GEO Task US-09-01a:
Critical Earth Observations Priorities

Weather Societal Benefit Area

GROUP ON
EARTH OBSERVATIONS

User Interface Committee

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Group on Earth Observations

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Advisory Group Members & Analyst

The following people served as expert panelists for the *ad hoc* Advisory Group for the Weather Societal Benefit Area under GEO Task US-09-01a. The Advisory Group supported the Analyst by identifying source materials, reviewing analytic methodologies, assessing findings, and reviewing this report:

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Group on Earth Observations

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Summary

The objective of GEO Task US-09-01a is to establish and conduct a process to identify critical Earth observation priorities within each Societal Benefit Area and those common to the nine SBAs.

This analysis focused on identifying those requirements for the Weather SBA. An *ad hoc* Advisory Group of 8 members from international organizations was assembled to help narrow the focus of the analysis, to help identify documents that identify Earth observation requirements for weather forecast applications, and to review the methodology and results presented in the preliminary report.

Documents that potentially contained information related to the observation requirements were identified through literature and internet searches and through Advisory Group recommendations. After evaluating the documents for their applicability to this task, approximately 25 were identified that provided information that could be used in the priority setting analysis.

A 4-level prioritization of the EO parameters was conducted, which resulted in a list of 30 parameters with observation characteristics expressed in terms of horizontal resolution**,** vertical resolution**,** observing cycle**,** delay of availability and accuracy. The information for the final list was drawn from international consensus documents and high level position papers and will be incorporated into a broad cross-SBA analysis to be performed by GEO to identify critical Earth observations across all nine SBAs.

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1. Introduction

This report articulates Earth observation priorities for the Weather SBA based on an analysis of publicly-available documents, including documents produced by Group on Earth Observations' Member Countries and Participating Organizations.

1.1. Group on Earth Observations

The Group on Earth Observations (GEO)[1] is an intergovernmental organization working to improve the availability, access, and use of Earth observations to benefit society. GEO is coordinating efforts to build a Global Earth Observation System of Systems (GEOSS)[2]. GEOSS builds on national, regional, and international observation systems to provide coordinated Earth observations from thousands of ground, airborne, and space-based instruments.

GEO is focused on enhancing the development and use of Earth observations in nine Societal Benefit Areas (SBA):

- Agriculture
- Biodiversity
- Climate
- Disasters
- Ecosystems
- Energy
- Health
- Water
- Weather

1.2. GEO Task US-09-01a

The objective of GEO Task US-09-01a is to establish and conduct a process to identify critical Earth observation priorities within each Societal Benefit Area and those common to the nine SBAs. Many countries and organizations have written reports, held workshops, sponsored projects, conducted surveys, and produced documents that specify Earth observation needs. In addition, researchers and practitioners have also identified and recommended key Earth observation needs in publications and peer-reviewed literature. Task US-09-01a focuses on compiling information on observation parameters from a representative sampling of these *existing* materials and analyzing across the materials to determine the priority observations.

[1] GEO Website: *http:// www.earthobservations.org*
[2] GEO 10-Year Implementation Plan: *http://www.earthobservations.org/documents.shtml*

This task considers all types of Earth observations, including ground, in situ, airborne, and space-based observations. The task includes both direct measurements and derived parameters as well as model products. This task seeks to identify Earth observation needs across a full spectrum of user types and communities in each SBA, including observation needs from all geographic regions with significant representation from developing countries.

GEO will use the Earth observation priorities resulting from this task to determine, prioritize, and communicate gaps in current and future Earth observations. GEO Member Countries and Participating Organizations can use the results in determining priority investment opportunities for Earth observations.

1.3. Purpose of Report

The primary purpose of this report is to articulate the critical Earth observation priorities for the Weather SBA. The intent of the report is to describe the overall process and specific methodologies used to identify documents, analyze them, and determine a set of Earth observation parameters and characteristics. The report describes the prioritization methodologies used to determine the priority Earth observations for this SBA. The report also provides information on key challenges faced, feedback on the process, and recommendations for process improvements.

The primary audience for this report is the GEO User Interface Committee (UIC), which is managing Task US-09-01a for GEO. The GEO UIC will use the results of this report in combination with reports from the other eight SBAs. The GEO UIC will perform a meta-analysis across all nine SBA reports to identify critical Earth observation priorities common to many of the SBAs. Based on the nine SBA reports, the GEO UIC will produce an overall Task US-09-01a report, including the common observations and recommendations for GEO processes to determine Earth observation priorities in the future.

The report's authors anticipate that the GEO Secretariat, Committees, Member Countries, Participating Organizations, Observers, Communities of Practice, and the communities associated with the Weather SBA are additional audiences for this report.

1.4. Scope of Report

This report addresses the Earth observation priorities for the Weather SBA. In particular, this report addressed the sub-areas Global Numerical Weather Prediction, Regional Numerical Weather Prediction, Synoptic Meteorology, Nowcasting and Very Short Range Forecasting, Seasonal and Inter-annual Forecasts, Aeronautical Meteorology, Atmospheric Chemistry, Ocean Applications, Agricultural Meteorology, and Hydrology within the Weather SBA (see Chapter 3 for more details).

The report provides some background and contextual information about the Weather SBA. However, this report is not intended as a handbook or primer on the Weather SBA, and a complete description of the Weather SBA is beyond the scope of this report. Please consult the GEO website for more information about the Weather SBA.

The report focuses on the Earth observations within the Weather SBA, independent of any specific technology or collection method. Thus, the report addresses the “demand” side of observation needs and priorities. The report does not address the specific source of the observations or the sensor technology involved with producing the observations. Similarly, any discussions of visualization tools, decision support tools, added-value products or system processing characteristics (e.g., data format, data outlet) associated with the direct use of the observations are beyond the scope of this report.

In this report, the term Earth observation refers to parameters and variables (e.g., physical, geophysical, chemical, biological) sensed or measured, derived parameters and products, and related parameters from model outputs. The term Earth observation priorities refers to the parameters deemed of higher significance that others for the given SBA, as determined through the methodologies described within. The report uses the terms “user needs” and “user requirements” interchangeably to refer to Earth observations that are articulated and desired by the groups and users in the cited documents. The term “requirements” is used generally in the report to reflect users’ wants and needs; the use in this report does not imply technical, engineering specifications.

Following this introduction, the report discusses the overall approach and methodologies used in this analysis (Chapter 2). Chapter 3 describes the Weather SBA and the specific sub-areas that were part of the analysis. Chapter 4 articulates the specific Earth observations for each Weather sub-area, and Chapter 5 presents the priority observations across the Weather SBA. Chapters 6 & 7 present additional findings from the analysis of the documents and any recommendations. The Appendices include the documents cited and sourced as well as any additional information describing aspects of the Weather SBA.

2. Methodology

This chapter documents the general process followed and specific methodologies used to identify documents, analyze them, determine Earth observation parameters and characteristics, and establish a set of priority Earth observations for this SBA.

2.1. Task Process

The GEO UIC established a general process for each of the SBAs to follow in order to ensure some consistency across the SBAs. This general process for each SBA involves 9 steps, as summarized in the following list:

Step 1: Identify Analyst and Advisory Group for the SBA
Step 2: Determine scope of topics within the SBA
Step 3: Identify documents regarding observation priorities for the SBA
Step 4: Develop analytic methods and priority-setting criteria
Step 5: Review and analyze documents for priority Earth observations needs
Step 6: Combine the information and develop a preliminary report
Step 7: Gather feedback on the preliminary report
Step 8: Perform any additional analysis
Step 9: Complete the report on Earth observations for the SBA

A detailed description of the general US-09-01a process is available at the Task website *http://sbageotask.larc.nasa.gov* or GEO website. Some steps in the process occurred simultaneously or iteratively, such as identifying documents (Step 3) and reviewing documents (Step 5).

2.2. Analyst and Advisory Group

The Weather SBA had an "Analyst" and an "Advisory Group" to conduct the process of identifying documents, analyzing them, and prioritizing the Earth observations. The Analyst served as the main coordinator to manage the activities.

2.2.1. Analyst

For the Weather SBA, the Analyst was Michael NYENHUIS. He is a physical geographer with research expertise in the fields of numerical permafrost modelling, cold regions research and fluvial geomorphology. Dr. Nyenhuis is a scientist at the Department of Geography of the University of Bonn and is commissioned by the German Federal Institute of Hydrology (BfG) to support Germany´s efforts to implement GEOSS on a national level. He is deeply involved in GEO by being a member of the German GEO delegation, the German GEO working group (D-GEO), and the GEO User Interface Committee (UIC). Dr. Nyenhuis has conducted studies on user requirements in the framework of an ESA funded GMES project on Marine and Coastal Environmental Information Services (MarCoast) and in the course of the development of the national German GEOSS Implementation Plan (D-GIP).

The Weather SBA Analyst served on a *pro bono* basis as a representative of GERMAY. The work has been conducted in the framework of a cooperative project of the Federal Institute of Hydrology (BfG) and the Department of Geography at the University of Bonn.

2.2.2. Advisory Group

The Advisory Group for the Weather SBA consisted of 5 scientific and programmatic experts from the fields of numerical weather prediction, weather observation systems. Table 1 shows the Advisory Group members.

GEO Task US-09-01a: Advisory Group for Weather SBA			
Name	**GEO Country or Organization**	**Affiliation**	**Geographic Region**
Manfred Kloeppel	ECMWF	ECMWF	Europe
Paul Counet	CEOS	EUMETSAT	International
Robert Husband	CEOS	EUMETSAT	International
Jochen Dibbern	EUMETNET	Network of European Meteorological Services	Europe
Jerome Lafeuille	WMO	WMO Space Observing Systems Division, OBS Department	International
Geoffrey Love	WMO	WMO Weather and Disaster Risk Reduction Department (WDS)	International
Wenijan Zhang	WMO	WMO Observing and Information Systems Department	International
Climate SBA liaison			
Stephan Bojinski	GCOS	GCOS Secretariat	International

Table 1 : AG Members, including: Name, GEO Member Country or Participating Organization, Organizational Affiliation, Geographic Region, Specialty/Area of Expertise.

The Analyst identified the Advisory Group members primarily through personal contacts and references. The Analyst attempted to recruit Advisory Group members from all geographic regions and multiple developing countries. The Analyst contacted 13 people to participate on the Advisory Group. 7 expressed interest; 5 did not respond; and 1 was unable to participate but provided document references or suggestions for other possible Advisory Group members. Finally, Advisory Group members were only recruited from international organizations. It is noted that WMO has established six Regional Associations, which are responsible for the coordination of meteorological, hydrological and related activities within their respective Regions: Region I (Africa), Regional II (Asia), Region III (South America), Region IV (North America, Central America and the Caribbean), Region V (South-West Pacific) and Region VI (Europe). Via memberships in these Regional Associations, developing countries are involved in different consultation processes of WMO.

The primary roles of the AG were to assist in identifying documents, assess methodologies and analytic techniques, review findings, and review reports. The primary contact with the AG was through emails and telephone calls; the Advisory Group met once (in person) during the course of the analysis.

2.3. Methodology

This chapter provides a general description of the processes, analytic methods, and approaches the Analyst used to identify documents, analyze them, and establish a set of priority Earth observations.

It responds to the existence of comprehensive requirement studies in the weather domain and describes decisions regarding priority-setting activities in relation to this situation.

2.3.1. Documents and other information sources

In an initial step, relevant information has been retrieved from the web pages of relevant international organizations (i.e., United Nations organizations, other international organizations, (space) agencies, application area expert networks and other user communities). Many of the documents used in this analysis have been identified and retrieved via these web pages. In addition, the advisory group reviewed the initial document list and provided amendments and updates to the list, e.g., by taking most recent versions of documents into account.

To identify missing documents and to close apparent information gaps in existing documents, interviews were conducted at various occasions and by directly involving selected experts, which represented specific application areas.

2.3.2. Analytic Methods

In the area of weather forecasting and related sciences, user requirement analyses have been conducted by different national, regional and international organizations for decades. The available information on user requirements for different application areas and different user communities are comprehensive and the corresponding mechanisms, which have been developed to gather these requirements, show a high level of maturity.

For example, the Rolling Requirements Review (RRR) of the World Meteorological Organization (WMO) gathers and analyzes requirements from a number of WMO programs representing different application areas. The RRR is a formalized mechanism with regular updates of requirements involving key user groups, stakeholders and organizations. These WMO requirements, together with requirements of other organizations, are recorded in a database maintained by WMO. Furthermore, capabilities of current space-based Earth observation systems are recorded in a database maintained by CEOS (Committee on Earth Observation Satellites) and assessed against user requirements. Suggestions for future developments of observation systems are made. The RRR process leads to a number of guidance documents, the so-called Statements of Guidance (SOG), which contain Earth observation priorities for a number of selected application areas. Additional existing documents and requirement analyses cover user needs expressed in preparation of satellite systems and services, such as the mission requirements for different satellite missions and programs of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) or of the European Space Agency (ESA).

The Analyst took advantage of this situation and summarized the most important findings of different studies conducted by the meteorological community. Chapter 4 includes excerpts from relevant documents for each identified application area. In addition, for each application area, tables list all relevant EO parameters which have been mentioned in the analyzed documents. The tables allow for an easy back-tracking of the mentioned EO parameters to the source documents, where further details on the parameters are available.

It needs to be highlighted that the considered studies have been conducted in the framework of international consultation processes. Therefore, their focus often lies on those requirements, which are significant on an international level and relevant for specific application areas and satellite missions without explicit consideration of regional or national priorities. Further documents covering regional and national interests need to be identified with support of GEO in the framework of future studies of GEO Task US-09-01a to analyze emerging regional and national user requirements in the context of GEOSS.

2.3.3. Prioritization Methods

The GEO Task US-09-01a envisages a meta-analysis of the results and observation needs expressed in existing, publicly-available documents compiled, e.g. by GEO Member Countries and Participating Organizations.

Priority EO parameters have already been determined in the framework of many of the studies available for this analysis. These priorities are the result of high-level international consultation processes involving major user/expert communities in the field of meteorology. Therefore, the Analyst decided to gather all EO parameters, which have been identified as priority EO by the individual organizations and application communities, in Chapter 5. Simple bibliographical methods to determine EO priorities, such as weighted indices and document weightings, have not been used in this meta-analysis. In case user/expert communities refrained from defining EO priorities for the respective application areas, no EO priorities have been mentioned in the Report. In addition, hyperlinks are provided to access online databases and publicly available documents, which provide detailed and up-to-date information on the observation requirements of priority Earth observation parameters.

In summary, a 4-level prioritization approach has been followed in this analysis:

- **Level 1:** All relevant EO parameters mentioned in the analyzed literature. Here, “relevant parameters” are all parameters mentioned, discussed, assessed in the available documents, irrespective of assigned priorities. (results presented in Chapter 4)
- **Level 2:** All EO parameters, which have been identified as priority parameters in the literature (cf. Chapter 5.1 for further information on methodology; results presented in Chapters 5.2.1 to 5.2.9)

- **Level 3:** Subset of the EO parameters identified under Level 2. High priority EO parameters are identified in a summary Table (cf. Chapter 5.1 for further information on methodology; results presented in Chapter 5.2.10, Table 13)
- **Level 4:** Subset of the EO parameters identified under Level 3. All parameters, which are relevant for at least two different application areas (if only two application areas have been mentioned, one of these needs to be R-NWP, G-NWP, NWC or SIA). A further prerequisite is a record in the databases and tables on EO characteristics, which have been identified in the literature. (results presented in Chapter 5.2.11, Table 14)

3. Weather SBA

This chapter provides summary information of the Weather SBA and the specific sub-areas. This chapter also discusses the specific documents used in the meta-analysis (general discussion rather than specifics on each document) and the broad user-types within the SBA.

3.1. Weather SBA Description

As detailed in the GEOSS 10-year Implementation Plan (TYIP), **activities within the Weather SBA aim at improving weather information, forecasting and warning**. The main topics and outcomes of the Weather SBA are characterized in the TYIP as follows: "The weather observations encompassed by GEOSS are based on the requirements for timely short- and medium-term forecasts. GEOSS can help fill critical gaps in the observation of – for example – wind and humidity profiles, precipitation, and data collection over ocean areas; extend the use of dynamic sampling methods globally; improve the initialization of forecasts; and increase the capacity in developing countries to deliver essential observations and use forecast products. Every country will have the severe weather event information needed to mitigate loss of life and reduce property damage. Access to weather data for the other societal benefit areas will be facilitated."

For each of the GEO SBAs, strategic targets have been defined in the TYIP. These two-, six- and ten-year targets have been reviewed and accepted by GEO Plenary VI (Nov. 2009, Washington DC) with a view to the visions and goals expressed in the TYIP and its accompanying Reference Document. The strategic targets have been reviewed through a process that includes a gap analysis and the GEOSS Monitoring and Evaluation framework to achieve alignment of the GEO 2009-2011 Work Plan and following Work Plans. Taken together, the strategic targets, the Work Plan and the Monitoring and Evaluation framework will constitute an updated holistic view of GEO, and thus allow for a ready grasp of the work and direction of GEO. GEO will review the strategic targets before each GEO Summit and recommend any adjustment. This review will be conducted in connection with the Monitoring and Evaluation framework.

The strategic targets respond to the call of the 2008 G8 Summit in Toyako to accelerate GEOSS efforts to meet the growing demand for Earth observations. Also, they are a further step towards addressing the challenges articulated by the 2002 World Summit on Sustainable Development, including the achievement of the Millennium Development Goals.

The current strategic target for the Weather SBA is cited from a strategic document prepared by the GEO Target Task Team (T3) (Document 12, Revision 1, accepted by GEO VI, 18th November 2009; GEO 2009, p. 19):

"Before 2015, GEO aims to:

14. Close critical gaps in meteorological and related ocean observations, and enhance observational and information capabilities for the protection of life and property, especially with regard to high-impact events, and in the developing world.

This will be achieved through:

- the programmes and activities of the World Meteorological Organization (WMO), and building on enhanced observational capabilities, which will:
    - monitor the performance and impact of global meteorological and related ocean observing systems, and facilitate the closure of critical gaps in observations and capabilities, utilizing a mix of space-based and *in-situ* observing systems as appropriate;
    - make progress towards implementing the Vision for the Global Observing System 2025;
    - encourage the design and implementation of optimal observational networks to better meet the needs of users for observational data;
    - promote the improvement of data assimilation, modeling systems, and verification and assessment techniques;
    - advance the use of observations in forecasting and warning services globally, advocate for research and development in key areas and encourage the rapid transfer of related research outcomes into operational use, especially in developing countries;
    - encourage more direct, two-way interactions between users, managers of observing systems and providers of forecasts, building on enhanced observational capabilities, to improve the forecast process;
    - provide integrated data collection and automated dissemination of observational data and products, as well as data discovery, access and retrieval services.

This will be demonstrated by:

- Identification and addressing of critical gaps in observational networks that reflect, in particular, the needs of developing countries, the need for continuity in space-based and in-situ observations, and the potential benefits of an interactive observing system to support user needs.
- Improvements in the range and quality of services for high impact weather forecasting due to the design, future development, and operation of global observing, data assimilation, numerical modelling, and user application techniques.
- More accurate, reliable and relevant weather analyses, forecasts, advisories and warnings of severe and other high impact hydrometeorological events enabled by enhanced observational capabilities."

3.2. Sub-areas

The following chapters provide an overview of the major application areas within the Weather SBA, which have been identified in the framework of this analysis. As a starting point for the list of application areas given below, the WMO Statements of Guidance (SOG) have been consulted. The SOG primarily cover application areas, which are deemed necessary to fulfill the requirements of WMO programs. However, these application areas are also the most important ones as regards the GEO Weather SBA as they address the requirements for weather information, forecasting and warning. The following chapters contain significant contributions from the SOG, which provide comprehensive descriptions of several application areas for which precise user requirements have been gathered and recorded by WMO in a quantitative way, and an assessment of corresponding observation priorities. All excerpts from the SOG are printed in *Italic*. The following application areas are covered by the SOG (document status given in parentheses):

- Global Numerical Weather Prediction (G-NWP) (9 December 2008)
- Regional Numerical Weather Prediction (R-NWP) (13 Feb 2009)
- Synoptic Meteorology (June 2008)
- Nowcasting and Very Short Range Forecasting (NWC/VSRF) (Jan 2009)
- Seasonal and Inter-annual Forecasts (SIA) (April 06/April 08)
- Aeronautical Meteorology (June 2008)
- Atmospheric Chemistry (July 2004)
- Ocean Applications (June 2008)
- Agricultural Meteorology (July 2004)
- Hydrology (July 2008)

3.2.1. Global numerical weather prediction (G-NWP)

"Global Numerical Weather Prediction (NWP) models are used to produce short- and medium-range weather forecasts (out to 15 days) of the state of the troposphere and lower stratosphere, with a horizontal resolution of typically 15-100 km and a vertical resolution of ~1km. Global NWP models are used to provide boundary conditions for regional NWP models; forecasters use NWP model outputs as guidance to issue forecasts of important weather variables.

