

GUIDANCE DOCUMENT: RESEARCH NEEDS OF COPERNICUS OPERATIONAL SERVICES

FINAL VERSION (30/10/2015)

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1. INTRODUCTION

The Regulation establishing the Copernicus Programme (EU 377/2014) notes in its preamble, that Copernicus should also benefit from the results provided by Horizon 2020, in particular through its activities in research and innovation for future Earth Observation technologies and applications. In this respect, the Commission is called upon to ensure appropriate synergy, transparency and clarity regarding the different aspects of Copernicus. This guidance document is thus designed to further elucidate the research needs as identified in the context of provision of operational services in Copernicus.

The Horizon 2020 "Space" work programme 2016 includes a topic on Copernicus services evolution with the title "EO-3-2016: Evolution of Copernicus services"¹.

The guidelines are intended to assist applicants in preparing their proposals in the context of the EO-3-2016 topic, and provide indicative guidance for the applicants, in order to optimally align the relevance of their proposals to Copernicus service objectives.

2. COPERNICUS PROGRAMME EVOLUTION

The Copernicus Regulation (EU 377/2014) establishes the Union Earth observation and monitoring programme, containing a service component ensuing delivery of information in the areas of atmosphere monitoring, marine environment monitoring, land monitoring, climate change, emergency management and security. The scope of these different service components is further defined in Art 5 of the regulation.

The corresponding Copernicus operational activities are set out in annual work programmes covering funding and **system evolution for the time period 2014-2020**. According to Article 12 of the Copernicus Regulation, the Copernicus annual work programme for Copernicus includes a forward-looking implementation plan. Thus an annex of a multi-annual Implementation plan of activities and the envisaged evolution of the programme is attached to the annual WP document.

The document describes the actions needed to implement Copernicus over the period of 2014-2020 and takes into account evolving user needs and technological developments. In particular, the implementation plan defines and updates as necessary the scope, architecture, governance and technical portfolios of the Copernicus services.

For further information on the current annual Copernicus service work programme with the larger multiannual context, and hence the scope of activities potentially expected to be included over the coming years into the Copernicus operational funding, see [*Annex to the Commission Implementing Decision C\(2015\) 767 final concerning the adoption of a financing decision for 2015 in the framework of the Copernicus Programme*](#)².

¹ See H2020 Space call 2016 with call identifier H2020-EO-2016

² http://www.copernicus.eu/sites/default/files/library/C_2015_767_F1_ANNEX.pdf, in particular pages 58 and following.

3. COPERNICUS EVOLUTION AND HORIZON 2020 PROJECT EXECUTION – SOME PRACTICAL TIMING CONSIDERATIONS

Immediate service maintenance and enhancement in response to the Copernicus work programme is part of operational tasks delegated in the Copernicus funding context, while long-term evolutions will need input from R&D performed outside the programme.

Copernicus operational services are not static, but need to evolve with recognised and emerging user requirements and state of the art methodologies. While immediate service maintenance and enhancement in response to the Copernicus work programme is part of operational tasks, it is the long-term evolutions which can benefit from input from R&D performed outside the Copernicus programme. A process has been put in place in the Copernicus services by the Entrusted Entities to review service evolution and any emerging adaptation needs as to their urgency, closeness to the operational delivery process, and availability of capacities.

The challenge is to have the results of Horizon 2020 R&D available in a sufficiently timely manner to support an informed discussion, if and under which conditions an evolution of the operational service portfolio of the Copernicus service is appropriate. The schedule of activities envisaged by proposers in Horizon 2020 "Space" topic EO-3-2016 should thus consider the overall planning of the Copernicus programme up to 2020 and its specific services concerned.

The time constraints imposed by typical project execution time scales in Horizon 2020 need to be taken into account when establishing research needs to be addressed in Horizon 2020. For example, research projects called for in the 2016 call will typically be conducting their research activities during 2017-2019, and any pre-operational prototypes resulting from these actions could thus be considered by service operators for integration at earliest in 2020 and during preparations of future post-2020 Copernicus activities.

Research activities envisaged by applicants in project proposals under Horizon 2020 "Space" topic EO-3 should therefore target long-term service evolution challenges based on the latest scientific state of the art.

It should be noted that funding of the H2020 project in no way commits the Commission or Copernicus service operators to deploy the outcomes from the research in the Copernicus operational services.

