyne (acetylene, $C_2H_2$) and ethane ($C_2H_6$) in the Post-EPS position paper.

The requirements tables cover the following species and groups:

| | | | |
|---|---|---|---|
| $H_2O$ | CO | $NO_2$ | $CH_2O$ |
| $O_3$ | $CO_2$ | $N_2O_5$ | PAN (Peroxyacetyl Nitrate) |
| $CH_4$ | ClO | $SO_2$ | VOCs (Volatile Organic Compounds) |
| $HNO_3$ | BrO | HDO | Aerosol & Cloud |
| $N_2O$ | HCl | $SF_6$ | |

**Table 2-2:** Requirement Products

## 2.3 Requirements Summary

The requirements tables in section 2.4 draw together the observational requirements as specified by particular agencies and programmes. They attempt to detail, in a quantitative manner where possible, the measurement variable and its attributes. Although self-explanatory, a summary and some general comments are given here.

Table 2-3 indicates the application area and programme for each product given in the requirements.

| Product | Application Area | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Ozone & UV | | | Composition-Climate | | | Air Quality | | |
| | Programme | | | | | | | | |
| | GMES | NASA | GCOS | GMES | NASA | GCOS | GMES | NASA | GCOS |
| $H_2O$ | | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | |
| $O_3$ | ✓ | ✓ | | ✓ | | ✓ | ✓ | ✓ | |
| $CH_4$ | | ✓ | | ✓ | | ✓ | | | |
| $HNO_3$ | ✓ | ✓ | | ✓ | | | ✓ | | |
| $N_2O$ | | ✓ | | ✓ | | ✓ | | | |
| CO | | ✓ | | ✓ | | | ✓ | ✓ | |
| $CO_2$ | | ✓ | | ✓ | ✓ | ✓ | | | |
| ClO | ✓ | ✓ | | | | | | | |
| BrO | ✓ | ✓ | | | | | | | |
| HCl | ✓ | ✓ | | | | | | | |
| $NO_2$ | ✓ | ✓ | | ✓ | | | ✓ | ✓ | |
| $N_2O_5$ | | | | | | | ✓ | | |
| $SO_2$ | | | | | | | ✓ | ✓ | |
| HDO | | ✓ | | ✓ | | | | | |
| $SF_6$ | | | | ✓ | | ✓ | | | |
| $CH_2O$ | | ✓ | | | | | ✓ | ✓ | |
| PAN | | | | | | | ✓ | | |
| VOCs | | | | | | | ✓ | ✓ | |
| Aerosol & Cloud | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

**Table 2-3:** Summary of Product Requirements by Application and Programme

### General Attributes and Features

There is, overall, good consistency in the products required by programmes for particular requirement types. There are some notable differences however.

The Decadal Survey requirements are, in many cases, an order of magnitude more stringent than others, for both vertical and horizontal resolution. On the other hand accuracy is often not specified and sampling and revisit times are vague in some instances. Such features may be due to the fact that the Decadal Survey covers not only “monitoring” but also “research” interests. It may be for this reason that it also has more species requirements relating to ozone and UV monitoring than the GMES programme.

GCOS, by definition, only has climate requirements (except that the aerosol ECV also covers air quality). It is the only source to specify measurement stability requirements, though does not have these in all cases.

### Requirements by Type

The requirement tables and the summary in Table 2-3 indicate that the largest number of products required is for the Ozone and UV application, with many requirements only coming out of the US Decadal Survey. In contrast, the GMES programme requires many composition-climate products, in conjunction with GCOS. For air quality almost all the products are drawn out both in the GMES and the Decadal Survey documents.

### Requirements by Product

Water vapour, ozone, nitric acid, carbon monoxide, nitrogen dioxide ($NO_2$), as well as cloud and aerosol measurements are required across the board for all three application areas. The first two of these products, $H_2O$ and $O_3$, are required with high (~1%) to medium (~10%) accuracy and good resolution (~10-100 km horizontal, ~<1-5 km vertical) and throughout the troposphere and stratosphere. As mentioned previously, the aerosol and cloud requirements are varied and, although collated in a single table, there are a number of individual and different products included.

Dinitrogen pentoxide ($N_2O_5$), sulphur dioxide ($SO_2$), peroxyacetyl nitrate (PAN) and volatile organics (VOCs) are only required in the context of air quality and pollution and so observations focus naturally in the troposphere and should generally include boundary layer sensitivity. In some cases high vertical resolution (e.g.1 km in the boundary layer) and frequent sampling or revisit times are specified (≤4 hours).

The halogen compounds ClO, BrO, HCl are only required for ozone and UV monitoring. Their involvement in ozone chemistry means that the measurements of relevance are in the stratosphere. $SF_6$ only appears in the climate context, as a stratospheric tracer. Requirements on resolution, accuracy and revisit time are relatively modest for all these species.

Methane, nitrous oxide, carbon dioxide, deuterated water vapour (HDO), and formaldehyde ($CH_2O$) are required for ozone/uv and composition climate and cover troposphere and stratosphere.

## *2.4 Requirements Tables*

Tables summarising the requirements are shown in the following pages. The data have been drawn together from a variety of sources including the requirements of US, European, and multi-national programmes.

There is a table for each product outlining the measurement requirements for all 3 application areas. Quantitative data on requirements for measurement height domain, resolution, sampling or revisit time, accuracy, coverage and stability is presented where available. In general only the minimum threshold requirements, indicating the level at which measurement may be considered useful for the application is shown.

H2O

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | NASA | US Decadal Survey | Health | MS | 5 | 3 | | | global | |
| Composition - Climate Interaction | GMES | Post-EPS Position Paper | Radiation | PBL | 75 | -- | 12 | 30% | global | |
| | | | Dynamics | FT | 250 | 3 | 12 | 20% | | |
| | | | Stratospheric H2O | LS | 250 | 3 | 12 | 30% | | |
| | | | | MS | 500 | 4 | 168 | 30% | | |
| | | | | US+M | 500 | 6 | 168 | 30% | | |
| | | | | Total Column | | | | | | |
| | GCOS | GCOS Satellite Requirements | ECV Water Vapour | PBL | 50 | 0.1 | 3 | 2% | | 0.3% |
| | | | | FT | 50 | 2 | 3 | 2% | | 0.3% |
| | | | | LS | 50 | 2 | 3 | 2% | | 0.3% |
| | | | | Total Column | 50 | 2 | 3 | 1% | | 0.3% |
| | NASA | US Dec Survey | Climate | Total Column | | | | | global | |
| Air Quality Monitoring & Forecasting | GMES | Post-EPS Position Paper | AQ Forecast & Monitoring | PBL | 20 | -- | 4 | 10% | global & regional | |
| | | | | FT | 50 | 4 | 4 | 20% | | |
| | NASA | US Dec Survey | Health | Total Column | 10 | | | | regional & global | |

O3

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | GMES | Post-EPS Position Paper | Ozone and UV Forecast; Ozone Trend | UT | 250 | 3 | 72 | 20% | global | |
| | | | | LS | 250 | 3 | 72 | 20% | | |
| | | | | MS | 500 | 4 | 72 | 20% | | |
| | | | | US+M | 500 | 6 | 168 | 20% | | |
| | | | | Trop Col | 75 | -- | 72 | 20% | | |
| | | | | Total Column | 75 | -- | 72 | 3% | | |
| | NASA | US Dec Survey | Health | MS | 5 | 3 | | | global | |
| Composition - Climate Interaction | GMES | Post-EPS Position Paper | Radiation; Dynamics | PBL | 75 | -- | 72 | 50% | global | |
| | | | | FT | 250 | 5 | 72 | 30% | | |
| | | | | LS | 250 | 3 | 72 | 20% | | |
| | | | | MS | 500 | 4 | 72 | 20% | | |
| | | | | US+M | 500 | 6 | 168 | 20% | | |
| | | | | Total Column | 75 | -- | 72 | 5% | | |
| | GCOS | GCOS Satellite Requirements | ECV Ozone | FT | 50 | 0.5 | 3 | 10% | global | 1% |
| | | | | MS | 100 | 3 | 3 | 5% | | 0.6% |
| Air Quality Monitoring & Forecasting | GMES | Post-EPS Position Paper | AQ Forecast & Concentration Monitoring | PBL | 20 | -- | 4 | 30% | global & regional | |
| | | | | FT | 50 | 5 | 4 | 30% | | |
| | | | | Total Column | 20 | -- | 4 | 5% | | |
| | NASA | US Decadal Survery | Health | PBL | 10 | | 48 | | regional & global | |
| | | | Chemical Weather | Trop Col | 5 | | 1 | | regional >5000km | |
| | | | Ch Weather - Ozone | FT | | 2 | | | global | |

## CH4

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | NASA | US Decadal Survery | Health | MS | 5 | 3 | | | global | |
| Composition - Climate Interaction | GMES | Post-EPS Position Paper | Emissions; Ozone-Climate | PBL | 50 | -- | 72 | 10% | global | |
| | | | | FT | 250 | 5 | 72 | 10% | | |
| | | | | LS | 250 | 3 | 72 | 20% | | |
| | | | | MS | 500 | 4 | 72 | 20% | | |
| | | | | Total Column | 50 | -- | 72 | 2% | | |
| | GCOS | GCOS Satellite Requirements | ECV CO2, CH4 & GHGs | Total Column | 250 | -- | 3 | 1% | | |
| Air Quality Monitoring & Forecasting | None applicable | | | | | | | | | |

## HNO3

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | GMES | Post-EPS Position Paper | Ozone Trend & Nitrogen Budget | LS | 250 | 4 | 72 | 50% | global | |
| | | | | MS | 500 | 4 | 72 | 50% | | |
| | | | | Strat Col | 250 | -- | 72 | 50% | | |
| | NASA | US Dec Survey | Health | MS | 5 | 3 | | | global | |
| Composition - Climate Interaction | GMES | Post-EPS Position Paper | Ozone-Climate; Nitrogen Budget | FT | 250 | -- | 72 | 50% | global | |
| | | | | LS | 250 | 3 | 72 | 20% | | |
| | | | | MS | 500 | 4 | 72 | 20% | | |
| | | | | Total Column | 50 | -- | 72 | 20% | | |
| Air Quality Monitoring & Forecasting | GMES | Post-EPS Position Paper | AQ Forecast Concentration | PBL | 20 | -- | 4 | 50% | global & regional | |
| | | | | FT | 50 | -- | 4 | 50% | | |

## N2O

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | NASA | US Dec Survey | Health | MS | 5 | 3 | | | global | |
| Composition - Climate Interaction | GMES | Post-EPS Position Paper | Ozone-Climate | LS | 250 | 3 | 72 | 20% | global | |
| | | | | MS | 500 | 4 | 72 | 20% | | |
| | GCOS | GCOS Sat Reqs | ECV CO2, CH4 & GHGs | | | | | | | |
| Air Quality Monitoring & Forecasting | None applicable | | | | | | | | | |

## CO

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | NASA | US Dec Survey | Health | MS | 5 | 3 | | | global | |
| Composition - Climate Interaction | GMES | Post-EPS Position Paper | Emissions; Ozone-Climate | PBL | 75 | -- | 72 | 50% | global | |
| | | | | FT | 250 | 5 | 72 | 30% | | |
| | | | | Total Column | 75 | -- | 72 | 25% | | |
| Air Quality Monitoring & Forecasting | GMES | Post-EPS Position Paper | AQ Forecast & Concentration Monitoring; Emissions | PBL | 20 | -- | 4 | 30% | | |
| | | | | FT | 50 | 5 | 4 | 30% | | |
| | | | | Total Column | 20 | -- | 4 | 25% | | |
| | NASA | US Decadal Survery | Health | PBL | 10 | 1 | 1 | | regional & global | |
| | | | | Total Column | -- | -- | -- | | | |
| | | | Land & Ecosystems | PBL | 0.1 | 1 | 24 | | regional & global | |
| | | | Chemical Weather | FT | 5 | 5 | 1 | | regional >5000km | |
| | | | Ch Weather - Ozone | FT | -- | 5 | -- | | | |

## CO2

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | NASA | US Decadal Survery | Health | MS | 5 | 3 | | | global | |
| Composition - Climate Interaction | GMES | Post-EPS Position Paper | Radiation | PBL | 50 | -- | 12 | 5% | global | |
| | | | Dynamics | FT | 250 | 5 | 24 | 5% | | |
| | | | Stratospheric H2O | LS | 250 | 3 | 168 | 5% | | |
| | | | | MS | 500 | 4 | 168 | 10% | | |
| | | | | US | 500 | 6 | 168 | 10% | | |
| | | | | Total Column | 50 | -- | 12 | 1% | | |
| | GCOS | GCOS Satellite | ECV CO2, CH4 & GHGs | Total Column | 250 | -- | 3 | 1% | | 0.3% |
| | NASA | US Dec Survey | Land/Ecosystems | Total Column | 0.1 | | 24 | | global | |
| Air Quality Monitoring & Forecasting | None applicable | | | | | | | | | |

## ClO

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | GMES | Post-EPS Position Paper | Ozone & Halogen Trend | LS | 250 | 4 | 72 | 50% | global | |
| | | | | MS | 500 | 4 | 72 | 50% | | |
| | | | | Strat Col | 250 | -- | 72 | 50% | | |
| | NASA | US Dec Survey | Health | MS | 5 | 3 | | | global | |
| Composition - Climate Interaction | None applicable | | | | | | | | | |
| Air Quality Monitoring & Forecasting | None applicable | | | | | | | | | |

BrO

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | GMES | Post-EPS Position Paper | Ozone & Halogen Trend | LS | 250 | 4 | 72 | 50% | global | |
| | | | | MS | 500 | 4 | 72 | 50% | | |
| | | | | Strat Col | 250 | -- | 72 | 50% | | |
| | NASA | US Dec Survey | Health | MS | 5 | 3 | | | global | |
| Composition - Climate Interaction | None applicable | | | | | | | | | |
| Air Quality Monitoring & Forecasting | None applicable | | | | | | | | | |

HCl

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | GMES | Post-EPS Position Paper | Ozone & Halogen Trend | LS | 250 | 4 | 72 | 50% | global | |
| | | | | MS | 500 | 4 | 72 | 50% | | |
| | | | | Strat Col | 250 | -- | 72 | 50% | | |
| | NASA | US Dec Survey | Health | MS | 5 | 3 | | | global | |
| Composition - Climate Interaction | None applicable | | | | | | | | | |
| Air Quality Monitoring & Forecasting | None applicable | | | | | | | | | |

## NO2

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | GMES | Post-EPS Position Paper | Ozone Trend & Nitrogen Budget | LS | 250 | 4 | 72 | 30% | global | |
| | | | | MS | 500 | 4 | 72 | 30% | | |
| | | | | US | 500 | 6 | 72 | 30% | | |
| | | | | Strat Col | 250 | -- | 72 | 20% | | |
| | NASA | US Dec Survey | Health | MS | 5 | 3 | | | global | |
| Composition - Climate Interaction | GMES | Post-EPS Position Paper | Emissions; Ozone-Climate | PBL | 75 | -- | 72 | 50% | | |
| | | | | FT | 250 | -- | 72 | 50% | | |
| | | | | Total column | 75 | -- | 72 | 2.6e15 cm-2 | | |
| Air Quality Monitoring & Forecasting | GMES | Post-EPS Position Paper | AQ Forecast & Concentration Monitoring; Emissions | PBL | 20 | -- | 4 | 30% | | |
| | | | | FT | 50 | -- | 4 | 50% | | |
| | | | | Total Column | 20 | -- | 4 | 2.6e15 cm-2 | | |
| | NASA | US Decadal Survery | Health | PBL | 10 | 1 | 1 | | regional & global | |
| | | | | Total Column | -- | -- | -- | | | |
| | | | Chemical Weather | Trop Col | 5 | -- | 1 | | regional >5000km | |
| | | | Ch Weather - Ozone | Total Column | -- | -- | -- | -- | global | |

## N2O5

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | None applicable | | | | | | | | | |
| Composition - Climate Interaction | None applicable | | | | | | | | | |
| Air Quality Monitoring & Forecasting | GMES | Post-EPS Position Paper | AQ Forecast | PBL | 20 | -- | 4 | 50% | night | |
| | | | | FT | 50 | -- | 4 | 50% | | |

SO2

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | None applicable | | | | | | | | | |
| Composition - Climate Interaction | None applicable | | | | | | | | | |
| Air Quality Monitoring & Forecasting | GMES | Post-EPS Position Paper | AQ Forecast | PBL | 20 | -- | 4 | 30% | | |
| | | | | FT | 50 | -- | 4 | 50% | | |
| | | | | Total Column | 20 | -- | 4 | 2.6e15 cm-2 | | |
| | NASA | US Decadal Survery | Health | PBL | 10 | 1 | 1 | | regional & global | |
| | | | | Total Column | -- | -- | -- | | | |
| | | | Chemical Weather | FT | 5 | -- | 1 | | regional >5000km | |
| | | | Ch Weather - Ozone | FT | -- | -- | -- | | | |

HDO

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | NASA | US Dec Survey | Health | MS | 5 | 3 | | | global | |
| Composition - Climate Interaction | GMES | Post-EPS Position Paper | Stratospheric H2O | LS | 250 | 3 | 168 | 20% | global | |
| | | | | MS | 500 | 4 | 168 | 20% | | |
| | | | | US | 500 | 6 | 168 | 20% | | |
| Air Quality Monitoring & Forecasting | None applicable | | | | | | | | | |

SF6

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | None applicable | | | | | | | | | |
| Composition - Climate Interaction | GMES | Post-EPS Position Paper | Ozone-Climate | LS | 250 | 3 | 168 | 20% | global | |
| | | | | MS | 500 | 4 | 168 | 20% | | |
| | | | | US | 500 | 6 | 168 | 20% | | |
| | GCOS | GCOS Sat Reqs | ECV CO2, CH4 & GHGs | | | | | | | |
| Air Quality Monitoring & Forecasting | None applicable | | | | | | | | | |

CH2O

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | NASA | US Decadal Survery | Health | MS | 5 | 3 | | | global | |
| Composition - Climate Interaction | None applicable | | | | | | | | | |
| Air Quality Monitoring & Forecasting | GMES | Post-EPS Position Paper | AQ Forecast; VOC Emissions | PBL | 20 | -- | 4 | 30% | | |
| | | | | FT | 50 | -- | 4 | 50% | | |
| | | | | Total Column | 20 | -- | 4 | 2.6e15 cm-2 | | |
| | NASA | US Decadal Survery | Health | PBL | 10 | 1 | 1 | | regional & global | |
| | | | | Total Column | -- | -- | -- | | | |
| | | | Chemical Weather | FT | 5 | -- | 1 | | regional >5000km | |
| | | | Ch Weather - Ozone | FT | -- | -- | -- | | | |

PAN

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | None applicable | | | | | | | | | |
| Composition - Climate Interaction | None applicable | | | | | | | | | |
| Air Quality Monitoring & Forecasting | GMES | Post-EPS Position Paper | AQ Forecast | PBL | 20 | -- | 4 | 50% | | |
| | | | | FT | 50 | -- | 4 | 50% | | |

VOCs

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | None applicable | | | | | | | | | |
| Composition - Climate Interaction | None applicable | | | | | | | | | |
| Air Quality Monitoring & Forecasting | GMES | Post-EPS Position Paper | VOC Emissions | PBL | 20 | -- | 4 | 50% | | |
| | | | | FT | 50 | -- | 4 | 50% | | |
| | NASA | US Decadal Survery | Health | PBL | 10 | 1 | 1 | | regional & global | |
| | | | | Total Column | -- | -- | -- | | | |

Aerosol & Cloud

| Application | Programme | Source | Driver | Height Domain | Horizontal Resolution (km) | Vertical Resolution (km) | Interval / Revisit Time (hrs) | Accuracy | Coverage | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozone Layer & Surface UV Monitoring and Forecasting | GMES | Post-EPS Position Paper | O3 Trend & Chemistry (Strat OD) | LS | 250 | 4 | 72 | 0.05 | global | |
| | | | | MS | 500 | 4 | 72 | 0.05 | | |
| | | | UV Forecast & Trend (UV OD) | Total Column | 50 | -- | 72 | 0.10 | | |
| | | | O3 Trend & Chemistry (PSCs) | LS | 250 | 4 | 72 | 0.10 | | |
| | NASA | US Dec Survey | Health (Particles) | Total Column | 5 | 3 | | | global | |
| Composition - Climate Interaction | GMES | Post-EPS Position Paper | Radiation; Emissions; Ozone-Climate (Aerosol OD) | PBL | 20 | -- | 24 | 0.05 | global | |
| | | | | FT | 50 | -- | 24 | 0.05 | | |
| | | | | LS | 250 | -- | 72 | 0.05 | | |
| | | | | MS | 500 | -- | 72 | 0.05 | | |
| | | | | Total Column | 50 | -- | 24 | 0.05 | | |
| | | | Radiation; Ozone-Climate (Absorption OD) | PBL | 20 | -- | 24 | 0.02 | | |
| | | | | FT | 50 | -- | 24 | 0.02 | | |
| | | | | Total Column | 50 | -- | 24 | 0.02 | | |
| | | | Radiation (Aer Phase Fn) | PBL | 20 | -- | 24 | 0.1 (asymmetry) | | |
| | | | | FT | 50 | -- | 24 | 0.10 | | |
| | | | Radiation (Cirrus OD) | UT | 100 | -- | 24 | 50% | | |
| | | | Radiation (Cirrus Phase Fn) | UT | 100 | -- | 24 | 0.17 | | |
| | GCOS | GCOS Satellite Requirements | ECV Aerosol (Aer OD) | Total Column | 1 | -- | 24 | 0.01 | | 0.005/decade |
| | | | ECV Aerosol (Albedo) | Total Column | 1 | -- | 24 | 0.02 | | 0.015/decade |
| | NASA | US Dec Survey | Climate (Aerosol & Cloud) | Total Column | 1 | -- | 72 | -- | global | |
| Air Quality Monitoring & Forecasting | GMES | Post-EPS Position Paper | AQ Forecast & Monitoring Emissions; Aviation (Aerosol OD) | PBL | 20 | -- | 4 | 0.05 | global & regional | |
| | | | | FT | 50 | -- | 4 | 0.05 | | |
| | | | | LS | 250 | 3 | 4 | 0.05 | | |
| | | | | Total Column | 20 | -- | 4 | 0.05 | | |
| | | | AQ Forecast & Monitoring Determination of PM val (Aerosol Type) | PBL | 20 | -- | 4 | 10% | | |
| | | | | FT | 50 | -- | 4 | 10% | | |
| | | | | Total Column | 20 | -- | 4 | 10% | | |
| | GCOS | GCOS Sat Req | ECV Aerosol | Trop Col | 100 | 2 | -- | -- | | |
| | NASA | US Decadal Survery | Health (Aerosol Type) | Total Column | 10 | -- | 4 | -- | global & regional | |
| | | | Tropospheric Weather | FT | -- | 0.2 | -- | -- | global | |
| | | | Ch Weather (OD, Type) | FT | 20 | 0.15 | -- | -- | global & regional | |

# 3 Current & Planned Missions

Missions targeting atmospheric composition have been in orbit over the last four decades. A number of missions are active currently and many under development. In this chapter current and planned missions, with instrumentation directly relevant to atmospheric composition, are collated.

A useful resource, covering Earth Observation missions and instruments in general, and including atmospheric composition, is

> "The Earth Observation Handbook, Climate Change Special Edition 2008", http://www.eohandbook.com/, prepared for CEOS by ESA.

This provides information on missions including launch date and lifetime, instrument complement and programme status.

## *3.1 Missions with AC Instruments*

Earth observation missions are planned and run by a number of organisations. A search for information, publically available on the internet, was carried out to determine, as best as possible, the current operations and the future plans of each agency. Basic data on missions and their atmospheric composition instruments, including orbit and time frame have been collected. Links to the source information and other relevant detail have been included where deemed appropriate.

### 3.1.1 NASA

The US programme of satellite missions is extensive and a link listing current NASA missions may be found at http://www.nasa.gov/missions/current/index.html. This includes links to most missions, including those relevant to observations for atmospheric composition; it also includes references to the operational NOAA missions. A similar (but not identical) list may be found at the GSFC site http://www.nasa.gov/centers/goddard/missions/index.html.

The current NASA missions of relevance are Terra, http://terra.nasa.gov/, Aqua http://aqua.nasa.gov/index.php, Aura http://aura.gsfc.nasa.gov/ and CALIPSO http://www.nasa.gov/mission_pages/calipso/main/index.html.
Future missions in the near timeframe include Glory, http://glory.gsfc.nasa.gov/ and OCO, http://oco.jpl.nasa.gov/, due for launch by 2009.
These missions all form part of the "Afternoon Constellation", sometimes called the A-Train.

Longer timescale developments are currently following the recommendations of the NRC Decadal Survey, http://www.nap.edu/catalog.php?record_id=11820. These

missions appear to be in early development at the current time. The missions with instruments targeting composition are ASCENDS, ACE, GEO-CAPE and GACM.

### 3.1.2 NOAA

NOAA is the agency responsible for operational observations in the US. General information on its programme of mission may be found at http://www.nesdis.noaa.gov/satellites.html.

The agency runs geostationary and polar orbiting missions under its GOES and POES programmes outlined at http://noaasis.noaa.gov/NOAASIS/ml/genlsatl.html.

In terms of atmospheric composition only the POES programme is of relevance directly, http://goespoes.gsfc.nasa.gov/poes/index.html.

Starting with NOAA-18, the POES platforms and the European MetOp series of EUMETSAT are operated in coordination, to provide low Earth orbit data with good temporal frequency, primarily for meteorological applications.

Details for the future of the POES programme, called NPOESS, are uncertain. The NPOESS Preparatory Project (NPP) is under way, http://jointmission.gsfc.nasa.gov/; the following missions are still under development at this time, http://www.ipo.noaa.gov/.

### 3.1.3 ESA

General information on European Space Agency (ESA) missions can be found at http://earth.esa.int/missions/.

Current missions directly relevant to atmospheric composition are ERS-2 (http://earth.esa.int/ers/), including the GOME-1 and ATSR-2 instruments, and Envisat (http://envisat.esa.int/), with MIPAS, SCIAMACHY, GOMOS and AATSR.

Planned programmes include the GMES Sentinel missions being carried forward with the European Union and EUMETSAT. Details for the GMES programme can be found at http://www.esa.int/esaLP/LPgmes.html. The full details of payloads are still under development at the present time but in terms of atmospheric compositions the most relevant missions are Sentinels 4 and 5, designed to target composition form GEO and LEO orbits, and Sentinel 3 which follows the ATSR instrument heritage and is therefore likely to have some cloud and aerosol capabilities of relevance.

ESA's other major Earth Observation initiative is the Earth Explorer programme. Missions now selected and under full development are listed at http://www.esa.int/esaEO/SEM9JP2VQUD_index_0_m.html. The only mission targeting aspects of composition is EarthCARE, developed in conjunction with JAXA and targeting clouds and aerosols. The next round of future Earth Explorer missions

is still in the selection process and described at
http://www.esa.int/esaLP/ESADQ0UHN6D_LPfuturemis_0.html.
There are currently 3 candidate missions with composition measurement potential, PREMIER, A-SCOPE and TRAQ.

### 3.1.4 EUMETSAT

EUMETSAT is the European organisation responsible for procuring and operation of operational satellites. The home page is http://www.eumetsat.int/.

A practical list of its current and planned satellite mission is given at
http://www.eumetsat.int/Home/Main/What_We_Do/Satellites/index.htm?l=en.

The programmes relevant to atmospheric composition are the EUMETSAT Polar System (EPS) with its MetOp series of satellites,
http://www.eumetsat.int/Home/Main/What_We_Do/Satellites/EUMETSAT_Polar_System/index.htm?l=en and the Meteosat programme with the MSG (Meteosat Second Generation) series,
http://www.eumetsat.int/Home/Main/What_We_Do/Satellites/Meteosat_Second_Generation/index.htm?l=en.

Technical details for these missions are also available at
http://www.esa.int/esaLP/LPmetop.html and
http://www.esa.int/SPECIALS/MSG/index.html

As mentioned in the NOAA programme section, POES and MetOp are operated in coordination.

### 3.1.5 Other Agencies

A number of other national programmes are relevant in the context of atmospheric composition measurement.

#### *3.1.5.1 Sweden*

The Swedish National Space Board is leading the Odin satellite project (http://www.snsb.se/eng_odin_intro.shtml and http://odin.ssc.se/).
Future developments are currently part of the ESA PREMIER mission.

#### *3.1.5.2 Canada*

Canada's space agency, CSA, launched SCISAT in 2003 which include the ACE occultation instrument, http://www.space.gc.ca/asc/eng/satellites/scisat/default.asp.
It is developing the SWIFT instrument which targets and ozone emission line but is focussed on determination of stratospheric winds,
http://www.swift.yorku.ca/index.html.

### 3.1.5.3 France

The French CNES agency currently has its PARASOL mission, http://smsc.cnes.fr/PARASOL/.

### 3.1.5.4 Japan

The Japanese Space Agency, JAXA, http://www.jaxa.jp/index_e.html, is a major partner in ESA's EarthCARE mission and is developing the GOSAT and GCOM-C missions, both relevant to atmospheric composition.
GOSAT http://www.jaxa.jp/projects/sat/gosat/index_e.html,
http://www.gosat.nies.go.jp/eng/proposal/proposal.htm,
GCOM-C
http://www.jaxa.jp/projects/sat/gcom/index_e.html.

### 3.1.5.5 China

The China Meteorological Administration, CMA, http://www.cma.gov.cn/english/, operates the Meteorological Satellite Program of China and covers both polar orbiting and geostationary series with its "Feng-Yun" satellites (abbreviated as FY).
The polar orbiting missions are odd numbered e.g. FY-1, FY-3, and the geostationary platforms are designated with even numbers, FY-2 and upwards.

## 3.2 Mission Summaries

Information on the missions outlined in the previous section is collated at the end of this section in Table 3-2, for current missions, and Table 3-3 **(a)**, for those planned.

Parameters listed include mission name, operating agency, orbit type and relevant position/equator-crossing time, lifetime (including planned extensions), and instrument name and type for AC instruments.

Orbits are distinguished as either low-Earth (LEO) or geostationary (GEO) and additional information provided as appropriate, e.g. equator crossing times for sun-synchronous (SS) LEO orbits, longitude for GEO orbits.

Instrument types have been classed into 9 basic groupings, with 5 nadir (or near-nadir) and 4 limb types. Solar occultation measurements, although measuring in limb geometry, are handled separately to "standard" limb instruments because of the different type of geographical coverage that they provide. They are listed in Table 3-1.[1]

| Instrument Type | Abbreviation |
|---|---|
| ***Nadir*** | |
| Infrared | IR |
| UV-Visible and/or Near-Infrared | UVN |
| Lidar | Lidar |
| Multi-Angle Polarimeter | MAP |
| Imager | Imager |
| ***Limb*** | |
| Infrared | IR |
| Millimetre/Sub-Millimetre | MM |
| UV-Visible and/or Near-Infrared | UVN |
| ***Solar Occultation*** | Occultation |

**Table 3-1: Instrument Types and Abbreviations**

[1] Cross-references to instrument types assigned in the WMO study *"Gap Analysis"*, by B. Bizzarri, WMO, 2nd Workshop on the Re-Design and Optimisation of the Space-Based GOS, Geneva, Switzerland, 21-22 June 2007, OPT2/Doc. 5 (11.VI.2007) are listed in Appendix A of this report.

## Current AC Mission Summary

| Mission | Agency | Orbit | Lifetime | | | AC Instruments | |
|---|---|---|---|---|---|---|---|
| Name(s) | | Type / Eq Crossing | Mission Start | Nominal End | Extended End | Name | Type |
| **Existing Missions** | | | | | | | |
| Aqua | NASA | LEO SS 13:30 | 2002 | 2007 | 2011 | AIRS<br>MODIS | IR nadir<br>Imager |
| Terra | NASA | LEO SS 10:30 | 2000 | 2005 | 2011 | MOPITT<br>MODIS | IR nadir<br>Imager |
| Aura | NASA | LEO SS 13:45 | 2004 | 2009 | 2013 | MLS<br>OMI<br>TES<br>HIRDLS | MW limb<br>UVN nadir<br>IR nadir<br>IR limb |
| CALIPSO | NASA | LEO SS 13:30 | 2006 | 2009 | | CALIOP | Aerosol-lidar |
| ERS-2 | ESA | LEO SS 10:30 | 1995 | 1998 | 2010 | GOME-1<br>ATSR-2 | UVN nadir<br>Imager |
| ENVISAT | ESA | LEO SS 10:00 | 2002 | 2007 | 2010 | SCIAMACHY<br>MIPAS<br>AATSR<br>GOMOS<br>MERIS | UVN nadir<br>IR limb<br>Imager<br>Occultation<br>Imager |
| NOAA-15 | NOAA | LEO SS 09:30 | 1998 | 2000 | 2008 | AVHRR-3 | Imager |
| NOAA-16 | NOAA | LEO SS 13:30 | 2001 | 2003 | 2008 | AVHRR-3<br>SBUV-2 | Imager<br>UVN nadir |
| NOAA-17 | NOAA | LEO SS 09:30 | 2002 | 2004 | 2008 | AVHRR-3<br>SBUV-2 | Imager<br>UVN nadir |
| NOAA-18 | NOAA | LEO SS 13:30 | 2005 | 2008 | 2011 | AVHRR-3<br>SBUV-2 | Imager<br>UVN nadir |
| Metop-A<br>Metop-2 | EUMETSAT | LEO SS 09:30 | 2007 | 2011 | | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager |
| MSG-1<br>Meteosat-8 | EUMETSAT | GEO 0 lon | 2002 | 2011 | | SEVIRI | Imager |
| MSG-2<br>Meteosat-9 | EUMETSAT | GEO 0 lon | 2005 | 2014 | | SEVIRI | Imager |
| Odin | SNSB | LEO SS 06:00 | 2001 | 2003 | 2009 | SMR<br>OSIRIS | MW limb<br>UVN nadir |
| SCISAT | CSA | LEO | 2003 | 2005 | 2009 | ACE | Occultation |
| PARASOL | CNES | LEO SS 13:30 | 2004 | 2006 | 2007 | Polder | MAP |
| FY-3A | CMA | LEO SS 10:10 | 2008 | 2011 | | VIRR<br>TOU/SBUS | Imager<br>UVN nadir |

**Table 3-2:** Current Missions relevant to Atmospheric Composition

## Planned AC Mission Summary

| Mission | Agency | Orbit | Lifetime | | | AC Instruments | |
|---|---|---|---|---|---|---|---|
| Name(s) | | Type / Eq Crossing | Mission Start | Nominal End | Extended End | Name | Type |
| **Planned Missions** | | | | | | | |
| Glory | NASA | LEO<br>SS 13:30 | 2009 | 2012 | | APS | MAP |
| OCO | NASA | LEO<br>SS 13:20 | 2009 | 2011 | | NIR Spectrometer | CO2 NIR nadir |
| ASCENDS | NASA | LEO<br>SS | 2013 | 2016 | | Lidar | CO2-lidar |
| GEO-CAPE | NASA | GEO<br>280 lon | 2016 | 2019 | | UVN Spectrometer<br>IR Spectrometer | UVN nadir<br>IR nadir |
| ACE | NASA | LEO<br>SS ~13:30 | 2013 | 2016 | | Lidar<br>Polarimeter<br>UVN Spectrometer | Aerosol-lidar<br>MAP<br>UVN nadir |
| GACM | NASA | LEO<br>SS | 2017 | 2020 | | UVN Spectrometer<br>IR Spectrometer<br>MW Spectrometer | UVN nadir<br>IR nadir<br>MW limb |
| Sentinel-3 [A-C] | ESA | LEO<br>SS ~10:00 | 2012 | 2026 | | SLSTR<br>OCLI | Imager<br>Imager |
| Sentinel-4 [A-B] | ESA | GEO<br>0 lon | 2017 | 2032 | | IR Spectrometer<br>UVN Spectrometer | IR nadir<br>UVN nadir |
| Sentinel-5 prec | ESA | LEO<br>SS ~10:00 | 2014 | 2020 | | IR Spectrometer<br>UVN Spectrometer | IR limb<br>UVN nadir |
| Sentinel-5 | ESA | LEO<br>SS ~10:00 | 2020 | 2027 | | UVN Spectrometer | UVN nadir |
| EarthCARE | ESA-JAXA | LEO<br>SS 10:30 | 2013 | 2016 | | ATLID<br>MSI | Aerosol-lidar<br>Imager |
| A-SCOPE | ESA | LEO | 2015 | 2018 | | Lidar | CO2-lidar |
| PREMIER | ESA-SSC | LEO<br>SS 10:30 | 2015 | 2018 | | IMIPAS<br>STEAM-R | IR limb<br>MW limb |
| TRAQ | ESA | LEO<br>not SS | 2015 | 2018 | | UVN Spectrometer<br>IR Spectrometer<br>Imager<br>Polarimeter | UVN nadir<br>IR nadir<br>Imager<br>MAP |

**Table 3-3** (a)**:** Planned Missions relevant to Atmospheric Composition

| Mission | Agency | Orbit | Lifetime | | | AC Instruments | |
|---|---|---|---|---|---|---|---|
| Name(s) | | Type / Eq Crossing | Mission Start | Nominal End | Extended End | Name | Type |
| **Planned Missions** | | | | | | | |
| NOAA-N' | NOAA | LEO SS 13:30 | 2009 | 2015 | | AVHRR-3 SBUV-2 | Imager UVN nadir |
| NPP | NOAA | LEO SS 10:30 | 2010 | 2014 | | OMPS VIIRS | UVN nadir IR nadir |
| NPOESS-1 | NOAA | LEO SS 13:30 | 2013 | 2017 | | OMPS VIIRS | UVN nadir IR nadir |
| NPOESS-2 | NOAA | LEO SS 13:30 | 2018 | 2022 | | OMPS VIIRS | UVN nadir IR nadir |
| Metop-1 | EUMETSAT | LEO SS 09:30 | 2011 | 2016 | | GOME-2 IASI AVHRR-3 | UVN nadir IR nadir Imager |
| Metop-3 | EUMETSAT | LEO SS 09:30 | 2015 | 2020 | | GOME-2 IASI AVHRR-3 | UVN nadir IR nadir Imager |
| MSG-3 Meteosat-10 | EUMETSAT | GEO 0 lon | 2011 | 2017 | | SEVIRI | Imager |
| MSG-4 Meteosat-11 | EUMETSAT | GEO 0 lon | 2013 | 2019 | | SEVIRI | Imager |
| Chinook | CSA | LEO SS ~06:00 | 2011 | 2016 | | SWIFT | O3 IR limb |
| GOSAT | JAXA | LEO SS 13:00 | 2008 | 2013 | | TANSO-FTS TANSO-CAI | IR nadir Imager |
| GCOM-C | JAXA | LEO | 2013 | 2018 | | SGLI | UVN nadir |
| FY-3 [B-G] | CMA | LEO SS | 2009 | 2018 | | VIRR TOU/SBUS | Imager UVN nadir |
| FY-4 O/ [A-E] | CMA | GEO | 2013 | 2024 | | MCSI | Imager |

***NOTES***

1) Instrument names are placeholders and may be subject to modification
2) Future programmes are subject to development and change

**Table 3-3** (b)**:** Planned Missions relevant to Atmospheric Composition

## 3.3 Measurement Capabilities by Type

Information on atmospheric composition instrumentation has been collated and classed in types. In order to reference mission measurements to requirements the capabilities of each type of instrument and measurement technique have been identified.