To initialise these models, an accurate estimate of the complete atmospheric state is required. Observations from surface-based, airborne and space-based platforms are all used to help define this initial state. The observational requirements for global NWP are based on the need to provide an accurate analysis of the complete atmospheric state at regular intervals (typically every 6 hours). Through a "data assimilation" system, new observations are used to update and improve an initial estimate of the atmospheric state provided by an earlier short-range forecast. […]" (WMO 2008b)

3.2.2. Regional numerical weather prediction (R-NWP)

"Regional Numerical Weather Prediction (NWP) models are intended to produce more detailed forecasts than those available from global models. The added detail is made possible by a finer computational grid on a specific area, more detailed specification of terrain, more sophisticated prescription of physical processes, and, ideally, denser and more frequent observations (with respect to global NWP) to specify appropriately detailed initial conditions. Because most regional models depend upon global models for their lateral boundary conditions, the duration of regional forecasts is effectively limited by the size of the computational domain to 2 or 3 days lead-time. This argument is also valid for variable-resolution models which are another way to "regionalize" the forecast, the most current technique being LAM (Limited Area Models). Typical horizontal resolutions are 2 to 10 times higher for regional models compared to global models. A typical vertical resolution for a regional model is the same as for a global model, except it has generally more levels in the lower troposphere and less in the stratosphere; the top level is generally lower compared to global models and it does not reach the mesosphere. Regional models are more likely to cover land areas than ocean, but oceanic buffer zones upstream from heavily populated areas are

often included. The tendency for the future is an increased variety of regional models operated in routine, for specific applications and very specific areas (aviation, marine, pollution and urban meteorology).

Most of the time regional models are initialized through the assimilation of observations. However they are sometimes operated in "dynamical adaptation mode", which means that their initial state is simply interpolated from the global analysis of the coupling model: in this case the regional model initial state is entirely dependent on the observations entering the global model. The regional data assimilation schemes often require more frequent analyses (every 6, 3 or 1h), and then more frequent observations with a shorter delivery delay. Otherwise, the regional data assimilation schemes use most of the observations entering the global models, on their area of interest. […]" (WMO 2009h)

3.2.3. Synoptic meteorology

"Synoptic Meteorology could be defined as the activity performed by a human forecaster when predicting the weather at time scales from one hour to several days, and at related space scales. Numerical Weather Prediction (NWP) output (global, regional and ensembles) play a vital role in forecasting; and information benefiting these models benefits synoptic meteorology. Many uses of the observations in synoptic meteorology are thus related to numerical models:

- *to evaluate the value of model output by comparing the analysis and early frames of a forecast (regarding timing, location and intensity of synoptic-scale features);*
- *to take appropriate mitigating action if a mismatch exists between model output and observations;*
- *to capture smaller-scale details that are unresolved by the models; and,*
- *to verify forecasts a posteriori.*

[…] *Contrary to a NWP data assimilation system, where the goal is to estimate each atmospheric variable on a more or less regular grid, synoptic meteorologists attempt to depict meteorological phenomena in an object-oriented way.* […]" (WMO 2008f)

3.2.4. Nowcasting and Very Short Range Forecasting

"Nowcasting is carried out in regional or national forecast centres the present moment, then, based on these observations and numerical weather prediction models (NWP) to make forecasts from zero to 2 hours. Very Short Range Forecasting (when meteorologists analyse observational data to make a diagnosis of the atmospheric state at VSRF) has a period of validity of up to 12 hours. Depending on the phenomena, nowcasting and VSRF cover spatial scales from the micro-alpha (hundreds of metres to 2 km) to the meso-alpha (200-2000 km). Temporal scales are from a few minutes to 12 or more hours. At the larger end of the spatial and temporal scales, there is a transition to synoptic scale phenomena such as extratropical and tropical cyclones.

While nowcasting is largely based on observational data, VSRFs are now being generated based on high-resolution regional numerical weather prediction models. These models will *increasingly be used to provide guidance for meteorologists making detailed nowcasts and VSRFs.*

While nowcasting can be done over any region, it is more frequently practised over areas having, for example, cities, airports, marine and lakes recreation areas or for special events and large venues such as the Olympics Games or other sport events, or special missions like interventions in wild fires, floods, polluted or contaminated areas, or regions where emergency forces have to act.

Nowcasting and VSRF techniques are particularly applicable to satisfy specific tasks of aeronautical meteorology such as Terminal Aerodrome Forecasts (TAF). We can actually say that Nowcasting and VSRF were first practiced and developed due to the needs of the aeronautical meteorology. The data requirements of aeronautical meteorology include and expand upon those of nowcasting and VSRF.

Nowcasting and VSRF techniques can be applied to many phenomena, but are most frequently used to forecast: (1) convective storms with attendant phenomena; (2) mesoscale features associated with extra-tropical and tropical storms; (3) fog and low clouds; (4) locally forced precipitation events; (5) sand and dust storms; (6) wintertime weather (ice, glazed frost, blizzards, avalanches), and, (7) wild fires and contaminated areas. While there is some commonality with synoptic meteorology in forecasting these phenomena, nowcasting focuses greater attention on short time scales and fine spatial resolution covering small geographic areas. In the last years there is a clear tendency to develop the nowcasting of "severe" weather, which requires a special operational routine for the issue of warnings, based on specific regional needs and following specific national or administrative regulations and thresholds. […]" (WMO 2009i)

3.2.5. Seasonal and Inter-annual Forecasts

"Coupled atmosphere-ocean models are used to produce seasonal-to-inter-annual forecasts of climate. While empirical and statistical methods are also used to predict climate conditions a season ahead, the present assessment [i.e. in the framework of the SOG] *of how well observational requirements are met relates only to the coupled model inputs. It is noted that historical data sets also play an important role in SIA prediction by supporting calibration and verification activities.*

Whilst such forecasting is still subject to much research and development, many seasonal forecast products are now widely available. The complexity of the component models ranges from simple models to full general-circulation-model representations of both the ocean and atmosphere. There is also large variation in the approach to the assimilation of initial data, with some of the simpler models assimilating only wind information while the more complex models usually assimilate sub-surface temperature information and satellite surface topography and temperature data. Indeed, major challenges remain in the development of assimilation techniques that optimise the use of observations in initialising models.

The time and space scales associated with seasonal-to-interannual variability (large scale, low frequency) suggest the key information for forecasts will derive mostly from the slow parts of the climate system, in particular the ocean, but also the land surface. When considering impacts such as rainfall deficiencies or increased temperatures over land, *however, there are very good reasons for considering variables associated with the land surface conditions. In particular, land surface moisture and vegetation should be specified and predicted. The models should also include up-to-date radiative forcing (e.g., greenhouse forcing), which are important for maximising skill in forecasts of land-surface air temperature anomalies relative to recent historical reference-normal periods.*

In this list of observation needs, the requirements for SIA forecasts are based on a consensus of the coupled atmosphere-ocean modelling community. It builds on the requirements for Global NWP and represents in addition those variables that are known to be important for initialising models or for testing and validating models. […]" (WMO 2008e)

3.2.6. Aeronautical Meteorology

"Aeronautical Meteorology has a global role, its users range from pilots, air traffic control and management to airline dispatch offices as well as airport authorities. En route forecasts for Instrument Flight Rules (IFR) flight planning purposes are mostly based on the International Civil Aviation Organization (ICAO) World Area Forecast System (WAFS), whereby fixed-time forecasts of wind, temperature and significant weather [SIGWX] *information are provided. The accuracy of upper wind and temperature forecasts is crucial for optimal flight planning, which apart from direct economical consequences also has an impact on the climate impact of aviation, i.e., its fuel consumption and resulting GHG emission. This forecast accuracy critically depends in turn on highly accurate observations of these parameters, in particular near jet streams where sharp gradients of wind speed and temperature lead to large absolute errors where such systems are incorrectly positioned.* […]" (WMO 2008a)

3.2.7. Atmospheric Chemistry

"Research has demonstrated the important consequences of [..] *changes* [i.e. changes of atmospheric composition associated with an increase in human population and activity, especially since the industrial revolution of the 19th century] *for climate, human health, the balance of ecosystems, and the ability of the atmosphere to cleanse itself of harmful pollutants and greenhouse gases. The awareness that chemical species in the atmosphere are key elements of the Earth system, and public concern about the impact of human activities, has led international organisations, such as WMO, UNEP and ICSU, to support national and international research programmes and assessments.*

On 27 May 2004, the partners in the International Global Observing Strategy (IGOS) approved the atmospheric chemistry theme report addressing the rationale and priorities in the next 15 years for an Integrated Global Atmospheric Chemistry Observations (IGACO) system. IGACO is a highly focused strategy for bringing together ground-based, aircraft, and satellite observations of 13 chemical species in the atmosphere using atmospheric forecast models that assimilate not only meteorological observations but also chemical constituents. The report [i.e. IGACO Theme Report] *critically assesses the status of current observing systems, the requirements on accuracy/precision and spatial/temporal resolution, and the current state of modelling chemical cycles in forecast and climate models. It recommends specific steps to be taken in a phased approach* […] *and forms the basis of this WMO OPAG/IOS Statement of Guidance on Atmospheric Chemistry.* […] *IGACO is the framework* *with which atmospheric composition observations will be brought together in the planned Global Earth Observations System of Systems* [GEOSS]. […]

The architecture of the IGACO system takes into account the fact that an integrated system for atmospheric chemistry observations is comprised not only of observational networks and satellites but also of quality assurance, data archiving and modelling facilities that are held together with efficient and universally accepted data flow mechanisms. […] *Essential components include a system for data collection from various sources, a system for distribution of the data to users and of archiving these data for establishing long-term records, as well as a system for end-to-end quality assurance and quality control that quantifies the uncertainties in the data.* […]

Four grand challenges in atmospheric chemistry underlie the environmental issues indicated above (a) tropospheric air quality; (b) atmospheric oxidation efficiency; (c) stratospheric chemistry and ozone depletion; and (d) chemistry - climate interactions. The scientific understanding of each challenge requires long-term observation of the atmosphere, and points firmly to the need to establish an integrated global atmospheric chemistry observation system. […] *It is possible to study and monitor the four grand challenges in atmospheric chemistry issues by observing a number of chemical compounds, aerosol properties, and other parameters.* […]*"* (WMO 2004b)

Atmospheric chemistry represents an important application area of weather related Earth observations. Observations of atmospheric chemistry serve a number of sub-areas in the field of weather forecasting. In addition, important application areas exist in the Health SBA (see Chapter 3.2.11). However, as the Report is focused on sub-areas of weather forecasting, and due to a strong cross-cutting nature of observations of atmospheric chemistry, requirements for Earth observations for atmospheric chemistry are covered in the chapters on G-/R-NWP, Synoptic Meteorology, NWC/VSRF and SIA.

In the framework of the European GMES (Global Monitoring for Environment and Security) initiative, different projects aim at the delivery of atmospheric services: "The pre-operational atmosphere service of GMES is currently provided through the FP7 project MACC, which is continuing and refining the provision of the main sets of data products provided by PROMOTE and GEMS, two projects funded by the European Space Agency and the European Commission respectively. MACC's product lines include data records on atmospheric composition for recent years, and current data for monitoring present conditions and forecasting the distribution of key constituents for a few days ahead. They address the following:

- Greenhouse gases
- Reactive gases […]
- Ozone layer and solar UV radiation
- Aerosols, which affect temperature, air quality and the transmission of solar radiation." (GMES 2009)

3.2.8. Ocean Applications

"Marine Meteorology and Oceanography have a global role and embrace a wide range of users from international shipping, fishing and other met-ocean activities on the high seas to

the various activities which take place in coastal and offshore areas and on the coast itself. In preparation of analyses, synopses, forecasts and warnings, knowledge is required of the present state of the atmosphere and ocean. There are three major met-ocean application areas that critically depend on highly accurate observations of met-ocean parameters: (a) Numerical Weather Prediction (NWP); (b) Seasonal to Inter-annual Forecast (SIA); and, (c) Met-Ocean Forecasts and Services (MOFS), including marine services and ocean mesoscale forecasting. […] *Met-ocean Services which refer to special elements, such as waves, storm surges, sea-ice, ocean currents, etc., critically depend on relevant observational data."* (WMO 2008d)

Met-ocean applications represent an important application area of weather related Earth observations. However, as the Report is focused on sub-areas of weather forecasting, and due to a strong cross-cutting nature of observations of ocean observations, requirements for Earth observations for ocean applications are covered in the chapters on G-/R-NWP, Synoptic Meteorology, NWC/VSRF and SIA.

3.2.9. Agricultural Meteorology

"Weather data are needed on a regular basis by the agriculture, forestry and fisheries sectors for both strategic and tactical applications. These data assist the land management agencies in a variety of projects such as monitoring air quality, rating fire danger, and providing information for research applications. The collection of agrometeorological data is critical for running different crop weather- yield models for the assessment of the state of the crops and for forecasting their yields. […]" (WMO 2004a)

3.2.10. Hydrology

"The collection of hydrological data is crucial to improve our understanding of the hydrological cycle. They contribute to weather and climate-related scientific and application issues, as well as to improved water resources management through better assessment methods. The availability of hydrological extremes also makes a contribution to the reduction of the impacts of disasters. […]" (WMO 2008c)

"Hydrometeorology is a branch of meteorology that deals with problems involving the hydrologic cycle, the water budget, and the rainfall statistics of storms. The boundaries of hydrometeorology are not clear-cut, and the problems of the hydrometeorologist overlap with those of the climatologist, the hydrologist, the cloud physicist, and the weather forecaster. Considerable emphasis is placed on determining, theoretically or empirically, the relationships between meteorological variables and the maximum precipitation reaching the ground. These analyses often serve as the bases for the design of flood-control and water-usage structures, primarily dams and reservoirs. Other concerns of hydrometeorologists include the determination of rainfall probabilities, the space and time distribution of rainfall and evaporation, the recurrence interval of major storms, snow melt and runoff, and probable wind tides and waves in reservoirs. The whole field of water quality and supply is of growing importance in hydrometeorology." (Encyclopædia Britannica 2009)

3.2.11. Additional application areas

It should be stressed that end-users of weather information and services are presently to be found in a variety of application areas, thus serving many SBAs including:

- Disasters, since most natural disasters either have an hydrometeorological origin or are affected in their development by weather conditions;
- Health, with increasing attention being paid by civil authorities to heat and cold waves, air quality, UV radiation, and the spreading of disease vectors resulting of meteorological and climate conditions;
- Energy, taking into account the direct impact of weather conditions on power demand as well as on the operating conditions of hydraulic and thermal power plants, wind and solar energy;
- Agriculture, as pointed out in the SOG on agricultural meteorology.

Weather information also plays a key role for transportation activities including not only aeronautical transportation as described above but also maritime and terrestrial transport.

The list of applications is much wider, but many other application areas are not yet at the stage where direct and precise requirements for weather data can be expressed. It is anticipated, however, that the GEO Task US-09-01a will contribute to the identification of further application areas of weather observations relevant for other SBAs. This will be pursued by a meta-analysis to be conducted by the UIC, which aims at identifying Earth observation priorities relevant for many SBAs. The author anticipates that additional application areas and associated requirements for weather observations beyond those covered in the Report will be identified in the framework of the UIC meta-analysis.

3.3. Documents

To perform this analysis, more than 50 documents have been gathered and reviewed regarding information on the need of Earth observation parameters for a number of different application areas. The identified documents have been assigned to seven different categories to better assess their level of representativeness and significance:

Category I. High-level international consensus documents on Earth observation requirements and priorities for ‘weather’ applications

Category II. High-level international position papers

Category III. High-level international programmatic documents

Category IV. Satellite mission requirement documents

Category V. National studies on Earth observation needs and priorities

Category VI. Regional studies on Earth observation needs and priorities

Category VII. Other relevant documents with background information

As Figure 1 illustrates, the majority of the available documents belong to Categories I and II. So far, the focus of the documents lies on international and European organizations and programs. In the framework of an update of this GEO user requirement study, further documents need to be identified by the meteorological expert community. The document database would especially benefit from further studies addressing regional and national Earth observation needs and priorities (belonging to Categories II, IV, V and VI) in other parts of the world.

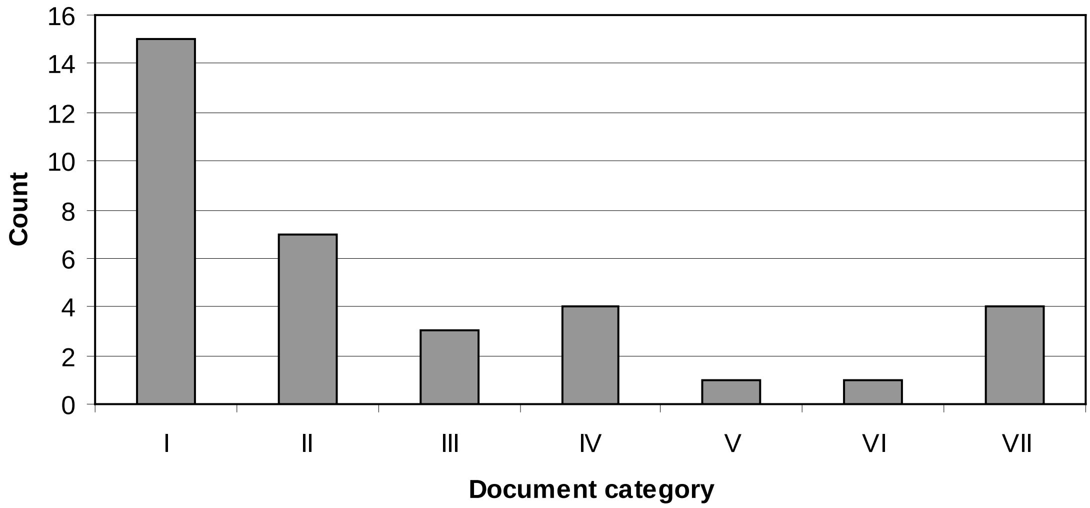

Figure 1 : Number of analyzed documents per document category.

In the following, the document categories are further described and examples for typical documents are given in each category.

Category I. High-level international consensus documents on Earth observation requirements and priorities for 'weather' applications

This category mainly includes the Statements of Guidance (SOG) compiled by WMO, which contain Earth observation priorities for a number of selected application areas of international/global relevance. The SOG have been compiled in the framework of the Rolling Requirements Review (RRR) of WMO, which is based on a database maintained by WMO and CEOS containing Earth observation requirements gathered from a number of international organizations representing different application areas. The SOG contain results of an assessment of the capabilities of current Earth observation systems with regard to user requirements and suggestions for future developments of observation systems. The RRR represents a formalized mechanism with regular updates of requirements involving key user groups, stakeholders and organizations.

The application areas covered by WMO documents and the WMO/CEOS database show that WMO already considers many application areas with a cross-cutting nature, which fall under different SBAs within the GEO context. However, as the thematic focus of the Weather SBA analysis lies on applications related to weather information, forecasting and warning, emphasis was placed on analyzing the WMO documents regarding requirements and priorities addressing meteorological applications.

Additionally, an important document of this category is the Dossier on the Space-based Component of the Global Observing System (GOS), which is compiled in the framework of the WMO Space Programme. The dossier reviews the status of existing satellite programs and provides information on available instruments. Long-term evolution of the programs is analyzed to discover possible gaps of service. Finally, a major achievement of the dossier is an analysis of the compliance of current Earth observation systems with user requirements.