4. LINK BETWEEN H2020 SERVICE EVOLUTION PROJECTS AND COPERNICUS SERVICES

The research and innovation action under Horizon 2020 "Space" call topic EO-3-2016 should aim at demonstrating the technical operational feasibility of a specific service evolution envisaged. The researchers are thus expected to demonstrate through their proof-of-concept or prototype the appropriateness for service evolution later on at European level. Proposers are recommended to include as output of their project a close examination of one or more possible scenarios how the project results could potentially be integrated into an operational service architecture and if it could be built on the existing observation data or if new observation requirements would be needed. Proposers should also keep in mind that the compatibility with INSPIRE should be ensured, e.g. as regards data reference frameworks and/or web services.

The EO-03-2016 call text states that "proposers are expected to demonstrate at the proposal stage an active link with the Copernicus service by suitable means". Such

demonstration of an “active link” is to be understood as the demonstration of the pertinence of the proposed research to the current operational service in question by demonstrating a clear understanding of the state of the art and requirements of the relevant aspects of the operational service provision, and describing the expected evolution of the state of the art as well as the technical feasibility of achieving this evolution. Additionally, the operationalisation of the research results should receive active attention during the course of the project to strengthen the readiness for an operational deployment in the future. Any further mechanisms for effective liaison with operational service providers in Copernicus are at the discretion of the proposers, but should be shown in the submitted proposal to be appropriate to the specific challenge tackled in the proposed research project.

In order to better facilitate uptake of the the research project results, the research project could, for example, establish a proof-of-concept or a prototype (accompanied with a white paper), which can act as reference for the independent assessment of Copernicus service evolution, in light of product extensions and service improvements.

5. IDENTIFIED NEEDS OF OPERATIONAL COPERNICUS SERVICES

5.1. Marine Environment Monitoring Service

At this stage, a review of the outcomes of the MyOcean2 scientific reports (delivered by MFCs and TACs WPs), the 2014 Lisbon User Workshop and the recent 2014 *MyOcean Science Days* held in Toulouse enable to identify a first list of key topical challenges and related R&D effort needed to support the evolution of the Marine Copernicus service at Horizon 2020. For the future, the Service Evolution Strategy will serve to derive potential research needs to be considered in corresponding research activities outside Copernicus.

The needs identified at this stage under Tier-3, suitable for Horizon 2020 activities are as follows.

5.1.1. Solving ocean dynamics at kilometric resolution

To support Copernicus users and decision-makers there is an increasing demand for model information on fine spatial scales and for a more complete representation of dynamical processes. This is relevant to all areas from the open ocean where the dynamics is significantly impacted by mesoscale to sub-mesoscale dynamics, to transition areas connecting coastal seas. It is also crucial that numerical models develop a resolution capacity compliant with the spatial scales that will be captured from space by future EO observing platforms (e.g. wide-swath altimetry, geostationary sensors, high resolution surface currents, high resolution SST, improved SSS etc.). Therefore numerical codes should be prepared to achieve smallest target effective resolution in the kilometric range. This objective requires R&D effort on numerical schemes and on adaptation of multi-scale and downscaling capabilities, interfaces with river hydrology, wave and sea-ice modelling components (as well as assimilation interfaces, to be treated jointly with topic 2 here below). In addition and consistently with the kilometric target, it will be necessary to develop new strategies and new algorithms to solve the model equations efficiently on next generation computing systems. This should result into improvements of code performance on most intensive HPC applications, which is crucial to sustain operational production.

5.1.2. Designing future observing systems and related assimilation methods

Regarding future observing systems (from space or in situ), the best possible rationality is required in the design and exploitation of observation networks and satellite constellations. This goal can be ideally achieved using observing system impact (Observing System Evaluations - OSEs) and design studies (Observing System Simulation Experiments - OSSEs) type experiments to extract the maximum information from data to improve product quality and optimize the assimilation of new observation types. OSEs and OSSEs are scientifically and technically feasible; they represent a useful investment when expanding an existing observing system, defining a new one, or preparing the assimilation of new data types or data with improved resolution/accuracy from space (e.g. sea surface topography, sea surface salinity, sea surface temperature, ocean colour, sea ice); they are also required for design studies to re-assess the sampling of the present in situ networks, define the required extensions or optimizations and prepare the assimilation of new in-situ data types taking into account the synergies with satellite observations (and in particular the Sentinel missions) (e.g. Argo including Bio-Argo, gliders, HF radars, ships, surface drifters, moorings). Such approaches enable to ensure a consistent assessment of observation data, assimilation techniques (such as 4DVAR) and forecast and analysis models upstream and downstream the definition and operation of space missions and complementary in-situ networks. This provides excellent framework for combining the various components required for Earth science and monitoring (space and in-situ observation systems, models and applications) through impact studies. This requires a consistent and shared approach at European level.

