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Atmosphere monitoring service -Scope and product portfolio

The scope of the GMES Atmosphere monitoring service is described.

It is the output of an independent panel of experts (Implementation Group). This Implementation Group has been established following a GMES User Workshop in 2006. It looked into the GMES activities and met nine times between June 2007 and December 2009. The Implementation Group analyzed in its final report the following issues: (1) service scope, (2) service architecture & functionality, (3) requirements for in situ and for (4) space observation infrastructure. This paper mostly concentrates on the service scope issue.

The purpose of this paper is to provide the basis for starting an operational GMES atmosphere service in 2014 and the subsequent service evolution.

This document is presented as a basis for discussions at the preparatory workshop on 27. October.

1. Introduction

1.1 The purpose of GMES Atmospheric Services (GAS)

Anthropogenic climate change is recognized as a major issue as the third millennium begins. The atmosphere, which acts as a reservoir for greenhouse gases and aerosols, as well as its interfacial fluxes, is the critical element of this issue.

For many other environmental issues, the atmosphere plays essential and diverse roles. Atmospheric mechanisms, which provide protection from UV rays or cause dispersion and conversion of pollutants deeply affect human health and the environment. The life of EU citizens is still on average shortened by 8 months due to the effects of air pollution and almost half the ecosystems within the European Union remain exposed to excessive eutrophication. European environment policies on air thus face significant challenges. As measures to address the impacts become increasingly complex and costly and sometimes requiring difficult tradeoffs, the best possible information on the status of the atmosphere is needed to ensure an effective policy cycle.

Atmospheric services already exist. The network of national weather services coordinated by WMO is achieving considerable and steadily growing success in monitoring and forecasting the dynamical and physical (in short: meteorological) properties of the atmosphere.

It is however through the chemosphere (i.e. the atmosphere with emphasis on its chemical components) that humankind demonstrates capacity, for better or (more often) for worse, to modify atmospheric properties and ultimately the climate. Here too atmospheric services already exist. International bodies like UN ECE-EMEP, WMO and the European Environment Agency coordinate, to some extent, the international monitoring and modelling of greenhouse gases, the ozone layer and air quality; these activities are further organised on a national scale. Following the implementation of the EU legislation on air pollution, air quality monitoring networks have been set up; emission inventories are developed and reported; modelling tools are playing a growing role. Still, the picture is far from complete: there are considerable needs and also potential for improving capacities and consistency.

Within GMES, GAS aims to integrate the monitoring and modelling of the physical and chemical state of the atmosphere on global and European scales.

1.2 Building GAS

The success of weather forecasting is due to the fact that the time behaviour of the meteorological atmosphere obeys a set of coupled time-dependent differential equations. In other words, the dynamics of the atmosphere are well represented by a model that can be implemented in numerical simulations, with such a growing efficiency that the term "model" has now come to refer to the numerical algorithm itself.

Currently, atmospheric chemistry and meteorology are mostly dealt with separately: dynamical analyses and forecasts (assumed not to depend upon chemical processes) provide the input dynamics to chemical modelling. However, the real atmosphere is a fully interacting medium, which will be best represented and forecast through **integration** of chemical and physical phenomena.

Through advances in science and computing power, this integrated dynamical approach is rapidly becoming feasible. The approach is dependant on the availability of satellite observations and ground based monitoring data on continental and global scale.

The principal tools of GAS are expected to be dynamic modelling, state-of-the-art atmospheric chemistry modules and data assimilation. Inverse modelling will also be used

extensively to infer emissions and depositions from the surface beneath the atmosphere (i.e. the atmosphere lower boundary condition) using measured concentrations.

The meteorological community has succeeded in gathering a strong research community, and setting up a number of centres endowed with considerable competence in numerical modelling. GMES, in its development of GAS, aims to combine these capacities with those developed in the field of emissions and air quality monitoring, modelling and projections, human health and ecosystems effects assessments and abatement response. Similarly, the experience gained by meteorological services and other capacities, for example for organizing operational observation from space, and setting up information/communication systems, should be fully exploited to achieve the objective to create an operational, sustainable atmospheric service at EU level.

In recent years, a series of focused research and development initiatives to improve modelling of the ozone layer, air quality and climate forcing have been undertaken. MACC, a pilot project for the core of GAS, will begin middle 2009. By that time, some key elements of the core service should be ready to run in preoperational mode. This provides a perspective to evolve smoothly and quickly toward the operational phase.

1.3 More benefits to more users

What are the benefits of such an integrated Atmosphere Service? Not only the overall picture of what happens in the atmosphere will be more detailed and more accurate, but also it will be clearer why things happen.

The largest advantages will occur in fields where both meteorological and environmental worlds meet. There will be improved understanding of climate and climate change. Complicated problems, such as the interaction between climate change and ozone layer depletion or air quality, will become easier to address. The GAS will provide more detailed information on trends in atmospheric concentrations, variations in sources and sinks of gases and aerosols, as well as underlying chemical processes. In addition, GAS will support improvement of weather forecasts.

Whereas meteorological surface fluxes of momentum and energy are dependent, predictable parts of the whole system, this is not the case for chemical components, as these fluxes also strongly depend on anthropogenic activity and policy choices. Through scenario studies, univocal forecasts will be expanded, when accounting for the chemosphere, into a series of forecast scenarios depending upon man-made decisions.

GAS is expected to serve a broad community of users. The core service, developed and maintained at the Community level and serving principal users in support of European environmental policies, is complemented by downstream services. The latter exploit the outputs of the core, facilitate further work at more local level, or serve more specific users and uses such as the efforts of the health community and local administration to reduce public exposure to the air pollution. Such a service chain concept provides a solution for integrating users and their needs in a flexible and efficient way.

Achieving a successful implementation of this scheme will be a major challenge for GAS.