Example document: Statement of Guidance for Global Numerical Weather Prediction (WMO 2008b)

Category II. High-level international position papers

The available position papers have been compiled in the framework of consultation processes for the development of different satellite systems, missions and services of EUMETSAT. With regards to representativeness and significance, these documents are largely comparable to *Category I* documents. Also, substantial detail on observational requirements is provided – the appendix of the position papers lists requirements regarding accuracy, spatial and temporal resolution and timeliness. It is noted, that the focus of *Category I* documents lies on technical aspects and observational requirements related to the EUMETSAT satellite systems Meteosat Third Generation (MTG) and Post-EPS (EPS stands for the EUMETSAT Polar System). EUMETSAT position papers have been compiled by Application Expert Groups (AEG), which represent user communities in the following application areas:

- MTG:
  - Global Numerical Weather Prediction
  - Regional Numerical Weather Prediction
  - Nowcasting and Very Short Range Forecasting
- Post-EPS:
  - Operational atmospheric chemistry monitoring
  - Atmospheric Sounding and Wind Profiling
  - Cloud, Precipitation and Large Scale Land Surface Imaging (CPL) – Meteorology, Hydrology, Climate
  - Ocean Surface Topography and Imaging

Whereas the MTG documents cover relevant application areas as regards the GEO Weather SBA, the Post-EPS positions papers are focused on dedicated applications of satellite missions, which provide relevant Earth observations for a number of application areas in the Weather SBA. However, these requirements do not address an application area in the context of the Weather SBA as such.

Example document: Observational requirements for ocean observations relevant to Post-EPS (EUMETSAT 2007)

Category III. High-level international programmatic documents

To complement the information on Earth observation priorities, the documents in *Category III* have been included in this analysis. These documents provide valuable background information on the programmatic framework of Earth observations in the weather domain. The documents include, e.g. the Vision for the Global Observing System (GOS) in 2025 (WMO 2009j) and preparatory documents for the WMO Integrated Global Observing System (WIGOS). The latter is "a concept for a comprehensive, coordinated and sustainable system of observing systems. WIGOS is based on all WMO Programmes' observational requirements. It will provide a single focus for the operational and management functions of all WMO observing systems as well as a framework and mechanism for interactions with WMO co-sponsored observing systems enabling integration, cooperation and coordination taking into account the multiplicity of perspectives and observing domains covered by WIGOS" (WMO 2009k).

Example document: WMO Vision for the GOS in 2025 (WMO 2009j)

Category IV. Satellite mission requirement documents

These documents have a strong technical focus on the specifications of satellite systems. In most cases, these satellites deliver Earth observation data for multiple application areas and beyond applications related to weather information, forecasting and warning. However, user needs are an important component of these documents and represent an important basis for the documented (technical) mission requirements. *Category IV* documents provided valuable additional information on specific user needs and user types beyond the information contained in *Category I* and *Category II* documents. For example, ESA 2007 contains four categories of users, which have been defined in the context of the European GMES (Global Monitoring of Environment and Security) initiative and characterizes them in detail:

- Operational users;
- Institutional national and regional organizations delegated to undertake specified activities;
- Research organizations;
- GMES Service Providers (ESA and EU)

Example document: Sentinel-3: Mission Requirements Document (ESA 2007)

Category V. National studies on Earth observation needs and priorities

Beyond global Earth observation requirements, the needs of regional and national user communities need to be considered in the framework of the GEO Task US-09-01a. For this analysis, only two national studies from Germany and the USA could be identified. However, they contain important information, e.g. on specific national needs for certain application areas and on planned satellite missions such as NPOESS or GOES-R.

Example document: Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond. (National Research Council 2007)

Category VI. Regional studies on Earth observation needs and priorities

The European GMES (Global Monitoring for Environment and Security) initiative launched different services, which provide Earth observation data and derived products on regional, European and global scales. The operational phase of GMES (envisaged for 2011) is currently prepared by pre-operational projects in five different application areas:

- Land Environmental Services (Project geoland2)
- Marine Environmental Services (Project MyOcean)
- Support to Emergencies and Humanitarian Aid (Project SAFER)
- Atmospheric Environmental Services (Project MACC)
- Support to security-related activities (Project G-MOSAIC)

In preparation of the above mentioned services (so-called “Core Services”), many projects have been conducted for specific application areas and user communities. Available documents prepared by these GMES projects represent an important information source for user requirements in the European context.

In the framework of future GEO user requirement studies, this document category needs to be amended with further documents on regional EO needs and priorities.

Example document: GMES Service Element PROMOTE U5 Core User Needs Dossier (GMES 2005)

Category VII. Other relevant documents with background information

Finally, documents were gathered, which contain relevant background information for this analysis. The simultaneous use of Earth observations within the Weather SBA and the Climate SBA is associated with synergistic effects. Therefore, reports on Earth observations for climate applications and associated programmatic implications are also relevant for the Weather SBA.

Category VII includes key reports by the Global Climate Observing System (GCOS), e.g. containing a list of priority observations called Essential Climate Variables (ECV). For more information on these documents, the reader is referred to the description of Category I documents in the Climate SBA report.

Example document: GCOS Essential Climate Variables (GCOS 2009)

A key premise for the SBA analysis is to assure a representative sampling of documents and information sources. This first systematic study on user requirements and Earth observation priorities for the Weather SBA follows a top-down approach to identify existing studies and documents. Thus, mainly studies of GEO Member States and Participating Organizations have been included in this analysis. The methods to conduct those studies have been developed and refined over many years to ensure a representative picture of the needs for Earth observation parameters for individual application areas primarily with a global perspective. In the framework of future studies on Earth observation priorities, additional documents need to be identified by GEO to further consider regional and national Earth observation priorities, explicitly addressing the needs of developing countries.

4. Earth Observations for Weather SBA

This chapter contains the results from the analysis of the documents and the specific observation parameters/characteristics that the analysis revealed for each sub-area.

The main information sources for this chapter are the SOG documents compiled and updated regularly by WMO. In addition, position papers by application expert groups (AEG) of EUMETSAT and ESA mission requirement documents have been analyzed and provided important additional information and observation needs.

Further to the information provided in the SOG, the reader is referred to the Dossier on the Space-based Component of the Global Observing System (GOS), which is compiled in the framework of the WMO Space Programme. This comprehensive documentation has been compiled annually since 2004 and is regularly presented by WMO to the annual meetings of the Coordination Group for Meteorological Satellites (CGMS). It is based on user requirements gathered by WMO and CEOS (documented in the WMO/CEOS Database on Observational Requirements) and the Application Expert Groups (AEG) of EUMETSAT. The EUMETSAT "requirements have been compiled with due consideration of the NOAA requirements for GOES-R and NPOESS" (WMO 2009b, p. 4). The dossier reviews the status of existing satellite programs and provides information on available instruments. Long-term evolution of the programs is analyzed to discover possible gaps of service.
Finally, a major achievement of the dossier is an analysis of the compliance of current Earth observation systems with user requirements (WMO 2009g). The level of compliance is determined for over one hundred geophysical parameters taking existent and potential future gaps and evolution potential into account. For each of the assessed parameters the dossier provides information on accuracy (RMS), horizontal resolution, vertical resolution when applicable (for profiles), observing cycle, and timeliness.

The following chapters contain significant contributions from the WMO Statements of Guidance (SOG). The SOG contain assessments of the relevance of Earth observation parameters for each application area considered within the Rolling Requirements Review (RRR) process. All excerpts from the SOG are printed in *Italic*. Being a major basis for the Rolling Requirements Review (RRR) process, the WMO/CEOS Database on Observational Requirements contains detailed observation characteristics for each of the parameters required by the individual user communities. The observational requirements for G-NWP can be found under WMO data requirements.

4.1.1. Earth Observations for Global Numerical Weather Prediction (G-NWP)

"The key model variables for which observations are needed are: 3-dimensional fields of wind, temperature and humidity, and the 2-dimensional field of surface pressure. Also important are boundary variables, particularly sea surface temperature, and ice and snow cover. Of increasing importance in NWP systems are observations of cloud and precipitation. In the latter part of the medium-range, the upper layers of the ocean become increasingly important, and so relevant observations are also needed.

Modern data assimilation systems are able to make effective use of synoptic observations. Observations are most easily used when they are direct measurements of the model variables *(temperature, wind, etc.), but recent advances have also facilitated the effective use of indirect measurements (e.g. satellite radiances, which are linked in a complex but known way to the model fields of temperature, humidity, etc.) and also the extraction of dynamical information from frequent (e.g. hourly) time series of observations.*

The highest benefit is derived from observations available in near real-time; NWP centres derive more benefit from observational data, particularly continuously generated a synoptic data (e.g. polar orbiting satellite data), the earlier they are received, with a goal of less than 30 minutes delay for observations of geophysical quantities that vary rapidly in time. However most centres can derive some benefit from data up to 6 hours old.

In general, conventional observations have limited horizontal resolution and coverage, but high accuracy and vertical resolution. Satellite data provide very good horizontal resolution and coverage but limited vertical resolution, and they are more difficult to interpret and use effectively. Single in situ observations from remote areas can occasionally be of vital importance. Also, a baseline network of in situ observations is currently necessary for "tuning" the use of some satellite data. Observations are more important in some areas than in others; it is desirable to make more accurate analyses in areas where forecast errors grow rapidly, e.g. bar clinic zones. Identifying these areas and "targeting" observations to them is an active area of research." (WMO 2008b, p. 1)

The SOG for G-NWP contains a consolidated assessment of the compliance of observational requirements with existing or planned observing systems and the reader is advised to refer to the current version of the SOG for G-NWP (SoG-Global-NWP.doc) for further details. In particular, the SOG discusses the capabilities of current observation technologies, evolution potential and existing gaps. According to the assessment, the main Earth observation parameters of interest for G-NWP are (cf. WMO 2008b):
.

- 3D wind field – horizontal component
- Surface pressure and surface wind
- 3D temperature field
- 3D humidity field
- Sea surface temperature
- Sea-ice
- Ocean sub-surface variables
- Snow
- Soil moisture
- Surface air temperature and humidity
- Land and sea-ice surface skin temperature
- Vegetation type and cover
- Clouds
- Precipitation
- Ozone
- Wave height, direction and period
- 3D aerosol
- 3D wind – vertical component (no present or planned capability; research required)

In the framework of the EUMETSAT user consultation process, position papers have been prepared, which contain user requirements for application areas to be supported by different

EUMETSAT satellite missions (MTG and Post-EPS). EUMETSAT (2002) addresses user requirements of MTG and provides a list of requirements for observation of specific geophysical variables for G-NWP. This list is based on WMO user requirements database (WMO 2009a) and has been reviewed by the application expert group on NWP and extended where necessary.

According to EUMETSAT (2002, pp. 9-10),

“the following geophysical variables are already analysed by advanced global NWP systems:

- 3D wind (horizontal component)
- 3D temperature
- surface pressure
- surface wind
- 3D humidity
- surface temperature (air)
- surface humidity (air)
- sea surface temperature
- sea ice cover
- snow cover
- soil moisture
- 3D ozone
- significant wave height
- wave direction
- wave period.

It is anticipated that the following additional variables will also be analysed in future, in the medium term:

- cloud cover
- cloud top height
- cloud base height
- 3D cloud water/ice
- surface precipitation
- land surface temperature
- sea-ice surface temperature
- snow water equivalent
- vegetation index and/or leaf area index.

It is anticipated that the following additional variables will also be analysed in future, in the longer term:

- sea-ice thickness
- 3D aerosol
- cloud drop size (cloud-top)
- 3D cloud drop size
- 3D precipitation
- 3D wind (vertical component)
- aerodynamic roughness length.

Important additional variables for which observations are required for model validation, rather than for assimilation, are:

- outgoing longwave radiation
- outgoing shortwave radiation
- surface emissivity spectrum
- albedo
- accumulated precipitation."

Focused on observations of the oceans, EUMETSAT 2007 discusses additional parameters for a number of applications, including G-NWP. Table 2 lists relevant ocean observations related to G-NWP (detailed user requirements are listed tabular form in EUMETSAT 2007).

Observations of atmospheric chemistry, which are relevant for G-NWP, are discussed in EUMETSAT (2006c, p. 8):
"The number of geophysical observables that are assimilated in near real time by NWP models is increasing, and by the post-EPS timeframe will include atmospheric constituents to improve the description of the radiation balance of the atmosphere and as tracers of atmospheric transport […]. Furthermore it is recognised that analysis and forecast of atmospheric composition and provision of support to Regional Air Quality modelling and forecast centres will progressively become a significant part of global NWP activities."

Near-real time ozone data are required for improved radiances in NWP models and as input data for surface UV forecast (ESA 2007b) and to improve radiance calculations and as proxy for lower stratospheric wind (EUMETSAT 2006c). 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 (EUMETSAT 2006c, ESA 2007b).

EUMETSAT (2006c, p. 13) concludes that "the accuracy of atmospheric heating/cooling rates calculated within NWP models can be improved by assimilating observations of the spatially/temporally variable constituents that are most significant. These are, principally, tropospheric humidity and cloud […] together with ozone, aerosol and stratospheric water vapour."

EUMETSAT (2006a) provides a list of geophysical variables with relevance to NWP. These variables are of highest priority in the framework of the Post-EPS mission "Clouds, Precipitation and large scale land surface imaging":

- Cloud cover profile
- Cloud optical depth
- Cloud top temperature
- Cloud liquid water profile and cloud ice profile
- Precipitation profile (liquid and solid)
- Precipitation rate at surface (liquid and solid)
- Aerosol optical depth (profile and total column)
- Surface soil moisture
- Land surface temperature
- Leaf Area Index (LAI)
- Photosynthetically Active Radiation (PAR)

- Snow cover

Relevant Earth observation parameters for G-NWP, which have been identified in the analyzed literature, are listed in Table 2.

Earth observation parameters for Global Numerical Weather Prediction (G-NWP)		Document references						
		WMO RRR	EUMETSAT User Consultation Process				ESA Sentinel mission requirements	
			MTG	Post EPS				
Parameter type	**Parameter**	**WMO 2008b, d**	**EUMETSAT 2002**	**EUMETSAT 2006a**	**EUMETSAT 2006b**	**EUMETSAT 2007**	**ESA 2007a**	**ESA 2007b**
Aerosol properties	3D aerosol	X	X					
	Aerosol effective radius (profile/totel)			X				
	Aerosol optical depth (profile/total)			X				
	Aerosol particle size	X						
	Aerosol particle type	X						
	Aerosol properties	X						
	Aerosol total column amounts	X						
	Aerosol type (profile/type)			X				
	High-aerosol events	X						
Atmospheric chemistry	Near real time ozone data							X
	Ozone fields	X	X					
	Total column ozone	X						
Cloud properties	Cloud base height	X	X	X				
	Cloud cover	X	X	X				
	Cloud drop effective radius (profile/at cloud top)			X				
	Cloud drop-size at cloud top	X	X					
	Cloud ice (profile/total column)			X				
	Cloud liquid water	X		X				
	Cloud mask			X				
	Cloud optical depth			X				
	Cloud top height	X	X	X				
	Cloud top temperature			X				
	Cloud water/ice amounts (3D distribution)	X	X					
	Cloud-drop size (3D distribution)	X	X					
	Clould ice effective radius (profile/at clould top)			X				
	Freezing level height in clouds			X				

Earth observation parameters for Global Numerical Weather Prediction (G-NWP)		Document references						
		WMO RRR	EUMETSAT User Consultation Process				ESA Sentinel mission requirements	
			MTG	Post EPS				
Parameter type	**Parameter**	**WMO 2008b, d**	**EUMETSAT 2002**	**EUMETSAT 2006a**	**EUMETSAT 2006b**	**EUMETSAT 2007**	**ESA 2007a**	**ESA 2007b**
	Melting layer depth in clouds			X				
Humidity	3D humidity	X	X					
	Specific humidity at surface				X			
	Surface air humidity	X	X					
	Troposphere humidity profiles	X						
	Water vapour profile				X			
	Water vapour total column				X			
Precipitation	3D precipitation		X					
	Accumulated precipitation	X	X	X				
	Precipitation (instantaneous)	X						
	Precipitation detection (solid/liquid)			X				
	Precipitation profile			X				
	Precipitation rate at surface (solid/liquid)			X				
	Precipitation type			X				
	Surface precipitation		X					
Pressure	Surface pressure	X	X		X			
Radiation	Component(s) of the Earth's radiation budget	X						
	Downwelling longwave irradiance at Earth surface			X				
	Downwelling shortwave irradiance at Earth surface			X				
	Downwelling solar irradiance at TOA			X				
	Outgoing longwave irradiance at Earth surface			X				
	Outgoing longwave irradiance at TOA			X				
	Outgoing longwave radiation fluxes	X	X					
	Outgoing shortwave irradiance at TOA			X				
	Outgoing shortwave radiation fluxes	X	X					

Earth observation parameters for Global Numerical Weather Prediction (G-NWP)		Document references						
		WMO RRR	EUMETSAT User Consultation Process				ESA Sentinel mission requirements	
			MTG	Post EPS				
Parameter type	**Parameter**	**WMO 2008b, d**	**EUMETSAT 2002**	**EUMETSAT 2006a**	**EUMETSAT 2006b**	**EUMETSAT 2007**	**ESA 2007a**	**ESA 2007b**
	Outgoing spectral irradiance at TOA			X				
	Shortwave cloud reflectance			X				
	Shortwave Earth surface bi-directional reflectance			X				
	Surface albedo	X	X	X				
	Surface emissivity (sea/land)			X				
	Surface emissivity spectrum		X					
	Thermal infra-red	X						
Salinity	Sea surface salinity					X		
Sea ice properties	Sea-ice cover	X	X			X		
	Sea-ice thickness	X	X			X		
	Sea-ice type	X				X		
Snow properties	Snow cover	X	X	X				
	Snow water equivalent	X	X	X				
Soil moisture	Soil moisture	X	X					
	Soil moisture profile			X				
	Surface soil moisture			X				
Temperature	Lake surface temperature			X				
	Land surface (skin) temperature	X	X	X	X			
	Sea sub-surface temperature	X						
	Sea surface temperature	X	X			X	X	
	Sea-ice surface (skin) temperature	X	X		X	X		
	Snow surface temerature			X				
	Surface air temperature	X	X		X			
	Temperature fields / profiles	X	X		X			
Vegetation	Fraction of absorbed PAR (fAPAR)			X				
	Leaf Area Index (LAI)			X				

Earth observation parameters for Global Numerical Weather Prediction (G-NWP)		Document references						
		WMO RRR	EUMETSAT User Consultation Process				ESA Sentinel mission requirements	
			MTG	Post EPS				
Parameter type	Parameter	WMO 2008b, d	EUMETSAT 2002	EUMETSAT 2006a	EUMETSAT 2006b	EUMETSAT 2007	ESA 2007a	ESA 2007b
	Normalised Difference Vegetation Index (NDVI)			X				
	Photosynthetically active radiation (PAR)			X				
	Vegetation cover	X	X					
	Vegetation type	X		X				
Wave properties	Wave direction	X	X			X		
	Wave forecast						X	
	Wave height	X	X			X		
	Wave period	X	X			X		
	Wave spectrum (2D)	X						
Ocean currents	Ocean current advection	X						
	Ocean current dynamics	X						
Wind	Aerodynamic roughness lengh		X					
	Horizontal wind speed (land surface)				X			
	Horizontal wind speed (sea surface)					X		
	Horizontal wind vectors (land surface)				X			
	Horizontal wind vectors (sea surface)				X	X		
	Surface wind	X	X					
	Vertical wind profile				X			
	Wind (3D) – horizontal component	X	X					
	Wind (3D) – vertical component	X	X					
	Wind forecast						X	

EUMETSAT 2006c: No explicit EO parameters have been mentioned explicitly as regards G-NWP. Please see text for further information.
WMO 2008d: EO parameters, which were listed in the SOG on ocean applications with relevance to met-ocean aspects of G-NWP are included in the WMO RRR column.

Table 2 : Earth observation parameters for Global Numerical Weather Prediction (G-NWP).

