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IRDAS - Differential Absorption Spectroscopy in the SWIR for Greenhouse Gas Monitoring using Coherent Signal Sources in a Limb Sounding Geometry

WP2 Report

Science Objectives and Observational Requirements of the ACCURATE Mission Concept

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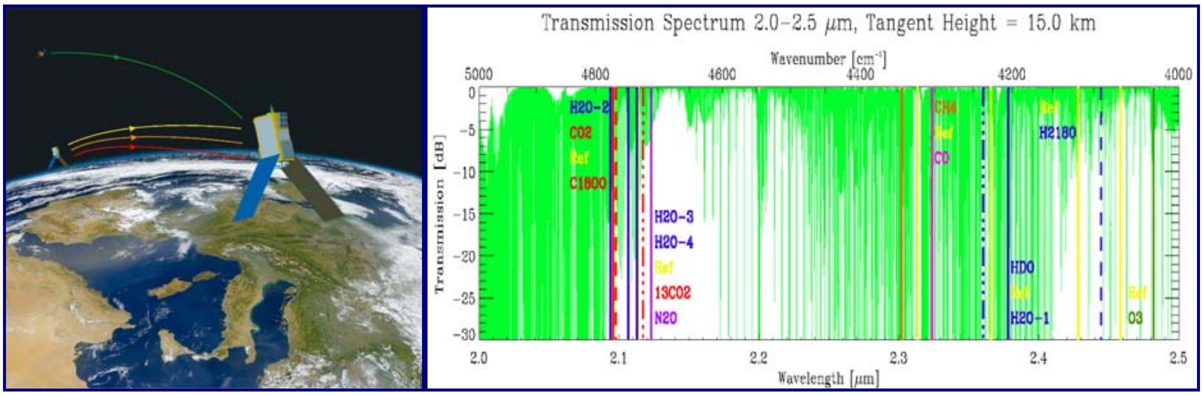

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Table of Contents

Scope of the Document

This document derives the observational requirements baseline for a mission concept following the ACCURATE mission proposed in 2005 [ACCU05]. The novel idea of that mission is to combine active microwave limb sounding with active limb sounding in the shortwave infrared band to enable very accurate measurements of the atmospheric state, including key trace species. The document describes the science objectives and observational requirements of the ACCURATE mission concept. The document is the output of WP2 in the IRDAS project.

The scope of the document is to consolidate the science objectives of the ACCURATE mission concept and establish the geophysical data requirements. The main traceable scientific and user observational requirements are collected and analyzed in support of the science objectives of the mission. The emphasis is on monitoring of climate change and on measuring and understanding key chemical constituents in the atmosphere.

The main requirements reference are observational requirements defined in the framework of WMO for climate monitoring, atmospheric chemical composition, and Numerical Weather Prediction (NWP). For climate monitoring the requirements are defined by the Global Climate Observing System (GCOS) in the report “Systematic observation requirements for satellite-based products for climate” [GCOS06]. The requirements on atmospheric chemical composition are defined in the Strategic Plan for Global Atmosphere Watch (GAW) [GAW07]. The NWP requirements are identified from the WMO observational requirements database.

Document Change Record

Issue	Date of Change	Where	Description of Change
v01	9. oct 2008	DMI	1st draft version
v02	31. oct 2008	DMI	Updated draft: including science goals, and tables on CGOS requirements
v03	21. Nov 2008	DMI	Included: Starting on Trace of observational requirements to WMO, CGOS and GWA Requirements. Examples are provided for H_2O and CO_2. References updated.
v04	24. Nov 2008	DMI	Observational requirements in appendix A are obtained from the WMO Database available on www.
v10	22. Dec 2008	DMI	Updated following actions from PM1. All observational requirements traced. Additional references to papers on isotopes included.
v11	15 Jan 2009	WEGC	Updated Section 2 (further science objectives refinement) and corresponding consistency updates to Sections 3 & 4
v20	15 Jan 2009	DMI	Updates from PB/U. York of 23 Dec. included. Updated according to the comments received from ESA on 5 January 2009.
v21	29 Jan 2009	WEGC	Further sub-editing updates throughout the document, especially for ensuring consistency with the state of recent and on-going ACCURATE-related activities.
v22	2 Feb 2009	DMI	Updated list of acronyms.
v23	22 Aug 2009	WEGC	Coherency updates with WP3-4 Scientific Impact and Synergies/Compl. report (esp. updated Tables 2-4, where Table 4 provides the link to the WP3-4 report).
v3	16 Sep 2009	WEGC	First complete version, including minor channel list adjustments based on IRDAS study results.
	Oct 2009	DMI, WEGC	Final version, having received final editing and also accounts for final ESA comments (the WP3-4 report will be kept consistent with this final report).

List of Acronyms

ACCURATE	Atmospheric Climate and Chemistry in the UTLS Region and climate Trends Explorer
ACE	Atmospheric Chemistry Experiment (Canadian solar occultation mission)
ACE+	Atmosphere and Climate Explorer (occultation mission studied by ESA 2002–2004)
ALPS	ACCURATE LIO Performance Simulator
ACTLIMB	Active Limb Sounding of Planetary Atmospheres
AOPC	Atmospheric Observation Panel on Climate
BW	Bandwidth (observational bandwidth, nominally corresponding to half the sampling rate)
B/T	Breakthrough
DLR/IPA	DLR Oberpfaffenhofen / Institut für Physik der Atmosphäre
DFB	Distributed Feedback laser
ECMWF	European Centre for Medium-Range Weather Forecasts (Reading, U.K.)
EGOPS	End-to-end Generic Occultation Performance Simulator
Envisat	Environmental Satellite (of the European Space Agency)
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
ESA	European Space Agency
FASCODE	FASt Atmospheric Signature CODE
FFG-ALR	Austrian Aeronautics and Space Agency of the Austrian Research Promotion Agency FFG
FOV	Field of View (remote sounding area sensed by receiver antennae or optics)
FWHM	Full Width at Half Maximum (line width measure for spectral lines and laser lines)
Galileo	European future global navigation satellite system
GAW	Global Atmosphere Watch
GCM	Global Circulation Model
GCOS	Global Climate Observing System
GHG(s)	Greenhouse gas(es)
GNSS	Global Navigation Satellite Systems (Global Navigation System, GPS, and Galileo)
GOMOS	Global Ozone Monitoring by Occultation of Stars (instrument on Envisat)
GOSAT	Greenhouse Gases Observing Satellite
GPS	Global Positioning System
GRAS	GNSS Receiver for Atmospheric Sounding
GRO	GNSS-LEO radio occultation (here Galileo & GPS L band signals, ~1.2 / 1.6 GHz)
HITRAN	High-resolution Transmission molecular absorption database
HT	Higher Troposphere (Equals UT)
IDL	Interactive Data Language (an interactive visual analysis software package)
IAEA	International Atomic Energy Agency
ICSU	International Council for Science
IGACO	Integrated Global Atmospheric Chemistry Observations
InGaAs	Indium-Gallium-Arsenide (IR optical detector material; also Extended InGaAs)
IOC	Intergovernmental Oceanographic Commission
IR	Infrared
IRDAS	Differential Absorption Spectroscopy in the SWIR for Greenhouse Gas Monitoring using Coherent Signal Sources in a Limb Sounding Geometry
l.o.s. wind	line-of-sight wind (denoting the wind speed along occultation rays)
LEO	Low Earth Orbit (or satellite in Low Earth Orbit)
LIO	LEO-LEO infrared laser occultation (here laser crosslink signals within 2–2.5 μm)
LMO	LEO-LEO microwave occultation (here microwave crosslink signals within 17–23 GHz and 178–183 GHz)

LRO	LEO-LEO radio occultation (here microwave crosslink signals within 17–23 GHz and 178–183 GHz)
LS	Lower Stratosphere (WMO: 100–10 hPa / ~15–35 km)
LT	Lower Troposphere (WMO: 1000–500 hPa / ~0–5 km)
MetOp	Meteorological Operational satellite (of EUMETSAT)
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MW	Microwave spectral region (3–300 GHz; here the 17–23&178–183 GHz regions)
NEP	Noise Equivalent Power (figure indicating optical detector sensitivity)
NWP	Numerical weather prediction
OCO	Orbiting Carbon Observatory
OOPC	Ocean Observation Panel on Climate
PBL	Planetary Boundary Layer
RF	Radio Frequency
RFM	Reference Forward Model
RH	Relative humidity
RMS, rms	Root Mean Square (average spread measure for statistical or total error)
SAF	Satellite Application Facility
SI	Système International (International system of fundamental physical units)
SNR	Signal-to-noise ratio
SWIR	Short wave infrared spectral region (1.5-3 μm; here referring to the 2–2.5 μm region)
TBL	Top of atmospheric boundary layer
T/H	Threshold
TOA	Top of the Atmosphere (in ACCURATE LIO generally referring to 60 km height)
TOPC	Terrestrial Observation Panel on Climate
Tx, Rx	Transmitter (Tx) resp. Receiver (Rx); also Transmitter resp. Receiver satellite
UNEP	United Nations Environment Programme
US	Upper Stratosphere (WMO: 10–1 hPa / ~35–50 km)
UT	Upper Troposphere (WMO: 500–100 hPa / ~5–15 km)
UTC	Universal Time Coordinated (worldwide standard time)
UTLS	Upper Troposphere & Lower Stratosphere region (WMO: 500–10 hPa / ~5–35 km)
WEGC	Wegener Center for Climate and Global Change
UniGraz	University of Graz (Austria)
VOC	Volatile Organic Compound
WALES	Water vapour Lidar experiment in space (ESA water vapor mission concept)
WMO	World Meteorological Organization
X/K band	Microwave band covering the frequencies 7–40 GHz
H_2O, CO_2, CH_4	water vapor, carbon dioxide, methane (ACCURATE target species)
N_2O, O_3, CO	nitrous oxide, ozone, carbon monoxide (ACCURATE target species)
$^{13}CO_2$, $C^{18}OO$	“heavy-carbon” and “heavy-oxygen” carbon dioxide main isotopologues (ACCURATE target isotopic species for carbon dioxide)
HDO, $H_2{}^{18}O$	“heavy-hydrogen” and “heavy-oxygen” water vapor main isotopologues (ACCURATE target isotopic species for water vapor)

1 Introduction

In this report the ACCURATE mission concept is evaluated and justified based on the science and user requirements from international organisations. Such a mission was first proposed as an ESA Earth Explorer Core Mission in 2005 [ACCU05], with the novel idea of measuring atmospheric chemical constituents by near-infrared laser occultation between two dedicated LEO satellites, in addition to microwave occultation as in a previous concept ACE+ [ESAACE+04].

Using the occultation technique at GPS frequencies the refractivity of the atmosphere can be accurately measured (GPS radio occultation) but with the use of higher frequencies in the microwave up to 200 GHz this also allows for measurements of water vapour and ozone by absorption [Kursinsk02]. By extending this idea even further to the SWIR range a wider range of constituents can be measured, including the greenhouse gases CO_2 and CH_4 [ACCU-PERF07]. This study aims to analyse the utility of occultation-based differential absorption spectroscopy of the atmosphere in the SWIR region, combined with the MW region, and to put this into context with observational requirements.

The baseline target geophysical variables are summarized in Table 2. For gaseous air it includes thermodynamic state variables (temperature, pressure, and water vapor), composition variables (key atmospheric trace species, where we target climate-relevant trace species, i.e., greenhouse gases such as CO_2, CH_4, and N_2O in addition to H_2O and O_3), and wind as the fundamental dynamical variable (where especially meridional wind/Brewer-Dobson circulation is targeted).

For the particulate suspensions in air, considered as by-products, the baseline includes free atmospheric aerosol (such as dust aerosol and stratospheric sulfate aerosol) as well as free atmospheric clouds (both liquid and ice clouds), where “free atmospheric” denotes that we do not focus on issues within the planetary boundary layer (PBL). Furthermore, cloud layering profiling (by SWIR signals) is pursued (aiding trace gas retrieval; cf. [ACCUPERF07]) and also turbulence strength is considered an interesting by-product.

The geometrical baseline will be a LEO-LEO crosslink configuration as available from ACE+ and ACCURATE studies (e.g., [ESAACE+04; ACCU05; ACCUPERF07; ACCUE-GOPS07]). The frequency channels baseline is a heritage of promising MW and IR channels from these studies as well. This is summarized by Table 3 and comprises channels from 8-30 GHz (cm-waves, MW), 175-200 GHz (mm-waves, MW), and 2-2.5 μm (SWIR).

A review of these channels has been performed as part of the ESA ACTLIMB study and the results are described in [TR-REVOCC]. Table 3 represents the baseline for channels as a result of that review and subsequent small adjustments based on the on-going ESA-ACTLIMB and ESA-IRDAS studies. In the latter study the IR channel selections were evaluated and confirmed also based on real high-resolution balloon spectra from solar occultation.