2. The scope of GAS Core Services (GACS)

2.1 Political environment

The GMES atmosphere service orientation paper and December 2006 user workshop conclusion document provide a good overview of relevant European level directives and regulations, as well as commitments of the European Union at the international level. The most relevant legal documents or policy initiatives are:

- 6th Environmental Action Programme (EC, DG ENV) setting out European environmental policy objectives for 2002-2012; mid-term review published recently <u>ec.europa.eu:8082/environment/newprg/index.htm</u>
- Shared Environmental Information system (SEIS) COM2008 (46) final: <u>http://ec.europa.eu/environment/seis/index.htm</u>
- INSPIRE Directive: <u>http://www.ec-gis.org/inspire/</u>
- Air quality legislation
 - § Clean Air for Europe programme (CAFE), in particular the Thematic Strategy on air Pollution ec.europa.eu/environment/air/index.htm
 - § The new Directive on ambient air quality and cleaner air for Europe including provisions for harmonised monitoring requirements for MS as well as informing the public and regulating fine particles $PM_{2.5}$ levels for the first time

http://register.consilium.europa.eu/pdf/en/07/st03/st03696.en07.pdf

- § Convention on long-range transboundary air pollution (CLRTAP) www.unece.org/env/lrtap/
- Climate changes policies
 - § UNFCC and Kyoto Protocol: <u>Unfcc.int/kyoto_protocol/2830.php</u>
 - § European Climate Change Programme (ECCP): ec.europa.eu:8082/environment/climat/eccpii.htm
 - § Green Paper on Adaptation to CC, White Paper to follow in fall 2008: ec.europa.eu:8082/environment/climat/adaptation/index.htm
 - § EC communication "Limiting Global Climate Change to 2° Celsius: The way ahead for 2020 and beyond." and related documents on EU climate policy <u>ec.europa.eu:8082/environment/climat/future_action.htm</u>
- Stratospheric Ozone
 - § Vienna Convention and Montreal Protocol: <u>ozone.unep.org</u>
 - § EU policy on ozone:

ec.europa.eu:8082/environment/ozone/community action.htm

- Solar Radiation
 - § Several EU policy initiatives in the filed of CCE (Climate Change Energy) including the promotion of renewable energies, increased energy efficiency and increased use of environmental technologies, e.g. Commission communication "20 20 by 2020 Europe's Climate Change Opportunity":

ec.europa.eu/energy/climate_actions/index_en.htm;

§ including a proposal for a directive on the promotion of the use of energy from renewable sources (23.1.2008):

ec.europa.eu/energy/climate_actions/doc/2008_res_directive_en.pdf

\$ and existing <u>Directive 2001/77/EC</u> on the promotion of the electricity produced from renewable energy source in the internal electricity market; Green paper: <u>A</u>

European Strategy for Sustainable, Competitive and Secure Energy; [http://ec.europa.eu/energy/green-paper-energy/index en.htm] Renewable energy road map [http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=

CELEX:52006DC0848:EN:NOT]

In addition, background documents have been produced in the above international context, which outline the challenges ahead and the current shortcomings to meet them with regard to atmospheric composition, and which GMES should help to address:

- The GCOS 2nd adequacy report, GCOS implementation plan and satellite supplement address inter alia the observational needs regarding a better understanding of the climate system <u>www.wmo.int/pages/prog/gcos/index.php?name=obervationneeds</u>
- The IPCC 4th Assessment report summarizes the current understanding regarding climate change: <u>www.ipcc.ch</u>
- The IGACO-Report establishes inter alia the requirements for observations of atmospheric composition at international level:
 www.wmo.int/pages/prog/arep/gaw/documents/gaw159.pdf

www.wmo.mt/pages/prog/arep/gaw/documents/gaw1

2.2 User communities

Users of GMES Atmosphere Services include the following:

- European institutions and agencies (European Commission: DG ENV, JRC, EEA,..)
- International bodies in support of conventions (e.g. CLRTAP/EMEP; IPCC; WMO; UNEP,..)
- National and regional authorities and environmental agencies, networks (EIONET, IMPEL...)
- National meteorological services
- Specific communities: modelling, research/science, EU research projects
- EU citizens
- Health services
- NGOs
- Other GMES services
- Private sector including industrial federations
- Less developed countries.

These users expect different types of products; generally it may be distinguished between users that need predominantly (a) **high-volume data/data products** based on monitoring or resulting from modelling, in contrast to those that rather need (b) **low-volume, but highly elaborated products**. Typical examples for (a) are e.g. the research/science community and meteorological services, while (b) are e.g. policy makers.

2.3 Concept of Core Services (CS) & Downstream services (DS)

The GMES Atmosphere Services will be based on a Core Service (CS or GACS), which provides data and products either directly to (end)-users or to the providers (="intermediate users") of Downstream Services (DS).

The DS are **outside the scope of EC**, in terms of both governance and funding. In practical terms however, all services using or benefiting from the GACS implementation should be considered GMES Atmosphere services. Whether they should be included in the GACS itself depends on the "European added value" of the services:

- A. CS will generally seek to provide information at scales such as pan-European, or even global.
- B. Information products should be provided through the CS if they are better generated once than many times in parallel by more local providers, according to the "economies of scale" principle. This does not however exclude "ensemble" products where synergy of products from multiple providers is used to improve the robustness or accuracy of the product.

Hence, the mission of the GACS will be to produce in real-time operational, generic, multipurpose data to monitor the composition of the atmosphere at global and European scale. The data will be composed of analyses of the state of the atmosphere for the current day, forecasts to a few days ahead, and homogeneous reanalyses of past periods. The Core Service will rely on GMES funding and provide direct support to European policies and information on global issues.

The GACS will also deliver these data services that are indispensable inputs for the DS. The DS, in turn, will seek to create targeted services tailored to meet specific user requirements. These specific products may extend to sectors far beyond air policy, such as health or transport. Expectations are that most DS will primarily support needs at national, regional and local level, generally through downscaling and assimilation of more specific/local information. Dependency on a common GACS should facilitate development, increase consistency, comparability and subsequent improvement of such DS.

Key characteristics of DS are hence their dependency on the GACS as well as the involvement of a decentralized network of service providers usually in close contact with specific users. This is of particular importance in the case of public information, where a "local face" for the information is required.

A typical example for the "division of labour" between CS and DS (in the field of Air Quality - AQ -) is the case of forecasting AQ levels to citizens: A number of regional/local DS provide citizens with relevant short-term forecasts on the quality of the air in their immediate environment, taking into account local specifics including microenvironment, culture and language. But these DS will depend on a GACS that will provide - as a result of larger-scale (regional/global) modelling - the necessary boundary conditions for the local models, improving the accuracy and reliability of the DS¹.

In the following, an indicative, non-exhaustive list of DS is presented:

<u>Air quality</u>

• Local air quality forecasts (urban scale).

¹ This concrete example already exists: e.g. (Downstream) services provided by AIRPARIF on AQ in "Ile de France" (Paris region) receive boundary conditions from FP6-project GEMS and their regional ENSEMBLE modelling component. <u>www.airparif.asso.fr/</u>

- Improved air-quality-related alerts and forecasts by health services supporting vulnerable communities (chronic obstructive pulmonary disease, respiratory diseases, asthma (including pollen-induced allergies);
- Supporting integrated air quality indices.
- Enhanced assessment of air quality within a specific region, supporting development of effective air pollution abatement measures through proper apportionment of sources and assessment of impacts (human exposure) etc.
- Improved air-quality-related alerts and forecasts for extreme events involving the combined effects of heat stress, high UV-B exposure and poor air quality;
- Analysis of national, regional and local air pollution abatement policies and measures through inverse modelling, validation/improvement of emission inventories and reconciling bottom-up and top-down emission inventories;
- Support to implementation of indicators related to following different aspects of policy effectiveness, as for example public exposure assessment, transboundary contributions (at a particular site/regions, rather than at large scale), footprint of cities, contribution from a transport mode etc.