The contribution of measurement techniques have been specified using the terms: significant, partial, and none. These terms are defined as:

| | |
|---|---|
| **significant** | meets a significant number of the requirement characteristics |
| **partial** | makes measurements of target and may meet some or none of the characteristics (still likely to be useful in an integrated sense e.g. with use of modelling, assimilation) |
| **none** | makes no useful measurements |

Tables have been generated for each of the 3 application areas and all products, as specified under “Distilled Requirements” in section 2.2. The tables are shown below.

| Application : | **Ozone Layer** |
|---|---|

| Products | Measurement Technique | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Nadir | | | | | Limb | | | Occultation | |
| | IR | UVN | Lidar | MAP | Imager | IR | MM | UVN | | |
| $H_2O$ | | | | | | | | | | |
| $O_3$ | | | | | | | | | | |
| $CH_4$ | | | | | | | | | | |
| $HNO_3$ | | | | | | | | | | |
| $N_2O$ | | | | | | | | | | |
| CO | | | | | | | | | | |
| $CO_2$ | | | | | | | | | | |
| ClO | | | | | | | | | | |
| BrO | | | | | | | | | | |
| HCl | | | | | | | | | | |
| $NO_2$ | | | | | | | | | | |
| HDO | | | | | | | | | | |
| $CH_2O$ | | | | | | | | | | |
| Aerosol/Cloud | | | | | | | | | | |

**Contribution :** none | partial | significant

**Table 3-4: Contribution of Measurement Types to Ozone Layer Requirements**

| Application : | **Composition-Climate** |
|---|---|

| Products | Measurement Technique | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Nadir | | | | | Limb | | | Occultation |
| | IR | UVN | Lidar | MAP | Imager | IR | MM | UVN | |
| $H_2O$ | | | | | | | | | |
| $O_3$ | | | | | | | | | |
| $CH_4$ | | | | | | | | | |
| $HNO_3$ | | | | | | | | | |
| $N_2O$ | | | | | | | | | |
| CO | | | | | | | | | |
| $CO_2$ | | | | | | | | | |
| $NO_2$ | | | | | | | | | |
| HDO | | | | | | | | | |
| $SF_6$ | | | | | | | | | |
| Aerosol/Cloud | | | | | | | | | |

**Contribution :** none | partial | significant

**Table 3-5: Contribution of Measurement Types to Composition-Climate Requirements**

| Application : | **Air Quality** |
|---|---|

| Products | Measurement Technique | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Nadir | | | | | Limb | | | Occultation |
| | IR | UVN | Lidar | MAP | Imager | IR | MM | UVN | |
| $H_2O$ | | | | | | | | | |
| $O_3$ | | | | | | | | | |
| $HNO_3$ | | | | | | | | | |
| CO | | | | | | | | | |
| $NO_2$ | | | | | | | | | |
| $N_2O_5$ | | | | | | | | | |
| $SO_2$ | | | | | | | | | |
| $CH_2O$ | | | | | | | | | |
| PAN | | | | | | | | | |
| VOCs | | | | | | | | | |
| Aerosol/Cloud | | | | | | | | | |

**Contribution :** none | partial | significant

**Table 3-6: Contribution of Measurement Types to Air Quality Requirements**

The classification applied to the contribution of measurement type to requirements is inevitably subjective and, in this case, also rather general in that it is intended to represent “typical” performances. As technologies evolve the contribution level is likely to change and these classifications will require re-evaluation.

# 4 Gap Analysis

## *4.1 Approach*

In comparing the application requirements with current and planned measurements to produce a "gap analysis" a number of aspects come into consideration.

Specifically, for a single instrument, the following questions arise:

1) How do measurements address application requirements on an individual basis such as atmospheric profiles or columns?
2) What geographical and temporal coverage are the measurements able to provide?

For example, limb-sounding typically provides good vertical resolution but is limited in its achievable horizontal resolution, whilst nadir sounding can access fine horizontal scales but are generally limited in distinguishing vertical structure unless an active sensor (e.g. radar, lidar) can be employed.

Low-Earth orbit (LEO) based instruments are able to provide good global coverage but have revisit times of several days. Geostationary missions on the other hand are designed to provide a high sampling interval, but cannot provide global coverage with a single platform. Solar occultation instruments, flown on LEO platforms, produce sparsely spaced data but may provide useful information where good accuracy and high sensitivity are required and geographical coverage is not a driver.

Other considerations include the number of missions to provide coverage and redundancy, the mission timescales both launch and duration.

The following analysis considers the application areas in turn and each of the measurement products individually. As a first step, the quality of the measurements from single instruments is examined and any general gaps in potential data availability highlighted. Then, sampling and revisit times required are considered and contrasted with the number of useful sensors which might be available and how this varies with time.

Tables have been produced for all cases where some useful measurements are expected. They are shown towards the end of the chapter in section 4.5 and use the same indicators and shading as used in the assignments of capabilities by measurement type i.e. the terms **significant**, **partial** and **none**, colour-coded appropriately.

The analysis covers each "Application Area" in turn, dealing with all the products for each area as indicated in Table 2-3 (chapter 2), which shows product requirements by application and programme.

## *4.2 Ozone Layer and Surface UV Monitoring and Forecasting*

### $H_2O$

- Many measurements providing partial contributions, with instruments meeting either vertical or horizontal resolution requirements
- No strong sampling or revisit time requirements
- Good overlap of current and planned missions
- No gaps up to ~2020

### $O_3$

- Many measurements, with limb MW and IR covering requirements most effectively; nadir instrumentation also provides useful input
- No strong sampling or revisit time requirements
- Reasonably good overlap of current and planned missions
- No gaps up to ~2020

### $CH_4$

- Requirements are minor and are partially satisfied by IR-limb and occultation measurements
- Little redundancy currently and none in planned missions
- Potential gaps in ~2014 and ~2019

### $HNO_3$

- Requirements covered by limb IR and MW instrumentation, with occultation sensors also providing relevant input
- Currently there is adequate coverage, but a potential gap ~2014 and low redundancy after ~2020

### $N_2O$

- Requirements are minor and are partially satisfied by IR and MW limb, as well as occultation sensors
- Little redundancy in period ~2013-14 and ~2019 onwards

### CO

- Requirements are minor and are partially satisfied many instrument types including limb and nadir sensors and all major wavelength ranges
- Good overlap between current and planned missions and significant redundancy
- No gaps up to at least 2020

### $CO_2$

- Requirements are minor and are met by future lidar and NIR sensors. Many instrument types partially meet requirements including limb, nadir and occultation sensors at all major wavelength ranges
- Good overlap between current and planned missions and significant redundancy.
- No gaps up to ~2020

### ClO

- MW limb sounding measurements are able to meet the requirements which have no major sampling or revisit time aspects.
- There is a low level of redundancy with reliance on single missions in parts of the timescale to 2020
- Potential gap in ~2014

### BrO

- Requirements are only partially met by MW limb sounding techniques
- There is a low level of redundancy with reliance on single missions in parts of the timescale to 2020
- Potential gap in ~2014

### HCl

- MW limb sounding measurements are able to meet the requirements which have no major sampling or revisit time aspects.
- There is a low level of redundancy with reliance on single missions in parts of the timescale to 2020
- Potential gap in ~2014

### $NO_2$

- Only IR limb measurements provide a significant contribution towards the requirements. UVN and occultation instrumentation provide partial contributions
- Few IR limb sensors exist in the mission plans and there is little redundancy as well as a measurement gap in year 2014
- There are multiple UVN nadir sensors providing good redundancy for their contributions

### HDO

- The requirements are minor and well met by IR nadir instrumentation which has good redundancy with no gaps apparent to 2020
- Limb MW and IR sensors are also able to provide partial contributions

### $CH_2O$

- The requirements are minor but only partially met by available instrumentation with UVN nadir and IR and MW limb providing good coverage up to 2020

### Aerosol & Cloud

- The requirements are well met by imager data and measurements from dedicated lidar and MAP (polarimeter) instruments. Other instrumentation is able to make partial contributions.
- Good redundancy throughout time frame to 2022
- No gaps evident

## *4.3 Composition-Climate Interaction*

### $H_2O$

- Many measurements available, with IR and MW limb making significant contributions and a number of techniques, including nadir sensors and occultation measurements, contributing partially
- There are some important revisit time requirements, including 12 and 3 hrs, which are impossible to meet without multiple missions if global coverage is required
- Multiple mission coverage for current missions, thinning slightly in 2012-2015, then more missions again in the period 2015-20
- Sampling too sparse throughout to meet most stringent revisit time requirements

### $O_3$

- MW and IR limb measurements contribute significantly, nadir measurements and occultation partially meet requirements
- GCOS requires a revisit time of 3 hrs, which is impossible without multiple missions for global coverage
- Multiple coverage for current and planned mission to 2020, however if revisit times are to be met and night time measurements are required there are significant gaps in orbit coverage

### $CH_4$

- IR limb observations contribute significantly to the requirements, with occultation making a partial contribution
- GCOS requires a revisit time of 3 hrs, for column measurements, which is impossible without multiple missions for global coverage
- Few missions, likely gaps in ~2014 and ~2019, little redundancy and sampling too sparse throughout to meet most stringent revisit time requirements

### $HNO_3$

- Requirements covered by limb IR and MW instrumentation, with occultation sensors also providing relevant input
- Mission coverage generally sufficient, however a potential gap in ~2014

### $N_2O$

- Requirements are well covered by limb IR and MW instrumentation, with occultation also contributing
- A gap is indicated in ~2014 and there is little or no redundancy

### CO

- Requirements are well covered with nadir IR and UVN, as well as MW limb sensors.
- Good mission coverage with redundancy and no apparent gaps to beyond 2020

### $CO_2$

- Requirements only partially met by the available instrumentation which consists of a number of UVN nadir instruments and the planned deployment of lidar and specialised NIR instruments
- GCOS requires a revisit time of 3 hrs, for column measurements, which is impossible without multiple missions for global coverage
- There is good mission coverage though a 3 hr revisit time is not evident in a consistent manner, day and night

### $NO_2$

- Requirements significantly addressed by UVN nadir sensors, with IR limb making a partial contribution
- Good mission coverage and redundancy to beyond 2020

### HDO

- Requirements covered by limb IR and MW instrumentation, with occultation sensors also providing relevant input
- Mission coverage generally sufficient, however a potential gap in ~2014

### $SF_6$

- IR limb observations contribute significantly to the requirements, with occultation making a partial contribution
- Few missions and little or no redundancy, a likely gap in ~2014

### Aerosol & Cloud

- The requirements are varied in terms of specific product type and some aspects can only be derived from dedicated instruments such as MAP (polarimeter) and lidar
- Broadly, the requirements are well met by imager data and measurements from dedicated lidar and MAP instruments
- Good redundancy throughout time frame to 2022
- No gaps evident

## *4.4 Air Quality Monitoring and Forecasting*

### $H_2O$

- Many measurements available, but only nadir IR sensors providing a significant contribution, with a number of techniques contributing partially including UVN-nadir, IR and MW limb
- Temporal sampling of 4 hours is a driving requirement for GMES requiring multiple missions
- Multiple mission coverage currently, thinning slightly in 2012-2015, then more missions again in the period 2015-20
- Sampling provided is marginal for requirements

### $O_3$

- UVN nadir measurements provide a significant contribution to the requirements, with several other techniques contributing including IR limb and nadir, MW limb, and occultation
- Temporal sampling of 4 hours is a driving requirement for GMES requiring multiple missions
- There is good multiple mission coverage but sampling provided marginal and inadequate if day and night coverage is required

### $HNO_3$

- Requirements are partially covered by IR limb and occultation sensors
- Temporal sampling of 4 hours is a driving requirement for GMES requiring multiple missions
- Mission coverage does not cover sampling requirements and is particularly sparse in the period ~2012-14 with little or no redundancy

### CO

- IR and UVN nadir measurements are able to significantly contribute to the requirements, with MW limb making a partial contribution
- GMES has a 4 hour sampling requirement but even more stringent is a Decadal Survey requirement of ~1 hour, though with only relevant regional coverage required
- There is good multiple mission coverage up to ~2020 but sampling provided may be marginal if day and night coverage is required

### $NO_2$

- UVN nadir measurements are able to significantly contribute to the requirements, with IR limb making a partial contribution
- GMES has a 4 hour sampling requirement; the Decadal Survey has a more stringent requirement of ~1 hour, though only for relevant regional areas
- There is good multiple mission coverage up to ~2020 but sampling provided may be marginal and inadequate if day and night coverage is required

### $N_2O_5$

- IR limb is the sole measurement technique to make a contribution to requirements and addresses these only partially
- There is a 4 hour sampling requirement from GMES which would require multiple missions to achieve global coverage
- There are few current or planned missions to cover this, providing little or no redundancy and no scope for achieving the sampling requirements

### $SO_2$

- UVN nadir measurements are able to significantly contribute to the requirements
- GMES has a 4 hour sampling requirement but even more stringent is a Decadal Survey requirement of ~1 hour, though with only relevant regional coverage required
- There is good multiple mission coverage up to ~2020 but sampling provided would be insufficient if day and night coverage is required

### $CH_2O$

- IR limb, UVN nadir and occultation sensors all make partial contributions to the requirements
- GMES has a 4 hour sampling requirement, the Decadal Survey has a requirement of ~1 hour, though with only relevant regional coverage required
- There is good multiple mission coverage up to ~2020 but sampling provided may be marginal and inadequate if day and night coverage is required

## PAN

- IR limb is the sole measurement technique to make a contribution to requirements and addresses these only partially
- There is a 4 hour sampling requirement from GMES which would require multiple missions to achieve global coverage
- There are few current or planned missions to cover this, providing little or no redundancy and no scope for achieving the sampling requirements

## VOCs

- IR and UVN nadir measurements are able to significantly contribute to the requirements, with IR limb making a partial contribution
- GMES has a 4 hour sampling requirement; the Decadal Survey has a requirement of ~1 hour over limited regional coverage
- There is good multiple mission coverage up to ~2020 and good sampling provided though it would not meet the most stringent requirement if day and night coverage is required globally

## Aerosol & Cloud

- The requirements are varied in terms of specific product type and some aspects can only be derived from dedicated instruments such as MAP and lidar
- Broadly, the requirements are well met by imager data and measurements from dedicated lidar and MAP (polarimeter) instruments, with a number of other sensors contributing
- There is a 4 hour sampling requirement from GMES which would require multiple missions to achieve global coverage
- Good redundancy throughout time frame to 2022
- No gaps evident

## 4.5 Analysis Tables

Tables follow for each application area:

1. Ozone layer and surface UV monitoring and forecasting
2. Composition-climate interaction
3. Air quality monitoring and forecasting

They are intended to summarise the contributions of instruments and missions and how they fit into the timescale of the next two decades or so.

### 4.5.1 Ozone Layer and Surface UV Monitoring and Forecasting

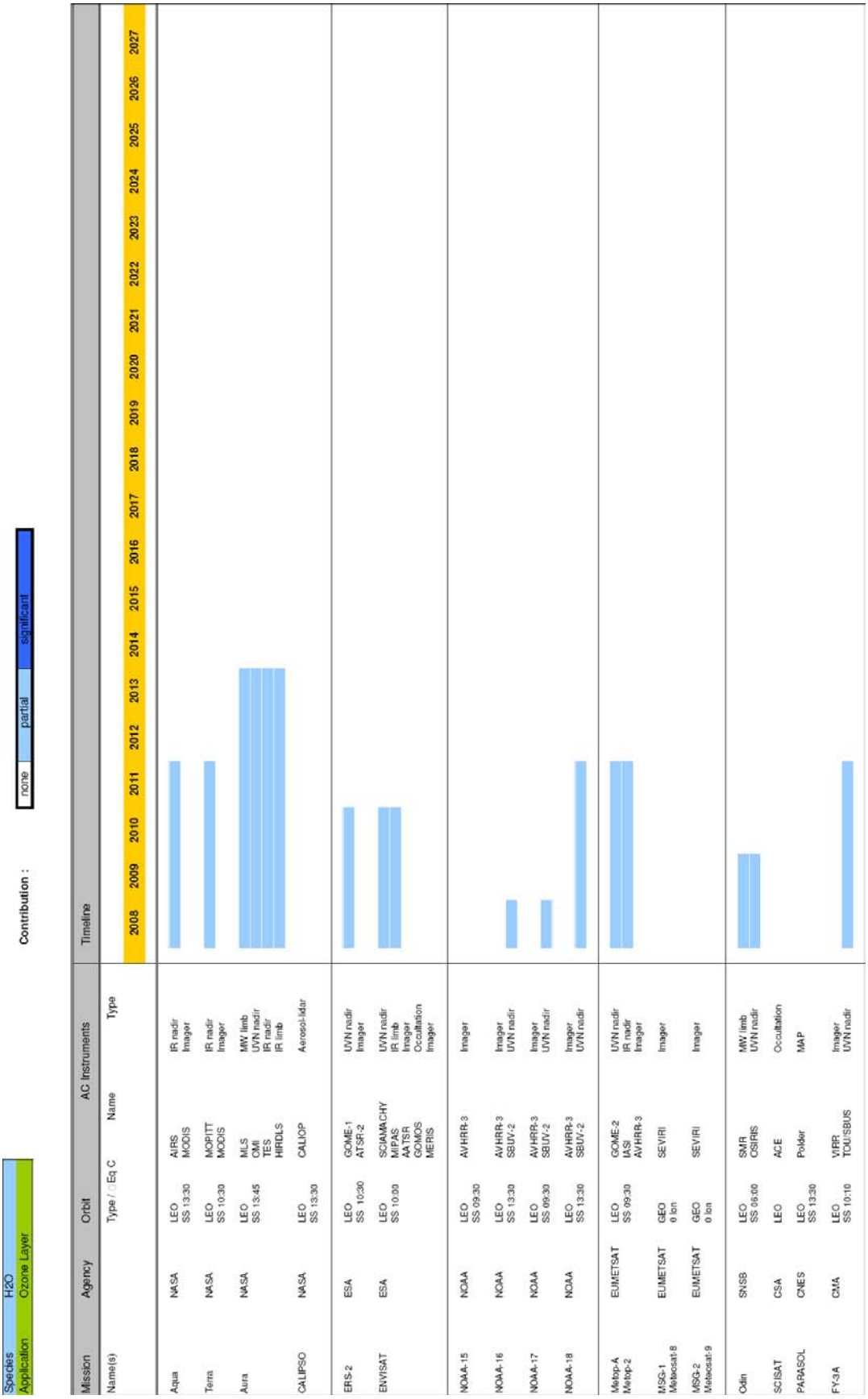


**Table 4-1: $H_2O$ Measurements from Current Missions for Ozone Layer Requirements**

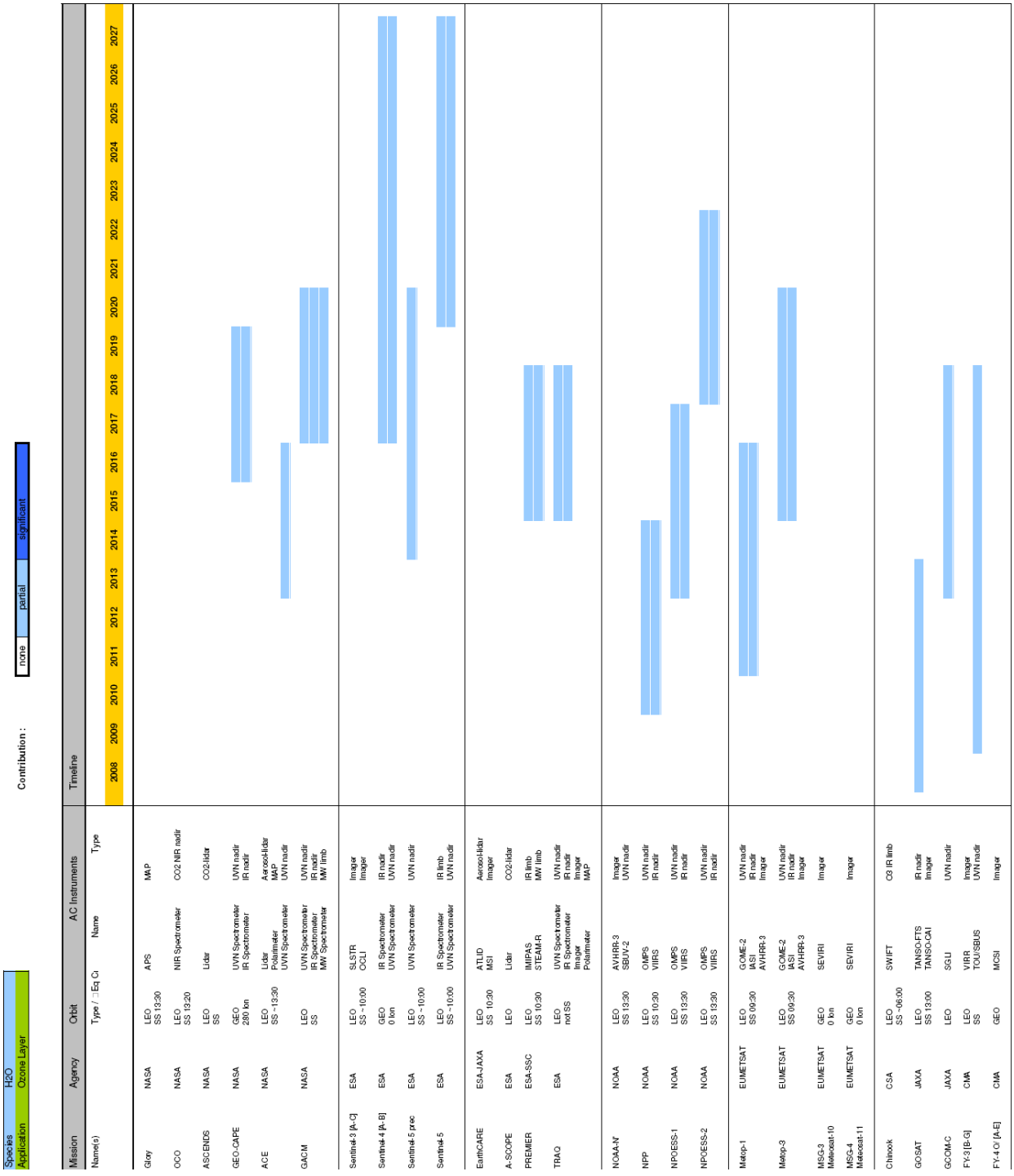


**Table 4-2: $H_2O$ Measurements from Planned Missions for Ozone Layer Requirements**

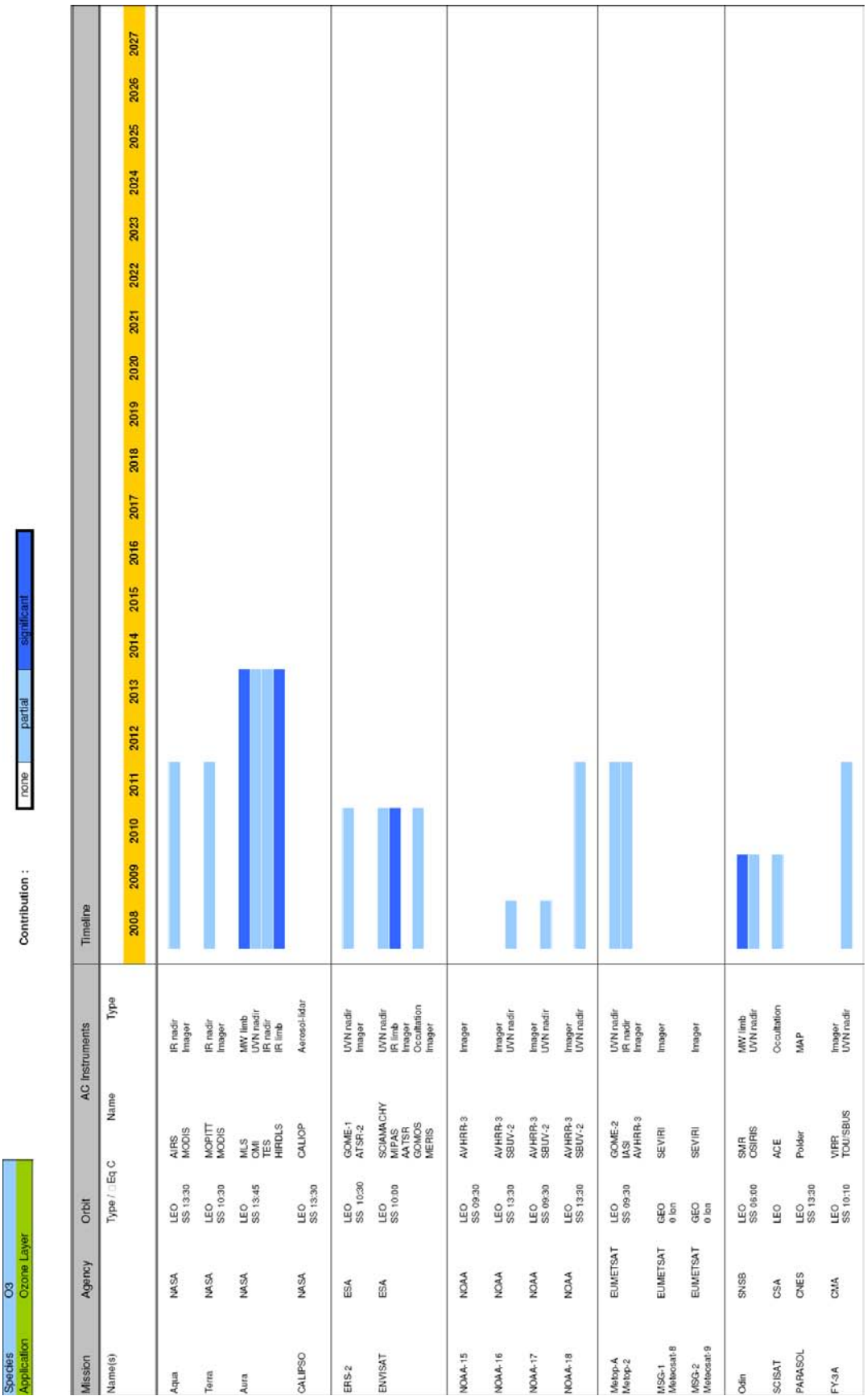


**Table 4-3: $O_3$ Measurements from Current Missions for Ozone Layer Requirements**

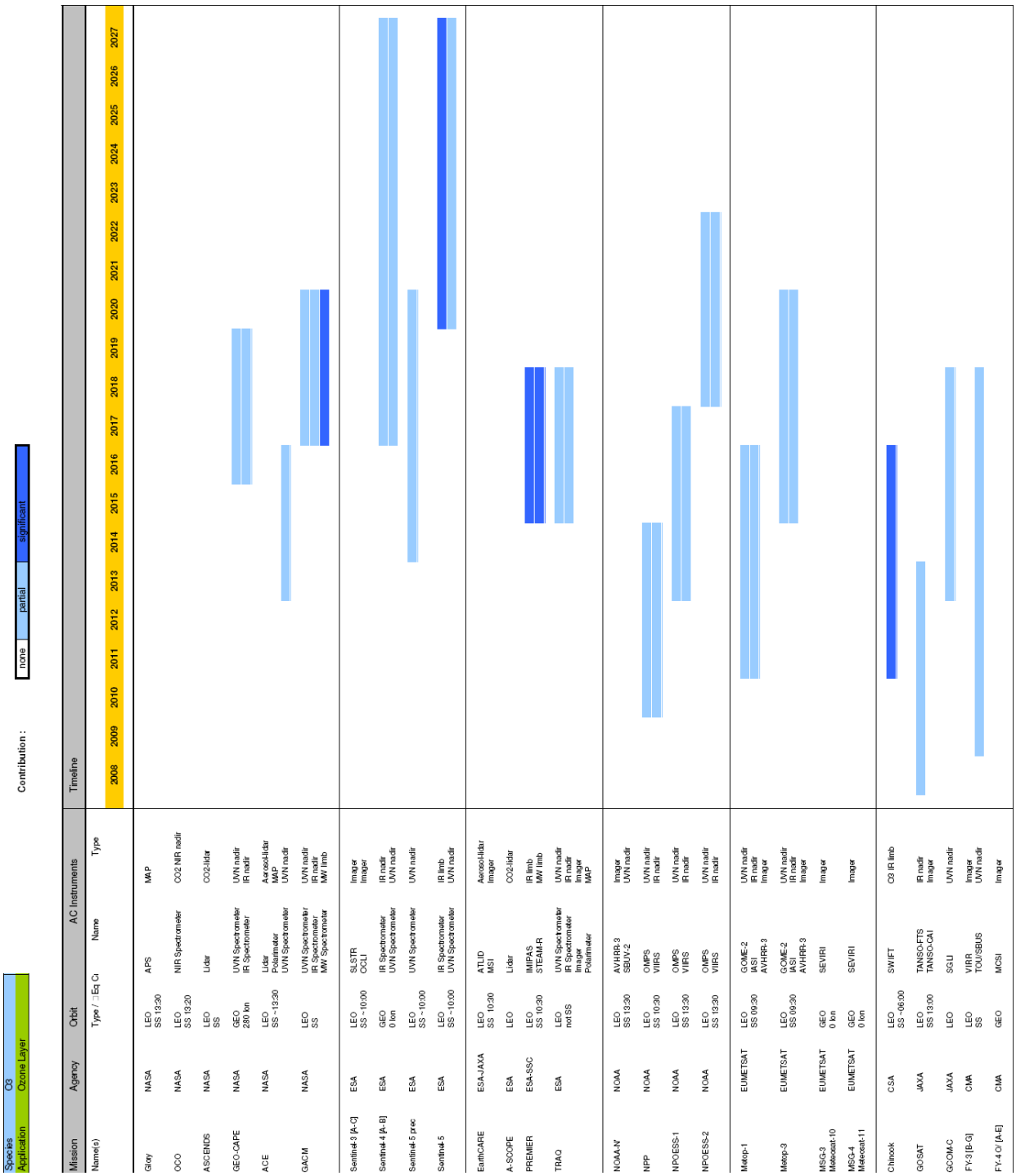


**Table 4-4: $O_3$ Measurements from Planned Missions for Ozone Layer Requirements**

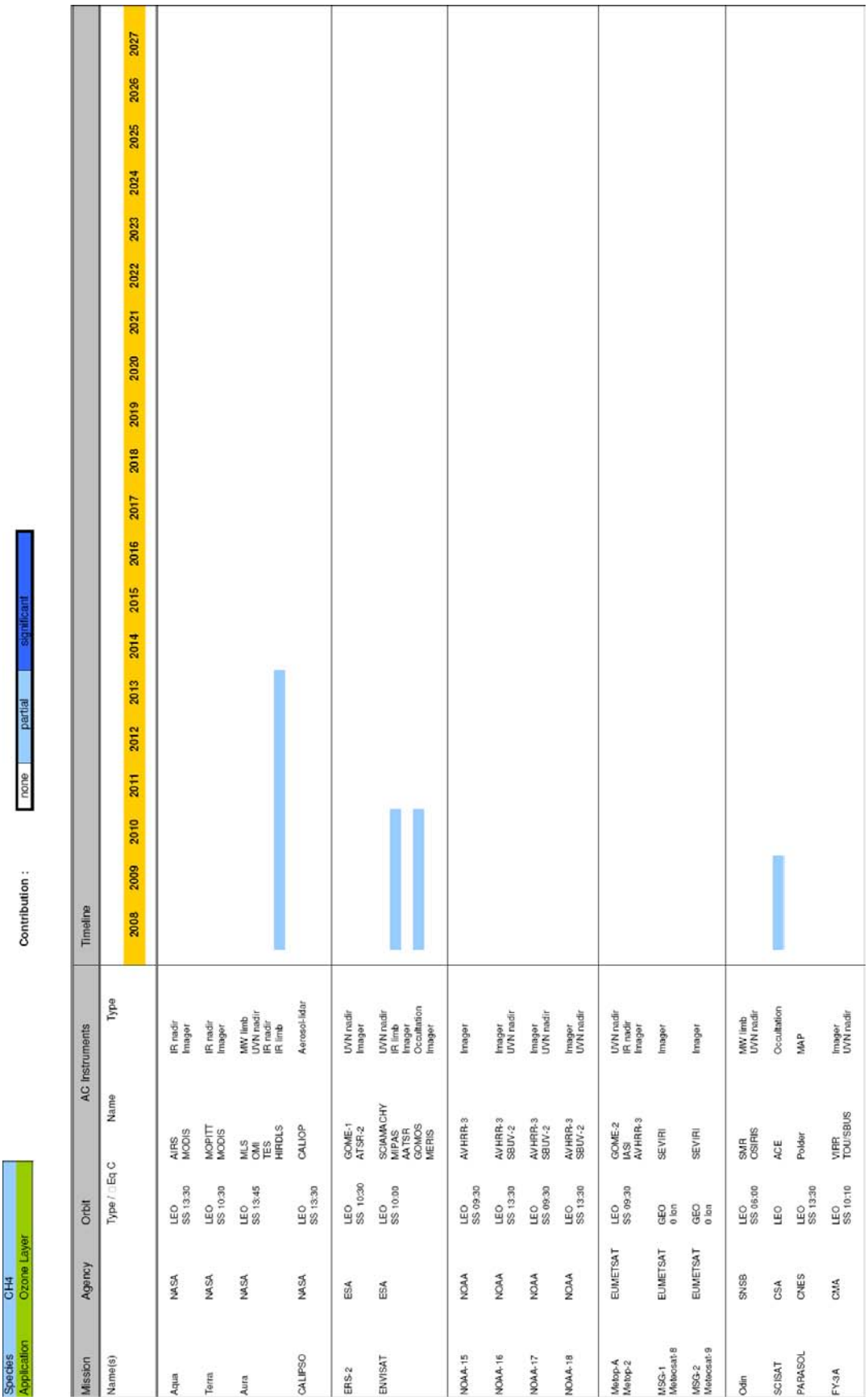


**Table 4-5: $CH_4$ Measurements from Current Missions for Ozone Layer Requirements**

Species CH4
Application Ozone Layer

Contribution : none | partial | significant

| Mission | Agency | Orbit | | AC Instruments | | Timeline | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name(s) | | Type / ..Eq Cr | | Name | Type | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 |
| Glory | NASA | LEO SS 13:30 | | APS | MAP | | | | | | | | | | | | | | | | | | | | |
| OCO | NASA | LEO SS 13:20 | | NIR Spectrometer | CO2 NIR nadir | | | | | | | | | | | | | | | | | | | | |
| ASCENDS | NASA | LEO SS | | Lidar | CO2-lidar | | | | | | | | | | | | | | | | | | | | |
| GEO-CAPE | NASA | GEO 280 lon | | UVN Spectrometer<br>IR Spectrometer | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| ACE | NASA | LEO SS ~13:30 | | Lidar<br>Polarimeter<br>UVN Spectrometer | Aerosol-lidar<br>MAP<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| GACM | NASA | LEO SS | | UVN Spectrometer<br>IR Spectrometer<br>MW Spectrometer | UVN nadir<br>IR nadir<br>MW limb | | | | | | | | | | | | | | | | | | | | |
| Sentinel-3 [A-C] | ESA | LEO SS ~ 10:00 | | SLSTR<br>OCLI | Imager<br>Imager | | | | | | | | | | | | | | | | | | | | |
| Sentinel-4 [A-B] | ESA | GEO 0 lon | | IR Spectrometer<br>UVN Spectrometer | IR nadir<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| Sentinel-5 prec | ESA | LEO SS ~10:00 | | UVN Spectrometer | UVN nadir | | | | | | | | | | | | | | | | | | | | |
| Sentinel-5 | ESA | LEO SS ~10:00 | | IR Spectrometer<br>UVN Spectrometer | IR limb<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| EarthCARE | ESA-JAXA | LEO SS 10:30 | | ATLID<br>MSI | Aerosol-lidar<br>Imager | | | | | | | | | | | | | | | | | | | | |
| A-SCOPE | ESA | LEO | | Lidar | CO2-lidar | | | | | | | | | | | | | | | | | | | | |
| PREMIER | ESA-SSC | LEO SS 10:30 | | IMIPAS<br>STEAM-R | IR limb<br>MW limb | | | | | | | | | | | | | | | | | | | | |
| TRAQ | ESA | LEO not SS | | UVN Spectrometer<br>IR Spectrometer<br>Imager<br>Polarimeter | UVN nadir<br>IR nadir<br>Imager<br>MAP | | | | | | | | | | | | | | | | | | | | |
| NOAA-N | NOAA | LEO SS 13:30 | | AVHRR-3<br>SBUV-2 | Imager<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| NPP | NOAA | LEO SS 10:30 | | OMPS<br>VIIRS | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| NPOESS-1 | NOAA | LEO SS 13:30 | | OMPS<br>VIIRS | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| NPOESS-2 | NOAA | LEO SS 13:30 | | OMPS<br>VIIRS | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| Metop-1 | EUMETSAT | LEO SS 09:30 | | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | | | | | | | | | | | | | | | | | | | | |
| Metop-3 | EUMETSAT | LEO SS 09:30 | | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | | | | | | | | | | | | | | | | | | | | |
| MSG-3<br>Meteosat-10 | EUMETSAT | GEO 0 lon | | SEVIRI | Imager | | | | | | | | | | | | | | | | | | | | |
| MSG-4<br>Meteosat-11 | EUMETSAT | GEO 0 lon | | SEVIRI | Imager | | | | | | | | | | | | | | | | | | | | |
| Chinook | CSA | LEO SS ~06:00 | | SWIFT | O3 IR limb | | | | | | | | | | | | | | | | | | | | |
| GOSAT | JAXA | LEO SS 13:00 | | TANSO-FTS<br>TANSO-CAI | IR nadir<br>Imager | | | | | | | | | | | | | | | | | | | | |
| GCOM-C | JAXA | LEO | | SGLI | UVN nadir | | | | | | | | | | | | | | | | | | | | |
| FY-3 [B-G] | CMA | LEO SS | | VIRR<br>TOU/SBUS | Imager<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| FY-4 O [A-E] | CMA | GEO | | MCSI | Imager | | | | | | | | | | | | | | | | | | | | |