The observational requirements for the ACCURATE mission concept are summarized in Table 4 and are traced to the requirements in the framework of WMO (Section 5, Table 5). ACCURATE is found to be capable of a comprehensive and unique contribution to fulfilling these requirements as part of the future global satellite observing system for climate, composition, and NWP.

With the science objectives and international recommendations ACCURATE can address and meet (Sections 2 and 3), it is highly complementary to passive radiometric atmospheric sounding capabilities, which focus on horizontal resolution and precision over accuracy, and can provide unprecedented climate benchmark data with high vertical resolution, accuracy, consistency, and long-term stability.

2 Science objectives

The science objectives for an ACCURATE mission are here defined based on the ACCURATE proposal [ACCU05], extended by later results which show, for example, that the wind field is also accessible [ACCUPERF07]. The primary foci are on climate research, climate monitoring, and composition trends and variability. Secondary science objectives are the study of atmospheric processes as well as the use of these observations in operational models for numerical weather prediction (NWP) and operational models for analysis and forecasting of atmospheric constituents and transport of pollution. There are also important spin-off benefits [ACCU05] but we focus here on the key goals expressed in the main objectives as these provide the basis for deriving the geophysical data and observational requirements.

The primary mission objectives of the ACCURATE mission (taking into account subsequent advancements past [ACCU05]) are listed here:

- Monitoring of climate variability and trends in thermodynamic variables (temperature, pressure, humidity), in greenhouse gases (H_2O, CO_2, CH_4, N_2O, O_3, CO) including H_2O and CO_2 isotopes, and in the wind field (meridional wind) as initial key components of long-term benchmark observations of climate in the atmosphere;

- Diagnosing changes in the thermal, chemical, radiative, dynamical, cloud, and aerosol structure in the UTLS region based on the consistent benchmark dataset obtained;

- Contribution to the detection and attribution of anthropogenic and natural climate and composition changes in the atmosphere, as well as of changes in the global carbon and water cycles, and support to climate change predictions via global reference data of climate benchmark quality;

- Validation of global circulation models (GCMs) in simulated mean climate and variability seen in atmospheric physics/chemistry/radiation variables in the UTLS;

- Testing and improvement, for example via data assimilation methods, of physics and chemistry parameterizations in GCMs, such as related to radiation and energy balance, and of the characterization of external forcing variations;

- Improvement of the understanding of climate forcing variations (e.g., greenhouse gases and aerosol) and of climate feedbacks determining magnitude and characteristics of climate changes, especially related to chemistry-climate interactions and the carbon and water cycles;

- Study of processes in the UTLS region at high vertical resolution, in the context of atmospheric physics and chemistry research, including aerosol, cloud, and dynamical variability studies;

- Provision of reference data for the calibration, validation, and analysis of data from other space missions or airborne/ground-based observing systems;

- Demonstration of the science value of the novel combined LEO-LEO microwave occultation and LEO-LEO infrared laser occultation technique (LMO+LIO).

These primary mission objectives from the ACCURATE proposal and subsequent adjustments are transformed into focused science objectives of a future ACCURATE mission. The focus here is on the innovative remote sensing method of combining the novel LEO-LEO infrared laser occultation (LIO) [ACCU05; ACCUPERF07], using a differential absorption spectroscopy technique in the shortwave infrared region, with the LEO-LEO microwave occultation method (LMO) [Kursinsk02; KircHoeg04; ESAACE+04].

The users of such a mission are grouped into three categories: Climate users, Atmospheric chemistry users, and NWP users. In Appendix A reference to the key international programmes defining these user requirements is given and respective Requirements Tables are listed. The primary science users of an ACCURATE mission are identified as the climate and atmospheric chemistry users. In Section 3 essential recommendations of international bodies are therefore summarized for these two user communities. For the implementation of those recommendations an ACCURATE mission can provide unique contributions. Contributions are also brought to NWP users, which is addressed as a secondary objective.

For climate a main science and research output of such a mission (as a single mission) is on improving the understanding of climate forcings and climate feedback mechanisms such as related to the chemistry-climate interactions and the carbon and water cycles. Also model testing, validation, and improvement are vital research objectives.

Monitoring of climate variability and change is a very important science goal of such a mission, however, it cannot be achieved over longer time scales (a decade and longer) with just one mission on its own. To detect anthropogenic climate and chemical changes in the atmosphere a long time series of measurements is needed. An initial ACCURATE mission, the estimated lifetime of which is > 3 years, can provide the first step in this time series and can also be used to validate and gauge other similar measurements. Follow-on missions need be implemented in order to achieve a period of > 10 years of measurements. By concept ACCURATE is perfectly suited to act as a long-term global backbone measurement system for monitoring the atmospheric state over decades.

Measurements of atmospheric constituents are also becoming increasingly important for forecasting of atmospheric composition (“chemical weather forecasting”). The first steps in this direction have been taken for example by the European GEMS project and there is a need for near real time satellite measurements of atmosphere composition [GEMS08]. ACCURATE can contribute independent data free of bias-correction needs for these applications.

The ACCURATE mission concept allows the measurement of profiles of CO_2. No other mission is currently capable of this and none are planned. JAXA’s GOSAT mission will provide total vertical CO_2 columns weighted towards the lower troposphere as standard data products, but not height profiles (the same was the goal for NASA’s OCO mission but launch failed and future is not clear). The need for measuring profiles of CO_2 – and other constituents – is presented by the user community in the recommendations from Global Atmosphere Watch under the WMO [GAW07].

Note that below the science objectives use very much similar wording as the ACCURATE mission objectives above; this is to show a clear trace. The order of the objectives is partly shifted to relatively increase the emphasis on the goals of measuring and understanding forcings, feedbacks and chemistry-climate interactions in the atmosphere.

Primary science objectives

1) Monitoring of climate variability and trends in thermodynamic variables (temperature, pressure, humidity), in greenhouse gases (H_2O, CO_2, CH_4, N_2O, O_3, CO) including H_2O and CO_2 isotopes, and in the wind field (meridional wind), and diagnostics of UTLS thermal, chemical, radiative, and dynamical changes, as an initial key component of long-term benchmark observations of climate in the atmosphere;

   Contribution to detection and attribution of anthropogenic and natural climate and composition changes in the atmosphere, as well as of changes in the global carbon and water cycles, and support of climate change predictions via global reference data of climate benchmark quality;

   Improvement of the understanding of climate forcing variations (e.g., greenhouse gases and aerosol) and of climate feedbacks determining magnitude and characteristics of climate changes, especially related to the carbon and water cycles and to climate-chemistry interactions;

2) Testing of global circulation models (GCMs) and improvement of their physics and chemistry parameterizations, such as related to radiation and energy balance, to enhance their predictive skill for simulating future climate and chemical composition;

   Validation of GCM runs, in simulated mean climate and climate variability seen in atmospheric physics/chemistry/radiation variables in the UTLS region;

3) Provision of reference data for the calibration, validation, and analysis of data from other space missions or airborne/ground-based observing systems;

   Demonstration of the science value of the novel combined LEO-LEO microwave occultation and LEO-LEO infrared laser occultation technique (LMO+LIO).

Secondary science objectives

1) Study of atmospheric processes in the UTLS region at high vertical resolution, in the context of atmospheric physics and chemistry research, including aerosol, cloud, and dynamical variability studies;

2) Use of the LMO+LIO measurements in NWP and atmospheric constituent models to improve on forecasting and analysis of weather conditions as well as of the atmospheric composition.

For information on spin-off benefits see the original ACCURATE proposal [ACCU05].

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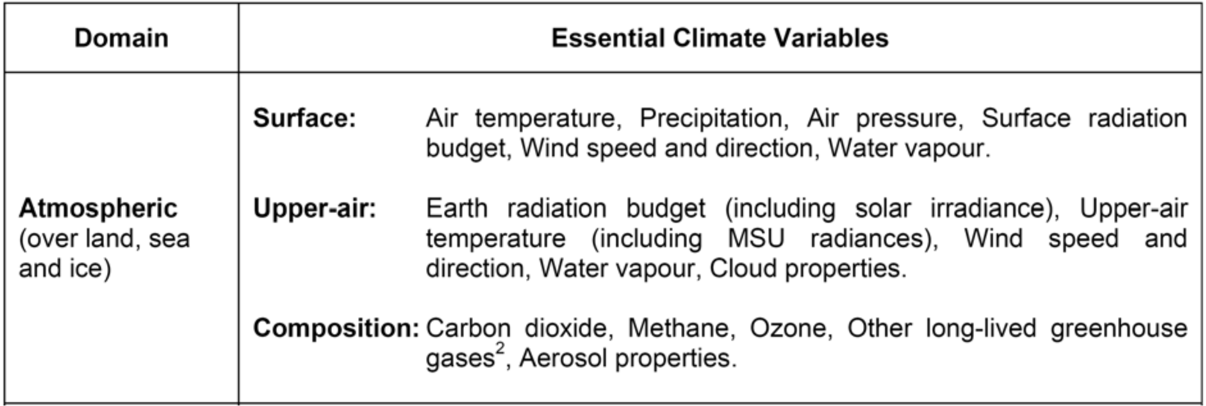
3 Recommendations from WMO and GCOS

Climate. The World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU) all jointly sponsor the Global Climate Observing System (GCOS), which attempts to ensure the availability of global observations of climate. GCOS was established in 1992 and has recently prepared two relevant reports: “Implementation plan for the global observing system for climate in support of the UNFCCC” [GCOS04] and a supplementary report, “Systematic observation requirements for satellite-based products for climate” [GCOS06]. In Table 1 of [GCOS04] the essential climate variables for the atmosphere are listed, which should be measured with particular priority.

Table 1. GCOS Essential Climate Variables (ECVs) for the Atmospheric Domain.



Domain	Essential Climate Variables	
Atmospheric (over land, sea and ice)	**Surface:**	Air temperature, Precipitation, Air pressure, Surface radiation budget, Wind speed and direction, Water vapour.
	Upper-air:	Earth radiation budget (including solar irradiance), Upper-air temperature (including MSU radiances), Wind speed and direction, Water vapour, Cloud properties.
	Composition:	Carbon dioxide, Methane, Ozone, Other long-lived greenhouse gases[2], Aerosol properties.

[2] Including nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6), and perfluorocarbons (PFCs).

Atmospheric chemistry. The WMO organizes the Global Atmosphere Watch (GAW) established in 1989. The main long-term objective of GAW is to establish a three-dimensional global atmospheric chemistry measurement network based on observations by ground stations, balloon, aircraft, satellites, and other remote sensing observations. The strategic plan for GAW [GAW07] includes the implementation of the Integrated Global Atmospheric Chemistry Observations (IGACO) strategy [IGACO04].

The development of GAW focal areas is summarized as follows in [GAW07]:

Ozone (O_3) plays a central role in physical, chemical, and radiative processes in the atmosphere. The success of the Vienna Convention on Protection of the Ozone Layer and its Montreal Protocol is undisputed. However, the need to continue observations of stratospheric ozone has been re-enforced in the early 21st century with the occurrence of ozone holes of unprecedented dimensions. Trends, both in the stratosphere and in the troposphere remain a topic of scientific debate. […Dobson and Brewer instruments…] Satellite retrievals have become mature, and the focus should be on establishing good calibration histories for validation purposes and to enable the transition from one sensor to another. Further integration of the ozone sonde networks and other sources of vertical profile information (Umkehr, Lidar and microwave) into one global network is needed. Implementation of near-real-time data delivery capabilities will further increase the value of these observations for numerical weather prediction and model validation. The recognition of the GAW ozone networks as comprehensive GCOS networks is a priority.

Of the greenhouse gases that are directly affected by anthropogenic activities, carbon dioxide (CO_2) has the largest total radiative effect, followed by chlorofluorocarbons (CFCs), methane (CH_4), tropospheric ozone (O_3), and nitrous oxide (N_2O). Reliable long-term estimates of sources and sinks appropriate to particular emission management scenarios require very high accuracy and precision observations of the abundance and the vertical distribution of CO_2 and CH_4 as well as their isotopes. The global networks are still incomplete and should be augmented with continuous measurements on the continents, the Arctic, the tropics, and the oceans. A challenge and opportunity is the validation and use of satellite observations that are becoming available. Apart from the major greenhouse gases CO_2 and CH_4, the emergence of substitutes for chemicals banned under the Montreal Protocol and regulated under the Kyoto Protocol needs to be closely monitored. Calibration standards for some of these compounds still need to be harmonized and an accuracy of observations achieved that is sufficient to verify emission inventories. The GAW CO_2 and CH_4 networks have already been identified as comprehensive networks in GCOS and the incorporation of the GAW N_2O, CFCs and SF_6 networks is a priority.