Climate forcing

• Identification, assessment and monitoring of regional/local sources and sinks of Greenhouse Gases and pollutants and related tracers in support of emission and sink verification and mitigation policy.

Stratospheric ozone and solar radiation

• Solar-radiation potential analysis, policy scenario analysis, energy yield mapping, support to electricity transmission network management together with site audits and plant management for solar power plants.

2.4 Perimeter of GACS and envisaged products/information to be delivered

The objective for the GACS is to produce outputs for the relevant users with their differing requirements, as identified above. These outputs should provide added value with regard to existing information and should not duplicate operational and sustainable services already in existence.

2.4.1 CS themes

The four primary themes of the GACS are:

- 1. Climate forcing (CF);
- 2. Air quality (AQ);
- 3. Stratospheric ozone (and UV);
- 4. Solar radiation.

These themes are to be complemented with horizontal services across the themes such as NRT satellite data provision and so-called toolboxes. In addition, there are specific

recommendations on the initial CS, such as the need for re-analysis, brought forward in following subsections.

AQ and CF represent the major components of the GACS and should be considered first priority, due to their relevance to many different kinds and types of users, their estimated uptake by downstream users (especially AQ) and the high relevance to policy and research (especially CF).

A second priority for the service should be **Stratospheric ozone**; while much already exists today to satisfy the high relevance of these data to policy, long-term funding of observations is not secured. Finally, solar radiation has relevance to policy, but a stronger focus on downstream users in the private industry.

The support of renewable energies in the field of **wind** is not considered to be part of the scope, as this would encroach upon already existing and future services provided by the meteorological bodies. In addition, unlike solar energy, wind energy is generally not affected by atmospheric composition parameters.

2.4.2 Added value of GACS

In order to properly justify a GACS there is a need to produce added value on existing services and products.

• The CS should fill the user-identified gaps in the accessible information on atmospheric chemistry and provide the needed monitoring data to support policy needs.

- § To fulfil its role regarding the monitoring of atmospheric chemistry/composition, observational data (space & in situ) from the themes AQ, CF and stratospheric ozone are essential. For stratospheric O₃, current efforts of collecting relevant observations are quite substantial already (à IGACO report¹), but there is a risk of degradation of the existing infrastructure due to lack of sustainable funding. For AQ, current efforts of collecting relevant information are similarly plentiful already. However, there are some identified gaps in spatial coverage, and in particular in ensuring effective access in NRT to support several CS.
- § CS should maximize the added value through optimization of combined use and common access of remote sensing and in-situ observation monitoring, overcoming current shortcomings that limit applicability of either. The combination through data assimilation, at EU scale, is expected to bring core added value to CS, while ensuring effective access to in-situ and satellite observation, including near real time (NRT) data. This in turn will facilitate acceptance and further improvement of CS and foster development of optimized downstream services. Solar energy technologies are an important example of this vision.
- § The **provision of GCOS essential climate variables (ECVs)** should be regarded as a priority for the atmosphere service and thus a main driver for the **climate forcing** service theme to be provided. The current situation in Europe is as follows:
 - Surface ECVs: Many centres already do this and meet user requirements, e.g. gridded monthly, seasonal and annual averages. However, research users, in particular, would like to have better and increased access.
 - Upper-air ECVs: Temperature, wind and radiation budget are already available from other providers. Access and user specification may need improvement

¹ <u>www.wmo.int/pages/prog/arep/gaw/documents/gaw159.pdf</u>

• Composition ECVs: There is a clear user requirement to do more than currently exists, especially with regard to gridded information.

• For environmental policies, the **establishment of trends** based on long-term data is extremely relevant: For this purpose, high precision data with regard to space and time over long periods of time (several decades) is needed. Whilst a number of databases with observational data already exist, their specific objectives and/or limited access show significant potential for CS to add value. CS should ensure proper archiving and effective access to the core data/information as identified by users.

- Besides its monitoring capabilities, the GACS CS should also have **forecasting and predictive** as well as **analysis capabilities:**
 - § The added value and the value for money should be in providing new common services and products with at least EU-wide coverage that support a range of policies across several sectors including climate change mitigation and adaptation, air pollution abatement, health and biodiversity, aviation plus other transport modes, weather forecasting etc.
 - § In some cases, CS added value may be ensured by cost-effective, optimized analysis methodologies through ensemble modelling benefiting from access to single harmonized data input.
 - § CS added value may come also from the economies of scale this should be demonstrated in advance through a solid user base.

2.4.3 **Prioritization of product types**

As regards the priorities within the four themes, the following recommendations are made:

- Addressing gaps in the information on atmospheric chemistry/composition should be regarded as an initial priority. The joint, proficient use of satellite and in situ data should be put to good use to address this priority.
- In addition, the CS should also enable **forecasting**, allow **predictions and analysis**. Policy relevance, user relevance, added value on existing services and/or economies of scale justify the inclusion of such services within CS.

For the latter services, the main areas of interest are:

- 'Low volume' information: indicators, aggregate information, added value documents such as assessments or scientific reports;
- Services with a strong user uptake and providing economies of scale such as services in the area of health and transportation (aviation, ground), supporting DS such as alert services for relevant events in air pollution and UV exposure;
- Provision of AQ scenarios (at European scale) to evaluate impact of policies or beneficial strategies to reduce pollution, especially because the step from calculating assimilated global and European 3D fields to prognostic fields is not very large;
- Confirmation of anthropogenic emissions (based on inverse modelling and satellite data) in MS as well as at global level (rapidly evolving economies) as well as the identification of sinks;
- Clarification of the contribution of emission sources (e.g. agriculture emissions of methane, NOx and N2O and forests emissions of VOCs, GHG, fires/sand-dust storms); validation / improvement of emission inventories.

• Importance of transboundary transport, including the hemispheric scale

Some other remarks:

- The theme CF should have an initial focus on **gridded data** for atmospheric composition, in addition to relevant observational data such as that derived through the insitu measurement infrastructure. The GACS evolution process may include a move from providing GCOS atmospheric ECVs on composition towards a provision of all GCOS ECVs, with contributions from the marine and land CS.
- **Reanalysis**: A focus of going back further in time (up to 1930, 40 with CC data), achieving better resolution & coupling upper air with ocean/land state parameters, using a multi-model approach with improved (and 4D) modelling capacities now available in order to provide better information as compared to existing efforts such as ERA-40 is clearly useful to climate modelling, but also for air quality and related fields. There are obvious advantages to including reanalysis work within a GACS and providing such an exercise at regular intervals, rather than depending on research funding outside of the operational service¹.

