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TABLE OF CONTENTS

1. Introduction

Atmospheric chemistry observations from space have been made for nearly 30 years. They have always been motivated by the concern about a number of environmental issues which are outlined below. Most of the space instruments have been designed for scientific research, improving the understanding of processes that govern stratospheric ozone depletion, climate change and the transport of pollutants. Long-term continuous time series of atmospheric trace gas data have been limited to stratospheric ozone and a few related species. According to current planning, meteorological satellites will maintain these observations over the next decade. They will also add some measurements of tropospheric climate gases, however their measurement being motivated by meteorology and vertical sensitivities / accuracies being marginal for atmospheric chemistry applications.

With the exception of stratospheric ozone, reliable long-term space-based monitoring of atmospheric constituents with quality attributes sufficient to serve atmospheric chemistry applications still need to be established. The general framework for this kind of measurements in synergy with ground-based and airborne measurements and integration with atmospheric models and data assimilation schemes has been outlined in IGOS-IGACO Theme Report /IGA2004/. That document includes also quantitative observation requirements, summarised for scientific and operational applications. Several other efforts have been made to identify the needs of long-term atmospheric composition data, such as the GMES-GATO report /GAT2004/, the Eumetsat position paper on observation requirements for nowcasting and very short range forecasting in 2015-2025 /EUM2003a/, and a Eumetsat-commissioned study to identify requirements for geostationary platforms in the context of Meteosat Third Generation /EUM2003b/. Usage of existing space data in the ESA GMES Service Element project PROMOTE /PRO2006/ provided further information. An ESA study on “Operational Atmospheric Chemistry Monitoring Missions” (“CAPACITY”) /Kel2005/ gathered all the various inputs and generated comprehensive observational requirements by environmental theme, by user group, and by observational system (ground / satellite). The study also assessed the contributions of existing missions to the fulfilment of these requirements, and identified priorities of observational techniques for future GMES Sentinel 4 and 5 missions. Tentative requirements at radiance level and other instrument and system related requirements were also identified. These requirements rely partly on a rich experience with the usage of existing similar instrumentation, and partly on retrieval simulations.

This mission requirements document is largely based on the results of the CAPACITY study. The observation requirements generated within that study are based on all the mentioned inputs, an additional user consultation workshop and further extensive discussions within and beyond the study team; they can be considered as the “state of the art” at this time. However, it should be noted that a thorough study to consolidate the translation of observation requirements into instrument requirements still needs to be done.

2. Background and Justification

2.1 Background

The human activities on a planetary scale are appreciably altering the processes that control the Earth's system. The system comprises a complex set of biological, physical and chemical processes taking place in and between the oceans, continents and the atmosphere. Our atmosphere has sufficient oxygen to maintain life, and quantities of trace gases, which serve to maintain the UV-protecting stratospheric ozone layer and a greenhouse effect that maintains habitable temperature conditions at the surface. The system of trace gases is maintained by a complex web of chemical processes that also serve to maintain the atmosphere in a sufficiently 'clean' condition for life to continue.

Historically, human activities have always interacted with the atmosphere, but the growth of population and industrialisation in the 19th and 20th century has led to dramatic changes in the Earth system. The developments of large mega-cities and the changes in land usage, occurring in the last 50 years, are two outstanding examples. Air pollution, the over-burdening of the atmosphere with emitted substances, has been known from the earliest times but it was always a local nuisance. In the 20th century pollution spread to regional and global scales and became a subject of concern both nationally and internationally. Table 1.1 lists some of the noticeable environmental effects attributable to the atmosphere. Although they appear in a roughly chronological order, all are still of current public concern.

Table 1.1. Some atmospheric problems attributed to human activities.

Climate Change and the Greenhouse Effect	The likely change in climate due to a continuing increase in the average global temperature, resulting from the increase in carbon dioxide (e.g. from industrial and vehicular combustion) and other trace gases such as methane, ozone and the HCFCs. Aerosols also play a part, by perturbing the Earth's radiative balance, both directly through the scattering and absorption of sunlight, and indirectly through the influence on clouds and the hydrological cycle. Changes in both tropospheric and stratospheric temperatures are likely to have negative (or amplifying) effects on many issues.
London Smog	Visible soot particles and sulfur dioxide, trapped in a static high pressure weather system, resulting from domestic heating and industrial activities. Now largely eliminated in the developed countries but still a problem in the developing world.
Los Angeles Smog or "summer" smog	Products of photo-oxidation, notably ozone and PAN, and other lachrymatory compounds, and particles, resulting from the photo-oxidation of industrial and vehicular emissions in the presence of sunlight. Endemic under static weather conditions throughout the world, despite countermeasures taken in the developed and developing world.
Acid Rain	Acid precipitation, which threatened natural ecosystems and forests over Europe and North America, resulting from industrial emissions of sulfur dioxide, which is photo-oxidised to form sulfate. Although sulfur emissions have been reduced, acidity is still a problem with the growing contribution of nitrogen compounds from industry and vehicles to acidity, and the SO_2 and NO_x from ships.
Ozone Depletion in the Stratosphere	Loss of ozone from the stratosphere with a consequent increase in UV radiation reaching the surface, resulting from the release of CFCs from industrial processes, which are inert in the troposphere but photolyse in the stratosphere. The ozone hole is a dramatic seasonal demonstration of such loss. Although the production of CFCs has been curbed, ozone depletion will

	remain for a long time because of the slow rate at which these compounds, still mostly present in the troposphere, diffuse to the stratosphere.
Nutrification of coastal waters and freshwater lakes; eutrophication	Change in coastal and freshwater ecosystems with the increased deposition of nitrogen compounds from the air. Resulting from industrial and vehicular emissions. Eutrophication and "tides" of poisonous algae are more obvious manifestations.
The increase in background tropospheric ozone.	Observed in the northern hemisphere, the increase is attributed to the intercontinental transport of photo-oxidants. Current background levels are comparable to those known to affect plant growth.
Enhanced aerosol and photo-oxidant levels due to biomass burning	Observed annually over the Atlantic and Indian Oceans, as well as South-East Asia as a result of biomass burning and agricultural activities in Africa, South America and Asia.
Aerosols in and downwind of regions of high population	Recently observed "brown cloud" over the western Indian Ocean, far from land; originates from industrial, agricultural and vehicular activities in the Indian subcontinent and South-East Asia and possibly China.
The intercontinental transport of pollutants and aerosols	These have been observed across the North Atlantic, Pacific and southern Indian Ocean
Stability of the Atmospheric Oxidation Efficiency	The efficiency of the atmosphere for removing greenhouse gases and pollutants has been called into question.

2.2 Justification

Issues related to changing atmospheric composition can be grouped into the following themes:

- Stratospheric Ozone and its impact on surface UV radiation,
- Air Pollution,
- Climate Change.

These affect human, animal and ecosystem health and have considerable economic consequences. Such effects have been recognised for some time and the public concern about the atmosphere is reflected in a number of international agreements.

- The Convention on Long-Range Transboundary Air Pollution (CLRTAP) (1979) with protocols on Sulfur (1985 & 1994), Nitrogen Oxides (1988), Volatile Organic Compounds (VOC) (1991), Heavy Metals (1998), Persistent Organic Compounds (POP) (1998), and Acidification, Nutrification and ground Level Ozone (1999).
- The Vienna Convention on the Protection of the Ozone Layer (1985) and the Montreal Protocol on Substances That Deplete the Ozone Layer (1987), and the subsequent adjustments and amendments.
- The Framework Convention on Climate Change (1992) and the Kyoto Protocol (1997).

The global nature of the problem requires a worldwide coordinated approach. The aim of these Protocols is to stem or reverse adverse environmental change. To be effective, these Protocols require timely, reliable and long-term information for assessment, monitoring and verification purposes. In addition to the need to ascertain the effectiveness of Protocols, there is a need to predict future change. Daily forecast systems are presently emerging in various stages of development. A number of local and national authorities are already providing air quality and UV forecasts to serve public awareness and provide advance warning systems similar to the weather forecast service. On a different level, an intense research effort is directed at climate predictions and understanding the consequences of global change. The quality of predictions very much depends on valid theoretical models and accurate measurements of the state and evolution of the atmosphere.

Observational data and theoretical models together result in increased understanding of atmospheric change. This synthesis is needed for policy assessment and, in general, to advance our knowledge.

The need for information on atmospheric composition is driven by the potentially huge impact that global atmospheric change has on human health and safety, ecosystem balance and socio-economic development. High level socio-economic benefits identified /1/ include:

- Understanding environmental factors affecting human health and well-being
- Understanding, assessing, predicting, mitigating and adapting to climate variability and change
- Improving weather information, forecasting and warning
- Improving management of energy resources

Direct needs for atmospheric composition information derive from monitoring and verification requirements of Protocols designed to regulate and mitigate the effects of human induced atmospheric change. This information is often needed on a country (signatory) by country basis. There is a need for independent global information for Protocol verification, separate from reporting obligations by individual signatories. This need calls for the ability to probe the atmospheric planetary boundary layer (PBL) on a global scale at high spatial and temporal resolution.

The process of policy formulation that leads to the implementation of Protocols is a multi-stage process, which starts with the scientific discovery of change, the assessment and understanding of the issues involved, checked by the usual process of scientific scrutiny and independent verification. Good quality observations and reliable theoretical models are essential at this explorative stage.

This stage is followed by the political process of policy formulation and appraisal of policies. Autonomy and self-reliance of the European Union and Member States requires the ability to carry out independent investigations and assessment of environmental and climate issues. There is a strategic need for reliable environmental and climate information to be available at the negotiating table when politicians and policy-makers need to decide on new policies. Access to high quality environment and climate data at all levels is required in order to be effective in policy negotiations.

Forecasts are necessary in order to anticipate episodes of risk to health and safety and to provide advance warnings to the public and the responsible authorities. Predictions of long-term environmental change are necessary in order to abate and mitigate the socioeconomic consequences and to formulate policy and research agendas for sustainable development. Here, information based on a combination of measurements and models turns out to be necessary, and in the case of forecast, the delivery of this information needs to take place in near-real time.

The need for stratospheric ozone information derives from the harmful effects of excess UV-B dose on health and biosphere. The Montreal Protocol calls for quadrennial ozone assessments and monitoring of stratospheric ozone concentrations and emissions of ozone destructing substances. Forecast of stratospheric ozone and surface UV prediction are possible and necessary in order to issue warnings and raise public awareness.

Understanding of the ozone layer behaviour includes that of the chemistry–climate interactions, which is a subject of scientific research. Continued assessment and improvement of regulatory action is needed until the recovery of the ozone layer is a fact, currently not expected to happen before 2050.

The need for air pollution monitoring and forecast is driven by health and safety directives and conventions. The Convention on Long-Range Trans-boundary Air Pollution (CLRTAP) and several EC directives regulate the emission of air pollutants. Air Quality (AQ) forecasts are important to serve as health warning in polluted areas. Environmental agencies need the AQ information in order to support implementation of regulatory actions on emissions from sources such as vehicular traffic and electric power generation. Reliability, timeliness, continuity and quality of this information is important. The temporal and spatial scale of requirements poses a challenge to both observational and modelling capability, ranging from street level to continental transport and from diurnal variability to decades of chemical lifetimes.

The need for climate information and prediction stems from the impact of climate change on society, which can be enormous. Policy on greenhouse gas regulation will deeply affect the energy resource management, the transport sector and the economy as a whole. The UN Framework Convention on Climate Change (UNFCCC) adopted at the Earth Summit of Rio de Janeiro in 1992 and the resulting Kyoto Protocol (1997) commits the signatories to cut emissions of greenhouse gases by 8% in the period 2008-2012 compared with 1990 levels. The EU and some hundred other nations have ratified the Protocol, but major players like the USA have not, whereas developing nations like China and India are not committed. Climate predictions are limited by a range of uncertainties depending on economic development scenarios assumed and on the validity of models employed to describe the Earth System. Understanding climate change includes understanding the chemistry-climate interactions at all levels in the atmosphere, indeed in the entire system Earth. This subject is one of the great challenges for future global observation and modelling development.

3. User Information Requirements

Operational Atmospheric Chemistry Monitoring will contribute to three major environmental themes:

(A) Stratospheric Ozone and Surface UV radiation
(B) Air Quality
(C) Climate

Further, three main drivers have been identified for operational *spaceborne* observations of atmospheric composition. These drivers are

(1) The provision of information on treaty verification and **protocol monitoring**
(2) The facilitation and improvement of operational applications and services, including forecasts, using **near-real time monitoring** information on the atmospheric composition
(3) The contribution to scientific understanding and knowledge acquisition for environmental **assessments** to support policy.

Each of the three overall drivers contributes to policy support. The first item with the direct delivery of the required monitoring information, the second one with applications and services using actual information and forecasts on the atmospheric state for warning systems and to support real-time decision making, and the third one via environmental assessments and their summaries for policy makers (WMO ozone assessments, European and global-scale environmental assessments on Air Quality and IPCC climate assessments).

Furthermore, in addition to the three overall drivers, *spaceborne* operational monitoring of atmospheric composition will be valuable:

- To promote scientific research with unique long-term consistent data products
- To contribute to numerical weather prediction (NWP), climate monitoring, and, in a broader perspective, Earth system monitoring
- To improve atmospheric correction for surface remote sensing
- To strengthen public awareness on environmental themes

Different levels of information will be needed, which can be associated with different user categories. On a first level of information there are the users that are involved in the monitoring of protocols and directives (**Compliance User**), e.g. governmental institutes on different administrative levels and international organisations associated with international treaties and protocols. The data requirements of these users are typically level-4 data requirements, such as long-term 3-dimensional global distributions of trace gases, aimed at complete monitoring of the atmospheric state and its evolution in time.

On a second level of information there are users that would like to apply the available data products to operational applications and **services**, e.g. meteorological institutes, to improve early-warning systems and to increase public awareness. These users typically need the data in near-real time, i.e., within a few hours after observation. NWP centres may wish to receive level-1 data (typically radiances) in order to process them to level-2 in near-real time and within the running applications.

The services may involve different user categories with specific data requirements, e.g., they may be directed to support policy-makers for control strategies and security, health and environmental law enforcement, e.g. on measures to be taken in air pollution episodes. The services can also be directed to the general public for health warnings (concentrations exceeding standards, UV radiation levels) and planning of outdoor activities (e.g. a Marathon in Athens) as well as for general awareness. Scientists could use actual information on the atmospheric composition for campaign planning and climate monitoring. Other specific organisations could use the data, e.g. to improve safety of air and road transport by provision of warnings on environmental hazards (forecast of plumes related to volcanic eruptions, extreme forest fires, etc.).

On a third level are scientists assessing the technical basis for abatement strategies, typically summarised in environmental assessment reports (**Technical User**) and the scientists using the information for (fundamental) scientific research (**Research User**). Key to these users is the understanding of the atmospheric state and its evolution. The data requirements are typically more stringent in comparison to the monitoring requirements and these users will require level 1 and/or level 2 data products in addition to level 4. The most important aspect of operational missions for these users is the perspective of unique long-term and homogeneous data sets with global coverage.

Table 3.1: Applications per environmental theme and user information

Environmental Theme Information	**Ozone Layer & Surface UV radiation A**	**Air Quality B**	**Climate C**
Protocols 1	UNEP Vienna Convention; Montreal and subs. Protocols CFC emission verification Stratospheric ozone, halogen and surface UV distribution and trend monitoring	UN/ECE CLRTAP; EMEP / Göteborg Protocol; EC directives EAP / CAFE AQ emission verification AQ distribution and trend monitoring	UNFCCC Rio Convention; Kyoto Protocol; Climate policy EU GHG and aerosol emission verification GHG/aerosol distribution and trend monitoring
Services 2	Stratospheric composition and surface UV forecast NWP assimilation and (re-) analysis	Local Air Quality (BL); Health warnings (BL) Chemical Weather (BL/FT) Aviation routing (UT)	NWP assimilation and (re-) analysis Climate monitoring Climate model validation
Assessments 3	Long-term global data records WMO Ozone assessments Stratospheric chemistry and transport processes; UV radiative transport processes Halogen source attribution UV health & biological effects	Long-term global, regional, and local data records UNEP, EEA assessments Regional & local PBL AQ processes; Tropospheric chemistry and long-range transport processes AQ source attribution AQ Health and safety effects	Long-term global data records IPCC assessments Earth System, climate, rad. forcing processes; UTLS transport-chemistry processes Forcing agents source attribution Socio-economic climate effects

4. Mission Requirements

4.1 Derivation and general characteristics of requirements

This section will provide the geophysical observation requirements (Level 2/3 data requirements) separately for each environmental theme and user category. The requirements have been generated for an integrated system, encompassing ground-based, airborne and satellite observations, and data integration tools such as data assimilation and inverse modelling tools including atmospheric models. However, in this document only the space data requirements are reproduced.

4.1.1 Data Requirements Table Format and Definition of Height Ranges

The data requirements are tabulated per theme (A,B,C) and per user category (1,2,3) following the structure defined in the previous section, i.e., for monitoring / compliance users (A1, B1, C1), for forecast / near-real time applications and services (A2, B2, C2) and for environmental assessments / technical and research users (A3, B3, C3). The requirements are further split into Level 2 satellite data requirements and auxiliary requirements. Thus, for example, Table A1 summarises the data requirements from spaceborne platforms for Theme A (ozone layer), user category 1 (monitoring, compliance user). Table 1 summarises the list of data requirement tables. The Data Requirements Tables are listed in the Appendix of this MRD. The auxiliary requirements are also described.

Table 4.1 List of the data requirements tables

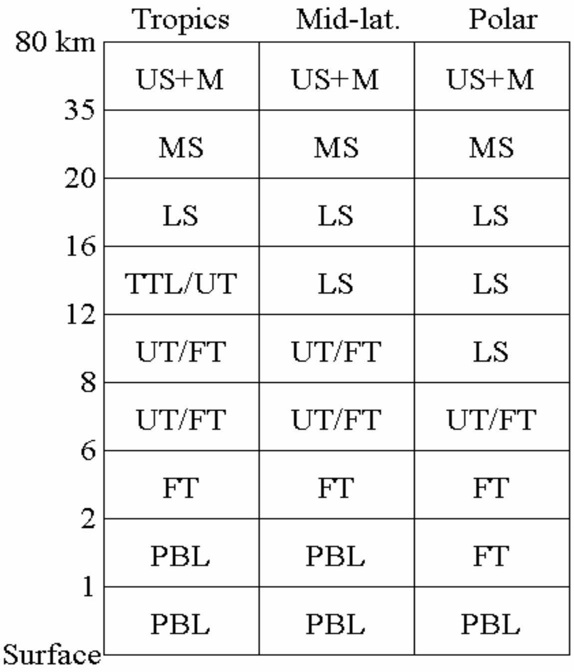
Table code	Environmental Theme	Application	User category
A1	Ozone Layer	Monitoring	Compliance
A2	Ozone Layer	Forecast	Near-real time
A3	Ozone Layer	Assessment	Technical/research
B1	Air Quality	Monitoring	Compliance
B2	Air Quality	Forecast	Near-real time
B3	Air Quality	Assessment	Technical/research
C1	Climate	Monitoring	Compliance
C2	Climate	Forecast	Near-real time
C3	Climate	Assessment	Technical/research

Table 4.2. Format of the data requirements tables

Ref code	Environmental Theme					
Requirement Data Product	Driver	Height Range	Horizontal resolution	Vertical resolution	Revisit Time	Uncertainty

The data requirements tables have the general format presented in Table 4.2. We distinguish per data product the relevant height range (for a profile) or a total column, or a partial column (e.g. tropospheric column). In general, the height-range requirements should be interpreted understanding that even when vertical profile information is required, information from column observations could still contribute to the application, although not fulfilling the vertical resolution requirement. Further, the required horizontal and vertical resolution and revisit time are given, for which the first value is a target requirement, and the second value, separated by a slash (/), is the threshold requirement. In the last column the threshold uncertainties that can be allowed for the given (threshold) resolution requirements are presented.

For the height ranges, reference is made to the compartments of the atmosphere that are commonly distinguished in atmospheric research. All boundaries should be interpreted as approximate values. In the troposphere distinction is made between the PBL, the Free Troposphere (FT), the Upper Troposphere (UT) and the Tropical Tropopause Layer (TTL). In the stratosphere a distinction is made between the lowermost stratosphere (LS), the middle stratosphere (MS), and the upper stratosphere (US). The mesosphere is denoted with (M).



	Tropics	Mid-lat.	Polar
80 km	US+M	US+M	US+M
35	MS	MS	MS
20	LS	LS	LS
16	TTL/UT	LS	LS
12	UT/FT	UT/FT	LS
8	UT/FT	UT/FT	UT/FT
6	FT	FT	FT
2	PBL	PBL	FT
1	PBL	PBL	PBL
Surface			

Fig. 4.1. *The atmospheric compartments that are distinguished for the height-range specifications in the data requirement tables. The boundaries have been set at fixed altitudes and latitudes for simplicity and only represent an approximation to the mean state neglecting atmospheric variability. Tropics [0 – 30 deg], Mid-latitudes [30 – 60 deg], Polar region [60 – 90 deg], in both hemispheres.*

The PBL typically extends up to less than 2 km above the Earth's surface. The PBL is usually thicker above continents than above oceans and typically up to less than 1 km altitude at polar regions. The FT is defined as the region between the top of the PBL and the tropopause. The tropopause in polar regions is typically at an altitude of ~8 km, at mid-latitudes at ~12 km, and at tropical latitudes near ~16 km. The TTL is located in the FT between about 12 and 16 km at tropical latitudes. The UT refers to tropospheric air above about ~6 km altitude. The LS refers to stratospheric air below ~20 km altitude. The MS represents the middle stratosphere between ~20 km (i.e. excluding the lowermost stratosphere) and ~35 km. The upper stratosphere plus mesosphere are defined to extend from ~35 km up to ~80 km altitude globally. No requirements for atmospheric composition above ~80 km have been specified. The given domains and their boundaries are all to be considered as a very much simplified of the real, variable atmosphere. Thus, none of the defined boundaries should be interpreted as hard numbers.