The reactive gases as a group are very diverse and include surface ozone (O_3), carbon monoxide (CO), volatile organic compounds (VOCs), oxidised nitrogen compounds (NO_x, NO_y), hydrogen (H_2), and sulphur dioxide (SO_2). These compounds determine the oxidizing capacity of the atmosphere and influence the formation of tropospheric ozone and aerosols, and are therefore relevant to air quality and climate. The surface-based observational network for most of these compounds is totally inadequate and a continuous challenge for the development of the programme. A wealth of information has been obtained through aircraft programmes that are of high priority for GAW, and limited information has been derived from satellites. The global trends of most of these compounds are not sufficiently well understood, and probably influenced by increasing emissions in Asia. The objectives are to expand the current networks and establish global networks, to further improve and institutionalise the quality assurance and control processes and to better integrate various data sources.

This is supported by the recommendations by the 14th WMO/IAEA Meeting of Experts on Carbon Dioxide Concentration and Related Tracers Measurement [WMO/IAEA]. The following two points are cited from their recommendations:

“d) Develop and implement long-term measurements of total column Greenhouse Gases at a number of sites in WMO-GAW and its partner stratospheric network NDAAC recognising the need for satellite calibration/validation and modelling.”

“f) Develop high-quality measurements of carbon cycle tracers that can be used to attribute natural fluxes to their controlling processes ($^{13}CO_2$, O_2/N_2, ^{18}OCO, stable isotopes in CH_4 and CO) and separate fossil fuel emissions ($^{14}CO_2$, CO…).”

The science objectives in Section 2 show that an ACCURATE mission can provide comprehensive and unique contributions for the implementation of both the climate and the atmospheric chemistry recommendations. Compared to several (implicit) expectations in the recommendations of what global satellite observing systems are capable of contributing in addition to ground-based systems, the ACCURATE concept (not yet thought of when the recommendations were written) can be expected to contribute significantly beyond expectations.

4 Definition of geophysical data requirements

Based on the science objectives (Section 2) the set of geophysical parameters as shown in Table 2 is to be measured by the ACCURATE mission (based on [TR-REVOCC]).

Table 2. Baseline set of geophysical parameters from LMO and LIO data.

		Target Parameters	Vertical domain				Target [km]	Threshold [km]
			LT	UT	LS	US		
MWO	**LMO**	refractivity	b.e.	×	×	×	5-50	7-40
		pressure	b.e.	×	×	×	5-50	7-40
		geopotential height	b.e.	×	×	×	5-50	7-40
		temperature	b.e.	×	×	×	5-50	7-40
		H_2O	b.e.	×	b.e.		5-18	7-12
		(O_3)		×	×	b.e.	5-35	10-30
		(liquid water)	b.e.	×			5-10	b.e.
		(ice water)	b.e.	×			5-18	b.e.
		(turbulence strength)	b.e.	×	b.e.		5-15	b.e.
ILO	**LIO**	H_2O	b.e.	×	×	b.e.	5-35	7-30
		CO_2	b.e.	×	×	b.e.	5-35	7-30
		$^{13}CO_2$	b.e.	×	×	b.e.	5-35	7-30
		$C^{18}OO$	b.e.	×	×	b.e.	5-35	7-30
		CH_4	b.e.	×	×		5-35	7-30
		N_2O	b.e.	×	×		5-35	7-30
		O_3		×	×	b.e.	5-35	10-30
		CO	b.e.	×	×		5-35	7-20
		HDO	b.e.	×			5-12	b.e.
		$H_2{}^{18}O$	b.e.	×			5-12	b.e.
		l.o.s. wind		×	×	b.e.	10-40	15-35
		(cloud layering)	b.e.	×	×		5-35	7-18
		(aerosol extinction)	b.e.	×	×		5-35	b.e.
		(turbulence strength)	b.e.	×	×	b.e.	5-35	b.e.

Following WMO definition of vertical domain (height ranges):
LT … Lower Troposphere [TBL ~2 km to 5 km]
UT … Upper Troposphere [5 km to 15 km]
LS … Lower Stratosphere [15 km to 35 km]
US … Upper Stratosphere [35 km to 50 km]

The “Target [km]” and “Threshold [km]” columns denote the target / threshold vertical domain ranges

b.e.: “best effort”, i.e., retrieved on a best-effort basis in a height range

l.o.s. wind: line-of-sight wind, i.e., the wind along the occultation limb paths that should be based on polar or near-polar orbits to access in particular meridional wind (focus on Brewer-Dobson circulation)

Parameters in parentheses: By-products, not parameters of primary interest or (for O_3 from LMO) an optional complementary product. The two water isotopes HDO and $H_2{}^{18}O$ are not in parentheses since they are core products but they are parameters of secondary interest and therefore have no explicit threshold domain specified (see also footnote 8 of Table 4 in Section 5). If only a reduced number of LIO measurement channels is affordable in a first demonstration mission, these two isotopes, and CO and O_3 if even more reduction needed, are optional (see also footnote 1 of Table 4 in Section 5).

The first group of primary science objectives of monitoring of climate variability and trends in the thermodynamic variables are achieved by the LMO profile measurements. The addition of near infrared measurements, LIO, is the novel idea in the ACCURATE mission concept as compared to the past ACE+ proposal and allows the measurements of key atmospheric constituents such as CO_2 as profiles in the UTLS region. ACCURATE provides the first high-quality profiling measurements of these species, including of isotopes that will help to increase retrieval accuracy ($^{13}CO_2$ for CO_2) or chemical ($C^{18}OO$) and thermodynamical (HDO, $H_2{}^{18}O$) understanding of processes in the free atmosphere (see also Section 5.3).

The data will contribute to the monitoring and detection of anthropogenic climate and chemical changes in the atmosphere, i.e., serving primary science objectives (cf. Section 2). The measurements are also necessary to achieve the additional primary science objective of an improved understanding of climate forcing variations and climate feedback mechanisms such as related to the chemistry-climate interactions.

For the further primary science objectives on testing, validation and improvement of climate models (GCMs), involving also data assimilation, both the thermodynamic variables and the consistent composition measurements are important constraints. The thermodynamic parameters from MWO, as available from the existing GPS radio occultation missions (the first few parameters listed under LMO in Table 2), are already being utilized in NWP models and the technique can be transferred to be used with GCMs in climate mode. The LMO and especially the LIO profiles will be very important new data sources of unprecedented accuracy to be assimilated into such models. Demonstrating the science value of the combined LMO+LIO dataset is thus in itself a complementary primary objective.

All the LMO and LIO profiles will have a high vertical resolution necessary also for the secondary science objective to study physics, chemistry, and dynamic variability of atmospheric processes in the UTLS region. For the secondary science objectives to support NWP and chemical composition forecasting, note that NWP models are now starting to include the prediction of the atmospheric constituents and aerosols; for example, first steps were taken in the GEMS project [GEMS08]. The LIO measurements will be a very valuable source of observational data for such advanced models while the basic LMO data will provide a strong thermodynamic constraint eliminating potential biases in the modeled and analyzed mass fields of the atmosphere.

The physical parameters of the ACCURATE mission concept are measured by utilizing two frequency bands. The LMO microwave band using frequencies in the ranges 8–30 GHz (cm-waves) and 175–200 GHz (mm-waves), and the LIO short-wave infrared band in the interval of 2–2.5 μm. In order to specify how ACCURATE covers the geophysical data requirements by its measurement design, Table 3 below shows the selected channels for the mission.

This selection reflects the up-to-date status as provided by the ESA-ACTLIMB study based on the heritage from [ACCUPERF07] and presented in the TR-REVOCC report [TR-REVOCC]. Further refinement of these channel selections as part of the on-going ESA-ACTLIMB and IRDAS studies has also been accounted for in Table 3, which shows the consolidated list. These refinement changes when finishing the report were minor and did not lead to changes in the requirement formulations given subsequently below.

Table 3. Baseline set of ACCURATE LMO and LIO channels.

Channel ID	**Channel Frequency**	**Channel Wavelength**	**Channel Utility**	**Target Parameters**
(X1) b.e.	9.70 GHz	3.0906 cm	p,T retrieval, Abs/Ref[H_2O] ~LT	p, T, H_2O
(X2) b.e.	13.50 GHz	2.2207 cm	p,T retrieval, Abs/Ref[H_2O] ~LT	p, T, H_2O
K1	17.25 GHz	1.7379 cm	p,T retrieval, Abs/Ref[H_2O] ~UT	p, T, H_2O
K2	20.20 GHz	1.4841 cm	p,T retrieval, Abs/Ref[H_2O] ~UT	p, T, H_2O
K3	22.60 GHz	1.3265 cm	p,T retrieval, Abs/Ref[H_2O] ~UT	p, T, H_2O
M1	179.00 GHz	1.6748 mm	Abs/Ref[H_2O] ~10-18 km	H_2O
M2	181.95 GHz	1.6477 mm	Abs[H_2O] ~10-18 km	H_2O
(M3) b.e.	191.85 GHz	1.5626 mm	Ref[O_3]	O_3
(M4) b.e.	195.35 GHz	1.5346 mm	Abs[O_3]	O_3
I01	4029.110 cm^{-1}	2.4819 μm	Abs[O_3]	O_3
I02	4037.21 cm^{-1}	2.4770 μm	Ref[O_3]	(Ref 1)
I03	4090.872 cm^{-1}	2.4445 μm	Abs[$H_2{}^{18}O$]	$H_2{}^{18}O$
I04	4098.56 cm^{-1}	2.4399 μm	Ref[$H_2{}^{18}O$]	(Ref 2)
I05	4204.840 cm^{-1}	2.3782 μm	Abs[H_2O-1] ~13-48 km	H_2O
I06	4227.07 cm^{-1}	2.3657 μm	Ref[H_2O, HDO, CO]	(Ref 3)
I07	4237.016 cm^{-1}	2.3602 μm	Abs[HDO]	HDO
I08	4248.318 cm^{-1}	2.3539 μm	Abs[CO]	CO
I09	4322.93 cm^{-1}	2.3133 μm	Ref[CH_4]	(Ref 4)
I10	4344.164 cm^{-1}	2.3019 μm	Abs[CH_4]	CH_4
I11	4710.341 cm^{-1}	2.1230 μm	Abs[N_2O]	N_2O
I12	4723.415 cm^{-1}	2.1171 μm	Abs[$^{13}CO_2$]	$^{13}CO_2$, CO_2
I13	4731.03 cm^{-1}	2.1137 μm	Ref[N_2O, $^{13}CO_2$, H_2O]	(Ref 5)
I14	4733.045 cm^{-1}	2.1128 μm	Abs[H_2O-4] ~4-8 km	H_2O
I15	4747.055 cm^{-1}	2.1066 μm	Abs[H_2O-3] ~5-10 km	H_2O
I16	4767.037 cm^{-1}	2.0977 μm	Abs[$C^{18}OO$-w1], wind retrieval	l.o.s. wind
I17	4767.041 cm^{-1}	2.0977 μm	Abs[$C^{18}OO$]	$C^{18}OO$
I18	4767.045 cm^{-1}	2.0977 μm	Abs[$C^{18}OO$-w2], wind retrieval	l.o.s. wind
I19	4770.15 cm^{-1}	2.0964 μm	Ref[$^{12}CO_2$, $C^{18}OO$, H_2O, wind]	(Ref 6)
(A01)	4771.617 cm^{-1}	2.0957 μm	possible alternative for I16	l.o.s. wind
I20	4771.621 cm^{-1}	2.0957 μm	Abs[$^{12}CO_2$]	CO_2
(A02)	4771.625 cm^{-1}	2.0957 μm	possible alternative for I18	l.o.s. wind
(D01)	4772.176 cm^{-1}	2.0955 μm	Abs[$^{13}CO_2$] demo (use as ref. I19)	$^{13}CO_2$, CO_2
I21	4775.803 cm^{-1}	2.0939 μm	Abs[H_2O-2] ~8-25 km	H_2O

Shaded areas: channels which are suggested to be used for ACCURATE demonstration purposes. If LIO demonstration only, the LMO channels K1 to K3 are not applicable (scientifically a less preferred option, since in this case LMO+LIO synergy is lost); the channels I16 to I21 are basic demo, the CH_4 channels I09 and I10 1st additional demo option, the stratospheric H_2O channels I05 and I06 2nd additional demo option, and as many further channels as affordable should be part of demonstration (I11-I15, etc.)

Channel No. and Channel ID in parentheses: optional channels (LMO X1, X2, M3, M4), alternative channels (LIO A01, A02), or demonstration-only channels (LIO D01)

b.e.: best effort – the X1 and X2 channels (focus LT domain) as well as M3 and M4 channels (focus O_3 complementary to LIO) are valuable optional channels and should be implemented on a best-effort basis

Ref 1 to Ref 6: reference channels for enabling differential transmission retrieval of trace species and l.o.s. wind as well as for detection and retrieval of by-products (cloud layering, aerosol ext., turb. strength; cf. Table 2)

demo: absorption line for demonstration purposes only, complementing I16-I21 ($^{13}CO_2$ channel D01)

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5 Observational requirements

5.1 ACCURATE observational requirements

The baseline observational requirements, derived to fulfill the geophysical data requirements (Section 4) and the underlying science objectives (Section 2), are presented in Table 4 below. These requirements on space-time properties, accuracies and timeliness are consistent with Tables 2 and 3, i.e., the parameter needs and the related design to measure them.