2.4.4 Limits / borderline of CS

While the line can be drawn between the GACS and its DS with relative ease, it is more difficult to define the limits of GACS with regard to services already existing today.

Hence, there are some ambiguities on the borderline of the CS, e.g.:

- In case of an "**existing service**", it should not become part of the CS, as we are aiming to build added value; however, integration in a CS may be considered in some cases in the process of service development;
- Some specialised, targeted **products for a direct user** should also be within the scope of GACS, especially if providing EU added value (e.g. policy relevance)
- With regard to **access to observational data**: here it is key to avoid duplication (e.g. with meteorological bodies): if data is already available somewhere, then this should not be done by the GACS; however, if such data is relevant for some GACS products or other GMES-CS, then these data should be included in the scope. For solar energies: as support is considered to be within scope of GACS, then the needed data/observations should be part of the GACS. Identified DS depending on observational data including meteorological data and raw satellite data should be able to obtain such data; it would therefore be appropriate to issue a "GMES label" for such data to show that it is included within the GACS umbrella, enabling open access to identified DS providers for GMES-related use.

A few examples, which also take into account the identified priorities (section 0) follow below.

¹ Large-scale re-analysis for climate purposes may become part of the GACS Core Service. Alternatively, funding for such efforts needs to come from R&D framework programmes. (e.g. cooperation with FP6 projects **ENSEMBLES**, http://ensembles-eu.metoffice.com/index.html, and CECILIA, <u>http://www.cecilia-eu.org/</u>). In AQ, reanalysis may be even more important due to larger number of pollutants/measurement methods/siting criteria which provide further challenges in ensuring a coherent picture and establish reliable long-term trends.

2.4.4.1 Atmospheric composition

In-situ and satellite observations already play a key role in the context of providing data needed for EU and MS obligations under EU legislation and in UNFCCC, CLTRAP and the Montreal Protocol. CS are not meant to duplicate or take over the established exchange mechanisms, but to provide added value following the principles described above. It is however likely that some existing data-flows will subsequently be modified to take advantage of GACS¹.

Satellite data

While GACS should not be considered as an alternate satellite data provider, there is scope within GACS for provision of validated and quality controlled selected set of (multi-sensor) **satellite data** of known measurement uncertainty (such as atmospheric column data on trace gases, aerosol distributions, solar radiation etc.). The greatest value is obtained from these data if user needs are considered, i.e. that for high-capacity AQ users, data is provided in conjunction with **maximal information on their vertical distribution**. Data are needed at high temporal and spatial resolution to monitor processes with a relatively short atmospheric lifetime.

The direct use of satellite data for other users without interpretation (e.g. DS) is limited.

Concentration data

In analogy to the above, GACS should not be considered as alternate in-situ observation data provider to the numerous networks already in place. However, the provision of ground-level **concentration data** for relevant pollutants such as PM2.5, PM10, O_3 , NO_2 in g/m3 is considered to be within GACS. These data should already carry the added value of GACS quality control, data assimilation with emission dispersion modelling and remote sensing incl. satellite observations to ensure adequate quality, comparability, spatial and temporal resolution.

To ensure the 'buy-in' by the users as well as facilitate further improvement of the service, individual components of the system (i.e. in-situ monitoring data, dispersion modelling outputs etc.) should also be available separately as GACS.

NRT in-situ and satellite data

The GAS user workshop (December 2006) included in the scope of GAS (

Table 1) the provision of NRT satellite-based products, which are not currently being provided operationally by satellite data providers.

NRT satellite products	Data type	Extension
Tropospheric O3 column	NRT satellite	Europe
Ozone profile	NRT satellite	Europe
SO2	NRT satellite	Europe

Table 1: required satellite products as identified in the Dec 2006 user workshop

¹ In such case, they should be recognized as DS, and appropriate account should be taken in ensuring that their needs are taken into account.

Tropospheric NO2	NRT satellite	Europe
CHOH (plus CHOCHO?)	NRT satellite	Europe
PM (types)	NRT satellite	Europe
CH4	NRT satellite	Europe
CO2 (CO?)	NRT satellite	Europe
Aerosol optical depth (column)	NRT satellite	Europe
Dust	NRT satellite	Europe
Solar radiation	NRT satellite (Meteosat)	Europe
O3 total column	NRT satellite	Global
Tropospheric NO2	NRT satellite	Global

GACS should support the better availability and usability of Level 2 and 3 satellite data, including radiance data. It is also evident that access to NRT in-situ data needs to be provided at least to modellers developing the assessment/forecasting of AQ, and most probably to its users as well (see §2 above).

GMES implementation should promote open data access policy; however the provision of basic observational data to end users should not be part of GACS. Access by high capacity users to the data collected in order to enable related CS should nonetheless be made possible within GACS.

2.4.4.2 Products other than atmospheric composition

Meteorological data

Meteorological data such as clouds (an important CC variable) or wind and precipitation (essential input in AQ assessments) are already provided in a sustainable and operational manner by the national meteorological services. Provision of such data should be beyond the scope of CS. The implementation of GACS should only ensure that GACS has an effective access to this data.

There may however be GACS products which build strongly on such input, but already present added value to GMES users; examples include filtering and resampling these data to feed directly in GACS models. Such products may be offered separately as part of GACS.

Sources and sinks

An important category to be considered is the information on sources and sinks, which is a) essential in determination of gridded information on atmospheric compositions, and b) one of the key policy indicators. GACS should not make an effort to disseminate the related information collected from different sources, or provide an additional layer in reporting EU emission data. However, the subsequent gridded maximum spatial/temporal resolution inventory, together with some more aggregated information, should be considered part of GACS.

There may be a number of related services envisioned such as validation/improvement of sources - emission inventories as well as sinks (refinement of atmospheric chemistry models, deposition etc.) through inverse modelling. They should be considered in the development of GACS as supporting tools in providing information of adequate and known quality. They should however at this moment not be systematically considered as specific CS, since some users may develop them as DS.

It is expected that source/sink-related GACS and DS will, through feedback, influence the data provided (similar, but to a lesser extent, can be claimed for the observational data).

Flexibility in the implementation of GACS should enable the possibility that in future some of the EU international reporting obligations may be taken over by GACS.

Toolboxes

Following in particularly the "economies of scale" rationale, there is scope for the provision of **toolboxes** based on additional modelling capabilities allowing to (interactively) further examine relevant phenomena, future scenarios / integrated assessment such as RAINS/GAINS, cost benefit analysis, to support adaptation strategies at various levels etc. Some of these toolboxes will need to be established in any case as part of the "generic services" of GACS supporting the sensitivity analysis, QA/QC, validation and further development of CS products.