4.1.2 Coverage and Sampling Requirements

In general, for each of the listed *satellite products* the target coverage is **global**. This requirement directly reflects the global nature of the three driving environmental themes. Only for the air quality theme, with its additional focus on local, regional and continental scale environmental air quality issues, the required coverage for European-scale operational applications is the European continent, including Turkey, and Europe's surrounding coastal waters as well as the closest parts of the North-Atlantic, which typically impact on the PBL in Europe by long-range transport.

The general target requirement on sampling is (near-)contiguous sampling. It is clear that no measurement (sub-)system can be envisioned, nor it is desirable or necessary, with continuous and global-scale sampling on the defined spatial resolution and with the defined revisit times. The integration of a single measurement (sub-)system in an integrated system may allow for 'data gaps' in time and space to a certain extent.

On the other hand, in order to have an efficient overall measurement system, the aim of the measurement (sub-)system should be to maximise the number of independent observations to be made by that measurement system, the sampling being mostly limited by the other data requirements on uncertainty, spatial resolution and revisit time. Subsystems with (severe) limitations in coverage and sampling will contribute less to the integrated system and therefore typically should have less priority for operational applications.

4.1.3 Uncertainty, Spatial Resolution and Revisit Time Requirements

The following strategy to the derivation of quantitative data requirements has been followed. At first, for each application a list of observables has been compiled for which the data requirements on spatial resolution and revisit time have been specified. In a next step, and on the basis of the given spatial resolution and revisit times, the requirements for the uncertainty have been specified.

This logic has been followed because the data requirements on spatial resolution and revisit time reflect the atmospheric variability of the observable, which is primarily a function of the time- and spatial scales of the atmospheric and surface processes that are relevant for the observable. Given the relevant temporal and spatial scales the *amount of variability* of the observable on these scales can be investigated. The amount of variability on a certain temporal and spatial scale is relevant for the derivation of the uncertainties. This approach also implies that the different requirements for an observable (uncertainty, spatial resolution, revisit time) cannot be assessed independent from each other.

4.1.3.1 Uncertainty Requirements

In data assimilation systems it is in the first place the (assumed) uncertainty of the measurement that determines the potential impact of the observation on the system. Therefore, the requirements on uncertainty are the most quantitative and, in fact, leading requirements, at least in comparison to the related requirements on spatial resolution and revisit time. The uncertainty for which the requirement is set will typically contain both a random component ('root mean square error') and a systematic ('bias error') component. The latter component should be established by a long-term validation with independent measurements. Constant biases are typically not considered most important. Requirements on regional biases and random errors are more difficult to define separately, and their relative importance will be dependent on the application (e.g. trends). The relative contributions of random errors and biases will also be very much dependent on the observational technique. The uncertainty requirements in the tables are to be understood as the root sum square of random and systematic errors.

A representation error may contribute to the uncertainty, which should be taken into account in the assessment of the uncertainty requirements. In general, the requirement is that the measurements be sufficiently representative for the given spatial resolution and revisit time. For satellite measurements the representation errors will typically contribute less to the uncertainty than for ground-based data, at least as long as the pixel sizes of the space data and the model grid sizes are of the same order of magnitude or the pixel sizes are larger.

General requirements on sampling and coverage have been specified above. Sampling is also constrained by the given spatial resolution and revisit time requirements. In some cases enhanced temporal or spatial sampling could somewhat relax the uncertainty requirement on an individual retrieval. However, the extent to which relaxation is possible typically depends on the forecast correlation lengths of the assimilation system. These are dependent on atmospheric conditions (see also below). The main limitation on sampling is that the additionally sampled observations need to be independent. A clear advantage of extensive, independent sampling is that a large number of available observations from prolonged data sets with stable retrievals and limited instrumental drifts during the mission lifetime typically will help the data assimilation system to better characterise the random and systematic components of the uncertainty. In this way sampling is related to the uncertainty.

The impact of observations with a certain uncertainty on a data assimilation system will also depend on the (assumed) model forecast uncertainties. These will typically vary from time to time and place to place. This is a complicating factor that has not been taken into account in the derivation of the measurement uncertainty requirements. It can be anticipated that at locations and times with small model uncertainty (e.g. because in-situ observations are available) the uncertainty requirements on the observations can be relaxed to a certain extent. This effect will become more important as models will improve in describing atmospheric transport and chemistry in the future. On the other hand, atmospheric composition is also to a large extent determined by intermittent processes and ‘unpredictable events’. Because of the unpredictable nature of atmospheric composition (in time and space) it is not desirable to relax a data requirement based on limited model uncertainties in transport or chemistry.

In conclusion, the uncertainties that are given for each of the observables should be read as the maximum (threshold) uncertainty that is allowed in order to obtain information on the observable at the specified spatial resolution and revisit time. Whether the uncertainty is reached with a single retrieval or with a combination of retrievals will depend on the sampling and measurement techniques used. Requirements for these have not been specified.

4.1.3.2 Horizontal Resolution Requirements

The horizontal resolution requirements are somewhat less quantitative than the uncertainty requirements. As a rule of thumb, the horizontal resolution should be at least a factor 2-3 smaller than the error correlation length in the model that is used in the assimilation of the observable. In fact, the assimilation typically combines the available observations within an area defined by the model forecast error correlation length. These are typically a function of altitude in the atmosphere and are mainly determined by the spatial scales of the relevant atmospheric processes and by the resulting spatial variabilities in the observables. Typically, the correlation length decreases from several hundreds of kilometres in the (lower) stratosphere to several tens of kilometres in the lower troposphere and even smaller in the

PBL. Correlation lengths in the upper stratosphere and mesosphere are typically smaller than in the lower stratosphere. In some special cases the observation of scales smaller than those defined by the model forecast error correlation length might be very useful as well, e.g., to validate the model on the cascade of processes as a function of spatial scale and parameterisations of sub-grid scale processes.

4.1.3.3 Vertical Resolution Requirements

The vertical resolution requirements are in the first place related to the gradients of the observable in the vertical direction. Present-day estimates of vertical correlations show very short correlation lengths in the lower stratosphere and UTLS region due to their stratified nature, and much longer correlation lengths in the well-mixed troposphere. In the middle and upper stratosphere the distributions of the observables vary more smoothly in space and the requirements can be limited to a few kilometres in vertical resolution. In contrast, in the UTLS the vertical gradients (and thus the model error correlation lengths) can be very steep and highly variable in time. This results in rather stringent requirements. The vertical gradients in the troposphere typically depend on the synoptic situation and are mainly controlled by convective events and large-scale subsidence. Note that, in contrast to turbulent mixing, convection can either steepen or smooth gradients. The faster overturning in the troposphere transports the information coming from observations more efficiently throughout the model vertical domain than in the UTLS. Therefore the vertical resolution requirements can typically be somewhat more relaxed in the free troposphere than in the UTLS region. Especially in the UTLS region and lower stratosphere the vertical fine-structure of models (dynamics) is not well tested due to a lack of high-resolution vertical information, e.g., with respect to atmospheric waves, and relevant for the general (Brewer-Dobson) circulation.

4.1.3.4 Revisit Time Requirements

Requirements on the revisit time can, in principle, be determined from examination of the anomaly correlations in an assimilation system. One could argue that if the anomaly correlation drops below a certain predefined threshold, the time evolution as described by the model is not sufficiently adequate and a new analysis based on observations, is needed. The lifetime of the analysis increments depends on the growth of the model forecast error in time. Following this argument the required update frequency would determine the required temporal resolution for an observable. However, it is difficult to estimate the extent to which future (and likely improved) models are able to describe the time evolution of the atmosphere. Current assimilation models have already proven skill for the prediction of stratospheric transport up to more than a week ahead (and possibly longer, depending on the required accuracy). Model skill to describe the evolution of tropospheric transport is much more limited because of the intermittent and unpredictable nature of several processes and events. The model skill on predictability is often limited by the predictability of the meteorological variables (wind, temperature) on which atmospheric composition typically has little influence, at least in the troposphere.

Here, instead of using extensive studies on the anomaly correlation or the model error growth per time step, the requirements on the revisit time for the observables are derived from the typical model forecast error correlation lengths and the atmospheric variability in time of the observable. For example, at the higher altitudes the observables with a diurnal cycle should be observed at least twice daily (e.g. day/night, etc.), while for the other observables daily to weekly observations would probably suffice. The required revisit time typically increases in the lower troposphere and PBL, as does the complexity of models to describe the time evolution of the atmosphere. Depending on the relevant atmospheric processes and the geographic location, the required revisit time in the PBL can typically vary from several times daily to less than one hour.

Finally, it is noted that the spatial and temporal resolutions that are or will be used in present-day and future atmospheric models play only a (minor) role for the resolution requirements, because the requirements are determined by the scales of atmospheric processes, which may be either resolved or sub-grid processes in a model. It should also be noted that revisit time requirements are typically not related to (either near-real time or offline) data delivery time requirements.

4.2 Geophysical observation requirements per application

4.2.1 Theme A: Stratospheric Ozone and Surface UV

4.2.1.1 Protocol Monitoring and Treaty Verification

4.2.1.1.1 Relevant Species and Processes

The Montreal Protocol and its subsequent Amendments and Adjustments form the main driver to the monitoring of stratospheric ozone and surface UV radiation. Long-term monitoring of the expected decrease in polar and global ozone loss in response to the measures taken based on the Montreal Protocol and its amendments is required. The ultimate goal is to obtain accurate information on the evolution of the ozone layer (total column) and its effect on surface UV, together with the monitoring of columns of ozone depleting substances (ODS); CFC's and their replacement HCFCs, and halons. Specifically information on the changes (trends) in chlorine loading is needed, both in the troposphere and in the stratosphere.

More detailed policy-relevant information includes the monitoring of the height distribution of ozone and ODS compounds, in addition to total column information. Ozone profile information also allows separation of long-term changes in tropospheric component, mainly relevant to the Air Quality and Climate themes, from changes in the stratospheric component relevant to the Montreal Protocol. These aspects are all considered under 'Assessment' in Section 3.3.

Another user requirement is that the sources of ODS need to be identified and quantified. Currently this is done bottom-up from country-wise official figures. However, independent verification by inverse modelling of the concentration distributions would be highly desirable. Limiting factor for inverse modelling of ODS is however their fairly homogeneous distribution.

The user requirements for operational surface UV radiation monitoring relevant to the Montreal and subsequent protocols need some consideration. In fact the protocols are directed to reduce UV increases that are related to (anthropogenic-induced) changes in total ozone column. On the other hand, the importance of these ozone-related long-term UV changes also need to be viewed in relation to (possibly larger) surface UV changes induced by long-term variations in other processes, including the locally and in time varying effects of clouds, aerosols and surface albedo.

For the long-term monitoring of the surface UV radiation it suffices to monitor on a global scale the *clear-sky UV Index* and the *daily UV dose*. The clear-sky UV Index is an adequate measure that is directly related to (variations or trends in) the total ozone column amount. Next to the total ozone column the main other modulators of the UV Index are the solar spectral irradiance, solar zenith angle and Sun-Earth distance, surface elevation, surface albedo, stratospheric temperatures (via ozone absorption) and aerosol optical parameters. A global daily monitoring of the noontime clear-sky UV Index will also give information on the occurrence of extreme values, which are typically related to ozone depletion events.

The daily UV dose is defined as the 280-400 nm spectrally-integrated erythemally-weighted surface irradiance integrated over daytime. In the interpretation of UV dose variations and trends due to ozone depletion other processes that may result in long-term changes in surface UV radiation levels should be taken into account. Most important for long-term UV dose monitoring, i.e., over decades, are possible systematic changes in the effects of clouds, aerosols, UV surface albedo, and the solar spectral irradiance.

4.2.1.1.2 Measurement Strategy and Data Requirements

Given the user requirements on long-term homogeneity and global coverage of the data sets and the trend requirements, the most advantageous approach for protocol monitoring is the integration of spaceborne and ground-based data in an assimilation system. Specific requirements call for spaceborne total ozone columns (5% RMS; 5% bias). The ozone profile should distinguish different atmospheric domains, at least including the lower troposphere, the upper troposphere, the lower stratosphere, and the upper stratosphere and mesosphere. The threshold ozone monitoring requirements can be summarised as follows: Horizontal resolution: 100 km; Vertical resolution: column (mandatory), 4 independent pieces of information (desirable); Temporal resolution: 24 hrs; Uncertainty: RMS 5%, bias 5%). Not that some of these requirements are covered under Assessment in Section 3.3.

Based on present-day experience with the assimilation of total ozone column information in chemistry-transport models, the required information can be obtained by global spaceborne observations with about 3-days revisit time such as typically provided by ERS-2 GOME. The user requirement on trend detection is rather stringent (~0.1% per year). Although this number applies to the zonal monthly means, the trend requirement is driving the uncertainty requirement of 3% on an individual total ozone column measurement. Neglecting biases, typically ~900 independent measurements per zonal band (of 100 km width) and per month would then suffice to reduce uncertainty by a factor 30 as required (3% => 0.1%).

The monitoring of (the trend in) the ODS in troposphere and stratosphere can be best performed using a representative surface network, measuring weekly background surface concentrations and total column amounts of the various regulated ozone depleting substances as listed by, e.g., WMO in the ozone assessment reports. In the data requirement table only the most abundant ODS are listed. Furthermore, especially ODS for which surface-based historical records are available at present are the most relevant for future protocol monitoring. A representative surface network, with at least one background station in each ~10 degrees latitude band, will typically suffice for the determination of total equivalent chlorine in the atmosphere as well as for the derivation of trends in CFC concentrations and trends in their emissions. For the annual trends, typically zonally averaged, weekly representative values with uncertainties of ~2% are needed for the CFCs and other long-lived ODS, and ~5% for the HCFCs.

Independent verification of ODS emissions by inverse modelling of the concentration distributions would be desirable. However, owing to the long chemical lifetime of the ODS, and hence their fairly uniform global distribution, this would be a challenging task. On the other hand, it has been shown already that trajectory analyses of surface-based time series of long-lived compounds sufficiently close to emission regions can be used to trace back the emissions to a certain region. Currently it is not foreseen that such detailed studies can be performed on an operational basis. Spaceborne observations of ODS columns are not likely to contain sufficient information to contribute significantly to inverse modelling of ODS emissions. A rather dense surface network would be required to derive country-based (monthly) ODS emission numbers, typically one station per country and further every 10000-100000 km^2.

Operational surface-based observations from a global representative surface network are needed for continuous validation of the ozone column spaceborne observations. Ozone sonde observations, especially in the polar regions, are needed to provide additional information on ozone that could be difficult to obtain by spaceborne observations, including the altitude(s) of extreme ozone loss.

The surface UV radiation requirements include a requirement on long-term time series and regional maps of the daily noontime clear-sky UV Index, typically with at most 1 index point accuracy. The uncertainty of a level-2 UV index product based on satellite observations should be better than ~10% for UV Index higher than 5 index points, and 0.5 index point for smaller UV Index values.

Given the known sensitivity of the UV Index for different parameters, the UV Index requirements can be translated into requirements for level-2 products, e.g., maximal a few percent of change in UV Index per change of 0.1 in aerosol optical depth. The relevant products include, besides the total ozone column, the solar spectral UV irradiance and its modulations over time, the aerosol optical depth and absorption optical depth and the UV surface albedo. Trace gases such as NO_2 and SO_2 absorbing in the UV spectral range have a very minor effect on UV radiation levels.

For the surface UV daily dose the estimated uncertainty requirement is 0.5 kJ m^{-2} (for reference: a maximum daily dose at tropical latitudes is ~ 8 kJ m^{-2}, typical values range from 1 to 5 kJ m^{-2}). Apart from the effect of clouds considered below (Section 3.1.3), the same level-2 products as for the clear-sky UV Index are needed to derive the daily UV dose.

4.2.1.1.3 Auxiliary Data Requirements

The ozone layer monitoring requires assimilation of the observations in an atmospheric model. Therefore, additional information is needed on the meteorological state of the stratosphere. At the time this information is assumed to be available from the analyses of NWP models.

For the attribution of UV changes to ozone changes, auxiliary information is needed on the global distribution and possible changes over time in:

- 3-D cloud optical and geometric parameters (mainly cloud optical depth and cloud cover)
- Stratospheric temperatures (determining the UV absorption for a given ozone amount)
- The UV extraterrestrial solar spectrum, covering the 200-400 nm spectral range
- 3-D aerosol optical parameters in the UV (mainly aerosol optical depth and single scattering albedo)
- 2-D UV surface albedo global distribution

The latter three bullets are covered in the data requirement table of A1-S. Stratospheric temperatures are assumed to be available with adequate accuracy from the analyses of NWP models.

Quantitative requirements on cloud properties are not yet available. However, given the large, often dominating effect of clouds on the daily UV dose and its changes over time and place, the required cloud information needs to be quite detailed in time and space in order to be able to derive information on surface UV variations and trends that can be related to ozone changes as required here for protocol monitoring. Typically, for the interpretation of the UV dose accurate cloud information is needed on cloud cover and cloud optical depth as a function of time over a day with time steps of about an hour or less. Here, it is assumed that the required information on cloud parameters will be available from existing or planned meteorological platforms (e.g. MSG, GOES). A good cloud mask (on/off) is the most crucial requirement.

In the mapping of the UV daily dose the various level-2 data products that are needed are typically gridded (level 3-4) before these are combined. Requirement on co-location of the various products are therefore not considered very stringent. The different products may be derived from different platforms, including for example a platform in low orbit for total ozone, the solar spectrum, aerosols, and surface albedo, and a geostationary platform for variables that typically change significantly over the day (cloud parameters and, possibly, aerosol parameters).

4.2.1.2 Near-Real Time Data Requirements

4.2.1.2.1 Relevant Species and Processes

Forecasts of ozone fields and surface UV radiation are required for different user groups. Near-real time ozone data are required for improved radiances in NWP models and as input data for surface UV forecast. For forecasts a data assimilation system is needed to integrate the near-real time observations and to combine these with transport information from the model forecast. It has been shown that with present-day NWP models reliable total ozone and clear-sky UV Index forecasts are possible up to ~1 week ahead.

Near-real time information on the ozone layer is also required during periods of severe (polar) ozone loss to inform policy-makers, the media and the general public. Currently, near-real time data relevant to Arctic ozone loss has been intended for scientific use only, e.g., related to Arctic measurement campaigns. Especially extensive ozone loss that takes place in the Arctic during cold winters is a cause of great concern due to its proximity to inhabited areas. Forecast of, e.g., the Antarctic vortex break-up would contain important information especially for some countries in the Southern Hemisphere including Argentina, Chile, New Zealand and some small islands.

For surface UV radiation forecasts, such as provided in most countries by the meteorological institutes, total ozone column forecast information is needed, typically for a few days ahead. Additional forecast information is required on clouds, aerosols and surface albedo. However, given the present-day uncertainties associated with the forecast of these additional parameters, current forecasts of surface UV radiation are often limited to so-called clear-sky values (at most including a fixed aerosol correction and in some countries taking into account known surface albedo variations). The reported clear-sky value therefore typically represents the most extreme case. Near-real time observations of aerosols and surface albedo are needed to reduce the uncertainty in their effect on the clear-sky UV predictions.

In some countries, an uncertainty range is presented on the UV Index forecast where the given range mainly reflects the prediction of the possible reduction of UV radiation by clouds. Improved cloud forecasts (mainly on cloud cover and cloud optical depth) would help to reduce the uncertainties that are associated with cloud predictions.

Note that UV Index forecasts need to report the highest expected value for the day, which is typically around noontime.

4.2.1.2.2 Measurement Strategy and Data Requirements

Modelling of the evolution of the ozone layer over a couple of days (e.g., up to ~10 days) requires information on the full three-dimensional ozone layer distribution. Based on the initial field, the meteorological forecasts will be used to transport ozone in all dimensions and this will result in a new ozone field from which the required forecast of the spatial distribution of the ozone columns can be derived.

In order to accurately forecast ozone columns, near-real time spaceborne ozone profile measurements are needed in the UTLS region and above. In the troposphere a measurement of the tropospheric column suffices. Total ozone column observations can also be used, although at the expense of accuracy. Typically for the ozone profile the required vertical resolution decreases from about 2 km (threshold) in the UTLS region to ~5 km in the upper stratosphere and mesosphere. If the complete ozone profile cannot be covered by the measurements, additional information will be needed from measurements of the total ozone column.

Near-real time availability of surface-based observations of total ozone columns is needed to complement and validate the spaceborne observations. Furthermore, a representative ozone sonde network is needed for validation of the assimilated ozone distribution. In-situ ozone profiles are also needed to enhance the vertical profile information in the troposphere and lower stratosphere.

Both ground-based measurements and spaceborne estimates of the UV dose and UV Index are needed for the validation of the UV forecasts. Although the quality of (derived) surface UV radiation measurements is highly correlated with the quality of the total ozone observations, some differences between both data sets will occur because clear-sky surface UV radiation products are additionally weighted with solar zenith angle, aerosol load, and surface albedo. Some information on possible long-term changes in the incoming UV solar irradiance at the top of the atmosphere would also contain valuable information for UV forecasts.

A complicating factor for validation of the spaceborne surface UV estimates is the variable presence of aerosols and clouds. Near-real time observations of the UV spectral aerosol (absorption) optical depth and UV spectral surface albedo will help to reduce uncertainties in UV forecasts. The required spectral range for these products is the 280 – 400 nm spectral region. The required spectral resolution is typically 5 to 10 nm in the UV-B range (280 – 320 nm) and 10 to 20 nm in the UV-A range (320 – 400 nm).

A requirement for the forecast model is that the dynamics of the stratosphere are well-predicted and also that changes in ozone due to dynamics can be distinguished from changes in ozone that are related to chemical and/or radiative processes. Good vertical resolution is crucial to better represent stratospheric waves. It has been shown that inclusion of a parameterisation of heterogeneous ozone loss processes can improve the forecasted ozone distribution. For the stratospheric radiation budget the most important gases to assimilate together with ozone are H_2O, CO_2, CH_4, and N_2O.