Table 4. Baseline set of ACCURATE LMO and LIO observational requirements.

		LMO				LIO				
		Temperature		Sp. Humidity		Trace Species[1]		l.o.s. Wind[2]		
Requirement		Target	Thres	Target	Thres	Target	Thres	Target	Thres	Units
Horizontal domain		global								
Horizontal sampling[3] (mean distance of adjacent profiles) to be achieved within:		900	1800	900	1800	900	1800	900	1800	[km]
time sampling[4]		12	24	12	24	12	24	12	24	[hrs]
No. of profiles per grid box per month[5]		40	30	40	30	40	30	40	30	
Vertical domain[6]		5-50	7-40	5-18[7]	7-12	5-35	7-30[8]	10-40	15-35	[km]
Vertical sampling	LT	0.5	1	0.5	1	0.5	1	0.5	1	[km]
	UT	0.5	1	0.5	1	0.5	1	0.5	1	[km]
	LS	0.5	1	0.5	1	0.5	1	0.5	1	[km]
	US	1	2.5	-	-	1	2.5	1	2.5	[km]
RMS accuracy[9]	LT	best-effort basis						-	-	Temp [K] Humi [%] Species [%] Wind [m/s]
	UT-bottom	1	2	10	20	4 (2)	10 (3)	best-effort basis		
	UT-≥10km	0.5	1	10	20	4 (2)	10 (3)	2	5	
	LS	0.5	1	10	-	4 (2)	10 (3)	2	5	
	US	1.5	3	-	-	best-effort basis		3	-	
Long-term stability (per decade)		0.1	0.15	2	3	0.5	1	0.5	1	
		[K/dec]		[%RH[10]/dec]		[%/dec]		[(m/s)/dec]		
Timeliness	Climate	7	14	7	14	7	14	7	14	[days]
	NWP[11]	1.5	3	1.5	3	1.5	3	1.5	3	[hrs]
Time domain[12]		> 3								[years]

[1] Trace species to include the ten gases H_2O, CO_2, $^{13}CO_2$, $C^{18}OO$, CH_4, N_2O, O_3, CO, HDO, $H_2{}^{18}O$; the latter up to four gases optional in a first demonstration of the novel method if only a reduced number of IR laser channels is affordable.

[2] Line-of-sight (l.o.s.) wind measurements shall focus on the meridional wind component ("Brewer-Dobson circulation").

[3] Horiz. sampling may be up to a factor of 2 coarser in a first demonstration mission if max. two satellites are affordable.

[4] Time sampling shall also sample over all local times within as small as possible UTC time period (e.g., within a season) or, alternatively, sample near fixed local time (in this case alignment with MetOp 9:30/21:30 orbit nodes preferred).

[5] No. of profiles to be fulfilled in global average by all grid boxes but also any individual grid box shall receive at least 80% of this number. Grid box is here defined as square of the horizontal sampling requirement (box of size Horiz. sampling [km] × Horiz. sampling [km]) or any box of equivalent size with at least 500 km length of its smaller dimension.

[6] Vertical domain to be sampled for adequate climate benchmark profiles retrieval capability with a horizontal displacement of the occultation tangent point location from 60 km to 3 km height of < 60 km (target) / < 120 km (threshold), and within an occultation event duration within 60 km to 3 km height of < 1 min (target) / < 5 min (threshold).

[7] Meeting the target upper boundary requirement implies full coverage of high-reaching convective cloud systems, up to and including the tropical tropopause (16-17 km), with LMO humidity measurements within and through such clouds.

[8] For the trace gas O_3 / CO, the concentration of which strongly decreases below / above about 15 km, the threshold lower / upper boundary requirement shall be 10 km / 20 km. Regarding the H_2O isotopes (HDO, $H_2{}^{18}O$), for which the sensitivity focus is the UT, these shall be retrieved within required accuracy over the best possible height range up to 12 km.

[9] Understood to be the accuracy for an individual occultation event over the required vertical domain at a vertical resolution consistent with the required sampling (i.e., a resolution of 2 x Vertical sampling [km]). The LMO temperature accu-

racy requirements shall be understood to decrease linearly from the UT-bottom = 5 km value until they reach the UT-≥10km value at 10 km; above, the height dependence shall be constant over the UTLS. The LMO humidity accuracy threshold requirement shall be understood to apply to global statistics over all latitudes (i.e., data from very dry regions may exceed this fractional accuracy). The LIO trace species CO_2 and its isotopes $^{13}CO_2$ and $C^{18}OO$ shall fulfill the more stringent accuracy requirements given in parentheses. All LIO accuracy requirements apply to clear-air measurements; cloud-perturbed vertical levels shall be flagged (e.g., via a co-retrieved cloud layering profile) and accuracies at these levels shall be as good as possible on a best-effort basis.

10) For LMO humidity measurements, stability is specified in terms of relative humidity (RH), a quantity with well-defined linear range over the vertical domain. There are standard formulae to convert between RH and specific humidity as functions of temperature and pressure.

11) Supporting NWP is a secondary but still relevant objective; its requirements shall thus be fulfilled on a best effort basis.

12) Climate monitoring and research prefer long-term observations over many years and decades; the pioneering ACCURATE mission should thus be followed by similar missions. The ACCURATE mission objectives themselves, however, can be fulfilled within the given time frame (3 years or more).

5.2 Traceability matrix for the observational requirements

The baseline ACCURATE observational requirements of Table 4 are traced to the user-specified international observational requirements as specified by GCOS/WMO, GAW/WMO and NWP/WMO and presented for reference information in Appendix A.

Table 5 shows one line for each required ACCURATE parameter, and the trace to the relevant international observational requirements is established; subsection 5.3 below then addresses the requirements parameter by parameter (By-products are listed in parentheses as geophysical parameters for completeness but they are not traced as the main parameters are.)

Table 5. Traceability matrix of ACCURATE vs GCOS-GAW-NWP/WMO parameters.

Geophysical parameter	GCOS/WMO	GAW/WMO	NWP/WMO
refractivity	(basis for temperature, H_2O)		
pressure	(basis for temperature, H_2O)		
geopotential height	(corresponding to the pressure)		
temperature	Atmospheric temperature profile - Higher troposphere (HT), Atmospheric temperature profile - Higher stratosphere & mesosphere (HS & M), Atmospheric temperature profile - Lower stratosphere (LS), Atmospheric temperature profile - Lower troposphere (LT)		Atmospheric temperature profile - Lower stratosphere (LS), Atmospheric temperature profile - Higher stratosphere & mesosphere (HS & M), Atmospheric temperature profile - Higher troposphere (HT), Atmospheric temperature profile - Lower troposphere (LT)
H_2O	Specific humidity profile - Higher troposphere (HT), Specific humidity profile - Lower stratosphere (LS), Specific humidity profile - Higher stratosphere & mesosphere (HS & M), Specific humidity profile - Lower troposphere (LT)	Specific humidity profile - Lower stratosphere (LS), Specific humidity profile - Higher troposphere (HT), Specific humidity profile - Higher stratosphere & mesosphere (HS & M), Specific humidity profile - Lower troposphere (LT)	Specific humidity profile - Higher troposphere (HT), Specific humidity profile - Lower troposphere (LT)
(liquid water)			
(ice water)			
(turbulence strength)			
CO_2	Trace gas profile CO2 - Lower troposphere (LT), Trace gas profile CO2 - Higher troposphere (HT), Trace gas profile CO2 - Lower stratosphere (LS), Trace gas profile CO2 - Higher stratosphere & mesosphere (HS & M)	Trace gas profile CO2 - Lower troposphere (LT)	
$^{13}CO_2$	Trace gas profile CO2 - Lower troposphere (LT), Trace gas profile CO2 - Higher troposphere (HT), Trace gas profile CO2 - Lower stratosphere (LS), Trace gas profile CO2 - Higher stratosphere & mesosphere (HS & M)	Trace gas profile CO2 - Lower troposphere (LT)	

$C^{18}OO$	Trace gas profile CO2 - Lower troposphere (LT), Trace gas profile CO2 - Higher troposphere (HT), Trace gas profile CO2 - Lower stratosphere (LS), Trace gas profile CO2 - Higher stratosphere & mesosphere (HS & M)	Trace gas profile CO2 - Lower troposphere (LT)	
CH_4	Trace gas profile CH4 - Higher stratosphere & mesosphere (HS & M), Trace gas profile CH4 - Lower stratosphere (LS), Trace gas profile CH4 - Higher troposphere (HT), Trace gas profile CH4 - Lower troposphere (LT)	Trace gas profile CH4 - Higher stratosphere & mesosphere (HS & M), Trace gas profile CH4 - Lower stratosphere (LS), Trace gas profile CH4 - Higher troposphere (HT), Trace gas profile CH4 - Lower troposphere (LT)	
N_2O		Trace gas profile N2O - Higher stratosphere & mesosphere (HS & M), Trace gas profile N2O - Lower stratosphere (LS), Trace gas profile N2O - Higher troposphere (HT), Trace gas profile N2O - Lower troposphere (LT)	
O_3	Ozone profile - Lower stratosphere (LS), Ozone profile - Higher stratosphere & mesosphere (HS & M), Ozone profile - Higher troposphere (HT)	Ozone profile - Lower stratosphere (LS), Ozone profile - Higher troposphere (HT), Ozone profile - Higher stratosphere & mesosphere (HS & M),	Ozone profile - Lower stratosphere (LS), Ozone profile - Higher troposphere (HT)
CO		Trace gas profile CO - Lower stratosphere (LS), Trace gas profile CO - Higher troposphere (HT), Trace gas profile CO - Lower troposphere (LT)	
HDO	Specific humidity profile - Higher troposphere (HT), Specific humidity profile - Lower troposphere (LT)	Specific humidity profile - Higher troposphere (HT), Specific humidity profile - Lower troposphere (LT)	Specific humidity profile - Higher troposphere (HT), Specific humidity profile - Lower troposphere (LT)
$H_2{}^{18}O$	Specific humidity profile - Higher troposphere (HT), Specific humidity profile - Lower troposphere (LT)	Specific humidity profile - Higher troposphere (HT), Specific humidity profile - Lower troposphere (LT)	Specific humidity profile - Higher troposphere (HT), Specific humidity profile - Lower troposphere (LT)
l.o.s. Wind (meridional wind)	Wind profile (horizontal component) - Higher troposphere (HT), Wind profile (horizontal component) - Lower stratosphere (LS), Wind profile (horizontal component) - Higher stratosphere & mesosphere (HS & M)		Wind profile (horizontal component) - Higher troposphere (HT), Wind profile (horizontal component) - Lower stratosphere (LS), Wind profile (horizontal component) - Higher stratosphere & mesosphere (HS & M)
(cloud layering)			
(aerosol extinction)			
(turbulence strength)			

5.3 Observational requirements compared in the UT region

In this subsection the observational requirements of the ACCURATE mission concept as defined in Table 4 are compared against the international observational requirements in the upper troposphere region. The upper troposphere UT is denoted Higher Troposphere HT in the WMO tables, and here for the purpose of comparison also the acronym HT is selected.

The HT region is selected here since all measured quantities are being measured in that region, which in many scientific cases is also the region of primary interest. However, the Tables in Appendix A contain also requirements on the other height domains so that one may compare the entries in Table 4 above also in non-HT regions, in particular in the LS region, directly with relevant Appendix A entries.

The requirements of the ACCURATE mission concept are compared against all three users groups in the Tables provided per parameter below. These user groups are the climate users (AOPC), the Atmosphere Chemistry users, and Global NWP users, if the relevant requirement is available in the HT region (cf. Table 5; not each user group has a requirement on each parameter).

Each requirement is expressed in terms of Horizontal Resolution, Vertical Resolution, Observing Cycle, Delay of Availability and Accuracy with each parameter described in terms of Goal, Breakthrough (B/T) and Threshold (T/H). The values are extracted from Appendix A.

The definition by WMO of Goal, Breakthrough (B/T) and Threshold (T/H) is the following:

- the “threshold” is the minimum requirement to be met to ensure that data are useful.
- the “goal” is an ideal requirement above which further improvements are not necessary.
- the “breakthrough” is an intermediate level between “threshold” and “goal” which, if achieved, would result in a significant improvement for the targeted application.