**Table 4-6: $CH_4$ Measurements from Planned Missions for Ozone Layer Requirements**

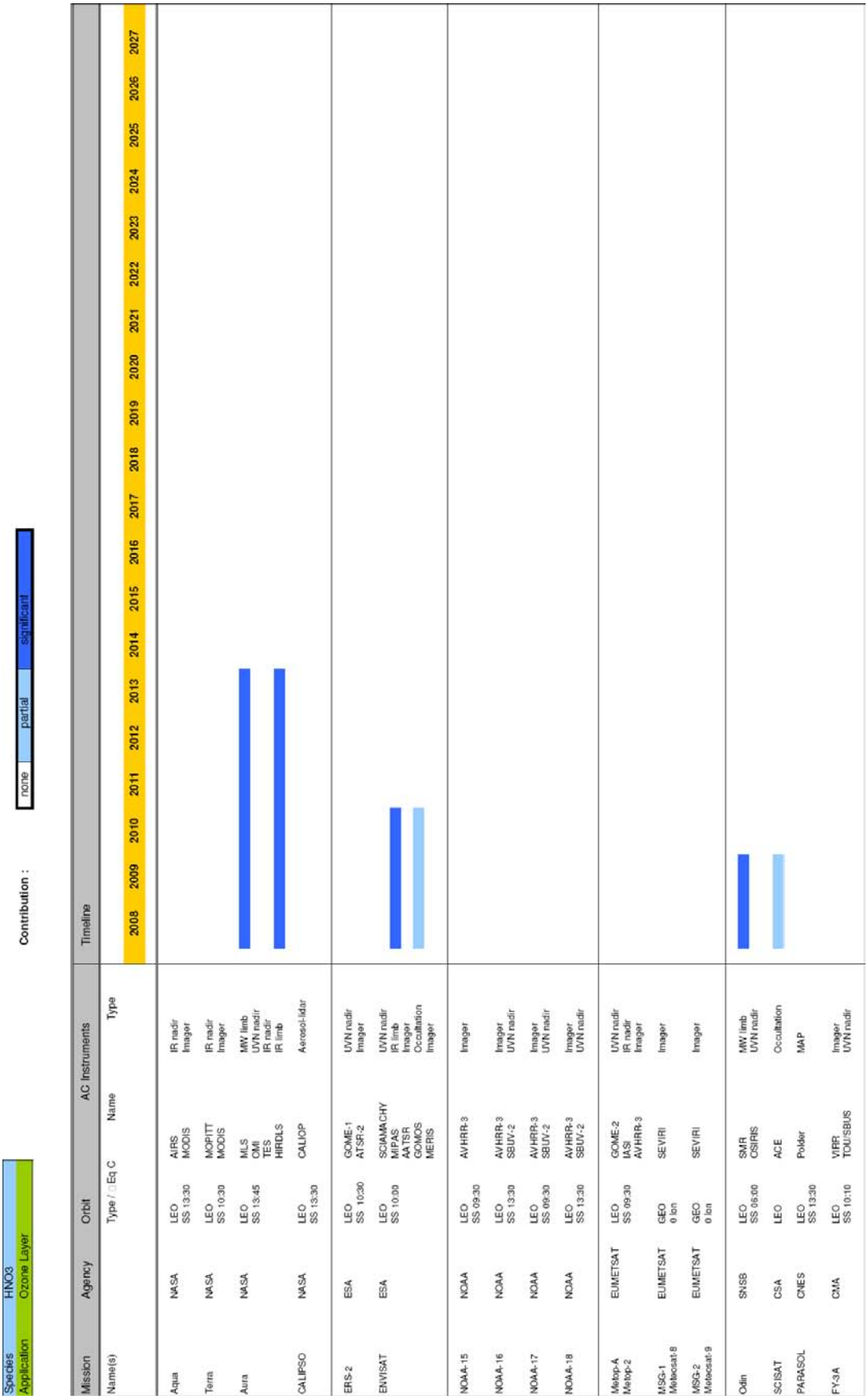


**Table 4-7: $HNO_3$ Measurements from Current Missions for Ozone Layer Requirements**

**Table 4-8: $HNO_3$ Measurements from Planned Missions for Ozone Layer Requirements**

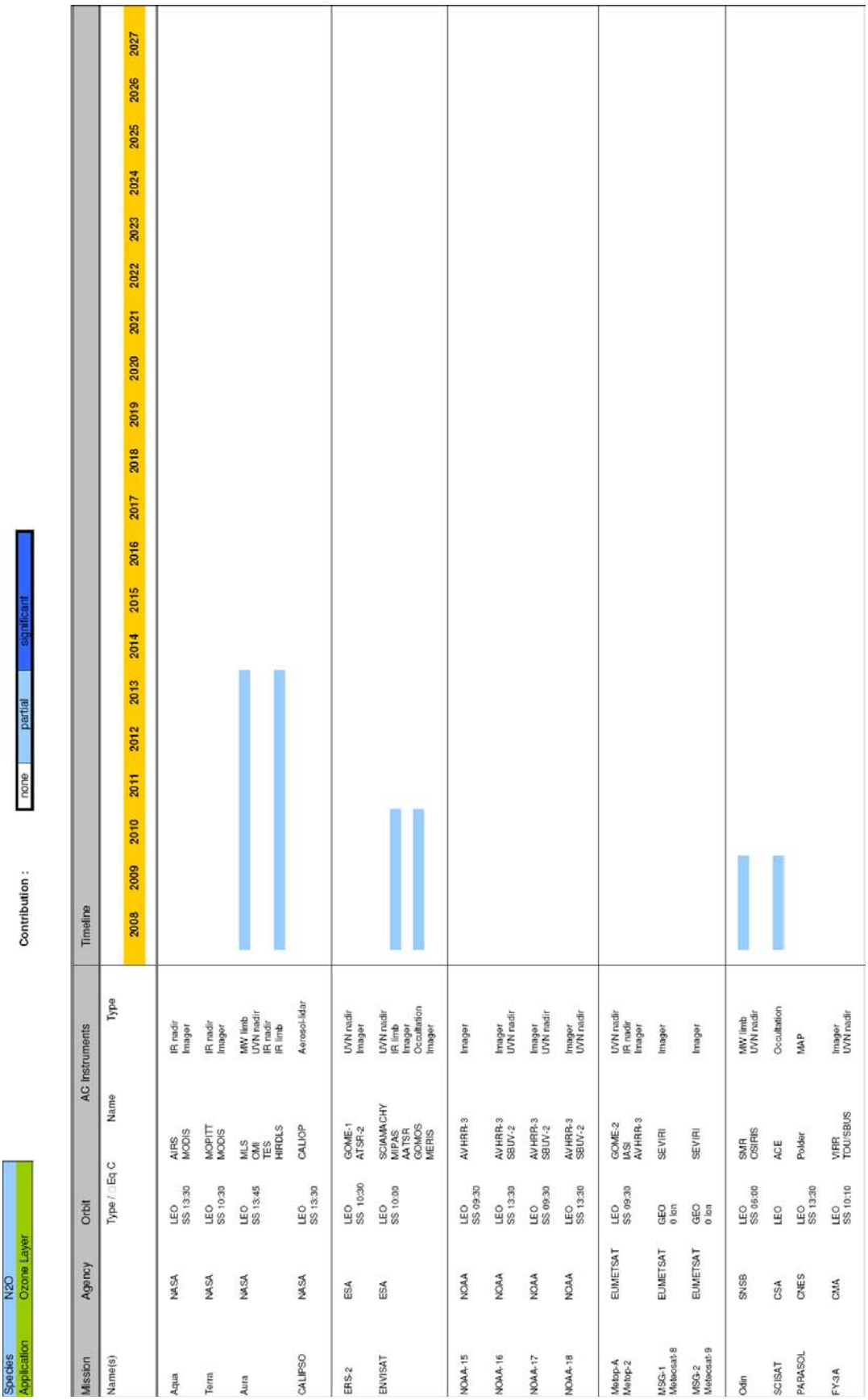


**Table 4-9: $N_2O$ Measurements from Current Missions for Ozone Layer Requirements**

Species: N2O
Application: Ozone Layer

Contribution: none | partial | significant

| Mission | Agency | Orbit | AC Instruments | | Timeline |
|---|---|---|---|---|---|
| Name(s) | | Type / ...Eq Cr | Name | Type | 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 |
| Glory | NASA | LEO SS 13:30 | APS | MAP | |
| OCO | NASA | LEO SS 13:20 | NIR Spectrometer | CO2 NIR nadir | |
| ASCENDS | NASA | LEO SS | Lidar | CO2-lidar | |
| GEO-CAPE | NASA | GEO 280 lon | UVN Spectrometer<br>IR Spectrometer | UVN nadir<br>IR nadir | |
| ACE | NASA | LEO SS ~13:30 | Lidar<br>Polarimeter<br>UVN Spectrometer | Aerosol-lidar<br>MAP<br>UVN nadir | |
| GACM | NASA | LEO SS | UVN Spectrometer<br>IR Spectrometer<br>MW Spectrometer | UVN nadir<br>IR nadir<br>MW limb | |
| Sentinel-3 [A-C] | ESA | LEO SS ~10:00 | SLSTR<br>OCLI | Imager<br>Imager | |
| Sentinel-4 [A-B] | ESA | GEO 0 lon | IR Spectrometer<br>UVN Spectrometer | IR nadir<br>UVN nadir | |
| Sentinel-5 prec | ESA | LEO SS ~10:00 | UVN Spectrometer | UVN nadir | |
| Sentinel-5 | ESA | LEO SS ~10:00 | IR Spectrometer<br>UVN Spectrometer | IR limb<br>UVN nadir | |
| EarthCARE | ESA-JAXA | LEO SS 10:30 | ATLID<br>MSI | Aeroso-lidar<br>Imager | |
| A-SCOPE | ESA | LEO | Lidar | CO2-lidar | |
| PREMIER | ESA-SSC | LEO SS 10:30 | IMIPAS<br>STEAM-R | IR limb<br>MW limb | |
| TRAQ | ESA | LEO not SS | UVN Spectrometer<br>IR Spectrometer<br>Imager<br>Polarimeter | UVN nadir<br>IR nadir<br>Imager<br>MAP | |
| NOAA-N | NOAA | LEO SS 13:30 | AVHRR-3<br>SBUV-2 | Imager<br>UVN nadir | |
| NPP | NOAA | LEO SS 10:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | |
| NPOESS-1 | NOAA | LEO SS 13:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | |
| NPOESS-2 | NOAA | LEO SS 13:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | |
| Metop-1 | EUMETSAT | LEO SS 09:30 | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | |
| Metop-3 | EUMETSAT | LEO SS 09:30 | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | |
| MSG-3<br>Meteosat-10 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | |
| MSG-4<br>Meteosat-11 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | |
| Chinook | CSA | LEO SS ~06:00 | SWIFT | O3 IR limb | |
| GOSAT | JAXA | LEO SS 13:00 | TANSO-FTS<br>TANSO-CAI | IR nadir<br>Imager | |
| GCOM-C | JAXA | LEO | SGLI | UVN nadir | |
| FY-3 [B-G] | CMA | LEO SS | VIRR<br>TOU/SBUS | Imager<br>UVN nadir | |
| FY-4 O [A-E] | CMA | GEO | MCSI | Imager | |

**Table 4-10: $N_2O$ Measurements from Planned Missions for Ozone Layer Requirements**

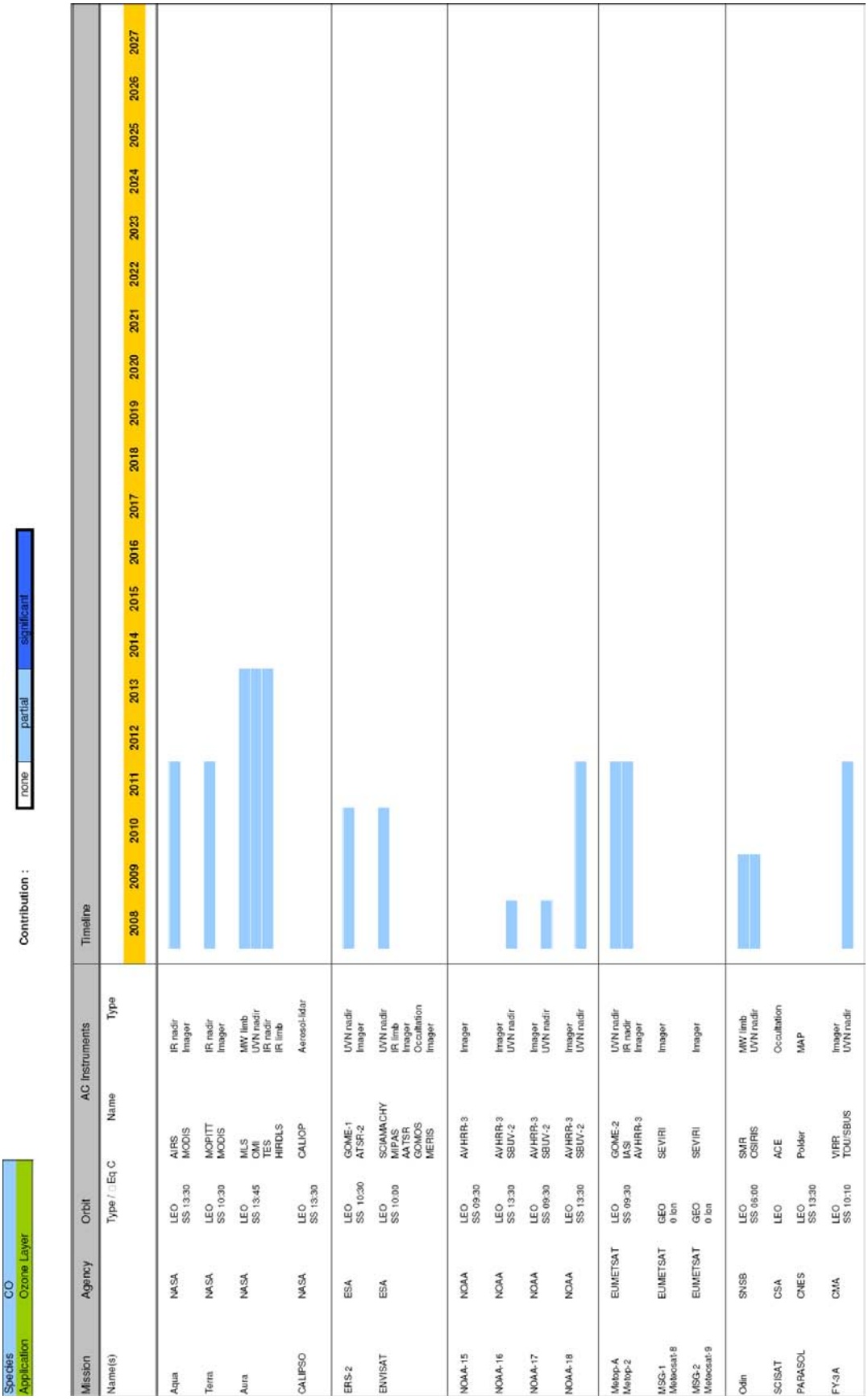


**Table 4-11: CO Measurements from Current Missions for Ozone Layer Requirements**

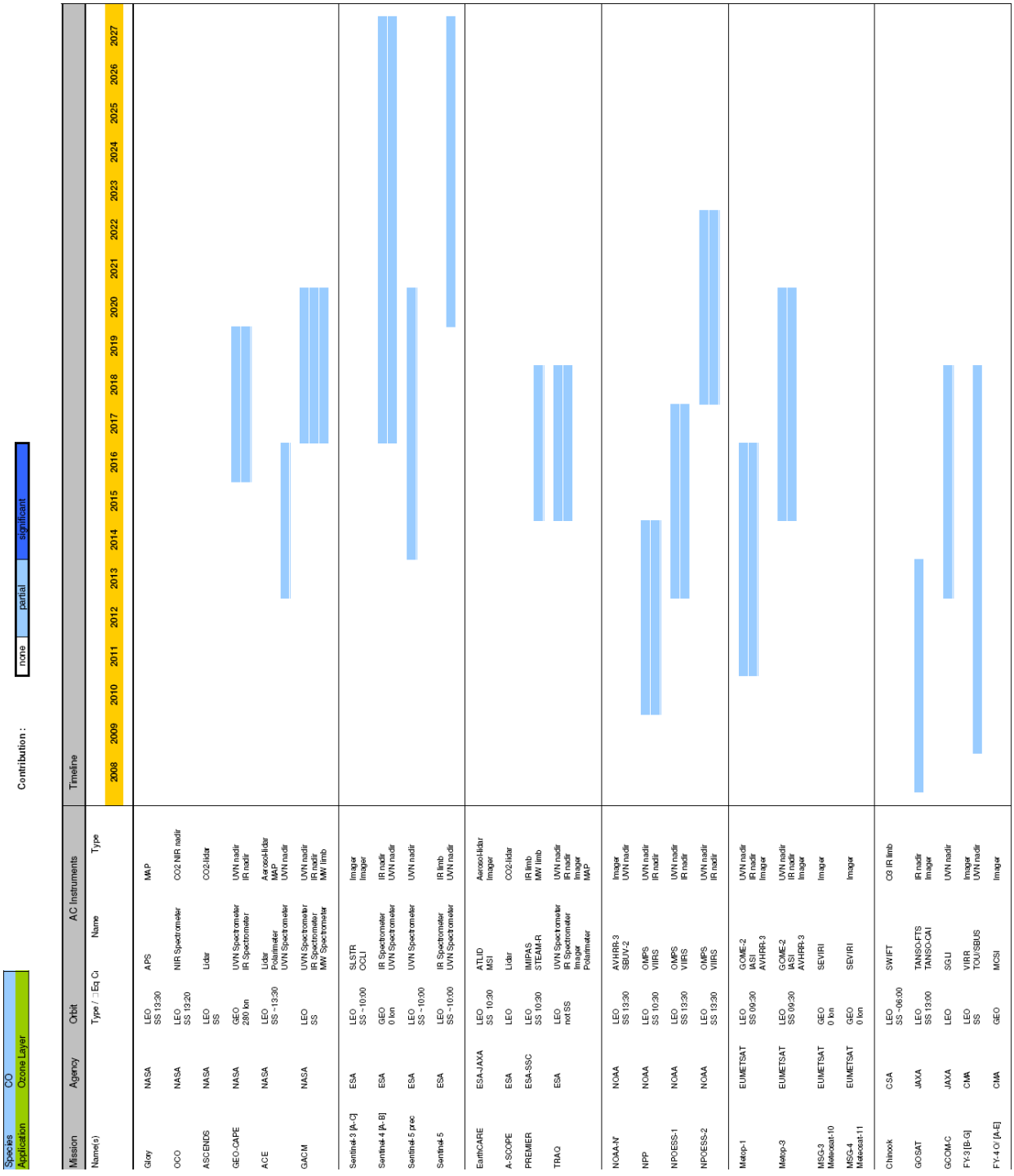


**Table 4-12: CO Measurements from Planned Missions for Ozone Layer Requirements**

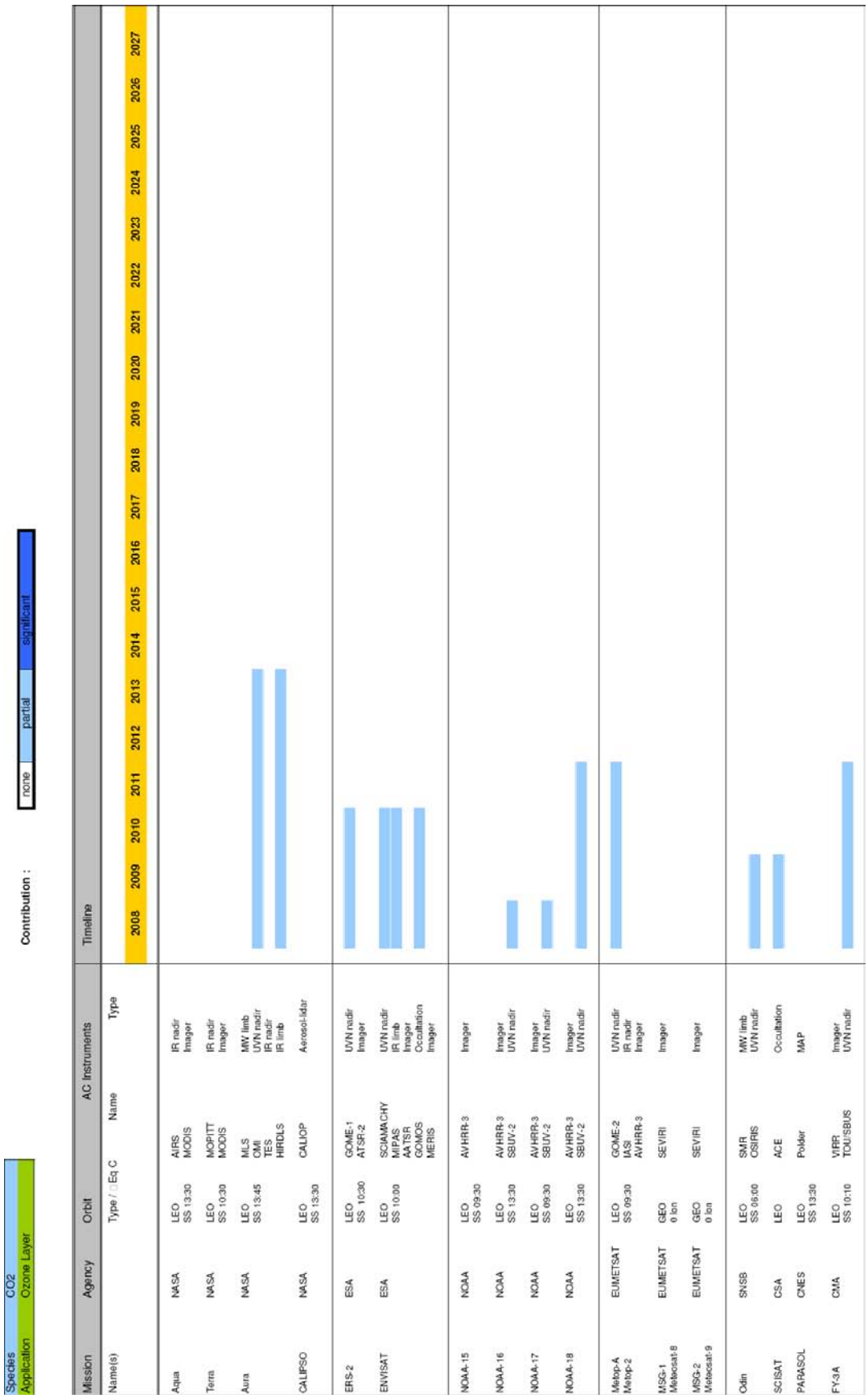


**Table 4-13: $CO_2$ Measurements from Current Missions for Ozone Layer Requirements**

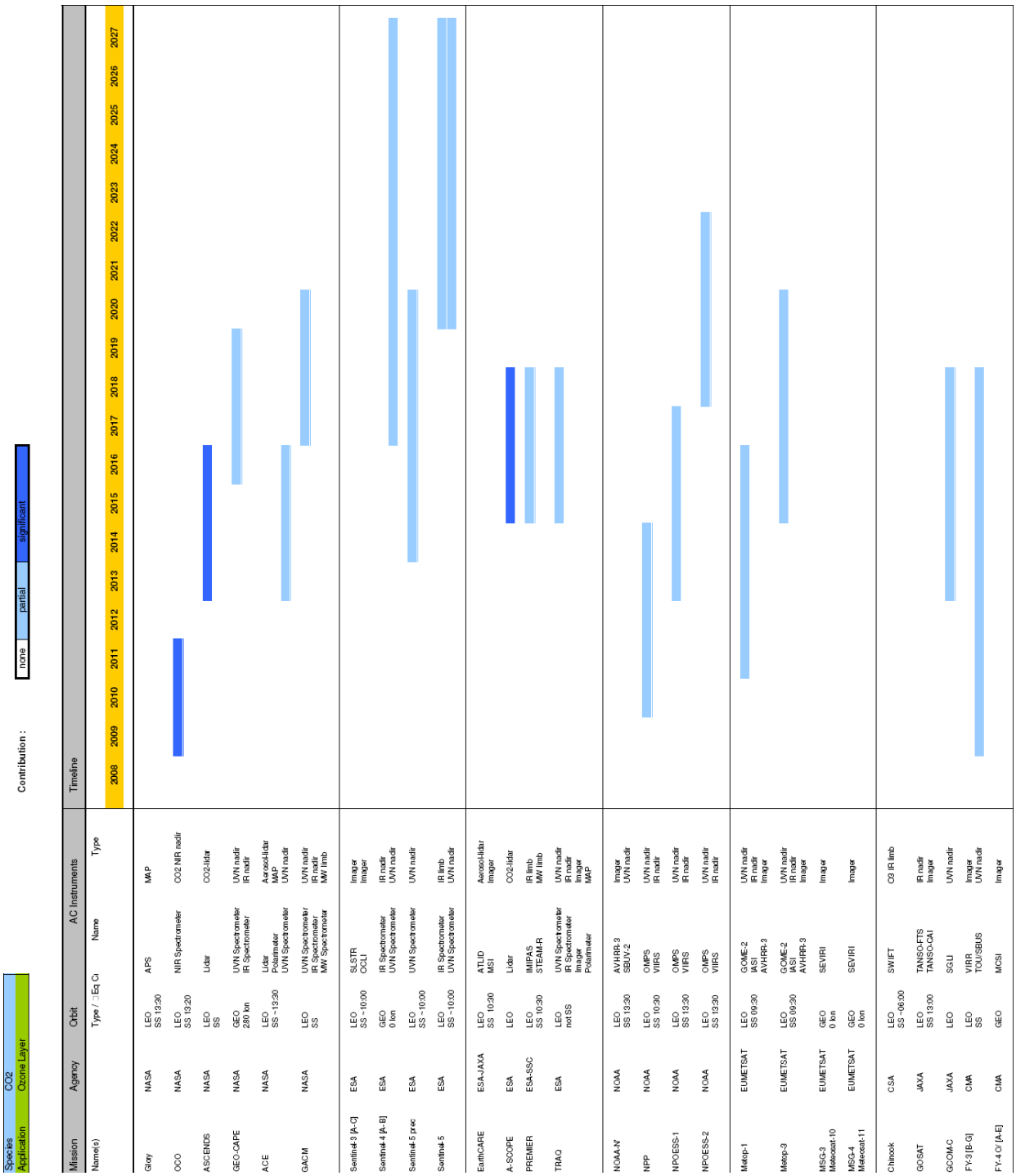


**Table 4-14: $CO_2$ Measurements from Planned Missions for Ozone Layer Requirements**

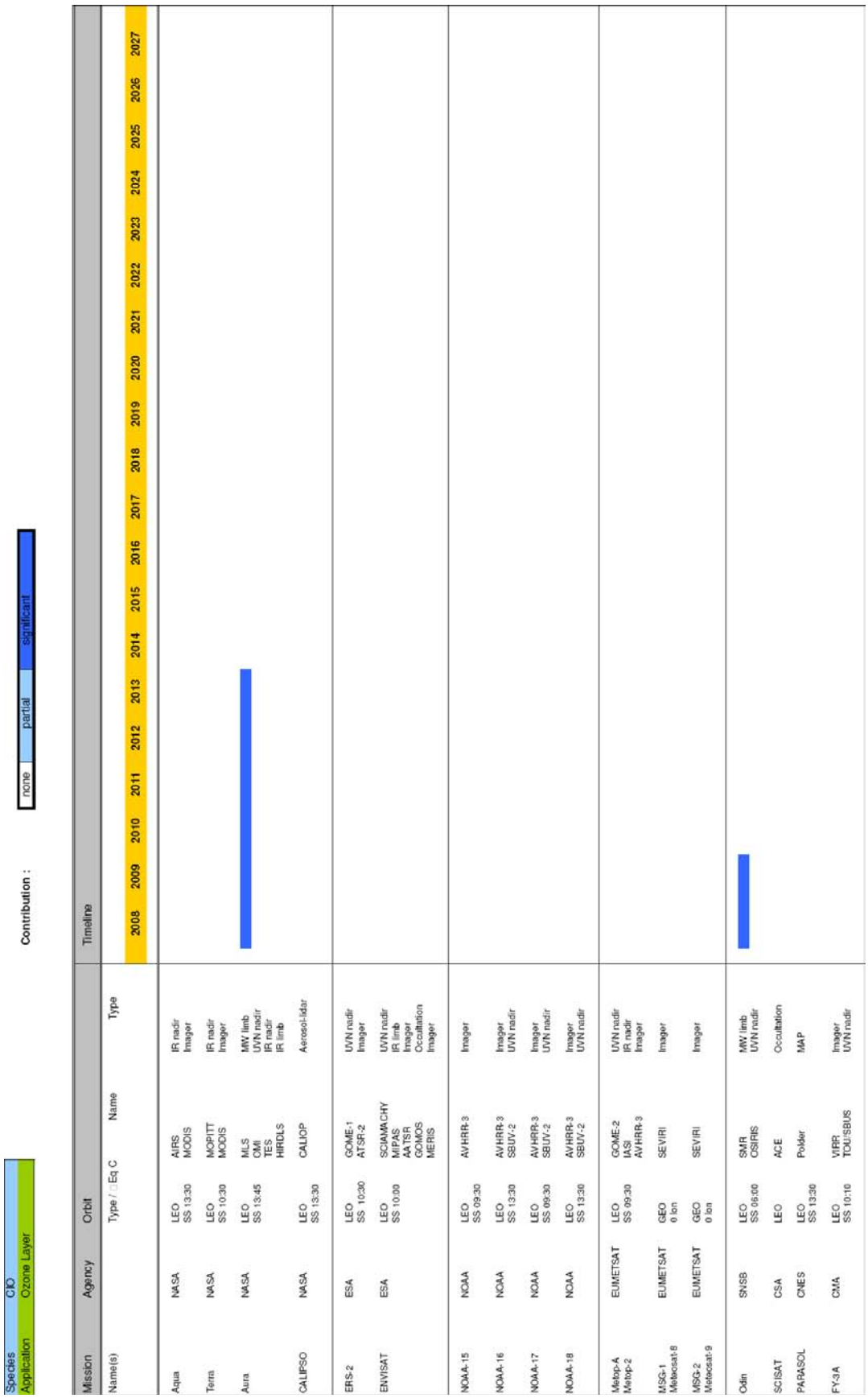


**Table 4-15: CIO Measurements from Current Missions for Ozone Layer Requirements**

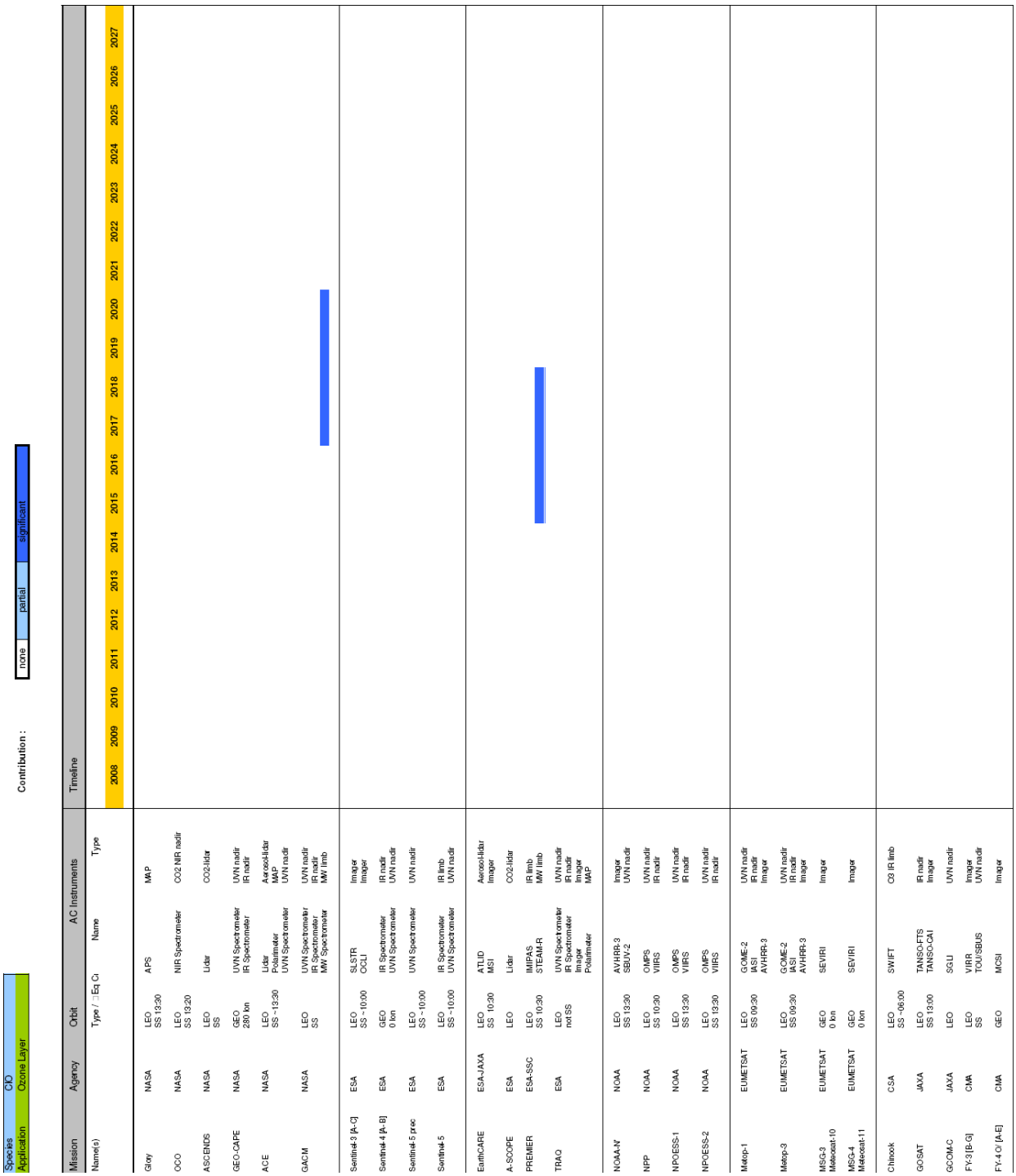


**Table 4-16: CIO Measurements from Planned Missions for Ozone Layer Requirements**

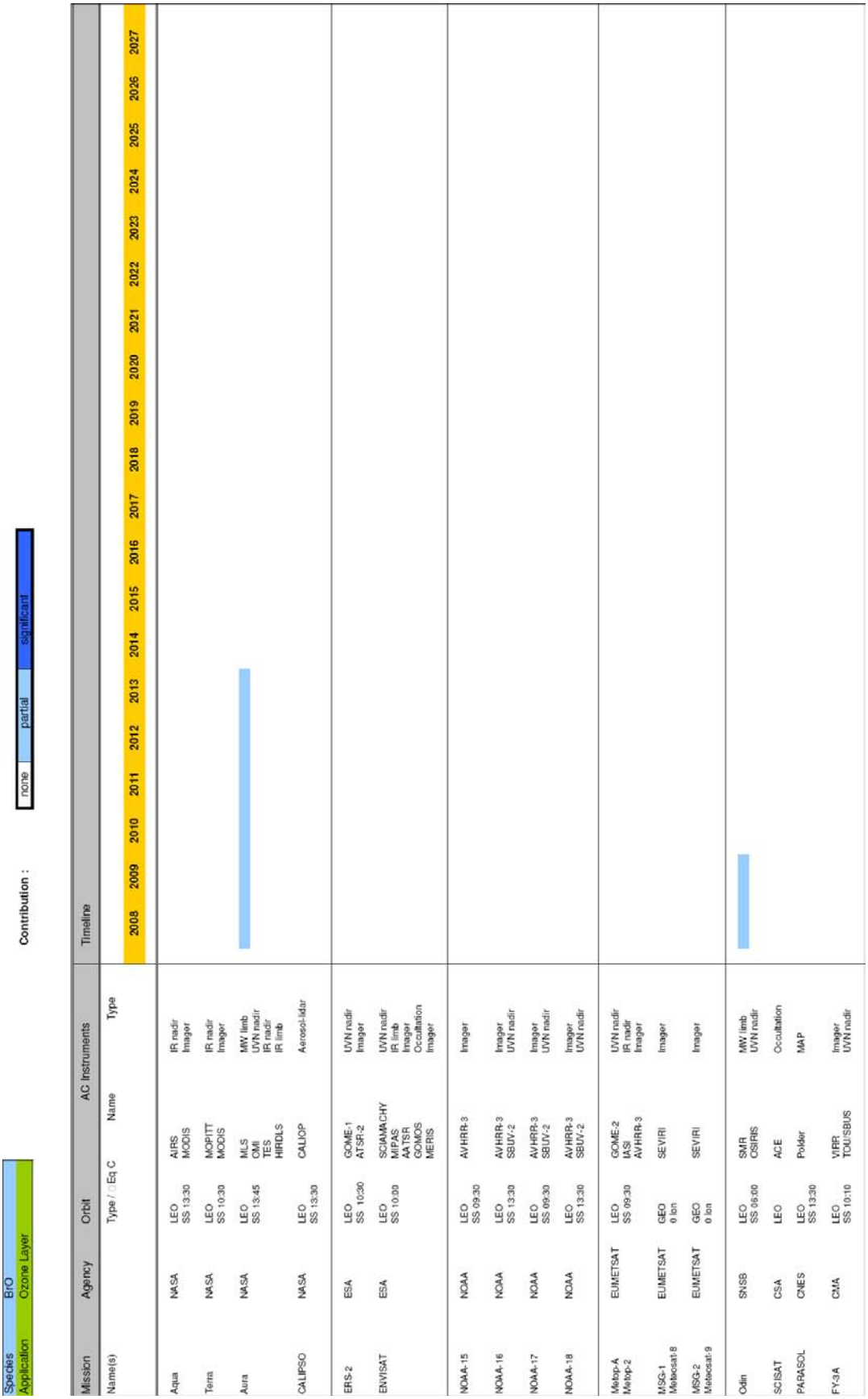


**Table 4-17: BrO Measurements from Current Missions for Ozone Layer Requirements**

Species: BrO
Application: Ozone Layer

Contribution: none | partial | significant

| Mission | Agency | Orbit | AC Instruments | | Timeline | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name(s) | | Type / ..Eq Cr | Name | Type | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 |
| Glory | NASA | LEO SS 13:30 | APS | MAP | | | | | | | | | | | | | | | | | | | | |
| OCO | NASA | LEO SS 13:20 | NIR Spectrometer | CO2 NIR nadir | | | | | | | | | | | | | | | | | | | | |
| ASCENDS | NASA | LEO SS | Lidar | CO2-lidar | | | | | | | | | | | | | | | | | | | | |
| GEO-CAPE | NASA | GEO 280 lon | UVN Spectrometer<br>IR Spectrometer | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| ACE | NASA | LEO SS ~13:30 | Lidar<br>Polarimeter<br>UVN Spectrometer | Aerosol-lidar<br>MAP<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| GACM | NASA | LEO SS | UVN Spectrometer<br>IR Spectrometer<br>MW Spectrometer | UVN nadir<br>IR nadir<br>MW limb | | | | | | | | | | | | | | | | | | | | |
| Sentinel-3 [A-C] | ESA | LEO SS ~10:00 | SLSTR<br>OCLI | Imager<br>Imager | | | | | | | | | | | | | | | | | | | | |
| Sentinel-4 [A-B] | ESA | GEO 0 lon | IR Spectrometer<br>UVN Spectrometer | IR nadir<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| Sentinel-5 prec | ESA | LEO SS ~10:00 | UVN Spectrometer | UVN nadir | | | | | | | | | | | | | | | | | | | | |
| Sentinel-5 | ESA | LEO SS ~10:00 | IR Spectrometer<br>UVN Spectrometer | IR limb<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| EarthCARE | ESA-JAXA | LEO SS 10:30 | ATLID<br>MSI | Aeroso-lidar<br>Imager | | | | | | | | | | | | | | | | | | | | |
| A-SCOPE | ESA | LEO | Lidar | CO2-lidar | | | | | | | | | | | | | | | | | | | | |
| PREMIER | ESA-SSC | LEO SS 10:30 | IMIPAS<br>STEAM-R | IR limb<br>MW limb | | | | | | | | | | | | | | | | | | | | |
| TRAQ | ESA | LEO not SS | UVN Spectrometer<br>IR Spectrometer<br>Imager<br>Polarimeter | UVN nadir<br>IR nadir<br>Imager<br>MAP | | | | | | | | | | | | | | | | | | | | |
| NOAA-N | NOAA | LEO SS 13:30 | AVHRR-3<br>SBUV-2 | Imager<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| NPP | NOAA | LEO SS 10:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| NPOESS-1 | NOAA | LEO SS 13:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| NPOESS-2 | NOAA | LEO SS 13:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| Metop-1 | EUMETSAT | LEO SS 09:30 | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | | | | | | | | | | | | | | | | | | | | |
| Metop-3 | EUMETSAT | LEO SS 09:30 | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | | | | | | | | | | | | | | | | | | | | |
| MSG-3<br>Meteosat-10 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | | | | | | | | | | | | | | | | | | | | |
| MSG-4<br>Meteosat-11 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | | | | | | | | | | | | | | | | | | | | |
| Chinook | CSA | LEO SS ~06:00 | SWIFT | O3 IR limb | | | | | | | | | | | | | | | | | | | | |
| GOSAT | JAXA | LEO SS 13:00 | TANSO-FTS<br>TANSO-CAI | IR nadir<br>Imager | | | | | | | | | | | | | | | | | | | | |
| GCOM-C | JAXA | LEO | SGLI | UVN nadir | | | | | | | | | | | | | | | | | | | | |
| FY-3 [B-G] | CMA | LEO SS | VIRR<br>TOU/SBUS | Imager<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| FY-4 O/ [A-E] | CMA | GEO | MCSI | Imager | | | | | | | | | | | | | | | | | | | | |