5.1.3. Developing seamless information chains linking dynamics, biogeochemistry and ecosystem essential variables

There is a strong requirement to improve our capacity to accurately assess the past and present state of the marine environment. Future operational marine services will benefit from the gradual improvement of tools to monitor (including retrospectively) the biogeochemical state of ocean and marine ecosystems in ocean basins and marginal seas, based on model-data integration and assimilation methodologies inherited from the physics. This will require the development of advanced data assimilation capabilities (e.g. combining state and parameter estimation, development of new modules linking optical properties in the near-surface ocean to biomass), combining ocean colour and sub-surface data from Bio-Argo, gliders and other relevant in-situ biogeochemical observations. This will also require strengthening the observing system of the “green” ocean at fine scales. The potential of future ocean colour satellites (e.g. Sentinel missions, geostationary satellites) and the development of complementary in-situ biogeochemical observations (e.g. bio-Argo) should induce, in particular, a the carbon/GHG cycle, to improve the representation of key processes such as breakthrough in the monitoring of regional/coastal areas and land-ocean interface. There is need for preparing the ground for these new data. Other R&D activities on the marine component of primary production, nutrient uptake, grazing in models, and on the modelling of higher trophic levels (plankton to fish) are also very relevant.

5.1.4. Seamless interactions between CMEMS and coastal monitoring systems

The coastal monitoring services operated by Member States or private groups form an important and strategic group of users of the CMEMS. However, the “one-way” vision of a core service delivering information to downstream users without feedback to upstream

providers has a number of limitations since the coastal strip should also to be considered as an “active” boundary layer that also influences the deep ocean region connected to coastal seas. It is therefore needed to develop the CMEMS in such a way as to enable more efficient interfacing with a large variety of coastal systems describing the physical, biogeochemical and ecosystem. This will require the provision of suitable connectivity between the Marine Service and downstream coastal systems, where adaptations at the level of regional seas benefit from user experience and practices.

Required R&D activities include, in particular, comprehensive impact studies of CMEMS boundary conditions on coastal systems (physics, biology), exploration of the benefit of two-way data exchange between coastal systems and CMEMS and definition of robust standards to ensure compatibility between CMEMS and downstream products and systems. An analysis of the impact of these R&D activities on applications and users should also be carried out (e.g. for the Marine Strategy Framework Directive).

5.2. Land Monitoring Service (pan-European and local land component)

5.2.1. Coastal monitoring, i.e. linkage and possible integration of land and marine information services

Both from land monitoring as well as from marine monitoring side, it is feasible to setup a monitoring service that focuses specifically on respectively the land side and the sea side of the coast line as such.

However, it is much less clear today what kind of information would be crucial to include in both services to get a better understanding of (environmental) interactions between both systems (such as estuaries, discharge of water and sediments), and how to best organise this, taking into account the specificity of (different) observation modes at both sides of the coastline, in terms of frequency, resolution, spectral characteristics.

Amongst other, and from a land perspective, an interesting focus would be on the ecosystem condition of coastal wetlands, based on the MAES ecosystem assessment framework, addressing main drivers of ecosystem change such as habitat change, hydrologic regime, overexploitation, pollution and nutrient enrichment.

5.2.2. LC/LU mapping and change mapping based on integrated radar and multi-spectral data

Throughout the reference years 2006, 2009 and 2012, it has been proven that a full and useful pan-European HR satellite image coverage is jeopardised in regions with high frequency cloud cover and/or low sun incidence angles. Despite considerable improvement to be expected from the Sentinel-2 satellite(s), these areas will continue to be sensitive in terms of suitable in phenological season image acquisition.

SAR imagery provides an alternative input data source for LULCC, however based on a fundamentally different physical process. Whereas classification techniques are available for both types of remote sensing, the question remains how to best combine and integrate both sources so as to obtain homogeneous full coverage high resolution information products, such as the Copernicus land HRLs.