The “Breakthrough” level may be considered as the best target, from a cost-benefit point of view, when planning or designing observing systems. If the “Goal” is reached at an essentially equal cost-benefit level also design towards goal is attractive. In the Tables below the “Target” requirement in Table 4 is generally associated with the WMO “Breakthrough” requirement, since the “Target” is meant to drive the main design criteria (“Goal” was in this case filled with expected values known to be achievable by ACCURATE in at least part of the domain). Exception to this type of matching was made in cases where it was considered more adequate to match “Target” with “Goal” (vertical resolution of trace species, delay of availability).

The order of the listing of the Tables per parameter reflects the order of the parameters in Table 5; if no Table is applicable a brief verbal explanation is given. Comments on the consistency of the ACCURATE with the international requirements follow in the Conclusions.

Refractivity, Pressure, and Geopotential height:

The user requirements for profiles of these measurement-technique-specific quantities are not directly traceable to the WMO user requirements as they are given in the tables in Appendix A. We instead refer to the requirements as given, e.g., by EUMETSAT in the GRAS SAF user requirement document [GRAS SAF]. Note in general that the temperature and specific humidity requirements below strongly co-specify these parameters, since they are pre-products in the occultation retrieval processing chain (see, e.g., [TR-REVOCC]).

Temperature:

		Horizontal Resolution			**Vertical Resolution**			**Observing Cycle**			**Delay of Availability**			**Accuracy**		
Requirement	**Application area**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**
Atmospheric temperature profile - Higher troposphere (HT)	AOPC	100 km	200 km	500 km	0.1 km	0.5 km	2 km	3 h	4 h	6 h	3 h	6 h	12 h	0.5 K	1 K	2 K
Atmospheric temperature profile - Higher troposphere (HT)	Global NWP	15 km	100 km	500 km	0.3 km	1 km	3 km	1 h	6 h	24 h	0.1 h	0.5 h	6 h	0.5 K	1 K	3 K
ACCURATE MISSION – Temperature (HT)		**300 km**	**900 km**	**1800 km**	**0.2 km**	**0.5 km**	**1 km**	**6 h**	**12 h**	**24 h**	**1.5 h**	**3 h**	**168 h**	**0.3 K**	**0.5 K**	**1 K**

Specific humidity (H_2O):

		Horizontal Resolution			**Vertical Resolution**			**Observing Cycle**			**Delay of Availability**			**Accuracy**		
Requirement	**Application area**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**
Specific humidity profile - Higher troposphere (HT)	AOPC	20 km	50 km	100 km	0.1 km	0.5 km	2 km	3 h	4 h	6 h	168 h	336 h	1440 h	2 %	5 %	20 %
Specific humidity profile - Higher troposphere (HT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.7 km	5 km	12 h	21.8 h	72 h	72 h	95.5 h	168 h	5 %	7.9 %	20 %
Specific humidity profile - Higher troposphere (HT)	Global NWP	15 km	50 km	250 km	0.5 km	1 km	3 km	1 h	6 h	12 h	0.1 h	0.5 h	6 h	2 %	5 %	10 %
ACCURATE MISSION – H_2O (HT)		**300 km**	**900 km**	**1800 km**	**0.2 km**	**0.5 km**	**1 km**	**6 h**	**12 h**	**24 h**	**1.5 h**	**3 h**	**168 h**	**2%**	**4%**	**10%**

CO_2:

		Horizontal Resolution			**Vertical Resolution**			**Observing Cycle**			**Delay of Availability**			**Accuracy**		
Requirement	**Application area**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**
Trace gas profile CO2 - Higher troposphere (HT)	AOPC	50 km	100 km	250 km	1 km	1.5 km	2 km	3 h	4 h	6 h	168 h	336 h	1440 h	1 %	1.3 %	2 %
ACCURATE MISSION – CO_2 (HT)		**300 km**	**900 km**	**1800 km**	**0.5 km**	**1 km**	**2 km**	**6 h**	**12 h**	**24 h**	**1.5 h**	**3 h**	**168 h**	**1 %**	**2 %**	**3 %**

CH_4:

		Horizontal Resolution			**Vertical Resolution**			**Observing Cycle**			**Delay of Availability**			**Accuracy**		
Requirement	**Application area**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**
Trace gas profile CH4 - Higher troposphere (HT)	AOPC	50 km	100 km	250 km	2 km	2.5 km	4 km	3 h	4 h	6 h	720 h	1440 h	4320 h	2 %	4 %	10 %
Trace gas profile CH4 - Higher troposphere (HT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	2 %	3.4 %	10 %
ACCURATE MISSION – CH_4 (HT)		**300 km**	**900 km**	**1800 km**	**0.5 km**	**1 km**	**2 km**	**6 h**	**12 h**	**24 h**	**1.5 h**	**3 h**	**168 h**	**2 %**	**4 %**	**10 %**

N_2O:

		Horizontal Resolution			Vertical Resolution			Observing Cycle			Delay of Availability			Accuracy		
Requirement	**Application area**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**
Trace gas profile N2O - Higher troposphere (HT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	2 %	4.3 %	20 %
ACCURATE MISSION – N_2O (HT)		**300 km**	**900 km**	**1800 km**	**0.5 km**	**1 km**	**2 km**	**6 h**	**12 h**	**24 h**	**1.5 h**	**3 h**	**168 h**	**2 %**	**4 %**	**10 %**

O_3:

		Horizontal Resolution			Vertical Resolution			Observing Cycle			Delay of Availability			Accuracy		
Requirement	**Application area**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**
Ozone profile - Higher troposphere (HT)	AOPC	5 km	20 km	100 km	0.5 km	1 km	2 km	3 h	9 h	72 h	720 h	1440 h	4520 h	10 %	15 %	30 %
Ozone profile - Higher troposphere (HT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.7 km	5 km	3 h	11.5 h	168 h	72 h	95.5 h	168 h	3 %	5.6 %	20 %
Ozone profile - Higher troposphere (HT)	Global NWP	15 km	100 km	250 km	1 km	2.2 km	10 km	1 h	6 h	12 h	0.1 h	0.5 h	6 h	5 %	10 %	20 %
ACCURATE MISSION – O_3 (HT)		**300 km**	**900 km**	**1800 km**	**0.5 km**	**1 km**	**2 km**	**6 h**	**12 h**	**24 h**	**1.5 h**	**3 h**	**168 h**	**2 %**	**4 %**	**10 %**

CO:

		Horizontal Resolution			Vertical Resolution			Observing Cycle			Delay of Availability			Accuracy		
Requirement	**Application area**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**
Trace gas profile CO - Higher troposphere (HT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
ACCURATE MISSION – CO (HT)		**300 km**	**900 km**	**1800 km**	**0.5 km**	**1 km**	**2 km**	**6 h**	**12 h**	**24 h**	**1.5 h**	**3 h**	**168 h**	**2 %**	**4 %**	**10 %**

The isotopologues $^{13}CO_2$, $C^{18}OO$, HDO, and $H_2{}^{18}O$:

The observational requirements on the isotopologues are given in Table 4 to be the same as for the regular CO_2 and H_2O species. The requirements trace for these isotopes is assumed here to the same WMO requirements as for the regular constituents (cf. Table 5) since isotope-specific WMO requirements are not given explicitly. In this report the respective CO_2 and H_2O Tables above can thus be considered to also provide the requirements for the isotopologues. However, measurements of these isotopes have been reported separately, as described for example in [Laemmer02], [Brennink03], [AlliFran07], [Schmidt05], and [Nassar07], and future refinement potential for these more specialized requirements exists.

Practically, $^{13}CO_2$, which in the free atmosphere has an extremely stable isotopic ratio to the main isotope $^{12}CO_2$ ($\delta^{13}C$ ratio variations < 0.05 %; e.g., [AlliFran07]), aids the $^{12}CO_2$ measurement to provide an optimized CO_2 retrieval. $C^{18}OO$ can provide, via its $\delta^{18}O$ ratio to CO_2 which reaches magnitudes of ~ 1 % in the stratosphere, highly useful information on ozone chemistry. This works because ozone isotope anomalies, carrying information on atmospheric processes, leave a clear mark in the $\delta^{18}O$ ratio of CO_2 (e.g., [Laemmer02], [Brennink03]). The water isotopes HDO and $H_2{}^{18}O$, where isotopic ratios amount to > 1 % or even often to > 10 %, are very valuable markers of hydrological processes, in particular of phase changes such as condensation and evaporation (e.g., [Schmidt05], [Nassar07]). An ACCURATE mission can provide profiles of the relevant isotopes within the given requirements, which definitely will be of high utility also for isotope-based science.

Line-of-sight wind (meridional wind):

		Horizontal Resolution			Vertical Resolution			Observing Cycle			Delay of Availability			Accuracy		
Requirement	**Application area**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**
Wind profile (horizontal component) - Higher troposphere (HT)	AOPC	100 km	200 km	500 km	0.5 km	0.65 km	1 km	3 h	4 h	6 h	3 h	6 h	12 h	2 m/s	3 m/s	5 m/s
Wind profile (horizontal component) - Higher troposphere (HT)	Global NWP	15 km	100 km	500 km	0.5 km	1 km	3 km	1 h	6 h	12 h	0.1 h	0.5 h	6 h	1 m/s	3 m/s	8 m/s
ACCURATE MISSION –l.o.s. Wind (HT)		**300 km**	**900 km**	**1800 km**	**0.5 km**	**1 km**	**2 km**	**6 h**	**12 h**	**24 h**	**1.5 h**	**3 h**	**168 h**	**1 m/s**	**2 m/s**	**5 m/s**

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6 Summary and Conclusions

This document has, after providing context on the ACCURATE mission concept (Section 1), summarized the scientific objectives (Section 2) and relevant recommendations of international bodies (Section 3) on which next the geophysical data requirements and related measurement design were based (Section 4). Subsequently, the ACCURATE observational requirements were derived consistent with the science objectives and data requirements and traced to international observational requirements from the WMO context (Section 5). The following main conclusions can be drawn.

The science objectives (Section 2) show that an ACCURATE mission can provide substantial contributions for the implementation of both the climate and the atmospheric chemistry recommendations of international bodies (Section 3). Compared to expectations in the recommendations of what global satellite observing systems are capable of contributing in addition to ground-based systems, the ACCURATE concept (not yet thought of when the recommendations were written) can be expected to contribute significantly beyond expectations. Contributions are also brought to NWP applications addressed as a secondary objective.

The trace-back and comparison of the ACCURATE observational requirements against the WMO-sponsored international observational requirements (Section 5; reference information Appendix A) could be explicitly performed for the key quantities temperature, specific humidity (H_2O), CO_2, CH_4, N_2O, CO, O_3, and line-of-sight wind (essentially meridional wind for targeted polar orbits with inclination within 80° to 100°). It was found that the requirements for accuracy and vertical resolution of the ACCURATE mission agree very well with or exceed the WMO requirements for all target parameters. For most parameters the ACCURATE “Target” level outperforms the WMO “Breakthrough” level or even meets the “Goal” level that is defined by WMO as an ideal requirement beyond which further improvements are not necessary (according to current understanding). Though not visible in the standard tables it is important to add that the ACCURATE long-term stability also meets stringent requirements formulated by WMO/GCOS (probably better than any other satellite observing system) because of its use of the self-calibrating occultation technique.

The WMO requirements on delay of availability (timeliness) are in general far exceeded at “Breakthrough” level regarding climate and atmospheric chemistry and are, assuming regular downlink to high-latitude ground stations, within “Threshold” level for the secondary objective of supporting NWP. Also the WMO requirements on observing cycle (time sampling) for global coverage are met for most parameters at “Breakthrough” or “Threshold” level. However, since the ACCURATE concept uses active limb sounding, which generally delivers relatively sparse horizontal sampling for small constellations (four satellites could meet the “Threshold” and twelve the “Target” requirements in Table 4 of Section 5), the horizontal resolution is clearly inferior to the WMO requirements. In practice, ACCURATE is thus highly complementary in information content to passive radiometric atmospheric sounding systems, which can provide excellent horizontal resolution and observing cycle but have their limitations in vertical resolution, accuracy, and stability.

In summary, an ACCURATE mission is found to be capable of a comprehensive and unique contribution to fulfilling the international observational requirements as a key part of the future global satellite observing system for climate, atmospheric composition, and NWP. It can provide an unprecedented climate benchmark dataset of the atmospheric thermodynamic, chemical, and dynamical state with high vertical resolution, accuracy, consistency, and long-term stability.

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Appendix A

A.1 GCOS requirements (WMO/CEOS Database)

Data Requirements for **GCOS:** 104 requirements found [WMO-DB08] and grouped by application area. Each requirement is expressed in terms of **Horizontal Resolution**, **Vertical Resolution**, **Observing Cycle**, **Delay of Availability** and **Accuracy** with each parameter described in terms of **Goal**, **Breakthrough (B/T)** and **Threshold (T/H)**. The document [GCOS06] contains almost the same GCOS requirements; in case of differences the evidently more adequate values are used

The GCOS requirements are grouped in three categories. Atmospheric Observation Panel on Climate (AOPC), Terrestrial Observation Panel on Climate (TOPC), and Ocean Observation Panel on Climate (OOPC). Here only the **observational requirements within AOPC are included**, this constitutes a total of 70 requirements.