**Table 4-18: BrO Measurements from Planned Missions for Ozone Layer Requirements**

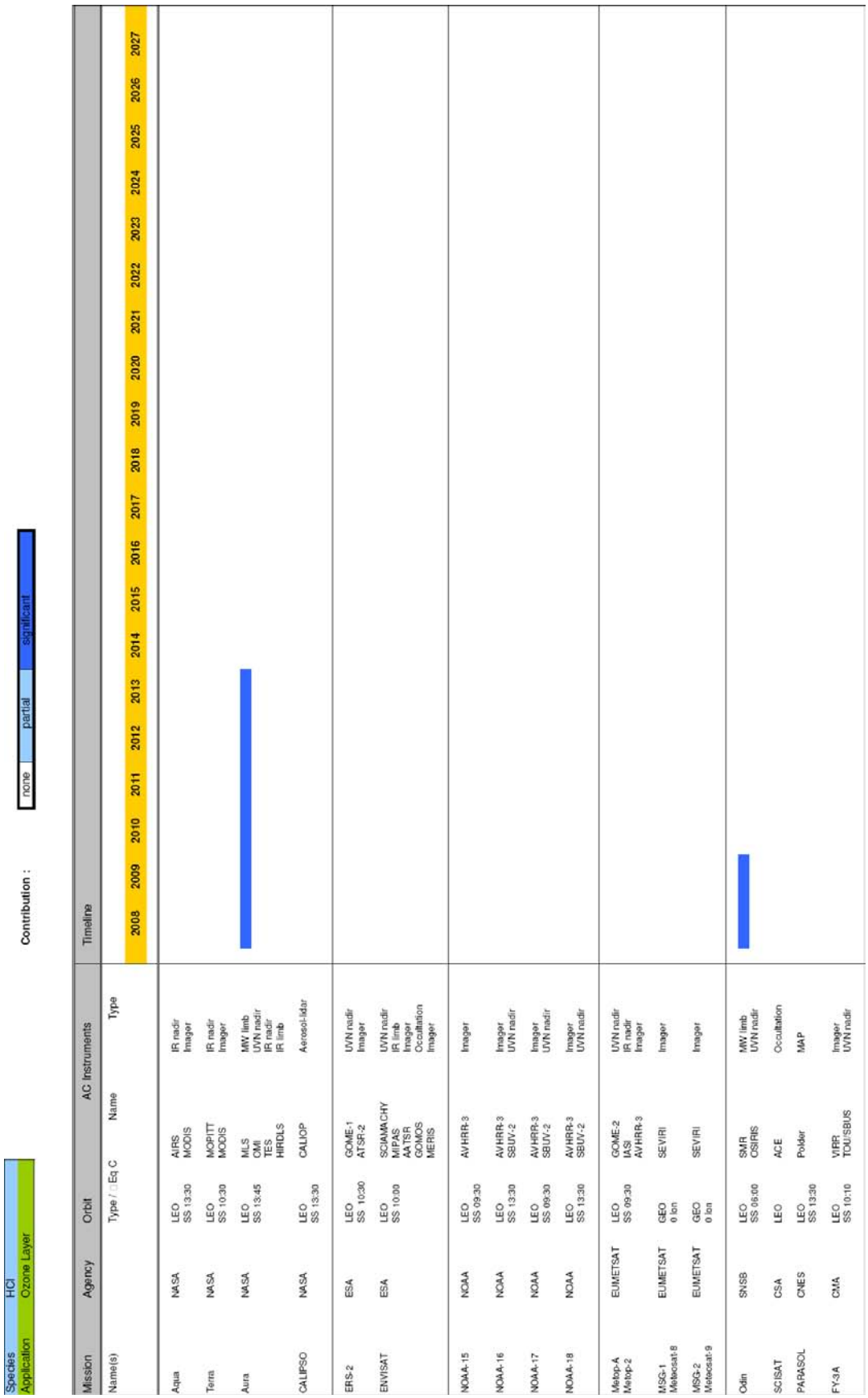


**Table 4-19: HCl Measurements from Current Missions for Ozone Layer Requirements**

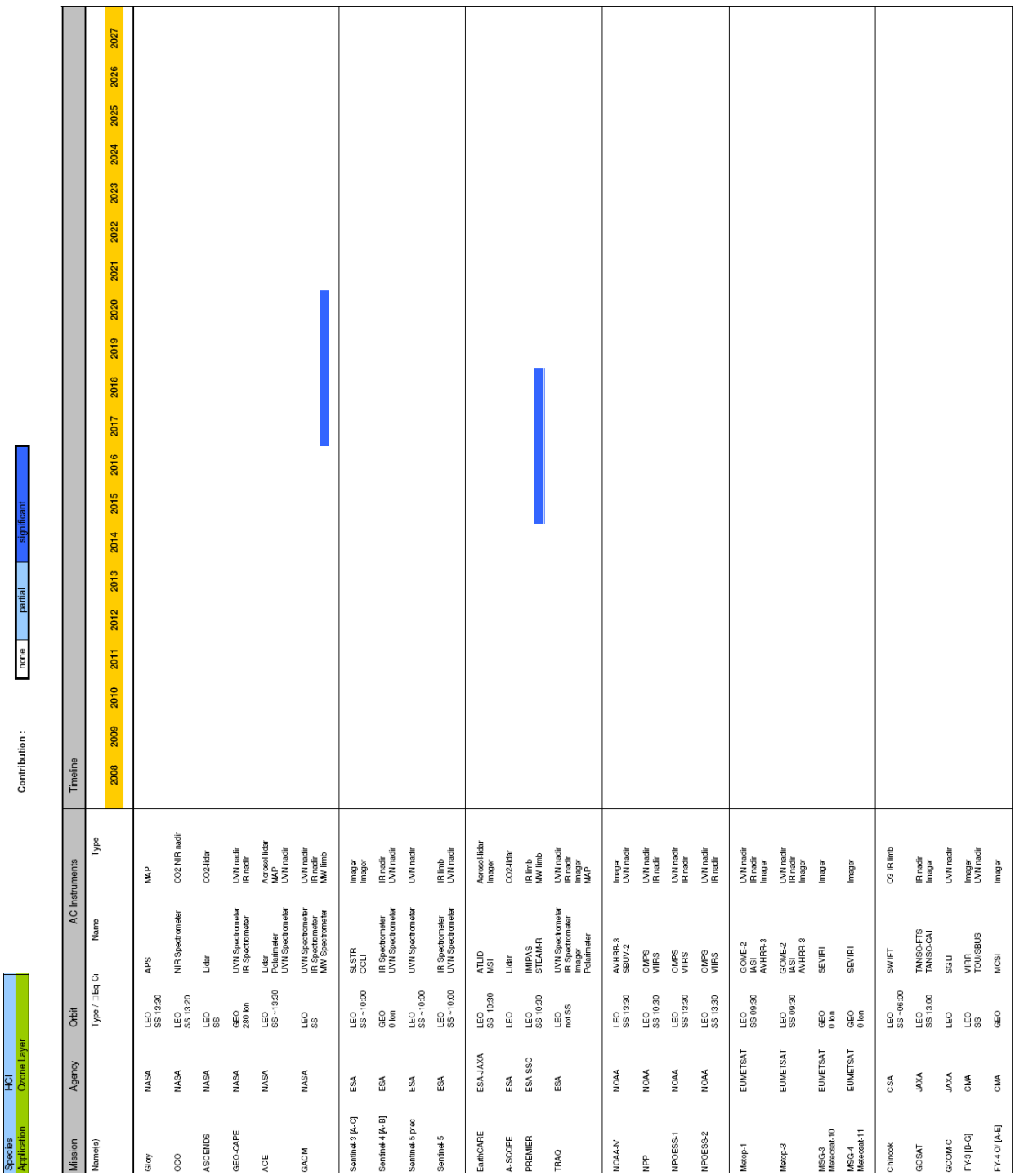


**Table 4-20: HCl Measurements from Planned Missions for Ozone Layer Requirements**

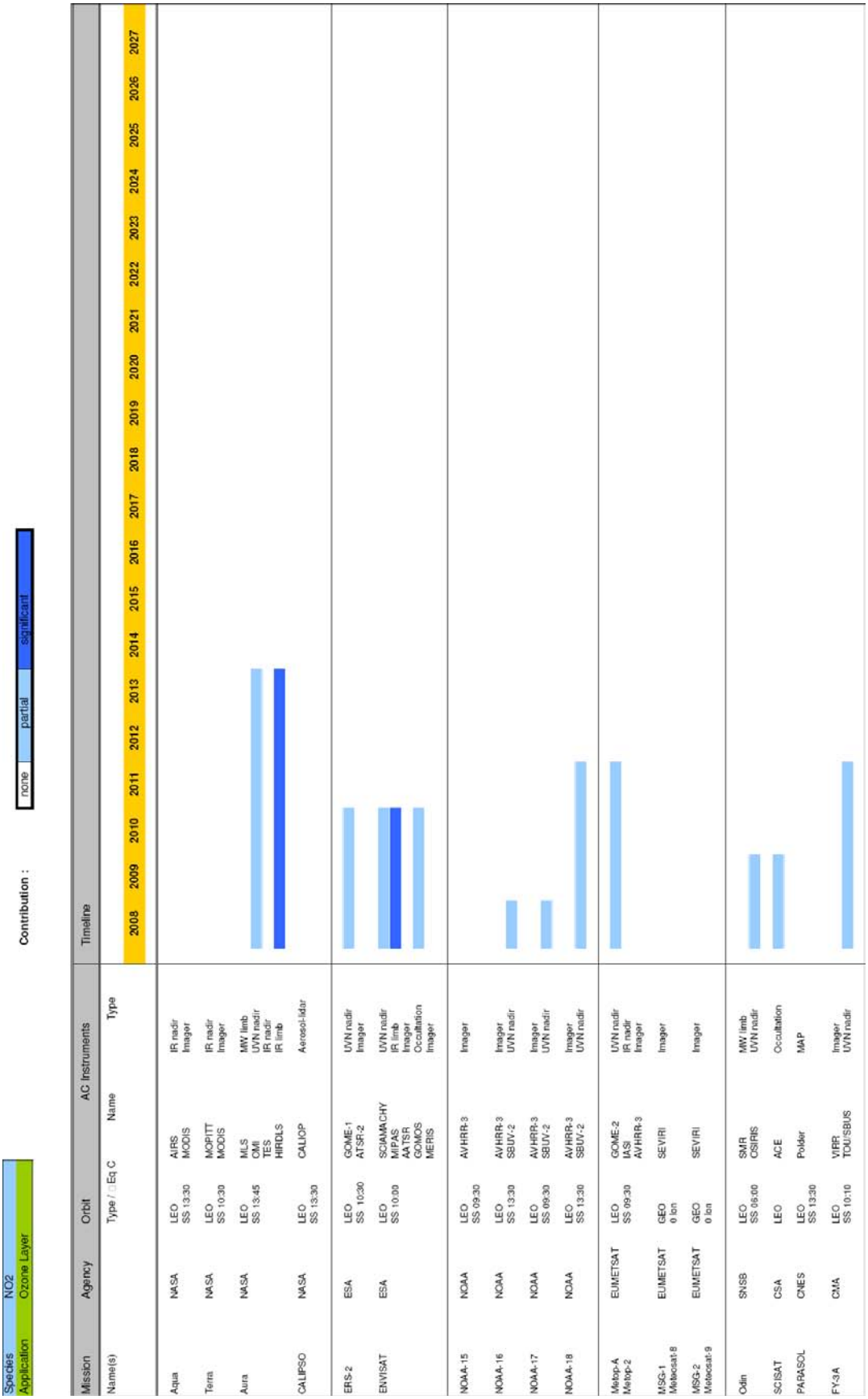


**Table 4-21: $NO_2$ Measurements from Current Missions for Ozone Layer Requirements**

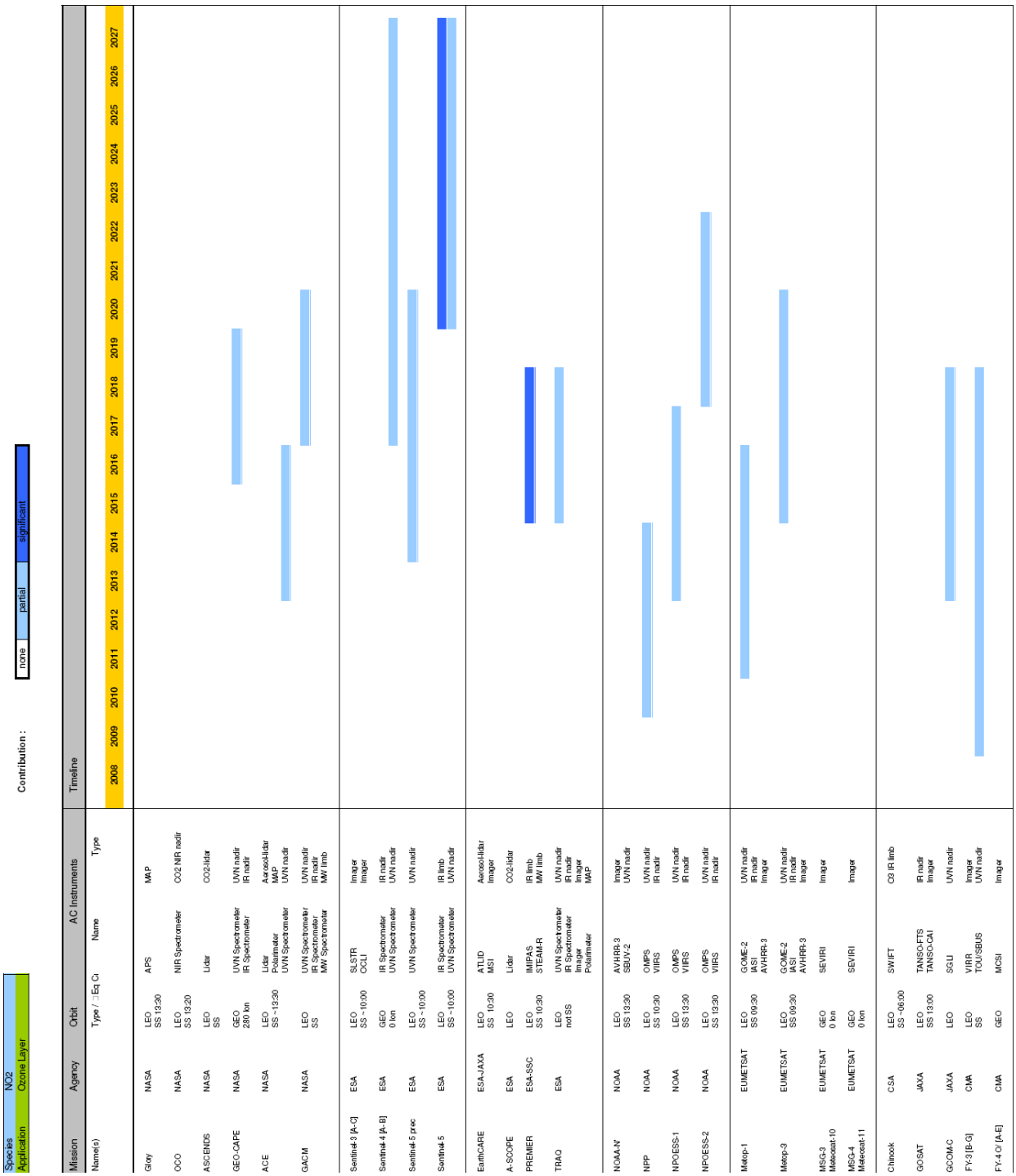


**Table 4-22: $NO_2$ Measurements from Planned Missions for Ozone Layer Requirements**

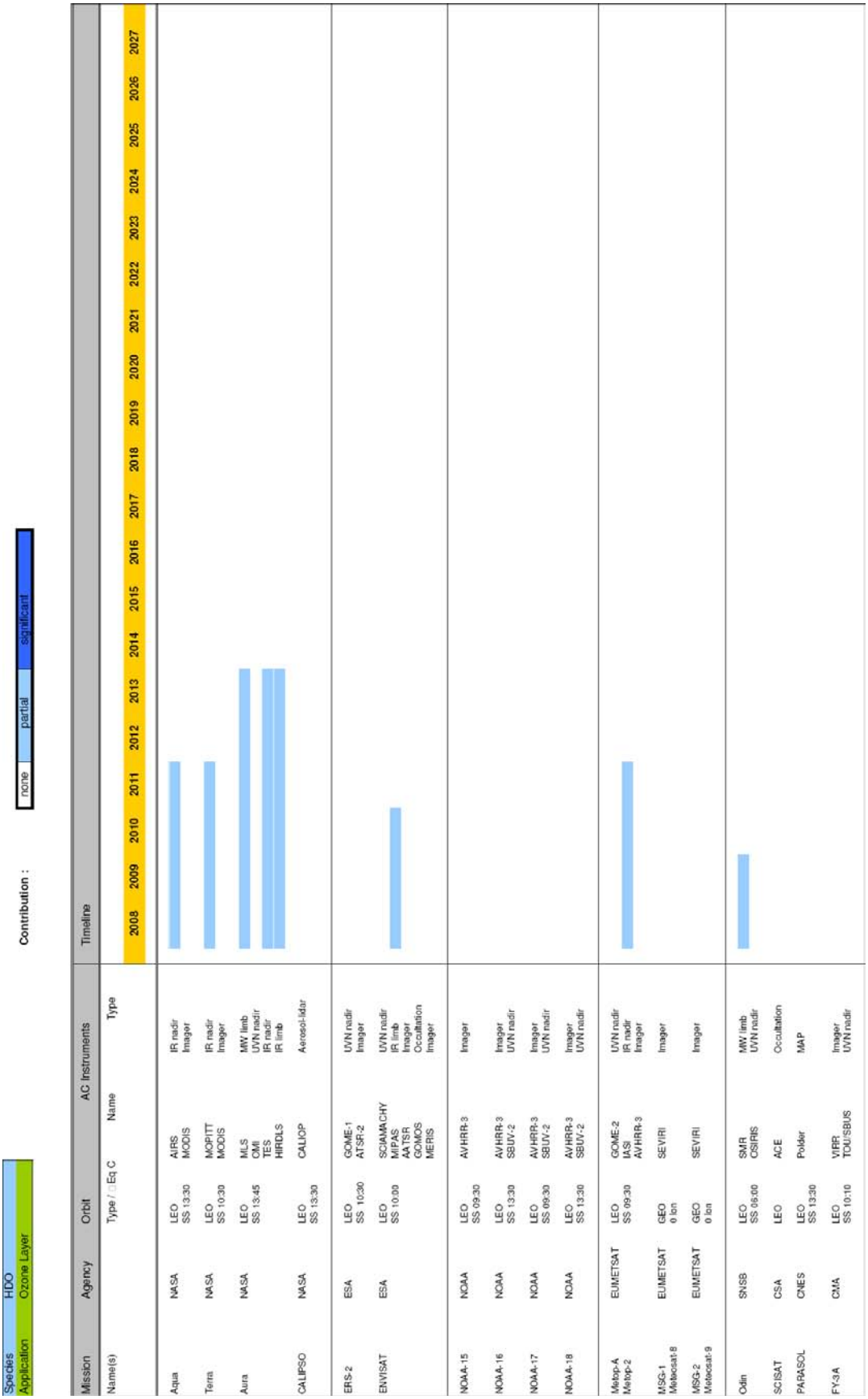


**Table 4-23: HDO Measurements from Current Missions for Ozone Layer Requirements**

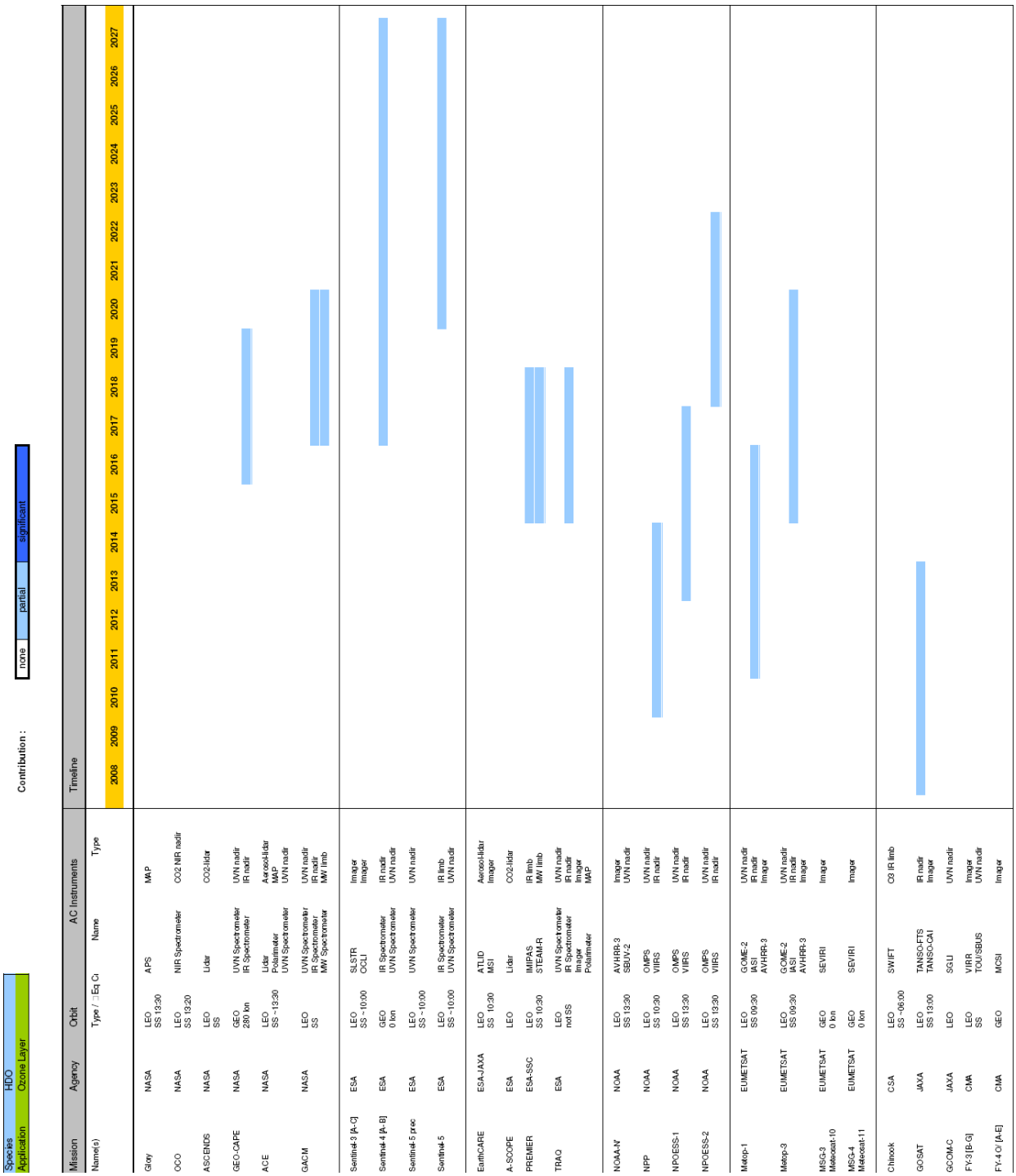


**Table 4-24: HDO Measurements from Planned Missions for Ozone Layer Requirements**

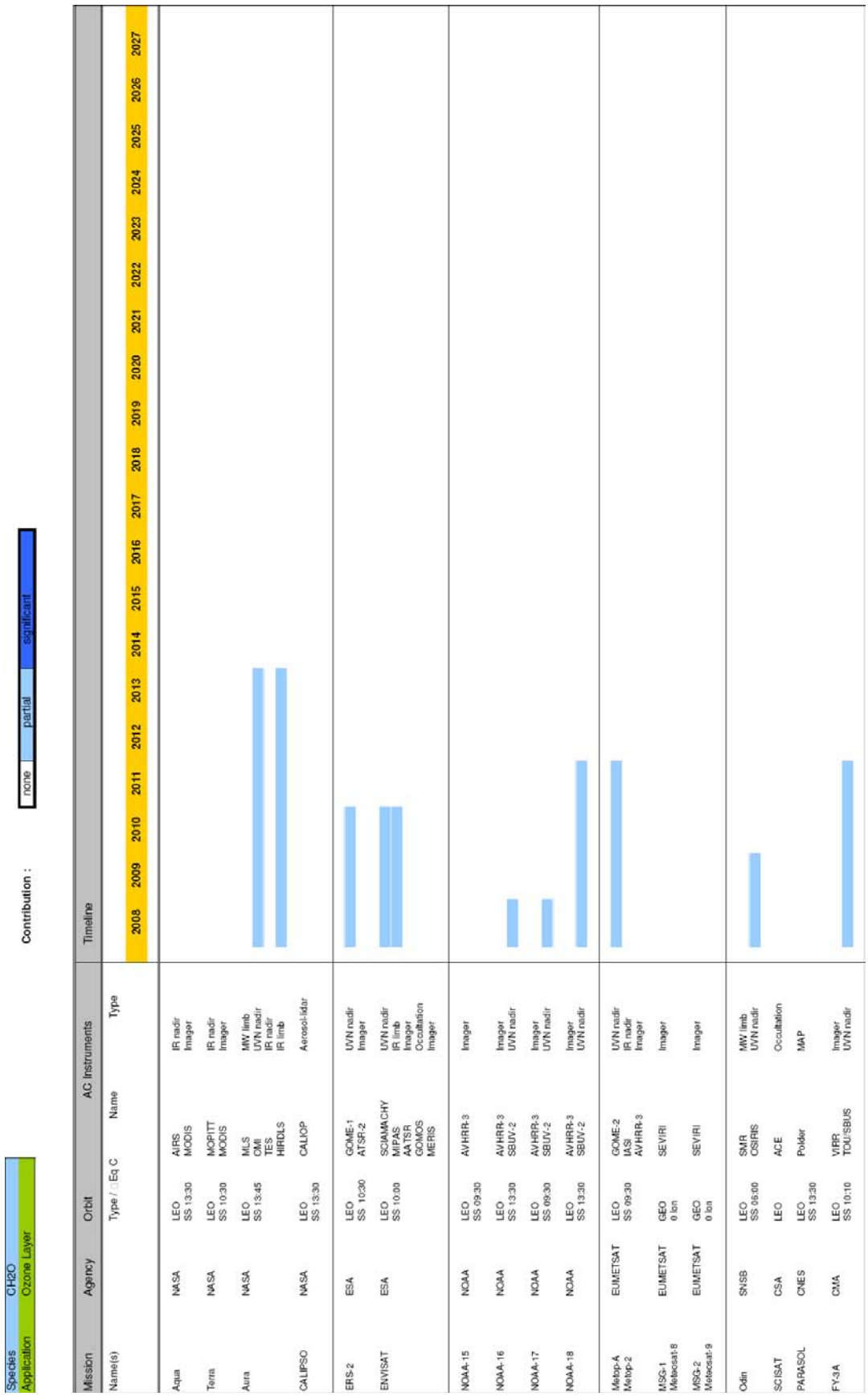


**Table 4-25: $CH_2O$ Measurements from Current Missions for Ozone Layer Requirements**

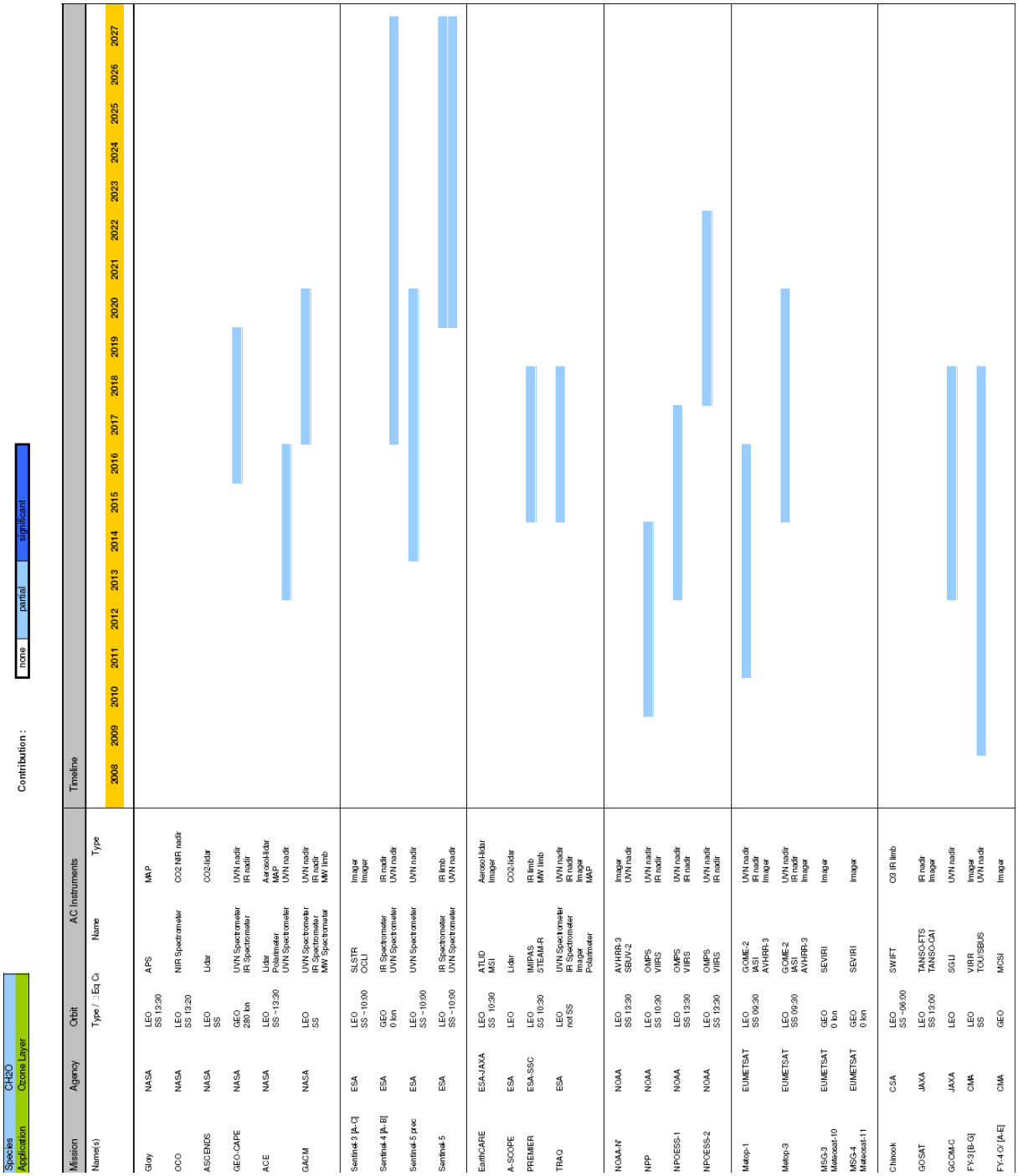


**Table 4-26: $CH_2O$ Measurements from Planned Missions for Ozone Layer Requirements**

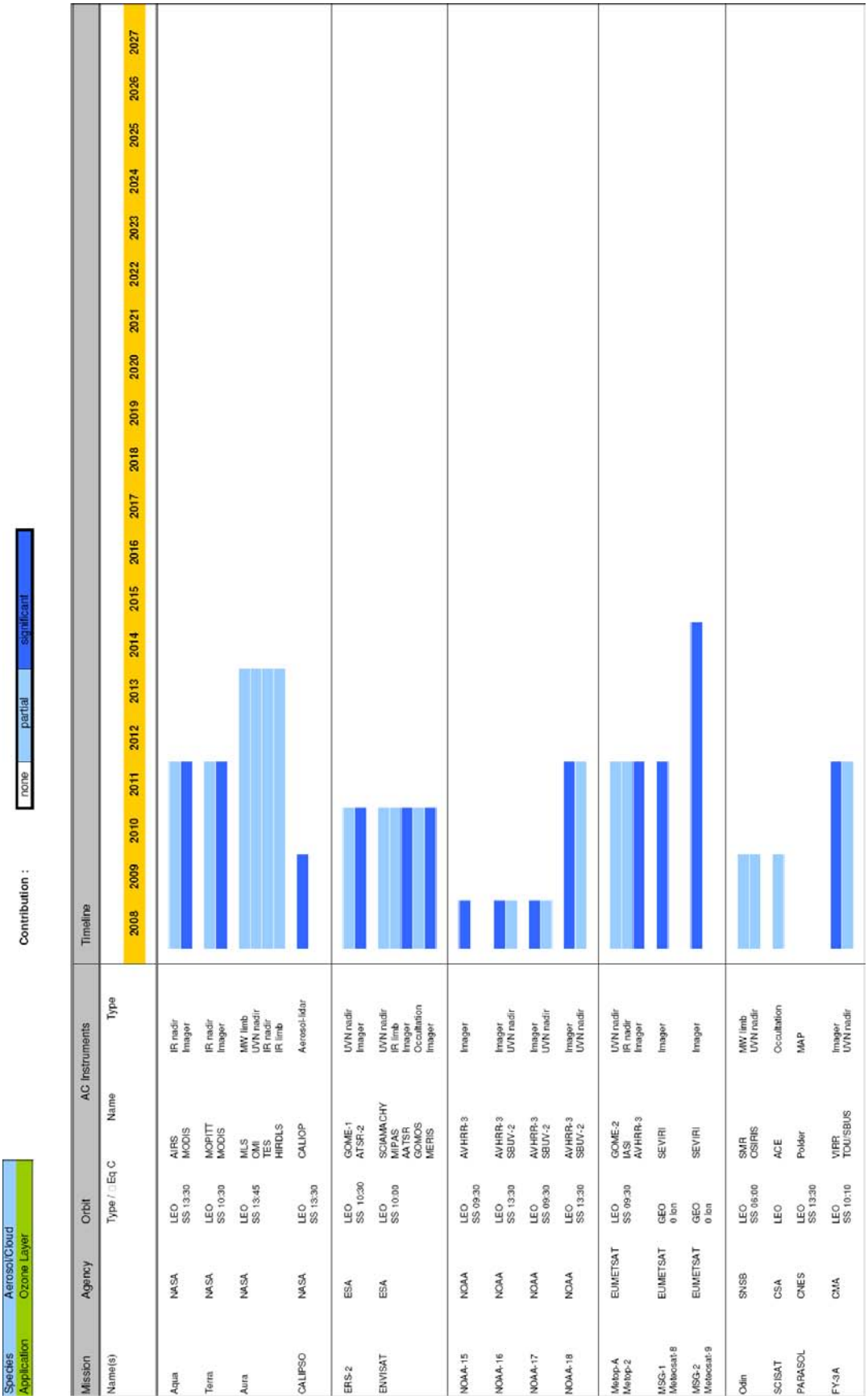


**Table 4-27: Aerosol & Cloud Measurements from Current Missions for Ozone Layer Requirements**

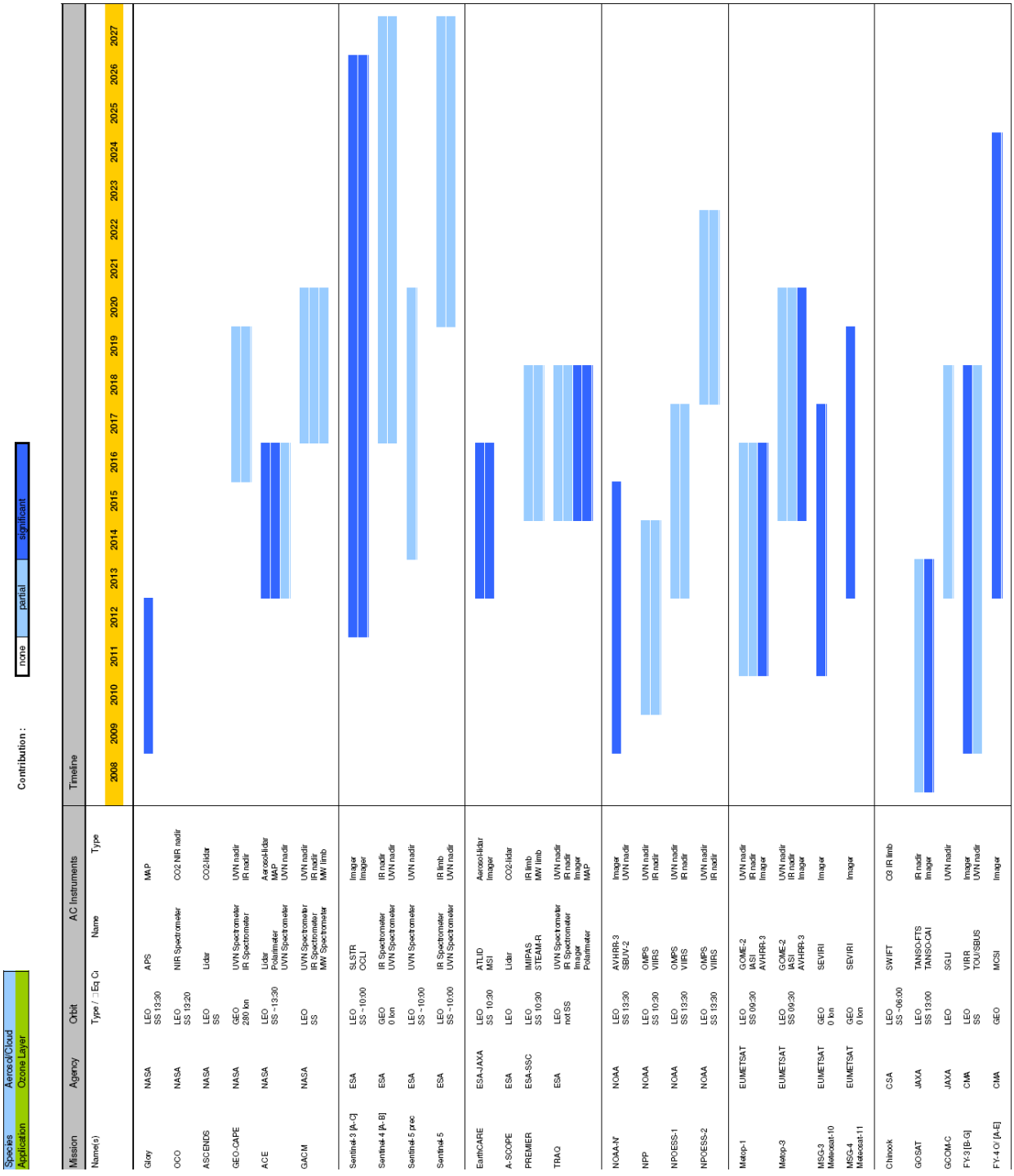


**Table 4-28: Aerosol & Cloud Measurements from Planned Missions for Ozone Layer Requirements**

### 4.5.2 Composition-Climate Interaction

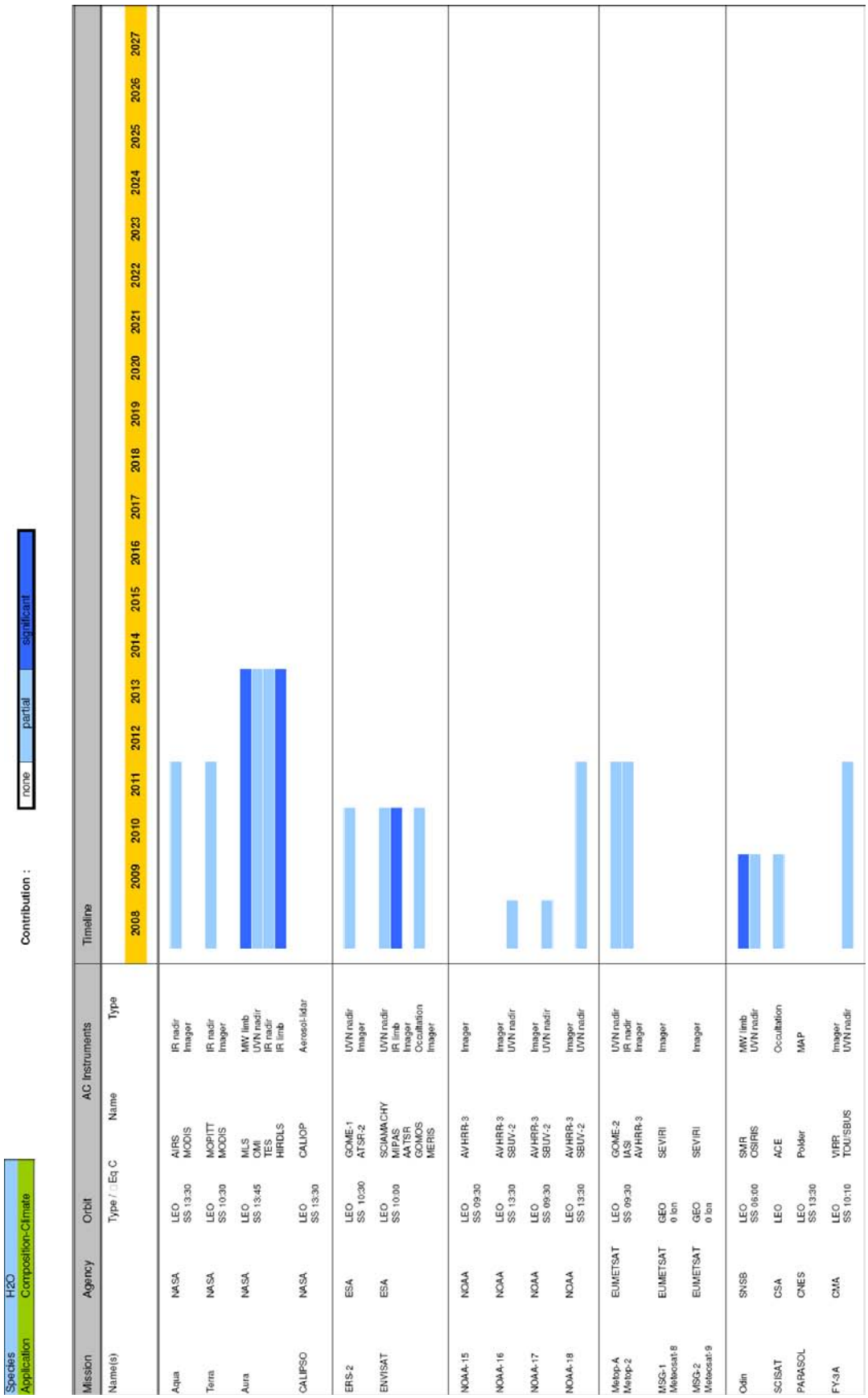


**Table 4-29: $H_2O$ Measurements from Current Missions for Composition-Climate Requirements**

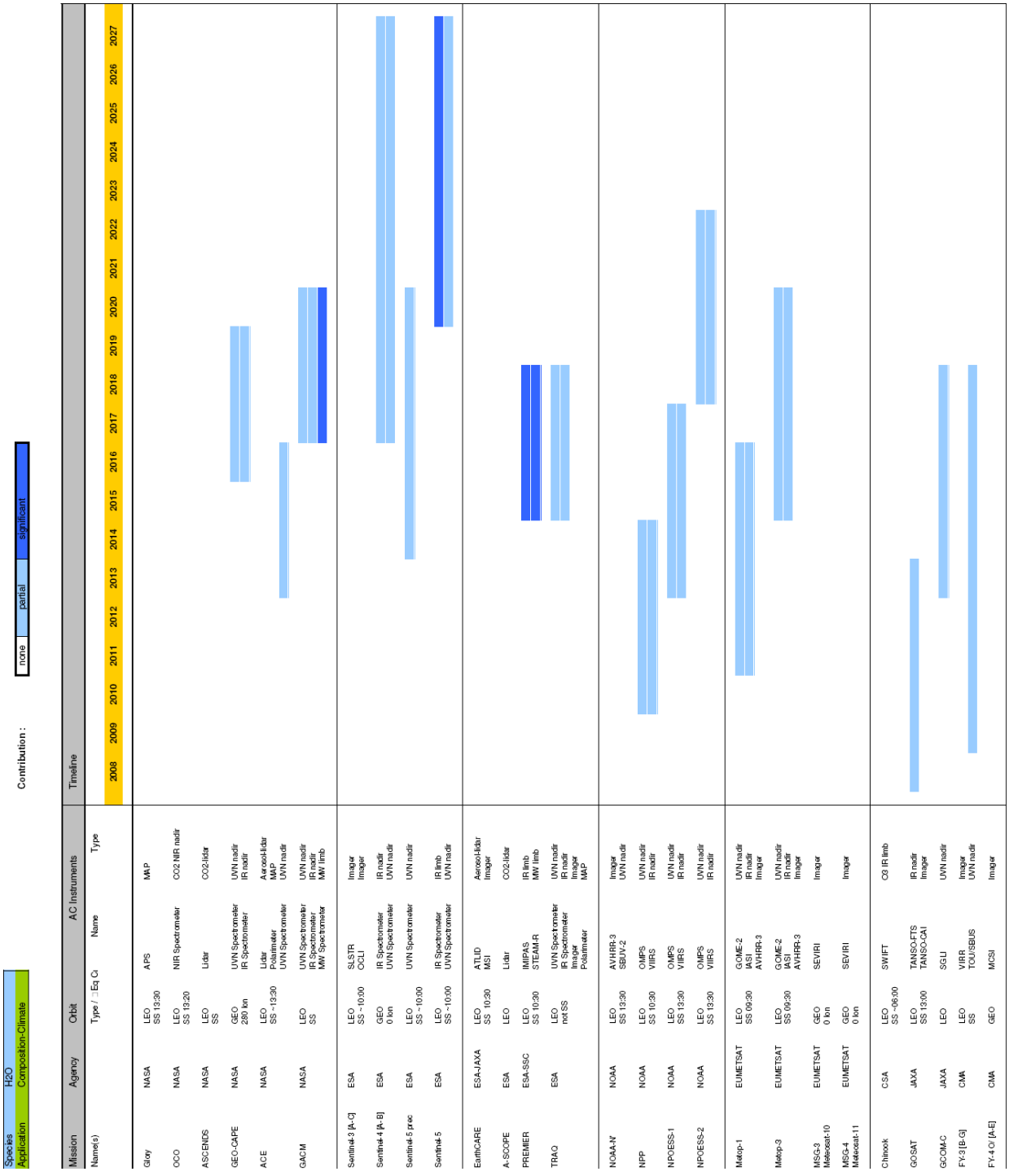


**Table 4-30: $H_2O$ Measurements from Planned Missions for Composition-Climate Requirements**

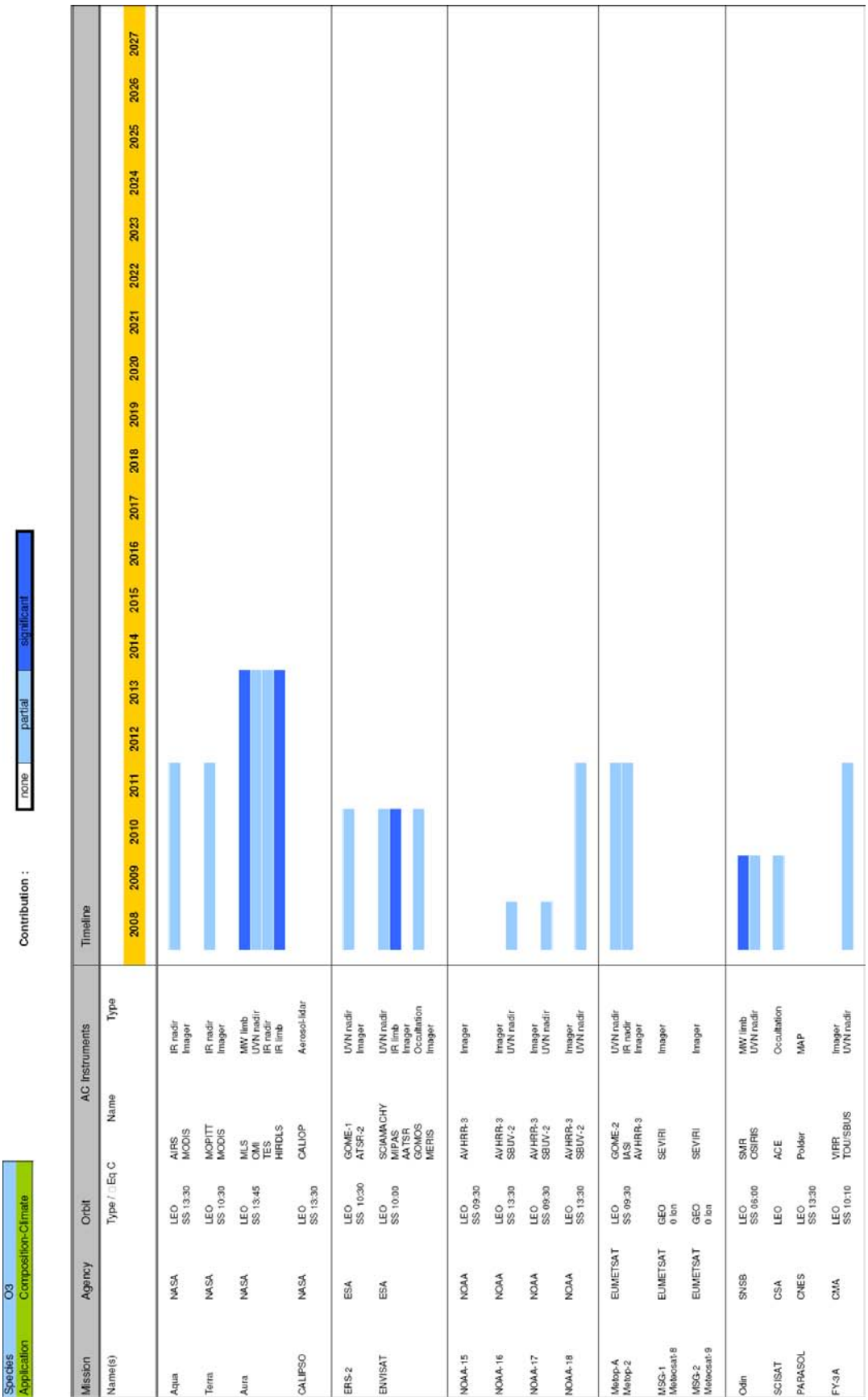


**Table 4-31: $O_3$ Measurements from Current Missions for Composition-Climate Requirements**

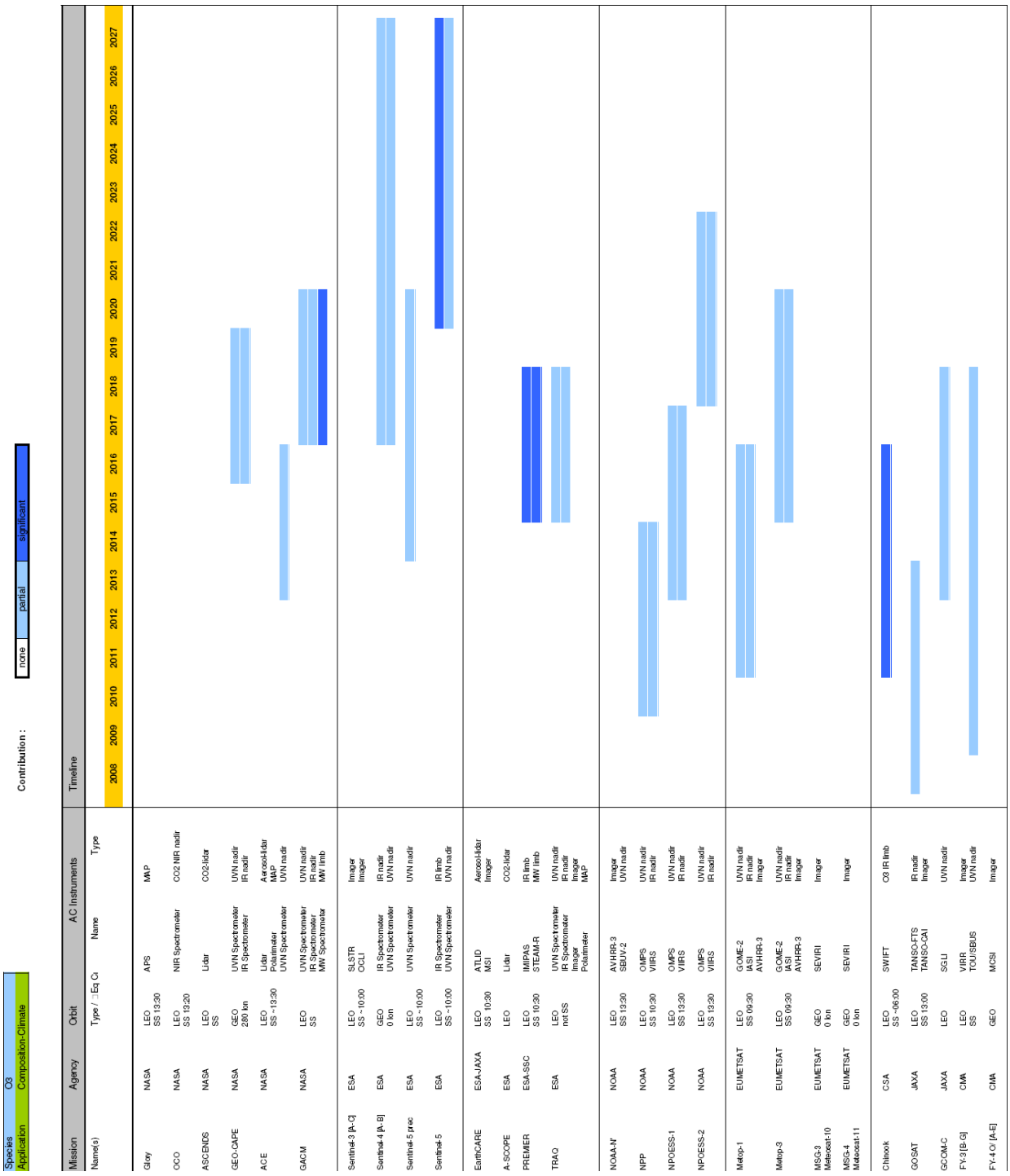


**Table 4-32: $O_3$ Measurements from Planned Missions for Composition-Climate Requirements**

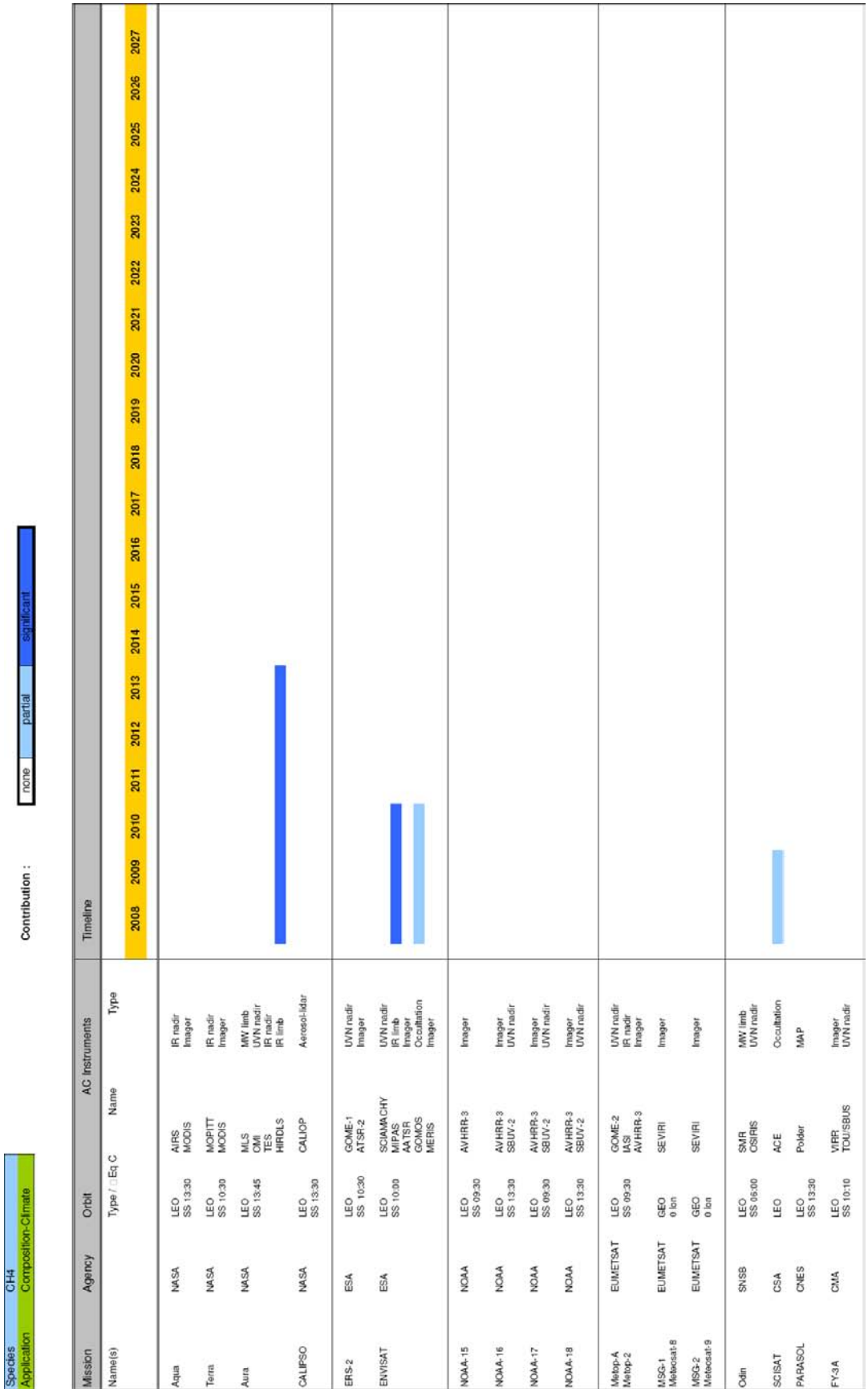


**Table 4-33: $CH_4$ Measurements from Current Missions for Composition-Climate Requirements**

Species: CH4
Application: Composition-Climate

Contribution : none | partial | significant

| Mission | Agency | Orbit | AC Instruments | | Timeline |