While all these services could be also considered as important DS, the following should be already now considered as CS:

- interactive toolbox enabling manipulation of inputs to data assimilation/models to further examine relevant phenomena;
- ability to describe future scenarios to obtain information on projected atmospheric composition, sources and sinks.

Forecasting and identification of pollution episodes

Building upon the assessment and forecasting CS specific information may be extracted linked to specific atmospheric events (e.g. long-range transport of air pollution, sand-dust storms, pollen, volcanoes, forest fires). Such CS should be explicitly targeting 'alert' DS linked to the further processing and dissemination such as health warnings and exposure recommendations, triggering short-term actions plans such as urban transport restriction measures etc.

2.4.5 Service output parameters

A **description of desired service outputs** for the different themes is attempted in the following.

For all services provided, **uncertainty assessments** are crucial, in particular for assimilation modelling.

The required **temporal and spatial resolutions** for CS parameters as listed in annex 3 should not be seen as absolute, as

- A. Temporal and spatial resolution often change whenever new measurement platforms or models are used;
- B. Data can easily be transformed into any resolution during the download process.

Data processing and assimilation may provide information which is superior to its individual components such as in-situ or space monitoring data both in resolution as well as in quality. The resolutions indicated are based on currently identified user needs and are intended as minimum values.

2.4.5.1 Air quality (AQ)

A GMES CS for AQ can provide added value regarding at least EU-wide surface monitoring, harmonization of AQ assessment, better integration of monitoring and modelling results, integration with satellite data and providing NRT concentration fields.

Further, the envisaged CS products for AQ are based on atmospheric composition data that may be categorised as follows:

1. Type of Pollutant:

- a. Ozone
- b. Particulate matter/aerosol/soot (this includes industrial emissions and anthropogenic dust, sea spray and geogenic dust)
- c. NO2
- d. SO2
- e. CO
- f. HCHO
- g. CHOCHO (Glyoxal; tracer of VOC emissions)
- h. C6H6

2. Parameters:

- a. Concentrations of pollutants (e.g. PM1, PM2.5, PM10): first and foremost 2D surface grids are required. For some applications, e.g. long-range transport of pollutants, aerosols for cloud formation modelling, 3D tropospheric grids are also needed;
- b. Integrated quantities (optical depths, columnar contents) and profiles;
- c. Other, such as sources and sinks (emission, deposition estimates, atmospheric removal rates).
- **3. Periods**¹ (including temporal resolution and provision frequency):
 - a. Historic data (data anywhere in the past, e.g. the last 10 years) as 3h time resolution and 1d/month/season/annual statistics; last year's data to be provided annually;
 - b. (Near) Real Time data ("now" 2) as 1h time series; to be provided hourly
 - c. Forecasts (one to several days ahead) as 1h time series; to be provided 6-hourly or daily;
 - d. Scenarios (several years ahead) as 1h/8h/1d/... annual statistics [and time series?]; to be provided annually.

The GACS products can be described as combinations of these three categories: see Table 2.

Table 2: CS Products for AQ: relevant combinations of pollutants, parameters and periods

		Parameters	
Period	Columns, AOD ³	Concentrations	Other

¹ Similar to this distinction of temporal extents, one might add a distinction in spatial extents: global and European.

² Particularly for public information, as near as possible approaching real time, e.g. to be approximated by forecasts in previous hours and NRT. Data should be provided within the next hour.

³ The definition of time series of columns, AODs etc needs further consideration.

Historic data (2000+)	O3, NO2, aerosol, clouds; 3h time series and annual statistics	O3, PM2.5, PM10, NO2, SO2, CO, HCHO	Data on emissions, atmospheric processes,
NRT	O3, NO2, aerosol, clouds; 1h time series	O3, PM1, PM10, NO2	Aerosols, clouds
Forecasts	Not relevant	O3, PM10, NO2	Aerosols, clouds
Scenarios	Not relevant	O3, PM10, NO2, SO2; 1h/3h/1d annual statistics	Aerosols, clouds

CS products on AQ may be used (i) directly, or (ii) as basis to elaborate more specifically tailored products (DS: find examples in section 2.3).

Direct use of CS products (both by high-capacity users and by low-volume users as described in section 2.2) may be made for

- Scientific understanding and development:
 - § Model validation
 - § Emission estimates for inventories, natural events
 - § Alerts of major pollution events (natural and anthropogenic)
 - § ...
- Policy scenario development
- Large scale assessments by European institutions and agencies
- Large scale compliance checking with AQ thresholds at MS level; e.g. O₃, PM, difficult for NO₂
- Public information on large scale for AQ (However, local information may be more relevant for public)
- Improving regional and global weather forecasting (e.g. clouds and fog, and air pollution radiative forcing)
- ...

2.4.5.2 Climate forcing (CF)

Services on climate forcing should include

- A. Monitoring of the state of the climate system (surface and upper air meteorology and composition) and its variability, and
- B. Integrated Global, European and regional concentration fields of key greenhouse gases (CO2, CH4 and related tracers, halogenated Hydrocarbons (CFCs, HCFCs, ..) enabling determination of sources and sinks
- The emphasis is on essential climate variables (as a minimum) and GCOS requirements;
- High spatial and temporal resolution of the analysis is essential;
- Include water vapour and GHG cycles as well as different emissions sources.

Where there is some information already available in an operational manner (i.e. clouds), the development of GACS in these areas should limit itself to the value added.

As outlined above (section 2.4.2), the emphasis with respect to climate forcing should lie in a provision of ECVs variables as gridded fields, with a focus on atmospheric composition. Climate (Earth System) modelling will remain outside the scope of the GACS.

Both the climate change as well as the air quality communities actually need very similar data, e.g. chemical composition, emissions, deposition fluxes, but for different purposes. Although the output of climate models is averaged over longer time spans, for the evaluation of many processes climate modellers need a fine resolution as well. Therefore, AQ and CF may be considered as a common issue within the GACS: While the user communities are different, the data requirements often overlap.

In addition, the large component for AQ and CF should also provide elaborated products going beyond the provision of atmospheric composition data targeting the low-volume CS users such as policy makers.

Annex 3.1 lists the envisaged products, their intended uses and the required parameters for AQ and CF.

2.4.5.3 Stratospheric ozone and UV services

The GAS user workshop (December 2006) asked for the following topics to be included:

- Improved and sustained monitoring of the current status and trends in stratospheric ozone depletion;
- Routine provision of updated Ozone, UV and solar radiation maps and forecasts;
- Historic European UV and solar radiation records and mapping;

See Annex 3.1 for the envisaged products.