4.1.2. Earth Observations for Regional Numerical Weather Prediction (R-NWP)

"[…] *The key model variables for which observations are needed are: 3-dimensional fields of wind, temperature and humidity, and the 2-dimensional field of surface pressure. They are the same as for global models. Also very important for regional models are boundary variables, variables describing the surface characteristics, observations of cloud and precipitation. On a time-range of 2 to 3 days, the description of the deep ocean and of the mesosphere is not needed, because it varies too slowly to affect the weather.*

Compared to global NWP, regional models draw less benefit from polar orbiting satellites, and more from geostationary satellites: because of their analysis frequency, they can exploit the observation continuity of a geostationary satellite on a particular area. The LAM [limited area models] *which are operated on densely populated regions are less dependent on satellite data in general than the global models, they are more dependent on surface in-situ observations, boundary layer observations (profilers, frequent sonde launches or aircraft measurements, GPS receiving stations, radars…).* […]" (WMO 2009h, p. 1)

As regards Earth observation needs of R-NWP in contrast to G-NWP, a number of differences have been highlighted by EUMETSAT (2001), especially:

- Stronger requirements on the spatial resolution of the observations due to the increased spatial resolution of R-NWP models;
- Stronger requirements on the timeliness and frequency of the observations, as R-NWP is applied for short-range forecasting and nowcasting purposes.

In addition, EUMETSAT (2001) mentions the need for targeted observations and model runs on demand in case of "challenging weather situations" and points out specific challenges related to the need to find appropriate techniques to couple LAMs to global models.

The SOG for R-NWP (WMO 2009h) contains an assessment of a number of parameters with regard to the compliance of current and planned observation systems with observational requirements. The assessed parameters correspond to the main Earth observation parameters of interest for G-NWP listed in Chapter 4.1.1 above (cf. WMO 2008b). The reader is advised to the SOG for R-NWP for further detail.

EUMETSAT (2001, pp. 17-18) lists a number of variables, which are used (assimilated) in regional NWP models today and in the future:

"Model variables and fields assimilated today:

- Surface pressure
- Vertical profiles of temperature, water vapour and wind
- 2m-temperature and humidity
- 10m wind
- Sea surface temperature
- Fraction of sea ice
- Snow depth
- Soil moisture
- Soil temperature

Model variables and fields intended for assimilation during 2001 – 2015:

- Vertical profiles of cloud liquid water, cloud ice and cloud snow
- Vertical profiles of cloud cover
- Vertical profiles of drop spectra in clouds
- Vertical profiles of precipitation fluxes (rain and snow)
- Vertical profiles of turbulent kinetic energy
- Vertical profiles of aerosols
- Particle spectra in clouds
- Vertical profiles of ozone
- Boundary layer height
- Wave height and spectra in coupled wave models
- Lake surface temperature
- Land surface, soil and vegetation properties:
  - Albedo, surface temperature, water content in soil, surface water (interception reservoir) and emissivity
  - Vegetation fraction, leaf area index, vegetation type (from which the roughness length due to vegetation only will be inferred)
  - Snow cover, snow depth and snow equivalent water
- Sea surface albedo
- Fraction of sea ice and ice thickness

Model variables and fields intended for assimilation in a longer time perspective:

- Soil and vegetation:
  - a differentiation of temperature and emissivity between the soil surface and the canopy
  - a determination of the two components of the roughness lengths: soil rugosity and vegetation type
  - a differentiation between the soil surface temperature (skin temperature) and the temperature in the soil
- Chemical substances, including natural and anthropogenic sources"

The following EO priorities are indicated in EUMETSAT (2001, pp. 23-24):
"The basic dynamic variables of the NWP models will remain the most important to be observed. Thus, we will require surface pressure over sea and profiles of horizontal wind, temperature and water vapour everywhere inside, outside and below clouds with highest priority. Due to the increased importance of moist model processes, very high priority should also be given to surface precipitation intensity. Very high priority should also be given to soil moisture, snow coverage, sea/lake surface temperatures, sea/lake ice coverage and profiles of aerosols."

EUMETSAT (2006a) provides a list of geophysical variables with relevance to NWP. These variables are of highest priority in the framework of the Post-EPS mission "Clouds, Precipitation and large scale land surface imaging":

- Cloud cover profile
- Cloud optical depth
- Cloud top temperature

- Cloud liquid water profile and cloud ice profile
- Precipitation profile (liquid and solid)
- Precipitation rate at surface (liquid and solid)
- Aerosol optical depth (profile and total column)
- Surface soil moisture
- Land surface temperature
- Leaf Area Index (LAI)
- Photosynthetically Active Radiation (PAR)
- Snow cover

Relevant Earth observation parameters for R-NWP, which have been identified in the analyzed literature, are listed in Table 3.

Earth observation parameters for Regional Numerical Weather Prediction (R-NWP)		Document references						
		WMO RRR	EUMETSAT User Consultation Process				ESA Sentinel mission requirements	
			MTG	Post EPS				
Parameter type	**Parameter**	**WMO 2009h, d**	**EUMETSAT 2001**	**EUMETSAT 2006a**	**EUMETSAT 2006b**	**EUMETSAT 2007**	**ESA 2007a**	**ESA 2007b**
Aerosol properties	Aerosol effective radius (profile/totel)			X				
	Aerosol optical depth (profile/total)			X				
	Aerosol profile		X					
	Aerosol type (profile/type)			X				
Atmospheric chemistry	Near real time ozone data							X
	Ozone profile		X					
Cloud properties	Cloud base height	X	X	X				
	Cloud cover	X		X				
	Cloud drop effective radius (profile/at cloud top)			X				
	Cloud drop-size at cloud top	X						
	Cloud ice (profile/total column)			X				
	Cloud liquid water	X	X	X				
	Cloud mask			X				
	Cloud optical depth			X				
	Cloud top height	X	X	X				
	Cloud top temperature			X				
	Cloud type			X				
	Cloud water/ice amounts (3D distribution)	X						
	Cloud-drop size (3D distribution)	X						
	Cloud-drop size profile		X					
	Clould ice effective radius (profile/at clould top)			X				
	Freezing level height in clouds			X				
	Melting layer depth in clouds			X				
Humidity	3D humidity	X						
	Specific humidity at surface				X			
	Surface air humidity	X	X					

Earth observation parameters for Regional Numerical Weather Prediction (R-NWP)		Document references						
		WMO RRR	EUMETSAT User Consultation Process				ESA Sentinel mission requirements	
			MTG	Post EPS				
Parameter type	**Parameter**	**WMO 2009h, d**	**EUMETSAT 2001**	**EUMETSAT 2006a**	**EUMETSAT 2006b**	**EUMETSAT 2007**	**ESA 2007a**	**ESA 2007b**
	Troposphere humidity profiles	X						
	Water vapour profile		X		X			
Precipitation	Accumulated precipitation	X		X				
	Precipitation (instantaneous)	X						
	Precipitation detection (solid/liquid)			X				
	Precipitation profile			X				
	Precipitation rate at surface (solid/liquid)		X	X				
	Precipitation type			X				
	Vertical precipitation flux		X					
Pressure	Surface pressure	X	X		X			
Radiation	Outgoing longwave irradiance at TOA			X				
	Outgoing shortwave irradiance at TOA			X				
	Radiation fluxes	X						
	Surface albedo	X	X	X				
	Surface emissivity (sea/land)	X						
Sea ice properties	Fraction of sea and lake ice		X					
	Sea-ice cover	X				X		
	Sea-ice drift					X		
	Sea-ice thickness	X	X			X		
	Sea-ice type	X				X		
Snow properties	Snow cover	X	X	X				
	Snow water equivalent	X	X	X				
Soil moisture	Soil moisture	X	X					
	Soil moisture profile			X				
	Surface soil moisture			X				
Temperature	Air temperature at surface (land)				X			
	Air temperature at surface (sea)				X			

Earth observation parameters for Regional Numerical Weather Prediction (R-NWP)		Document references						
		WMO RRR	EUMETSAT User Consultation Process				ESA Sentinel mission requirements	
			MTG	Post EPS				
Parameter type	**Parameter**	**WMO 2009h, d**	**EUMETSAT 2001**	**EUMETSAT 2006a**	**EUMETSAT 2006b**	**EUMETSAT 2007**	**ESA 2007a**	**ESA 2007b**
	Air temperature profile (PBL)				X			
	Lake surface temperature		X	X	X			
	Land surface (skin) temperature	X	X	X				
	Sea sub-surface temperature	X						
	Sea surface temperature	X	X		X	X	X	
	Sea-ice surface (skin) temperature	X				X		
	Snow surface temerature			X				
	Soil temperature profile			X				
	Surface air temperature	X						
	Temperature fields / profiles	X	X		X			
Vegetation	Fraction of vegetation		X	X				
	Leaf Area Index (LAI)			X				
	Normalised Difference Vegetation Index (NDVI)			X				
	Vegetation cover	X	X					
	Vegetation type	X						
Wave properties	Sea roughness	X						
	Wave direction	X	X			X		
	Wave forecast						X	
	Wave height	X	X			X		
	Wave period	X	X			X		
Wind	Horizontal wind profile		X		X			
	Horizontal wind vectors (land surface)				X			
	Horizontal wind vectors (sea surface)				X			
	Surface wind	X	X					
	Turbulence profile (wind variability)				X			
	Turbulent kinetic energy profile		X					

Earth observation parameters for Regional Numerical Weather Prediction (R-NWP)		Document references						
		WMO RRR	EUMETSAT User Consultation Process				ESA Sentinel mission requirements	
			MTG	Post EPS				
Parameter type	**Parameter**	**WMO 2009h, d**	**EUMETSAT 2001**	**EUMETSAT 2006a**	**EUMETSAT 2006b**	**EUMETSAT 2007**	**ESA 2007a**	**ESA 2007b**
	Vertical wind profile		X		X			
	Wind (3D) – horizontal component	X						
	Wind (3D) – vertical component	X						
	Wind forecast						X	
Diverse	Boundary layer (PBL) height		X					
	Height of the top of PBL				X			
EUMETSAT 2006c: No EO parameters have been mentioned explicitly as regards R-NWP in the Atmospheric Chemistry SOG. Please see text for further information. **WMO 2008d:** EO parameters, which were listed in the SOG on ocean applications with relevance to met-ocean aspects of R-NWP, are included in the WMO RRR column.								

Table 3: Earth observation parameters for Regional Numerical Weather Prediction (R-NWP).

4.1.3. Earth Observations for Synoptic meteorology

For synoptic meteorology, the most important tools are NWP models and the Earth observation parameters discussed above in chapters 5.1.1 and 5.1.2 also apply to synoptic meteorology (WMO 2008f). There is additional interest in in-situ observations, e.g. made by weather radars and observations from the oceans where surface-based data are sparse. As stated in the SOG (WMO 2008f, p. 1), "*forecasters tend to look at individual observing systems separately, so that the impact of the different observing systems discussed in this SOG* [synoptic meteorology] *by data source rather than by meteorological parameter*. […]"

Relevant Earth observation parameters for Synoptic Meteorology, which have been identified in the analyzed literature, are listed in Table 4.

Earth observation parameters for Synoptic Meteorology		**Document references**	
		WMO RRR	**EUMETSAT User Consultation Process (Post EPS)**
Parameter type	**Parameter**	**WMO 2008f, d**	**EUMETSAT 2006a**
Aerosol properties	3D aerosol	X	
	Aerosol particle size	X	
	Aerosol particle type	X	
	Aerosol properties	X	
	Aerosol total column amounts	X	
	High-aerosol events	X	
Atmospheric chemistry	Ozone fields	X	
	Total column ozone	X	
Cloud properties	Cloud base height	X	
	Cloud cover	X	
	Cloud drop-size at cloud top	X	
	Cloud imagery		X
	Cloud liquid water	X	
	Cloud mask		X
	Cloud top height	X	X
	Cloud type	X	
	Cloud water/ice amounts (3D distribution)	X	
	Cloud-drop size (3D distribution)	X	
Humidity	3D humidity	X	
	Surface air humidity	X	
	Troposphere humidity profiles	X	
	Water vapour imagery		X
Precipitation	Accumulated precipitation	X	
	Precipitation (instantaneous)	X	
	Precipitation type	X	
Pressure	Mean sea level pressure	X	
	Surface pressure	X	
	Vertical pressure	X	
Radiation	Component(s) of the Earth's radiation budget	X	
	Outgoing longwave radiation fluxes	X	
	Outgoing shortwave radiation	X	

Earth observation parameters for Synoptic Meteorology		Document references	
		WMO RRR	**EUMETSAT User Consultation Process (Post EPS)**
Parameter type	**Parameter**	**WMO 2008f, d**	**EUMETSAT 2006a**
	fluxes		
	Radiation fluxes	X	
	Surface albedo	X	
	Surface emissivity (sea/land)	X	
	Thermal infra-red	X	
Sea ice properties	Sea-ice cover	X	
	Sea-ice thickness	X	
	Sea-ice type	X	
Snow properties	Snow cover	X	
	Snow water equivalent	X	
Soil moisture	Soil moisture	X	
Temperature	Land surface (skin) temperature	X	
	Sea sub-surface temperature	X	
	Sea surface temperature	X	
	Sea-ice surface (skin) temperature	X	
	Surface air temperature	X	
	Temperature fields / profiles	X	
Vegetation	Vegetation cover	X	
	Vegetation type	X	
Wave properties	Sea roughness	X	
	Wave direction	X	
	Wave height	X	
	Wave period	X	
	Wave spectrum (2D)	X	
Ocean currents	Ocean current advection	X	
	Ocean current dynamics	X	
Wind	Surface wind	X	
	Wind (3D) – horizontal component	X	
	Wind (3D) – vertical component	X	
	Wind (boundary layer/troposheric)	X	
Diverse	Height of the top of PBL		X
	Height of tropopause		X
	Visibility	X	

EUMETSAT 2006a: P-EPS missions also cover G-/R-NWP parameters. In this table, only those parameters are listed, which are contained in the priorities list (annex) and contain an explicit reference to Synoptic Meteorology. This does not imply that G-/R-NWP parameters, which are deemed necessary for Synoptic Meteorology (e.g. in the WMO SOG) and which fall within the scope of the P-EPS mission are irrelevant.
EUMETSAT 2006b, 2007; ESA 2007a, b: No explicit reference has been made to parameters relevant for Synoptic Meteorology. Therefore, no parameters from these missions are listed here. It is noted, however, that these mission also cover G-/R-NWP parameters, which are relevant for Synoptic Meteorology.
EUMETSAT 2006c: No EO parameters have been mentioned explicitly as regards Synoptic Meteorology. Please see text for further information.
WMO 2008d: EO parameters, which were listed in the SOG on ocean applications with relevance to met-ocean aspects of Synoptic Meteorology, are included in the WMO RRR column.
WMO 2008f: It has been explicitly stated in the SOG on Synoptic Meteorology that G- and R-NWP data requirements are equally important for Synoptic Meteorology. Therefore, these parameters are retained in this list.

Table 4: Earth observation parameters for Synoptic Meteorology.

4.1.4. Earth Observations for Nowcasting and Very Short Range Forecasting

"[…] *Nowcasting and VSRF observational requirements are best satisfied by frequently identifying the location, intensity, movement and evolution of the phenomena being monitored. Important variables are:*

- *clouds and precipitation;*
- *surface meteorological variables: pressure, wind, temperature, moisture, present weather and precipitation accumulation (or snow layer) and recently, data like land cover and structure;*
- *3-dimensional (3-D) wind field;*
- *3-D humidity field; and,*
- *3-D temperature field.* […]" (WMO 2009i, p. 7)

In the SOG on Nowcasting and VSRF (WMO 2009i), each of the variables listed above is assessed to determine the compliance of existing or planned observation systems with observational requirements.

Further to the Earth observation parameters listed in WMO (2009i), a detailed list of meteorological phenomena is provided in EUMETSAT (2003). These phenomena are grouped into the following categories (please refer to EUMETSAT (2003) for further information on required observations and details on required spatial and temporal resolutions and application areas):

- Precipitation
- Wind
- Could
- Visibility
- Aviation turbulence
- Pollution (e.g. volcanic ash, toxic chemical releases, ozone concentration)

In addition to these meteorological categories, observations on the land surface (e.g. ice depth or fires) and on the Ocean (e.g. wave height) are relevant to this application area.

A number of forecasting and modelling techniques, which have been developed for specific application fields are listed in EUMETSAT (2003) under the following categories:

- Convection forecasting techniques
- Non-convective forecasting techniques
- Ocean models
- Land surface and hydrological models
- Dispersion, chemistry and biological models

For the techniques and models applied in these categories, a huge number of observations is needed and Nowcasting and VSRF would benefit from improved observation capabilities (please refer to EUMETSAT 2003 for details). No list of priority observations has been provided. Instead, a priority level as regards the expected benefit for each parameter to be observed is given.

Relevant Earth observation parameters for Nowcasting and Very Short Range Forecasting, which have been identified in the analyzed literature, are listed in Table 5.

Earth observation parameters for Nowcasting and Very Short Range Forecast (NWC / VSRF)		Document references				
		WMO RRR	EUMETSAT User Consultation Process			
			MTG	Post EPS		
Parameter type	**Parameter**	**WMO 2009i**	**EUMETSAT 2003**	**EUMETSAT 2006a**	**EUMETSAT 2006b**	**EUMETSAT 2007**
Aerosol properties	Aerosol effective radius (profile/totel)		X	X		
	Aerosol optical depth (profile/total)		X	X		
	Aerosol total column amounts		X			
Atmospheric chemistry	Airborne toxic material		X			
	Carbon dioxide		X			
	Carbon monoxide		X			
	CFC11		X			
	CFC12		X			
	HCHO, Formaldehyde		X			
	Methane		X			
	NO, Nitric Oxide		X			
	NO2 (and other gaseous absorbers)		X			
	NO2, Nitrogen Dioxide		X			
	Nutrient concentration		X			
	Ozone profile		X			
	PAN		X			
	SO2, Sulphur Dioxide		X			
	VOC, Volatile Organic Compounds		X			
Cloud properties	Cloud amount profile below 2km		X			
	Cloud base height	X				
	Cloud cover	X		X		
	Cloud drop effective radius (profile/at cloud top)		X	X		
	Cloud drop-size at cloud top	X				
	Cloud imagery			X		
	Cloud liquid water	X		X		
	Cloud mask			X		
	Cloud optical depth			X		

Earth observation parameters for Nowcasting and Very Short Range Forecast (NWC / VSRF)		Document references				
		WMO RRR	EUMETSAT User Consultation Process			
			MTG	Post EPS		
Parameter type	**Parameter**	**WMO 2009i**	**EUMETSAT 2003**	**EUMETSAT 2006a**	**EUMETSAT 2006b**	**EUMETSAT 2007**
	Cloud structures indication upward motion		X			
	Cloud top height	X	X	X		
	Cloud top temperature			X		
	Cloud type	X		X		
	Cloud water phase			X		
	Cloud water/ice amounts (3D distribution)	X				
	Cloud-drop size (3D distribution)	X				
	Clould ice effective radius (profile/at clould top)			X		
	Could pattern	X				
	Fog area		X			
	Fog top		X			
	Height of melting layer		X			
	Height of Tropopause			X		
	Mesoscale cloud rotation		X			
	Surface illumination		X			
Humidity	3D humidity	X				
	Low level moisture		X			
	Moisture fields (3D)	X				
	Surface air humidity	X				
	Troposphere humidity profiles	X	X			
	Upper and mid-level humidity	X				
	Water vapour profile				X	
	Water vapour total column	X				
	Water vapur imagery			X		
Precipitation	Accumulated precipitation	X				
	Convective rainfall rate	X				
	Hail > 2cm diameter		X			

Earth observation parameters for Nowcasting and Very Short Range Forecast (NWC / VSRF)		Document references				
		WMO RRR	EUMETSAT User Consultation Process			
			MTG	Post EPS		
Parameter type	**Parameter**	**WMO 2009i**	**EUMETSAT 2003**	**EUMETSAT 2006a**	**EUMETSAT 2006b**	**EUMETSAT 2007**
	Precipitation (instantaneous)	X				
	Precipitation intensity	X				
	Precipitation profile		X			
	Precipitation type	X				
	Rain rate		X			
	Total precipitable water	X				
Pressure	Mean Sea Level pressure		X			
	Surface pressure	X			X	
Radiation	Radiation fluxes	X				
	Surface albedo	X		X		
	Surface emissivity (sea/land)	X				
	UV albedo		X			
	UV-A intensity		X			
Salinity	Salinity		X			X
Sea ice properties	Sea-ice cover	X	X			
	Sea-ice thickness	X				
	Sea-ice type	X				
Snow properties	Snow cover	X		X		
	Snow crust		X			
	Snow crystal size profile		X			
	Snow depth		X	X		
	Snow fraction		X			
	Snow water equivalent	X		X		
Soil moisture	Soil moisture	X				
	Soil moisture profile			X		
	Soil type		X			
	Surface soil moisture			X		
Temperature	Air temperature at surface (land)	X			X	