		Horizontal Resolution			**Vertical Resolution**			**Observing Cycle**			**Delay of Availability**			**Accuracy**		
Requirement	**Application area**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**
Specific humidity profile - Higher troposphere (HT)	AOPC	20 km	50 km	100 km	0.1 km	0.5 km	2 km	3 h	4 h	6 h	168 h	336 h	1440 h	2 %	5 %	20 %
Downwelling solar radiation at TOA	AOPC	100 km	200 km	500 km				3 d	4 d	6 d	3 d	7 d	24 d	1 W/m2	1.3 W/m2	2 W/m2
Cloud top temperature	AOPC	100 km	200 km	500 km				3 h	4 h	6 h	3 h	6 h	12 h	0.3 K	0.4 K	0.6 K
Outgoing short-wave radiation at TOA	AOPC	100 km	200 km	500 km				3 h	4 h	6 h	3 h	6 h	24 h	5 W/m2	6.5 W/m2	10 W/m2
Outgoing long-wave radiation at TOA	AOPC	100 km	200 km	500 km				3 h	4 h	6 h	3 h	6 h	24 h	5 W/m2	6.5 W/m2	10 W/m2
Wind profile (horizontal component) - Higher troposphere (HT)	AOPC	100 km	200 km	500 km	0.5 km	0.65 km	1 km	3 h	4 h	6 h	3 h	6 h	12 h	2 m/s	3 m/s	5 m/s
Wind profile (horizontal component) - Lower stratosphere (LS)	AOPC	100 km	200 km	500 km	0.5 km	0.65 km	1 km	3 h	4 h	6 h	3 h	6 h	12 h	2 m/s	3 m/s	5 m/s
Wind profile (horizontal component) - Higher stratosphere & mesosphere (HS & M)	AOPC	100 km	200 km	500 km	0.5 km	1 km	3 km	3 h	3.8 h	6 h	3 h	6 h	12 h	2 m/s	3 m/s	7 m/s

Atmospheric temperature profile - Higher troposphere (HT)	AOPC	100 km	200 km	500 km	0.1 km	0.5 km	2 km	3 h	4 h	6 h	3 h	6 h	12 h	0.5 K	1 K	2 K
Cloud cover	AOPC	99 km	100 km	500 km				3 h	4 h	6 h	3 h	6 h	12 h	10 % (Max)	15 % (Max)	20 % (Max)
Atmospheric temperature profile - Higher stratosphere & mesosphere (HS & M)	AOPC	100 km	200 km	500 km	2 km	2.5 km	3 km	3 h	4 h	6 h	3 h	6 h	12 h	0.5 K	1 K	3 K
Cloud ice profile - Total column	AOPC	100 km	200 km	500 km				3 h	4 h	6 h	3 h	6 h	12 h	10 g/m2	15 g/m2	20 g/m2
Specific humidity profile - Lower stratosphere (LS)	AOPC	50 km	100 km	200 km	2 km	2.5 km	3 km	3 h	4 h	6 h	168 h	336 h	1440 h	2 %	5 %	20 %
Specific humidity profile - Higher stratosphere & mesosphere (HS & M)	AOPC	50 km	100 km	200 km	2 km	3 km	5 km	3 h	4 h	6 h	168 h	336 h	1440 h	2 %	5 %	20 %
Specific humidity profile - Total column	AOPC	50 km	100 km	200 km				3 h	4 h	6 h	168 h	336 h	1440 h	1 kg/m2	1.4 kg/m2	3 kg/m2
Ozone profile - Lower stratosphere (LS)	AOPC	50 km	75 km	100 km	0.5 km	1 km	3 km	3 h	9 h	72 h	720 h	1440 h	4520 h	5 %	8 %	20 %
Ozone profile - Troposphere column	AOPC	5 km	10 km	50 km				3 h	9 h	72 h	720 h	1440 h	4520 h	5 DU	8 DU	15 DU
Downwelling long-wave radiation at the Earth surface	AOPC	25 km	50 km	100 km				3 h	4 h	6 h	24 h	48 h	120 h	5 W/m2	6.5 W/m2	10 W/m2
Precipitation index (daily cumulative)	AOPC	100 km	200 km	500 km				12 h	16 h	24 h	24 h	72 h	288 h	1 mm/d	1.3 mm/d	2 mm/d
Ozone profile - Higher stratosphere & mesosphere (HS & M)	AOPC	50 km	100 km	500 km	0.5 km	1 km	3 km	3 h	9 h	48 h	720 h	1440 h	4520 h	5 %	8 %	20 %
Ozone profile - Higher troposphere (HT)	AOPC	5 km	20 km	100 km	0.5 km	1 km	2 km	3 h	9 h	72 h	720 h	1440 h	4520 h	10 %	15 %	30 %
Atmospheric temperature profile - Lower stratosphere (LS)	AOPC	100 km	200 km	500 km	2 km	2.5 km	3 km	3 h	4 h	6 h	3 h	6 h	12 h	0.5 K	1 K	2 K
Snow cover	AOPC	100 km	200 km	500 km				24 h	48 h	168 h	6 h	12 h	24 h	10 % (Max)	13 % (Max)	20 % (Max)
Ozone profile - Lower troposphere (LT)	AOPC	5 km	10 km	50 km	0.5 km	1 km	2 km	3 h	9 h	72 h	720 h	1440 h	4520 h	10 %	13 %	20 %

Trace gas profile CH4 - Higher stratosphere & mesosphere (HS & M)	AOPC	50 km	100 km	250 km	2 km	2.5 km	4 km	3 h	4 h	6 h	720 h	1440 h	4320 h	2 %	4 %	10 %
Trace gas profile CH4 - Higher troposphere (HT)	AOPC	50 km	100 km	250 km	2 km	2.5 km	4 km	3 h	4 h	6 h	720 h	1440 h	4320 h	2 %	4 %	10 %
Trace gas profile CH4 - Lower troposphere (LT)	AOPC	10 km	20 km	50 km	2 km	2.5 km	3 km	3 h	4 h	6 h	720 h	1440 h	4320 h	2 %	4 %	10 %
Trace gas profile CO2 - Lower troposphere (LT)	AOPC	10 km	50 km	500 km	0.5 km	1 km	2 km	3 h	6 h	12 h	168 h	336 h	1440 h	1 %	1.3 %	2 %
Trace gas profile CH4 - Lower stratosphere (LS)	AOPC	50 km	100 km	250 km	2 km	2.5 km	4 km	3 h	4 h	6 h	720 h	1440 h	4320 h	2 %	4 %	10 %
Land surface temperature	AOPC	1 km	10 km	500 km				24 h	48 h	72 h	3 h	4 h	6 h	1 K	1.3 K	2 K
Precipitation rate (solid) at the surface	AOPC	100 km	200 km	500 km				3 h	4 h	6 h	3 h	6 h	12 h	0.1 mm/h	0.3 mm/h	2 mm/h
Cloud top height	AOPC	100 km	200 km	500 km				3 h	4 h	6 h	3 h	6 h	12 h	0.5 km	1 km	2 km
Precipitation rate (liquid) at the surface	AOPC	100 km	200 km	500 km				3 h	4 h	6 h	3 h	6 h	12 h	0.1 mm/h	0.3 mm/h	2 mm/h
Downwelling short-wave radiation at the Earth surface	AOPC	25 km	50 km	100 km				24 h	48 h	120 h	24 h	72 h	720 h	5 W/m2	6.5 W/m2	10 W/m2
Wind vector over sea surface (horizontal)	AOPC	10 km	50 km	500 km				1 h	3 h	6 h	3 h	6 h	12 h	0.5 m/s	1 m/s	5 m/s
Sea surface temperature	AOPC	10 km	50 km	500 km				3 h	6 h	24 h	3 h	6 h	12 h	0.25 K	0.4 K	1 K
Significant wave height	AOPC	25 km	50 km	250 km				3 h	4 h	6 h	3 h	6 h	12 h	0.1 m	0.3 m	2 m
Snow water equivalent	AOPC	100 km	200 km	500 km				24 h	48 h	168 h	6 h	12 h	24 h	5 mm	6.5 mm	10 mm
Wind profile (horizontal component) - Lower troposphere (LT)	AOPC	100 km	200 km	500 km	0.5 km	1 km	2 km	3 h	4 h	6 h	3 h	6 h	12 h	2 m/s	3 m/s	5 m/s
Atmospheric temperature profile - Lower troposphere (LT)	AOPC	100 km	200 km	500 km	0.1 km	0.2 km	0.5 km	3 h	4 h	6 h	3 h	6 h	12 h	0.5 K	1 K	2 K

Specific humidity profile - Lower troposphere (LT)	AOPC	10 km	15 km	25 km	0.1 km	0.2 km	1 km	3 h	4 h	6 h	168 h	336 h	1440 h	2 %	4 %	15 %
Cloud water profile (> 100 µm) - Total column	AOPC	100 km	200 km	500 km				3 h	4 h	6 h	3 h	6 h	12 h	5 kg/m2	10 kg/m2	20 kg/m2
Cloud water profile (< 100 µm) - Total column	AOPC	100 km	200 km	500 km				3 h	4 h	6 h	3 h	6 h	12 h	10 kg/m2	20 kg/m2	50 kg/m2
Air temperature (at surface)	AOPC	25 km	50 km	100 km				3 h	6 h	12 h	24 h	36 h	48 h	0.1 K	0.15 K	0.3 K
Trace gas profile CO2 - Total column	AOPC	50 km	100 km	500 km				3 h	4 h	6 h	720 h	1440 h	4320 h	1 %	1.3 %	2 %
Ozone profile - Total column	AOPC	5 km	10 km	50 km				3 h	9 h	72 h	720 h	1440 h	4520 h	5 DU	8 DU	15 DU
Aerosol optical depth (VIS+IR) - Higher Stratosphere & Mesosphere column	AOPC	1 km	2 km	10 km				1 d	2 d	7 d	7 d	14 d	60 d	0.01 1/km	0.015 1/km	0.02 1/km
Aerosol absorption optical depth (VIS) - Higher Troposphere column	AOPC	1 km	2 km	10 km				1 d	2 d	7 d	7 d	14 d	60 d	0.004 1/km	0.01 1/km	0.02 1/km
Aerosol absorption optical depth (VIS) - Lower Troposphere column	AOPC	1 km	2 km	10 km				1 d	2 d	7 d	7 d	14 d	60 d	0.004 1/km	0.01 1/km	0.02 1/km
Aerosol optical depth (VIS+IR) - Lower Troposphere column	AOPC	1 km	2 km	10 km				1 d	2 d	7 d	7 d	14 d	60 d	0.01 1/km	0.015 1/km	0.02 1/km
Aerosol extinction coefficient (VIS) - Higher stratosphere & mesosphere (HS & M)	AOPC	10 km	20 km	100 km	0.5 km	0.65 km	1 km	1 d	2 d	7 d	7 d	14 d	60 d	0.01 1/km	0.015 1/km	0.02 1/km
Aerosol extinction coefficient (VIS) - Higher troposphere (HT)	AOPC	10 km	20 km	100 km	0.5 km	0.65 km	1 km	1 d	2 d	7 d	7 d	14 d	60 d	0.01 1/km	0.015 1/km	0.02 1/km
Aerosol extinction coefficient (VIS) - Lower stratosphere (LS)	AOPC	10 km	20 km	100 km	0.5 km	0.65 km	1 km	1 d	2 d	7 d	7 d	14 d	60 d	0.01 1/km	0.015 1/km	0.02 1/km
Aerosol extinction coefficient (VIS) - Lower troposphere (LT)	AOPC	10 km	20 km	100 km	0.5 km	0.65 km	1 km	1 d	2 d	7 d	7 d	14 d	60 d	0.01 1/km	0.015 1/km	0.02 1/km
Trace gas profile CO2 - Troposphere column	AOPC	10 km	50 km	500 km				3 h	4 h	6 h	168 h	336 h	1440 h	1 %	1.3 %	2 %
Aerosol optical depth (VIS+IR) - Lower Stratosphere column	AOPC	1 km	2 km	10 km				1 d	2 d	7 d	7 d	14 d	60 d	0.01 1/km	0.015 1/km	0.02 1/km