Assimilation of tracer observations of SF_6 or CO_2 could be used to better separate between ozone transport and ozone chemical processing. Currently, parameterisations on ozone loss are based on the prediction of temperature. Ozone loss processing can be better constrained by observations of PSCs, enhanced ClO, and aerosol extinction.

Operational in-situ aircraft measurements in the UTLS region, co-located with ozone observations, of H_2O, CO, HNO_3 and HCl would be desirable to better constrain the stratosphere-troposphere exchange processes. Operational spaceborne observations of these gases in the UTLS region could possibly contribute as well.

Finally, near real time data delivery for this application implies that the data needs to be available to an operational modelling environment within a couple of hours after observation. In that case a significant part of today's observations can still be used for the analysis on which the required forecast for tomorrow will be based.

4.2.1.2.3 Auxiliary Data Requirements

Ozone forecasts rely on an operational assimilation system including the meteorological analysis and forecast of stratospheric transport. The required meteorological fields, up to at least one week ahead, can only be delivered by NWP centres. Therefore, it is foreseen that forecast services will be run by these meteorological centres. The operational atmospheric composition products will contribute to the overall assimilation system. Significant experience will be obtained in the GEMS project that will start in 2005.

UV radiation forecasts are typically most relevant for clear-sky conditions as these typically represent the maximum level that can possibly be obtained. However, forecasts including the effect of clouds would be more realistic. Therefore, improved all-sky UV radiation forecasts would profit from improved forecasts of cloud parameters. Most important parameters for all-sky UV Index forecasts are, next to the information on ozone, aerosols and surface albedo, cloud cover, especially around noontime, and cloud optical depth.

For forecasts of the UV dose, a forecast of (the distribution of) the sunshine duration over the coming days would be the most crucial parameter, together with the above-mentioned cloud parameters relevant for the UV Index.

Improving cloud forecasts, especially with the aim to improve surface radiation forecasts, is extremely challenging. Even with near-real time availability of cloud observations current scientific knowledge of cloud processing likely does not allow for accurate forecasts of cloud distribution for the purpose of improving UV forecasts for typically 24 hours ahead. No requirements on cloud parameters are available.

Global radiation (pyranometer) measurements from the surface radiation networks could be another independent set of observations that can account for the cloud and aerosol effects on UV. Also, forecasts of global radiation are becoming available from NWP centres and these could give additional information that is useful to improve upon the UV forecasts.

4.2.1.3 Assessment

4.2.1.3.1 Relevant Species and Processes

More detailed policy information than required for direct protocol monitoring (total ozone column, surface UV; Section 3.1) will be based on the monitoring of the height distribution of ozone and ODS compounds, related compounds and parameters other than ozone that affect the surface UV radiation. For example, ozone profile information is necessary in order to separate long-term changes in the troposphere ozone component, mainly relevant to the Air Quality and Climate themes, from changes in the stratospheric component relevant to the Montreal Protocol.

For the ODS altitude information would also give indication on the effectiveness of treaty implementation. Desirable is information on the stratospheric halogen loading, which includes also reservoir species such as HCl, $ClONO_2$, HBr and $BrONO_2$. In addition, monitoring of these reservoir species might be relevant for another reason: it is anticipated that changes in reservoir species typically would precede changes in total chlorine content and therefore would give an early indication of changes in equivalent chlorine. Certain active chlorine and bromine components (ClO and BrO) and PSCs are indicators of the amount, severity and extent of ozone depletion events, which is additional relevant information for treaty verification.

The main drivers for a better understanding of the ozone layer evolution and long-term changes in surface UV radiation are the following long-term science questions:

- Understanding of the trends in total ozone, largely by examination of the evolution of the ozone layer and the changes in the ozone distribution over time
- Understanding of the effects on the ozone layer of the policy measures taken in response to the Montreal Protocol and its amendments

- Understanding of the global ozone chemical budget, including the relative roles of denitrification, heterogeneous chemistry and other ozone loss processes
- Understanding of the processes resulting in interactions between ozone recovery and climate change, related to radiation, dynamics and/or chemistry
- Understanding of the long-term changes in surface UV radiation levels, their attribution to either total ozone changes or other processes, and their effects on health and the environment
- Understanding of the distribution of the ozone depleting substances and the trends in their concentrations

To answer these questions the scientific users require long-term global monitoring of the three-dimensional distribution of ozone, ozone depleting source gases, and some other long-lived key gases in the stratosphere, as well as stratospheric aerosols and PSCs. To understand changes in surface UV radiation additional information is needed on the various processes that affect surface UV radiation, most importantly besides ozone: clouds, aerosols, surface albedo and the solar spectrum.

Long-term operational data sets will be most essential to validate ‘slow’ processes in atmospheric chemistry models. With ‘slow’ processes reference is made to processes that are predicted to have significant effect on, e.g., the ozone layer on the long term, although the direct effect can be difficult to obtain from dedicated measurements that are typically limited to short time periods. One such ‘slow’ process is, e.g., the continuous increase of CO_2 and other greenhouse gases concentrations in the atmosphere, which is predicted to affect the ozone layer by inducing changes in, e.g., the temperature distribution in the stratosphere. Another example is the observed slow increase in stratospheric water vapour, partly caused by CH_4 increases, but largely not well understood. Further, the increase in stratospheric N_2O concentrations is expected to enhance the relative role of the nitrogen cycle in stratospheric chemistry.

Operational measurements of atmospheric composition can mostly be limited to the longer-lived compounds. The measurement of short-lived compounds on an operational basis is considered of less relevance because a lack of scientific understanding of a certain chemical or physical process is likely to benefit more from dedicated (campaign) measurements than from operational data. Operational measurements, however, can help to quantify the relative importance of different (fast) processes on the long term, e.g. in relation to the contribution of the hydrogen, nitrogen and halogen cycles to the chemical ozone budget.

4.2.1.3.2 Measurement Strategy and Data Requirements

The monitoring of changes in the vertically-resolved concentration distributions in the global stratosphere is crucial to understand the long-term evolution of the ozone layer. Long-term ozone changes occur at different altitudes and at each altitude different chemical, dynamical and radiative processes play a role. Vertical resolution is most critical in the UTLS region where stratosphere-troposphere exchange processes result in large gradients in the ozone distribution. A target vertical resolution of 1 km is given for spaceborne ozone observations, with a threshold of 3 km resolution. Especially in the latter case the spaceborne observations in the UTLS would benefit if complemented by more detailed ground-based and airborne observations. In the middle and upper stratosphere the ozone distribution is less variable and the required vertical resolution is typically relaxed to 3-5 km. Total column information is needed in cases when the vertical profile is not covered in all atmospheric domains. Spaceborne observations of the tropospheric column (in combination with an averaging kernel) would help to distinguish from total ozone observations between changes in tropospheric ozone and changes in stratospheric ozone. Ground-based networks and airborne UTLS observations are needed to enhance the profile information on tropospheric ozone and to better quantify changes in the net ozone flux from the stratosphere into the troposphere.

Monitoring of the total stratospheric halogen loading requires spaceborne stratospheric profile observations of the main reservoir gases: HCl, $ClONO_2$, HBr and $BrONO_2$. The reservoir gases are spatially and temporally much more variable than the ODS. Vertical profiles with about 3 km resolution covering the lower and middle stratosphere suffice. Additional HNO_3 stratospheric profile information is desirable to observe possible long-term changes in denitrification. Typically a zonal mean uncertainty of ~20% could be allowed for data that is representative for a few days to one week. For some gases an uncertainty for a 1000 km-average has been specified to account for anticipated longitudinal variations in these compounds.

The uncertainty requirements for ClO (for enhanced levels) and BrO of ~50% are set, e.g. as occurring in spring in the polar stratosphere. For protocol monitoring these short-lived gases, responsible for at least 50% of springtime stratospheric ozone loss, are mainly desirable to detect the number, location and extent of events with excessive ozone loss, i.e. statistics. For the same reason the data requirement on PSCs is also limited to detection only (instead of full characterisation, see the section on ‘ozone layer: understanding’).

Several long-lived gases are important to be monitored for a better understanding of the evolution of the ozone layer. These include at least H_2O, CH_4, N_2O and HNO_3. The gases play multiple roles in the stratospheric physical system. Most important is the long-term trend of these gases as well as information on possible changes in their vertical and zonal distributions, e.g., changes in the HNO_3 distribution can be related to long-term changes in denitrification. Also NO_2 observations are considered very useful in this respect.

Ground-based networks of surface concentrations and total columns are most suited for the determination of trends in ODS, of which the most important are CFC-11, CFC-12 and HCFC-22. Desirable information for understanding the ozone layer evolution in response to policy measures taken in response to the Montreal Protocol and its amendments would be further the measurement of the gases CFC-113, HCFC-123, HCFC-141b, HCFC-142b, CCl_4, Halon 121, Halon 1301 and Halon 2402. In this list CH_3CCl_3 is neglected because it is assumed to be of minor relevance for ozone depletion after 2010. Spaceborne observations are useful to complement the ground-based measurements and to verify the representativeness of the ground-based networks for global trend determination of the ODS concentrations. Spaceborne profile observations of other source gases such as CH_3Cl and CH_3Br as well as reservoir gases such as HCl, $ClONO_2$ would further aid understanding the diminishing role of the anthropogenic ODS to the ozone layer evolution.

Spaceborne measurements of SO_2 and volcanic aerosol would be needed for understanding the ozone layer evolution in case of severe volcanic eruptions polluting the stratosphere for a couple of years, e.g., comparable to the effect of the Pinatubo eruption in 1991.

Understanding of surface UV radiation changes and their possible effects on health and the environment requires long-term spaceborne monitoring of the 3-D ozone distribution (i.e., preferably ozone profiles), the UV aerosol optical depth, the UV aerosol absorption optical depth or single scattering albedo, the UV surface albedo, and the extraterrestrial solar spectrum in the UV range.

Finally, operational ground-based measurements from a representative global network are needed for continuous validation of the mentioned spaceborne measurements and derived surface UV products.

4.2.1.3.3 Auxiliary Data Requirements

For the ozone assessment the interpretation of the combination of ground-based observations and spaceborne observations would be most beneficial if the observations are assimilated in chemistry-transport models. The main auxiliary requirement is therefore on the availability of state-of-the-art chemistry-transport models, preferably covering the atmosphere from the surface to the mesosphere and making use of analysis fields of NWP models, detailed emission databases (both natural and anthropogenic), and adequate chemical schemes.

In addition, the interpretation of long-term variations and trends in stratospheric composition requires information on climate and climate evolution. Especially relevant is climate monitoring of the variations and trends in the main meteorological parameters in the stratosphere and mesosphere (temperature, air density, winds, Brewer-Dobson circulation, etc).

4.2.2 Theme B: Air Quality

4.2.2.1 Protocol Monitoring and Treaty Verification

4.2.2.1.1 Relevant Species and Processes

Within the Air Quality theme the main drivers for protocol monitoring are the EMEP and Gothenburg Protocols of the UN/ECE CLRTAP convention, the National Emission Ceilings, as well as complementary regulations related to EU Air Quality policy, e.g. in relation to the CAFÉ (Clean Air for Europe) program (Table 3.1). The user requirements include the monitoring of the total abundances and concentration distribution of the regulated gases and aerosols as well as the detection and source attribution of the related emissions for verification. In order to observe peak concentration levels, e.g. as related to rush hours or to accidental chemical releases, monitoring of hourly surface concentrations are typically needed. In order to monitor the effect of policy measures it is necessary to be able to derive information on trends in concentrations and emissions within a time frame of maximum a few years.

Air Quality data requirements primarily should respond to the need for information on pollution levels at ground level and in the planetary boundary layer (PBL, typically between surface and ~1-2 km altitude) where they impact on the health and safety of people and of the biosphere. However, additional information on the composition of the adjacent free troposphere is also important as boundary condition to the PBL. The long-range transport and free-tropospheric photochemistry determine the background concentrations of the longer-lived pollutants on which locally pollution builds up.

The compounds for which the surface concentrations are regulated include O_3, SO_2, NO_x, Particulate Matter (PM10, PM2.5, PM1 in ($\mu g\ .m^{-3}$), denoting particles with diameters smaller than, respectively, 10, 2.5 and 1 microns), CO, benzene (C_6H_6), Poly Aromatic Hydrocarbons (PAHs), and some heavy metals (Pb, Ni, As, Cd, and Hg). Regulations on PM1 are anticipated.

Driving the requirements on emissions are the National Emission Ceiling Directives for SO_2, NO_x, Volatile Organic Compounds (VOCs), NH_3 and fine particulate matter. Also the CLRTAP convention, which includes Europe, Russia, US and Canada, sets emission ceilings on SO_2, NO_x, VOCs and NH_3, by the EMEP and Gothenburg protocols. The Gothenburg protocol also regulates surface ozone levels.

With reference to the GMES-GATO report /GAT2004/ it is recommended to anticipate possible future regulation of ship emissions. The most important ship emissions include CO, NO_2, SO_2 and particles. Concentrations of these compounds need to be monitored for operational shipping in harbours, main waterways, and over coastal waters.

4.2.2.1.2 Measurement Strategy and Data Requirements

Traditionally, the requirements for monitoring and verification of air quality have been formulated based on the means already available for verification and enforcement, which consist of ground-based networks at the local and regional authority level. Even though the data quality issue is addressed in the EC framework directive, at present these data are often of limited use in a global observation network because of lack of standardisation of the instruments employed and the data generated. Furthermore, continental and hemispherical or global coverage cannot be obtained by ground-based networks in practice. An optimal strategy for air quality protocol monitoring and verification would be based on a synthesis of satellite observations, ground-based networks and air quality model information through data assimilation on different spatial scales.

It has been shown that local to regional air quality models are very useful to complement the ground-based networks, e.g. to interpolate in time and space. However the models are also essential because these include meteorological information on the PBL, e.g. based on NWP model output. For example, the PBL height is crucial for the surface concentration levels that are attained as it determines the extent of the planetary boundary layer and as such the atmospheric volume in which surface emissions are injected. Other meteorological variables that can be delivered by the air quality model and are essential for the surface pollution levels include the wind speed and direction, turbulent mixing, temperature, water vapor, UV radiation, clouds and convection. In addition the model can include detailed information on natural emissions, also based on surface characteristics such as vegetation and snow cover. For example, ozone levels in rural, moderately polluted regions are known to be very sensitive to meteorology-dependent isoprene and monoterpene emissions.

Spaceborne observations can help to fill in gaps in the surface networks, although global-scale satellite measurements cannot be expected to be of sufficient resolution and accuracy to deliver accurate information on local surface concentration levels. Spaceborne observations are crucial, however, for the boundary conditions of the air quality models. These models are typically limited to a certain region and therefore highly dependent on appropriate boundary conditions, especially for the meteorology and the longer-lived compounds. These boundary conditions, e.g. for chemical compounds over the oceans, can typically be delivered by global model output in which satellite observations of tropospheric composition have been assimilated.

Inverse modelling will be needed to derive emissions based on concentration distributions. Currently, the intrinsic limitations of ground-based observations also hamper the emission verification using inverse modelling. Independent observations from satellites will help to better constrain the inverse modelling. Note that especially the performance of the air quality model will be crucial for the quality of the emissions that can be inferred using inverse modelling techniques. It is anticipated that with the increasing level of detail incorporated in the air quality models the uncertainties related to inverse modelling of emissions will become smaller in the coming years. In order to derive emissions on a country-by-country basis or better the density of the surface network should be typically 10000-100000 km^2, with at least one measurement station per country.

The surface network for protocol monitoring should be representative for the polluted regions in Europe and include at least surface concentration measurements of O_3, SO_2, NO_x, PM10, PM2.5, PM1, CO, benzene (C_6H_6), Poly Aromatic Hydrocarbons (PAHs), ammonia (NH_3) and heavy metals (Pb, Ni, As, Cd, and Hg). Note that requirements for ground-based measurements are limited to compounds for which spaceborne observations play a role, i.e., requirements for, e.g., PAHs, ammonia and heavy metals have not been derived. Long-term homogeneous measurement series are needed in order to derive trends in the surface pollution levels. About 10% uncertainty on individual measurements should be sufficient both for the hourly peak levels and for the detection of small long-term trends in monthly mean peak values.

The satellite measurements of trace gases should include preferably tropospheric profiles of O_3, SO_2, NO_2, CO and formaldehyde (CH_2O), at least separating the PBL from the free troposphere. The threshold vertical resolution requirement is for a tropospheric column measurement, in combination with an averaging kernel in order to have information on the sensitivity of the satellite measurement as a function of altitude. Note that formaldehyde is required because it will contain important information to constrain the VOC emissions.

The required revisit times are typically between half-hour (target) to several hours and are directly related to the protocol requirements to observe hourly peak pollution values, in combination with the fast chemistry and mixing time scales of the PBL. The revisit time requirements are typically for daytime only (this is the threshold requirement) as photochemistry is a major driver for the pollution levels. The extension to full 24 hour coverage, i.e., including the night-time evolution, is a target requirement and can be a useful additional constraint to air quality models, especially for ozone and nitrogen compounds (NO_X, N_2O_5, HNO_3, PAN).

The uncertainty requirements typically do not pertain to very clean or background levels. However, it is still needed to measure in the background atmosphere and to assign these pixels as being background or below the detection limit. This is especially true for SO_2, NO_2 and CH_2O satellite observations for which the threshold uncertainty is expressed in absolute terms. Column amounts of $<1.3\cdot10^{15}$ molecules cm^{-2} correspond to background conditions, with column average concentrations below 1 ppbv. The uncertainty is given in absolute terms ($1.3\cdot10^{15}$ molecules cm^{-2}) and corresponds, e.g., for NO2 with 100% relative uncertainty for a column of $1.3\cdot10^{15}$ molecules cm^{-2} to <10% uncertainty for columns larger than $1.3\cdot10^{16}$ molecules cm^{-2}. Note that satellite NO_2 measurements are assumed to suffice for constraining NO_x emissions and ambient levels. This assumption sets some basic requirements on the chemical scheme to be used in the Air Quality model for the NO/NO_2 conversions.

Maximum uncertainties for PM10 and PM2.5 surface concentrations have been fixed in absolute terms at two times the measured background concentration in Europe /Din2004/. For PM1 requirements could not be specified as information on the background concentrations is lacking.

The vertical resolution requirements on the satellite observations of aerosol optical depth are similar to the satellite requirements on trace gases, with a target to distinguish between aerosols in the PBL and free troposphere and a threshold for the tropospheric aerosol optical depth. The required uncertainty (0.05) is again expressed in absolute terms and based on different earlier assessments. The aerosol optical depth observations can be used to constrain the surface concentrations of PM. Information from satellite on aerosol type would be desirable.

The requirement on ship emissions extends the need for surface measurements to coastal waters. These ground-based measurements should include at least CO, NO_2, SO_2 and particles. The same compounds over coastal waters measured from satellite would add significantly to the ship data.

In addition to the monitoring network for surface concentrations, ground-based observations are also needed for the validation of the models and satellite observations in the troposphere. The observations should include ozone profiles from the sonde network as well as tropospheric column data at representative sites for the validation of the modelled and spaceborne observations of tropospheric ozone. Lidar observations at specific sites are very useful to validate the vertical tropospheric profiles of O_3, NO_2, SO_2 and CH_2O. PBL concentration profiles from towers at a few locations would also help to validate satellite data and models.

4.2.2.1.3 Auxiliary Data Requirements

Air quality protocol monitoring relies heavily on the combination of ground-based observations, air quality models and satellite data. The main auxiliary requirement is therefore on the availability of state-of-the-art air quality models making use of analysis fields of NWP models, detailed emission databases (both natural and anthropogenic), adequate chemical schemes and detailed descriptions of surface-atmosphere exchange processes.

4.2.2.2 Near-Real Time Data Requirements

4.2.2.2.1 Relevant Species and Processes

The main societal drivers for air quality forecasting are health and safety warnings (Table 3.1). Surface concentration predictions are needed from local street-level to regional and national scales. Typically the maximum delay time allowed for data delivery is very short, about 30 minutes. The so-called Air Quality index, according to EC directives, is based on a mixture of O_3, NO_2, PM10, SO_2, and CO. These compounds are affecting respiratory health. Because particle size is important, distinction is made between PM10, PM2.5 and PM1. Particles are possibly also related to cardiovascular health. Metals in particles could also be an issue.

With respect to safety natural hazards such as volcanic eruption, forest fires and man-made hazards such as biomass burning and chemical and nuclear releases require plume transport and dispersion model forecast fed by observations. An additional driver here is air traffic management, including both air routing and early warnings for the mentioned unpredictable events.

An important requirement for health and safety is further near-real time source detection and attribution of the emissions of aerosols and aerosol and ozone precursors (NO_2, SO_2, and CO).

Additional information on methane (CH_4), water vapour (H_2O), formaldehyde (CH_2O) as well as the UV-VIS photolysis rates is important for the forecasting of the photochemical activity. These observations are needed to constrain the chemical conversion rates and help to determine the atmospheric residence time of pollutants.

4.2.2.2.2 Measurement Strategy and Data Requirements

The optimal strategy for air quality forecasting is similar to the strategy for air quality monitoring described in section 4.1 and based on a synthesis of satellite observations, ground-based networks and air quality model information through data assimilation on different spatial scales. The main difference is the requirement on the timely availability of the forecast information.

Typically, environmental agencies require air quality forecasts for the day to be available in the early morning. The time delivery requirement on the observations for air quality forecasts is therefore mainly determined by the need for the data to be available for the integrated forecast system at the time that the analysis run is performed on which the forecast run will be based. In practice, the analysis run will have to be performed in the late evening or early night in order to do a forecast run that finishes in early morning. The delivery time requirement is therefore about several hours. Given that the daytime observations are most relevant, the most stringent delivery requirements are for the last daytime measurements of the day. The user requirements on the timely availability of the forecasts prevents the need for observations of the same day as for which the forecast is being made. This is true for satellite observations as well as for observations of the ground-based networks.

The revisit time satellite data requirements are for daytime only (threshold), except for N_2O_5, HNO_3 and PAN for which especially night-time observations would be desirable, given their role in the night-time NO_y budget, which is an important constraint on the amount of NO_x

released from reservoir species after sunrise. The threshold revisit time requirements of 2 hours are mainly related to the diurnal cycle of air pollution levels as well as the short timescales of the mixing and chemical processes in the PBL.