Earth observation parameters for Nowcasting and Very Short Range Forecast (NWC / VSRF)		Document references				
		WMO RRR	EUMETSAT User Consultation Process			
			MTG	Post EPS		
Parameter type	**Parameter**	**WMO 2009i**	**EUMETSAT 2003**	**EUMETSAT 2006a**	**EUMETSAT 2006b**	**EUMETSAT 2007**
	Air temperature at surface (sea)	X				
	Air temperature profile				X	
	Fire temperature			X		
	Lake surface temperature		X			
	Land surface (skin) temperature > 500K	X				
	Mean temperature	X				
	Sea sub-surface temperature	X				
	Sea surface temperature	X				
	Sea-ice surface (skin) temperature	X				
	Snow surface temerature			X		
	Soil temperature		X	X		
	Surface air temperature	X				
	Surface stability		X			
	Surface temperature		X			
	Temperature fields / profiles	X	X			
Vegetation	Leaf Area Index (LAI)		X	X		
	Normalised Difference Vegetation Index (NDVI)			X		
	Vegetation cover	X				
	Vegetation stress		X			
	Vegetation type	X	X	X		
Wave properties	Sea roughness	X				
	Wave direction	X	X			X
	Wave height	X	X			X
	Wave period	X	X			
	Wave spectrum (2D)		X			
Wind	Horizontal wind profile		X			
	Horizontal wind speed (land surface)		X		X	

Earth observation parameters for Nowcasting and Very Short Range Forecast (NWC / VSRF)		Document references				
		WMO RRR	EUMETSAT User Consultation Process			
			MTG	Post EPS		
Parameter type	**Parameter**	**WMO 2009i**	**EUMETSAT 2003**	**EUMETSAT 2006a**	**EUMETSAT 2006b**	**EUMETSAT 2007**
	Horizontal wind speed (sea surface)		X		X	X
	Horizontal wind vectors (sea surface)				X	X
	Local wind maxima	X				
	Surface wind	X	X			
	Turbulence profile (wind variability)				X	
	Vertical wind profile	X	X			
	Wind (3D) – horizontal component	X				
	Wind (3D) – vertical component	X				
	Wind convergence	X				
	Wind field	X				
	Wind shear	X				
Ocean currents	Current vector		X			
	Geostrophic ocean surface currents					X
	Surface currents		X			X
Diverse	Air mass parameters	X				
	Air mass properties	X				
	Algal Bloom		X			X
	Atmosheric stability	X				
	Boundary layer (PBL) height		X			
	Change in land height		X			
	Convergence of PBL		X			
	Depth of surface water		X			
	Fire location		X	X		
	Height of the top of PBL			X		
	Lightning information	X	X			
	Ocean topography					X
	Sea surface elevation		X			
	Smoke location		X	X		

Earth observation parameters for Nowcasting and Very Short Range Forecast (NWC / VSRF)		Document references				
		WMO RRR	EUMETSAT User Consultation Process			
			MTG	Post EPS		
Parameter type	**Parameter**	**WMO 2009i**	**EUMETSAT 2003**	**EUMETSAT 2006a**	**EUMETSAT 2006b**	**EUMETSAT 2007**
	Surface ice accretion		X			
	Visibility	X	X			
	Water clarity		X			X
EUMETSAT 2001, 2002, 2006c; ESA 2007a, b: No explicit reference has been made to parameters relevant for NWC/VSRF. Therefore, no parameters from these missions are listed here. It is noted, however, that these missions also cover G-/R-NWP parameters, which are relevant for NWC/VSRF. **EUMETSAT 2006a, b:** P-EPS missions also cover G-/R-NWP parameters. In this table, only those parameters are listed, which are contained in the priorities list (annex) and contain an explicit reference to NWC/VSRF. This does not imply that G-/R-NWP parameters, which are deemed necessary for NWC/VSRF (e.g. in the WMO SOG) and which fall within the scope of the P-EPS mission are irrelevant.						

Table 5: Earth observation parameters for Nowcasting and Very Short Range Forecast (NWC / VSRF).

4.1.5. Earth Observations for Seasonal and Inter-annual Forecasts (SIA)

The SOG of Seasonal and Inter-annual Forecasts (WMO 2008e) assesses of how well observational requirements are met by current observation systems. As coupled ocean-atmosphere models are used to produce seasonal-to-inter-annual forecasts, the SOG focuses on the needs for coupled model inputs. The following priority Earth observation parameters are listed and discussed in detail:

- Sea-surface temperature
- Ocean wind stress
- Sub-surface temperature
- Salinity
- Ocean topography
- Surface heat and freshwater fluxes
- Ocean current data
- In-situ sea level
- Atmospheric data
- Snow cover
- Soil moisture and terrestrial properties:
- Sea-Ice cover and thickness

[…] *"In this list of observation needs, the requirements for SIA forecasts are based on a consensus of the coupled atmosphere-ocean modelling community. It builds on the requirements for Global NWP and represents in addition those variables that are known to be important for initialising models or for testing and validating models."* […] (WMO 2008e, p. 1)

In a complement to the SOG made in 2008, the following data needs for long-range forecast are discussed:

- Sea-surface temperature (SST)
- Data used to force the ocean model, such as wind stresses.
- High quality, time homogeneous equatorial data: temperature, salinity and velocities.
- Broad-scale ocean sub-surface Temperature and Salinity data
- Real-time delivery of satellite derived sea level data.
- Soil moisture
- Snow cover, depth and mass.
- Atmospheric initial conditions (Time variation in the composition of the atmosphere needs to be known and accounted for: greenhouse gases, tropospheric aerosols, volcanic aerosols, and stratospheric ozone; near real-time data is needed, and in many cases both horizontal variations and the vertical profile are required.)

A strong need for sustainable data is highlighted in the SOG complement to assess and improve long-range forecast models, whose quality is still affected by model errors (WMO 2008e).

EUMETSAT 2002 lists additional parameters relevant for SIA:

"extended requirements or additional variables to be analysed in support of seasonal and inter-annual forecasting: sea surface temperature (with higher accuracy), vegetation type, fraction of photo-synthetically active radiation, ocean topography (surface height), ocean salinity, ocean chlorophyll, ocean suspended sediment, ocean yellow substance."

Relevant Earth observation parameters for Seasonal and Inter-annual Forecasts (SIA), which have been identified in the analyzed literature, are listed in Table 6.

Earth observation parameters for Seasonal and Inter-annual Forecasts (SIA)		Document references			
		WMO RRR	EUMETSAT User Consultation Process		
			MTG	Post EPS	
Parameter type	**Parameter**	**WMO 2008e, d**	**EUMETSAT 2002**	**EUMETSAT 2006a**	**EUMETSAT 2007**
Aerosol properties	3D aerosol	X	X		
	Aerosol particle size	X			
	Aerosol particle type	X			
	Aerosol properties	X			
	Aerosol total column amounts	X			
	High-aerosol events	X			
	Troposphere aerosol	X			
	Volcanic aerosol	X			
Atmospheric chemistry	Greenhouse gases	X			
	Ozone fields	X	X		
	Total column ozone	X			
	Stratospheric ozone	X			
Cloud properties	Cloud base height	X	X		
	Cloud cover	X	X		
	Cloud drop-size at cloud top	X	X		
	Cloud liquid water	X			
	Cloud top height	X	X		
	Cloud water/ice amounts (3D distribution)	X	X		
	Cloud-drop size (3D distribution)	X	X		
Humidity	3D humidity	X	X		
	Surface air humidity	X	X		
	Troposphere humidity profiles	X			
Precipitation	3D precipitation		X		
	Accumulated precipitation	X	X		
	Precipitation (instantaneous)	X			
	Surface precipitation		X		
Pressure	Surface pressure	X	X		
Radiation	Component(s) of the Earth's radiation budget	X			

Earth observation parameters for Seasonal and Inter-annual Forecasts (SIA)		Document references			
		WMO RRR	EUMETSAT User Consultation Process		
			MTG	Post EPS	
Parameter type	**Parameter**	**WMO 2008e, d**	**EUMETSAT 2002**	**EUMETSAT 2006a**	**EUMETSAT 2007**
	Latent heat fluxes	X			
	Outgoing longwave radiation fluxes	X	X		
	Outgoing shortwave radiation fluxes	X	X		
	Radiation fluxes	X			
	Surface albedo	X	X		
	Surface emissivity (sea/land)	X			
	Surface emissivity spectrum		X		
	Surface heat flux	X			
	Thermal infra-red	X			
Salinity	Sea surface salinity	X			X
Sea ice properties	Sea-ice cover	X	X		
	Sea-ice thickness	X	X		
	Sea-ice type	X			
Snow properties	Snow cover	X	X		
	Snow depth	X			
	Snow mass	X			
	Snow water equivalent	X	X	X	
Soil moisture	Soil moisture	X	X		
	Surface soil moisture			X	
Temperature	Land surface (skin) temperature	X	X		
	Sea sub-surface temperature	X			
	Sea surface temperature	X	X		
	Sea-ice surface (skin) temperature	X	X		
	Surface air temperature	X	X		
	Temperature fields / profiles	X	X		
Vegetation	Fraction of absorbed PAR (fAPAR)	X		X	X
	Leaf Area Index (LAI)	X			
	Photosynthetically active radiation (PAR)		X		

Earth observation parameters for Seasonal and Inter-annual Forecasts (SIA)		Document references			
		WMO RRR	EUMETSAT User Consultation Process		
			MTG	Post EPS	
Parameter type	**Parameter**	**WMO 2008e, d**	**EUMETSAT 2002**	**EUMETSAT 2006a**	**EUMETSAT 2007**
	Vegetation cover	X	X		
	Vegetation type	X	X	X	
Wave properties	Sea roughness	X			
	Wave direction	X	X		
	Wave height	X	X		
	Wave period	X	X		
	Wave spectrum (2D)	X			
Wind	Aerodynamic roughness lengh		X		
	Surface wind	X	X		
	Surface wind direction (over ocean)	X			
	Surface wind speed (over ocean)	X			
	Wind (3D) – horizontal component	X	X		
	Wind (3D) – vertical component	X	X		
	Ocean current advection	X			
	Ocean current dynamics	X			
Ocean currents	Ocean surface currents	X			X
Diverse	Ocean chlorophyll		X		X
	Ocean color	X			
	Ocean suspended sediment		X		X
	Ocean yellow substance		X		X
	Sea level	X			
	Sea surface topography	X	X		X
	Surface water discharge	X			

EUMETSAT 2001, 2002: A number of EO parameters have been listed in EUMETSAT 2002, which are important for SIA Forecasts in addition to parameters relevant for G-NWP. The document on R-NWP (EUMETSAT 2001) does not refer to SIA Forecasts - thus EO parameters relevant for R-NWP (and SIA) are not included in the above table.
EUMETSAT 2006a, 2007: P-EPS missions also cover G-/R-NWP parameters. In this table, only those parameters are listed, which are contained in the priorities list (annex) and contain an explicit reference to SIA Forecasts. This does not imply that G-/R-NWP parameters, which are deemed necessary for SIA Forecasts (e.g. in the WMO SOG) and which fall within the scope of the P-EPS missions are irrelevant.

Earth observation parameters for Seasonal and Inter-annual Forecasts (SIA)		Document references			
		WMO RRR	EUMETSAT User Consultation Process		
			MTG	Post EPS	
Parameter type	**Parameter**	**WMO 2008e, d**	**EUMETSAT 2002**	**EUMETSAT 2006a**	**EUMETSAT 2007**
EUMETSAT 2006b: The only EO parameter, which has been mentioned explicitly as regards SIA Forecasts is Sea Surface Temperature (SST). Therefore, no extra column has been added to this table. **EUMETSAT 2006c; ESA 2007a, b:** No EO parameters have been mentioned explicitly as regards SIA Forecasts. Please see text for further information regarding the importance of EO of Atmospheric Chemistry (EUMETSAT 2006c) for SIA Forecasts. **WMO 2008d:** EO parameters, which were listed in the SOG on ocean applications with relevance to met-ocean aspects of SIA Forecasts are included in the WMO RRR column. **WMO 2008e:** It has been explicitly stated in the SOG on SIA Forecasts that G- and R-NWP data requirements are equally important for SIA Forecasts. Therefore, these parameters are retained in this list.					

Table 6: Earth observation parameters for Seasonal and Inter-annual Forecasts (SIA).

4.1.6. Earth Observations for Aeronautical Meteorology

[…] *"The forecasts of SIGWX* [significant weather] *-information are issued by the two World Area Forecast Centers London and Washington at a high degree of automation, containing information on phenomena such as:*

- *convective activity;*
- *icing in clouds and freezing precipitation, clear air turbulence, both in the vicinity of jet streams and near convection; and,*
- *gravity wave activity.*

Many of these phenomena occur on a scale of a few km in the horizontal and less than 1 km in the vertical, and persist in time from minutes to a few hours. They need to be derived from larger-scale information in the NWP models by algorithmic methods, depending heavily on correct information of horizontal and vertical shear, moisture (including super-saturation) and Super Cooled Liquid Water Content (SLWC), and sometimes boundary layer information, such as low-level moisture content or depth of a stagnant layer upstream of mountains or hills generating gravity waves.

Individual Flight Information Regions (FIR) are served by Meteorological Watch Offices (MWO) with a responsibility to issue SIGMET information giving precise location, intensity and movement of these phenomena when they occur. For route forecasts in Visual Meteorological Conditions (VMC), highly detailed information on visibility, cloud ceiling height and topographically induced features (coastal stratus, upslope fog, orographic cloud), needs to be provided to clients. For Terminal Aerodrome Forecasts (TAF), landing forecasts (TREND) and warnings as well as emerging new forecasts for the terminal area, nowcasting and very-short-range forecasting of local conditions such as visibility, cloud base height, convection, 3-D wind and vertical temperature profile is required.

In addition to the phenomena indicated above (convective systems, heavy precipitation, icing, and high winds), particular emphasis is placed on:

- *low-level wind shear and turbulence;*
- *freezing precipitation;*
- *super cooled large cloud droplets ("freezing drizzle droplets");*
- *low visibility and ceiling situations; and,*
- *snow fall and black ice formation.*

For the benefit of air traffic management, airline dispatch offices and airport authorities, short-range forecasts of weather phenomena affecting airways or the acceptance rate of hub airports are required. These include deep convection, lightning, strong winds including crosswinds and gusts, low-level wind shear and turbulence, snow and sand storms, and very low ceiling and visibility values. […]" (WMO 2008a)

Relevant Earth observation parameters for Aeronautical Meteorology, which have been identified in the analyzed literature, are listed in Table 7.

Earth observation parameters for	Document reference

Aeronautical Meteorology		WMO RRR
Parameter type	**Parameter**	**WMO 2008a**
Aerosol properties	3D aerosol	X
	Aerosol particle size	X
	Aerosol particle type	X
	Aerosol properties	X
	Aerosol total column amounts	X
	High-aerosol events	X
	Volcanic ash clouds	X
Atmospheric chemistry	Ozone fields	X
	Total column ozone	X
Cloud properties	Cloud base height	X
	Cloud cover	X
	Cloud drop-size at cloud top	X
	Cloud liquid water	X
	Cloud pattern	X
	Cloud top height	X
	Cloud type	X
	Cloud water/ice amounts (3D distribution)	X
	Cloud-drop size (3D distribution)	X
	Could ceiling height	X
	Gravity waves	X
Humidity	3D humidity	X
	Moisture fields (3D)	X
	Surface air humidity	X
	Troposphere humidity profiles	X
	Upper and mid-level humidity	X
	Water vapour total column	X
Precipitation	Accumulated precipitation	X
	Convective rainfall rate	X
	Precipitation (instantaneous)	X
	Precipitation intensity	X
	Precipitation type	X
	Total precipitable water	X
Pressure	Surface pressure	X
Radiation	Component(s) of the Earth's radiation budget	X
	Outgoing longwave radiation fluxes	X
	Outgoing shortwave radiation fluxes	X
	Radiation fluxes	X
	Surface albedo	X
	Surface emissivity (sea/land)	X
	Thermal infra-red	X
Sea ice properties	Sea-ice cover	X
	Sea-ice thickness	X
	Sea-ice type	X
Snow properties	Snow cover	X
	Snow water equivalent	X
Soil moisture	Soil moisture	X
Temperature	Air temperature at surface (land)	X
	Air temperature at surface (sea)	X

Earth observation parameters for Aeronautical Meteorology		Document reference
		WMO RRR
Parameter type	**Parameter**	**WMO 2008a**
	Land surface (skin) temperature	X
	Land surface (skin) temperature > 500K	X
	Mean temperature	X
	Sea sub-surface temperature	X
	Sea surface temperature	X
	Sea-ice surface (skin) temperature	X
	Surface air temperature	X
	Temperature fields / profiles	X
Vegetation	Vegetation cover	X
	Vegetation type	X
Wave properties	Sea roughness	X
	Wave direction	X
	Wave height	X
	Wave period	X
	Wave spectrum (2D)	X
Wind	Local wind maxima	X
	Surface wind	X
	Vertical wind profile	X
	Wind (3D) – horizontal component	X
	Wind (3D) – vertical component	X
	Wind convergence	X
	Wind direction	X
	Wind field	X
	Wind shear	X
	Wind speed	X
Ocean currents	Ocean current advection	X
	Ocean current dynamics	X
Diverse	Air mass parameters	X
	Air mass properties	X
	Atmospheric stability	X
	Lightning information	X
	Visibility	X
EUMETSAT 2006a, c, 2007; ESA 2007a, b: No EO parameters have been mentioned explicitely as regards Aeronautical Meteorology. **EUMETSAT 2006b:** The only two EO parameters, which has been mentioned explicitely as regards Aeronautical Meteorology are Air Temperature Profile and Water Vapur Profile. Therefore, no extra column has been added to this table.		

Table 7: Earth observation parameters for Aeronautical Meteorology.

4.1.7. Earth Observations for Ocean Applications

"The key met-ocean variables to be observed and forecasted in support of NWP and SIA are addressed in the Numerical Weather Prediction and the Seasonal to Inter-annual Forecast Statements of Guidance (SOG). […] *This Statement of Guidance* [Ocean Applications] *provides a brief discussion of the key met-ocean observational requirements for Met-Ocean Services,* […]. *In particular, variables, such as precipitation, air temperature, humidity and*

cloud cover, required for marine services, and surface heat fluxes required for NWP, are addressed in the global and regional NWP SOG.

The requirements for met-ocean forecasts and services stipulated here are based on a consensus of the met-ocean modelling and forecasting communities. It builds on the requirements for global and regional wave modelling and forecasting, marine meteorological services, including sea-ice, and ocean mesoscale forecasting, and represents in addition those variables that are known to be important for initialising, testing and validating models and assimilation, as well as for providing services." (WMO 2008d, p. 1)

The following Earth observation parameters are the key variables for met-ocean applications and are discussed in the SOG in detail:

- Wind-Wave parameters (significant wave height, dominant wave direction, wave period, 1D frequency spectral wave energy density, and 2-D frequency-direction spectral wave energy density)
- Sea Level
- Sea-Ice parameters (thickness, coverage / concentration, type / form, and movement)
- Sea-Surface Temperature (SST)
- Sub-surface Temperature, Salinity and Density
- Ocean Colour
- 3-D Ocean Currents
- Bathymetry, Coastal Topography and Shorelines
- Surface Wind over the Ocean and Coastal Areas (10m)
- Surface pressure
- Visibility

EUMETSAT (2007) discusses requirements for ocean observations relevant for the Post-EPS mission and concludes that "data requirements of the user groups […] can be discussed separately in terms of surface topography requirements and imaging requirements. The main geophysical variables required by these communities, relevant to an ocean topography mission are:

- Ocean topography and global sea level
- Ocean geostrophic currents
- Significant wave height
- Sea ice thickness

[…]

The main geophysical variables required from an ocean imaging mission are:

- Ocean wind vectors
- Surface currents
- Wave spectra
- Biogeochemical variables (ocean colour)
- Sea surface salinity
- Sea surface temperature
- Sea ice (extent, concentration, type and drift). "

Met-ocean applications represent an important application area of weather related Earth observations. Due to a strong cross-cutting nature of observations of ocean observations, requirements for Earth observations for ocean applications are contained in the summary tables for G-/R-NWP, Synoptic Meteorology, NWC/VSRF and SIA (cf. Chapters 4.1.1 to 4.1.5).