2.4.5.4 Solar radiation (renewable energies)

The GACS can provide added value for Solar Radiation regarding an EU-wide monitoring, and integration with other GMES services. Besides high-quality satellite-derived solar radiation, the renewable energy industry would benefit from improved quality and access to meteorological observations. Closer partnership between in situ observation networks and industry would stimulate expansion and qualitative enhancement of the observation infrastructure.

The outputs envisaged to be provided by a CS for this theme are:

- Access to Satellite-derived (Meteosat) continental data of Global Horizontal Irradiance (GHI) and possibly also Direct Normal Irradiance (DNI);
- Access to in-situ solar radiation observations (global, diffuse and direct irradiance measured by meteorological services, BSRN, GEBA, and IDMP networks), including other meteorological parameters (air temperature, wind speed and direction, humidity, etc.);
- Prepared (filtered, resampled etc.) solar model data inputs comprising from relevant observational data and GACS AQ and CF CS outputs, e.g. ozone, water vapour, aerosols, atmospheric turbidity (as an alternative to water vapour and aerosols), cloud parameters, snow cover (NRT data needed);
- Genuine CS products such as time series, averages, maps.

The satellite-derived CS output products are listed in detail in Annex 3.

The solar radiation theme is closely linked to other Atmosphere Core Services (such as Air Quality and Climate Forcing) as it depends on similar data, for the provision of high-quality solar radiation products (as inputs to solar radiation models)

2.5 Cross-cutting issues to other services

The GACS has a need to acquire satellite observations delivered by other GMES services, specifically those related to land or ocean parameters. The latter two services will most probably need operational access to GACS products as well. Hence it is important to design data access procedures allowing easy implementation of data streams between the GMES core services.

The HALO FP6-project focused on the data acquisition and data exchange requirements of the interacting parts of the three integrated projects MERSEA, GEOLAND and GEMS. Common data demands and direct product exchanges are discussed in detail in the HALO

documents^{1,2}. The HALO recommendations are also applicable to the GACS and to the other GMES services. Cross-cutting issues and relevant dependencies between marine, land, emergency and the atmosphere service have been adequately identified, as follows:

- Sources and sinks:
 - § A **Global Fire Assimilation Capability** describing the biomass burning emissions into the atmosphere and the associated changes in carbon stock and land cover is needed.
 - § GMES should encourage the scientific development of **ecosystem models incorporating the carbon cycle explicitly** in the marine and land monitoring services.
 - § The three Earth system pillars of GMES (Land, Marine, and Atmosphere) should **contribute jointly to the monitoring of carbon and nitrogen sinks and sources** with the ultimate goal of supplying the factual basis for political decisions regarding climate change and air pollution. The GACS addresses source attribution from atmospheric observations; the Land and Marine CS model the terrestrial and oceanic stocks and fluxes.
- Reanalysis:
 - § As discussed above, GMES should include a new atmosphere re-analysis in support of the ocean re-analysis that will be produced by the marine fast track service.
 - § Interactions between services:
 - § The Land, Ocean and Atmosphere services each need to generate or acquire the best possible estimates of interfacial fluxes of momentum, radiation, sensible heat, latent heat and interfacial fluxes of a number of atmospheric constituents including carbon dioxide, nitrogen, water vapour and aerosol.
 - § It is important to have **consistent high-resolution datasets** with Land/Marine for cross-cutting issues needing all three, e.g. climate change.
 - § GMES marine and atmosphere monitoring systems should be encouraged to maintain close scientific and operational contacts with existing numerical weather prediction services so as to coordinate and further develop the multitude of

¹ HALO - Harmonised Coordination of the Atmosphere, Land, and Ocean IPs in GMES. Final Activity Report. ECMWF, 2007. <u>www.ecmwf.int/research/EU_projects/HALO/pdf/final_activity_report_070705.pdf</u>

² Kaiser et al. HALO Final Scientific Report (Annex 2 of HALO Final Activity Report). 2007. www.ecmwf.int/research/EU_projects/HALO/pdf/HALO_final_scientific_070620.pdf

interfaces already implemented between the pre-operational and operational systems; e.g.

- o Ocean modelling requires atmospheric forcing fields, primarily wind stress;
- o The systems exchange carbon dioxide as well as dust and sea salt aerosols;
- Ocean currents, waves, and winds interact to modify all the above mentioned fluxes;
- Atmospheric seasonal forecasts improve by using advanced marine seasonal forecasts;

In addition:

- A **transversal GMES element for Climate Change** will require important inputs from the atmosphere service; in addition, other relevant ECVs must be delivered by Marine and Land services.
- **Emissions from shipping** may be envisioned for the future in connection with future services provided by GMES in the field of maritime safety & surveillance.
- The Emergency Response core service evolution envisions a facilitating of early warning systems (EWS). Model dispersion data sets are essential in the **emergency response to chemical or nuclear accidents**. Their provision should be considered within the GACS evolution in order to support the ERCS EWS.

Annex A: Detailed list of data products

A.1 Data products for Air Quality and Climate Forcing

Inter- mediate use of CS products	Direct use of CS products	End users	CS product	Pollu- tant	Para- meters	Period	Exten- sion	Spatial Reso- lution	Uncerta inty ¹⁸
AIR QUA	LITY								
-	Info on EU- wide AQ[3] ²	General public	EU-wide AQ maps	PM2.5, PM10, O3, NO, NO2, SO2	Surface concen- tration	NRT, 3-day forecast, (historic, scenarios)	Euro- pe	25 km	• 30%
-	Large scale AQ assessment (including compliance AQ thresholds)	EU/ national/ local authorities	EU-wide AQ maps and interme diate data	PM2.5, PM10, O3, NO, NO2, SO2, CO ³	Surface concen- tration	Historic, NRT, 3-day forecast	Euro- pe	25 km	• 30%
-	Scientific und/dev: - Model validation	Science Commu- nity	Global and EU-wide maps and interme diate data	PM1, PM2.5, PM10, O3, NO, NO ₂ , CO, SO ₂ 4 HCHO	All	Historic	Euro- pe; global	BTC ⁵	<u>, </u>
-	Scientific und/dev: - Emission data ⁶	Science Commu- nity	Science report on emission data	PM2.5, PM10, NO, NO2, HCHO, O3, CO,	Emissions of source types	Historic	Euro- pe; global	BTC	

¹ The percentage indicates the typical uncertainty of an individual concentration value. BTC: Better than current.