The satellite measurements of trace gases should include preferably tropospheric profiles of O_3, H_2O, SO_2, NO_2, CO and formaldehyde (CH_2O), at least separating the PBL from the free troposphere. The threshold vertical resolution requirement is a tropospheric column, in combination with an averaging kernel in order to have information on the sensitivity of the satellite measurement as a function of altitude. Note that formaldehyde is required because it contains information on the amount of photochemical activity caused by hydrocarbons. Water vapour profile information is important for the effect of relative humidity on aerosols as well as for the primary OH production, which controls the photochemical activity together with the ozone concentration and UV-VIS actinic flux.

The aerosol requirements on the satellite observations are on the aerosol optical depth and the aerosol type, with a target to distinguish between aerosols in the PBL and free troposphere and a threshold for the total tropospheric aerosol optical depth. The required uncertainty (0.05) is expressed in absolute terms and is based on different earlier assessments. The aerosol types to be distinguished include at least standard categories such as sulphate, dust, sea salt, organic carbon (OC), black carbon (BC), and mixed aerosol. The requirement on aerosol type is that mis-assignments should be limited to less than about 10% of the cases.

For air traffic management the threshold coverage requirements on aerosol optical depth and SO_2 are global scale, while all other air quality forecast applications have a threshold coverage requirement which is limited to Europe and its coastal waters (see Section 2.4)

Ground-based networks can significantly add to the air quality forecasts, especially by adding information on the local scale. The measurements should preferably include O_3, and H_2O profiles from sonde measurements, as well as surface concentrations of O_3, SO_2, NO_2, CO, CH_4 and CH_2O from a representative network. Information on surface CH_4 concentrations is relevant, because CH_4, although being relatively well-mixed, is an important competitor for the OH radical, and therefore variations in its abundance affects the lifetime of other compounds, especially CO.

Finally, near-real-time data delivery for this application implies that the data needs to be available to an operational modelling environment within a couple of hours after observation. In this case a significant part of today's observations can still be used for the analysis on which the required forecast for tomorrow (etc.) will be based. It should be noted that current practice of data time handling at ECMWF is not favourable for Air Quality forecasts. Data are collected twice a day (till 3 am and 3 pm) to provide forecasts in the morning and evening. For Air Quality forecasts it would likely make sense to include also the late afternoon observations of today in the Air Quality forecast for tomorrow, which should be available to operational agencies in the very early morning of the day to come.

4.2.2.2.3 Auxiliary Data Requirements

Air quality forecasting relies heavily on the combination of ground-based observations, air quality models and satellite data. The main auxiliary requirement is therefore on the availability of state-of-the-art air quality forecast model making use of analysis fields of NWP models, detailed emission databases (both natural and anthropogenic), adequate chemical schemes and detailed descriptions of surface-atmosphere exchange processes.

4.2.2.3 Assessment

4.2.2.3.1 Relevant Species and Processes

In order to feed into environmental assessments and within the Air Quality theme the main drivers for understanding are the following long-term science questions:

- What is the impact on air quality of the spatial and temporal variations and possible trends in the **oxidising capacity**?
- What is the impact on air quality of spatial and temporal variations and possible trends in the **long-range transport** of longer-lived compounds and aerosols?
- What is the impact on air quality of long-term changes in the distribution and total burden of the tropospheric ozone, carbon monoxide and methane **background levels**?
- Can we relate the observed changes in atmospheric pollution levels to changes in certain emissions (**source attribution**)?

To answer these questions scientific users require long-term data sets of the total abundances and global concentration distribution of the pollutants as well as the detection and source attribution of the related emissions. For trend detection typically, monthly mean to annual values are needed in order to be able to relate changes in concentration levels to changes in emissions, possibly in response to policy measures.

The oxidising capacity of the atmosphere is largely governed by the OH and tropospheric ozone budget. Analysis of the causes for changes in the OH production and loss rates can be derived from simultaneous measurements of the global distribution (and spatial and temporal changes therein) of the longer-lived compounds in the OH budget, including H_2O, O_3, NO_x, CO, CH_4, CH_2O and higher hydrocarbons, in combination with numerical modelling of chemistry, transport and mixing, emission and deposition, and UV-VIS radiative transfer for the photolysis rates.

Important for the tropospheric ozone budget are the mixing and transport processes, including stratosphere-troposphere exchange, ozone deposition, the ozone precursor gases (mainly NO_x, CO and CH_2O) and their chemistry, photolysis rates (mainly of NO_2 and O_3), water vapour and temperature. *The trend of tropospheric ozone* requires accurate monitoring of the tropospheric ozone profile.

Information on long-range transport is most important for CO, NO_x, NO_y, O_3, and aerosols.

The trend of tropospheric ozone, carbon monoxide and methane requires accurate monitoring of the tropospheric ozone profiles and of CO and methane surface concentrations at background stations.

Inverse modelling will be used to derive emissions. Required emissions include aerosol emissions and aerosol and ozone precursor emissions including SO2, NO2 and CO.

4.2.2.3.2 Measurement Strategy and Data Requirements

The target coverage for understanding air quality issues should be global. The threshold coverage for the PBL can be Europe, incl. coastal waters, and for the free troposphere the threshold coverage includes at least parts of the North-Atlantic that impact on the surface air quality levels in Europe. The European scale mainly refers to use in scientific assessments by, e.g., the European Environmental Agency and understanding of European scale air quality issues.

To understand the oxidising capacity of the atmosphere related to air quality issues, measurements are needed of the global distribution (and spatial and temporal changes therein) of the longer-lived compounds in the OH and tropospheric ozone budgets, including H_2O, O_3, NO_x, CO, CH_4, CH_2O and higher hydrocarbons, most notably isoprene and monoterpenes. Additional information would come from observations of the UV-VIS actinic flux, and N-reservoir species, especially at night, including HNO_3, PAN, organic nitrates and N_2O_5.

The revisit time satellite data requirements are typically for daytime only. However, for example for O3, CO, and especially N_2O_5, HNO_3 and PAN night-time observations would certainly be worthwhile. The N-compounds would give information on the night-time NO_y budget, which is an important constraint on the amount of NO_x released from reservoir species after sunrise. The threshold revisit time requirements of 2 hours are mainly related to the diurnal cycle of air pollution levels as well as the short timescales of the mixing and chemical processes in the PBL.

The understanding of long-range transport of pollutants requires global observations on: CO, NO_x, NO_y, O_3, aerosol optical depth, aerosol type, POPs, and Hg. Distinction between PBL and free troposphere would be desirable, although the threshold requirement for the satellite observations related to long-range transport are on the tropospheric column (in combination with an averaging kernel). The assumption is that the height at which transport takes place can be traced from the model's meteorological information.

The trend of tropospheric ozone and methane requires accurate monitoring of the tropospheric ozone profile and methane surface concentrations.

For source attribution the requirements are on aerosol observations and aerosol and ozone precursor observations, including SO_2, NO_2 and CO. Formaldehyde is required because it will contain important information to constrain the VOC emissions.

The aerosol requirements on the satellite observations are on the aerosol optical depth and the aerosol type, with a target to distinguish between aerosols in the PBL and free troposphere and a threshold for the total tropospheric aerosol optical depth. The required uncertainty (0.05) is expressed in absolute terms and based on different earlier assessments. The aerosol types to be distinguished include at least standard categories such as sulphate, dust, sea salt, organic carbon (OC), black carbon (BC), and mixed aerosol. The requirement on aerosol type is that mis-assignments should be limited to less than about 10% of the cases.

Note that satellite NO_2 measurements are assumed to suffice to constrain NO_x emissions and NO_x ambient levels. This assumption sets some basic requirements on the chemical scheme that is to be used in the Air Quality model for the NO/NO_2 conversions.

Separate measurements of the isotopes (12C, 13C, 14C) of C for CO (and possibly CH4) could be useful, both spaceborne and ground-based to distinguish between, e.g., fossil fuel and biomass burning emissions.

A representative ground network is needed for the validation of the Air Quality models and the spaceborne observations. Surface concentrations typically suffice. Additional measurements of PBL profiles (Lidars, Towers) at specific sites would be useful to validate PBL mixing processes in the models.

Spaceborne estimates of the spectral actinic flux profile, necessary to determine photodissociation rates, would be desirable, especially in combination with validation of the surface level actinic fluxes using a representative surface network of UV radiation measurements. Methods exist to translate spectral UV irradiance measurements into spectral actinic fluxes. The most relevant spectral range is the 280-420 nm spectral region as the most important photodissociation reactions are limited to this range. The required spectral resolution is typically ~5 nm.

4.2.2.3.3 Auxiliary Data Requirements

Air quality forecasting heavily relies on the combination of ground-based observations, air quality models and satellite data. The main auxiliary requirement is therefore on the availability of state-of-the-art air quality forecast model making use of analysis fields of NWP models, detailed emission databases (both natural and anthropogenic), adequate chemical schemes and detailed descriptions of surface-atmosphere exchange processes.

4.2.3 Theme C: Climate

4.2.3.1 Protocol Monitoring and Treaty Verification

4.2.3.1.1 Relevant species and processes

Within the climate theme the main drivers for protocol monitoring are the UNFCCC and the resulting Kyoto Protocol (for CO2, CH4, N2O, HFCs, PFCs and SF6), as well as complementary regulations related to EU climate policy (Climate Change Committee), see Table 3.1. The user requirements include the monitoring of the total abundances and global concentration distribution of the radiatively active gases and aerosols as well as the detection and source attribution of the related emissions. Typically, monthly mean values are needed. It would be highly desirable to be able to derive yearly trends in concentrations and emissions within a timeframe of a decade or less.

Several of the regulated greenhouse gases are ‘well-mixed’, i.e., their abundance in the troposphere and lower stratosphere is almost uniform over the globe. Good examples include the gases SF_6, CF_4, HFCs (HFC-134a is the most abundant), and CFCs (CFC-11 and CFC-12 are the most abundant). The atmospheric residence time of these gases is very long compared to the mixing time scales of the troposphere (typically in the order of months to one year). However, continuing but unevenly distributed emissions will maintain a latitudinal gradient and a global trend. Possible future changes in the zonal distribution of emissions, e.g. from mid-latitudes to (sub-)tropical latitude bands, may affect the latitudinal gradient. Inverse modelling can be used to trace the latitudinal concentration distribution of well-mixed gases back to latitudinal emission distributions. The applicability of inverse modelling for verification purposes was analysed recently in quite some detail in an inverse modelling workshop at Ispra /Ber2003/. HCFCs (of which HCFC-22 is the most abundant) are not inert in the troposphere. Therefore, the column data of these compounds will contain variability due to atmospheric transport, in addition to latitudinal gradients. Also the columns of N_2O and CH_4, and to a lesser extent, CFCs and CO_2 will contain variability introduced by transport, mainly in the stratosphere. Clearly, dynamically-induced variabilities need to be corrected for before the column data of these gases can be used in addition to the surface measurements for the inverse modelling of emissions (see section 5.1.3).

CO_2 and CH_4 are also often referred to as 'well-mixed', however these gases are not completely inert in the PBL and have large and variable natural sources and sinks, besides their anthropogenic emissions. For this reason the concentration distribution of these gases show more spatial and temporal variability in the troposphere. Especially for CO_2 there is a strong diurnal cycle in the PBL, mainly due to the respiration and photosynthesis of the vegetation. Natural CH_4 emissions (mainly from wetlands) are very uncertain, but the available observations also suggest large variability. Also anthropogenic CH_4 emissions are assumed to be more variable than anthropogenic CO_2 emissions because of their origins in, e.g., agriculture (rice paddies, ruminants), landfills, coal mining and related to fossil-fuel production.

Ozone and aerosols are relatively short-lived and show large variability in time and space throughout the atmosphere. For the ozone radiative forcing we should further make a distinction between tropospheric and stratospheric ozone as changes in their distribution and their trends have very different origins. Stratospheric ozone is expected to recover in the coming decades (see the Ozone Layer theme), in response to the measures taken on the emissions of halogenated compounds. Although a potent greenhouse gas, tropospheric ozone is nowadays mainly subject to air quality regulations (see the Air Quality theme). Ozone is not emitted but photochemically produced in the atmosphere. The two major precursor gases for tropospheric ozone are NO_2 and CO (besides CH_4 and non-methane hydrocarbons). It is anticipated that especially the NO_x and CO emissions may become subject to regulation in the future if climate policy measures are to be taken to reduce the radiative forcing by tropospheric ozone. NO_2 and CO are both short-lived and therefore show large variability throughout the troposphere.

For the direct effect of tropospheric aerosols on climate the aerosol radiative properties are crucial, especially the aerosol extinction ('cooling') and aerosol absorption ('warming') optical depth. Large volcanic eruptions can inject large amounts of aerosol into the stratosphere, which can also have considerable climate effects over prolonged periods of time.

4.2.3.1.2 Measurement Strategy and Data Requirements

A representative surface network with stations in different latitude bands separated by ~10 degrees latitude will be well suited to monitor (changes in) the latitudinal gradient and trend of well-mixed gases. The monitoring at a certain station should include a surface concentration, representative of the tropospheric background abundance in the latitude band, and a total column, representative of the total atmospheric abundance in the latitude band. The surface concentration observations will allow to derive information on (changing) zonal monthly emission distributions and yearly emission trends using inverse modeling. The total column measurements will confirm the representativeness of the surface observations. Weekly-representative observations will typically suffice to arrive at the required monthly means for concentrations and emissions. In order to be able to derive trends over a decadal time-frame the uncertainty on the individual observations should be very small. It is estimated that about 2% uncertainty for weekly-representative surface-based observations would typically suffice in this respect. Enhanced sampling, e.g. hourly or daily observations, can also help to reduce the uncertainties. The network should measure the regulated gases, including CO_2, CH_4, N_2O, SF_6, CF_4, HFCs, and (H)CFCs. A high-density surface network is needed to derive emissions on a country-by-country basis, typically one station every 10000-100000 km^2 and with at least one station per country. This would be very valuable. Sites should be close to emission regions for this purpose.

For CO_2 and CH_4, the global yearly trend in concentrations and emissions and the zonal distribution of the abundance and (monthly) emissions can be obtained from a representative surface network, as explained above. However, zonal distributions are of limited use for protocol verification. In order to better separate the variable natural emissions from the (more constant, although likely increasing) anthropogenic emissions, additional information on the spatial concentration and emission distribution may be derived from spaceborne observations. The same is true for the CO and NO_2 concentrations and CO and NO_x emissions. Although tropospheric profile information with global coverage will likely be optimal to constrain emissions, tropospheric columns or total column, in combination with an averaging kernel, with horizontal resolutions of 10x10 km^2 (target) to 50-50 km^2 (threshold) are estimated to contain sufficient information to improve upon emission estimates from surface networks alone and especially help to improve emission estimates on country-by-country basis, as typically required for the protocols.

From available results on inverse modeling, the required uncertainty for spaceborne CO_2, CH_4, CO and NO_2 column observations in order to be useful for improved emission estimates have been derived. The uncertainty of an individual CO_2 column retrieval on the given horizontal resolution and with 6 to 12 hours revisit times (to capture the diurnal cycle) typically needs to be better than ~0.5% with sensitivity to the PBL. For the CH_4 columns, on the same horizontal resolution but with only 1-day to 3-days revisit time (to capture the synoptic variability), the uncertainty of an individual retrieval needs to be better than ~2% with sensitivity to the PBL. For the much more variable CO columns, ~25% uncertainty would suffice, while for NO_2 columns a maximum absolute uncertainty of $\sim 1.3 \cdot 10^{15}$ molecules cm^{-3} has been derived. The latter requirement in absolute terms implies that spaceborne observations of the variations in the background NO_2 concentrations are not considered relevant.

By assimilation of sufficiently long and homogeneous time series, possible biases in the satellite columns can likely largely be accounted for by analysis of the observation minus forecast fields, especially in combination with the assimilation of the observations from surface networks. Further, if needed to reduce uncertainties, combinations of independent observations over a certain region and/or time period can be made to retrieve emissions over longer periods (e.g. months to years) and/or larger regional domains (e.g. continents). Crucial for the CO_2, CH_4, CO and NO_2 column observations is the requirement for sensitivity to the PBL in order to be able to relate column variability with emissions. If the columns would reflect mainly the variability in the free troposphere, the inverse modeling is very much less constrained and emission estimates are likely limited to values representative of (very) large regions or hemispheres.

Tropospheric ozone, CO, NO_2 and aerosols are short-lived and show variability in time and space to an extent that cannot be captured by surface-based networks or in-situ observations and thus their global distribution is best monitored by spaceborne observations. However, a distributed surface network is needed for the validation of the spaceborne measurements, either columns or profiles. Spaceborne tropospheric profiles should have at least ~5 km vertical resolution in order to contain at least two points outside the tropics and three points within in the tropical troposphere.

Monitoring of the height distribution of tropospheric aerosols from satellite is considered of minor relevance for climate monitoring, except to distinguish between tropospheric and stratospheric (volcanic) aerosols. For the inverse modelling of aerosol emissions the data requirements are comparable to those for NO_x and CO emissions, i.e., total aerosol optical depth on similar horizontal resolutions and with a revisit time between 6 hours (target) to 3-days (threshold). The shortest revisit time would be needed to include monitoring of dust storms with very-short lived large aerosol particles.

For the selection of ozone depleting halogen compounds the requirements in the tables are limited to the three Montreal gases that are responsible for the majority of climate forcing by halogenated compounds (CFC-11, CFC-12 and HCFC-22).

4.2.3.1.3 Auxiliary Requirements

For long-term monitoring of the three-dimensional state of the atmospheric composition it is considered essential to assimilate the available observations in an atmospheric-chemistry numerical transport model in order to make optimal use of the available meteorological information. Furthermore, the (institutional) users will prefer complete, gridded and validated data sets with well-established uncertainties in terms of accuracy and possible biases. These requirements can be best fulfilled by an assimilation system, e.g. by systematic analysis of observation minus forecast error fields. Cross validation between different data sets will be facilitated by an assimilation system.

In the case of using column observations to retrieve emissions the aid of a numerical transport model is also needed in order to be able to correct for dynamically-induced column variabilities that should not be related to emissions.

Another important requirement for inverse modelling of emissions is the availability of a priori emission distributions, both for the anthropogenic and the natural emissions. These inventories do exist and are widely available. Nevertheless, the spatio-temporal patterns of these inventories may still be very uncertain in many cases.

4.2.3.2 Near-Real Time Data Requirements

4.2.3.2.1 Relevant Species and Processes

Climate monitoring relies to a large extent on the NWP centres, and especially on the re-analysis projects that these centres perform. For various reasons it would be impracticable if the assimilation of atmospheric composition data by NWP centres would be limited to reanalyses projects and would be excluded from the near-real time processing. NWP centres also do not have the resources to maintain different systems. Moreover, it also could lead to inconsistencies between different model versions. Therefore, in order to improve climate monitoring it is most advantageous to include atmospheric composition observations in near-real time in the operational assimilation system of the NWP centres.

Driving the near-real time data requirements for the climate theme is therefore the assimilation of atmospheric composition observations in NWP models in order to improve the analysis of the physically coupled climate system. Depending on the improvement of the analyses also improvement of the weather forecasts can be envisioned, although atmospheric composition typically impacts the atmosphere most on the longer, climatic time scales.

In addition to climate monitoring, a service to make near-real-time data sets quickly available to NWP and climate research centres will allow for a continuous process of validation of the latest NWP and climate models for present-day atmospheric conditions. Near-real-time validation of adjustments in NWP models is crucial to the NWP centres. Also the capability of a climate model to simulate the latest changes in the atmospheric state is generally considered as an important model requirement to gain confidence in its ability to simulate future climate change.

In order to justify the efforts, it is required that atmospheric composition data that are intended for assimilation in NWP models should have a non-negligible impact on the model simulations. Here, two types of contributions can be distinguished: a direct impact of the atmospheric composition observations on the physical climate system, e.g., stratospheric ozone largely determines stratospheric heating rates; and an indirect impact by improving the application of other available observations. One example of the latter effect is the impact of atmospheric composition on model-simulated radiances, e.g. to constrain the temperature profile retrieval or the outgoing long-wave radiation at the top of the atmosphere.

The most important chemical species for NWP is water vapour. Water vapour plays a central role in the atmosphere, e.g. in the atmospheric radiation and energy budgets, in the hydrological land-ocean-atmosphere system and in several parameterisations such as for convection and precipitation formation. Accurate profiles of water vapour are needed in NWP models, throughout the troposphere and also in the lower to middle stratosphere.

In the PBL atmospheric composition impacts on the atmospheric absorption with the largest contributions coming from aerosol absorption, water vapour, CO_2, and ozone. Also the scattering of solar radiation by aerosol particles has significant effect on how the physical climate manifests, e.g. on surface temperature and incident solar radiation. Aerosols also impact on several other remote sensing observations and improved characterisation in NWP models will reduce uncertainties related to aerosol correction.

In the free troposphere the same components as in the PBL are relevant for NWP, although the effect of the spatial and temporal variability in CO_2 is probably negligible in the free troposphere and only long-term trend monitoring is required.

In the upper troposphere and lower stratosphere water vapour, (ice) particles including cirrus and PSCs, and ozone impact on the physical climate. Observations of ozone, water vapour,

CO_2, CH_4, and N_2O throughout the stratosphere are important for the radiation budget. The assimilation of radiatively active gases will improve the simulation of the local heating rates and outgoing long-wave radiation at the top of the atmosphere.

Observations of inert stratospheric tracers, e.g. SF_6 or HF, but also other tracers including CO_2, CH_4, N_2O, HDO, will help to better constrain the large-scale transport in the stratosphere. These observations will be complementary to direct observations of the wind vector, planned by, e.g., the ESA mission ADM Aeolus. Direct observations of the wind vector observations will constrain in the first place the dominant large-scale motions that are most relevant on the short-term to NWP. In addition, tracer observations will help to better constrain the residual Brewer-Dobson circulation and associated vertical and lateral motions. Tracers represent air masses and have a memory of the flow over the preceding time.