4.1.8. Earth Observations for Agricultural Meteorology

"Agricultural meteorology is one of the fields of hydrometeorology for which satellite data are very important. Agrometeorological parameters are very variable in time and space. Ground observations do not provide end–users with required spatial and temporal resolution. Information about large areas can only be obtained by remote sensing. […]" (WMO 2004a, p. 1)

Table 8 lists all Earth observation parameters, which are discussed in the SOG, however, without providing details on observational requirements such as spatial and temporal resolution or accuracy (this information is available in the WMO/CEOS database, WMO 2009a).

Earth observation parameters for Agricultural Meteorology		**Document reference**
		WMO RRR
Parameter type	**Parameter**	**WMO 2004a**
Precipitation	Precipitation	X
Radiation	Solar radiation	X
Snow properties	Snowmelt	X
Soil moisture	Soil moisture	X
Temperature	Frost conditions	X
	Soil temperature	X
Vegetation	Leaf area index (LIA)	X
	Plant phenology	X
	Vegetation type/cover	X
Diverse	Aeolian sediment load	X
	Fire	X
	Snowmelt	X
WMO 2004a: Certainly, many EO parameters of other fields of weather prediction (e.g. NWP, SIA Forecasts) are also relevant for Agricultural Meteorology. As there are no references to additional EO parameters in the SOG on Agricultural Meteorology, only those parameters with specific importance for Agricultural Meteorology have been included in this table.		

Table 8: Earth observation parameters for Agricultural Meteorology.

4.1.9. Earth Observations for Hydrology

"For most of the presently available observations, the adequacy of observational networks varies largely from region to region and observations for some of the variables described below are inadequate in terms of spatial and temporal coverage. As a methodological approach it has become evident, that observations of hydrological variables on global and regional scales in a continuous and consistent manner will require integrated observation

systems making use of both terrestrial as well as satellite observations. The use of data assimilation techniques using data from these integrated networks and multi-platform observations will give rise to improved products and services. […]" (WMO 2008c, p. 1)

Following the Terrestrial Observation Panel on Climate (TOPC) and an expert meeting on the Establishment of a Global Terrestrial Network – Hydrology (GTN-H), 11 hydrometeorological variables with a high observation priority have been identified (GCOS 2000). These variables are discussed in the SOG in detail:

- Surface water discharge
- Surface water storage fluxes
- Groundwater fluxes
- Precipitation (liquid / solid)
- Isotope signatures
- Evaporation
- Vapour pressure / Relative humidity
- Soil moisture / Soil wetness
- Snow cover, depth, and water equivalent and glaciers
- Biogeochemical (BGC) fluxes from land to ocean
- Water Use

In addition to the 11 hydrometeorological variables, also listed in GCOS (2000), the SOG discusses the following variables:

- Land surface temperature
- Vegetation type and NDVI
- Short-wave and Long-wave outgoing radiation at Top of Atmosphere (TOA).

Relevant Earth observation parameters for Hydrometeorology, which have been identified in the analyzed literature, are listed in Table 9.

Earth observation parameters for Hydrometeorology		Document references	
		WMO RRR	EUMETSAT User Consultation Process (Post EPS)
Parameter type	**Parameter**	**WMO 2008c**	**EUMETSAT 2006a**
Humidity	Vapour pressure	X	
Precipitation	Accumulated precipitation		X
	Precipitation / Isotope signatures	X	
	Precipitation depth	X	
	Precipitation detection (solid/liquid)	X	
	Precipitation rate at surface (solid/liquid)		X
	Precipitation type	X	
Radiation	Downwelling shortwave irradiance at Earth surface		X
	Outgoing longwave irradiance at Earth surface		X
	Outgoing longwave irradiance at TOA	X	X
	Outgoing shortwave irradiance at TOA		X
	Shortwave cloud reflectance		X

Earth observation parameters for Hydrometeorology		Document references	
		WMO RRR	**EUMETSAT User Consultation Process (Post EPS)**
Parameter type	**Parameter**	**WMO 2008c**	**EUMETSAT 2006a**
	Shortwave Earth surface bi-directional reflectance		X
	Surface albedo		X
	Surface emissivity (TIR window)		X
Snow properties	Snow cover	X	X
	Snow depth	X	
	Snow detection		X
	Snow status (wet/dry)		X
	Snow water equivalent	X	X
Soil moisture	Soil moisture	X	
	Soil moisture profile		X
	Soil type		X
	Surface soil moisture		X
Temperature	Land surface (skin) temperature	X	X
	Snow surface temerature		X
	Soil temperature profile		X
Vegetation	Fraction of absorbed PAR (fAPAR)		X
	Fraction of vegetated land		X
	Leaf Area Index (LAI)		X
	Normalised Difference Vegetation Index (NDVI)	X	X
	Vegetation type	X	X
Hydroshere properties	Evaporation	X	
	Ground water fluxes	X	
	Surface water discharge	X	
	Surface water storage fluxes	X	
	Water use	X	
Diverse	Biogeochemical transport	X	
	Fire fractunal cover		X
	Fire temperature		X
	Frozen soil and permafrost		X
	Glaciers	X	
WMO 2008c: This table lists only high priority EO parameters, which have been mentioned in the WMO SOG on Hydrology. The list includes the 11 hydrometeorological variables with high observation priority as identified by the Terrestrial Observation Panel on Climate (TOPC) (GCOS 1997, confirmed by GCOS 2000)			

Table 9: Earth observation parameters for Hydrometeorology.

5. Priority Earth Observations for Weather SBA

5.1. General Description

The chapter contains all parameters, which are regarded as key or priority variables in the analyzed literature. Summary tables in each sub-chapter contain the exact language used to describe the relevance of parameters in the cited documents. In addition, it contains excerpts from the WMO SOG, which provide information on necessary improvements and developments of different observation systems. These excerps are printed in *Italic*.

5.2. Priority Observations

Earth observation requirements in chapters 5.1.1 to 5.1.10 are related to the application areas covered by the WMO Statements of Guidance (SOG). The excerpts from the SOG are printed in *Italic*. Further information can be found in WMO 2009a and WMO 2009b-g (cf. Chapter 4).

5.2.1. Priority observations for Global numerical weather prediction (G-NWP)

According to the WMO SOG on G-NWP (WMO 2008b, p. 7),

"Global NWP centres:

- *make use of the complementary strengths of in situ and satellite-based observations;*
- *have shown strong positive impact from advanced microwave sounding instruments (such as AMSU-A);*
- *are starting to take advantage of high spectral resolution sounders with improved vertical resolution (such as AIRS, IASI, CrIS);*
- *are advancing in the use of 4D data assimilation systems to benefit from more frequent measurements (e.g. from geostationary satellites, from AMDAR) and from measurements of cloud, precipitation, ozone, etc.;*
- *would benefit from increased coverage of aircraft data, particularly from ascent/descent profiles;*
- *would benefit from more timely availability of all observations, in particular satellite data, and from several types of in situ measurement that are made but not currently disseminated globally.*

The critical atmospheric variables that are not adequately measured by current or planned systems are (in order of priority):

- *wind profiles at all levels;*
- *temperature and humidity profiles of adequate vertical resolution in cloudy areas;*
- *precipitation;*
- *snow equivalent water content."*

Table 10 provides a summary of the priority Earth observations for G-NWP as mentioned in the analyzed literature.

Priority Earth observations for G-NWP		**Document references**					
			EUMETSAT User Consultation Process				
		WMO RRR	**MTG**				**Post-EPS**
		WMO 2008b	**EUMETSAT 2002**				**EUMETSAT 2006c**
Parameter type	**Parameter / parameter type**	**"main parameters of interest"**	**"analysed today"**	**"analysed in the future, medium term"**	**"analysed in the future, longer term"**	**"important additional variables for model validation"**	**"constituents that are most significant to improve NWP calculations of atmospheric heating/cooling rates"**
Aerosol properties	3D aerosol	X			X		X
Atmospheric chemistry	Ozone	X	X				X
Cloud properties	Cloud base height			X			
	Cloud cover			X			
	Cloud drop-size at cloud top				X		
	Cloud top height			X			
	Cloud water/ice amounts (3D distribution)			X			
	Clloulds	X					X
Humidity	3D humidity field	X	X				
	Surface air humidity	X	X				
	Troposphere humidity profiles						X
	Water vapour (stratosheric)						X
Precipitation	3D precipitation				X		
	Accumulated precipitation					X	
	Precipitation	X					
	Surface precipitation			X			
Pressure	Surface pressure	X	X				
Radiation	Outgoing longwave radiation fluxes					X	
	Outgoing shortwave radiation fluxes					X	
	Surface albedo					X	
	Surface emissivity spectrum					X	

Priority Earth observations for G-NWP		Document references					
			EUMETSAT User Consultation Process				
		WMO RRR	MTG				Post-EPS
		WMO 2008b	EUMETSAT 2002				EUMETSAT 2006c
Parameter type	**Parameter / parameter type**	**"main parameters of interest"**	**"analysed today"**	**"analysed in the future, medium term"**	**"analysed in the future, longer term"**	**"important additional variables for model validation"**	**"constituents that are most significant to improve NWP calculations of atmospheric heating/cooling rates"**
Sea ice properties	Sea-ice (cover)	X	X				
	Sea-ice thickness				X		
Snow properties	Snow (cover)	X	X				
	Snow water equivalent		X	X			
Soil moisture	Soil moisture	X	X				
Temperature	Land surface (skin) temperature	X		X			
	Sea surface temperature	X	X	X			
	Sea-ice surface (skin) temperature	X					
	Surface air temperature	X	X				
	3D temperature field	X	X				
Vegetation	Leaf Area Index (LAI)			X			
	Vegetation cover	X					
	Vegetation type	X					
Wave properties	Wave direction	X	X				
	Wave height	X	X				
	Wave period	X	X				
Wind	Aerodynamic roughness lengh				X		
	Surface wind	X	X				
	Wind (3D) – horizontal component	X	X				
	Wind (3D) – vertical component	X			X		
Diverse	Ocean sub-surface variables	X					

Table 10: Priority Earth observation parameters for G-NWP.

5.2.2. Priority observations for Regional numerical weather prediction (R-NWP)

According to the WMO SOG on R-NWP (WMO 2009h, p. 8),

"Regional NWP centres:

- *make use of the same observations as global NWP centres, except the ones in the upper stratosphere and mesosphere, plus some local surface-based observing systems (like radars which are normally unused in global NWP);*
- *are less dependent on polar orbiting satellites than global centres, slightly more dependent on geostationary satellites and on surface-based observing systems;*
- *have more operational constraints on the assimilation computer cost, which makes it more difficult than in global modelling to draw the full benefits from 4D data assimilation systems;*
- *are faced with a huge variety of observation density, depending on the area they operate;*
- *would still benefit from increased coverage of aircraft data in all the regions of the globe, particularly from ascent/descent profiles;*
- *are likely to draw more benefits in the future from radar data and from ground-based GPS stations (which are very new observations in terms of assimilation).*

The critical atmospheric variables that are not adequately measured by current or planned systems are (in order of priority):

- *wind profiles at all levels;*
- *temperature and humidity profiles of adequate vertical resolution in cloudy areas;*
- *precipitation;*
- *snow equivalent water content;*
- *soil moisture."*

Table 11 provides a summary of the priority Earth observations for R-NWP as mentioned in the analyzed literature.

Priority Earth observations for R-NWP		**Document references**		
		WMO RRR	**EUMETSAT User Consultation Process**	
			MTG	
		WMO 2008b, 2009h	**EUMETSAT 2001**	
Parameter type	**Parameter / parameter type**	**"key model variables; observations equal to G-NWP"**	**"assimilated today; very high priority"**	**"intended for assimilation during 2001-2015"**
Aerosol properties	3D aerosol	X		
	Aerosol (vertical profile)		X	X
Atmospheric chemistry	Ozone	X		X
Cloud properties	Cloud cover			X
	Cloud drop spectra			X
	Cloud ice			X

Priority Earth observations for R-NWP		Document references		
		WMO RRR	EUMETSAT User Consultation Process	
			MTG	
		WMO 2008b, 2009h	EUMETSAT 2001	
Parameter type	**Parameter / parameter type**	**"key model variables; observations equal to G-NWP"**	**"assimilated today; very high priority"**	**"intended for assimilation during 2001-2015"**
	Cloud snow			X
	Clouds	X		
	Particle spectra in clouds			X
Humidity	2m-humidity		X	
	3D humidity field	X		
	Surface air humidity	X		
	Water vapor (vertical profile)		X	
Precipitation	Precipitation	X		
	Surface precipitation intensity		X	
	Vertical rain/snow profile			X
Pressure	Surface pressure	X	X	
Radiation	Surface albedo			X
Sea ice properties	Sea-ice (cover)	X	X	
Snow properties	Snow (cover)	X	X	X
	Snow depth		X	X
	Snow water equivalent			X
Soil moisture	Soil moisture	X	X	
Temperature	2m-temperature		X	
	3D temperature field	X		
	Lake surface temperature		X	X
	Land surface (skin) temperature	X		
	Sea surface temperature	X	X	
	Sea-ice surface (skin) temperature	X		
	Soil temperature		X	
	Surface air temperature	X		
Vegetation	Leaf Area Index (LAI)			X
	Vegetation cover	X		X
	Vegetation type	X		X
Wave properties	Wave direction	X		
	Wave height	X	X	
	Wave period	X		
	Wave spectra			X
Wind	10m wind		X	
	Surface wind	X		
	Wind (3D) – horizontal component	X		
	Wind (3D) – vertical component	X	X	
Diverse	Boundary layer height			X
	Ocean sub-surface variables	X		
	Turbulent kinetic energy (vertical profile)		X	

Table 11: Priority Earth observation parameters for R-NWP.

5.2.3. Priority observations for Synoptic meteorology

According to the WMO SOG on Synoptic meteorology (WMO 2008f, pp. 4),

"NWP models are the most important tool for synoptic prediction, leading to a strong dependence on the same data as identified as sources for NWP. Thus, the SOG for global and regional NWP applies for Synoptic Meteorology as well. Information that best complements these data is found in satellite imagery and weather radar data; their usage is further supported by their good temporal and spatial resolution. Surface data, because of their good representation of the conditions where people are living, are also essential. There still is concern for oceanic areas, where significant phenomena such as cyclogenesis occur, but surface-based data are sparse. Another concern is the quality of cloud cover and base height estimates in remote areas, and especially during the night, some progress is expected in this area from new satellite sensors over the next decade."

In the SOG on Synoptic meteorology (WMO 2008f), no explicit observation priorities are defined.

5.2.4. Priority observations for Nowcasting and Very Short Range Forecasting

According to the WMO SOG on Nowcasting and Very Short Range Forecasting (WMO 2009i, pp. 7-8),

"Key nowcasting and VSRF parameters for which observational data are required are:

- *clouds and precipitation;*
- *dust;*
- *surface variables: pressure, wind, temperature, humidity, present weather, visibility and precipitation accumulation, snow layer, land cover or structure;*
- *3-D wind field;*
- *3-D humidity field; and,*
- *3-D temperature field."*

The EUMETSAT position paper on NWC / VSRF (EUMETSAT 2003) contains a list of nearly 240 relevant observation parameters (cf. Chapter 4.1.4), which are of "very high", "high" or "medium" priority regarding the expected benefit of the observation for the application area. For details, please see EUMETSAT 2003.

5.2.5. Priority observations for Seasonal and Inter-annual Forecasts

The following key points from the WMO SOG on Seasonal and Inter-annual Forecasts (WMO 2008e) are summarized:

- The following data needs are discussed in the complement to the SOG:
    - Sea-surface temperature (SST)
    - Data used to force the ocean model, such as wind stresses.

- o High quality, time homogeneous equatorial data: temperature, salinity and velocities.
- o Broad-scale ocean sub-surface Temperature and Salinity data
- o Real-time delivery of satellite derived sea level data.
- o Soil moisture
- o Snow cover, depth and mass.
- o Atmospheric initial conditions (Time variation in the composition of the atmosphere needs to be known and accounted for: greenhouse gases, tropospheric aerosols, volcanic aerosols, and stratospheric ozone; near real-time data is needed, and in many cases both horizontal variations and the vertical profile are required.)

- ▪ The quality of LRF is still much affected by model errors, and there is a real need for suitable data to assess and improve models.
- ▪ Historical data sets play an important role in SIA prediction by supporting calibration and verification activities

Table 12 provides a summary of the priority Earth observations for SIA as mentioned in the analyzed literature.

Priority Earth observations for SIA		**Document references**		
		WMO RRR		**EUMETSAT User Consultation Process**
				MTG
		WMO 2008e	**WMO 2008e**	**EUMETSAT 2002**
Parameter type	**Parameter / parameter type**	**"priority Earth observation parameters"**	**"data needs for long-range forecast"**	**"additional [to NWP] parameters relevant for SIA"**
Aerosol properties	Troposphere aerosol		X	
	Volcanic aerosol		X	
Atmospheric chemistry	Greenhouse gases		X	
	Stratospheric ozone		X	
Radiation	Surface heat flux	X		
Salinity	Sea surface salinity	X	X	X
Sea ice properties	Sea-ice cover	X		
	Sea-ice thickness	X		
Snow properties	Snow cover	X	X	
	Snow depth		X	
	Snow mass		X	
Soil moisture	Soil moisture	X	X	
Temperature	Sea sub-surface temperature	X	X	
	Sea surface temperature	X	X	X
Vegetation	Fraction of absorbed PAR (fAPAR)			X
	Vegetation type			X
Wind	Ocean wind stress	X	X	

Priority Earth observations for SIA		Document references		
		WMO RRR		EUMETSAT User Consultation Process
				MTG
		WMO 2008e	WMO 2008e	EUMETSAT 2002
Parameter type	**Parameter / parameter type**	**"priority Earth observation parameters"**	**"data needs for long-range forecast"**	**"additional [to NWP] parameters relevant for SIA"**
Ocean currents	Ocean current data	X		
Diverse	Atmosheric data	X		
	Ocean chlorophyll			X
	Ocean suspended sediment			X
	Ocean yellow substance			X
	Sea level	X	X	
	Ocean topography	X		X
	Surface freshwater flux	X		

Table 12: Priority Earth observation parameters for SIA.

5.2.6. Priority observations for Aeronautical Meteorology

According to the WMO SOG on Aeronautical Meteorology (WMO 2008a, pp. 4-5), the following conclusions are drawn:

"For upper-level temperature and wind forecasts the SOG for global NWP apply for operational forecast production, locally higher vertical resolution is required for development and verification of turbulence forecast algorithms.

For Meteorological Watch purposes (issuance of warnings), satellite imagery, and higher-level products such as multi-spectral images, provide good guidance for location and intensity of convection, but only scanning radars in networks combined with lightning detection systems currently have the cycle times of less than 10 min required for air traffic control; the next generation of geostationary satellites with new scanning strategies is getting closer to these requirements.

For turbulence and gravity wave detection and prediction, current in-situ instruments have acceptable vertical resolution, but are not available in sufficient density for all areas of the globe. The AMDAR / ACARS / ADS is a data source with a high potential to fill existing data gaps in the medium term, water vapour imagery is beginning to show potential for subjective detection of steepening waves and vorticity advection, leading to Clear Air Turbulence.

For forecasts and warnings in the terminal area, in-situ and ground-based remote-sensor technology has the potential to meet requirements, but its high cost inhibits general, global availability. In particular, the possible extension of data requirements for new aviation forecasts and warnings for the larger approach-and departure areas, to be developed in close collaboration with ICAO, meso-networks, including lightning detection, LIDAR and Doppler WXR may become necessary for larger airports.