Trace gas profile CO2 - Higher stratosphere & mesosphere (HS & M)	AOPC	250 km	350 km	500 km	2 km	3 km	4 km	3 h	4 h	6 h	720 h	1440 h	4320 h	1 %	1.3 %	2 %
Air pressure over sea surface	AOPC	200 km	300 km	500 km				3 h	6 h	24 h	3 h	6 h	12 h	0.5 hPa	0.65 hPa	1 hPa
Aerosol absorption optical depth (VIS) - Lower Stratosphere column	AOPC	1 km	2 km	10 km				1 d	2 d	7 d	7 d	14 d	60 d	0.004 1/km	0.01 1/km	0.02 1/km
Aerosol absorption optical depth (VIS) - Higher Stratosphere & Mesosphere column	AOPC	1 km	2 km	10 km				1 d	2 d	7 d	7 d	14 d	60 d	0.004 1/km	0.01 1/km	0.02 1/km
Aerosol optical depth (VIS+IR) - Higher Troposphere column	AOPC	1 km	2 km	10 km				1 d	2 d	7 d	7 d	14 d	60 d	0.01 1/km	0.015 1/km	0.02 1/km
Air pressure over land surface	AOPC	200 km	300 km	500 km				3 h	6 h	24 h	3 h	6 h	12 h	0.5 hPa	0.65 hPa	1 hPa
Outgoing long-wave Earth surface	AOPC	25 km	50 km	100 km				3 h	4 h	6 h	24 h	48 h	120 h	5 W/m2	6.5 W/m2	10 W/m2
Trace gas profile CO2 - Higher troposphere (HT)	AOPC	50 km	100 km	250 km	1 km	1.5 km	2 km	3 h	4 h	6 h	168 h	336 h	1440 h	1 %	1.3 %	2 %
Short-wave Earth surface bi-directional reflectance	AOPC	25 km	50 km	100 km				3 h	4 h	6 h	24 h	48 h	120 h	5 % (Max)	6.5 % (Max)	10 % (Max)
Specific humidity profile - Troposphere column	AOPC	10 km	25 km	200 km				3 h	4 h	6 h	168 h	336 h	1440 h	1 kg/m2	1.4 kg/m2	3 kg/m2
Trace gas profile CH4 - Troposphere column	AOPC	10 km	20 km	50 km				3 h	4 h	6 h	720 h	1440 h	4320 h	2 %	4 %	10 %
Trace gas profile CH4 - Total column	AOPC	10 km	50 km	250 km				3 h	4 h	6 h	720 h	1440 h	4320 h	2 %	4 %	10 %
Trace gas profile CO2 - Lower stratosphere (LS)	AOPC	250 km	350 km	500 km	1 km	2 km	4 km	3 h	4 h	6 h	720 h	1440 h	4320 h	1 %	1.3 %	2 %
Air specific humidity (at surface)	AOPC	25 km	50 km	100 km				3 h	4 h	6 h	24 h	48 h	72 h	1 %	1.3 %	2 %

A.2 Chemical requirements–Global Atmosphere Watch (WMO database)

The selected set of 72 observational requirements on atmospheric chemistry copied from the WMO database on observational requirements [WMO-DB08].

Each requirement is expressed in terms of **Horizontal Resolution**, **Vertical Resolution**, **Observing Cycle**, **Delay of Availability** and **Accuracy** with each parameter described in terms of **Goal**, **Breakthrough (B/T)** and **Threshold (T/H)**.

		Horizontal Resolution			**Vertical Resolution**			**Observing Cycle**			**Delay of Availability**			**Accuracy**		
Requirement	**Application area**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**
Trace gas profile CFC 11 - Higher stratosphere & mesosphere (HS & M)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Aerosol profile - Higher stratosphere & mesosphere (HS & M)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	2.2 km	10 km	6 h	9.5 h	24 h	12 h	28.9 h	168 h	10 %	12.6 %	20 %
Trace gas profile HCl - Higher stratosphere & mesosphere (HS & M)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	2 %	2.7 %	5 %
Trace gas profile CFC 12 - Higher stratosphere & mesosphere (HS & M)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile CH4 - Higher stratosphere & mesosphere (HS & M)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	2 %	3.4 %	10 %
Trace gas profile ClONO2 - Higher stratosphere & mesosphere (HS & M)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile BrO - Higher stratosphere & mesosphere (HS & M)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile COS - Lower stratosphere (LS)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	12 h	21.8 h	72 h	24 h	45.9 h	168 h	15 %	17.8 %	25 %
Trace gas profile HNO3 - Higher stratosphere & mesosphere (HS & M)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile COS - Lower troposphere (LT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	12 h	21.8 h	72 h	24 h	45.9 h	168 h	15 %	17.8 %	25 %
Trace gas profile CO - Lower stratosphere (LS)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %

Trace gas profile HCHO - Total column	Atmospheric chemistry	50 km	107.7 km	500 km				24 h	30.2 h	48 h	72 h	95.5 h	168 h	5 %	7.2 %	15 %
Trace gas profile COS - Higher troposphere (HT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	12 h	21.8 h	72 h	24 h	45.9 h	168 h	15 %	17.8 %	25 %
Trace gas profile CH4 - Lower stratosphere (LS)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	2 %	3.4 %	10 %
Trace gas profile BrO - Higher troposphere (HT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Specific humidity profile - Lower stratosphere (LS)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.7 km	5 km	12 h	21.8 h	72 h	72 h	95.5 h	168 h	5 %	7.9 %	20 %
Ozone profile - Lower stratosphere (LS)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.7 km	5 km	3 h	11.5 h	168 h	72 h	95.5 h	168 h	3 %	5.6 %	20 %
Specific humidity profile - Higher troposphere (HT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.7 km	5 km	12 h	21.8 h	72 h	72 h	95.5 h	168 h	5 %	7.9 %	20 %
Ozone profile - Higher troposphere (HT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.7 km	5 km	3 h	11.5 h	168 h	72 h	95.5 h	168 h	3 %	5.6 %	20 %
Trace gas profile HNO3 - Lower stratosphere (LS)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile HNO3 - Higher troposphere (HT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile NO - Lower stratosphere (LS)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile N2O - Higher stratosphere & mesosphere (HS & M)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	2 %	4.3 %	20 %
Trace gas profile SO2 - Lower stratosphere (LS)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	12 h	21.8 h	72 h	24 h	45.9 h	168 h	10 %	12.6 %	20 %
Trace gas profile NO2 - Higher troposphere (HT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile NO - Higher troposphere (HT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile CO - Higher troposphere (HT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %

Trace gas profile CH4 - Higher troposphere (HT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	2 %	3.4 %	10 %
Specific humidity profile - Higher stratosphere & mesosphere (HS & M)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.7 km	5 km	12 h	21.8 h	72 h	72 h	95.5 h	168 h	5 %	7.9 %	20 %
Trace gas profile NO2 - Lower stratosphere (LS)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile CH4 - Lower troposphere (LT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	2 %	3.4 %	10 %
Trace gas profile CFC 11 - Higher troposphere (HT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile HCl - Higher troposphere (HT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.1 km	1.5 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	2 %	2.7 %	5 %
Trace gas profile HCl - Lower stratosphere (LS)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	2 %	2.7 %	5 %
Trace gas profile OH - Lower stratosphere (LS)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	9.1 %	30 %
Trace gas profile OH - Higher troposphere (HT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.1 km	1.5 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	9.1 %	30 %
Cloud imagery	Atmospheric chemistry	100 km	126 km	200 km				3 h	4.8 h	12 h	72 h	95.5 h	168 h			
Aerosol profile - Lower troposphere (LT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.7 km	5 km	6 h	9.5 h	24 h	12 h	28.9 h	168 h	5 %	7.9 %	20 %
Trace gas profile CFC 11 - Lower troposphere (LT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile CO2 - Lower troposphere (LT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	2 %	2.7 %	5 %
Trace gas profile CFC 12 - Lower stratosphere (LS)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile NO2 - Total column	Atmospheric chemistry	50 km	107.7 km	500 km				24 h	30.2 h	48 h	72 h	95.5 h	168 h	5 %	7.2 %	15 %
Specific humidity profile - Lower troposphere (LT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.7 km	5 km	6 h	13.7 h	72 h	72 h	95.5 h	168 h	5 %	7.9 %	20 %

Trace gas profile HNO3 - Lower troposphere (LT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile NO2 - Lower troposphere (LT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile NO - Lower troposphere (LT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile CO - Lower troposphere (LT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Ozone profile - Total column	Atmospheric chemistry	25 km	39.7 km	100 km				6 h	12 h	48 h	3 h	11.5 h	168 h	6 DU	9 DU	20 DU
Ozone profile - Lower troposphere (LT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.7 km	5 km	3 h	11.5 h	168 h	72 h	95.5 h	168 h	3 %	5.6 %	20 %
Trace gas profile OH - Lower troposphere (LT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.1 km	1.5 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	9.1 %	30 %
Trace gas profile ClO - Higher troposphere (HT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile SO2 - Lower troposphere (LT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	12 h	21.8 h	72 h	24 h	45.9 h	168 h	10 %	12.6 %	20 %
Trace gas profile N2O - Lower troposphere (LT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	2 %	4.3 %	20 %
Trace gas profile ClO - Lower troposphere (LT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile CFC 12 - Lower troposphere (LT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile BrO - Lower troposphere (LT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile OH - Higher stratosphere & mesosphere (HS & M)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	9.1 %	30 %
Trace gas profile ClONO2 - Lower stratosphere (LS)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile BrO - Lower stratosphere (LS)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %

Trace gas profile CFC 12 - Higher troposphere (HT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile ClONO2 - Higher troposphere (HT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile CFC 11 - Lower stratosphere (LS)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile ClO - Higher stratosphere & mesosphere (HS & M)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile NO2 - Higher stratosphere & mesosphere (HS & M)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile NO - Higher stratosphere & mesosphere (HS & M)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.6 km	4 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Trace gas profile N2O - Lower stratosphere (LS)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	2 %	4.3 %	20 %
Trace gas profile N2O - Higher troposphere (HT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	2 %	4.3 %	20 %
Aerosol profile - Lower stratosphere (LS)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.7 km	5 km	6 h	9.5 h	24 h	12 h	28.9 h	168 h	10 %	12.6 %	20 %
Aerosol profile - Higher troposphere (HT)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.7 km	5 km	6 h	9.5 h	24 h	12 h	28.9 h	168 h	10 %	12.6 %	20 %
Trace gas profile SO2 - Higher troposphere (HT)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	12 h	21.8 h	72 h	24 h	45.9 h	168 h	10 %	12.6 %	20 %
Trace gas profile ClO - Lower stratosphere (LS)	Atmospheric chemistry	100 km	171 km	500 km	1 km	1.4 km	3 km	6 h	9.5 h	24 h	72 h	95.5 h	168 h	5 %	6.3 %	10 %
Ozone profile - Higher stratosphere & mesosphere (HS & M)	Atmospheric chemistry	50 km	107.7 km	500 km	1 km	1.7 km	5 km	3 h	7.6 h	48 h	72 h	95.5 h	168 h	5 %	8.5 %	25 %

A.3 NWP requirements (WMO database)

The selected set of 130 observational requirements on Global NWP copied from the WMO database on observational requirements [WMO-DB08].

Each requirement is expressed in terms of **Horizontal Resolution**, **Vertical Resolution**, **Observing Cycle**, **Delay of Availability** and **Accuracy** with each parameter described in terms of **Goal**, **Breakthrough (B/T)** and **Threshold (T/H)**.