|---|---|---|---|---|---|
| Name(s) | | Type / ☐Eq Cr | Name | Type | 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 |
| Glory | NASA | LEO SS 13:30 | APS | MAP | |
| OCO | NASA | LEO SS 13:20 | NIR Spectrometer | CO2 NIR nadir | |
| ASCENDS | NASA | LEO SS | Lidar | CO2-lidar | |
| GEO-CAPE | NASA | GEO 280 lon | UVN Spectrometer<br>IR Spectrometer | UVN nadir<br>IR nadir | |
| ACE | NASA | LEO SS ~13:30 | Lidar<br>Polarimeter<br>UVN Spectrometer | Aerosol-lidar<br>MAP<br>UVN nadir | |
| GACM | NASA | LEO SS | UVN Spectrometer<br>IR Spectrometer<br>MW Spectrometer | UVN nadir<br>IR nadir<br>MW limb | |
| Sentinel-3 [A-C] | ESA | LEO SS ~10:00 | SLSTR<br>OCLI | Imager<br>Imager | |
| Sentinel-4 [A-B] | ESA | GEO 0 lon | IR Spectrometer<br>UVN Spectrometer | IR nadir<br>UVN nadir | |
| Sentinel-5 prec | ESA | LEO SS ~10:00 | UVN Spectrometer | UVN nadir | |
| Sentinel-5 | ESA | LEO SS ~10:00 | IR Spectrometer<br>UVN Spectrometer | IR limb<br>UVN nadir | |
| EarthCARE | ESA-JAXA | LEO SS 10:30 | ATLID<br>MSI | Aerosol-lidar<br>Imager | |
| A-SCOPE | ESA | LEO | Lidar | CO2-lidar | |
| PREMIER | ESA-SSC | LEO SS 10:30 | IMIPAS<br>STEAM-R | IR limb<br>MW limb | |
| TRAQ | ESA | LEO not SS | UVN Spectrometer<br>IR Spectrometer<br>Imager<br>Polarimeter | UVN nadir<br>IR nadir<br>Imager<br>MAP | |
| NOAA-N' | NOAA | LEO SS 13:30 | AVHRR-3<br>SBUV-2 | Imager<br>UVN nadir | |
| NPP | NOAA | LEO SS 10:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | |
| NPOESS-1 | NOAA | LEO SS 13:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | |
| NPOESS-2 | NOAA | LEO SS 13:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | |
| Metop-1 | EUMETSAT | LEO SS 09:30 | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | |
| Metop-3 | EUMETSAT | LEO SS 09:30 | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | |
| MSG-3<br>Meteosat-10 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | |
| MSG-4<br>Meteosat-11 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | |
| Chinook | CSA | LEO SS ~06:00 | SWIFT | O3 IR limb | |
| GOSAT | JAXA | LEO SS 13:00 | TANSO-FTS<br>TANSO-CAI | IR nadir<br>Imager | |
| GCOM-C | JAXA | LEO | SGLI | UVN nadir | |
| FY-3 [B-G] | CMA | LEO SS | VIRR<br>TOU/SBUS | Imager<br>UVN nadir | |
| FY-4 Cr [A-E] | CMA | GEO | MCSI | Imager | |