 2 This could also be defined for intermediate use, with downstream providers providing it to the end users.

- 3 Tracer included in CLRTAP and precursor of O_{3}
- ⁴ SO2 not relevant at European, but at global level

⁵ Accuracy requirements (BTC: "better than current"): Several of the foreseen product do already exist to some degree, and are based on surface monitoring and modelling, without satellite data. These products cannot be provided by satellite data solely. Satellite data, as additional information, may however improve the existing products. For those products, it is more suitable to require from CS products that they improve the current accuracy ("Better Than Current") than attempting to catch the desired accuracy in one overall accuracy percentage. The other WGs should then estimate the accuracy improvement due to inclusion (assimilation) of satellite data. The same applies to some degree to spatial resolution. ⁶ Global emission inventories with a good regional resolution (at least 20 km) are essential for all UNEP regulations, post-Kyoto, AQ and CC. So far inventories have been worked out in the framework of funded projects which does not guarantee consistence and continuity.

Inter- mediate use of CS products	Direct use of CS products	End users	CS product	Pollu- tant	Para- meters	Period	Exten- sion	Spatial Reso- lution	Uncerta inty ¹⁸
-	AQ mana- gement	EU/ nat/ local authorities	Concen- tration scenarios	CHOCHOPM1,PM2.5,SurfacePM10,concen-03, NO2trationScenariosScenarios		BTC ¹⁴	• 30%		
Input for down- stream (DS) local forecast, alerts,	DS local forecast, alerts,	Local authorities and public ¹	EU-wide AQ and emission maps	U-wide Q and nission laps PM2.5, PM10, NO2, O3 HCHO, CO, SO2 NRT		NRT	Euro- pe	• 50 km	• 30%
Input for DS local AQ assess- ment	Info on local AQ	Local authorities and stakeholder	EU-wide AQ maps	PM2.5, PM10, NO2, O3	Surface concs	Historic	Euro- pe	• 50 km	
Input for DS scenario develop- ment	Local AQ scenarios	Local authorities and stakeholder	EU-wide AQ maps	PM2.5, PM10, NO2, O3	3D concs, surface concs	Scenarios	Euro- pe	BT	C ¹⁴
Scientific under- standing /develop- ment Input for emission estimates	Better info on air pollution in general Better emission inventories,	All stakeholder Authorities and stakeholder	Columns, AODs, surface monitoring data EU-wide	PM1, PM2.5, PM10, NO2, O3 HCHO, C6H6, CO, SO2	All 3D conc grids	Historic Historic	Euro- pe; global Euro- pe; global	BT Scier repo	C ¹⁴
CLIMAT	E FORCINO	Ĵ							
Scientific under - standing /develop- ment	Sustained monitoring of climate system and its compo- sition (input for climate research, modelling,.)	Scientific Community nity	3D distribution maps, inter- mediate data	CO2, CH4, O3, aerosols (type resolved), gaseous precursors: CO, SO2, NO _x , VOCs Haloge nated Hydrocarbo ns (CFCs, HCFCs,)	3D gridded fields, concen- trations	monthly/ seasonal	global	• x : 10-50 km	
Scientific	Under	Scientific	Distribu-	Surface	3D gridded	monthly/	global	• x :	

"local" refers to spatial extent: includes regional and even national for small countries.

Inter- mediate use of CS products	Direct use of CS products	End users	CS product	Pollu- tant	Para- meters	Period	Exten- sion	Spatial Reso- lution	Uncerta inty ¹⁸
under- standing /develop- ment	standing of atmosphere dynamics and thermo- dynamic parameters (input for climate research, modelling,.)	Commu- nity	tion maps, inter mediate data, long-term records	para- meters ¹ : Tair, precipita- tion, p(air), surface radiation budget, wind speed /direction Water vapour	fields	seasonal		1-10 km	
	Under standing of atmosphere dynamics and thermo- dynamic parameters (input for climate research, modelling,.)	Scientific Commu- nity	Distribu- tion maps, interme diate data, long-term records	Upper air parameter s ¹⁷ : earth radiation budget (+ solar irradiance), upper-air T (+MSU radiances), wind speed /direction, cloud properties	3D gridded fields, vertical profiles	monthly/ seasonal	global	1000- 5000 km & 50 km	
Input for policy makers, conven- tions, NGOs, public	Determi- nation of sources and sinks	Scientific Commu- nity	maps, interme- diate data	CO2 surface, CH4 surface, Haloge nated Carbons (CFCs, HFCFs) Anomalies from expected climatology	Surface fluxes, gridded fields	Monthly, seasonal	Glo bal, Euro- pean		

¹ Not a priority for the CS, (compare sections 3.2 and 3.5).

Data products for for O3 and UV A.2

Product	Output type	Use/case description	Extension	Provision	Temporal Resolution	Spatial reso- lution	Forecast	Uncertainty	Accuracy	Operational precision
USER TY	PE: High-	capacity, interr	nediate us	sers: e.g	research, met se	ervices/fore	ecastin	g, satell	ite age	ncies
Improved	+ sustained	l monitoring of	current st	tatus an	d trends in strate	ospheric Og	deple	tion,		
O3 depleti	ng gases &	changes of UV	radiation	n						
O3 total column (TOC)	long-term record	e.g. ozone research: global changes, trends, validation of satellite missions, O3- climate interactions	global		daily	• x: 500-1000 km		1-3%	Long -term drift wi- thin 1%	
Ozone profiles (T/LS, O ₃ sondes)	long-term record, verti- cally resolved	e.g. ozone research: modelling of ozone distribution by UT/LS dynamics, validation of sat observations, O ₃ -climate interactions	global		daily	• x: 500-1000 km, • z: 0.1-1 km, to 30-35 km		3- 10%	Long -term drift wi- thin 1%	
Ozone 3D distr. oceans (UT/LS, airborne)	long-term record, verti- cally resolved	e.g. ozone research: heterogeneous processes contr. By O ₃ incl. Air traffic	global: oceans		daily ¹	• x: 10-10000 km, • z: 0.1- 1km betw. 0- 12 km		1-3%	Long -term drift wi- thin 1%	
Ozone profiles (US, lidars, micro- waves	long-term record, verti- cally resolved	e.g. ozone research: chemical processes, recovery of the O_3 layer and O_3 hole	global		daily ²	• x: 1000- 5000 km; • z: 1- 5km		3- 15%	Long -term drift wi- thin 1%	
Other requi	red variable	25								
polar stratos- pheric clouds	long-term record, verti- cally resolved	e.g. ozone research	global		hourly	300km • x, 1-2km • z			<1% long- term drift	