Although tracer information would be most profitable on longer, seasonal and climatic time scales, it is hypothesised that sufficiently accurate inert tracer profile measurements with the given target revisit time may also positively impact on the stratospheric dynamics on short time scales. However, because absolute tracer concentrations are being measured and mixing ratios are conserved during transport this would possibly also require accurate information on the atmospheric density profile in the stratosphere as well as information on gravity waves. At this stage it is rather uncertain what could be the impact of tracer observations for NWP on short time scales relevant to weather prediction.

It is noted that stratospheric observations of the tracers CH_4 and HDO, in addition to H_2O, can help to better constrain the stratospheric water vapour budget.

4.2.3.2.2 Measurement Strategy and Data Requirements

For NWP and climate monitoring applications the three-dimensional water vapour distribution in the PBL, free troposphere and stratosphere is required with global coverage. Therefore, an integrated approach of spaceborne observations, a representative global in-situ network of radiosonde and surface-based remote-sensing techniques is needed, coupled with model information. Two-to-three kilometre vertical resolution for H_2O would be very advantageous, threshold for the satellite contribution is the distinction of PBL, free tropospheric and stratospheric water vapour sub-columns. For climate purposes the target horizontal resolution in the troposphere is about 10x10 km^2, although water vapour spatial variability is large and structures with less than one kilometre are associated with e.g. fronts. Uncertainty of column data typically needs to be better than ~5% to improve upon current modelling capabilities of weather centres. Tropospheric water vapour has a strong diurnal cycle and the required revisit time for spaceborne observations is typically ~6 hours. The revisit time can be limited to one day to one week (threshold) in the stratosphere. Given the spatio-temporal variability in water vapour the optimal strategy to water vapour is likely combined use of ground-based systems (e.g. GPS), radiosondes, polar orbiting and geostationary platforms.

Aerosol absorption and aerosol scattering are important for the radiation budget and atmospheric corrections. Threshold requirements for operational use include the separation of the total extinction optical depth in an absorption and scattering contribution. Distinction between boundary-layer, free-tropospheric, and stratospheric aerosol would be advantageous, as well as further aerosol characterisation, in particular the aerosol phase function given the important radiative effects of aerosols. The same set of requirements applies to cirrus and PSC ice particles (optical depth, phase function) albeit limited to the higher altitudes. Spatial scales for aerosol are typically comparable to water vapour. Revisit times for tropospheric aerosols can typically be limited to about one (target) to a few days (threshold) and to a couple of days to a week in the stratosphere.

Ozone profile information is most relevant in the stratosphere and upper troposphere where the (variation in) ozone radiative forcing is most effective. Tropospheric ozone threshold requirements are limited to column observations (in combination with an averaging kernel), while distinction between the PBL and free troposphere would be advantageous. In the UTLS region, co-located profile observations of O_3 with HNO_3, HCl and/or CO are desirable to help to constrain stratosphere-troposphere exchange processes. Hereto, the observations need to be both rather accurate and have high vertical resolution (1 km target, 3 km threshold).

In-situ CO_2 observations in the PBL and total column CO_2 observations can be obtained from a surface network. Spaceborne CO_2 column observations (in combination with an averaging kernel), if sufficiently accurate to include the naturally occurring column variability that is caused by the diurnal respiration of the vegetation, can help to provide global coverage. The column data need to be sensitive to the PBL. A representative surface network would be needed for validation and corrections of possible biases.

As explained in the former section, tracers can constrain the stratospheric circulation. Suitable candidates are inert gases as SF6 and HF, but other long-lived compounds such as CO_2, N_2O, CH_4 and HDO can be used as well. The tracer that can be observed most accurately needs to be measured. The required uncertainty is directly related to the gradient over the specified spatial resolution (100-200 km horizontally, 1-3 km vertically). Target revisit times are about 12 hours. With the threshold revisit time of one week, only information on the circulation on seasonal to multi-annual time scales will be obtainable.

For the radiation budget, stratospheric profiles are required for the radiatively active gases H_2O, O_3, CO_2, CH_4 and N_2O. The stratospheric water vapour budget can be constrained by measurements of H_2O, HDO and CH_4. Profiles are needed with three-to-five kilometre vertical resolution throughout the stratosphere.

Finally, near real time data delivery for this application implies that the data needs to be available to an operational modelling environment within a couple of hours after observation. In that case a significant part of today's observations can still be used for the analysis of the day.

4.2.3.2.3 Auxiliary Data Requirements

The main users for near-real time data within the climate theme are the NWP centres. These centres need near-real-time information on numerous aspects of the land-atmosphere-ocean-cryosphere system that all contribute to the analysis of the atmosphere and therefore to the initial state on which the weather prediction is based, and on which climate monitoring relies. Atmospheric composition is one of the key elements for the monitoring of the climate system.

4.2.3.3 Assessment

4.2.3.3.1 Relevant Species and Processes

Within the Climate theme the operational data requirements for understanding need to be based on long-term science questions relevant to understand the interactions between atmospheric composition and the physical climate. The relevant issues are typically addressed in the regular IPCC scientific assessments.

Important science questions that require long-term operational monitoring are related to:

- Understanding of the radiative forcing of climate and the changes in forcing over time, including possible volcanic eruptions, and also including the forcing of climate on local to regional scales
- Understanding of the abundance, evolution, and, if relevant, spatial distribution of the forcing agents
- Understanding of the stratospheric water vapour budget and the monitoring of the water vapour trend in the UTLS and above.
- Understanding of the role of the ozone layer evolution on climate change
- Understanding of the role of possible changes in the ***Brewer-Dobson circulation*** on climate change, including possible changes in the position and strength of the polar and sub-tropical jets, changes in the position and strength of the inter-tropical conversion zone (ITCZ) as well as changes in the mesosphere (air density)
- Understanding of the role of long-term changes in the oxidising capacity of the troposphere for its effect on the atmospheric residence time of the climate gases
- Concentration monitoring for the detection and attribution of long-term changes in the natural as well as anthropogenic emissions of the forcing agents and their precursors

Data requirements related to the understanding of the role of atmospheric composition changes for climate have been laid down in the ACECHEM Report for Assessment /ESA2001/ and the report of the preceding ACE requirements study /Ker2001/]. The reader is referred to these documents for additional scientific background.

4.2.3.3.2 Measurement Strategy and Data Requirements

The processes underlying the interactions between climate change and atmospheric composition change are typically rather slow (months, years, decades) and therefore can only be better understood by increasing the amount of available long-term and homogeneous data sets on atmospheric composition. Although global coverage is required for most observations, the Upper Troposphere-Lower Stratosphere (UTLS) layer it probably the most important atmospheric domain because it is both chemically and radiatively very active. However, other atmospheric layers are relevant as well, e.g. the long-term trend in stratospheric water vapour is badly understood and this needs to be monitored by long-term accurate global-scale profile measurements including the stratosphere above the UTLS layer. Profiles of H_2O, HDO and CH_4 are needed with three-to-five kilometre vertical resolution. Column data can be useful and should be given in combination with an averaging kernel. For the radiation budget vertical profiles are required for the radiatively active gases H_2O, O_3, CO_2, CH_4 and N_2O in both the UTLS and the overlying stratosphere. Tracer measurements to constrain the Brewer-Dobson circulation also need to extend over the full stratosphere, and possibly should even include parts of the mesosphere. Changes in the mesosphere, e.g., in air density, could give also indication of temperature changes in the middle atmosphere. Suitable tracer candidates for diagnosing the Brewer-Dobson circulation are typically inert gases such as SF_6 and HF, but other long-lived compounds such as CO_2, N_2O, CH_4 and HDO can be useful as well. Likely the tracers that can be observed most accurately need to prevail.

Atmospheric composition related climate processes in the troposphere include, e.g., gaseous and aerosol absorption and aerosol scattering in the PBL, secondary aerosol formation relevant for cloud formation, aerosol deposition on ice surfaces affecting the ice surface albedo and oceanic dimethylsulfide (DMS) also affecting cloud condensation nucleii.

In-situ observations in the UTLS by operational aircraft measurements will be useful in addition to satellite measurements and should include preferably O3, CO, NOy (or HNO3), NOx, HCl and H2O. The airborne measurements can especially help to better constrain stratosphere-troposphere exchange as well as chemical processes

Surface-based atmospheric composition measurements contributing to understanding of climate are most relevant to monitor the long-term evolution in the long-lived gases. In addition the networks are crucial for the validation of the global-scale satellite measurements. The need for a detailed knowledge on the 3-D water vapour distribution and its changes over time would be improved by surface-based networks such as the radiosonde network and GPS-based configurations. The monitoring of the 3-D distribution of ozone and aerosols would be improved by surface based monitoring of surface concentrations and total columns as well as a network of profile measurements of sondes and LIDARs.

4.2.3.3.3 Auxiliary Data Requirements

Climate research centres need long-term information on numerous aspects of the land-atmosphere-ocean-cryosphere system that all contribute to the analysis of the climate system. Atmospheric composition is only one component of the Earth System. The usefulness of atmospheric composition data for the study on climate change will partly depend on the information that will be available for the other components of the Earth System.

Data Requirements Tables

A1	Theme: Category:	**Ozone Layer** **Protocol Monitoring**

Requirement / Data Product	Driver	Height Range	Horizontal resolution (km)	Vertical resolution (km)	Revisit Time (hours)	Uncertainty
O3	Trend	Total column	50 / 100	--	24 / 24*3	3%
Spectral UV surface albedo	Surface UV Trend	Surface	10 / 50	--	24 / 24*3	0.1
Spectral UV solar irradiance	Surface UV Trend	Top of Atmosphere	--	--	Daily / Monthly	2%
UV Aerosol Optical Depth	Surface UV Trend	Total column	10 / 50	--	24 / 24*3	0.1
UV Aerosol Absorption Optical Depth	Surface UV Trend	Total column	10 / 50	--	24 / 24*3	0.02

A2

Theme: **Ozone Layer**
Category: **Near-Real Time Data**

Requirement Data Product	Driver	Height Range	Horizontal resolution (km)	Vertical resolution (km)	Revisit Time (hours)	Uncertainty
O3	Ozone and UV Forecast	UT	20 / 100	0.5 / 2	6 / 24*3	20%
		LS	50 / 100	0.5 / 2	6 / 24*3	20%
		MS	100 / 200	2 / 3	6 / 24*3	20%
		US+M	100 / 200	3 / 5	12 / 24*7	20%
		Troph. column	10 / 50	--	6 / 24*3	20%
		Total column	50 / 100	--	6 / 24*3	5%
Spectral UV surface albedo	UV Forecast	Surface	10 / 50	--	6 / 24*3	0.1
Spectral UV solar irradiance	UV Forecast	Top of Atmosphere	--	--	Daily / Monthly	2%
UV Aerosol Optical Depth	UV Forecast	Total column	10 / 50	--	6 / 24*3	0.1
UV Aerosol Absorption Optical Depth	UV Forecast	Total column	10 / 50	--	6 / 24*3	0.02
Strat. Aerosol Optical Depth	Ozone loss	LS	50 / 100	0.5 / 2	6 / 24*3	0.05
		MS	50 / 200	1 / 3	12 / 24*7	0.05
		Stratosphere	50 / 200	--	6 / 24*7	0.05
ClO	Ozone loss	LS	50 / 200	2 / part. column	24 / 24*7	50%
		MS	100 / 200	2 / part. column	24 / 24*7	50%
		Stratosphere	50 / 200	--	24 / 24*7	50%
NO2	Ozone loss	LS	50 / 200	2 / part. column	24 / 24*7	20%
		MS	100 / 200	2 / part. column	24 / 24*7	20%
		Stratosphere	50 / 200	--	24 / 24*7	20%
PSC occurrence	Ozone loss	LS	50 / 100	0.5 / 2	6 / 24*3	< 10% mis-assignments
SF6	Tracer	LS	50 / 200	1 / 2	6 / 24*3	10%
		MS	100 / 200	2 / 3	12 / 24*7	10%
CO2 (as tracer alternative to SF6)	Tracer; Radiation budget	LS	50 / 200	1 / 2	6 / 24*3	10%
		MS	100 / 200	2 / 3	12 / 24*7	10%
H2O	Radiation budget; ST exchange	UT	20 / 100	0.5 / 2	6 / 24*3	20%
		LS	50 / 100	1 / 2	6 / 24*3	20%
		MS	100 / 200	2 / 3	12 / 24*7	20%
N2O (as tracer alternative to SF6)	Tracer; Radiation budget	LS	50 / 100	1 / 2	6 / 24*3	20%
		MS	50 / 200	2 / 3	12 / 24*7	20%
		US	50 / 200	3 / 5	12 / 24*7	20%
CH4 (as tracer alternative to SF6)	Tracer; Radiation budget	LS	50 / 200	1 / 2	6 / 24*3	20%
		MS	100 / 200	2 / 3	12 / 24*7	20%
HCl	ST exchange	LS	Co-located with O3	Co-located with O3	Co-located with O3	20%
HNO3	ST exchange	LS	Co-located with O3	Co-located with O3	Co-located with O3	20%
CO	ST exchange	UT+LS	Co-located with O3	Co-located with O3	Co-located with O3	20%

A3

Theme:
Category:

Ozone Layer Assessment

Requirement Data Product	Driver	Height Range	Horizontal resolution (km)	Vertical resolution (km)	Revisit Time (hours)	Uncertainty
O3	Ozone and UV Trend; Ozone loss; Surface UV, Ozone-Climate interaction	UT	20 / 100	1 / 3	6 / 24*3	20%
		LS	50 / 100	1 / 3	6 / 24*3	10%
		MS	100 / 200	2 / 3	6 / 24*3	20%
		US+M	100 / 200	3 / 5	6 / 24*7	20%
		Troph. column	10 / 50	--	6 / 24*3	20%
		Total column	50 / 100	--	6 / 24*3	10%
Spectral UV surface albedo	Surface UV	Surface	10 / 50	--	6 / 24*3	0.1
UV Aerosol Optical Depth	Surface UV	Total column	10 / 50	--	6 / 24*3	0.1
UV Aerosol Absorpton Optical Depth	Surface UV	Total column	10 / 50	--	6 / 24*3	0.02
Spectral UV solar irradiance	Surface UV	Top of Atmosphere	--	--	monthly	2%
H2O	Ozone-Climate interaction	LS	50 / 100	1 / 3	12 / 24*3	15% (1000 km)
		MS	100 / 200	2 / 3	12 / 24*7	15% (1000 km)
		US	100 / 200	3 / 5	12 / 24*7	15% (1000 km)
		Stratosphere	50 / 200	--	12 / 24*7	15% (1000 km)
N2O	Ozone-Climate interaction	LS	50 / 100	1 / 3	12 / 24*3	10% (ZA)
		MS	100 / 200	2 / 3	12 / 24*7	10% (ZA)
		US	100 / 200	3 / 5	12 / 24*7	10% (ZA)
		Stratosphere	50 / 200	--	12 / 24*7	10% (ZA)
CH4	Ozone-Climate interaction	LS	50 / 100	1 / 3	12 / 24*3	10% (ZA)
		MS	100 / 200	2 / 3	12 / 24*7	10% (ZA)
		US	100 / 200	3 / 5	12 / 24*7	10% (ZA)
		Stratosphere	50 / 200	--	12 / 24*7	10% (ZA)
HNO3	Ozone Trend; Dinitrification	LS	50 / 100	1 / 3	12 / 24*3	30% (1000 km)
		MS	100 / 200	2 / 3	12 / 24*7	30% (1000 km)
		Stratosphere	50 / 200	--	12 / 24*7	30% (1000 km)
CFC-11	Ozone trend	LS	50 / 100	1 / 3	12 / 24*3	5% (ZA)
		MS	100 / 200	2 / 3	12 / 24*7	5% (ZA)
		Stratosphere	50 / 200	--	12 / 24*7	5% (ZA)
CFC-12	Ozone trend	LS	50 / 100	1 / 3	12 / 24*3	5% (ZA)
		MS	100 / 200	2 / 3	12 / 24*7	5% (ZA)
		Stratosphere	50 / 200	--	12 / 24*7	5% (ZA)
HCFC-22	Ozone trend	LS	50 / 100	1 / 3	12 / 24*3	20% (ZA)
		MS	100 / 200	2 / 3	12 / 24*7	20% (ZA)
		Stratosphere	50 / 200	--	12 / 24*7	20% (ZA)
ClO	Ozone loss	LS	50 / 100	1 / 3	12 / 24*3	30% (1000 km)
		MS	100 / 200	2 / 3	12 / 24*7	30% (1000 km)
		Stratosphere	50 / 200	--	12 / 24*7	30% (1000 km)
BrO	Ozone loss	LS	50 / 100	1 / 3	12 / 24*3	30% (1000 km)
		MS	100 / 200	2 / 3	12 / 24*7	30% (1000 km)
		Stratosphere	50 / 200	--	12 / 24*7	30% (1000 km)
NO2	Ozone loss	LS	50 / 100	1 / 3	12 / 24*3	30% (1000 km)
		MS	100 / 200	2 / 3	12 / 24*7	30% (1000 km)

		Stratosphere	50 / 200	--	12 / 24*7	30% (1000 km)
Aerosol surface density	Ozone loss	LS	50 / 100	1 / 3	12 / 24*3	100% (1000 km)
		MS	100 / 200	2 / 3	12 / 24*7	100% (1000 km)
		Stratosphere	50 / 200	--	12 / 24*7	100% (1000 km)
PSC occurrence	Ozone loss	LS	50 / 100	1 / 3	12 / 24*3	< 10% mis-assignments
HCl	Chlorine trend	LS	50 / 100	1 / 3	12 / 24*3	30% (1000 km)
		MS	100 / 200	2 / 3	12 / 24*7	30% (1000 km)
		Stratosphere	50 / 200	--	12 / 24*7	30% (1000 km)
ClONO2	Chlorine trend	LS	50 / 100	1 / 3	12 / 24*3	30% (1000 km)
		MS	100 / 200	2 / 3	12 / 24*7	30% (1000 km)
		Stratosphere	50 / 200	--	12 / 24*7	30% (1000 km)
HBr	Bromine trend	LS	50 / 100	1 / 3	12 / 24*3	30% (1000 km)
		MS	100 / 200	2 / 3	12 / 24*7	30% (1000 km)
		Stratosphere	50 / 200	--	12 / 24*7	30% (1000 km)
BrONO2	Bromine trend	LS	50 / 100	1 / 3	12 / 24*3	30%
		MS	100 / 200	2 / 3	12 / 24*7	30%
		Stratosphere	50 / 200	--	12 / 24*7	30%
CH3Cl	Bromine trend	LS	50 / 100	1 / 3	12 / 24*3	30%
		MS	100 / 200	2 / 3	12 / 24*7	30%
		Stratosphere	50 / 200	--	12 / 24*7	30%
CH3Br	Bromine trend	LS	50 / 100	1 / 3	12 / 24*3	5% (ZA)
		MS	100 / 200	2 / 3	12 / 24*7	5% (ZA)
		Stratosphere	50 / 200	--	12 / 24*7	5% (ZA)
SO2 enhanced	Ozone loss	LS	50 / 100	1 / 3	12 / 24*3	50%
		MS	100 / 200	2 / 3	12 / 24*7	50%
		Stratosphere	50 / 200	--	12 / 24*7	50%
Volcanic aerosol	Ozone loss	LS	50 / 100	1 / 3	12 / 24*3	
		MS	100 / 200	2 / 3	12 / 24*7	< 10% mis-assignments
		Stratosphere	50 / 200	--	12 / 24*7	

B1

Theme: **Air Quality**
Category: **Protocol Monitoring**

Requirement / Data Product	Driver	Height Range	Horizontal resolution (km)	Vertical resolution (km)	Revisit Time (hours)	Uncertainty
O3	Interpolation of Surface network; Boundary condition; UV actinic fluxes	PBL	5 / 20	--	0.5 / 2	10%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	25%
		Total Column	50 / 100	--	24 / 24*3	3%
NO2	Interpolation of Surface network; Emissions; Boundary condition	PBL	5 / 20	--	0.5 / 2	10%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
CO	Interpolation of Surface network; Emissions; Boundary condition	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	25%
		Total Column	5 / 20	--	0.5 / 2	25%
SO2	Interpolation of Surface network; Emissions; Boundary condition	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	$1.3^{e}15$ molec cm-2
CH2O	Interpolation of Surface network; VOC Emissions; Boundary condition	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	$1.3^{e}15$ molec cm-2
Aerosol OD	Interpolation of Surface network; Emissions; Boundary condition; UV actinic fluxes	PBL	5 / 20	--	0.5 / 2	0.05
		FT	5 / 50	--	0.5 / 2	0.05
		Tropospheric Column	5 / 20	--	0.5 / 2	0.05
		Total Column	5 / 20	--	0.5 / 2	0.05
Aerosol Type	Translation Aerosol OD to PM surface concentrations	PBL	5 / 20	--	0.5 / 2	< 10% mis-assignments
		FT	5 / 50	--	0.5 / 2	< 10% mis-assignments
		Tropospheric Column	5 / 20	--	0.5 / 2	< 10% mis-assignments
		Total Column	5 / 20	--	0.5 / 2	< 10% mis-assignments