For en route forecasts for VFR flights, ground based observations are not meeting the required data density except for some densely populated areas. Satellite imagery and specialised products have acceptable horizontal resolution, but lack the information on visibility and ceiling height for low cloud. Promising new research satellites with a capacity to detect cloud base height will be monitored for operational usability over the next years.

For the detection of volcanic ash clouds and eruptions, satellite remote-sensing has significantly detection capability. Close cooperation with the CTBTO in using seismic and sonic data is improving the detection of volcanic outbreaks in remote areas."

The key variables to be observed and forecast in aeronautical meteorology (beyond those already addressed in the NWP and Nowcasting and Very Short Range Forecasting SOGs and not repeated where requirements are considered identical) are briefly discussed below [in the SOG]" (WMO 2008a, p. 2):

- 3-D Wind and Temperature Fields
- Surface and near-surface wind
- Humidity fields
- Cloud and liquid / ice water content
- Visibility and cloud ceiling height
- Gravity waves
- Volcanic Ash.

5.2.7. Priority observations for Ocean Applications

According to the WMO SOG on Ocean Applications (WMO 2008d, pp. 9-10),

- *"Satellite data are the only means for providing high-resolution data in key ocean areas where in situ observations are sparse or absent;*
- *In general, in situ met-ocean data and observations are insufficient for marine services (in particular, for monitor and warning marine-related hazards) and marginal for assimilation in ocean models, including wave models;*
- *Many met-ocean measurements have not been well integrated into NHMSs; and,*
- *In general, there is a requirement for fast delivery of met-ocean data.*

The critical met-ocean variables that are not adequately measured (more accurate and frequent measures and better spatial/temporal resolution are required) by current or planned systems are:

- *Waves parameters;*
- *Sea level; and*
- *Visibility."*

The SOG on Ocean Applications (WMO 2008d) lists the following key variables for met-ocean applications:

- Wind-Wave parameters (significant wave height, dominant wave direction, wave period, 1D frequency spectral wave energy density, and 2-D frequency-direction spectral wave energy density)
- Sea Level
- Sea-Ice parameters (thickness, coverage / concentration, type / form, and movement)
- Sea-Surface Temperature (SST)
- Sub-surface Temperature, Salinity and Density
- Ocean Colour
- 3-D Ocean Currents
- Bathymetry, Coastal Topography and Shorelines
- Surface Wind over the Ocean and Coastal Areas (10m)
- Surface pressure
- Visibility

5.2.8. Priority observations for Agricultural Meteorology

"Regarding agricultural meteorology needs, it is concluded [in the SOG on Agricultural Meteorology, WMO 2004a, p. 3] *that:*

- *soil moisture and temperature data at strategically located stations to depths of 50-100 cm every 5-7 days are needed for monitoring drought and for soil moisture model initialization / verification;*
- *aeolian sedimentation loads along with comprehensive analysis of wind must be included in the standard agrometeorological stations of NMHSs in order to analyze the impact of sand storms on agriculture*
- *leaf area index and land cover measurements with higher spatial resolution are needed ; the polar orbiting instruments should be enhanced to resolve sub 1 km features; and*
- *multifrequency synthetic aperture radar systems could offer significant improvements for canopy structure and water content determinations."*

A list of relevant Earth observation parameters for Agricultural Meteorology is given in Table 9 (cf. Chapter 4.1.8). However, the SOG does not contain priorities for these observations.

5.2.9. Priority observations for Hydrology

According to the WMO SOG on Hydrology (WMO 2008c, pp. 8-9),

- "[…] *Precipitation depth and type are routinely observed on an hourly to daily basis at synoptic weather stations but there are large regional differences in coverage; spatial and temporal coverage of rainfall observations is improving using ground radar techniques. Global scale observations from satellite borne radars, as well as microwave imagers and sounders are routinely available. Quantitative precipitation observations from satellite measurements are getting closer to meet accuracy requirements especially when cross-calibrated with in-situ observations. Unfortunately however, these data and information sources are not yet routinely used by national hydrological services. For operational purposes, the number of established Hydrological Radars is increasing;*

- *Terrestrial measurements of evaporation are declining in terms of spatial coverage; flux towers numbers are very limited, with data not readily available on a global scale;*
- *Acceptable data on a real extent of snow cover has improved with the transition from AVHRR to MODIS; passive microwave instruments (i.e., AMSR) have improved estimates of the thickness of dry snow. These snow cover measurements will be acceptable for mesoscale modelling and snowmelt runoff forecasting;*
- *Addition of microwave instruments (AMSU and AMSR) provide enhanced observational capabilities for snow water equivalent and soil moisture, however operational continuity of AMSR is not assured;*
- *Observations on snow and ice is expected to improve after the launch of CRYOSAT II;*
- *Runoff observations (levels in rivers, lakes and reservoirs) can now be supplemented by radar altimetry instruments flown on ENVISAT and likewise JASON and TOPEX may be used for this purpose;*
- *Gravimetric measurements of changes in large aquifers from GRACE and GOCE are nearing a stage where they could be used operationally;*
- *A number of additional satellite-derived variables are, or will be, extremely useful to hydrology, including but not limited to: precipitation rates and totals, latent and sensible heat, surface-air temperature and humidity, and surface winds;*
- *In most fields of applications, satellite information has not been used operationally for hydrological purposes, although the extent of use is probably increasing;*
- *Focus needs to be placed on the integration of in-situ and space-based observations for hydrological applications in a comparable space and time domain and of acceptable accuracy. The latter would require increased efforts to assess observation quality through intercomparison and (re)-calibration projects and include estimates of uncertainty;*
- *In general, access to hydrological data and observations of all variables mentioned is insufficient for many research and development purposes and for practical applications by national Hydrological Services."*

According to WMO (2008c), following GCOS (2000) the following Earth observation parameters are of highest priority for hydrometeorological applications:

- Surface water discharge
- Surface water storage fluxes
- Groundwater fluxes
- Precipitation (liquid / solid)
- Isotope signatures
- Evaporation
- Vapour pressure / Relative humidity
- Soil moisture / Soil wetness
- Snow cover, depth, and water equivalent and glaciers
- Biogeochemical (BGC) fluxes from land to ocean
- Water Use

In addition to the 11 hydrometeorological variables, also listed in GCOS (2000), the SOG discusses the following variables:

- Land surface temperature
- Vegetation type and NDVI

- Short-wave and Long-wave outgoing radiation at Top of Atmosphere (TOA).

5.2.10. Summarized Earth observation priorities for Weather SBA

In Table 13, the most important Earth observation parameters identified in the analysed literature have been listed (Level 3 prioritization). Detailed information on observation characteristics for these parameters has not been included in this table. This decision has been taken in coordination with the Advisory Group and in the light of the complexity and comprehension of the data. Furthermore, the different user requirement databases and documents are updated regularly and should be consulted for further information on the Level-3 priority parameters.

Therefore, hyperlinks to the relevant databases and documents containing observation characteristics for the Earth observation parameters listed in Table 13 are provided here:

- WMO Statements of Guidance:
  - WMO 2004a: SOG Agricultural Meteorology
  - WMO 2004b: SOG Atmospheric Chemistry
  - WMO 2008a: SOG Aeronautical Meteorology
  - WMO 2008b: SOG Global Numerical Weather Prediction (G-NWP)
  - WMO 2008c: SOG Hydrology
  - WMO 2008d: SOG Ocean Applications
  - WMO 2008e: SOG Seasonal and Inter-annual Forecasts (SIA)
  - WMO 2008f: SOG Synoptic Meteorology
  - WMO 2009h: SOG Regional Numerical Weather Prediction (R-NWP)
  - WMO 2009i: SOG Nowcasting and Very Short Range Forecasting

- WMO 2009a: WMO/CEOS databases on observational requirements, instruments and reception systems

- EUMETSAT position papers:
  - EUMETSAT 2001: Requirements for Observations for Regional NWP
  - EUMETSAT 2002: Requirements for Observations for Global NWP

No.	Parameter type	Parameter / parameter type	Document references
1	**Aerosol properties**	3D aerosol	**EUMETSAT 2001, 2002, WMO 2008b, 2009h**
2		Aerosol (vertical profile)	**EUMETSAT 2001**
3		Dust	**WMO 2009i**
4		Troposphere aerosol	**WMO 2008e**
5		Volcanic ash	**WMO 2008a, 2008e**
6	**Atmospheric chemistry**	Greenhouse gases	**WMO 2008e**
7		Ozone	**EUMETSAT 2001, 2002, WMO 2008b, 2009h**
8		Stratospheric ozone	**WMO 2008e**
9	**Cloud properties**	Cloud base height	**EUMETSAT 2002**
10		Cloud ceiling height	**WMO 2008a**
11		Cloud cover	**EUMETSAT 2001, 2002**
12		Cloud drop-size at cloud top	**EUMETSAT 2002**

No.	Parameter type	Parameter / parameter type	Document references
13		Cloud drop spectra	**EUMETSAT 2001**
14		Cloud ice	**EUMETSAT 2001**
15		Cloud snow	**EUMETSAT 2001**
16		Cloud top height	**EUMETSAT 2002**
17		Cloud water/ice amounts (3D distribution)	**EUMETSAT 2002, WMO 2008a**
18		Clouds	**WMO 2008b, 2009h, 2009i**
19		Gravity waves	**WMO 2008a**
20		Particle spectra in clouds	**EUMETSAT 2001**
21	**Humidity**	2m humidity	**EUMETSAT 2001**
22		3D humidity field	**EUMETSAT 2001, 2002, WMO 2008a, 2008b, 2009i**
23		Surface air humidity	**EUMETSAT 2001, 2002, WMO 2008b, 2009i**
24		Vapour pressure	**WMO 2008c**
25		Water vapour (vertical profile)	**EUMETSAT 2001**
26	**Precipitation**	3D precipitation	**EUMETSAT 2002**
27		Accumulated precipitation	**WMO 2009i**
28		Precipitation	**WMO 2008b, 2009h, 2009i**
29		Precipitation (liquid/solid)	**WMO 2008c**
30		Surface precipitation	**EUMETSAT 2002**
31		Surface precipitation intensity	**EUMETSAT 2001**
32		Vertical rain/snow profile	**EUMETSAT 2001**
33	**Pressure**	Surface pressure	**EUMETSAT 2001, 2002, WMO 2008b, 2009h, 2009i**
34	**Radiation**	Surface albedo	**EUMETSAT 2001**
35		Surface heat flux	**WMO 2008e**
36	**Salinity**	Sea surface salinity	**EUMETSAT 2002, WMO 2008e**
37	**Sea ice properties**	Sea-ice (cover)	**EUMETSAT 2001, 2002, WMO 2008b, 2008e, 2009h**
38		Sea-ice thickness	**EUMETSAT 2002, WMO 2008e**
39	**Snow properties**	Snow (cover)	**EUMETSAT 2001, 2002, WMO 2008b, 2008c, 2008e, 2009h, 2009i**
40		Snow depth	**EUMETSAT 2001, WMO 2008c, 2008e**
41		Snow mass	**WMO 2008e**
42		Snow water equivalent	**EUMETSAT 2001, 2002, WMO 2008c**
43	**Soil moisture**	Soil moisture	**EUMETSAT 2001, 2002, WMO 2008b, 2008c, 2008e, 2009h**
44	**Temperature**	2m temperature	**EUMETSAT 2001**
45		3D temperature field	**EUMETSAT 2002, WMO 2008a, 2008b, 2009h, 2009i**
46		Lake surface temperature	**EUMETSAT 2001**
47		Land surface (skin) temperature	**EUMETSAT 2002, WMO 2008b, 2009h**
48		Sea sub-surface temperature	**WMO 2008e**
49		Sea surface temperature	**EUMETSAT 2001, 2002, WMO 2008b, 2008e, 2009h**
50		Sea-ice surface (skin) temperature	**EUMETSAT 2001, WMO 2008b, 2009h**
51		Soil temperature	**EUMETSAT 2001**
52		Surface air temperature	**EUMETSAT 2002, WMO 2008b, 2009h, 2009i**
53	**Vegetation**	Fraction of absorbed PAR (fAPAR)	**EUMETSAT 2002, WMO 2008e**
54		Leaf Area Index (LAI)	**EUMETSAT 2002, WMO 2009h**
55		Vegetation cover	**EUMETSAT 2001, WMO 2008b, 2009h**
56		Vegetation type	**EUMETSAT 2001, 2002, WMO 2008b, 2009h**
57	**Wave properties**	Wave direction	**EUMETSAT 2002, WMO 2008b, 2009h**
58		Wave height	**EUMETSAT 2001, 2002, WMO 2008b, 2009h**

No.	Parameter type	Parameter / parameter type	Document references
59		Wave period	**EUMETSAT 2002, WMO 2008b, 2009h**
60		Wave spectra	**EUMETSAT 2001**
61	**Wind**	3D wind field	**WMO 2008a, 2009i**
62		10m wind	**EUMETSAT 2001**
63		Aerodynamic roughness length	**EUMETSAT 2002**
64		Ocean wind stress	**WMO 2008e**
65		Surface wind	**EUMETSAT 2001, 2002, WMO 2008a, 2008b, 2009i**
66		Wind (3D) – horizontal component	**EUMETSAT 2002, WMO 2008b, 2009h**
67		Wind (3D) – vertical component	**EUMETSAT 2002, WMO 2008b, 2009h**
68	**Ocean currents**	Ocean current data	**WMO 2008e**
69	**Hydrosphere properties**	Evaporation	**WMO 2008c**
70		Ground water fluxes	**WMO 2008c, 2008e**
71		Surface water discharge	**WMO 2008c**
72		Surface water storage fluxes	**WMO 2008c**
73		Water use	**WMO 2008c**
74	**Diverse**	Atmospheric data	**WMO 2008e**
75		Biogeochemical fluxes from land to oceans	**WMO 2008c**
76		Boundary layer height	**EUMETSAT 2001**
77		Glaciers	**WMO 2008c**
78		Ocean chlorophyll	**EUMETSAT 2002**
79		Ocean sub-surface variables	**WMO 2008b, 2009h**
80		Ocean suspended sediment	**EUMETSAT 2002**
81		Ocean topography	**EUMETSAT 2002, WMO 2008e**
82		Ocean yellow substance	**EUMETSAT 2002**
83		Sea level	**WMO 2008e**
84		Surface cover/structure	**WMO 2009i**
85		Turbulent kinetic energy (vertical profile)	**EUMETSAT 2001**
86		Visibility	**WMO 2008a, 2009i**

Table 13: Priority Earth observation parameters for the Weather SBA.

5.2.11. Priority Earth observation characteristics for the Weather SBA

In order to facilitate the meta-analysis of the UIC, which will be conducted to compare the priority EO for all nine SBAs, a decision has been taken to apply a 4th prioritization step to the EO parameters identified in Table 13 above. Table 14 represents a comprehensive listing of observation characteristics for a number of priority EO parameters, which have been determined according to the Level-4 prioritization methodology described in Chapter 2.3.3. Each EO parameter characteristic (requirement) is expressed in terms of Horizontal Resolution**,** Vertical Resolution**,** Observing Cycle**,** Delay of Availability and Accuracy with each parameter described in terms of Goal**,** Breakthrough (B/T) and Threshold (T/H) (further description of how these limits were defined, see: WMO 2009a, EUMETSAT 2001, 2002)**.** It is highlighted that the WMO requirements undergo a regular review process and that the most up to date observation characteristics are to be found in the literature under:

- WMO 2009a: WMO/CEOS databases on observational requirements, instruments and reception systems

				Horizontal Resolution			Vertical Resolution			Observing Cycle			Delay of Availability			Accuracy		
Parameter type	**Parameter**	**Source**	**Application area**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**
Atmospheric chemistry	Ozone	WMO	Global NWP	15 km	100 km	250 km				1 h	6 h	12 h	0.1 h	0.5 h	6 h	5 DU	10 DU	20 DU
			Regional NWP	10 km	29.2 km	100 km				0.5 h	1.145 h	6 h	0.25 h	0.5 h	2 h	5 DU	7.9 DU	20 DU
		EUMETSAT	Global NWP	250 km	100 km	15 km				12 h	3 h	1 h	4 h	n/a	1 h	20 DU	10 DU	5 DU
			Regional NWP	200 km	n/a	3 km	2 km	n/a	100 m	24 h	n/a	3 h	n/a	n/a	n/a	20%	n/a	5%
Cloud properties	Cloud Cover	WMO	Global NWP	5 km	15 km	50 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	5% (Max)	10% (Max)	20% (Max)
		EUMETSAT	Global NWP	250 km	15 km	5 km				12 h	3 h	1 h	4 h	n/a	1 h	20%	10%	5%
			Regional NWP	50 km	10 km	3 km				3 h	1 h	0.5 h				20%	n/a	5%
	Cloud water/ice amounts (3D distribution)	EUMETSAT	Global NWP	250 km	100 km	5 km	5 km	2 km	0.2 km	12 h	6 h	1 h	4 h	n/a	1 h	50%	20%	5%
			Regional NWP	200 km	30 km	3 km	2 km	1 km	100 m	12 h	3 h	0.5 h				50%	n/a	5%
Humidity	3D humidity field	EUMETSAT	Global NWP	250 km	50 km	15 km	3 km	1 km	0.5 km	12 h	3 h	1 h	4 h	n/a	1 h	20%	10%	5%
	Surface air humidity	WMO	Global NWP	15 km	50 km	250 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	2%	5%	10%
			Nowcasting / VRSF	5 km	10.8 km	50 km				0.25 h	0.397 h	1 h	0.08 h	0.147 h	0.5 h	1 kg/m2	1.7 kg/m2	5 kg/m2
		EUMETSAT	Global NWP	250 km	50 km	15 km				12 h	3 h	1 h	4 h	n/a	1 h	15%	10%	5%
			Regional NWP	50 km	n/a	3 km				3 h	n/a	0.5 h				10%	n/a	5%
Precipitation	Precipitation*	WMO	Global NWP	10 km	30 km	100 km				1 h	3 h	12 h	24 h	120 h	720 h	0.5 mm/d	2 mm/d	5 mm/d
			Regional NWP	10 km	29.2 km	250 km				0.5 h	1.442 h	12 h	24 h	74.6 h	720 h	0.5 mm/d	1.077 mm/d	5 mm/d
			Agricultural Meteorology	10 km	17.1 km	50 km				24 h	34.6 h	72 h	24 h	30.2 h	48 h	2 mm/d	3.4 mm/d	10 mm/d
		EUMETSAT	Global NWP	250 km	50 km	5 km				180 h	24 h	24 h	180 h	n/a	24 h	5 mm/d	1 mm/d	0.5 mm/d
			Regional NWP	50 km	10 km	3 km				3 h	1 h	0.5 h				1 mm/h		0.1 mm/h
Pressure	Surface pressure (over land)	WMO	Global NWP	15 km	100 km	500 km				1 h	6 h	12 h	0.1 h	0.5 h	6h	0.5 hPa	0.99 hPa	1 hPa