¹ limited according to flight schedules² limited according to weather conditions

Product	Output type	Use/case description	Extension	Provision	Temporal Resolution	Spatial reso- lution	Forecast	Uncertainty	Accuracy	Operational precision
ozone- destruc tive species (CIOx, NOx,)	long-term record, verti- cally resolved	e.g. ozone research	global		hourly	300km • x, 1-2km • z			<1% long- term drift	
reservoir species (CLy)	long-term record, verti- cally resolved	e.g. ozone research	global		hourly	300km • x, 1-2km • z			<1% long- term drift	
Routine pr	ovision of t	updated ozone 1	naps and	UV fore	ecasts					
ТОС	fields	e.g. ozone research : TOC distribution vs. UT/LS dynamics	global	NRT	daily	10km • x, ground & sat assim.				1-2%
ozone profiles	fields	e.g. ozone research : 3D O ₃ distribution vs. UT/LS dynamics	global			10km • x, ground & sat assim.				
UV-B, UV index	fields	e.g. ozone research, val of UV mosels	global	NRT	daily	10km • x, ground & sat assim.				1-5%
need for at	tmosphere	dynamics & the	rmodyna	mics inc	l. clouds					
Historic El Global UV spectral irra diances	long-term records	e.g. UV research: UV RT models; trends	Europe + neigh- bor hood		several scans daily for different SZAs	500- 1000km • x		1-5%	Long -term drift wi- thin 3%	
Global UV narrow band (multi channel) irradiance	long-term records	e.g. UV research: short-time variations, UV climatol, val of UV models	Europe + neigh- bor hood		Hourly & higher sums	100-500 km • x		5 - 10%	Long -term drift wi- thin 3%	
Global erythemal irradiance (daily doses, max/min) and UV- index	long-term records, maps	e.g. UV research: UV climate and health, application of UV models	Europe + neigh- bor hood		Hourly & higher doses	100-500 km • x		5 - 10%	Long -term drift wi- thin 3%	
USER TY	PE: Core-p	product direct u	sers: e.g.	policy r	nakers, authoriti	es, environ	mental	agenci	es,	
convention	ns, citizens	1		4 4	1			.: _		
O3 denleti	+ sustained ng gases &	Windiation	current s	iaius an	u trenas in strato	spheric O_3	aepie	non,		

Product	Output type	Use/case description	Extension	Provision	Temporal Resolution	Spatial reso- lution	Forecast	Uncertainty	Accuracy	Operational precision
тос	long-term analyses, geograph. resolved	e.g. Montreal Protocol - trends, documentation of O3 recovery, O3- climate interactions	global		Annually, seasonally	1000km • x, ground & sat assimilat ed			Long -term drift wi thin 1%	
Ozone profiles (UT/LS, US)	long-term record, 3D resolved	e.g. Montreal protocol - trends, O3 recovery, Kyoto - O3/climate, UT/LS chem - air traffic and long- range transport	global		Monthly, seasonally	100- 5000km • x, 0.1-5km • z			Long -term drift wi- thin 1-3%	
Global UV spectral irra- diances	long-term records /changes, typical regions	e.g. O3/climate, UV/environ- ment, UV/health	Europe + neigh- bor hood		Monthly, seasonally	typical regions			Long -term drift wi- thin 3%	
Global erythemal irradiance (daily doses, max/min) and UV- index	long-term records/ changes, geograph. resolved	e.g. O3/climate, UV/environ- ment, UV/health	Europe + neigh- bor hood		Monthly/ seasonally/ annually	typical regions, zonal belts			Long -term drift wi- thin 3%	
Routine pro	vision of up	dated ozone and	UV forece	ists						
ТОС	maps	e.g. met services, citizen	Global	daily	Daily AVGs	100 km • x, ground & satellite assimi- lated	1-5 days 1			1-5%
UV-B at surface	maps	e.g. met services, citizen	Global	daily	Daily totals /extremes	100 km • x, ground & satellite assimi- lated	1-5 days 20			1-5%
Historic Eu	ropean UV	records and map	ping							
UV-B at surface	long-term changes, maps	e.g. climate change, environmen- tal impacts	+ neigh- bor hood		Monthly/ seasonally/ annually	typical regions, zonal belts				
USER TY	PE: Down	stream provider	rs: e.g. pr	ivate sec	ctor/industry, hea	lth service	s, NG(Js, tour	ISM	

¹ current state-of-the-art technologies, still in progress

Product	Output type	Use/case description	Extension	Provision	Temporal Resolution	Spatial reso- lution	Forecast	Uncertainty	Accuracy	Operational precision
Improved + O3 depletin	sustained n g gases & U	nonitoring of cur JV radiation	and tren	ds in stratospheric	O ₃ depletion	n,				
TOC / UV-B / UV-Index at surface	actual values	e.g. operational public health protection information	Region nal	NRT	daily	regional		1-3% TOC ; 5-10% UV ²⁰		
Routine pro	vision of up	dated ozone and	UV foreca	asts						
UV-B / UV-Index at surface	maps, actual values, short- term forecasts	e.g. operational public health protection information	Region nal	NRT	daily	regional	1-5 days 20			$\frac{1-5\%}{\mathop{\rm maps}^2_0}$
Historic Eu	ropean UV 1	records and map	oing							
UV-B at surface	long-term records and statistics	e.g. downstream assessments	Regio nal, Europe + Neigh- bor hood		hourly, daily, monthly averages	Regional or 1x1 degree horizon- tal; ground & sat assimil.		Long- term drift <3% for data;1 -3% for maps		

A.3 Data products for solar radiation

					Tempora				
Product	Output	Use/case	Extent	Delivery		Spatia	l	Forecas	Accurac
	type	description			resolutio	resoluti	on	t	У
High-cap	acity int	ermediate i	Isers rese	arch met	services				
Global Horizontal Irradiance Direct Normal Irradiance	time series, averages, maps	Scientific understanding of short and long-term variability, including extreme events such as volcano eruptions	Europe (Africa, Asia)	archive, forecasts	15-min instant- aneous, hourly, daily, monthly	1-3 km (MSG)		3-12 hours, 1-7 days	
Core-pro	duct dire	ect end users	: policy ma	kers, auth	orities/age	ncies, ir	iteri	national	
organisati	ons, citize	Policy							
Global Horizontal Irradiance	long-term averages, maps	development and monitoring Public information	Europe (Africa, Asia)	archive	long-term monthly	1-3 km (MSG)			
Downstream	n providers:	value-adding pro	widers: (solar	energy proje	ct developme	nt, financi	ng, p	olant operat	ion,
electricity n	etwork mana	igement)]	1			
Global Horizontal Irradiance (GHI) Direct Normal Irradiance (DNI)	time series, averages, maps	Energy yield assessment for plant siting & project development; Site audits for financing and insurance; Power plant monitoring and operation; Electricity network management, Energy performance modelling and certification of buildings.	Europe (Africa, Asia)	archive, NRT, forecasts	15-min instant- aneous, hourly, daily, monthly	1-3 km (MSG)	3-1 1-7 sea fore	2 hours, days, sonal ecasts	Bias (archive data): DHI < 3%, DNI <6%