		Horizontal Resolution			**Vertical Resolution**			**Observing Cycle**			**Delay of Availability**			**Accuracy**		
Requirement	**Application area**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**
Precipitation rate (solid) at the surface	Global NWP	5 km	15 km	50 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	0.1 mm/h	0.5 mm/h	1 mm/h
Land surface temperature	Global NWP	5 km	15 km	250 km				0.5 h	3 h	6 h	0.1 h	0.5 h	6 h	0.5 K	1 K	4 K
Wind profile (horizontal component) - Lower stratosphere (LS)	Global NWP	15 km	100 km	500 km	0.5 km	1 km	3 km	1 h	6 h	12 h	0.1 h	0.5 h	6 h	1 m/s	3 m/s	5 m/s
Long-wave Earth surface emissivity	Global NWP	5 km	15 km	50 km				24 h	120 h	720 h	24 h	120 h	720 h	0.5 % (Max)	1 % (Max)	3 % (Max)
Sea-ice surface temperature	Global NWP	5 km	15 km	250 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	0.5 K	1 K	4 K
Air specific humidity (at surface)	Global NWP	15 km	50 km	250 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	2 %	5 %	10 %
Wind vector over sea surface (horizontal)	Global NWP	15 km	100 km	250 km				1 h	6 h	12 h	0.1 h	0.5 h	6 h	0.5 m/s	2 m/s	3 m/s
Specific humidity profile - Higher troposphere (HT)	Global NWP	15 km	50 km	250 km	0.5 km	1 km	3 km	1 h	6 h	12 h	0.1 h	0.5 h	6 h	2 %	5 %	10 %
Cloud imagery	Global NWP	0.99 km	1 km	5 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h			
Atmospheric temperature profile - Lower stratosphere (LS)	Global NWP	15 km	100 km	500 km	0.3 km	1 km	3 km	1 h	6 h	24 h	0.1 h	0.5 h	6 h	0.5 K	1 K	3 K
Cloud ice profile - Higher troposphere (HT)	Global NWP	5 km	15 km	50 km	0.2 km	1 km	2 km	1 h	3 h	12 h	0.1 h	0.5 h	6 h	20 %	50 %	100 %

Precipitation rate (liquid) at the surface	Global NWP	5 km	15 km	50 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	0.1 mm/h	0.5 mm/h	1 mm/h
Wind vector over land surface (horizontal)	Global NWP	15 km	100 km	250 km				1 h	6 h	12 h	0.1 h	0.5 h	6 h	0.5 m/s	2 m/s	3 m/s
Cloud cover	Global NWP	5 km	15 km	50 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	5 % (Max)	10 % (Max)	20 % (Max)
Wind speed over sea surface (horizontal)	Global NWP	15 km	100 km	250 km				1 h	6 h	12 h	0.1 h	0.5 h	6 h	0.5 m/s	1.5 m/s	2 m/s
Soil moisture	Global NWP	5 km	15 km	100 km				0.125 d	1 d	5 d	0.125 d	1 d	5 d	10 g/kg	20 g/kg	50 g/kg
Specific humidity profile - Total column	Global NWP	15 km	50 km	250 km				1 h	6 h	12 h	0.1 h	0.5 h	6 h	1 kg/m2	2 kg/m2	5 kg/m2
Specific humidity profile - Lower troposphere (LT)	Global NWP	15 km	50 km	250 km	0.3 km	1 km	3 km	1 h	6 h	12 h	0.1 h	0.5 h	6 h	2 %	5 %	10 %
Outgoing long-wave radiation at TOA	Global NWP	10 km	30 km	100 km				1 h	3 h	12 h	24 h	120 h	720 h	5 W/m2	10 W/m2	20 W/m2
Cloud ice profile - Lower troposphere (LT)	Global NWP	5 km	15 km	50 km	0.2 km	1 km	2 km	1 h	3 h	12 h	0.1 h	0.5 h	6 h	20 %	50 %	100 %
Cloud water profile (> 100 µm) - Higher troposphere (HT)	Global NWP	5 km	15 km	50 km	0.2 km	1 km	2 km	1 h	3 h	12 h	0.1 h	0.5 h	6 h	20 %	50 %	100 %
Cloud water profile (< 100 µm) - Higher troposphere (HT)	Global NWP	5 km	15 km	50 km	0.2 km	1 km	2 km	1 h	3 h	12 h	0.1 h	0.5 h	6 h	20 %	50 %	100 %
Cloud water profile (> 100 µm) - Lower troposphere (LT)	Global NWP	5 km	15 km	50 km	0.2 km	1 km	2 km	1 h	3 h	12 h	0.1 h	0.5 h	6 h	20 %	50 %	100 %
Cloud water profile (< 100 µm) - Lower troposphere (LT)	Global NWP	5 km	15 km	50 km	0.2 km	1 km	2 km	1 h	3 h	12 h	0.1 h	0.5 h	6 h	20 %	50 %	100 %
Air pressure over land surface	Global NWP	15 km	100 km	500 km				1 h	6 h	12 h	0.1 h	0.5 h	6 h	0.5 hPa	0.99 hPa	1 hPa
Air temperature (at surface)	Global NWP	15 km	50 km	250 km				1 h	6 h	12 h	0.1 h	0.5 h	6 h	0.5 K	1 K	2 K
Air pressure over sea surface	Global NWP	15 km	100 km	500 km				1 h	6 h	12 h	0.1 h	0.5 h	6 h	0.5 hPa	0.99 hPa	1 hPa

Sea surface temperature	Global NWP	5 km	15 km	250 km				3 h	24 h	120 h	3 h	24 h	120 h	0.3 K	0.5 K	1 K
Wind profile (horizontal component) - Higher stratosphere & mesosphere (HS & M)	Global NWP	50 km	100 km	500 km	1 km	2 km	3 km	1 h	6 h	12 h	0.1 h	0.5 h	6 h	1 m/s	5 m/s	10 m/s
Outgoing short-wave radiation at TOA	Global NWP	10 km	30 km	100 km				1 h	3 h	12 h	24 h	120 h	720 h	5 W/m2	10 W/m2	20 W/m2
Ozone profile - Lower stratosphere (LS)	Global NWP	15 km	100 km	250 km	1 km	2.2 km	10 km	1 h	6 h	12 h	0.1 h	0.5 h	6 h	5 %	10 %	20 %
Cloud water profile (> 100 µm) - Total column	Global NWP	5 km	15 km	50 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	10 kg/m2	17.1 kg/m2	50 kg/m2
Atmospheric temperature profile - Higher stratosphere & mesosphere (HS & M)	Global NWP	50 km	100 km	500 km	0.3 km	1 km	3 km	1 h	6 h	24 h	0.1 h	0.5 h	6 h	0.5 K	3 K	5 K
Ozone profile - Total column	Global NWP	15 km	100 km	250 km				1 h	6 h	12 h	0.1 h	0.5 h	6 h	5 DU	10 DU	20 DU
Dominant wave period	Global NWP	15 km	50 km	250 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	0.25 s	0.5 s	1 s
Cloud base height	Global NWP	5 km	15 km	50 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	0.2 km	0.5 km	1 km
Short-wave Earth surface bi-directional reflectance	Global NWP	10 km	30 km	100 km				1 h	3 h	12 h	24 h	120 h	720 h	1 % (Max)	2 % (Max)	5 % (Max)
Ozone profile - Lower troposphere (LT)	Global NWP	15 km	100 km	250 km	1 km	2.2 km	10 km	1 h	6 h	12 h	0.1 h	0.5 h	6 h	5 %	10 %	20 %
Ozone profile - Higher troposphere (HT)	Global NWP	15 km	100 km	250 km	1 km	2.2 km	10 km	1 h	6 h	12 h	0.1 h	0.5 h	6 h	5 %	10 %	20 %
Wind profile (vertical component) - Higher troposphere (HT)	Global NWP	15 km	200 km	500 km	0.5 km	2 km	3 km	1 h	6 h	12 h	0.1 h	0.5 h	6 h	1 cm/s	4.99 cm/s	5 cm/s
Downwelling short-wave radiation at the Earth surface	Global NWP	10 km	30 km	100 km				1 h	3 h	12 h	24 h	120 h	720 h	1 W/m2	10 W/m2	20 W/m2
Outgoing long-wave Earth surface	Global NWP	10 km	30 km	100 km				1 h	3 h	12 h	24 h	120 h	720 h	1 W/m2	10 W/m2	20 W/m2
Outgoing spectral radiance at TOA	Global NWP	10 km	30 km	100 km				0.004 d	0.0125 d	5 d	24 h	120 h	720 h	5 % (Max)	10 % (Max)	20 % (Max)

Wind speed over land surface (horizontal)	Global NWP	15 km	100 km	250 km				1 h	6 h	12 h	0.1 h	0.5 h	6 h	0.5 m/s	1.5 m/s	2 m/s
Short-wave cloud reflectance	Global NWP	10 km	30 km	100 km				1 h	3 h	12 h	24 h	120 h	720 h	1 % (Max)	3 % (Max)	10 % (Max)
Aerosol profile - Total column	Global NWP	15 km	50 km	250 km				1 h	6 h	24 h	0.1 h	0.5 h	6 h	10 %	20 %	50 %
Downwelling long-wave radiation at the Earth surface	Global NWP	10 km	30 km	100 km				1 h	3 h	12 h	24 h	120 h	720 h	1 W/m 2	10 W/m 2	20 W/m 2
Leaf Area Index (LAI)	Global NWP	2 km	10 km	50 km				1 d	5 d	10 d	0.125 d	1 d	10 d	5 % (Max)	10 % (Max)	20 % (Max)
Wind profile (vertical component) - Lower stratosphere (LS)	Global NWP	15 km	200 km	500 km	0.5 km	2 km	3 km	1 h	6 h	12 h	0.1 h	0.5 h	6 h	1 cm/s	4.99 cm/s	5 cm/s
Atmospheric temperature profile - Higher troposphere (HT)	Global NWP	15 km	100 km	500 km	0.3 km	1 km	3 km	1 h	6 h	24 h	0.1 h	0.5 h	6 h	0.5 K	1 K	3 K
Normalized Differential Vegetation Index (NDVI)	Global NWP	2 km	10 km	50 km				1 d	5 d	10 d	0.125 d	1 d	10 d	5 % (Max)	10 % (Max)	20 % (Max)
Atmospheric temperature profile - Lower troposphere (LT)	Global NWP	15 km	100 km	500 km	0.3 km	1 km	3 km	1 h	6 h	24 h	0.1 h	0.5 h	6 h	0.5 K	1 K	3 K
Sea-ice thickness	Global NWP	15 km	50 km	250 km				1 d	5 d	30 d	1 d	5 d	30 d	20 cm	50 cm	100 cm
Ozone profile - Higher stratosphere & mesosphere (HS & M)	Global NWP	15 km	100 km	250 km	1 km	2.2 km	10 km	1 h	6 h	12 h	0.1 h	0.5 h	6 h	5 %	10 %	20 %
Snow cover	Global NWP	5 km	15 km	100 km				3 h	24 h	120 h	3 h	24 h	120 h	10 % (Max)	20 % (Max)	50 % (Max)
Cloud ice profile - Total column	Global NWP	5 km	15 km	50 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	5 g/m2	10 g/m2	20 g/m2
Significant wave height	Global NWP	15 km	50 km	250 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	0.1 m	0.3 m	0.5 m
Wind profile (horizontal component) - Lower troposphere (LT)	Global NWP	15 km	100 km	500 km	0.5 km	1 km	3 km	1 h	6 h	12 h	0.1 h	0.5 h	6 h	1 m/s	3 m/s	5 m/s
Dominant wave direction	Global NWP	15 km	50 km	250 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	10 degrees	15 degrees	30 degrees

Snow water equivalent	Global NWP	5 km	15 km	100 km				3 h	24 h	120 h	3 h	24 h	120 h	2 mm	10 mm	20 mm
Wind profile (horizontal component) - Higher troposphere (HT)	Global NWP	15 km	100 km	500 km	0.5 km	1 km	3 km	1 h	6 h	12 h	0.1 h	0.5 h	6 h	1 m/s	3 m/s	8 m/s
Sea-ice cover	Global NWP	5 km	15 km	100 km				0.125 d	1 d	5 d	0.125 d	1 d	5 d	5 % (Max)	10 % (Max)	20 % (Max)
Wind profile (vertical component) - Lower troposphere (LT)	Global NWP	15 km	200 km	500 km	0.5 km	2 km	3 km	1 h	6 h	12 h	0.1 h	0.5 h	6 h	1 cm/s	4.99 cm/s	5 cm/s
Sea-ice type	Global NWP	10 km	25 km	100 km				0.125 d	1 d	5 d	0.125 d	1 d	5 d	4 classes	3 classes	2 classes
Aerosol profile - Lower stratosphere (LS)	Global NWP	15 km	50 km	250 km	0.2 km	2.99 km	3 km	1 h	6 h	24 h	0.1 h	0.5 h	6 h	10 %	20 %	50 %
Wind profile (vertical component) - Higher stratosphere & mesosphere (HS & M)	Global NWP	15 km	200 km	500 km	0.5 km	2 km	3 km	1 h	6 h	12 h	0.1 h	0.5 h	6 h	1 cm/s	4.99 cm/s	5 cm/s
Cloud top height	Global NWP	5 km	15 km	50 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	0.2 km	0.5 km	1 km
Aerosol profile - Higher stratosphere & mesosphere (HS & M)	Global NWP	15 km	50 km	250 km	0.2 km	2.99 km	3 km	1 h	6 h	24 h	0.1 h	0.5 h	6 h	10 %	20 %	50 %
Cloud drop size (at cloud top)	Global NWP	5 km	15 km	50 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	1 µm	2 µm	5 µm
Aerosol profile - Lower troposphere (LT)	Global NWP	15 km	50 km	250 km	0.2 km	2.99 km	3 km	1 h	6 h	24 h	0.1 h	0.5 h	6 h	10 %	20 %	50 %
Aerosol profile - Higher troposphere (HT)	Global NWP	15 km	50 km	250 km	0.2 km	2.99 km	3 km	1 h	6 h	24 h	0.1 h	0.5 h	6 h	10 %	20 %	50 %
Precipitation index (daily cumulative)	Global NWP	10 km	30 km	100 km				1 h	3 h	12 h	24 h	120 h	720 h	0.5 mm/d	2 mm/d	5 mm/d
Cloud water profile (< 100 µm) - Total column	Global NWP	5 km	15 km	50 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	10 kg/m2	20 kg/m2	50 kg/m2

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