B2

Theme: Air Quality
Category: Near-Real Time

Requirement Data Product	Driver	Height Range	Horizontal resolution (km)	Vertical resolution (km)	Revisit Time (hours)	Uncertainty
O3	Air Quality Forecast; UV actinic fluxes	PBL	5 / 20	--	0.5 / 2	10%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	25%
		Total Column	50 / 100	--	12 / 24*3	5%
NO2	Air Quality Forecast	PBL	5 / 20	--	0.5 / 2	10%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
CO	Air Quality Forecast	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Ttropospheric Column	5 / 20	--	0.5 / 2	25%
		Total Column	5 / 20	--	0.5 / 2	25%
Aerosol OD	Air Quality Forecast; UV actinic fluxes	PBL	5 / 20	--	0.5 / 2	0.05
		FT	5 / 50	--	0.5 / 2	0.05
		Ttropospheric Column	5 / 20	--	0.5 / 2	0.05
		Total Column	5 / 20	--	0.5 / 2	0.05
Aerosol Type	Air Quality Forecast	PBL	5 / 20	--	0.5 / 2	< 10% mis-assignments
		FT	5 / 50	--	0.5 / 2	< 10% mis-assignments
		Ttropospheric Column	5 / 20	--	0.5 / 2	< 10% mis-assignments
		Total Column	5 / 20	--	0.5 / 2	< 10% mis-assignments
H2O	Air Quality Forecast	PBL	5 / 20	--	0.5 / 2	10%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	10%
		Total Column	5 / 20	--	0.5 / 2	10%
SO2	Air Quality Forecast	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
CH2O	Air Quality Forecast	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
HNO3	Air Quality Forecast	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
N2O5 (night)	Air Quality Forecast	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	50%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
PAN	Air Quality Forecast	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
Spectral UV surface albedo	UV actinic fluxes	Surface	5 / 20	--	24 / 24*3	0.1

B3 Theme: Category: Air Quality Assessment

Requirement Data Product	Driver	Height Range	Horizontal resolution (km)	Vertical resolution (km)	Revisit Time (hours)	Uncertainty
O3	Phot. Acitivity; Ox. Capacity; Background	PBL	5 / 20	--	0.5 / 2	10%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	25%
		Total Column	5 / 20	--	0.5 / 2	3%
NO2	Emissions; Phot. Acitivity; Ox. Capacity	PBL	5 / 20	--	0.5 / 2	10%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
CO (+ isotopes)	Ox. Capacity; Emissions; Background	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	25%
		Total Column	5 / 20	--	0.5 / 2	25%
Aerosol OD	Emissions; UV actinic fluxes	PBL	5 / 20	--	0.5 / 2	0.05
		FT	5 / 50	--	0.5 / 2	0.05
		Tropospheric Column	5 / 20	--	0.5 / 2	0.05
		Total Column	5 / 20	--	0.5 / 2	0.05
Aerosol Type	Emissions	PBL	5 / 20	--	0.5 / 2	< 10% mis-assignments (for all altitude ranges)
		FT	5 / 50	--	0.5 / 2	
		Tropospheric Column	5 / 20	--	0.5 / 2	
		Total Column	5 / 20	--	0.5 / 2	
H2O	Ox. Capacity	PBL	5 / 20	--	0.5 / 2	10%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	10%
		Total Column	5 / 20	--	0.5 / 2	10%
SO2	Emissions	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
CH2O	Phot. Activity; VOC emissions	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
HNO3	Ox. Capacity	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
N2O5 (nighttime)	Ox. Capacity	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
Organic Nitrates	Ox. Capacity	PBL	5 / 20	--	0.5 / 2	30%
Spectral UV surface albedo	UV actinic fluxes	Surface	5 / 20	--	24 / 24*3	0.1

C1	Theme: Category:	**Climate** **Protocol Monitoring**

Requirement / Data Product	Driver	Height Range	Horizontal resolution (km)	Vertical resolution (km)	Revisit Time (hours)	Uncertainty
CO2 (PBL sensitive)	Emissions	Tropospheric column	10 / 50	--	6 / 12	0.5%
		Total column	10 / 50	--	6 / 12	0.5%
CH4 (PBL sensitive)	Emissions	Tropospheric column	10 / 50	--	24 / 24*3	2%
		Total column	10 / 50	--	24 / 24*3	2%
O3	Radiative forcing	Troposphere	10 / 50	2 / 5	12 / 24*3	20%
		Tropospheric column	10 / 50	--	12 / 24*3	25%
		Total column	50 / 100	--	24 / 24*3	3%
NO2 (PBL sensitive)	Emissions	Troposphere	10 / 50	2 / 5	12 / 24*3	50%
		Tropospheric column	10 / 50	--	12 / 24*3	1.3·(10)15 cm^{-}
		Total column	10 / 50	--	12 / 24*3	1.3·(10)15 cm^{-2}
CO (PBL sensitive)	Emissions	Troposphere	10 / 50	2 / 5	12 / 24*3	20%
		Tropospheric column	10 / 50	--	12 / 24*3	25%
		Total column	10 / 50	--	12 / 24*3	25%
Aerosol OD	Emissions; Radiative forcing	Troposphere	10 / 50	--	6 / 24*3	0.05
		LS	50 / 100	1 / part. column	12 / 24*3	0.05
		MS	50 / 200	2 / part. column	12 / 24*3	0.05
		Total column	10 / 50	--	12 / 24*3	0.05
Aerosol absorption OD	Radiative forcing	Troposphere	10 / 50	--	6 / 24*3	0.01
		Total column	10 / 50	--	6 / 24*3	0.01

C2

Theme: **Climate**
Category: **Near-Real Time**

Requirement / Data Product	Driver	Height Range	Horizontal resolution (km)	Vertical resolution (km)	Revisit Time (hours)	Uncertainty
O3	Radiation; Dynamics	PBL	5 / 50	--	6 / 24	30%
		Tropospheric column	10 / 50	--	6 / 24*3	25%
		LS	50 / 100	0.5 / 2	6 / 24*3	10%
		MS	50 / 200	1 / 3	6 / 24*7	20%
		US+M	50 / 200	3 / 5	6 / 24*7	20%
		Total column	50 / 100	--	6 / 24*3	5%
H2O	Radiation; Dynamics; Hydrological cycle; Stratospheric H2O	PBL	5 / 50	--	1 / 6	50%
		FT	10 / 50	0.5 / 2	1 / 6	30%
		UT	10 / 100	0.5 / 2	1 / 6	30%
		LS	50 / 100	0.5 /2	3 / 24	20%
		MS	50 / 200	1 / 3	6 / 24*7	20%
		US	50 / 200	3 / 5	6 / 24*7	20%
		Total column	10 / 50	--	6 / 24*3	5%
CO2	Radiation; Tracer	PBL	5 / 50	--	6 / 12	10%
		MS	50 / 200	1 / 3	12 / 24*7	10%
		US	50 / 200	1 / 3	12 / 24*7	10%
		Total column	1 / 20	--	1 / 12	2%
CH4	Radiation; Tracer	LS	50 / 100	1 / 3	12 / 24*3	20%
		MS	50 / 200	1 / 3	12 / 24*3	20%
		Total column	10 / 50	--	12 / 24*3	2%
N2O	Radiation; Tracer	LS	50 / 100	1 / 3	12 / 24*3	20%
		MS	50 / 200	1 / 3	12 / 24*3	20%
		US	50 / 200	3 / 5	12 / 24*3	20%
		Total Column	10 / 50	--	12 / 24*3	2%
Aerosol OD	Radiation	PBL	5 / 10	--	1 / 6	0.05
		Troposphere	5 / 50	--	3 / 24	0.05
		LS	50 / 100	1 / part. column	12 / 24*3	0.05
		MS	50 / 200	1 / part. column	12 / 24*3	0.05
Aerosol absorption OD	Radiation	PBL	5 / 10	--	1 / 6	0.01
		Troposphere	5 / 50	--	3 / 24	0.01
Cirrus OD	Radiation	UT	10 / 100	--	6 / 24	100%
SF6	Tracer	LS	50 / 100	1 / 3	12 / 24*7	10%
		MS	50 / 200	1 / 3	12 / 24*7	10%
		US	50 / 200	3 / 5	12 / 24*7	10%
HDO	Tracer; Stratospheric H2O	LS	50 / 100	1 / 3	12 / 24*7	10%
		MS	50 / 200	1 / 3	12 / 24*7	10%
		US	50 / 200	3 / 5	12 / 24*7	10%
HF (alternative tracer)	Tracer	LS	50 / 100	1 / 3	12 / 24*7	10%
		MS	50 / 200	1 / 3	12 / 24*7	10%
		US	50 / 200	3 / 5	12 / 24*7	10%
Aerosol phase function	Radiation	PBL	5 / 10	--	1 / 6	0.1 on asymmetry factor
		Troposphere	5 / 50	--	3 / 24	0.1 on asymmetry factor
Cirrus phase function	Radiation	UT	10 / 100	--	6 / 24	0.1 on a. factor

C3

Theme:
Category:

Climate Assessment

Requirement Data Product	Driver	Height Range	Horizontal resolution (km)	Vertical resolution (km)	Revisit Time (hours)	Uncertainty
O3	Radiative Forcing; Oxidising Capacity; Tracer; Ozone recovery	Troposphere	10 / 50	1 / 3	6 / 24*3	30%
		Tropospheric Column	10 / 50	--	6 / 24*3	25%
		UT	20 / 100	0.5 / 2	6 / 24*3	20%
		LS	50 / 100	0.5 / 2	6 / 24*3	20%
		MS	50 / 100	2 / 3	6 / 24*3	20%
		US+M	100 / 200	3 / 5	6 / 24*7	20%
		Total Column	50 / 100	--	6 / 24*3	3%
H2O	Radiative Forcing; Oxidising Capacity; Tracer; O3 recovery; Stratospheric H2O	PBL	1 / 20	--	6 / 24	30%
		Troposphere	10 / 50	1 / 3	6 / 24*3	30%
		Tropospheric Column	10 / 50	--	6 / 24*3	10%
		UT	20 / 100	0.5 / 2	6 / 24*3	20%
		LS	50 / 100	0.5 / 2	6 / 24*3	20%
		MS	50 / 100	2 / 3	6 / 24*7	20%
		US+M	100 / 200	3 / 5	6 / 24*7	20%
		Total Column	50 / 100	--	6 / 24*3	10%
CO2	Radiative Forcing; Tracer	MS	50 / 100	2 / 3	12 / 24*3	10%
		Total Column (PBL sensitive)	10 / 50	--	1 / 12	0.5%
CH4	Radiative Forcing; Oxidising Capacity; Tracer; Stratospheric H2O	LS	50 / 100	1 / 3	12 / 24*3	20%
		MS	50 / 100	2 / 3	12 / 24*3	20%
		Total Column (PBL sensitive)	10 / 50	--	12 / 24*3	2%
N2O	Radiative Forcing; Tracer; N budget	LS	50 / 100	1 / 3	12 / 24*3	20%
		MS	50 / 100	2 / 3	12 / 24*3	20%
		US	50 / 100	3 / 5	12 / 24*7	20%
		Total Column (PBL sensitive)	10 / 50	--	12 / 24*3	2%
CO	Ozone and CO2 precursor	Troposphere	10 / 50	1 / 3	12 / 24*3	30%
		Troposph. Col. (PBL sensitive)	10 / 50	--	12 / 24*3	25%
		UT	20 / 100	1 / 3	12 / 24*3	20%
		LS	50 / 100	1 / 3	12 / 24*3	20%
NO2	Ozone and Aerosol precursor	Troposphere	10 / 50	1 / 3	6 / 24*3	30%
		Troposph. Col. (PBL sensitive)	10 / 50	--	12 / 24*3	1.3·(10)15 cm^{-2}
		UT	20 / 100	1 / 3	6 / 24*3	50%
		LS	50 / 100	1 / 3	12 / 24*3	50%
		MS	50 / 200	2 / 3	12 / 24*3	30%
		Total Column	50 / 100	--	12 / 24*3	10%
CH2O	Oxidising Capacity	Troposphere	10 / 50	1 / 3	6 / 24*3	30%
		Troposph. Col. (PBL sensitive)	10 / 50	--	12 / 24*3	1.3·(10)15 cm^{-2}
		UT	20 / 100	1 / 3	6 / 24*3	30%
		Total Column (PBL sensitive)	10 / 50	--	12 / 24*3	1.3·(10)15 cm^{-2}

HNO3	N budget	Troposphere	10 / 50	1 / 3	6 / 24*3	30%
		UT	20 / 100	1 / 3	6 / 24*3	20%
		LS	50 / 100	1 / 3	12 / 24*3	20%
		MS	50 / 200	2 / 3	12 / 24*3	20%
		Total Column	10 / 50	--	12 / 24*3	20%
Cirrus OD	Radiative Forcing	UT	10 / 100	--	6 / 24	100%
PSC occurrence (day + night)	Radiative Forcing	LS	50 / 100	0.5 / 2	6 / 24*3	< 10% mis-assignments
Aerosol OD	Radiative Forcing	PBL	5 / 20	--	6 / 24	0.05
		Troposphere	10 / 50	--	6 / 24	0.05
		LS	50 / 100	1 / part. column	12 / 24*3	0.05
		MS	50 / 200	2 / part. column	12 / 24*3	0.05
		Total Column	10 / 50	--	12 / 24*3	0.05
Aerosol absorption OD	Radiative Forcing	Troposphere	5 / 50	--	6 / 24	0.01
		Total Column	5 / 50	--	6 / 24	0.01
Spectral solar irradiance	Radiative Forcing	Top of Atmosphere	--	--	24 / 24*7	2%
HCl	Ozone recovery	LS	50 / 100	1 / 3	12 / 24*3	20%
CH3Cl	Ozone recovery	LS	50 / 100	1 / 3	12 / 24*3	20%
		MS	50 / 200	2 / 3	12 / 24*3	20%
		Stratosphere	50 / 100	--	12 / 24*3	20%
CH3Br	Ozone recovery	LS	50 / 100	1 / 3	12 / 24*3	20%
		MS	50 / 200	2 / 3	12 / 24*3	20%
		Stratosphere	50 / 100	--	12 / 24*3	20%
SF6	Tracer	LS	50 / 100	1 / 3	12 / 24*7	10%
		MS	50 / 200	2 / 3	12 / 24*7	10%
		US	50 / 200	3 / 5	12 / 24*7	10%
HDO	Tracer; Stratospheric H2O	LS	50 / 100	1 / 3	12 / 24*7	10%
		MS	50 / 200	2 / 3	12 / 24*7	10%
		US	50 / 200	3 / 5	12 / 24*7	10%
		Stratosphere	50 / 100	--	12 / 24*7	10%
HF	Tracer	LS	50 / 100	1 / 3	12 / 24*7	10%
		MS	50 / 200	2 / 3	12 / 24*7	10%
		US	50 / 200	3 / 5	12 / 24*7	10%
CFC-11	Radiative Forcing	LS	50 / 100	1 / 3	12 / 24*7	20%
		MS	50 / 200	2 / 3	12 / 24*7	20%
		Stratosphere	50 / 100	--	12 / 24*7	20%
CFC-12	Radiative Forcing	LS	50 / 100	1 / 3	12 / 24*7	20%
		MS	50 / 200	2 / 3	12 / 24*7	20%
		Stratosphere	50 / 100	--	12 / 24*7	20%
HCFC-22	Radiative Forcing	UT	20 / 100	1 / 3	12 / 24*3	20%
		LS	50 / 100	1 / 3	12 / 24*3	20%
		MS	50 / 200	2 / 3	12 / 24*3	20%
		Stratosphere	50 / 100	--	12 / 24*3	20%
H2O2	Oxidising Capacity	Troposphere	10 / 50	1 / 3	6 / 24*3	30%
		UT	20 / 100	1 / 3	6 / 24*3	30%
N2O5	N budget	Troposphere	10 / 50	--	6 / 24*3	30%
		UT	20 / 100	1 / 3	6 / 24*3	30%
		LS	50 / 100	1 / 3	12 / 24*3	50%
		MS	50 / 200	1 / 3	12 / 24*3	50%
		Stratosphere	50 / 100	--	12 / 24*3	50%
PAN	N budget	Troposphere	10 / 50	--	6 / 24*3	30%
		UT	20 / 100	1 / 3	6 / 24*3	30%
		Total column	10 / 50	--	6 / 24*3	30%
CH3COCH3	Oxidising Capacity	Troposphere	10 / 50	--	6 / 24*3	30%

		UT	20 / 100	1 / 3	6 / 24*3	30%
		Total column	10 / 50	--	6 / 24*3	30%
C2H6	Oxidising Capacity	Troposphere	10 / 50	--	6 / 24*3	50%
		UT	20 / 100	1 / 3	6 / 24*3	50%
		Total column	10 / 50	--	6 / 24*3	50%
ClO (for enhanced levels)	Ozone Recovery	LS	50 / 100	1 / 3	12 / 24*3	20%
		MS	50 / 200	2 / 3	12 / 24*3	20%
		Stratosphere	50 / 100	--	12 / 24*3	20%
ClONO2	Ozone Recovery	LS	50 / 100	1 / 3	12 / 24*3	20%
		MS	50 / 200	2 / 3	12 / 24*3	20%
		Stratosphere	50 / 100	--	12 / 24*3	20%
SO2 (for enhanced levels)	Volcanoes	Troposphere	10 / 50	1 / 3	6 / 24*3	50%
		LS	50 / 100	1 / 3	12 / 24*3	50%
		MS	50 / 200	2 / 3	12 / 24*3	50%
		Total column	10 / 50	--	6 / 24*3	50%
Aerosol phase function	Radiative Forcing; Volcanoes	Troposphere	10 / 50	--	6 / 24	0.1 on asymmetry factor
		LS	50 / 100	1 / part. column	12 / 24*3	0.1 on asymmetry factor
		MS	50 / 200	2 / part. column	12 / 24*3	0.1 on asymmetry factor
		Total column	10 / 50	--	6 / 24	0.1 on asymmetry factor
Cirrus phase function	Radiative Forcing	UT	10 / 100	--	6 / 24	0.1 on asymmetry factor

4.3 Application priorities and contributions of existing and planned missions

Of the three types of applications considered in the previous section, the protocol monitoring and near-real-time services account fully for the operational character of the Sentinel-4/-5 mission and therefore have the highest priority. The third category, environmental assessment, covers important aspects such as support to IPCC assessment; however in this case there is no clear user relationship. Requirements related to assessment applications are therefore of lower priority in the context of a GMES mission and are not supposed to drive the mission concept.

An extensive survey of the potential contributions of other existing and planned space missions to the fulfillment of the mission requirements has been carried out /Kel2005/. As a result, at the time of the foreseen GMES mission (in the decade 2010-2020), two families of satellites are expected to be operational. The European Metop / EPS mission will carry the UV-vis sounder "GOME-2" and the FTIR "IASI" (both in nadir-viewing geometry), the NOAA NPOESS mission will have the UV-vis sounder "OMPS" (limb and nadir) and the IR sounder "CRIS" (nadir) on board. The preliminary assumption is that European users will have access to NPOESS data, although this would need to be verified.

UV-vis observations will be available once per day from each of the instruments and are expected to cover requirements of application A1 (stratospheric ozone and surface UV – treaty verification and protocol monitoring). They will provide a small contribution to other stratospheric applications, limited by their lack of vertical resolution and only partial coverage of required species. Their contribution to tropospheric applications is marginal since, due to their large ground pixels, most of the measurements are contaminated by clouds and the horizontal and temporal resolutions are too coarse.

IR observations will be made twice per day by IASI and by CRIS. These will make a contribution to tropospheric applications, in particular as they have the potential to provide some altitude resolution for a subset of the needed species. However, these measurements are not suited to obtain the crucial information on PBL composition, and their spectral resolution limits the profiling capabilities.

There are three overall requirements that cannot be met by the planned systems and therefore need to be addressed by GMES Sentinels 4 and 5:

- High temporal and spatial resolution space-based measurements of tropospheric composition including the PBL for Air Quality applications (B1, B2, B3)

- High spatial resolution and high precision monitoring of tropospheric climate gases (CH_4, CO (precursor) and CO_2) and aerosols with sensitivity to PBL concentrations (C1)

- High vertical resolution measurements in the upper troposphere/lower stratosphere region for Stratospheric Ozone/Surface UV and Climate near-real time and assessment applications (A2, A3, C2, C3).

5. Preliminary System Concepts

5.1 Candidate remote sensing techniques and mission scenarios

Possible remote sensing principles and specifications have been investigated in /Kel2005/ which includes an extensive assessment of the capabilities of spaceborne atmospheric chemistry instrumentation (existing and proposed for Sentinels 4 and 5) with respect to the observational requirements in Chapter 4 of this document, a prioritisation of instrument types per application as well as further references justifying individual specifications for suggested space instruments. Following the results of this study, potential implementation of the required observations can be identified as described below.

5.1.1 High temporal and spatial resolution space-based measurements of tropospheric composition, including the planetary boundary layer (PBL), for air quality applications

Suitable instrument types with sensitivity to required chemical constituents are

- a UV-visible spectrometer to cover the most important species listed in section 4.2.2 and to provide PBL sensitivity (daytime);
- a SWIR spectrometer (2.3 µm) for the CO total column with PBL sensitivity (daytime); and possibly another SWIR channel for aerosol (daytime);
- a thermal IR spectrometer for CO and O_3 vertical profiles, possibly complementary species and day and night coverage of species.

The mission scenario may depend on the key observational requirements for this mission which are the temporal sampling of 0.5 – 2 h and horizontal sampling of 5 – 20 km. Given

- the uncertainty of the temporal sampling requirement in the absence of any spaceborne atmospheric composition data coming even near to it and of suitable observation system simulation experiments,
- the fact that in another assessment of geophysical observation requirements for the same application, a team tasked by Eumetsat /EUM2006/ arrived at a threshold temporal sampling requirement of 4 hours,
- the fact that the trade-off between temporal sampling and geographical coverage depends on the setting of priorities among various air quality applications,

a range of combined temporal sampling and geographical coverage requirements can be identified as follows, for the time being without preference for any among them:

- temporal sampling of 1 hour covering Europe and surrounding areas (30°W - 45°E [@40°N] and 30°N - 65°N) and daily global coverage at fixed local time;
- temporal sampling of 2 hours covering the most polluted latitude ranges of 25/30º (target / threshold) to 65/60º (target / threshold) at all longitudes and temporal resolution of 6 hours at lower latitudes; no sampling of high latitudes required;

- temporal sampling of 4 hours globally.

The general target requirement on sampling is (near-)contiguous sampling. The integration of the space-borne data within a data assimilation framework may allow for data gaps in time and space to a certain extent.