5.2.3. *Automated change monitoring based on Sentinel data time series*

Whereas the existing portfolio of land monitoring services provides high quality LC/LU mapping and change mapping services, the overall production process needed to cover the pan-European 6M km² extent still suffers from too big an elapsed time between image acquisition and final information product. The way forward to remedy to this situation is by exploring and setting up a methodological approach for automated change monitoring based on indicators that can be derived directly from Sentinel data time series. (See as well section 5.2.6).

5.2.4. *Improved permanent grassland identification methods*

Both the pre-operational FP7 land service project done Geoland-2 and the GMES Initial operations land service provided a methodological framework for the detection and identification of permanent grasslands in Europe. However, neither of them proved to be fully mature for mapping this LC/LU class with a sufficiently high accuracy level throughout the biogeographical variability of Europe. A broad variation in natural, semi-natural and agricultural grasslands, combined with a diversity of grassland management approaches, and a potential confusion with some young croplands make this a particularly complex challenge. Improved image coverage is to be expected from Sentinel 2, complementary information from Sentinel 1, as well as combination with in-situ data sources such as LPIS and/ or LUCAS should open a perspective on a robust classification approach.

5.2.5. *Crop area and crop status monitoring*

The use of Sentinel-1 and Sentinel-2 imagery enables systematic mapping of global crop area extent and seasonal crop biophysical parameters. This should facilitate a significant scale up in the accuracy of crop yield and production estimates, especially when integrated with information derived from lower resolution (near-) daily sensor data, including those from the future Sentinel-3 satellite. The take up of this new imagery is further facilitated by the increased access to open reference data sets, such as parcel reference systems (e.g. LPIS), EU Member States' and other national ortho-photo repositories, and generic infrastructure information. Furthermore, novel data collection techniques, using mobile devices, UAVs and crowd-sourcing mechanisms can support validation and accuracy assessment, esp. when guided by geo-statistical sampling approaches. The following questions would need to be addressed:

- How to benefit from the complementarity between S-1 and S-2 imagery for crop delineation and crop status monitoring? For S-2 the emphasis should be on the use of spectral bands in the red-edge and short-wave infrared bands (beyond NDVI correlated parameters).
- How does the synergetic use of S-1 and S-2 imagery enhances the derivation of temporal crop parameters from lower resolution instruments, in particular those of Sentinel-3?
- How does the combination of Sentinel imagery with digital reference data, including ground observations, lead to enhanced information products and mutual benefits for different actors in the food production chain (e.g. farmers, farm services, food processing, regional and national authorities)?

- How can common methodologies in this domain be benchmarked and shared amongst different crop production systems, including those in food insecure countries?

5.2.6. *Methodology to provide yearly incremental updates in HRL layers*

Policy decision makers request for ever up to date land related information, at an increased pace of update frequencies. In order to do so, the land monitoring service is challenged to move from 3 or 6-yearly update cycles of pan-European products towards yearly incremental updates. An approach has to be developed to combine full coverage inventories with incremental spatially partial updates. The following questions would need to be addressed:

- How to ensure robustness of the method covering several years?
- How to deal with the spatial patchwork of imagery within a one year acquisition season? When are full coverages needed?
- How to present and use “time-hybrid” information?

5.2.7. *Feasibility of geo-hazards as a local component*

Geo-hazards are events caused by geological features and processes. An increased vulnerability of major urban areas to earthquakes is seen because of rapid growth of urban centres and the increased risk of land sliding, subsidence, flooding or erosion caused by heavy rainfall and/or human activities in many regions. Such vulnerabilities can be associated also to historical mining activities or geological formations. The specific challenge is to find an approach to identify those urban zones and regions that are prone to the most common geo hazards on land. The identification of potential geo-hazard risk zones can include the use of Urban Atlas together with the EU-DEM.

5.3. Land Monitoring Service (Global land component)

5.3.1. *High volume data processing lines*

International conventions and many EU policies require a global vision to be implemented and monitored in an efficient way. With the launch of SENTINEL 1 and the future launch of SENTINEL 2, large volume of satellite earth observation data at high resolution will be available at world level. So far, data processing lines have been mainly set up to process data at country and local level with algorithms calibrated and validated at these specific levels. Current processing lines and algorithms need thus to be adapted to answer to the needs. They should allow digesting in near real time the large volume of data, producing data composites but also deriving calibrated and validated variables at world level. The approach should be applied to different thematic areas.