**Table 4-34: $CH_4$ Measurements from Planned Missions for Composition-Climate Requirements**

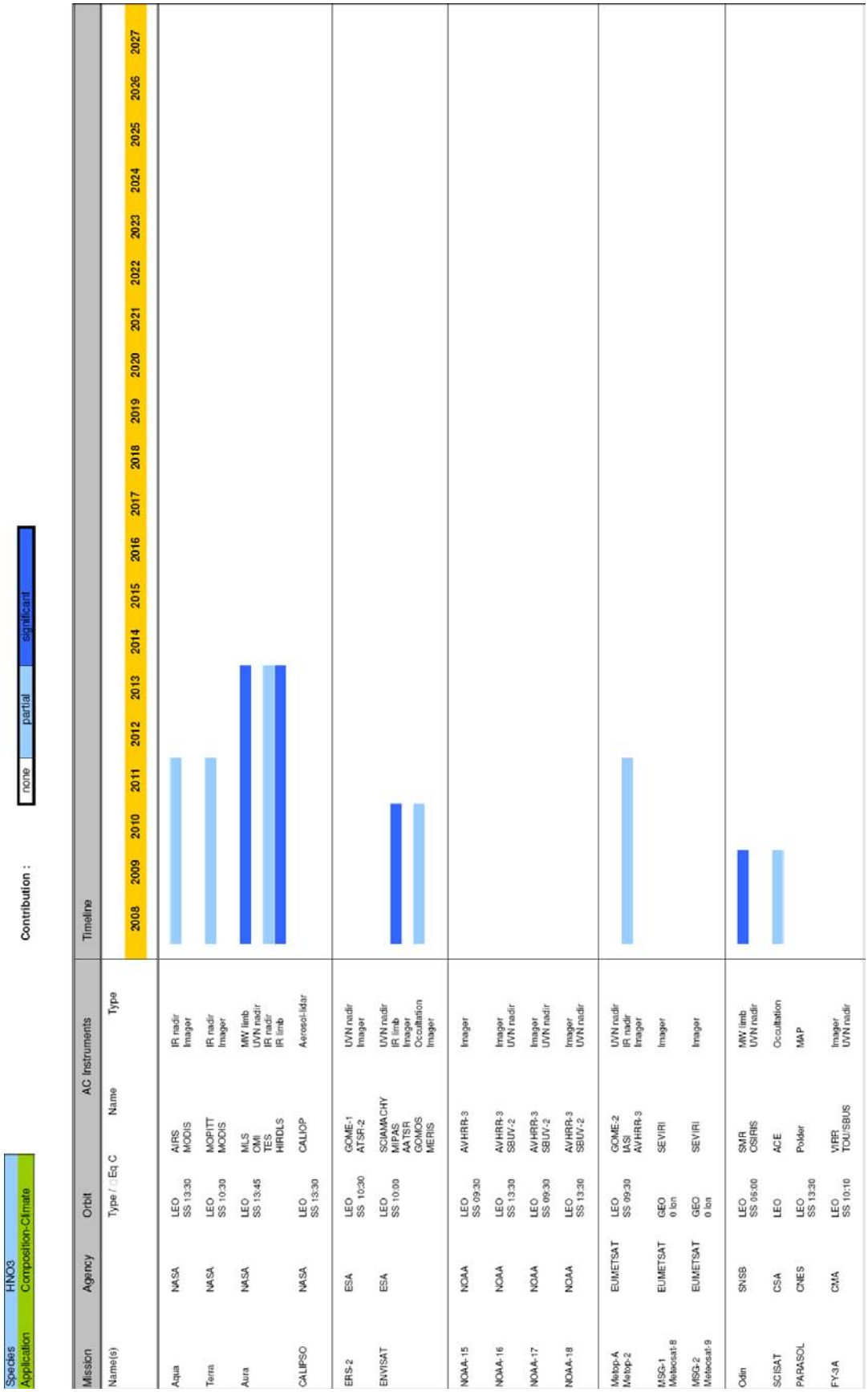


**Table 4-35:$HNO_3$ Measurements from Current Missions for Composition-Climate Requirements**

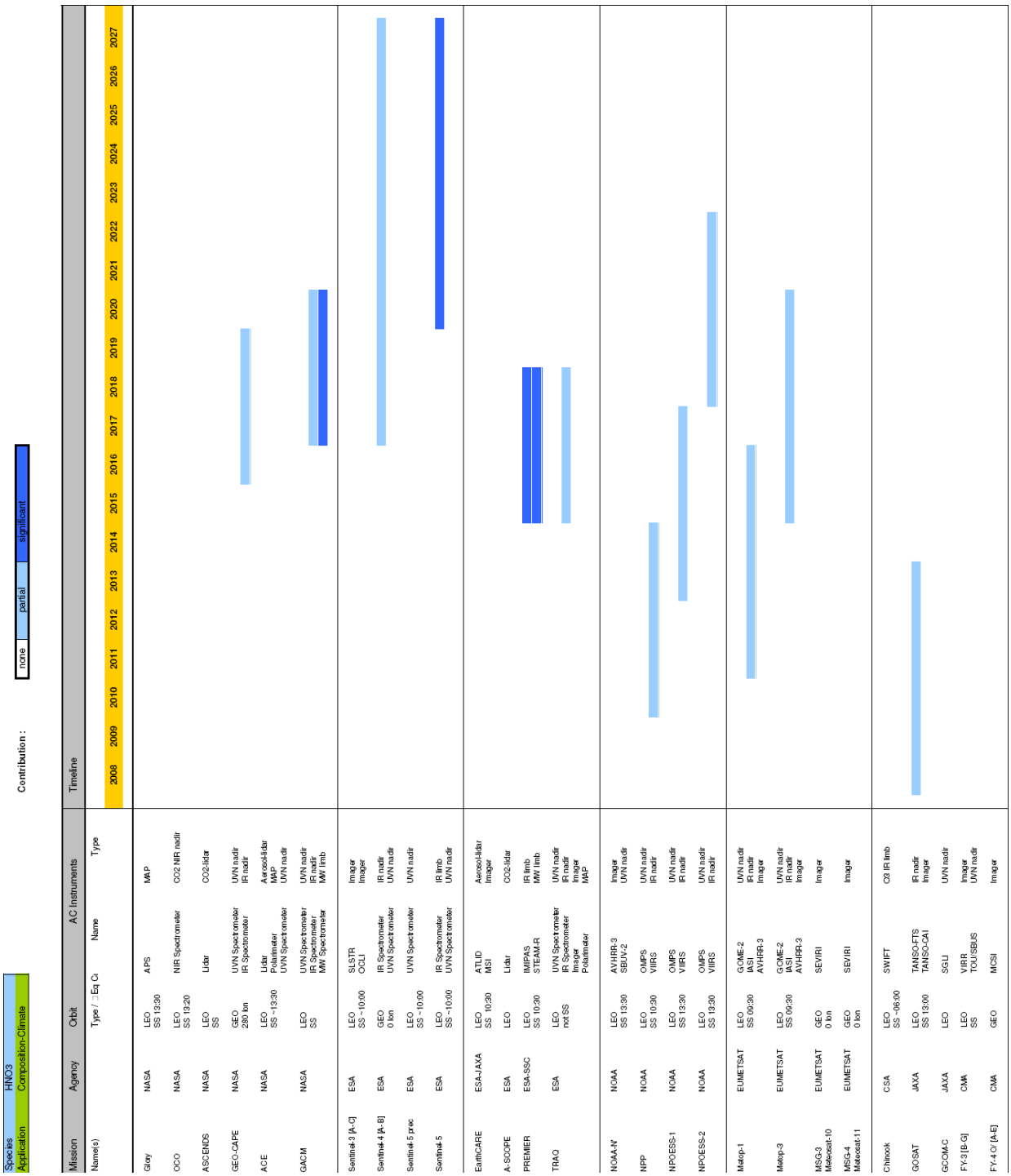


**Table 4-36: $HNO_3$ Measurements from Planned Missions for Composition-Climate Requirements**

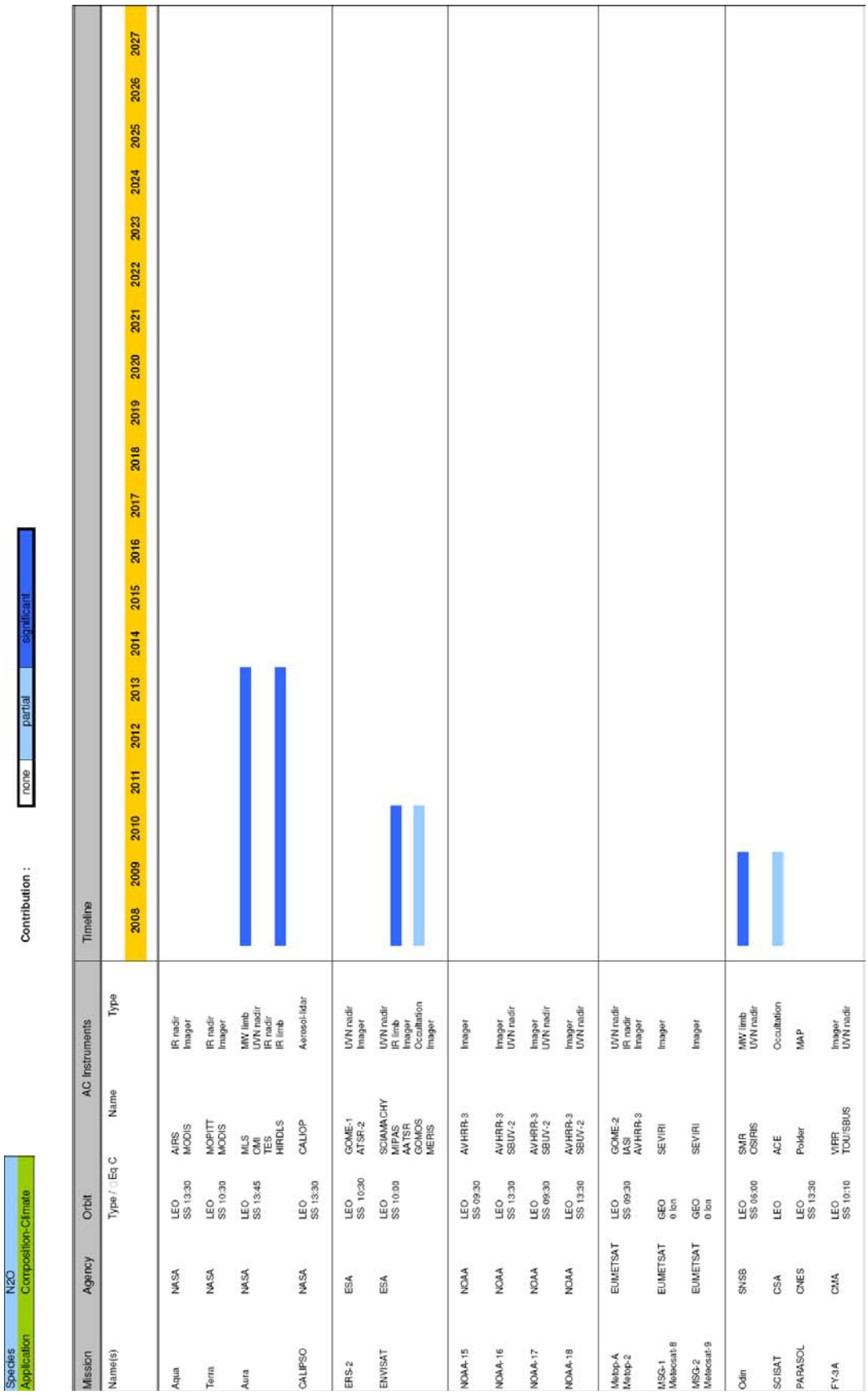


**Table 4-37:$N_2O$ Measurements from Current Missions for Composition-Climate Requirements**

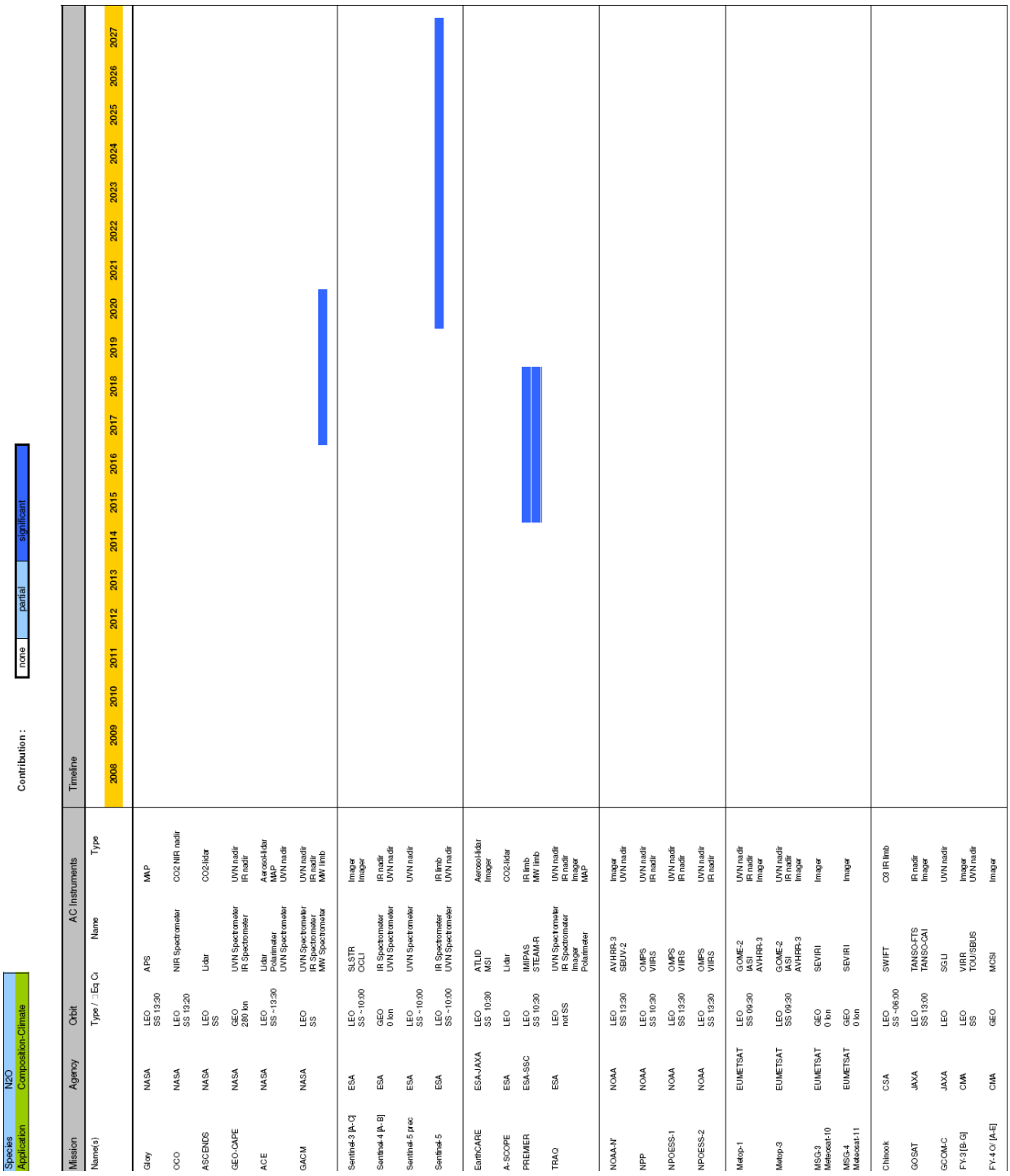


**Table 4-38: $N_2O$ Measurements from Planned Missions for Composition-Climate Requirements**

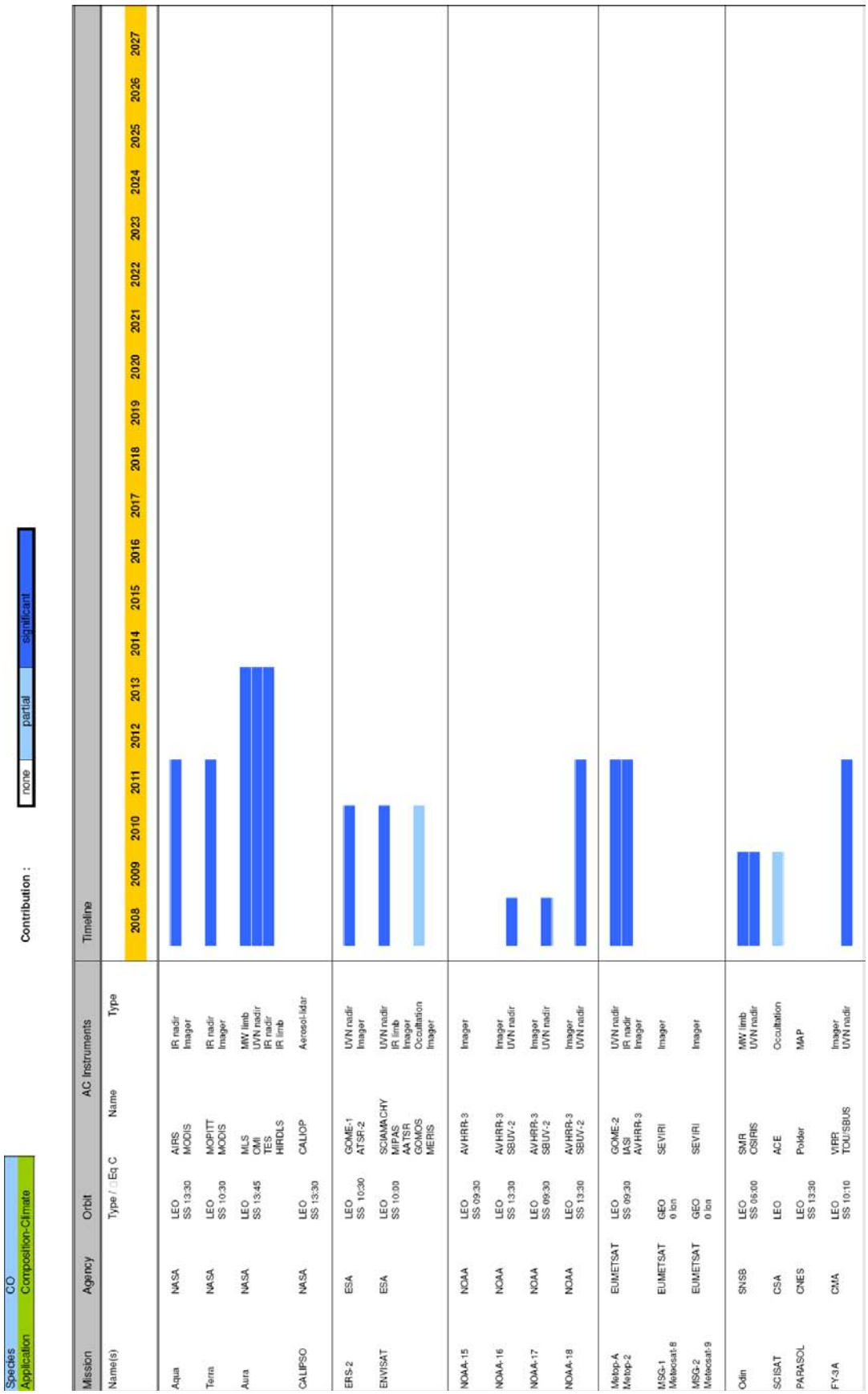


**Table 4-39: CO Measurements from Current Missions for Composition-Climate Requirements**

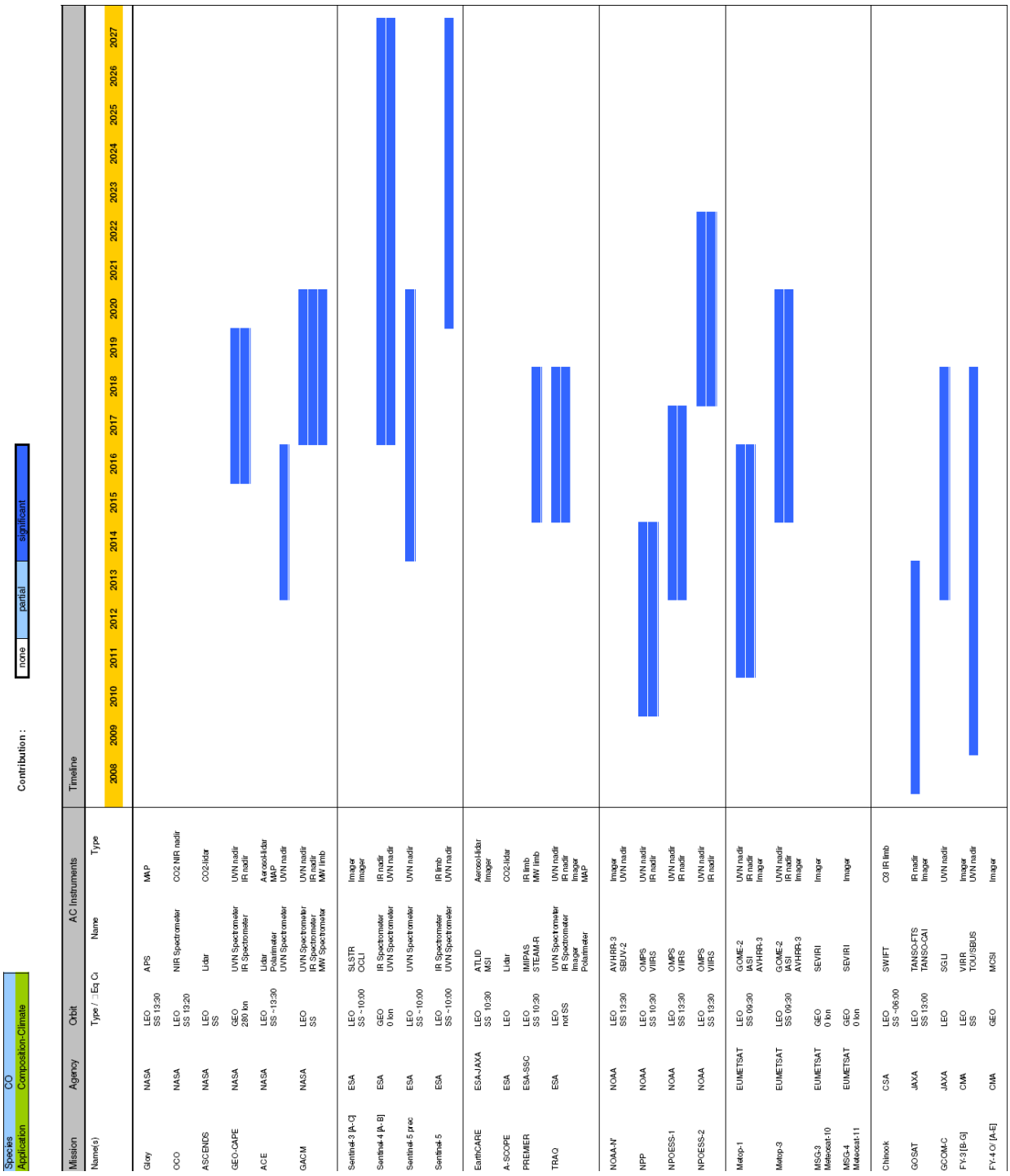


**Table 4-40: CO Measurements from Planned Missions for Composition-Climate Requirements**

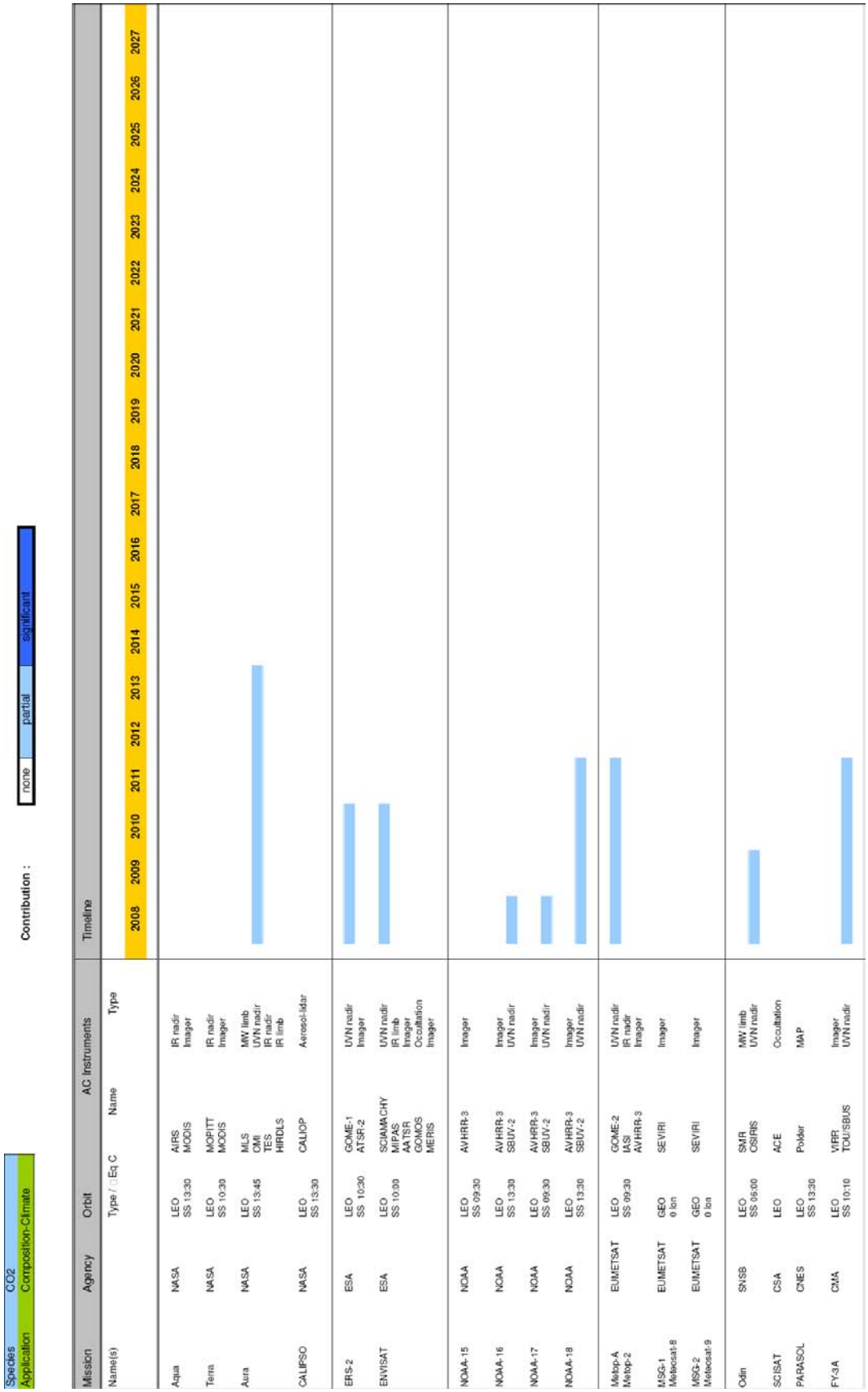


**Table 4-41: $CO_2$ Measurements from Current Missions for Composition-Climate Requirements**

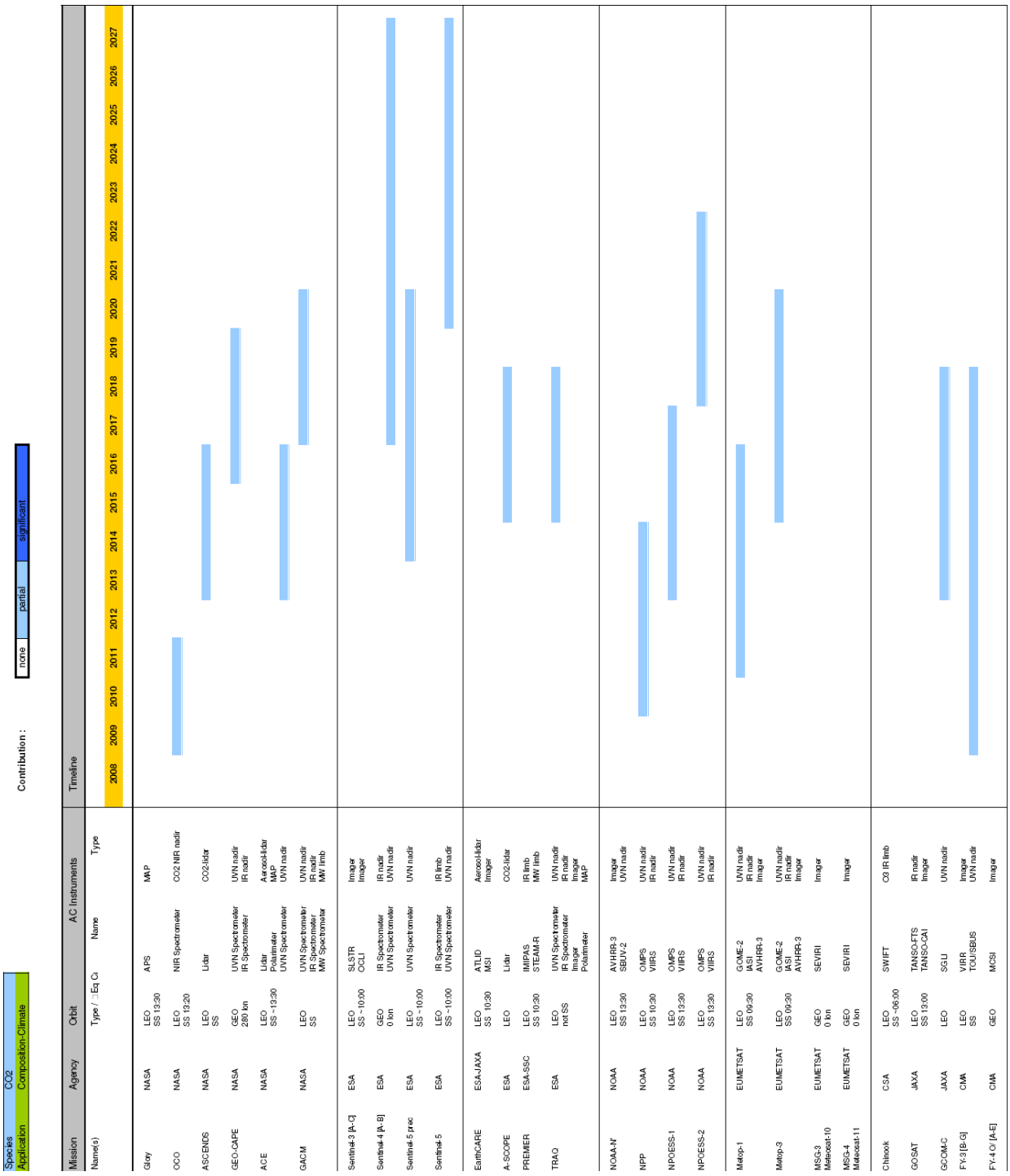


**Table 4-42: $CO_2$ Measurements from Planned Missions for Composition-Climate Requirements**

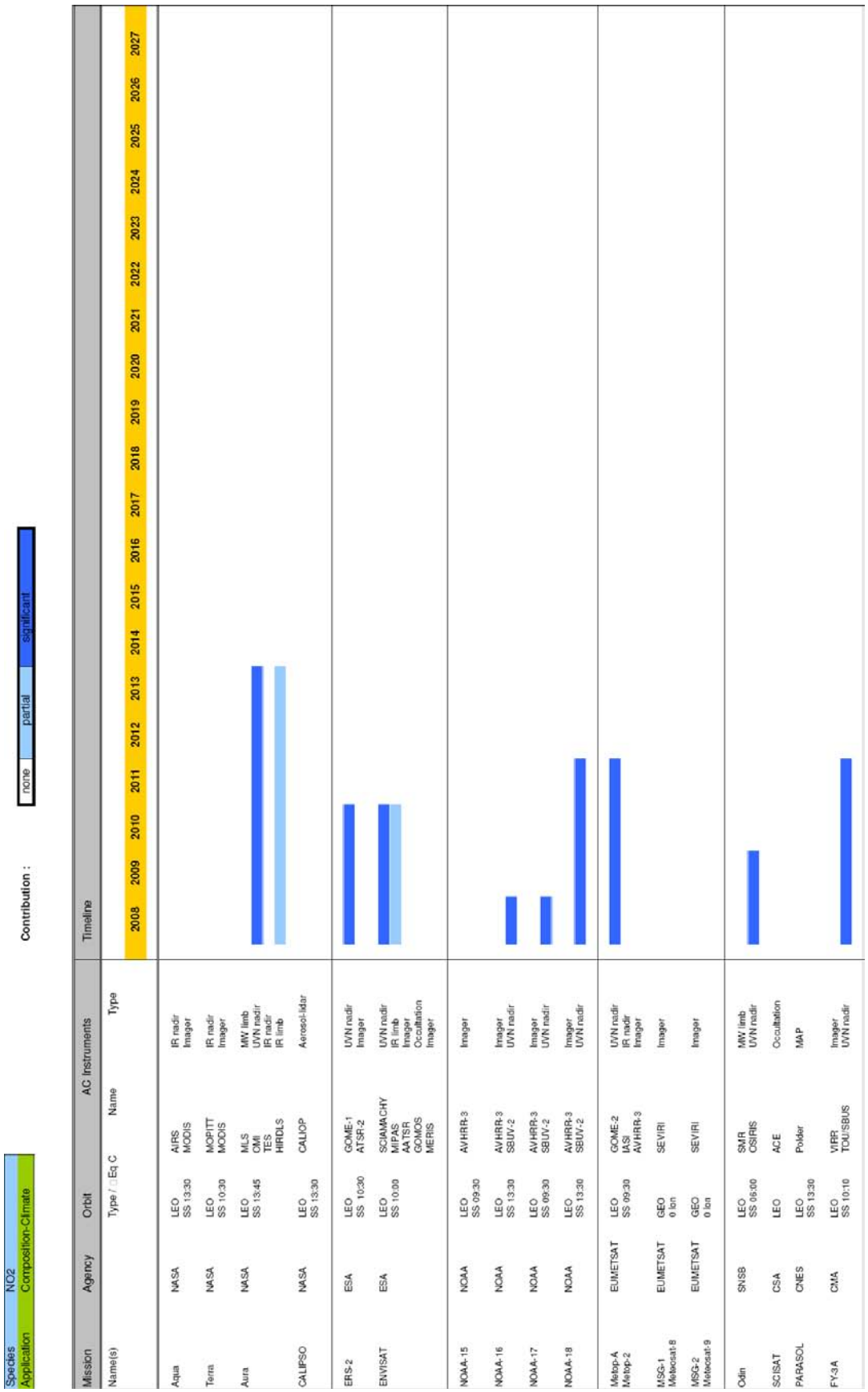


**Table 4-43: $NO_2$ Measurements from Current Missions for Composition-Climate Requirements**

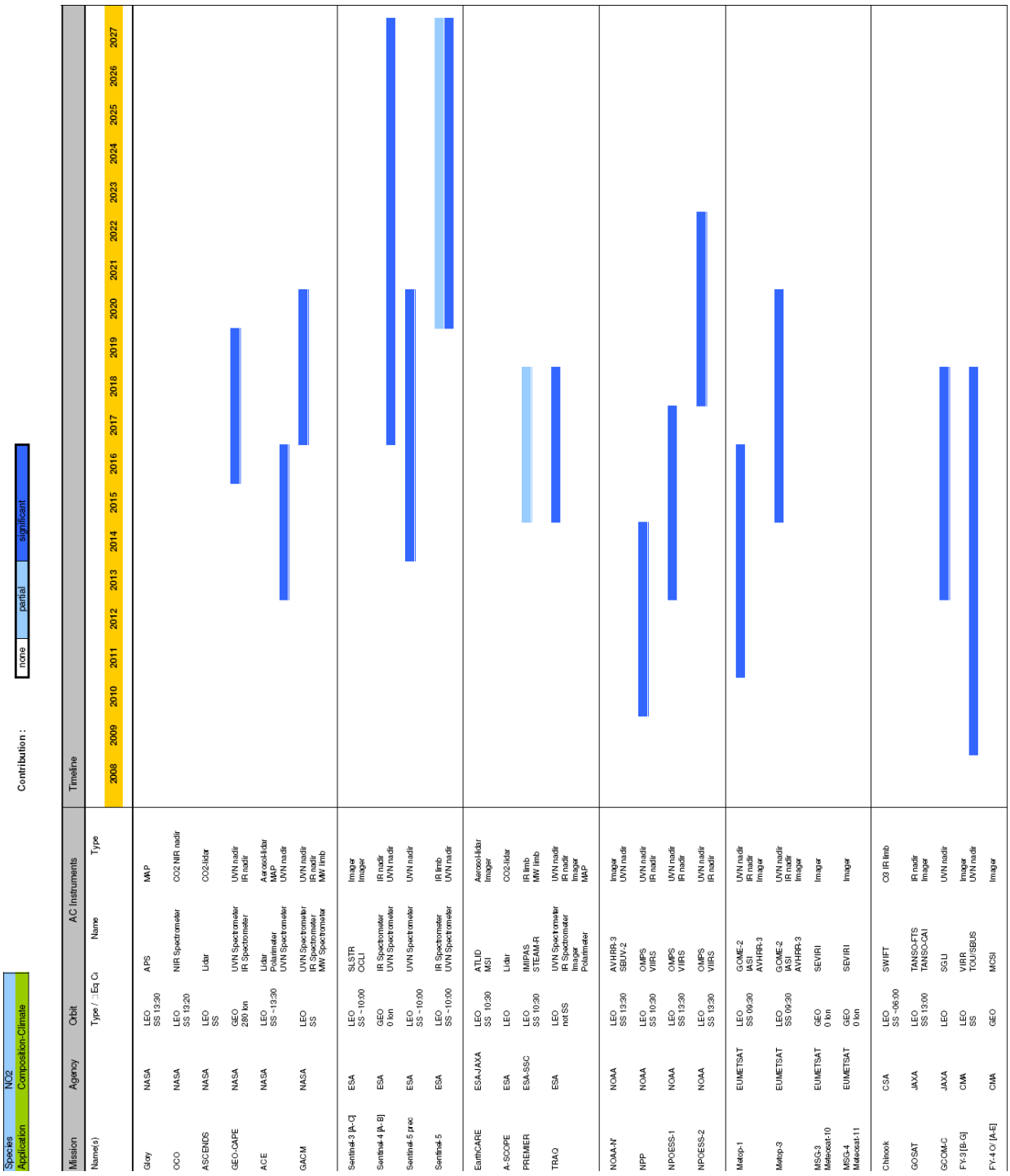


**Table 4-44: $NO_2$ Measurements from Planned Missions for Composition-Climate Requirements**

Species HDO
Application Composition-Climate

Contribution : none partial Significant

| Mission | Agency | Orbit | AC Instruments | | Timeline |
|---|---|---|---|---|---|
| Name(s) | | Type / Eq C | Name | Type | 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 |
| Aqua | NASA | LEO SS 13:30 | AIRS<br>MODIS | IR nadir<br>Imager | |
| Terra | NASA | LEO SS 10:30 | MOPITT<br>MODIS | IR nadir<br>Imager | |
| Aura | NASA | LEO SS 13:45 | MLS<br>OMI<br>TES<br>HIRDLS | MW limb<br>UVN nadir<br>IR nadir<br>IR limb | |
| CALIPSO | NASA | LEO SS 13:30 | CALIOP | Aerosol-lidar | |
| ERS-2 | ESA | LEO SS 10:30 | GOME-1<br>ATSR-2 | UVN nadir<br>Imager | |
| ENVISAT | ESA | LEO SS 10:00 | SCIAMACHY<br>MIPAS<br>AATSR<br>GOMOS<br>MERIS | UVN nadir<br>IR limb<br>Imager<br>Occultation<br>Imager | |
| NOAA-15 | NOAA | LEO SS 09:30 | AVHRR-3 | Imager | |
| NOAA-16 | NOAA | LEO SS 13:30 | AVHRR-3<br>SBUV-2 | Imager<br>UVN nadir | |
| NOAA-17 | NOAA | LEO SS 09:30 | AVHRR-3<br>SBUV-2 | Imager<br>UVN nadir | |
| NOAA-18 | NOAA | LEO SS 13:30 | AVHRR-3<br>SBUV-2 | Imager<br>UVN nadir | |
| Metop-A<br>Metop-2 | EUMETSAT | LEO SS 09:30 | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | |
| MSG-1<br>Meteosat-8 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | |
| MSG-2<br>Meteosat-9 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | |
| Odin | SNSB | LEO SS 06:00 | SMR<br>OSIRIS | MW limb<br>UVN nadir | |
| SCISAT | CSA | LEO | ACE | Occultation | |
| PARASOL | CNES | LEO SS 13:30 | Polder | MAP | |
| FY-3A | CMA | LEO SS 10:10 | VIRR<br>TOU/SBUS | Imager<br>UVN nadir | |

**Table 4-45: HDO Measurements from Current Missions for Composition-Climate Requirements**

Species: HDO
Application: Composition-Climate

Contribution : none | partial | significant

| Mission | Agency | Orbit | AC Instruments | | Timeline |
|---|---|---|---|---|---|
| Name(s) | | Type / ☐Eq Cr | Name | Type | 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 |
| Glory | NASA | LEO SS 13:30 | APS | MAP | |
| OCO | NASA | LEO SS 13:20 | NIR Spectrometer | CO2 NIR nadir | |
| ASCENDS | NASA | LEO SS | Lidar | CO2-lidar | |
| GEO-CAPE | NASA | GEO 280 lon | UVN Spectrometer<br>IR Spectrometer | UVN nadir<br>IR nadir | |
| ACE | NASA | LEO SS ~13:30 | Lidar<br>Polarimeter<br>UVN Spectrometer | Aerosol-lidar<br>MAP<br>UVN nadir | |
| GACM | NASA | LEO SS | UVN Spectrometer<br>IR Spectrometer<br>MW Spectrometer | UVN nadir<br>IR nadir<br>MW limb | |
| Sentinel-3 [A-C] | ESA | LEO SS ~10:00 | SLSTR<br>OCLI | Imager<br>Imager | |
| Sentinel-4 [A-B] | ESA | GEO 0 lon | IR Spectrometer<br>UVN Spectrometer | IR nadir<br>UVN nadir | |
| Sentinel-5 prec | ESA | LEO SS ~10:00 | UVN Spectrometer | UVN nadir | |
| Sentinel-5 | ESA | LEO SS ~10:00 | IR Spectrometer<br>UVN Spectrometer | IR limb<br>UVN nadir | |
| EarthCARE | ESA-JAXA | LEO SS 10:30 | ATLID<br>MSI | Aerosol-lidar<br>Imager | |
| A-SCOPE | ESA | LEO | Lidar | CO2-lidar | |
| PREMIER | ESA-SSC | LEO SS 10:30 | IMIPAS<br>STEAM-R | IR limb<br>MW limb | |
| TRAQ | ESA | LEO not SS | UVN Spectrometer<br>IR Spectrometer<br>Imager<br>Polarimeter | UVN nadir<br>IR nadir<br>Imager<br>MAP | |
| NOAA-N' | NOAA | LEO SS 13:30 | AVHRR-3<br>SBUV-2 | Imager<br>UVN nadir | |
| NPP | NOAA | LEO SS 10:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | |
| NPOESS-1 | NOAA | LEO SS 13:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | |
| NPOESS-2 | NOAA | LEO SS 13:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | |
| Metop-1 | EUMETSAT | LEO SS 09:30 | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | |
| Metop-3 | EUMETSAT | LEO SS 09:30 | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | |
| MSG-3<br>Meteosat-10 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | |
| MSG-4<br>Meteosat-11 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | |
| Chinook | CSA | LEO SS ~06:00 | SWIFT | O3 IR limb | |
| GOSAT | JAXA | LEO SS 13:00 | TANSO-FTS<br>TANSO-CAI | IR nadir<br>Imager | |
| GCOM-C | JAXA | LEO | SGLI | UVN nadir | |
| FY-3 [B-G] | CMA | LEO SS | VIRR<br>TOU/SBUS | Imager<br>UVN nadir | |
| FY-4 Cr [A-E] | CMA | GEO | MCSI | Imager | |

**Table 4-46: HDO Measurements from Planned Missions for Composition-Climate Requirements**

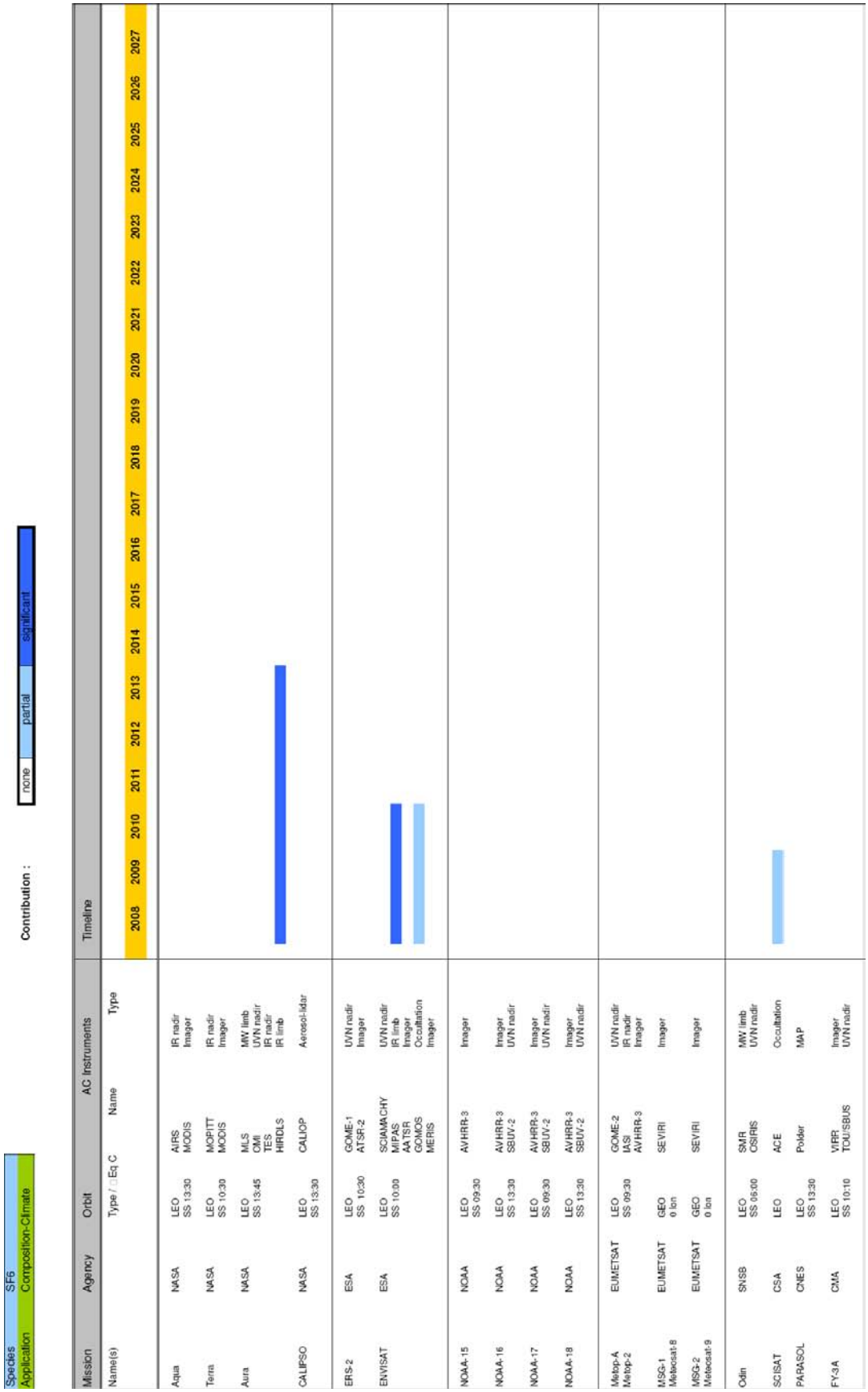


**Table 4-47: $SF_6$ Measurements from Current Missions for Composition-Climate Requirements**

Species: SF6
Application: Composition-Climate

Contribution : none | partial | significant

| Mission | Agency | Orbit | AC Instruments | | Timeline |
|---|---|---|---|---|---|
| Name(s) | | Type / ☐Eq Cr | Name | Type | 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 |
| Glory | NASA | LEO SS 13:30 | APS | MAP | |
| OCO | NASA | LEO SS 13:20 | NIR Spectrometer | CO2 NIR nadir | |
| ASCENDS | NASA | LEO SS | Lidar | CO2-lidar | |
| GEO-CAPE | NASA | GEO 280 lon | UVN Spectrometer<br>IR Spectrometer | UVN nadir<br>IR nadir | |
| ACE | NASA | LEO SS ~13:30 | Lidar<br>Polarimeter<br>UVN Spectrometer | Aerosol-lidar<br>MAP<br>UVN nadir | |
| GACM | NASA | LEO SS | UVN Spectrometer<br>IR Spectrometer<br>MW Spectrometer | UVN nadir<br>IR nadir<br>MW limb | |
| Sentinel-3 [A-C] | ESA | LEO SS ~10:00 | SLSTR<br>OCLI | Imager<br>Imager | |
| Sentinel-4 [A-B] | ESA | GEO 0 lon | IR Spectrometer<br>UVN Spectrometer | IR nadir<br>UVN nadir | |
| Sentinel-5 prec | ESA | LEO SS ~10:00 | UVN Spectrometer | UVN nadir | |
| Sentinel-5 | ESA | LEO SS ~10:00 | IR Spectrometer<br>UVN Spectrometer | IR limb<br>UVN nadir | |
| EarthCARE | ESA-JAXA | LEO SS 10:30 | ATLID<br>MSI | Aerosol-lidar<br>Imager | |
| A-SCOPE | ESA | LEO | Lidar | CO2-lidar | |
| PREMIER | ESA-SSC | LEO SS 10:30 | IMIPAS<br>STEAM-R | IR limb<br>MW limb | |
| TRAQ | ESA | LEO not SS | UVN Spectrometer<br>IR Spectrometer<br>Imager<br>Polarimeter | UVN nadir<br>IR nadir<br>Imager<br>MAP | |
| NOAA-N' | NOAA | LEO SS 13:30 | AVHRR-3<br>SBUV-2 | Imager<br>UVN nadir | |
| NPP | NOAA | LEO SS 10:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | |
| NPOESS-1 | NOAA | LEO SS 13:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | |
| NPOESS-2 | NOAA | LEO SS 13:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | |
| Metop-1 | EUMETSAT | LEO SS 09:30 | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | |
| Metop-3 | EUMETSAT | LEO SS 09:30 | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | |
| MSG-3<br>Meteosat-10 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | |
| MSG-4<br>Meteosat-11 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | |
| Chinook | CSA | LEO SS ~06:00 | SWIFT | O3 IR limb | |
| GOSAT | JAXA | LEO SS 13:00 | TANSO-FTS<br>TANSO-CAI | IR nadir<br>Imager | |
| GCOM-C | JAXA | LEO | SGLI | UVN nadir | |
| FY-3 [B-G] | CMA | LEO SS | VIRR<br>TOU/SBUS | Imager<br>UVN nadir | |
| FY-4 Cr [A-E] | CMA | GEO | MCSI | Imager | |