				Horizontal Resolution			Vertical Resolution			Observing Cycle			Delay of Availability			Accuracy		
Parameter type	**Parameter**	**Source**	**Application area**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**
			Regional NWP	10 km	29.2 km	250 km				0.5 h	1.442 h	12 h	0.5 h	0.79 h	2 h	0.5 hPa	0.63 hPa	1 hPa
		EUMETSAT	Global NWP	250 km	100 km	15 km				12 h	6 h	1 h	4 h		1 h	3 hPa	1 hPa	0.5 hPa
			Regional NWP															
Salinity	Sea surface salinity	WMO	Seasonal / International Forecasts	100 km	135.7 km	250 km				30 d	37.8 d	60 d	9 d	21.3 d	120 d	0.1 psu	0.144 psu	0.3 psu
		EUMETSAT	Global NWP	250 km	100 km	15 km				720 h	480h	360 h	720 h	n/a	360 h	0.3 psu	0.2 psu	0.1 psu
Sea ice properties	Sea-ice (cover)	WMO	Global NWP	5 km	15 km	100 km				0.125 d	1 d	5 d	0.125 d	1 d	5 d	5% (Max)	10% (Max)	20% (Max)
			Regional NWP	25 km	31.5 km	50 km				0.5 d	1.205 d	7 d	0.3 d	0.646 d	3 d	5% (Max)	10.8% (Max)	50% (Max)
		EUMETSAT	Global NWP	250 km	15 km	5 km				120h	24 h	24 h	120 h	n/a	3 h	50%	10%	5%
			Regional NWP	50 km	10 km	3 km				24 h	6 h	3 h				50%	n/a	5%
	Sea-ice thickness	EUMETSAT	Global NWP	250 km	100 km	15 km				720 h	48 h	24 h	4 h	n/a	1 h	1 m	1 m	0.5 m
Snow properties	Snow (cover)	WMO	Global NWP	5 km	15 km	100 km				3 h	24 h	120 h	3 h	24 h	120 h	10% (Max)	20% (Max)	50% (Max)
			Regional NWP	5 km	18.4 km	250 km				12 h	28.9 h	168 h	6 h	9.5 h	24 h	10% (Max)	17.1% (Max)	50% (Max)
			Nowcasting / VRSF	5 km	10.8 km	50 km				1 h	5.2 h	144 h	1 h	1.8 h	6 h	10% (Max)	12.6% (Max)	20% (Max)
			Hydrology	0.1 km	1 km	100 km				24 h	45.9 h	168 h	24 h	43.6 h	144 h	5% (Max)	7.9% (Max)	20% (Max)
		EUMETSAT	Regional NWP	50 km	10 km	3 km				24 h	6 h	3 h				50%	n/a	5%
	Snow water equivalent	EUMETSAT	Global NWP	250 km	15 km	5 km				120 h	6 h	1 h	24 h	n/a	1 h	20 mm	10 mm	5 mm
Soil moisture	Soil moisture	WMO	Global NWP	5 km	15 km	100 km				0.125 d	1 d	5 d	0.125 d	1 d	5 d	10 g/kg	20 g/kg	50 g/kg
			Regional NWP	5 km	18.4 km	250 km				1 d	1.9 d	7 d	7 d	10 d	30 d	10 g/kg	17.1 g/kg	50 g/kg
			Seasonal / International Forecasts	50 km	107.7 km	500 km				1 d	1.9 d	7 d	1 d	1.9 d	7 d	10 g/kg	17.1 g/kg	50 g/kg
			Agricultural Meteorology	0.1 km	0.215 km	1 km				1 d	1.9 d	7 d	1 d	1.7 d	5 d	10 g/kg	17.1 g/kg	50 g/kg
		EUMETSAT	Global NWP	250 km	100 km	5 km				120 h	24 h	3 h	120 h	n/a	3 h	20 g/kg	20 g/kg	5 g/kg

				Horizontal Resolution			Vertical Resolution			Observing Cycle			Delay of Availability			Accuracy		
Parameter type	**Parameter**	**Source**	**Application area**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**
			Regional NWP	50 km	10 km	1 km	2 layers	n/a	5 layers	24 h	6 h	1 h				50 g/kg	n/a	10 g/kg
Temperature	3D temperature field	EUMETSAT	Global NWP	500 km	100 km	15 km	3 km	1 km	0.5 km	24 h	6 h	1 h	4 h	n/a	1 h	3 K	1 K	0.5 K
	Land surface (skin) temperature	WMO	Global NWP	5 km	15 km	250 km				0.5 h	3 h	6 h	0.1 h	0.5 h	6 h	0.5 K	1 K	4 K
			Regional NWP	10 km	29.2 km	250 km				0.5 h	1.442 h	12 h	0.5 h	0.794 h	2 h	0.5 K	1 K	4 K
		EUMETSAT	Global NWP	250 km	15 km	5 km				12 h	3 h	1 h	4 h	n/a	1 h	4 K	1 K	0.5 K
	Sea-ice surface (skin) temperature	WMO	Global NWP	5 km	15 km	250 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	0.5 K	1 K	4 K
			Regional NWP	5 km	13.6 km	100 km				0.5 h	1.442 h	12 h	0.5 h	0.794 h	2 h	0.5 K	1 K	4 K
		EUMETSAT	Global NWP	500 km	15 km	5 km				12 h	3 h	1 h	4 h	n/a	1 h	4 K	1 K	0.5 K
	Sea surface temperature	EUMETSAT	Global NWP	250 km	5 km	5 km				120 h	24 h	3 h	120 h	n/a	3 h	2 K	0.5 K	0.3 K
			Regional NWP	50 km	10 km	1 km				24 h	6 h	1 h				1.5 K	n/a	0.5 K
	Surface air temperature	EUMETSAT	Global NWP	250 km	100 km	15 km				12 h	6 h	1 h	4 h	n/a	1 h	2 K	1 K	0.5 K
Vegetation	Fraction of absorbed PAR (fAPAR)	WMO	Seasonal / International Forecasts	50 km	107.7 km	500 km				7 d	11.4 d	30 d	1 d	3.1 d	30 d	5% (Max)	6.3% (Max)	10% (Max)
		EUMETSAT	Global NWP	250 km	50 km	5 km				720 h	240 h	180 h	720 h	n/a	24 h	10%	10%	5%
	Leaf Area Index (LAI)	WMO	Agricultural Meteorology	0.01 km	0.1 km	10 km				5 d	5.6 d	7 d	1 d	1.7 d	5 d	5% (Max)	6.3% (Max)	10% (Max)
	Vegetation cover**	WMO	Global NWP	2 km	10 km	50 km				1 d	5 d	10 d	0.125 d	1 d	10 d	5% (Max)	10% (Max)	20% (Max)
			Regional NWP	10 km	17.1 km	50 km				7 d	11.4 d	30 d	1 d	1.9 d	7 d	1% (Max)	1.7% (Max)	5% (Max)

				Horizontal Resolution			Vertical Resolution			Observing Cycle			Delay of Availability			Accuracy		
Parameter type	**Parameter**	**Source**	**Application area**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**
			Agricultural Meteorology	1 km	2.2 km	10 km				1 d	1.9 d	7 d	1 d	1.7 d	5 d	5% (Max)	6.3% (Max)	10% (Max)
		EUMETSAT	Regional NWP	50 km	10 km	3 km				1 m	6 h	0.5 h				30%	n/a	10%
	Vegetation type	WMO	Seasonal / International Forecasts	50000 m	107721.7 m	500000 m				7 d	11.4 d	30 d	1 d	1.9 d	7 d	18 classes	14.3 classes	9 classes
			Hydrology	10 m	46.4 m	1000 m				7 d	26.2 d	365 d	1 d	3.1 d	30 d	50 classes	23.2 classes	5 classes
		EUMETSAT	Global NWP	250 km	15 km	5 km				720 h	240 h	180 h	720 h	n/a	24 h	18 classes	12 classes	9 classes
			Regional NWP															
Wave properties	Wave direction	WMO	Global NWP	15 km	50 km	250 km				1 h	3 h	12 h	0.1 h	3 h	12 h	10 degrees	15 degrees	30 degrees
			Regional NWP	10 km	17.1 km	50 km				1 h	2.3 h	12 h	0.5 h	0.794 h	2 h	10 degrees	12.6 degrees	20 degrees
		EUMETSAT	Global NWP	250 km	50 km	15 km				12 h	3 h	1 h	4 h	n/a	1 h	20 degrees	15 degrees	10 degrees
	Wave height	WMO	Global NWP	15 km	50 km	250 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	0.1 m	0.3 m	0.5 m
			Regional NWP	10 km	17.1 km	50 km				1 h	2.3 h	12 h	1 h	1.3 h	2 h	0.1 m	0.126 m	0.2 m
		EUMETSAT	Global NWP	250 km	50 km	15 km				12 h	3 h	1 h	4 h	n/a	1 h	0.5 m	0.3 m	0.25 m
			Regional NWP	50 km	10 km	3 km				3 h	1 h	0.5 h				0.2 m	n/a	0.1 m
	Wave period	WMO	Global NWP	15 km	50 km	250 km				1 h	3 h	12 h	0.1 h	0.5 h	6 h	0.25 s	0.5 s	1 s
			Regional NWP	10 km	17.1 km	50 km				1 h	2.3 h	12 h	0.5 h	0.794 h	2 h	0.5 s	0.63 s	1 s
		EUMETSAT	Global NWP	250 km	50 km	15 km				12 h	3 h	1 h	4 h	n/a	1 h	1 s	1 s	0.5 s
Wind	Surface wind	EUMETSAT	Global NWP	250 km	100 km	15 km				12 h	3 h	1 h	4 h	n/a	1 h	5 m/s	2 m/s	0.5 m/s
			Regional NWP	50 km	n/a	3 km				3 h	n/a	0.5 h				3 m/s	n/a	1 m/s
	Wind (3D) – horizontal component	WMO	Global NWP	15 km	100 km	250 km				1 h	6 h	12 h	0.1 h	0.5 h	6 h	0.5 m/s	2 m/s	3 m/s
			Regional NWP	10 km	29.2 km	250 km				0.5 h	1.442 h	12 h	0.5 h	0.794 h	2 h	0.5 m/s	1.077 m/s	5 m/s

				Horizontal Resolution			Vertical Resolution			Observing Cycle			Delay of Availability			Accuracy		
Parameter type	**Parameter**	**Source**	**Application area**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**	**Goal**	**B/T**	**T/H**
		EUMETSAT	Global NWP	500 km	100 km	15 km	3 km	1 km	0.5 km	24 h	6 h	1 h	4 h	n/a	1 h	8 m/s	3 m/s	1 m/s
	Wind (3D) – vertical component	EUMETSAT	Global NWP	500 km	200 km	15 km	3 km	2 km	0.5 km	12 h	6 h	1 h	4 h	n/a	1 h	5 cm/s	5 cm/s	1 cm/s
Diverse	Ocean topography	WMO	Seasonal / International Forecasts	25 km	39.7 km	100 km				7 d	11.4 d	30 d	2 d	3.9 d	15 d	1 cm	1.6 cm	4 cm
		EUMETSAT	Global NWP	100 km	50 km	15 km				360 h	240 h	120 h	360 h	n/a	48 h	4 cm	2 cm	1 cm

*** Precipitaion:** WMO: Precipitation index (daily cumulative)
EUMETSAT G-NWP: accumulated precipitation
EUMETSAT R-NWP: Surface precipitation rate (liquid)

**** Vegetation Cover:** WMO: Normalized Differential Vegetation Index (NDVI)
EUMETSAT: Normalized Differential Vegetation Index (NDVI)

Table 14: Priority Earth observation characteristics for the Weather SBA.

6. Analysts Comments and Recommendations

This chapter contains the personal views of the Analyst on the overall process of the US-09-01a Task and personal perspectives on the establishment of possible future user requirement studies under the GEO umbrella.

6.1. Process and Methodology

The overall Task management of US-09-01a and the 9-step process to identify EO priorities, which has been developed by the Task Leads, proved to be very helpful to conduct this analysis. In-person meetings of the Analysts and monthly teleconferences were very valuable to facilitate progress of the analysis.

The timeframe of the analysis (approx. 1 year) and available human resources certainly imposed restrictions as regards (A) Advisory Group establishment, (B) the process of identifying and gathering documents and (C) the level of detail of the meta-analysis and the resulting Report. In detail:

(A) The establishment of an Advisory Group for the Weather SBA analysis was a rather time consuming task. Overall, it took nearly half a year to gather a small group of experts and until the group could hold the first meeting (in person at WMO Headquarters). However, once established, the group provided many helpful comments to the Analyst.

(B) As mentioned above, the Report is primarily based on international consensus documents such as the Statements of Guidance by WMO or European studies in preparation of different satellite missions. There is a considerable lack of literature addressing national and regional user requirements. These requirements may not be represented in the existing literature in spite of the extensive international consultations, which have been conducted, e.g. under the umbrella of WMO. In some cases, GEO member states may have already conducted relevant user requirement studies, but where not able to provide an English version of the study results within the available time (approx. half a year from GEOSEC letter requesting documents and general support to the Task). Thus, further documents addressing regional and national user requirements need to be identified in the framework of future user requirement studies under GEO. To assure a broad availability of suitable documents, support by relevant stakeholders representing different geographical regions needs to be achieved by their participation in the GEO user requirement process.

(C) The existence of advanced user requirement studies in the weather domain proved to be extremely helpful for identifying EO priorities for the Weather SBA. However, a comprehensive illustration including lists of observation characteristics (i.e. accuracy, spatial/temporal resolution, timeliness etc.) for each of the relevant application areas within the Weather SBA proved to be impossible in the framework of this analysis. Due to the limitations in terms of resources and time, only a small subset of priority parameters has bee chosen for which observation characteristics have been included in the Report. Due to regular updates, which are applied to the WMO database on observation requirements, the subset of parameters in the Report only represents a snapshot of the current situation.

6.2. Recommendations

<u>General recommendations:</u>

(1) The SBA studies completed under US-09-01a should be seen as a first step in developing a sustained mechanism to gather user requirements in the context of GEOSS. A coordinated process with regular updates and, if appropriate, long-term storage of the gathered user requirements is considered necessary. This involves investments in terms of human and (limited) technical resources and requires consultations with organizations, programmes, initiatives and countries which conduct their own activities and mechanisms to analyse user requirements.

(2) It is anticipated that the results of US-09-01a will be used as a basis for a gap analysis of existing and planned Earth observation components (including observation systems, information services and other components) in the context of GEOSS. Such an analysis is seen as an important opportunity to identify new application areas for 'meteorological' Earth observations in the broader GEOSS context and to demonstrate the (societal) benefit of these Earth observations beyond applications such as weather forecasting. It is recommended to closely coordinate further steps with other relevant groups within GEO, especially with the Science and Technology Committee (STC), which should consider the results of US-09-01a in a planned investigation of algorithm and modelling requirements in the context of the GEO Tasks ST-09-01 and ST-09-02.

(3) The Analysts have developed different methods to identify relevant Earth observations and priorities. Development of a common methodology, which enables identification and analysis of requirements in all SBAs, should be considered for future studies under GEO. The Analyst suggests initiating a consultation process among responsible GEO Task Team members and experts from WMO, who are responsible for the development and conduction of the Rolling Requirements Review.

<u>Technical recommendations:</u>

(4) Advisory Groups with a minimum number of participants should be established before the start of the meta-analysis.
(5) A dedicated mid-term workshop of the Task should be hold to present first results of the analysis and to discuss methods and results in breakout groups for each of the SBAs and, if necessary, application areas. Experts should be identified to support the workshop and to increase participation and interest in the Task.

Appendix A: Acronyms

AEG	EUMETSAT Application Expert Group
AG	Advisory Group
BfG	German Federal Institute of Hydrology
CEOS	Committee on Earth Observation Satellites
CGMS	Coordination Group for Meteorological Satellites
CPL	Cloud, Precipitation and Large Scale Land Surface Imaging
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential Climate Variables
EO	Earth observation
EPS	EUMETSAT Polar System
ESA	European Space Agency
EUMETNET	Network of European Meteorological Services
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
fAPAR	Fraction of absorbed PAR
FIR	Flight Information Region
FP7	Seventh Framework Programme of the European Union
GCOS	Global Climate Observing System
GEMS	Global and regional Earth-system (Atmosphere) Monitoring using Satellite and in-situ data
GEO	Group on Earth Observation
GEOSEC	Secretariat of GEO
GEOSS	Global Earth Observation System of Systems
GHG	Greenhouse gas
GMES	Global Monitoring for Environment and Security
G-NWP	Global Numerical weather prediction
GOES-R	Geostationary Operational Environmental Satellite, R-series
GOS	WMO Global Observing System
ICAO	International Civil Aviation Organization
ICSU	International Council for Science
IFR	Instrument Flight Rules
IGACO	Integrated Global Atmospheric Chemistry Observations
IGOS	International Global Observing Strategy
LAM	Limited Area Model
LIA	Leaf area index
MACC	Monitoring Atmospheric Composition and Climate
MTG	Meteosat Third Generation
MWO	Meteorological Watch Office
NDVI	Normalized Differenced Vegetation Index
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NWC	Nowcasting
PAR	Photosynthetically active radiation
PBL	Planetary boundary layer
Post-EPS	Post EUMETSAT Polar System
PROMOTE	PROtocol MOniToring for the GMES Service Element: Atmosphere
R-NWP	Regional Numerical weather prediction
RRR	WMO Rolling Review of Requirements

SBA	Societal Benefit Area
SIA	Seasonal and inter-annual forecasts
SIGWX	Significant Weather (in aviation)
SLWC	Super Cooled Liquid Water Content
SOG	WMO Statement of Guidance
SST	Sea-surface temperature
STC	GEO Science and Technology Committee
TAF	Terminal Aerodrome Forecasts
TOA	Top of atmosphere
TTT (T3)	GEO Target Task Team
TYIP	GEOSS 10-year Implementation Plan
UIC	User Interface Committee
UNEP	United Nations Environment Programme
VMC	Visual Meteorological Conditions
VSRF	Very short range forecast
WAFC	World Area Forecast Center
WAFS	World Area Forecast System
WIGOS	WMO Integrated Global Observing System
WMO	World Meteorological Organization

Appendix B: References

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Documents and References Consulted

A list of the documents consulted in the broader analysis is available at http://sbageotask.larc.nasa.gov/weather.html

Appendix C: Input to the Cross-SBA Analysis

At the conclusion of the individual SBA priority-setting analysis, the Weather Analyst provided input on the overall critical Earth observation parameters for the Weather SBA for inclusion in the Cross-SBA meta-analysis. Upon receiving input from the SBA Analysts, the Cross-SBA Analyst reviewed the priorities and combined observation parameters that are the same or very similar but have different names (e.g., precipitation intensity and precipitation duration). In some cases, the Cross-SBA Analyst extracted observation parameters from aggregated observation categories that were identified as priorities by individual SBAs and included these observation parameters as input to the Cross-SBA analysis. As a result, the number of observation priorities identified by individual SBAs may vary from the number of observations that were included in the Cross-SBA analysis. To the extent possible, the Cross-SBA Analyst focused on retaining the observation parameter terminology employed by the majority of the SBAs, in order to minimize regrouping and splitting of observations.

The Weather SBA Analyst determined the overall critical Earth observation priorities for the Weather SBA by using a 4-level approach to rank the observation categories, as described in Sections 2.3.3 and Chapter 5. Based on the results of the prioritization analysis, the 29 observations listed below have the highest rankings and, thus, are considered to be the observation priorities for the Weather SBA. The Cross-SBA Analyst included these 29 observations in Methods 1-3 of the Cross-SBA analysis. Accounting for differences in observation terminology across the SBAs, the Weather Team effectively contributed 31 observation parameters to Methods 1-3 of the Cross-SBA analysis.

The Weather SBA Analyst designated all of the 29 observations as having “High” priority for numerical weighing in Cross-SBA Methods 2 and 3. However, the Cross-SBA methodology is based on each SBA designating a roughly equal number of observation parameters as “High,” “Medium,” and “Low” priority. Thus, the Cross-SBA Analyst utilized the list of “15 Most Critical” observations from Method 4 to divide the observation parameters into “High” and “Low” priority categories for Methods 2 and 3. In other words, the Cross-SBA Analyst considered the “15 Most Critical” observations from Method 4 to be “High” priority, and the remaining to be “Low” priority.

For Method 4, the Cross-SBA Analyst included the priority observations in red text as the “15 Most Critical” observations. Accounting for differences in observation terminology across the SBAs, the Weather Team effectively contributed 17 observation parameters to Method 4 of the Cross-SBA analysis.

3D humidity field (upper level humidity)
3D temperature field (upper level temperature)
Cloud Cover
Cloud water/ice amounts (3D distribution)
Fraction of absorbed PAR (fAPAR)
Land surface (skin) temperature
Leaf Area Index (LAI)
Ocean topography
Ambient Ozone
Column Ozone
Stratospheric Ozone

Precipitation
Sea surface salinity
Sea surface temperature
Sea-ice (cover)
Sea-ice surface (skin) temperature
Sea-ice thickness
Snow (cover)
Snow water equivalent
Soil moisture
Surface air humidity
Surface air temperature
Surface pressure (over land)
Surface wind speed
Surface wind direction
Vegetation cover
Vegetation type
Wave direction
Wave height
Wave period
Upper level winds