It is possible that the thermal IR spectrometer can be dropped if IASI and CRIS data will be available. This will depend on the performance of these instruments – which have not been optimised for trace gas measurements - and on the capabilities of atmospheric models and assimilation schemes to transport their measurement information to the time and place of the Sentinel UV-vis observations. This possibility is therefore most obvious for the case of a LEO platform flying in tandem with Metop or NPOESS, and less likely for other local times, for non-sunsynchronous LEOs or for GEO. While the tandem flight facilitates the synergy between short-wave observations on the Sentinel platform and IR observations by IASI / CRIS, the advantage of flying at a different local time would be an improvement of the diurnal coverage of measurements globally. Both aspects still need quantitative investigation.

The trade-off among mission scenarios depends on feasibility and cost, but also on priority settings (global vs. regional mission) and end-user performance, which needs to be assessed in retrieval simulations followed by observation system simulation experiments (involving data assimilation and inverse modelling techniques). This trade-off needs to be performed in preparatory technical and scientific studies.

5.1.2 High spatial resolution and high precision monitoring of tropospheric climate gases (CH_4, CO (precursor) and CO_2) and aerosols with sensitivity to PBL concentrations for climate protocol monitoring

- monitoring CO_2 with the accuracy necessary to serve operational applications such as treaty verification is considered immature at this time /Bre2003/, /Kel2005/. Experience with upcoming research missions needs to be awaited before a meaningful decision on an operational CO_2 mission can be taken. This goal will therefore not be further considered in this document.

- CO and aerosols can be observed in the same way as for the air quality mission; CH_4 with PBL sensitivity can be measured in the 2.3 μm band as CO.

This mission requires global coverage, with emphasis on inhabited areas. Due to the large overlap of requirements, it can best be combined with the LEO (part of the) air quality mission, be it in sun-synchronous or inclined orbit.

5.1.3 High vertical resolution measurements in the upper troposphere/lower stratosphere region for stratospheric ozone/surface UV and climate near-real time and assessment applications

These data will best be obtained by limb-sounding spectrometers in either the thermal IR or in the mm-wave region. However, scientific prototypes of both sensing techniques on Envisat and EOS-Aura are just being assessed for their operational capabilities; the most suitable technique cannot be identified yet.

5.1.4 Overall system

In conclusion, the following implementation priorities are recommended, subject to further system analyses:

1. a satellite with UV-vis, SWIR and thermal IR (see 5.1.1 on possible reduction) spectrometers serving air quality and climate protocol monitoring in LEO. This satellite is common to all temporal sampling / geographical coverage requirement scenarios and will provide continuity and improvement with respect to the OMI and Sciamachy missions. The orbit could be either sun-synchronous or inclined; this will have no impact at the level of the specifications given below.
2. an extension of this mission to obtain regularly ≤ 1 - 4 hours revisit time as required for air quality applications. This extension could consist of other LEO satellites or a GEO platform carrying instrumentation with similar Level 1b performance specifications.
3. a limb-sounding mission observing the UTLS either in the mm-wave or infrared region to serve stratospheric ozone / surface UV and climate near real time and assessment applications. Maturation of this application needs to be awaited, so this mission will not be further considered in this document at this time.

5.2 Specification for LEO mission

5.2.1 UV-VIS-NIR

5.2.1.1 Geometrical requirements

Table 5.1: LEO UV-VIS geometrical requirements

Parameter	Nominal Value	Units
Spatial sampling distance along/across track (at nadir)	5/5 – 20/20 for λ>295nm 20/20 – 100/100 for λ<295nm	km^2
Knowledge of geolocation	<10%	spatial sampling distance

The spatial sampling distance requirement is relaxed for λ<295nm because this wavelength range is only sensitive to stratospheric ozone, which has less horizontal structure than the signal arising from the troposphere.

The target requirement on the spatial sampling distance off-nadir is for the same that is realised by the nadir view; the threshold requirement is for the same solid angle as the nadir view.

The spatial element containing 70% (90%) of the integrated energy of a point source, shall be smaller than 100% (150%) of the spatial sampling distance in each direction.

The co-registration of all spectral elements in the UV-VIS-NIR shall be better than 1% (goal) / 5% (threshold) of the spatial sampling distance.

The co-registration knowledge between the SWIR band and the O_2-A band shall be better than 10% of the spatial sampling distance of the SWIR band.

Measurements shall be taken for SZAs < 92 deg, however given the degraded Level 2 data product quality at very high SZAs, the orbit should be optimised for a maximum SZA for 80 deg.

For similar reason, the maximum observation zenith angle (angle between zenith and line of sight) should be assumed to be 66 deg.

5.2.1.2 Spectral Requirements

The UV-VIS-NIR band can be used to measure several trace gases and information on aerosols and clouds. From the spectral windows as given in Table 5.2 it follows that the instrument should cover the wavelength ranges from 270 to 500 nm, 610 to 680 nm and from 755 to 775 nm.

Table 5.2 Spectral ranges for the LEO UV-VIS-NIR band

Level-2 data product	**Wavelength range [nm]**	**Priority, comments**
Ozone vertical profile	270 – 330	A
Sulphur dioxide	308 – 325	A
Total ozone	325 – 337	A
Formaldehyde	337 – 360	A
Rayleigh scattering (cloud), aerosol absorption	360 – 400	A, gaps may be acceptable in this range
Nitrogen dioxide	405 – 500	A
Glyoxal	430 – 460	B
O_2-O_2 (cloud)	460 – 490	A/B
Water vapour and cloud (effective scattering height)	590 – 640 or 610 – 680 or 710 – 750	B. This band is not needed if concomitant H_2O data are available from IR measurements
O_2-A (cloud, aerosol)	750 – 775	A
Aerosol	336-340 360-375 380-384 400-430 440-460	B

The spectral resolution and spectral sampling ratio (spectral sampling divided by the spectral resolution) shall be as specified in table 5.3.

Table 5.3 Spectral resolution and spectral sampling ratio for the LEO UV-VIS-NIR band

Wavelength range [nm]	**Spectral resolution [nm]**	**Spectral sampling ratio**
270-300	1.0	At least 3 [1])
300-500	0.5	At least 3 [1])
590-640 or 610-680 or 710-750	0.2	At least 2 [1])
750-775	0.05 (goal) / 0.2 (threshold)	At least 3 [1])

[1]) A spectral sampling factor of 6 is desirable but of lower priority than the S/N.

The knowledge of the spectral calibration shall be better than or equal to 0.02 spectral pixel for wavelengths smaller than 300 nm and 0.01 spectral pixel for wavelengths larger than or equal to 300 nm. This requirement will be fulfilled by analysis of in-flight data of solar irradiance, using known Fraunhofer lines, and Earth radiance data, using Fraunhofer lines and atmospheric absorption features. Since the spectrum will be undersampled, this analysis depends on high spectral stability between the solar and atmospheric measurements, to limit errors due to resampling. The fitting process also depends on high radiometric accuracy and signal-to-noise ratios of the radiance and irradiance spectra.

The spectral stability between two solar measurements shall be better than 0.05 spectral pixel.

The shape of the instrument spectral response function (ISRF, end-to-end spectral response of the instrument) shall be known for all applicable wavelengths and viewing angles to an accuracy of 1% (1σ) for the spectral range where the ISRF is at least 1% of the maximum response at the centre wavelength.

Note that the requirement on possible broad wings of the slit function is partially included in the offset requirement.

5.2.1.3 Radiometric requirements

Radiometric Requirements for the Earth reflectance and radiance

The Earth reflectance is the radiance divided by the solar irradiance and serves as the basis for almost all retrievals.

For the radiometric requirements for the radiance measurements, four scenarios are considered. These scenarios are a minimum and maximum radiance case for tropical (solar zenith angle 0 degrees) and high-latitude (solar zenith angle 75 degrees) situations. For the signal-to-noise requirements the low albedo (“minimum”) cases applicable, for saturation requirements the maximum radiance cases are applicable.

The signal-to-noise for Earth reflectance and radiance shall be better than specified in table 5.4. The specification applies to the lowest radiance level with the exception of the Mg lines around 283 nm and the Ca II HK lines around 395 nm. For the O_2-A band, the SNR is specified separately for the continuum and the absorption lines.

Table 5.4. Earth reflectance and radiance signal-to-noise requirements for LEO UV-VIS-NIR band, per spectral sample

Level-2 data product	**Wavelength range [nm]**	**Signal-to-noise tropical**	**Signal-to-noise High latitude**
Ozone vertical profile	270 – 330	100 (270 nm) 1000 (310 nm) 1000 (330 nm)	50 (270 nm) TBD 1000 (310 nm) 1000 (330 nm)
Sulphur dioxide	308 – 325	1000	400
Total ozone	325 – 337	800	400
Formaldehyde	337 – 356	1000	400
Bromine monoxide (prio B)	345 – 360	1000	400
Nitrogen dioxide	405 – 465	1050	450
Glyoxal [1])	430 – 460	-	-
O_2-O_2 (cloud)	460 – 490	1500	650
Water vapour	590-640 or 610-680 or 710-750	700	700
O_2-A (cloud)	750 – 775	200 (for lowest radiance in the band) 1000 (for continuum)	200 (for lowest radiance in the band) 1000 (for continuum)

[1]) Glyoxal is considered as a by-product rather than a species driving the requirements. It has a weak spectral signature, temporal averages will be retrieved only.

The absolute radiometric accuracy of the Earth reflectance and the radiance shall be better than 1-2 % (1σ). This includes all instrumental error sources, including eg. straylight, but excludes errors in radiometric standards.

The relative radiometric accuracy of the Earth reflectance and the radiance (viewing angle dependency with respect to the nadir viewing direction) shall be better than 0.25% (1σ).

The relative radiometric accuracy of Earth reflectance and the radiance (fast spectrally varying component: variations with periods between 0.1-3 nm) for wavelengths λ > 310nm shall be less than 0.01% peak-peak (target) or less than 0.05% peak-peak (threshold), for λ < 310nm it shall be less than 0.1%.

The relative radiometric accuracy of Earth reflectance and the radiance (slowly spectrally varying component: variations with periods between 10 and 100 nm) shall be less than 2% peak-peak.

No saturation shall occur for the radiance levels of the reference scenarios.

Radiometric Requirements for the irradiance measurements

S/N requirements for solar irradiance

Regular solar measurements (via diffuser) are needed for calibration of Earth reflectance and for spectral calibration using Fraunhofer lines.

The signal-to-noise for the irradiance measurements shall be better than specified in table 5.5.

Table 5.5. Irradiance signal-to-noise for LEO UV-VIS-NIR band, given per spectral sample

Wavelength range [nm]	**Required irradiance signal-to-noise**
270-310	1000 (at 270 nm) 3000 (at 310 nm)
310-400	3000
400-500	4500
590-640 or 610-680 or 710-750	2000
750-775	1500

The absolute radiometric accuracy of the irradiance shall be better than 1-2% (1σ). This includes all instrumental error sources, including eg. straylight, but excludes errors in radiometric standards.

The relative radiometric accuracy of Earth reflectance and the radiance (fast spectrally varying component: variations with periods between 0.1-3 nm) for wavelengths $\lambda > 310$nm shall be less than 0.01% peak-peak (target) or less than 0.05% peak-peak (threshold), for $\lambda < 310$nm it shall be less than 0.1%.

The relative radiometric accuracy of Earth reflectance and the radiance (slowly spectrally varying component: variations with periods between 10 and 100 nm) shall be less than 2% peak-peak.

No saturation shall occur for the solar irradiance measurements.

Polarization

The light reflected by the Earth and the atmosphere can be linearly polarized. Therefore it is important that the instrument is polarization insensitive.

The instrument polarization sensitivity shall be less than 0.5%.

5.2.2 SWIR

This section provides the specifications for a CO and CH_4 dedicated SWIR band at 2.3µm and additional options. With the specified instrument requirements the threshold observation requirements for CO and CH_4 total columns (25% for a 1 10^{18} molecules/cm^2 minimum total column for CO and 2 % for CH_4) are met for solar zenith angles ranging from 10 up to 70 degrees and surface albedo down to 0.05.

Simulations including the effect of aerosol scattering indicate that the uncertainty data requirements for CH_4 (uncertainty better than 2%) are not met under the following conditions:

- Low albedo (<0.05) in combination with high SZA (60-70 degrees), and high AOT (>0.5) soot, sulphate and marine particles
- High albedo (>0.3) and high AOT (>0.5) dust and marine particles (in particular for desert sites)

To meet the requirements under these conditions as well, either additional light path information should be available, or the properties of aerosols (type, optical depth, height distribution) should be known for the location and time at which the trace gas measurement are performed to allow a first order correction of the scattering effect. This information could possibly be provided by measurements in other wavelength ranges, as for example

a) the O_2 A-band; however, the light path characterisation at 0.76µm is not fully representative of that at 2.3µm;

b) a band in the 1.40-1.75µm range containing spectral information on CH_4 and CO_2. Light path characterisation for CH_4 would be obtained by “calibration” against CO_2: under the assumption that the aerosol effect (and surface albedo) is similar for both, the ratio of CH_4 to CO_2 columns will be retrieved. This ratio will then be multiplied by the best estimate actual CO_2 column to obtain the actual CH_4 column. This method is being applied to Sciamachy data;

c) a band in the 1.94-2.03µm range containing strong CO_2 lines which can be used to retrieve vertically resolved information on aerosol. This is a less mature option.

Option a) is part of this preliminary system concept. Options b) and c) are promising possibilities to improve the accuracy of the CH_4 total column; as by-products they would contribute information on aerosol (as a geophysical product) as well as on CO_2 (however not with the expectation to fulfil operational requirements). Taking into account the maturity of the options and the fact that one CH4 band is already included, option b) is required with priority B and option c) with priority C.

5.2.2.1 Geometrical requirements

Table 5.6: LEO SWIR geometrical requirements

Parameter	Nominal Value	Units
spatial resolution along/across track (at nadir)	5/5 to 20/20	km
Knowledge of geolocation	<10%	spatial resolution

The target requirement on the spatial resolution off-nadir is for the same that is realised by the nadir view; the threshold requirement is for the same solid angle as the nadir view.

The spatial resolution is defined here as the size of the spatial element containing 90% of the integrated energy of a point source.

The spatial sampling distance along/across track shall not be larger than the spatial resolution.

The co-registration of all spectral elements in the SWIR shall be better than 1% (goal) / 5% (threshold) of the spatial sampling distance.

The co-registration knowledge between

- the SWIR band and the O_2-A band
- the SWIR band and a possible TIR band for CO (2100-2200 cm^{-1})

shall be better than 1% (goal) / 10% (threshold) of the spatial sampling distance of the SWIR band.

5.2.2.2 Spectral requirements

Table 5.7: LEO SWIR spectral requirements

Parameter	Nominal Value	Units
Spectral requirements		
Wavelength ranges	1400-1750 (B) 1940-2030 (C) 2305-2385 (A)	nm
Spectral resolution	<0.25	nm
Spectral oversampling factor [1])	>2	-
Knowledge of wavelength calibration [2])	<0.002	nm

Stability of wavelength calibration [3])	<0.005	nm

[1]) A spectral oversampling factor of 6 is desirable but of lower priority than the S/N.

[2]) The requirement on knowledge of spectral calibration will be fulfilled by analysis of solar and Earth-shine spectra, relying on the specified spectral stability.

[3]) Timescale for the spectral stability requirement is the time between two solar measurements.

The shape of the instrument spectral response function (ISRF, end-to-end spectral response of the instrument) shall be known for all applicable wavelengths and viewing angles to an accuracy of 1% (1σ) for the spectral range where the ISRF is at least 1% of the maximum response at the centre wavelength.

Note that the requirement on possible broad wings of the slit function is partially included in the radiometric offset requirement below.

5.2.2.2 Radiometric requirements

Four scenarios are considered: a minimum and a maximum radiance case (dark and bright surface or cloud) for a tropical and a high-latitude situation. The bright case should be used to check for saturation, the dark for meeting the S/N requirement.

Table 5.8: LEO SWIR radiometric scenarios (sza = solar zenith angle)

Description	**sza**	**Surface albedo**	**Maximum radiance level** [10^{12} photons /(s SR cm^2 nm)]		
			1400-1750	**1940-2030**	**2305-2385**
Tropical Bright	10°	0.65	35	35	16.6
Tropical Dark	10°	0.05	1.0	1.0	1.2
High-latitude Bright	70°	0.65	8.5	8.5	5.8
High-latitude Dark	70°	0.05	0.5	0.5	0.4

Table 5.9 lists the required S/N of the Earth reflectance and radiance for a spectral bin size of 0.125 nm assuming a spectral oversampling factor of 2, at maximum radiance levels as given in Table 5.8. The table contains the S/N requirements both for the tropical (sza = 10) and for the high-latitude (sza=70) case. The S/N requirement is driven by the CO total column uncertainty requirement rather than by the CH_4 total column requirements

Table 5.9: LEO SWIR Earth reflectance and radiance S/N requirements for spectral bin size of 0.125 nm assuming a spectral oversampling factor of 2

Radiometric scenario	**S/N requirement**		
	1400-1750	**1940-2030**	**2305-2385**

Tropical (sza=10^o)	1000	1000	170
High-latitude (70^o)	100	100	90

S/N requirements for solar irradiance

Regular solar measurements (via diffuser) are needed for calibration of Earth reflectance and for spectral calibration using Fraunhofer lines. A signal-to-noise ratio of at least 1500 is needed at an irradiance of 30 / 15 / 8.5 x 10^{13} photons/(cm^2 s nm) for 1400-1750 / 1940-2030 / 2305-2385 nm.

Radiometric accuracy requirements

Table 5.10: LEO SWIR radiometric accuracy requirements

Parameter	Nominal Value	Units
Relative radiometric accuracy of the Earth reflectance, radiance and irradiance (slow varying component, variations with periods ~100 nm)	< 1.5 % peak-to-peak	
Relative radiometric accuracy of Earth reflectance, radiance and irradiance (fast spectrally varying component: variations with periods between 0.1-1 nm)	< 0.2 % peak-to-peak	
Absolute radiometric accuracy of Earth reflectance, radiance and irradiance	2 % (1σ)	
Offset correction accuracy (i.e. determination of the baseline (zero-level) for the radiance)	< 0.3 %	Of maximum radiance signal in spectral range

Dynamic Range

The dynamic range of the instrument should allow for the maximum radiance (110% of values in Table 5.8) and irradiance to be measured without detector saturation. For solar irradiance and calibration measurements (for example sun over diffuser calibration) the instrument should not be saturated by looking directly into the sun via an on-board diffuser.

Polarisation

In case the trace gas spectrometer channels can not be build polarisation insensitive, the instrument shall provide means to measure the polarisation state of the incoming light as a function of wavelength. In this case the polarisation of the incoming light has to be measured parallel and perpendicular to optical plane of the spectrometer (parallel and perpendicular to the spectrometer slit).

5.2.3 TIR

5.2.3.1 Geometrical requirements

Table 5.11: LEO TIR geometrical requirements

Parameter	**Nominal Value**	**Units**
spatial resolution (at nadir, 90% integrated energy, along/across track)	5x5 – 12x12	km^2
Knowledge of geolocation	<10%	spatial resolution

The instrument spatial response function shall be flat within a diameter of 80% of the spatial resolution, to within 5% peak-to-peak.

The spatial response function needs to be characterised within a diameter of 200% of the spatial resolution.

Horizontal sampling distance : one measurement is required in each 50x50 km^2 field within the swath.

The target requirement on the spatial sampling distance off-nadir is for the same that is realised by the nadir view; the threshold requirement is for the same solid angle as the nadir view.

5.2.3.2 Spectral requirements

Spectral bands and resolutions are required as per Table 5.12. Further study on band 3 is needed to decide on its value for CH_4 (with respect to SWIR band) and its potential to substitute band 1 for HNO_3.

Table 5.12: LEO TIR spectral requirements

Spectral band	**Spectral range [cm^{-1}]**	**Spectral resolution [1]) [cm^{-1}]**	**target species**	**priority**
1	800 – 850	0.17 – 083	C_2H_6	3
2	860 – 900	0.125 – 0.25	HNO_3	2
3	1030 – 1080	0.125 – 0.25	O_3	1
4	1120 – 1160	0.17 – 083	volcanic SO_2	alternative to band 5 [2])
5	1280 – 1360	0.17 – 0.5	CH_4 (, HNO_3, volcanic SO_2)	2
6	2140 – 2180	0.125 – 0.25	CO	1
7	2700 – 2760	0.17 – 083	CH_4 column	1st choice alternative to band 5 [2])
8	2760 – 2900	0.17 – 083	CH_4 column	2nd choice alternative to band 5 [2])

[1]) Full Width at Half Maximum (FWHM) of the Instrument Spectral Response Function (ISRF); in case of a Fourier Transform Spectrometer, this is to be understood as apodised spectral resolution ($1/OPD_{max}$).

[2]) Band 4 is an alternative to the SO_2 measurements in band 5, bands 7 (first choice) and 8 (second choice) are alternatives to the CH_4 measurements in band 5.

A spectral oversampling factor of 2 is required.

The knowledge of the instrument spectral response function (ISRF) shall be such that for any spectral sample/channel the associated radiometric uncertainty will below 0.05 K (goal) / 0.1 K (threshold) (NEDT at 280 K) for a spatially homogeneous scene.

The absolute accuracy of the spectral calibration is required to be $\Delta\nu/\nu < 1\times10^{-6}$ (1σ).

5.2.3.4 Radiometric requirements

The noise-equivalent temperature difference shall be less than the values specified in Table 5.13 for a blackbody temperature of 280K.

Table 5.13: LEO TIR NeΔT requirements

Spectral band	Spectral range [cm^{-1}]	NeΔT [K] @ 280K
1	800 – 850	0.05 – 0.1
2	860 – 900	0.05 – 0.1
3	1030 – 1080	0.05 – 0.1
4	1120 – 1160	0.05 – 0.1
5	1280 – 1360	0.05 – 0.2
6	2140 – 2180	0.05 – 0.15
7	2700 – 2760	0.1 – 0.3
8	2760 – 2900	0.1 – 0.3

Absolute radiometric accuracy shall be less than 0.5K at 280K surface temperature.

Radiometric stability shall be better than 0.05 – 0.1K over one orbit at 280K surface temperature.

Relative ratiometric accuracy – spectral: RMS differences between brightness temperatures of different spectral samples/channels of the same spatial sample shall be < 0.1 K for a scene temperature of 280 K.