**Table 4-48: $SF_6$ Measurements from Planned Missions for Composition-Climate Requirements**

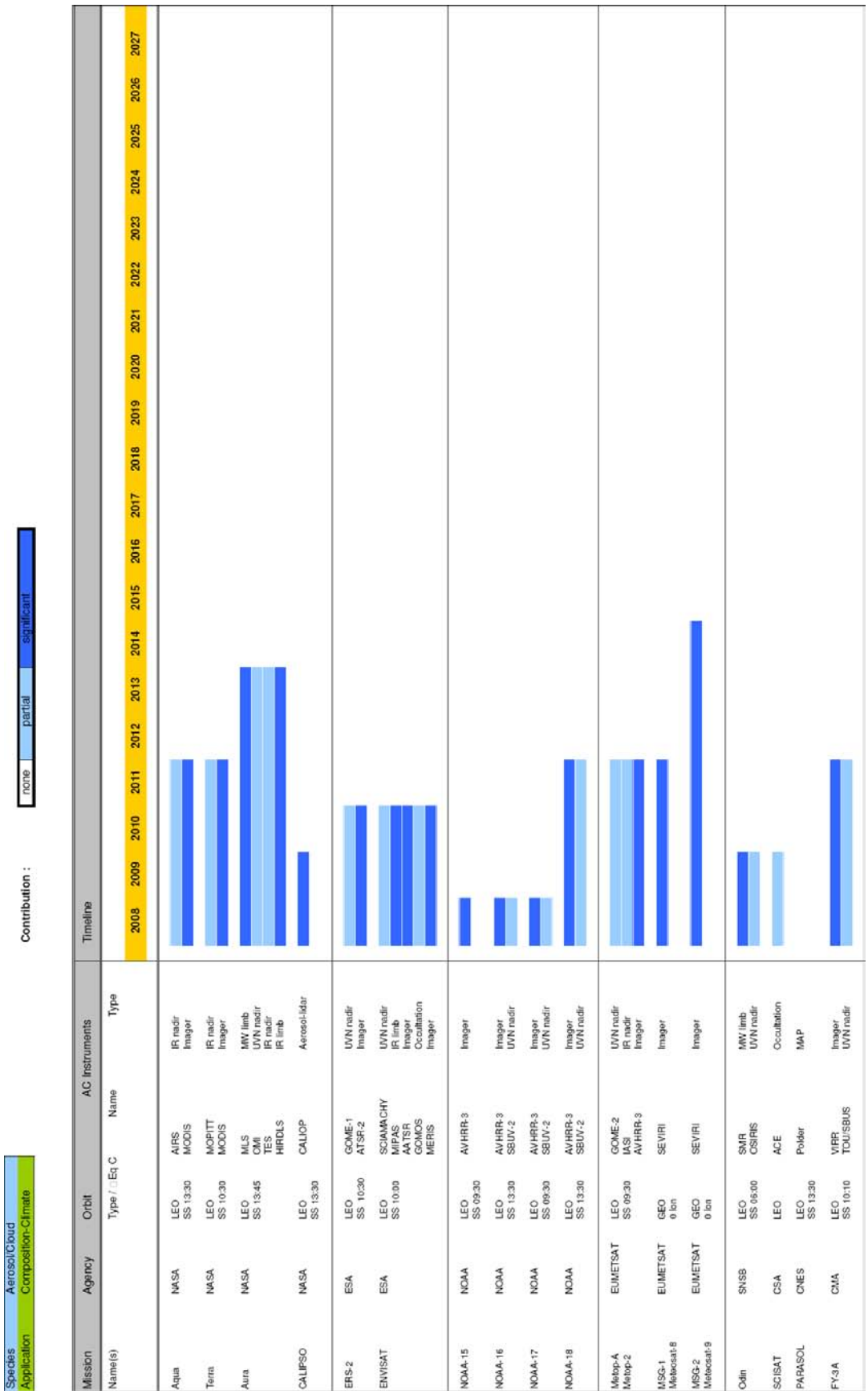


**Table 4-49: Aerosol & Cloud Measurements from Current Missions for Composition-Climate Requirements**

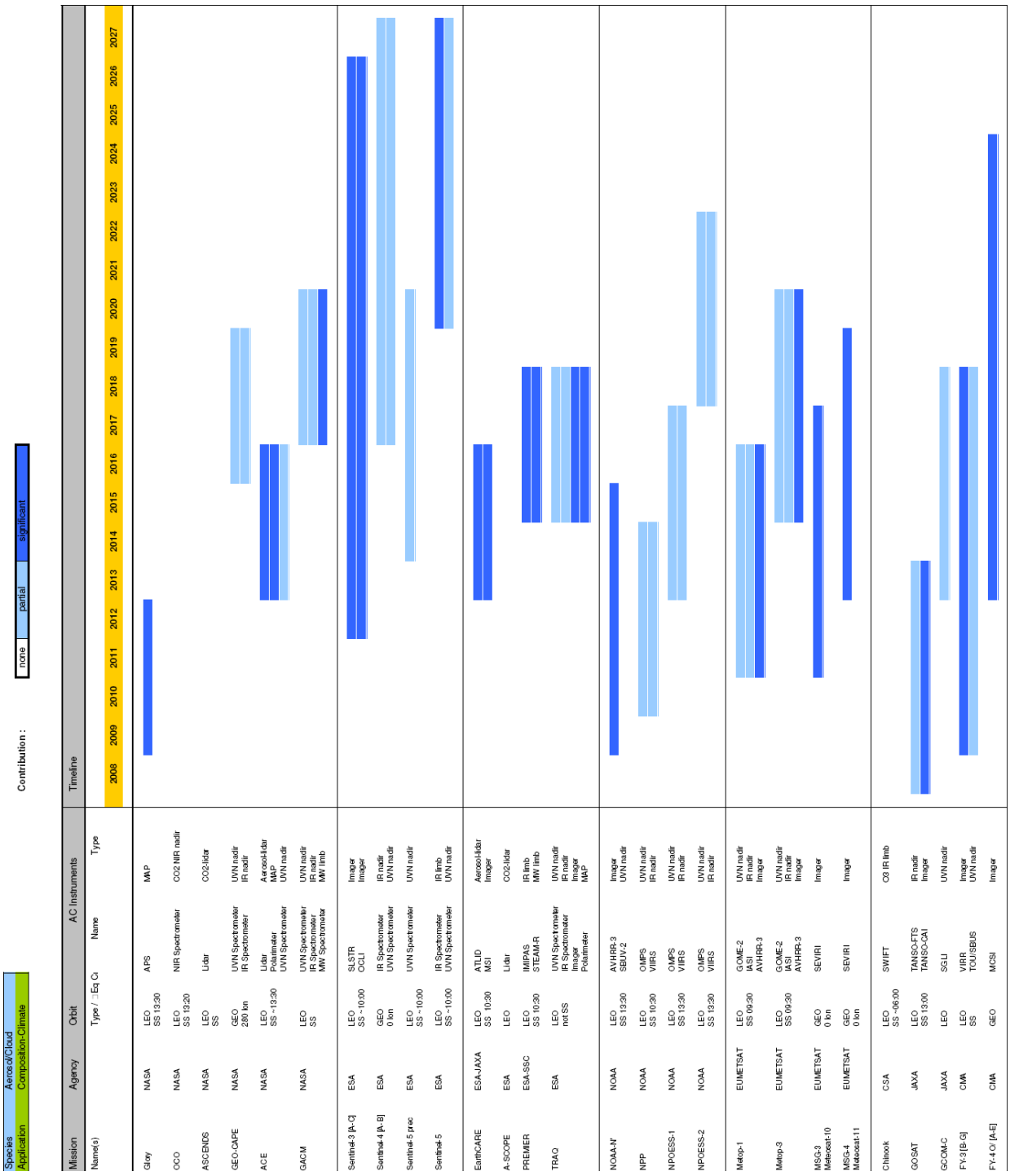


**Table 4-50: Aerosol & Cloud Measurements from Planned Missions for Composition-Climate Requirements**

### 4.5.3 Air Quality Monitoring and Forecasting

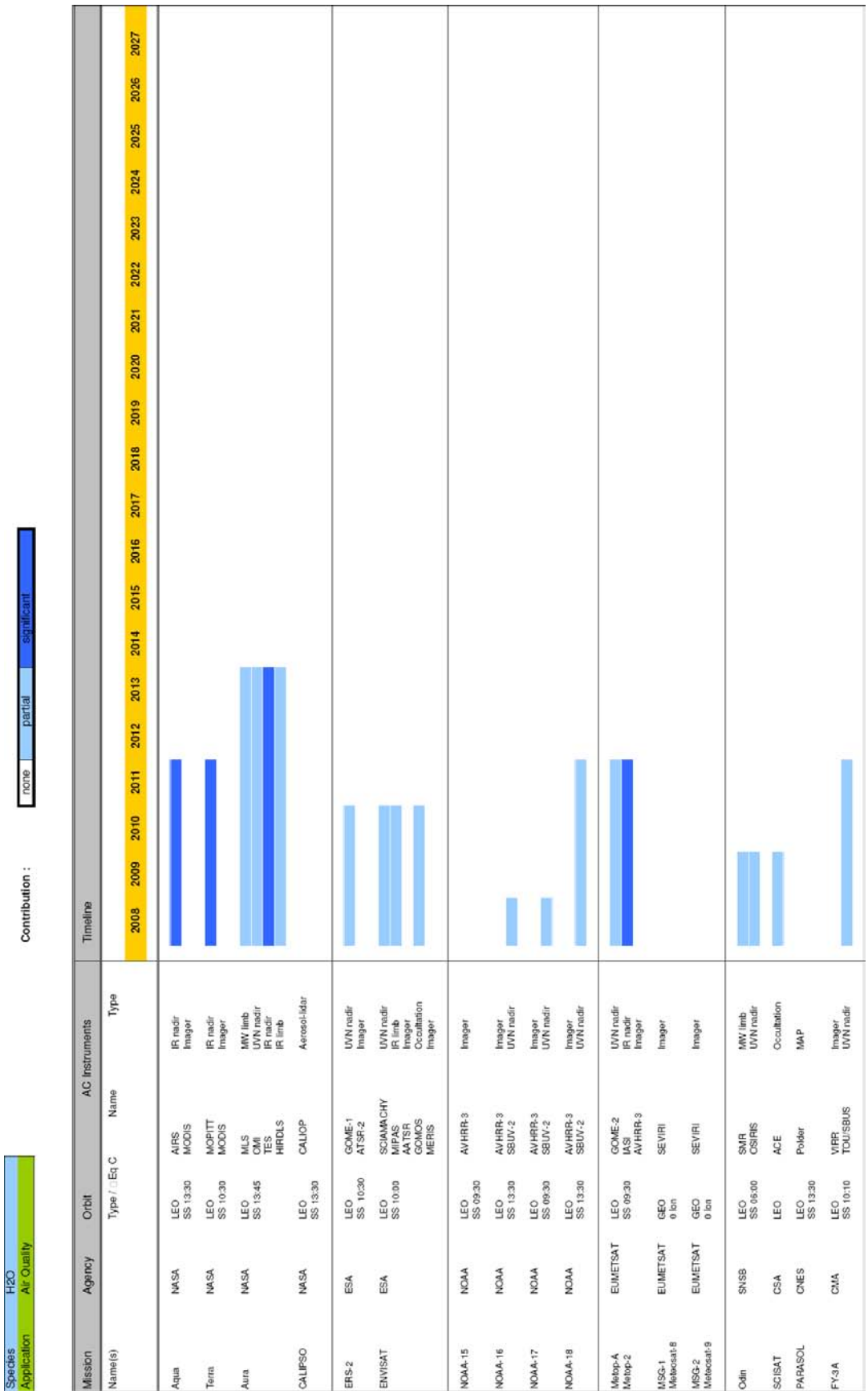


**Table 4-47: $H_2O$ Measurements from Current Missions for Air Quality Requirements**

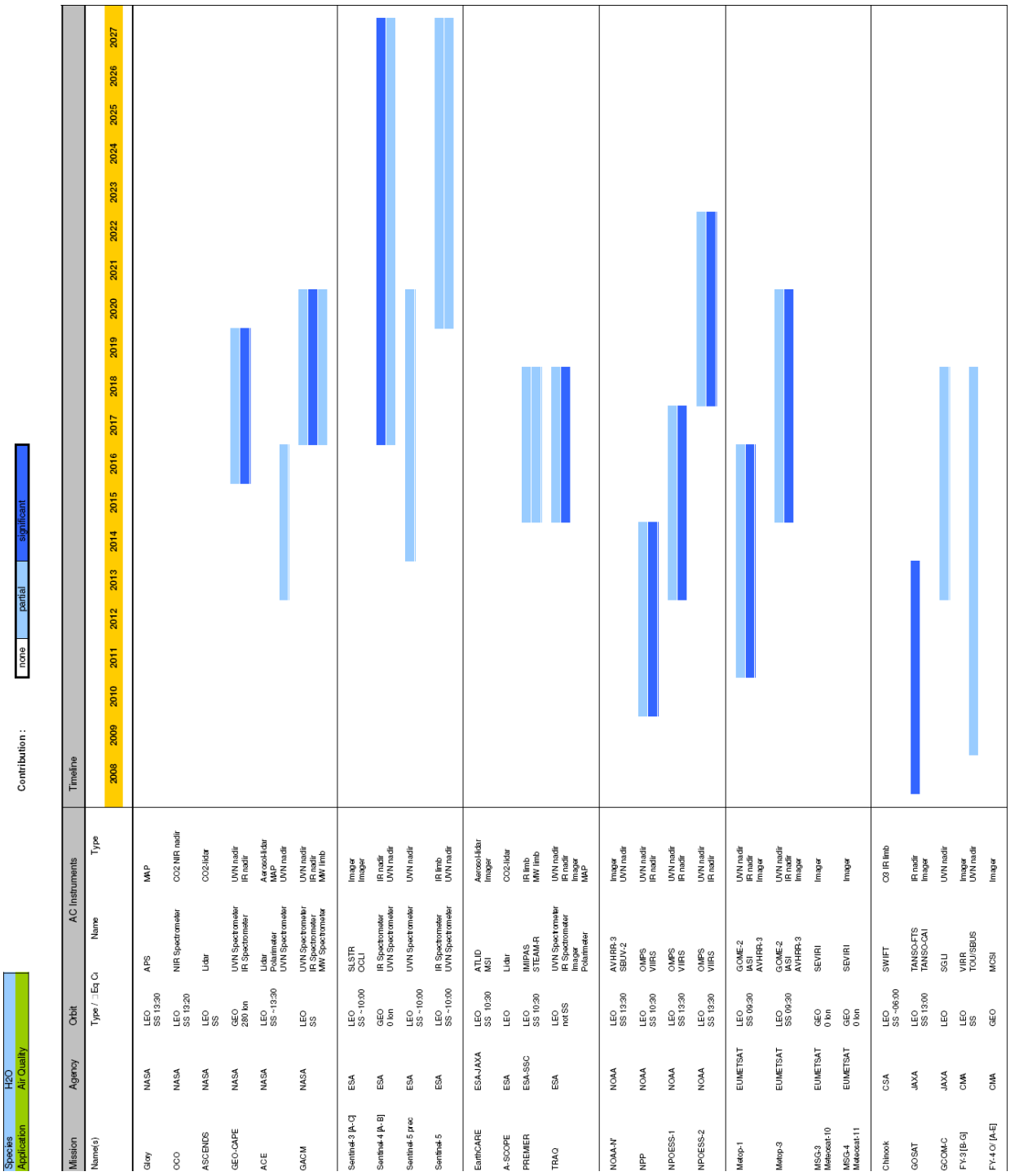


**Table 4-48: $H_2O$ Measurements from Planned Missions for Air Quality Requirements**

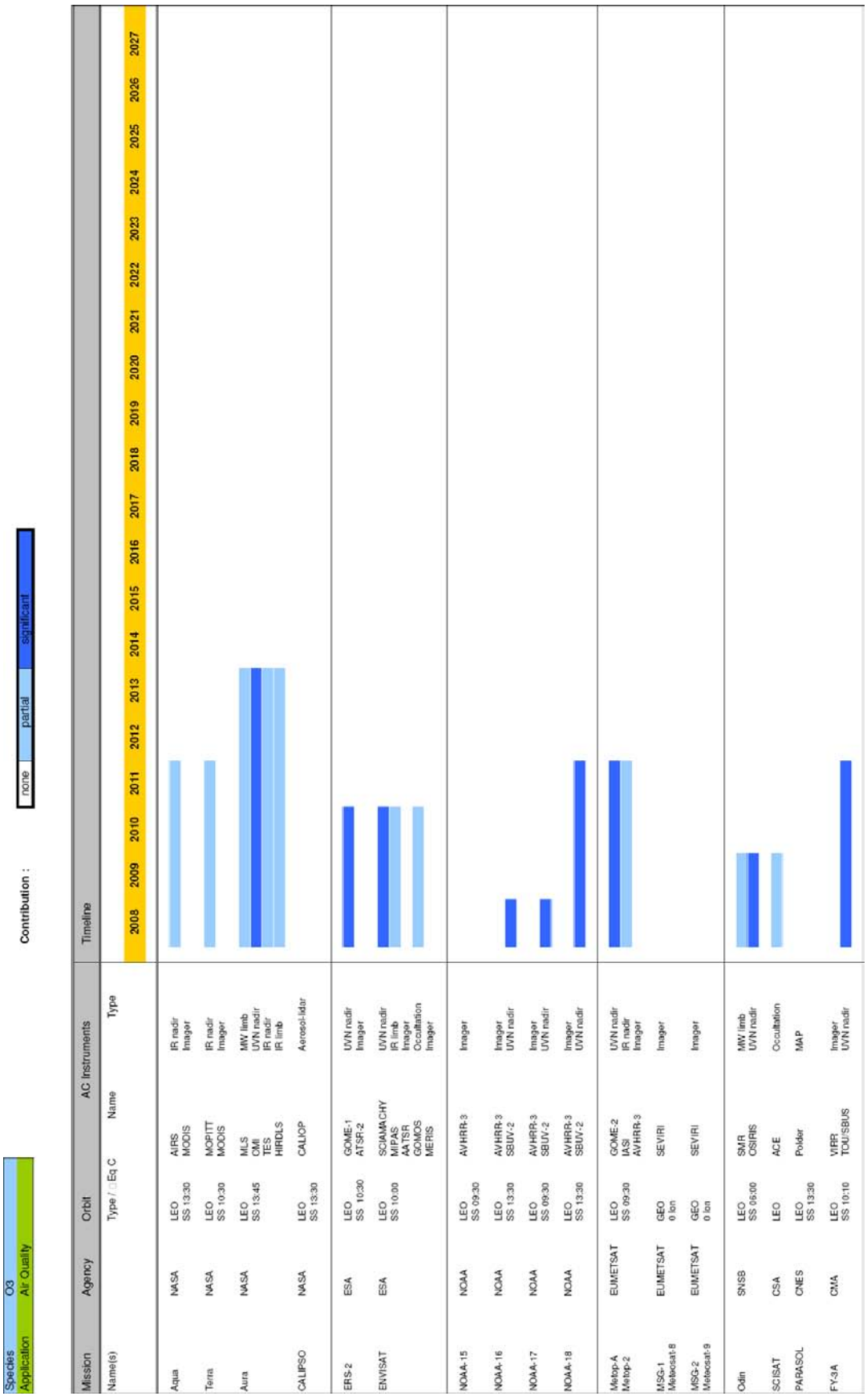


**Table 4-49: $O_3$ Measurements from Current Missions for Air Quality Requirements**

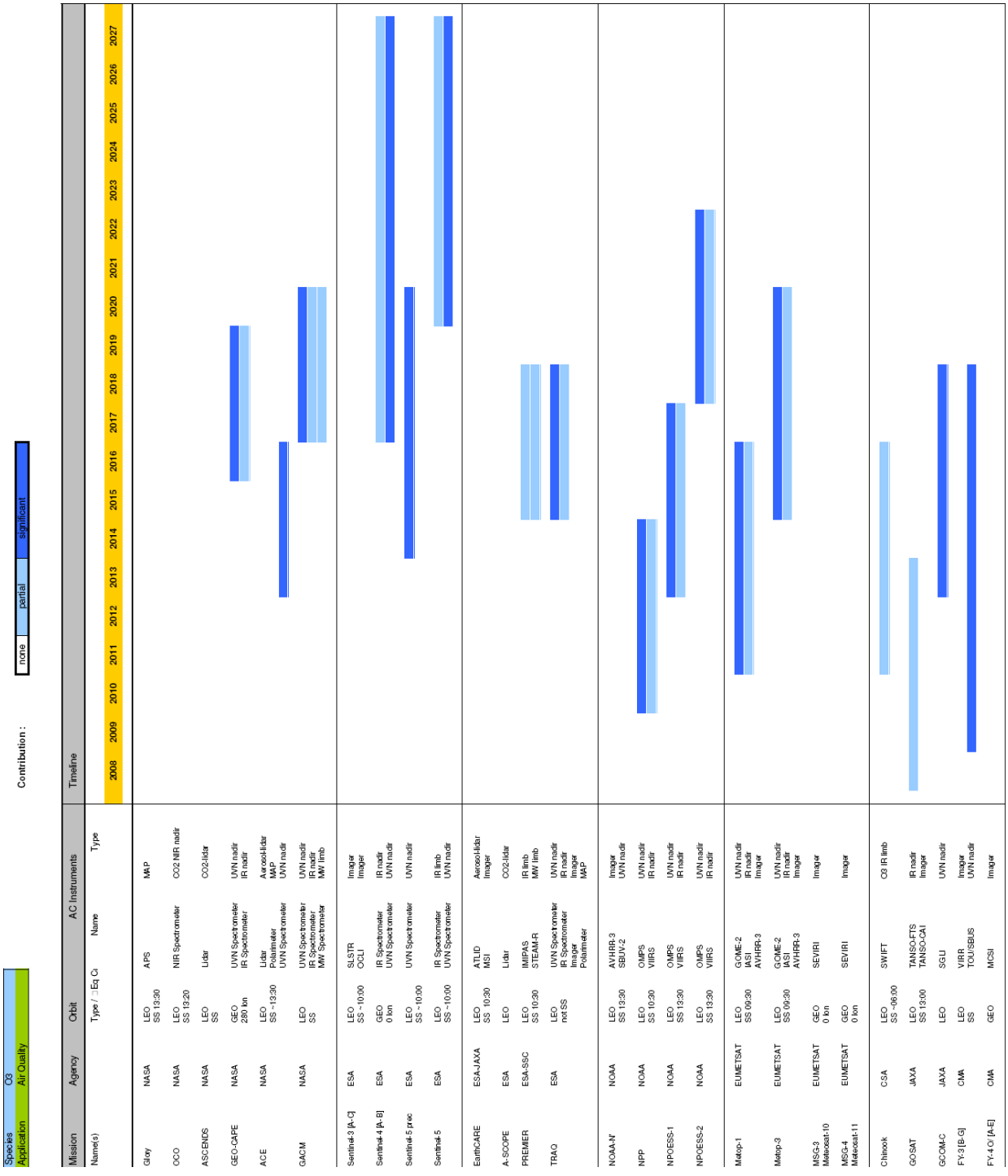


**Table 4-50: $O_3$ Measurements from Planned Missions for Air Quality Requirements**

Species: HNO3
Application: Air Quality

Contribution : none | partial | significant

| Mission | Agency | Orbit | AC Instruments | | Timeline |
|---|---|---|---|---|---|
| Name(s) | | Type / Eq C | Name | Type | 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 |
| Aqua | NASA | LEO SS 13:30 | AIRS | IR nadir | |
| | | | MODIS | Imager | |
| Terra | NASA | LEO SS 10:30 | MOPITT | IR nadir | |
| | | | MODIS | Imager | |
| Aura | NASA | LEO SS 13:45 | MLS | MW limb | |
| | | | OMI | UV/N nadir | |
| | | | TES | IR nadir | |
| | | | HIRDLS | IR limb | |
| CALIPSO | NASA | LEO SS 13:30 | CALIOP | Aerosol-lidar | |
| ERS-2 | ESA | LEO SS 10:30 | GOME-1 | UV/N nadir | |
| | | | ATSR-2 | Imager | |
| ENVISAT | ESA | LEO SS 10:00 | SCIAMACHY | UV/N nadir | |
| | | | MIPAS | IR limb | |
| | | | AATSR | Imager | |
| | | | GOMOS | Occultation | |
| | | | MERIS | Imager | |
| NOAA-15 | NOAA | LEO SS 09:30 | AVHRR-3 | Imager | |
| NOAA-16 | NOAA | LEO SS 13:30 | AVHRR-3 | Imager | |
| | | | SBUV-2 | UV/N nadir | |
| NOAA-17 | NOAA | LEO SS 09:30 | AVHRR-3 | Imager | |
| | | | SBUV-2 | UV/N nadir | |
| NOAA-18 | NOAA | LEO SS 13:30 | AVHRR-3 | Imager | |
| | | | SBUV-2 | UV/N nadir | |
| Metop-A | EUMETSAT | LEO SS 09:30 | GOME-2 | UV/N nadir | |
| Metop-2 | | | IASI | IR nadir | |
| | | | AVHRR-3 | Imager | |
| MSG-1 Meteosat-8 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | |
| MSG-2 Meteosat-9 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | |
| Odin | SNSB | LEO SS 06:00 | SMR | MW limb | |
| | | | OSIRIS | UV/N nadir | |
| SCISAT | CSA | LEO | ACE | Occultation | |
| PARASOL | CNES | LEO SS 13:30 | Polder | MAP | |
| FY-3A | CMA | LEO SS 10:10 | VIRR | Imager | |
| | | | TOU/SBUS | UV/N nadir | |

**Table 4-51: $HNO_3$ Measurements from Current Missions for Air Quality Requirements**

Species HNO3
Application Air Quality

Contribution : none partial significant

| Mission | Agency | Orbit | AC Instruments | | Timeline | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name(s) | | Type / ☐Eq Cr | Name | Type | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 |
| Glory | NASA | LEO SS 13:30 | APS | MAP | | | | | | | | | | | | | | | | | | | | |
| OCO | NASA | LEO SS 13:20 | NIR Spectrometer | CO2 NIR nadir | | | | | | | | | | | | | | | | | | | | |
| ASCENDS | NASA | LEO SS | Lidar | CO2-lidar | | | | | | | | | | | | | | | | | | | | |
| GEO-CAPE | NASA | GEO 280 lon | UVN Spectrometer<br>IR Spectrometer | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| ACE | NASA | LEO SS ~13:30 | Lidar<br>Polarimeter<br>UVN Spectrometer | Aerosol-lidar<br>MAP<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| GACM | NASA | LEO SS | UVN Spectrometer<br>IR Spectrometer<br>MW Spectrometer | UVN nadir<br>IR nadir<br>MW limb | | | | | | | | | | | | | | | | | | | | |
| Sentinel-3 [A-C] | ESA | LEO SS ~10:00 | SLSTR<br>OCLI | Imager<br>Imager | | | | | | | | | | | | | | | | | | | | |
| Sentinel-4 [A-B] | ESA | GEO 0 lon | IR Spectrometer<br>UVN Spectrometer | IR nadir<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| Sentinel-5 prec | ESA | LEO SS ~10:00 | UVN Spectrometer | UVN nadir | | | | | | | | | | | | | | | | | | | | |
| Sentinel-5 | ESA | LEO SS ~10:00 | IR Spectrometer<br>UVN Spectrometer | IR limb<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| EarthCARE | ESA-JAXA | LEO SS 10:30 | ATLID<br>MSI | Aerosol-lidar<br>Imager | | | | | | | | | | | | | | | | | | | | |
| A-SCOPE | ESA | LEO | Lidar | CO2-lidar | | | | | | | | | | | | | | | | | | | | |
| PREMIER | ESA-SSC | LEO SS 10:30 | IMIPAS<br>STEAM-R | IR limb<br>MW limb | | | | | | | | | | | | | | | | | | | | |
| TRAQ | ESA | LEO not SS | UVN Spectrometer<br>IR Spectrometer<br>Imager<br>Polarimeter | UVN nadir<br>IR nadir<br>Imager<br>MAP | | | | | | | | | | | | | | | | | | | | |
| NOAA-N' | NOAA | LEO SS 13:30 | AVHRR-3<br>SBUV-2 | Imager<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| NPP | NOAA | LEO SS 10:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| NPOESS-1 | NOAA | LEO SS 13:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| NPOESS-2 | NOAA | LEO SS 13:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| Metop-1 | EUMETSAT | LEO SS 09:30 | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | | | | | | | | | | | | | | | | | | | | |
| Metop-3 | EUMETSAT | LEO SS 09:30 | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | | | | | | | | | | | | | | | | | | | | |
| MSG-3<br>Meteosat-10 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | | | | | | | | | | | | | | | | | | | | |
| MSG-4<br>Meteosat-11 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | | | | | | | | | | | | | | | | | | | | |
| Chinook | CSA | LEO SS ~06:00 | SWIFT | O3 IR limb | | | | | | | | | | | | | | | | | | | | |
| GOSAT | JAXA | LEO SS 13:00 | TANSO-FTS<br>TANSO-CAI | IR nadir<br>Imager | | | | | | | | | | | | | | | | | | | | |
| GCOM-C | JAXA | LEO | SGLI | UVN nadir | | | | | | | | | | | | | | | | | | | | |
| FY-3 [B-G] | CMA | LEO SS | VIRR<br>TOU/SBUS | Imager<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| FY-4 Q [A-E] | CMA | GEO | MCSI | Imager | | | | | | | | | | | | | | | | | | | | |

**Table 4-52: $HNO_3$ Measurements from Planned Missions for Air Quality Requirements**

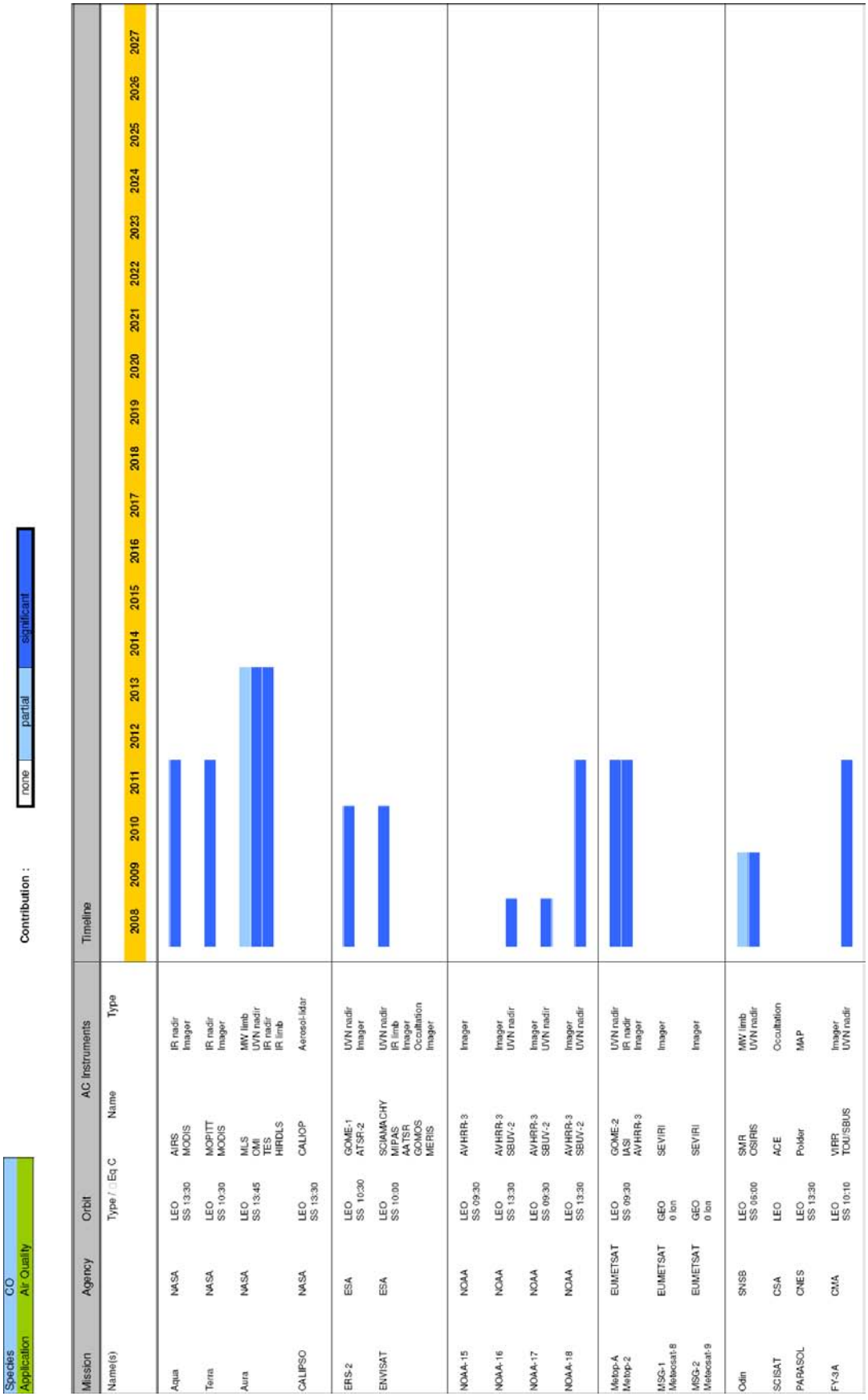


**Table 4-53: CO Measurements from Current Missions for Air Quality Requirements**

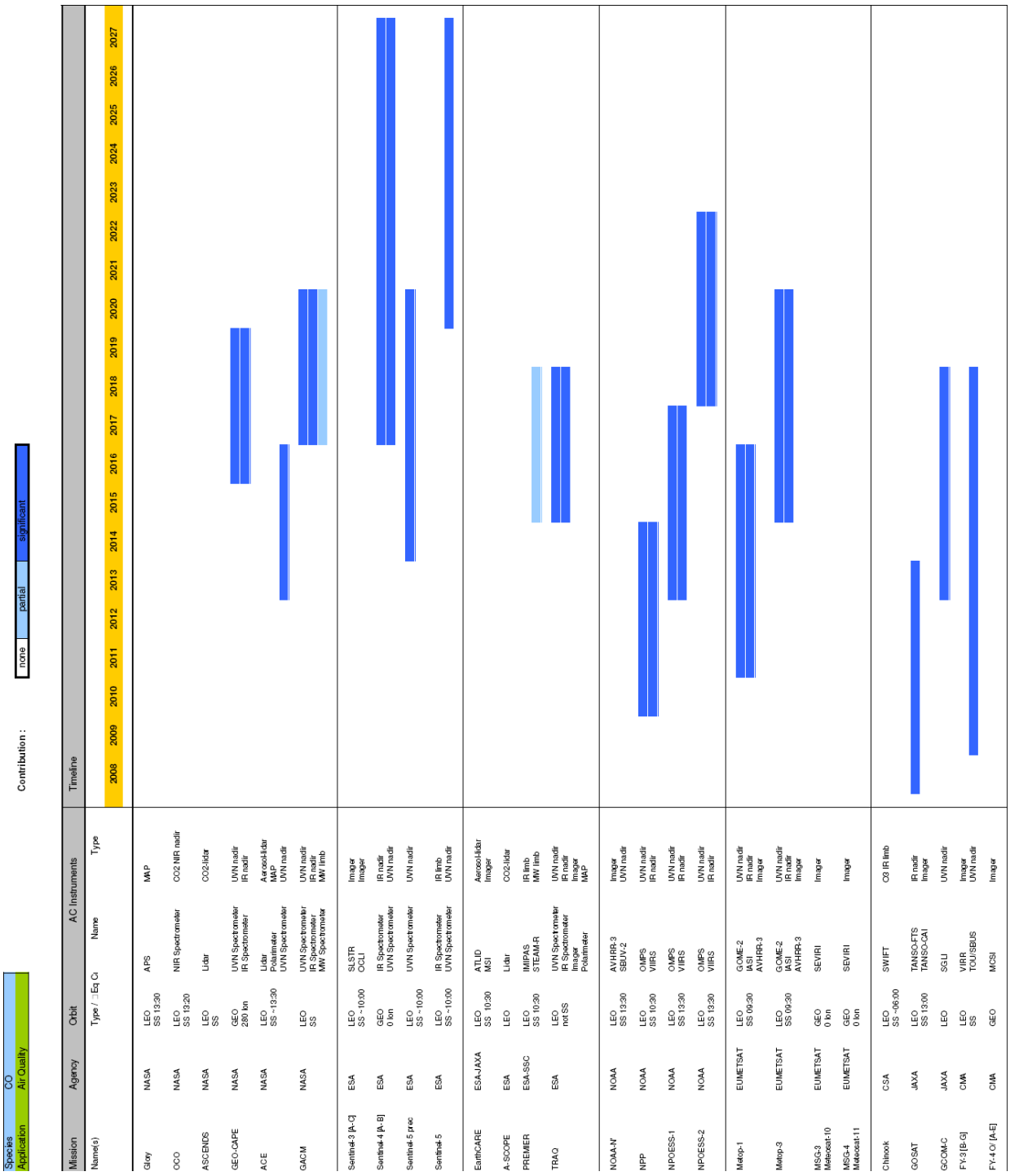


**Table 4-54: CO Measurements from Planned Missions for Air Quality Requirements**

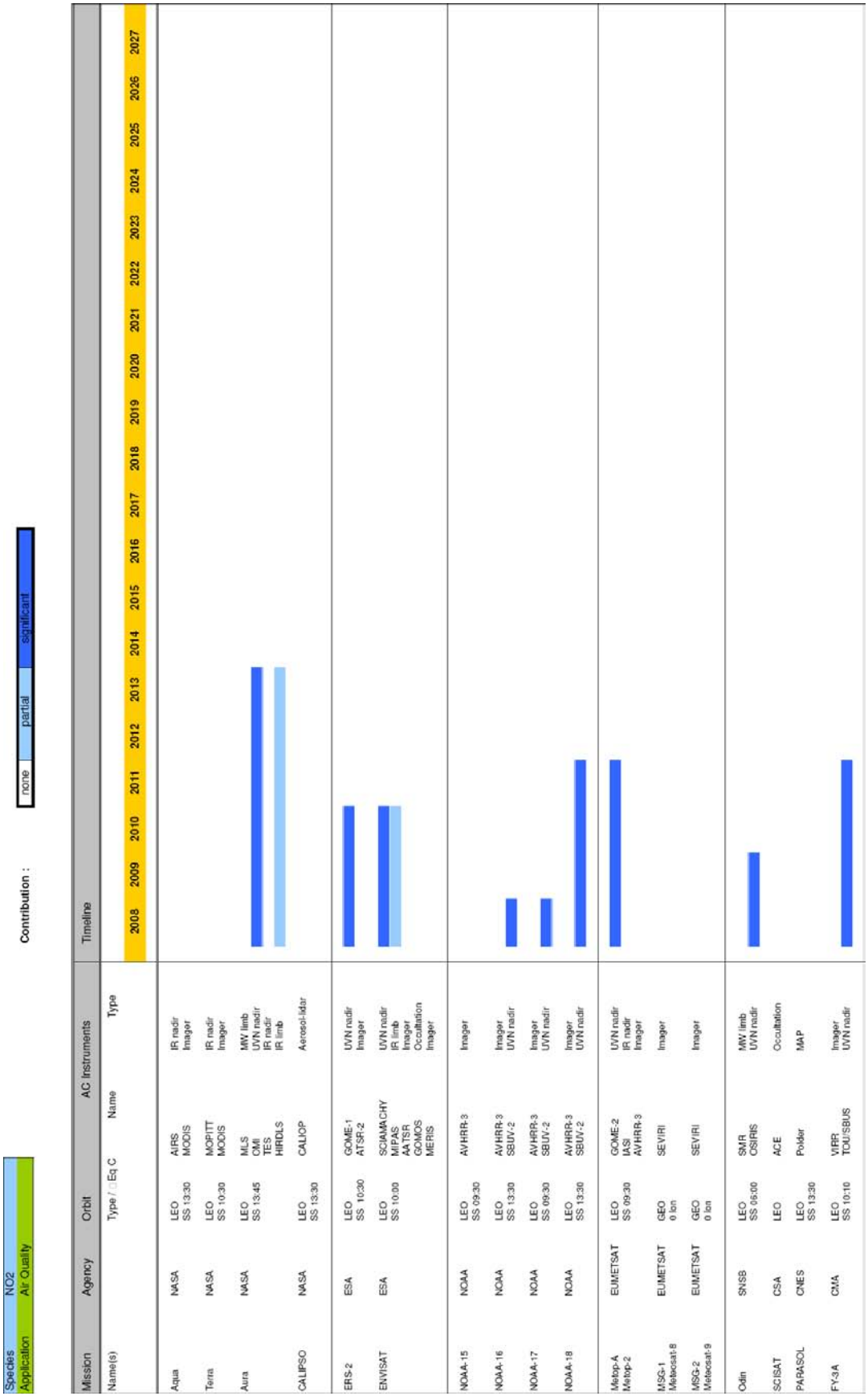


**Table 4-55: $NO_2$ Measurements from Current Missions for Air Quality Requirements**

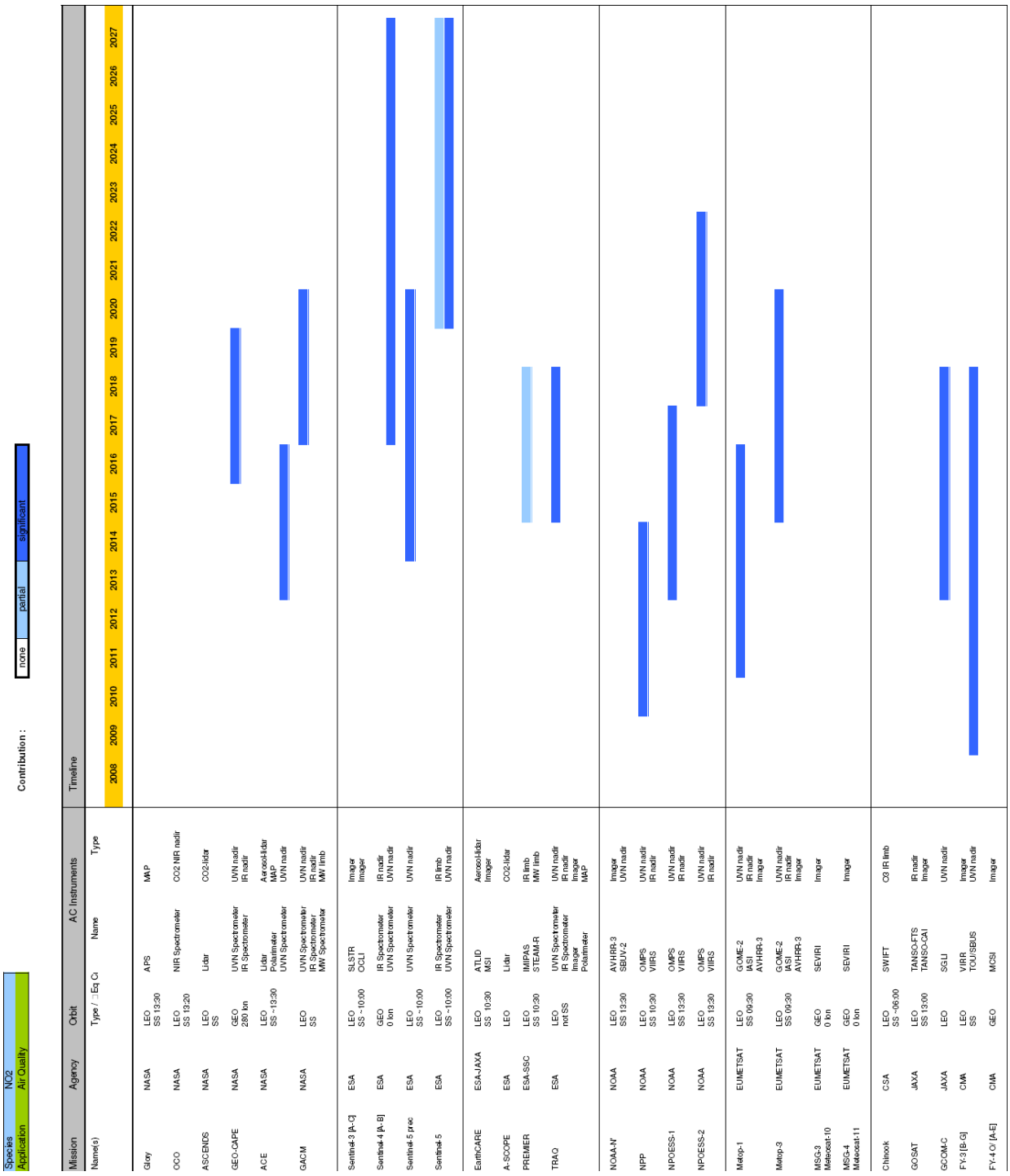


**Table 4-56: $NO_2$ Measurements from Planned Missions for Air Quality Requirements**

Species: N2O5
Application: Air Quality

Contribution : none | partial | significant

| Mission | Agency | Orbit | AC Instruments | | Timeline |
|---|---|---|---|---|---|
| Name(s) | | Type / □ Eq C | Name | Type | 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 |
| Aqua | NASA | LEO SS 13:30 | AIRS | IR nadir | |
| | | | MODIS | Imager | |
| Terra | NASA | LEO SS 10:30 | MOPITT | IR nadir | |
| | | | MODIS | Imager | |
| Aura | NASA | LEO SS 13:45 | MLS | MW limb | |
| | | | OMI | UV/N nadir | |
| | | | TES | IR nadir | |
| | | | HIRDLS | IR limb | |
| CALIPSO | NASA | LEO SS 13:30 | CALIOP | Aerosol-lidar | |
| ERS-2 | ESA | LEO SS 10:30 | GOME-1 | UV/N nadir | |
| | | | ATSR-2 | Imager | |
| ENVISAT | ESA | LEO SS 10:00 | SCIAMACHY | UV/N nadir | |
| | | | MIPAS | IR limb | |
| | | | AATSR | Imager | |
| | | | GOMOS | Occultation | |
| | | | MERIS | Imager | |
| NOAA-15 | NOAA | LEO SS 09:30 | AVHRR-3 | Imager | |
| NOAA-16 | NOAA | LEO SS 13:30 | AVHRR-3 | Imager | |
| | | | SBUV-2 | UV/N nadir | |
| NOAA-17 | NOAA | LEO SS 09:30 | AVHRR-3 | Imager | |
| | | | SBUV-2 | UV/N nadir | |
| NOAA-18 | NOAA | LEO SS 13:30 | AVHRR-3 | Imager | |
| | | | SBUV-2 | UV/N nadir | |
| Metop-A | EUMETSAT | LEO SS 09:30 | GOME-2 | UV/N nadir | |
| Metop-2 | | | IASI | IR nadir | |
| | | | AVHRR-3 | Imager | |
| MSG-1 Meteosat-8 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | |
| MSG-2 Meteosat-9 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | |
| Odin | SNSB | LEO SS 06:00 | SMR | MW limb | |
| | | | OSIRIS | UV/N nadir | |
| SCISAT | CSA | LEO | ACE | Occultation | |
| PARASOL | CNES | LEO SS 13:30 | Polder | MAP | |
| FY-3A | CMA | LEO SS 10:10 | VIRR | Imager | |
| | | | TOU/SBUS | UV/N nadir | |

**Table 4-57: $N_2O_5$ Measurements from Current Missions for Air Quality Requirements**

Species N2O5
Application Air Quality

Contribution : none partial significant

| Mission | Agency | Orbit | AC Instruments | | Timeline | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name(s) | | Type / ☐Eq Cr | Name | Type | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 |
| Glory | NASA | LEO SS 13:30 | APS | MAP | | | | | | | | | | | | | | | | | | | | |
| OCO | NASA | LEO SS 13:20 | NIR Spectrometer | CO2 NIR nadir | | | | | | | | | | | | | | | | | | | | |
| ASCENDS | NASA | LEO SS | Lidar | CO2-lidar | | | | | | | | | | | | | | | | | | | | |
| GEO-CAPE | NASA | GEO 280 lon | UVN Spectrometer<br>IR Spectrometer | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| ACE | NASA | LEO SS ~13:30 | Lidar<br>Polarimeter<br>UVN Spectrometer | Aerosol-lidar<br>MAP<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| GACM | NASA | LEO SS | UVN Spectrometer<br>IR Spectrometer<br>MW Spectrometer | UVN nadir<br>IR nadir<br>MW limb | | | | | | | | | | | | | | | | | | | | |
| Sentinel-3 [A-C] | ESA | LEO SS ~ 10:00 | SLSTR<br>OCLI | Imager<br>Imager | | | | | | | | | | | | | | | | | | | | |
| Sentinel-4 [A-B] | ESA | GEO 0 lon | IR Spectrometer<br>UVN Spectrometer | IR nadir<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| Sentinel-5 prec | ESA | LEO SS ~10:00 | UVN Spectrometer | UVN nadir | | | | | | | | | | | | | | | | | | | | |
| Sentinel-5 | ESA | LEO SS ~10:00 | IR Spectrometer<br>UVN Spectrometer | IR limb<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| EarthCARE | ESA-JAXA | LEO SS 10:30 | ATLID<br>MSI | Aerosol-lidar<br>Imager | | | | | | | | | | | | | | | | | | | | |
| A-SCOPE | ESA | LEO | Lidar | CO2-lidar | | | | | | | | | | | | | | | | | | | | |
| PREMIER | ESA-SSC | LEO SS 10:30 | IMIPAS<br>STEAM-R | IR limb<br>MW limb | | | | | | | | | | | | | | | | | | | | |
| TRAQ | ESA | LEO not SS | UVN Spectrometer<br>IR Spectrometer<br>Imager<br>Polarimeter | UVN nadir<br>IR nadir<br>Imager<br>MAP | | | | | | | | | | | | | | | | | | | | |
| NOAA-N' | NOAA | LEO SS 13:30 | AVHRR-3<br>SBUV-2 | Imager<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| NPP | NOAA | LEO SS 10:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| NPOESS-1 | NOAA | LEO SS 13:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| NPOESS-2 | NOAA | LEO SS 13:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| Metop-1 | EUMETSAT | LEO SS 09:30 | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | | | | | | | | | | | | | | | | | | | | |
| Metop-3 | EUMETSAT | LEO SS 09:30 | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | | | | | | | | | | | | | | | | | | | | |
| MSG-3<br>Meteosat-10 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | | | | | | | | | | | | | | | | | | | | |
| MSG-4<br>Meteosat-11 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | | | | | | | | | | | | | | | | | | | | |
| Chinook | CSA | LEO SS ~06:00 | SWIFT | O3 IR limb | | | | | | | | | | | | | | | | | | | | |
| GOSAT | JAXA | LEO SS 13:00 | TANSO-FTS<br>TANSO-CAI | IR nadir<br>Imager | | | | | | | | | | | | | | | | | | | | |
| GCOM-C | JAXA | LEO | SGLI | UVN nadir | | | | | | | | | | | | | | | | | | | | |
| FY-3 [B-G] | CMA | LEO SS | VIRR<br>TOU/SBUS | Imager<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| FY-4 Q [A-E] | CMA | GEO | MCSI | Imager | | | | | | | | | | | | | | | | | | | | |

**Table 4-58: $N_2O_5$ Measurements from Planned Missions for Air Quality Requirements**

**Table 4-59: $SO_2$ Measurements from Current Missions for Air Quality Requirements**

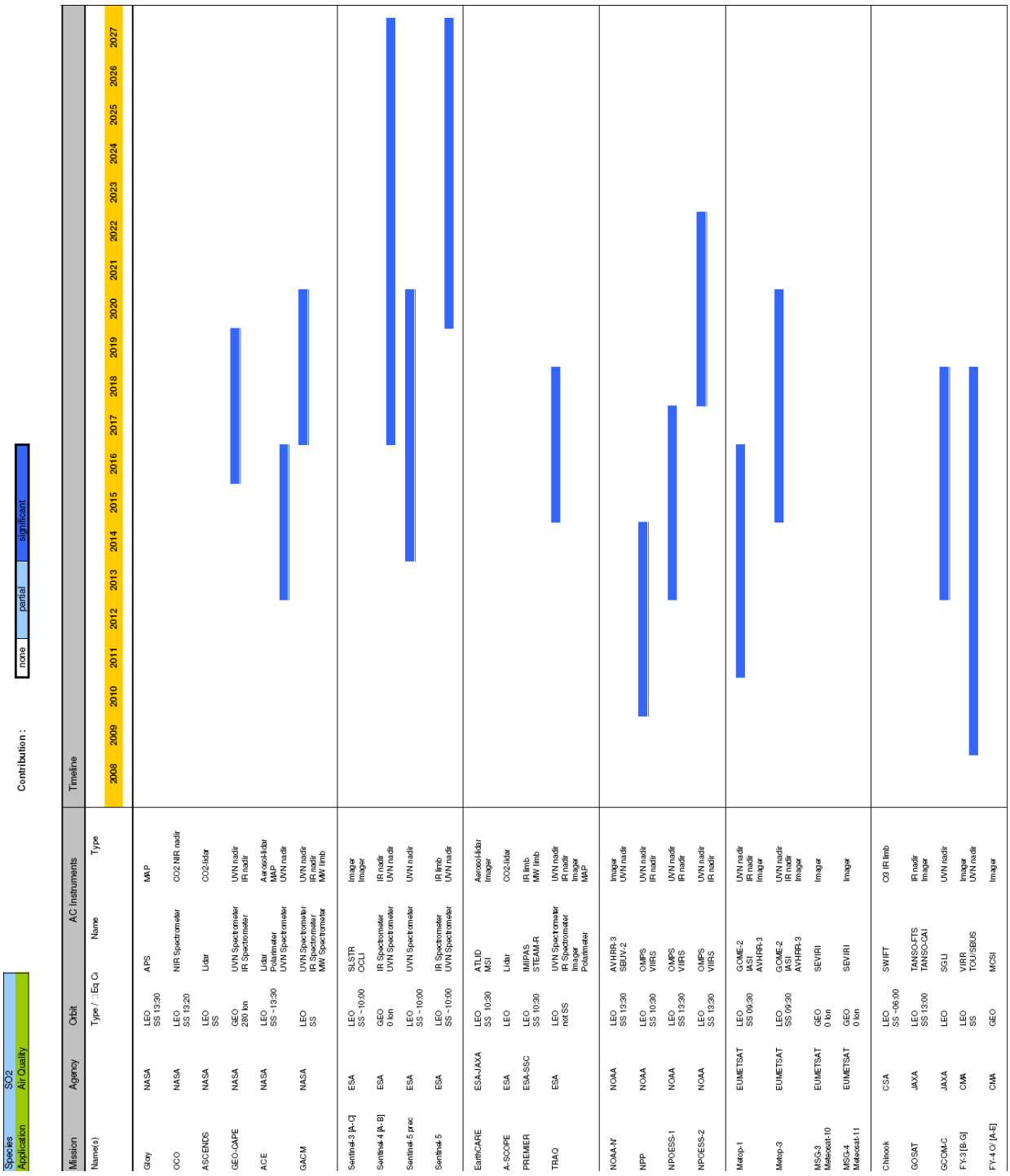


**Table 4-60: $SO_2$ Measurements from Planned Missions for Air Quality Requirements**

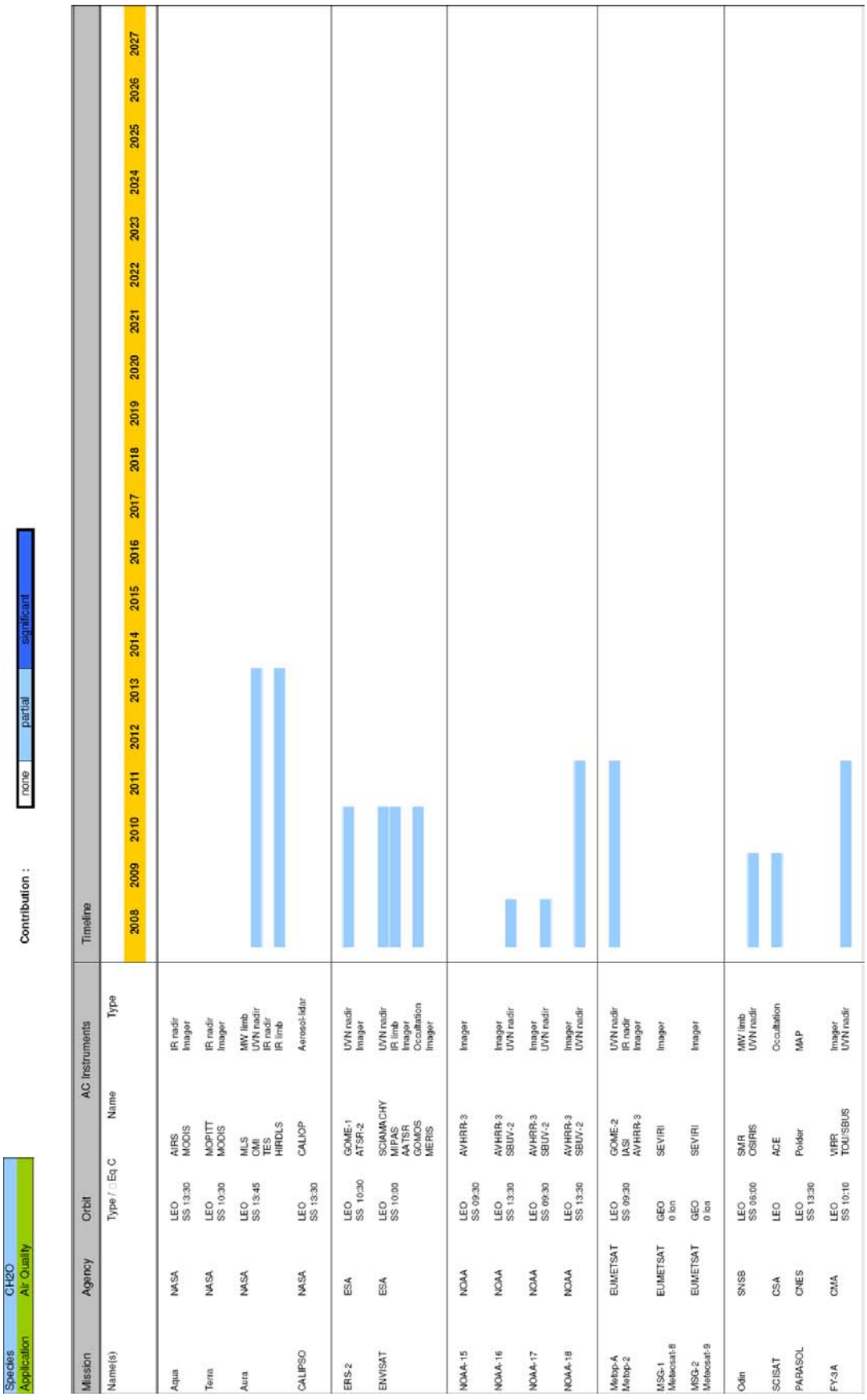


**Table 4-61: $CH_2O$ Measurements from Current Missions for Air Quality Requirements**

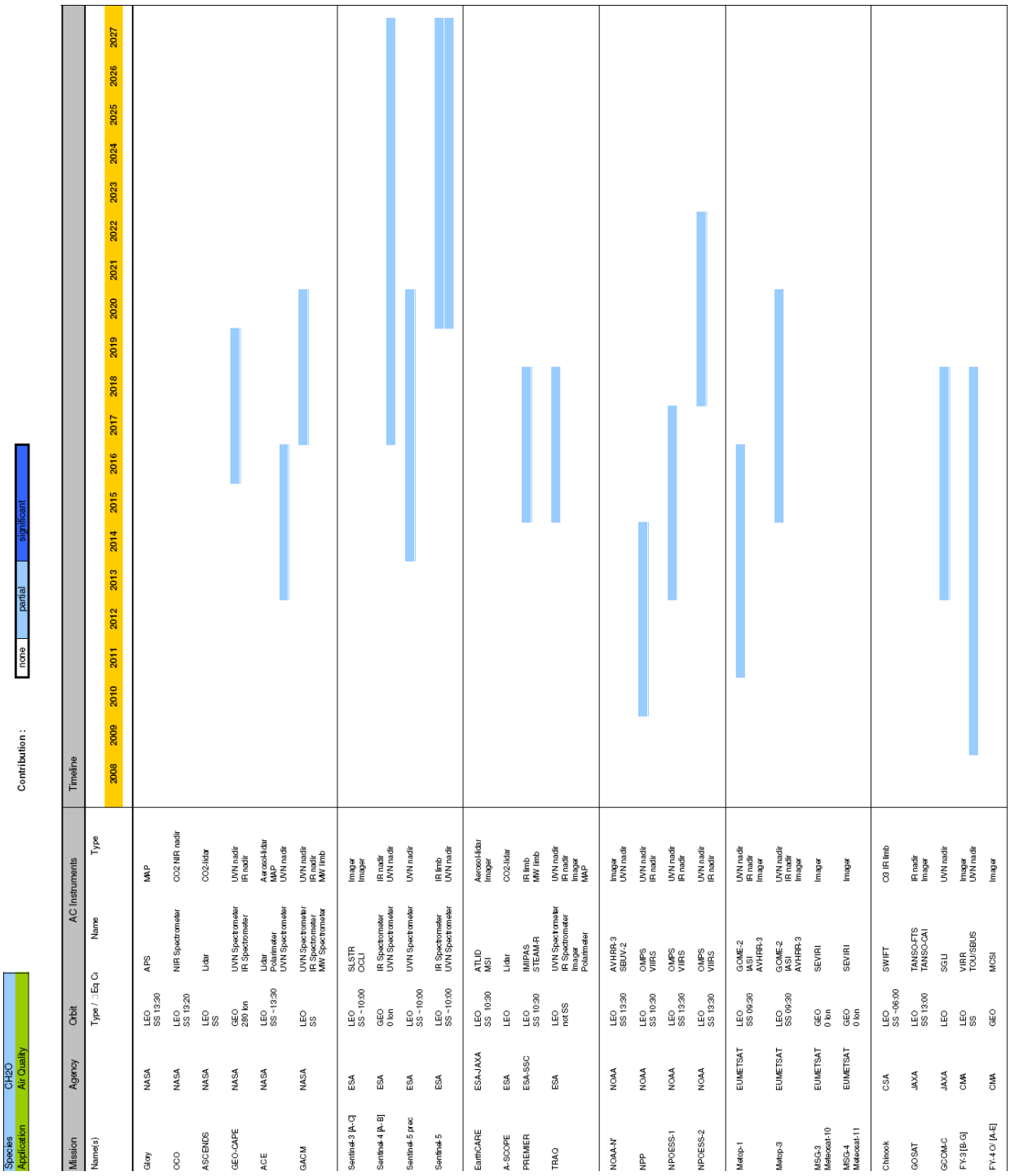


**Table 4-62: $CH_2O$ Measurements from Planned Missions for Air Quality Requirements**

Species: PAN
Application: Air Quality

Contribution : none | partial | significant

| Mission | Agency | Orbit | AC Instruments | | Timeline |
|---|---|---|---|---|---|
| Name(s) | | Type / Eq C | Name | Type | 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 |
| Aqua | NASA | LEO SS 13:30 | AIRS | IR nadir | |
| | | | MODIS | Imager | |
| Terra | NASA | LEO SS 10:30 | MOPITT | IR nadir | |
| | | | MODIS | Imager | |
| Aura | NASA | LEO SS 13:45 | MLS | MW limb | |
| | | | OMI | UV/N nadir | |
| | | | TES | IR nadir | |
| | | | HIRDLS | IR limb | |
| CALIPSO | NASA | LEO SS 13:30 | CALIOP | Aerosol-lidar | |
| ERS-2 | ESA | LEO SS 10:30 | GOME-1 | UV/N nadir | |
| | | | ATSR-2 | Imager | |
| ENVISAT | ESA | LEO SS 10:00 | SCIAMACHY | UV/N nadir | |
| | | | MIPAS | IR limb | |
| | | | AATSR | Imager | |
| | | | GOMOS | Occultation | |
| | | | MERIS | Imager | |
| NOAA-15 | NOAA | LEO SS 09:30 | AVHRR-3 | Imager | |
| NOAA-16 | NOAA | LEO SS 13:30 | AVHRR-3 | Imager | |
| | | | SBUV-2 | UV/N nadir | |
| NOAA-17 | NOAA | LEO SS 09:30 | AVHRR-3 | Imager | |
| | | | SBUV-2 | UV/N nadir | |
| NOAA-18 | NOAA | LEO SS 13:30 | AVHRR-3 | Imager | |
| | | | SBUV-2 | UV/N nadir | |
| Metop-A | EUMETSAT | LEO SS 09:30 | GOME-2 | UV/N nadir | |
| Metop-2 | | | IASI | IR nadir | |
| | | | AVHRR-3 | Imager | |
| MSG-1 Meteosat-8 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | |
| MSG-2 Meteosat-9 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | |
| Odin | SNSB | LEO SS 06:00 | SMR | MW limb | |
| | | | OSIRIS | UV/N nadir | |
| SCISAT | CSA | LEO | ACE | Occultation | |
| PARASOL | CNES | LEO SS 13:30 | Polder | MAP | |
| FY-3A | CMA | LEO SS 10:10 | VIRR | Imager | |
| | | | TOU/SBUS | UV/N nadir | |

**Table 4-63: PAN Measurements from Current Missions for Air Quality Requirements**

Species: PAN
Application: Air Quality

Contribution : none | partial | significant

| Mission | Agency | Orbit | AC Instruments | | Timeline | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name(s) | | Type / ☐Eq Cr | Name | Type | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 |
| Glory | NASA | LEO SS 13:30 | APS | MAP | | | | | | | | | | | | | | | | | | | | |
| OCO | NASA | LEO SS 13:20 | NIR Spectrometer | CO2 NIR nadir | | | | | | | | | | | | | | | | | | | | |
| ASCENDS | NASA | LEO SS | Lidar | CO2-lidar | | | | | | | | | | | | | | | | | | | | |
| GEO-CAPE | NASA | GEO 280 lon | UVN Spectrometer<br>IR Spectrometer | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| ACE | NASA | LEO SS ~13:30 | Lidar<br>Polarimeter<br>UVN Spectrometer | Aerosol-lidar<br>MAP<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| GACM | NASA | LEO SS | UVN Spectrometer<br>IR Spectrometer<br>MW Spectrometer | UVN nadir<br>IR nadir<br>MW limb | | | | | | | | | | | | | | | | | | | | |
| Sentinel-3 [A-C] | ESA | LEO SS ~10:00 | SLSTR<br>OCLI | Imager<br>Imager | | | | | | | | | | | | | | | | | | | | |
| Sentinel-4 [A-B] | ESA | GEO 0 lon | IR Spectrometer<br>UVN Spectrometer | IR nadir<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| Sentinel-5 prec | ESA | LEO SS ~10:00 | UVN Spectrometer | UVN nadir | | | | | | | | | | | | | | | | | | | | |
| Sentinel-5 | ESA | LEO SS ~10:00 | IR Spectrometer<br>UVN Spectrometer | IR limb<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| EarthCARE | ESA-JAXA | LEO SS 10:30 | ATLID<br>MSI | Aerosol-lidar<br>Imager | | | | | | | | | | | | | | | | | | | | |
| A-SCOPE | ESA | LEO | Lidar | CO2-lidar | | | | | | | | | | | | | | | | | | | | |
| PREMIER | ESA-SSC | LEO SS 10:30 | IMIPAS<br>STEAM-R | IR limb<br>MW limb | | | | | | | | | | | | | | | | | | | | |
| TRAQ | ESA | LEO not SS | UVN Spectrometer<br>IR Spectrometer<br>Imager<br>Polarimeter | UVN nadir<br>IR nadir<br>Imager<br>MAP | | | | | | | | | | | | | | | | | | | | |
| NOAA-N' | NOAA | LEO SS 13:30 | AVHRR-3<br>SBUV-2 | Imager<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| NPP | NOAA | LEO SS 10:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| NPOESS-1 | NOAA | LEO SS 13:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| NPOESS-2 | NOAA | LEO SS 13:30 | OMPS<br>VIIRS | UVN nadir<br>IR nadir | | | | | | | | | | | | | | | | | | | | |
| Metop-1 | EUMETSAT | LEO SS 09:30 | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | | | | | | | | | | | | | | | | | | | | |
| Metop-3 | EUMETSAT | LEO SS 09:30 | GOME-2<br>IASI<br>AVHRR-3 | UVN nadir<br>IR nadir<br>Imager | | | | | | | | | | | | | | | | | | | | |
| MSG-3<br>Meteosat-10 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | | | | | | | | | | | | | | | | | | | | |
| MSG-4<br>Meteosat-11 | EUMETSAT | GEO 0 lon | SEVIRI | Imager | | | | | | | | | | | | | | | | | | | | |
| Chinook | CSA | LEO SS ~06:00 | SWIFT | O3 IR limb | | | | | | | | | | | | | | | | | | | | |
| GOSAT | JAXA | LEO SS 13:00 | TANSO-FTS<br>TANSO-CAI | IR nadir<br>Imager | | | | | | | | | | | | | | | | | | | | |
| GCOM-C | JAXA | LEO | SGLI | UVN nadir | | | | | | | | | | | | | | | | | | | | |
| FY-3 [B-G] | CMA | LEO SS | VIRR<br>TOU/SBUS | Imager<br>UVN nadir | | | | | | | | | | | | | | | | | | | | |
| FY-4 Q [A-E] | CMA | GEO | MCSI | Imager | | | | | | | | | | | | | | | | | | | | |

**Table 4-64: PAN Measurements from Planned Missions for Air Quality Requirements**

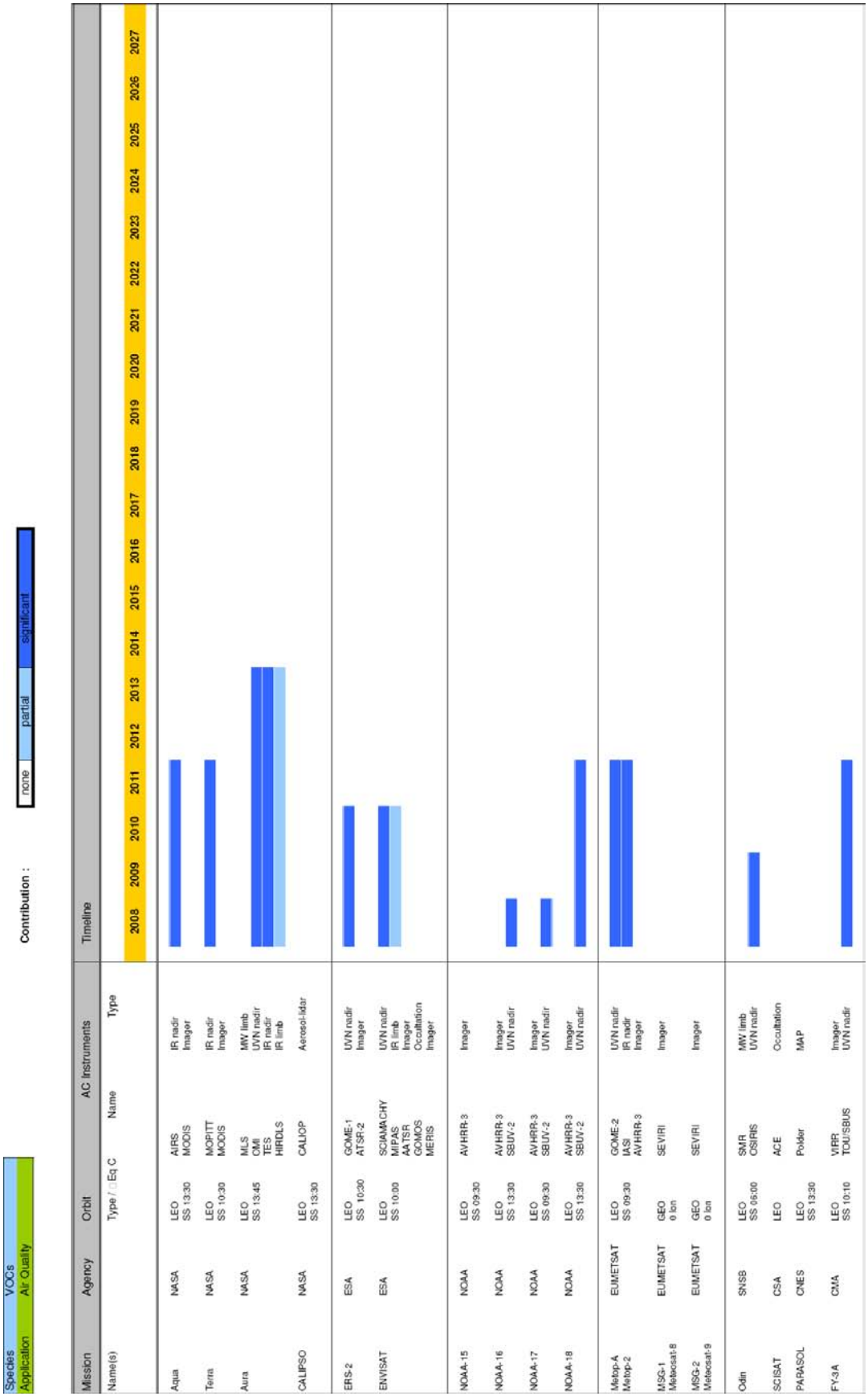


**Table 4-65: VOC Measurements from Current Missions for Air Quality Requirements**

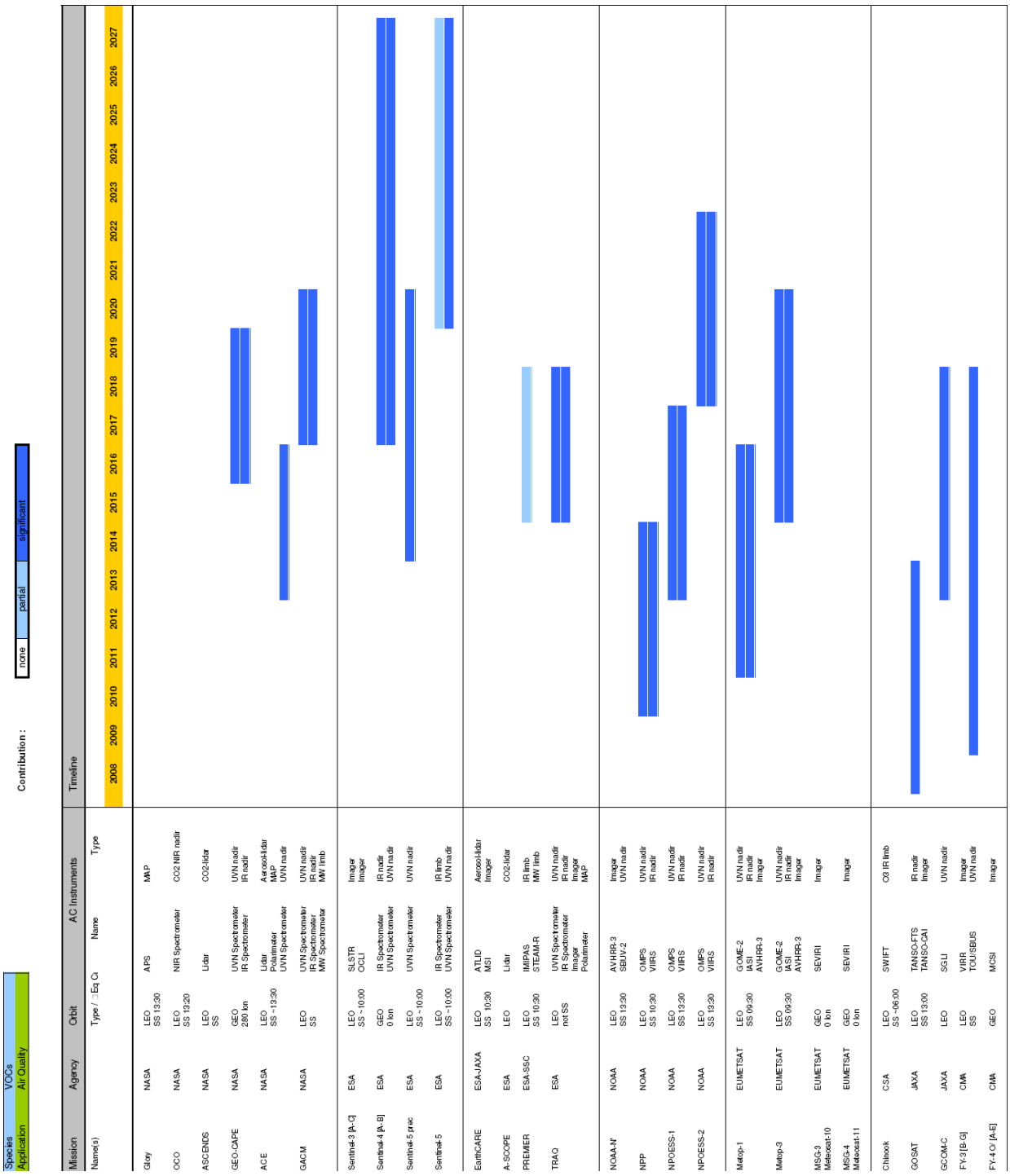


**Table 4-66: VOC Measurements from Planned Missions for Air Quality Requirements**

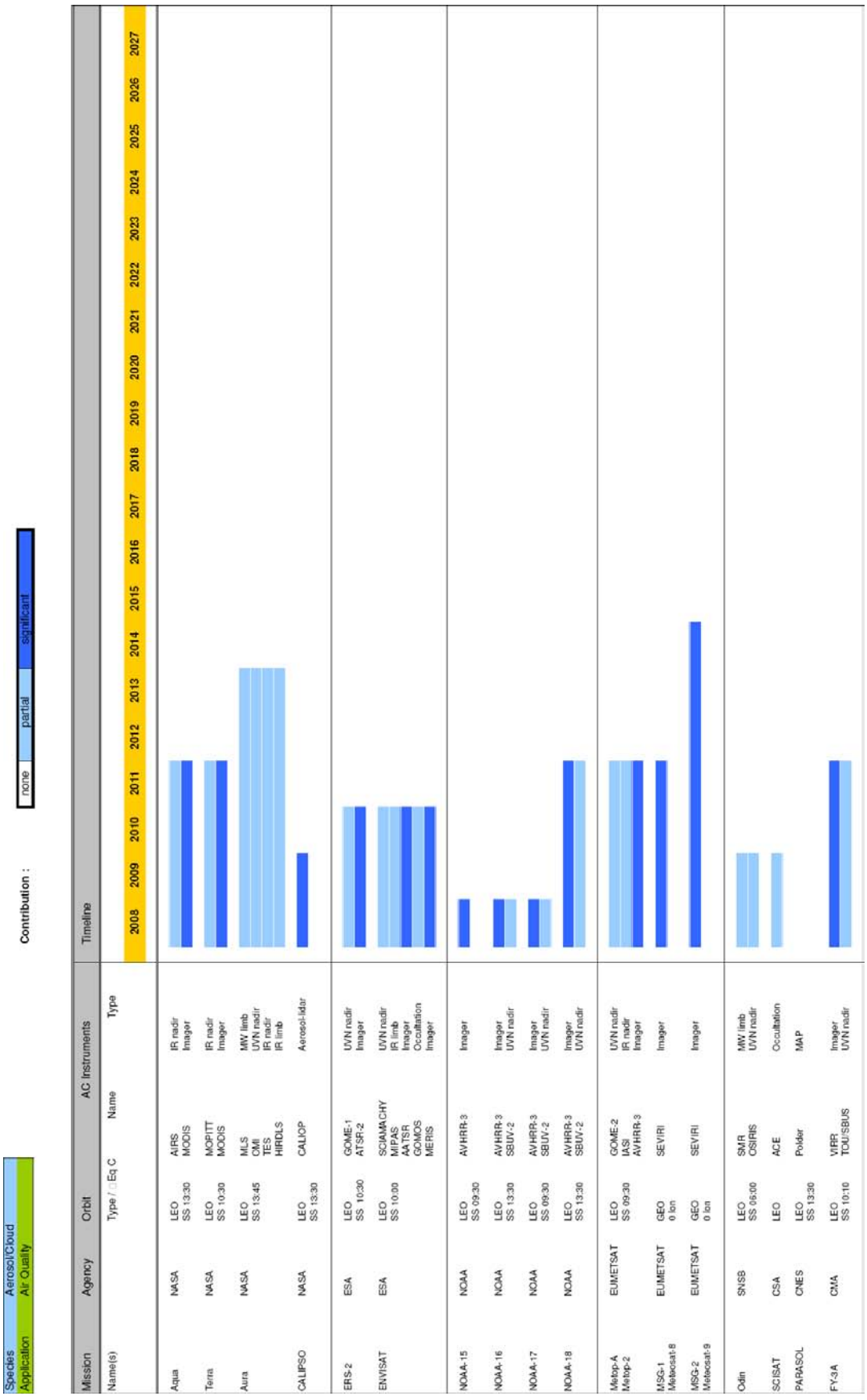


**Table 4-67: Aerosol & Cloud Measurements from Current Missions for Air Quality Requirements**

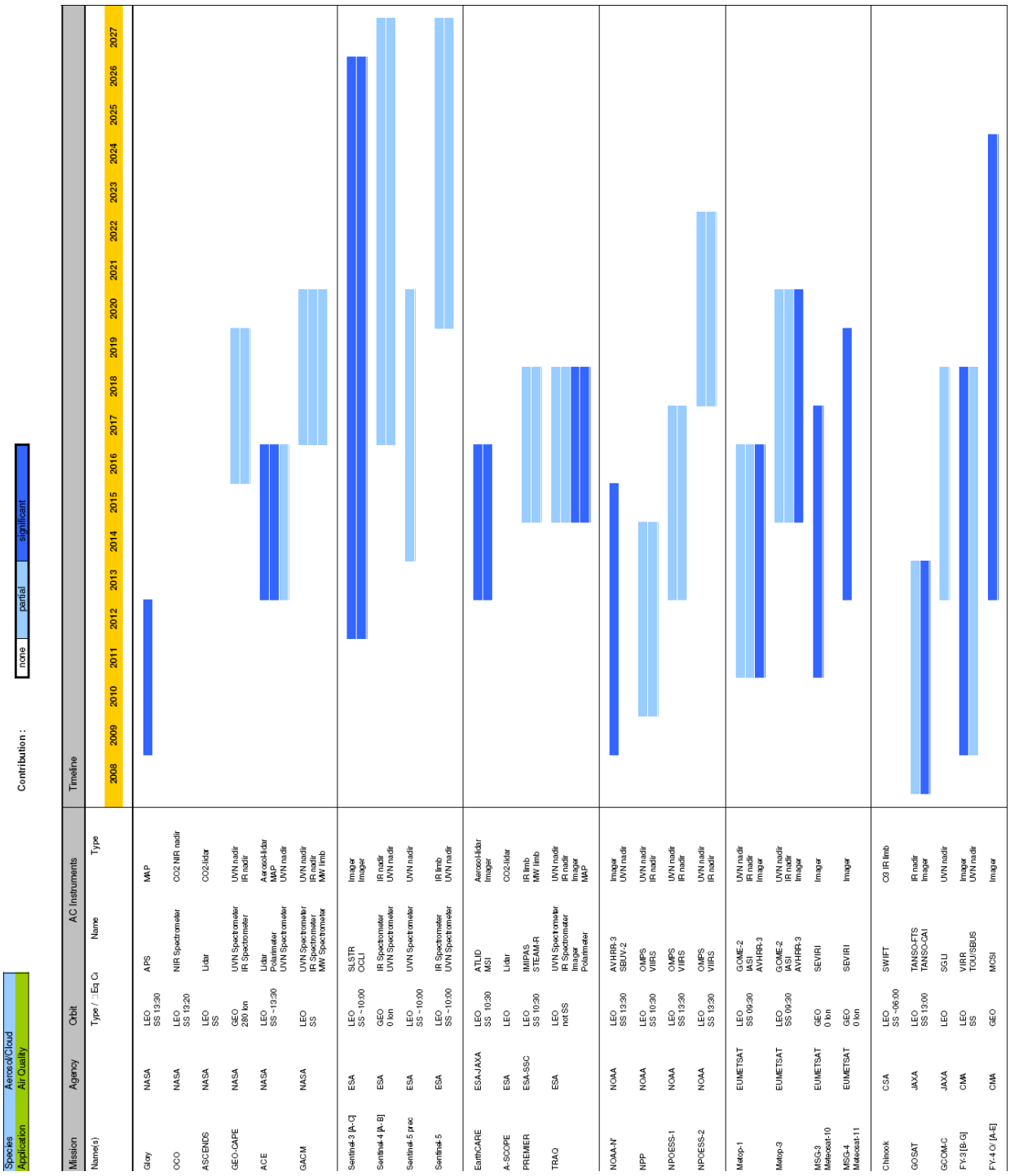


**Table 4-68: Aerosol & Cloud Measurements from Planned Missions for Air Quality Requirements**

# 5 Summary & Comment

## *5.1 Summary of Report*

### Requirements

Requirements for atmospheric composition measurements have been drawn together from a variety of sources including information from US, European, multinational and national programmes. The emphasis is on atmospheric monitoring over the next decade and beyond, though it should be noted that the US Decadal Survey requirements include more detailed research aspects also.

A list of required products and relevant application areas has been identified and collected, and detailed, quantitative data on requirements for measurement height domain, resolution, sampling or revisit time, accuracy, coverage and stability presented where available.

### Missions

Information on current and planned missions by national and international agencies and organisations has been collected and atmospheric composition capability identified. Mission parameters have been collated and instruments classified into measurement type groups.

The capabilities of measurement types in terms of addressing the products and applications have been assigned so that, in conjunction with the information on missions, an analysis of how the missions address the requirements can be made.

### Analysis

An analysis to compare application requirements with the capabilities of current and planned missions has been carried out. It is an attempt to bring together information on requirements and missions. The interpretation of this information is made in a general sense, however, and a number of implicit assumptions are made, including the capability of generic instrument types and the nature of the requirements.

The analysis indicates the potential of the current and planned suite of missions to address the identified applications in the time frame from 2008 to ~2025. It is assumed that data delivery and compatibility issues are overcome. Mission failure and associated redundancies are treated without detailed examination of mission risks.

## 5.2 Comment

The work carried out in this study is intended to serve as a guide and reference and include a collection of useful information. For any specific application, a more detailed examination of requirements and the capabilities of available and planned measurements would need to be made.

A number of questions and issues naturally arise:

- Can all the data be brought together?
- Is the data compatible?
- Is timely delivery of data an issue (e.g. for forecasting applications), how feasible is it?
- Are there operational issues for current missions? (e.g. product quality, lifetime)
- What is the probability of instrument or mission failure?
- How should redundancy be handled?

Planned missions have a number of uncertainties associated with them such as:

- What is their selection status?
- What is the probability of launch date shift or delay?
- Are there orbit options?

The development of missions is a continually evolving process and even the measurement requirements are likely to change as atmospheric science progresses. Work updating the work presented here in some context seems likely to be appropriate in the future.

***Acknowledgement***

*The author would like to thank Dr Ernest Hilsenrath and Dr Brian Killough for their numerous inputs, constructive comments and helpful discussions during the course of this study.*

# A Instrument Types in this Study and the WMO Study

In this study, instrument types have been classed into 9 basic groupings, with 5 nadir (or near-nadir) and 4 limb types and solar occultation.

These and associated types used in the WMO Study,

> *"Gap Analysis",* B. Bizzarri, WMO , 2nd Workshop on the Re-Design and Optimisation of the Space-Based GOS, Geneva, Switzerland, 21-22 June 2007, OPT2/Doc. 5 (11.VI.2007)

are indicated in Table A-1.

| Instrument Type | Abbreviation | WMO "Gap Analysis" Associated Types |
|---|---|---|
| ***Nadir*** | | |
| Infrared | IR | 3. IR temperature/humidity sounding from LEO<br>4. IR temperature/humidity sounding from GEO<br>23. Cross-nadir IR spectrometry from LEO<br>24. Cross-nadir IR spectrometry from GEO |
| UV-Visible and/or Near-Infrared | UVN | 21. Cross-nadir short-wave spectrometry from LEO<br>22. Cross-nadir short-wave spectrometry from GEO |
| Lidar | Lidar | 20. Lidar-based missions |
| Multi-Angle Polarimeter | MAP | |
| Imager | Imager | 1. Multipurpose VIS/IR imagery from LEO<br>2. Multipurpose VIS/IR imagery from GEO |
| ***Limb*** | | |
| Infrared | IR | 26. Limb-sounding IR spectrometry |
| Millimetre/Sub-Millimetre | MM | 27. Limb-sounding Sub-millimetre wave spectrometry |
| UV-Visible and/or Near-Infrared | UVN | 25. Limb-sounding short-wave spectrometry |
| | | |
| ***Solar Occultation*** | Occultation | |

**Table A-1: Instrument Types and Abbreviations**

The WMO report is extensive, covering 29 instrument types. As indicated in the table, it includes composition measurements, but focuses on meteorology and also includes surface and radiation budget instruments. Although wide in scope it does not cover instrument performance or application areas in detail. It nevertheless provides a useful reference for some instrument types relevant to atmospheric composition and so is referenced here.