Relative radiometric accuracy – spatial: RMS differences between brightness temperatures of different spatial samples of the same spectral sample/channel shall be < 0.1 K for a 280 K target temperature.

Requirements shall be met over a dynamic range covering surface / cloud top temperatures from 180 to 330 K. Relaxation of this requirement may be possible at the lower end which is driven by cloud top temperatures.

5.2.4 Cloud imager

The TIR instrument shall be supported by a cloud imager. The cloud images shall be used to direct the TIR instrument to a cloud-free pixel (or the most homogeneous pixel when no cloud-free pixel exists) within the 50x50 km^2 field.

The cloud imager shall cover the same swath as the TIR spectrometer.

The spatial sampling distance of the cloud imager shall be less than 1km (at nadir), the MTF at Nyquist frequency > 0.2.

Spatial co-registration knowledge between the TIR instrument and the cloud imager shall be 10% of the TIR spatial resolution in both directions. Temporal synchronisation shall be < 10s.

Spectral channels and NeΔT values (at 280K) are specified in Table 5.14.

Table 5.14: LEO cloud imager spectral and radiometric requirements

	λ_{center}	$\Delta\lambda$	NEDT	absolute radiometric accuracy	priority
	µm	µm	K		
NIR	1.2	0.1	0.1	1.5%	B
MWIR	3.7	0.2	0.05	0.18K	A
TIR	10.8	0.5	0.05	0.33K	A

5.3 Specification for GEO mission

5.3.1 General geometric requirements

The FOV should at least cover Europe in E-W direction from 30°W - 45°E (@40°N) and in N-S direction from 30°N - 65°N.

The geolocation of the individual pixels must be known with a precision of 10 % of the spatial resolution.

The co-registration knowledge between spectral bands / instruments shall be better than 5% of the spatial resolution (the coarser resolution if they are different).

5.3.2 UV-VIS-NIR

5.3.2.1 Temporal requirements

The instrument shall cover the FOV within 0.5 - 1 hour.

5.3.2.2 Spatial requirements

In addition to the coverage requirement under 5.3.1, coverage of the Sahara is required as a reflectance calibration target for the solar backscatter instrument. The expected frequency of this vicarious calibration is weekly to monthly.

The spatial sampling distance (at sub-satellite point) shall not be larger than 5 x 5 km^2 (in the spectral range sensitive to stratospheric ozone, ie. 290-310nm, this may be relaxed to 50 x 50 km^2 if needed to achieve the SNR). It is assumed to increase off-nadir with constant solid angle.

The spatial element containing 70% (90%) of the integrated energy of a point source, shall be smaller than 100% (150%) of the spatial sampling distance in each direction.

The co-registration knowledge between the same spatial pixels in the different spectral groups (channels) should be 10% of a spatial pixel.

Within any spectral group (channel), every pixel in the spectral direction shall observe the same ground scene. The image distortion shall not be more than 10% of a ground pixel.

5.3.2.3 Spectral Requirements

Spectral Coverage

The instrument shall measure the TOA radiance and the solar irradiance over the spectral ranges given in the 5.15.

Table 5.15: GEO short-wave spectral coverage requirements. W.r.t. priorities please refer to the explanations below.

	Wavelength Range		Relevant Atmospheric Species	Products	Priority
	Min [nm]	Max [nm]			
	290	310	O_3	Stratospheric O_3 Column	A
	310	400	O_3, SO_2, H_2CO, NO_2, BrO, Fraunhofer Lines, aerosol, surface	Total and trop. O_3, SO_2, HCHO, O_4, AAI, SSA, AOT(UV), surface albedo, CTH (Ring)	A
	400	500	NO_2, O_4, aerosol, surface	NO_2, O_3, CTH, AOT(Vis) , surface albedo	A
	755	775	O_2 A-band, surface	ALH, CTH, COT, AOT(NIR), surface albedo	A/B

Remarks:

- The lowest UV window 290 – 300 nm is specified to derive the stratospheric O_3 from geostationary measurements. To derive tropospheric O_3 from the combination of the Hartley and Huggins band was successfully demonstrated by /Mun1998/ and /Liu2005/.
- Concomitant H_2O data are assumed to be available from the infrared sounder on MTG.
- Main purpose of the O_2 A channel (755 – 775 nm) with its high spectral resolution is to estimate a mean aerosol layer height, as investigated by /Roz1994/, /Tim1994/, /Tim1995/, /Koo1997/, etc.. The aerosol layer height (ALH) is important to quantitatively determine tropospheric trace gas concentrations under polluted conditions. As aerosol from pollution is mostly concentrated within the PBL /Ans2002/, /Wan2002/, the aerosol effect on nadir

observations is from that height region. As an alternative to the estimate of the ALH from O_2 A-band absorption measurements, it might therefore be an option to use the PBL height from meteorological analysis as an aerosol layer estimate. PBL height can be estimated for example from analysing meteorological fields w.r.t. a temperature inversion. The O_2-A band channel with high spectral resolution is therefore priority B. Cloud top height and optical thickness can be determined alternatively from low spectral resolution (approx. 0.5 nm) O_2 A-band measurements. An O_2-A channel with spectral resolution of approx. 0.5 nm is therefore ranked as "A". With OMI on EOS-AURA techniques will be studied to determine cloud top height from O_4-absorption and/or Raman scattering /Bee2001/. The quality of the results of this techniques is currently under evaluation. In case they deliver results of similar quality as from O_2-A band spectroscopy, the O_2-A band moderate resolution channel might also become priority "B".

- The CO band in the SWIR has been dropped, taking into account results of technical studies done in preparation of Eumetsat MTG.

Spectral Resolution

The instrument spectral resolution shall be less than or equal to the values presented in Table 5.16.

Table 5.16: GEO short-wave spectral resolution requirements

Wavelength Range		Spectral Resolution
Min [nm]	**Max [nm]**	**FWHM [nm]**
290	310	< 1
310	400	< 0.5
400	500	< 0.5
755	775	< 0.5 A < 0.06 B

Spectral Sampling

The spectral sampling distance shall be no more than 1/3 of the spectral resolution.

Spectral Stability

The instrument shall be stable within 1/20 of a spectral pixel (dispersion direction) between an Earth radiance and a solar irradiance measurement.

The instrument spectral knowledge should be known to 1/50 spectral pixel using adequate on-ground and in-flight spectral calibration techniques (analysis of solar Fraunhofer lines and atmospheric absorption features).

Spectral response function

The shape of the instrument spectral response function (ISRF, end-to-end spectral response of the instrument) shall be known for all applicable wavelengths and viewing angles to an accuracy of 1% (1σ) for the spectral range where the ISRF is at least 1% of the maximum response at the centre wavelength.

5.3.2.4 Radiometric Requirements

Radiometric Resolution (SNR) for Earth Reflectance

The radiometric resolution is specified in term of signal-to-noise (SNR) associated to a reference radiance (see Table 5.17) at which the SNR is computed.

The Earth's reflectance shall be measured with a signal-to-noise larger than or equal to the values given in Table 5.17 for the specified reference radiance. Between the spectral points specified, the values needs to be interpolated.

Table 5.17: GEO short-wave SNR requirements (per spectral resolution element)

Wavelength [nm]	Minimum Radiance	Reference Radiance	Maximum Radiance	Signal-to-Noise
	[photons/(cm^2 s sr nm]	[photons/(cm^2 s sr nm]	[photons/(cm^2 s sr nm]	
290	5 E+10	6 E+10	7 E+10	100
300	1 E+11	1.1 E+11	1.7 E+11	300
305	3.3 E+11	3.5 E+11	2.0 E+12	500
312	1.9 E+12	2.0 E+12	1.0 E+13	1000
320	6.8 E+12	7.3 E+12	2.3 E+13	1500
350	1.4 E+13	1.9 E+13	5 E+13	1800
450	1.8 E +13	3.8 E +13	1.5 E+14	2500
550	1 E+13	3.1 E+13	1.5 E+14	2500
775	4.5 E +12	2.6 E +13	1.5 E+14	2000

The reference radiance is calculated with MODTRAN (s/c at geostationary distance, observed region at 55°N, fall equinox, 12 LT, 1976 US standard atmosphere, UV-Vis: albedo 0.3, SWIR: albedo 0.1, tropospheric/background stratospheric aerosol, no cloud, no preciptation). The maximum and minimum radiance are also calculated with MODTRAN (same conditions but for maximum observed region at 0°N and albedo 1.0 and for minimum ground point at lat. 55°N, long 0° with ground albedo 0.01).

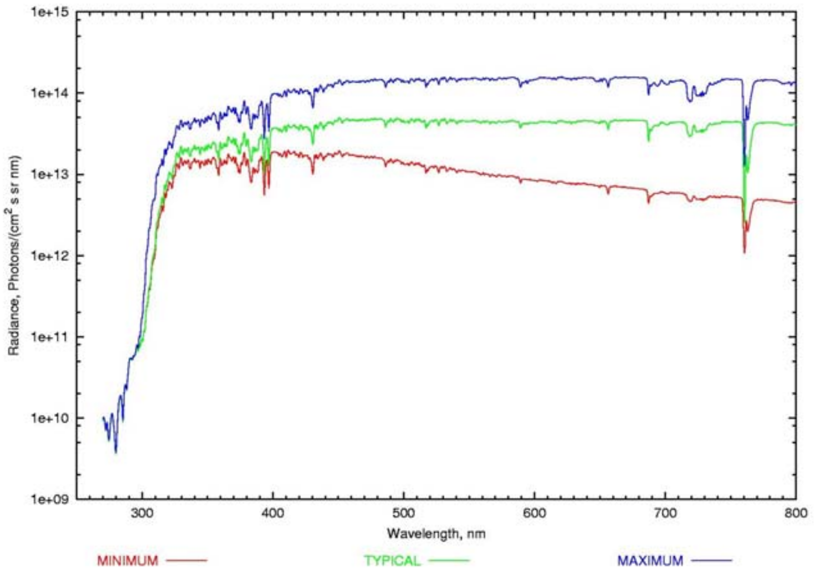


Fig. 5.1 UV-VIS nadir radiance reference spectra. Maximum, reference and minimum reference radiance.

Radiometric Resolution (SNR) for the solar irradiance measurements

The solar irradiance shall be measured with a signal-to-noise larger than or equal to the values given in Table 5.18 for the specified reference irradiance. Between the spectral points specified, the values need to be interpolated.

Table 5.18: GEO solar irradiance SNR Requirements (per spectral resolution element). A 10% margin to avoid saturation is already included.

Wavelength [nm]	Reference = Maximum Irradiance	Signal-to-Noise
	[photons/(cm^2 s nm]	
290	1 E+14	1000
300	7 E+13	1500
305	1.2 E+14	2500
312	1.1 E+14	3000
320	1.4 E+14	3000
350	2.1 E+14	3500
450	5.1 E+14	4000
550	5.6 E+14	4000
770	5.2 E+14	4000

Dynamic Range

The dynamic range of the instrument should allow for the maximum radiance as defined in Table 5.17 (high albedo, overhead sun, SSP …) and irradiance as in Table 5.18 to be measured without detector saturation. For solar irradiance and calibration measurements (for example sun over diffuser calibration) the instrument should not be saturated by looking directly into the sun via an on-board diffuser.

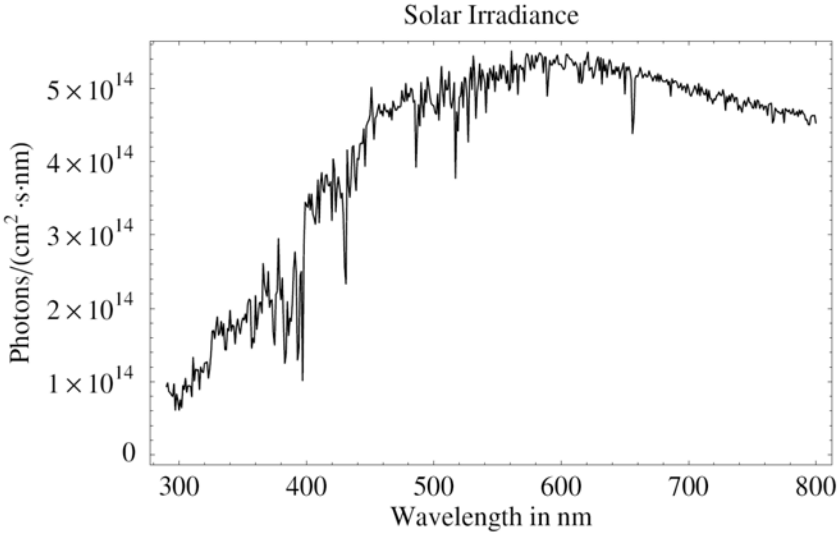


Fig. 5.2 Solar Irradiance spectrum.

Radiometric Accuracy

The absolute radiometric accuracy of Earth reflectance is required to be < 2-3 %. This includes all instrumental error sources, including eg. straylight, but excludes errors in radiometric standards.

The relative radiometric accuracy of the Earth reflectance (viewing angle dependency) shall be better than 0.25% (1σ).

The relative radiometric accuracy of Earth reflectance (fast spectrally varying component: variations with periods between 0.1-3 nm) for wavelengths $\lambda > 310$nm shall be less than 0.01% peak-peak (target) or less than 0.05% peak-peak (threshold), for $\lambda < 310$nm it shall be less than 0.1%.

Calibration Requirements

- In case the trace gas spectrometer channels can not be build polarisation insensitive, the instrument shall provide means to measure the polarisation state of the incoming light as a function of wavelength. In this case the polarisation of the incoming light has to be measured parallel and perpendicular to optical plane of the spectrometer (parallel and perpendicular to the spectrometer slit).
- Long term drifts in the radiometric calibration (after in-orbit radiometric calibration) should not exceed TBD.

5.3.3 TIR

5.3.3.1 Temporal requirements

The instrument shall cover the FOV within 0.5 - 2 hours.

In case of a Fourier Transform Spectrometer, the duration of an interferogram shall be shorter than the typical time scale of change in the observed scene, eg. by cloud. This can be assumed to be of the order of 1 minute.

5.3.3.2 Geometrical requirements

Table 5.19: GEO TIR geometrical requirements

Parameter	Nominal Value	Units
spatial resolution (at sub-satellite point, 70% integrated energy)	5x5 – 15x15	km^2
Knowledge of geolocation	<10%	spatial resolution

90% of the integrated energy of a pixel shall be contained within an area smaller than 150% of the spatial resolution in both directions.

The horizontal sampling distance shall be the same as the spatial resolution (contiguous sampling).

Horizontal sampling distance and spatial resolution are assumed to vary with latitude and longitude with constant solid angle of the observation.

The pointing stability during the sampling time for the complete FOV shall be better than 10% of the spatial resolution.

5.3.3.3 Spectral Requirements

Spectral bands and resolutions are required as per Table 5.20.

Table 5.20: GEO TIR spectral requirements

Spectral band	Spectral range [cm^{-1}]	Spectral resolution [1] [cm^{-1}]	target species	priority
1	860 – 900	0.25 – 0.5	HNO_3	2
2	1030 – 1080	0.25 – 0.5	O_3	1
3	2140 – 2180	0.25 – 0.5	CO	1

[1] Full Width at Half Maximum (FWHM) of the Instrument Spectral Response Function (ISRF); in case of a Fourier Transform Spectrometer, this is to be understood as apodised spectral resolution ($1/OPD_{max}$).

A spectral oversampling factor of 2 is required.

The knowledge of the instrument spectral response function (ISRF) shall be such that for any spectral sample/channel the associated radiometric uncertainty will below 0.05 K (goal) / 0.1 K (threshold) (NEDT at 280 K) for a spatially homogeneous scene.

The absolute accuracy of the spectral calibration is required to be $\Delta\nu/\nu < 1\times10^{-6}$ (1σ).

5.3.3.4 Radiometric requirements

The noise-equivalent temperature difference shall be less than the values specified in Table 5.21 for a blackbody temperature of 280K.

Table 5.21: GEO TIR NeΔT requirements

Spectral band	Spectral range [cm^{-1}]	NeΔT [K] @ 280K
1	860 – 900	0.05 – 0.1
2	1030 – 1080	0.05 – 0.1
3	2140 – 2180	0.05 – 0.15

Absolute radiometric accuracy shall be less than 0.5K at 280K brightness temperature.

The absolute radiometric accuracy of the radiances shall be better than or equal to 0.5 K (1σ).

Radiometric stability shall be <0.1K (1σ) within 24 hours.

Requirements shall be met over a dynamic range covering surface / cloud top temperatures from 180 to 330 K. Relaxation of this requirement may be possible at the lower end which is driven by cloud top temperatures.

6. Data Usage

Application areas have been discussed in chapters 3 and 4. It should be noted that near real time delivery of data is required for all three environmental issues, supporting

- UV dose and UV index forecast: near real time data delivery for this application implies that the data needs to be available to an operational modelling environment within a couple of hours after observation. In that case a significant part of today's observations can still be used for the analysis on which the required forecast for tomorrow (etc.) will be based.
- weather forecast and climate monitoring: The main users for near-real time data within the climate theme are the NWP centres. These centres need near-real-time information on numerous aspects of the land-atmosphere-ocean-cryosphere system that all contribute to the analysis of the atmosphere and therefore to the initial state on which the weather prediction is based, and on which climate monitoring relies. Atmospheric composition is one of the key elements for the monitoring of the climate system.
- air quality forecast: An important requirement for health and safety is further near-real time source detection and attribution of the emissions of aerosols and aerosol and ozone precursors (NO_2, SO_2, and CO). Additional information on methane (CH_4), water vapour (H_2O), formaldehyde (CH_2O) as well as the UV-VIS photolysis rates is important for the forecasting of the photochemical activity. These observations are needed to constrain the chemical conversion rates and help to determine the atmospheric residence time of pollutants. Finally, near real time data delivery for this application implies that the data needs to be available to an operational modelling environment within a couple of hours after observation. In that case a significant part of today's observations can still be used for the analysis on which the required forecast for tomorrow (etc.) will be based. It should be noted that current practice of data time handling at ECMWF is not favourable for Air Quality forecasts. Data are collected twice a day (till 3 am and 3 pm) to provide forecasts in the morning and evening. For Air Quality forecasts it would likely make sense to include also the late afternoon observations of today in the Air Quality forecast for tomorrow, which should be available to operational agencies in the very early morning of the day to come.

Exact delivery time requirements have not been established yet, however a typical value is 3 hours after sensing.

7. Synergies and International Context

Current plans for other atmospheric composition measurements from space during the timeframe foreseen for GMES Sentinels 4 and 5 are limited to those from the Eumetsat METOP and the US NPOESS platforms. These will provide UV-vis data serving stratospheric applications, however with far too large pixel sizes to be useful for tropospheric uses. They will also provide thermal IR data which could be used in synergistic way, or possibly even replacing some of the required observations. This depends on the temporal and spatial separation of the measurements and the yet to be determined capabilities of assimilation / modelling systems to transport the measurement information in time and space).

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List of Tables

List of Figures

List Acronyms and Abbreviations

ACE	Atmospheric Chemistry Explorer
ACECHEM	Atmospheric Composition Explorer for chemistry and climate interaction
ADM	Atmospheric Dynamics Mission
ALH	aerosol layer height
AOD, AOT	Aerosol Optical Depth
AQ	air qualilty
BL	boundary layer
CAFE	Clean Air For Europe
CAPACITY	Composition of the Atmosphere: Progress to Applications in the user Community
CFC	chloro-fluoro-carbon
CLRTAP	Convention on the Long Range Transboundary Air Pollution
CRIS	Cross-track Infrared Sounder
EAP	Environmental Action Programme
EC	European Commission
ECE	Economic Commission for Europe
ECMWF	European Centre for Medium-range Weather Forecast
EEA	European Environmental Agency
EMEP	Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air pollutants in Europe
EOS	Earth Observing System
EPS	European Polar System
ERS	European Remote Sensing Satellite
FOV	field of view
FT	free troposphere
FTIR	Fourier-Transform Infrared
FTS	Fourier-Transform Spectrometer
FWHM	full width at half maximum
GATO	Global Atmospheric Observations
GEMS	Global Environment Monitoring System
GEO	geostationary
GHG	greenhouse gas
GMES	Global Monitoring for Environment and Security
GOES	Geostationary Operational Environmental Satellite
GOME	Global Ozone Monitoring Experiment
GPS	Global Positioning System
HCFC	halogenated chloro-fluoro-carbon
IASI	Infrared Atmospheric Sounding Interferometer
IFOV	instantaneous field of view
IGACO	Integrated Global Atmospheric Chemistry Observations
IGOS	Integrated Global Observing Strategy
ILS	instrument line shape
IMG	Interferometric Greenhouse
IPCC	Intergovernmental Panel on Climate Change
IRS	Infrared Sounder

ITCZ	Intertropical Convergence Zone
LEO	low Earth orbit
LIDAR	light detection and ranging
LS	lower stratosphere
METOP	Meteorological Operational Satellite
MODTRAN	Moderate Resolution Transmission Code
MOPD	maximum optical path difference
MSG	Meteosat second generation
MTG	Meteosat third generation
NIR	near infrared
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operation Environmental Satellite System
NWP	numerical weather prediction
ODS	ozone depleting substance
OMI	Ozone Monitoring Instrument
OMPS	Ozone Monitoring and Profiling Suite
PAH	polycyclic aromatic hydrocarbon
PAN	peroxy-acetyl-nitrate
PBL	planetary boundary layer
PM	particulate matter
PMS	polarisation measurement system
POP	persistent organic pollutant
PROMOTE	Protocol Monitoring for the GMES Service Element: Atmosphere
PSC	polar stratospheric cloud
S/N, SNR	signal to noise ratio
SSP	sub-satellite point
SWIR	short-wave infrared
SZA	solar zenith angle
TIR	thermal infrared
TOA	top of atmosphere
TTL	tropical tropopause layer
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	upper stratosphere
UT	upper troposphere
UTLS	upper troposphere / lower stratosphere
UV	ultraviolett
VIS	visible
VOC	volatile organic compound
WMO	World Meteorological Organisation