5.3.2. *Automated change detection and monitoring based on Sentinel data time series*

Whereas the existing portfolio of land monitoring services provides high quality land cover and land use mapping, and change mapping services, the overall production process mainly based on data classification approach still suffers from too big an elapsed time between image acquisition and final information product. The way forward to

remedy to this situation is by exploring and setting up a methodological approach for automated change monitoring process directly derived from Sentinel data time series. This process should allow the provision of yearly incremental updates in the land cover / land use layers ensuring robustness of the method and information consistency for decision makers.

5.3.3. *Multi-source data integration*

Satellite systems were and are so far the primary sources of information for global monitoring. Today, the emergence of global connectivity and of alternative and light Earth Observation technologies may drive us to reconsider the unique role of satellite data. Data collections such as based on ground – in situ sensors, crowd sourcing or unmanned aerial vehicles should be taken into account and integrated with satellite systems to provide efficient and reliable information at global level. Systems and infrastructure which integrate in a seamless manner these data sources should be developed.

5.4. **Atmosphere Monitoring Service**

5.4.1. *Up-to-date Anthropogenic emissions estimates*

Emissions from human activities are an essential input to both global and European-scale atmospheric composition modelling and forecasting. Emissions of aerosols and gases are derived from a number of officially reported quantities that characterize activity levels of different sources (industrial, transportation or residential...) at the country level. A consequence is that inventories of anthropogenic emissions are lagging behind reality by a few years, the time needed for these quantities to be estimated and compiled. This is an issue, because emissions vary significantly from year to year, reflecting economic activity or implementation of new policy measures. Also, certain emissions dynamically depend on parameters that are observed and/or can be forecast, such as meteorology (wind, temperature...) or road traffic and there are thus possibilities to assess and forecast their short-term variations. Research is needed:

- to fast-track the process of estimating emissions so that input to models can be up-to-date;
- to identify meaningful proxies and methods that can be used to quantify emissions with a much shorter delay or even to forecast them;
- to quantify emission sources that can be linked to e.g. meteorological conditions (residential heating, air conditioning...) or other observed quantities (traffic...);
- to further develop inverse modelling techniques to help refine and update emission estimates.

5.4.2. *Data assimilation and future Sentinels*

CAMS critically depends on the capabilities to process and assimilate a wide range and variety of space-borne observations. While some of the associated challenges are of a generic nature (addressing for instance on methodological aspects, data volumes or representativeness issues...), other challenges are instrument-specific. Assimilation of

observations from the upcoming Sentinels 4 and 5 constitutes an objective of paramount importance for the early 2020s. Research is needed:

- to prepare for these observations using Observing System Simulation Experiments (OSSEs);
- to address open issues on the optimal use of observations: multispectral radiances assimilation, assimilation of combined level-2 products vs assimilation of individual level-2 products;
- to enable multivariate assimilation of chemically-related constituents;
- to investigate practical approaches to estimate the error variance-covariance matrix (B);
- to evaluate the impact of assimilation on forecast skill and how long in time improved initial conditions benefit the forecasts of chemical species and of particulates;
- to prepare for long term reanalyses of atmospheric constituents.

5.4.3. Coupling and downscaling methods for air quality modelling and forecasting

Air quality forecasting down to the urban scales require coupling a hierarchical chain of different models from the global to local scales. A considerable associated challenge is that the representations of chemical processes in the different models of the chain generally differ. Statistical downscaling approaches as well as the addition of complementary data (e.g. in situ data, traffic density information) should be taken into account in order to address the local scale. Research is needed:

- to develop effective coupling methods that allow to pass on chemical boundary conditions information across the scales;
- to stimulate downstream applications for the urban environment.

5.4.4. Quantifying uncertainties for atmospheric composition forecasts and hindcasts

There is strong user demand on quantifying the uncertainties associated with CAMS products. While simple ensemble-based methods are currently used, there is considerable scope for improving such methods, for instance in investigating error budgets and error growth as well as in developing well-suited metrics. Communication of these uncertainties to varied audiences (including e.g. policy and decision making) is also an area for investigation. Research is needed:

- to identify practical ways of quantifying the uncertainty associated with CAMS products;
- to understand fundamental aspects of error propagation and error growth in atmospheric composition modelling, underpinning progress on medium- to long-range predictability of atmospheric composition;

- to investigate ensemble methods that are compatible with a stringent time-critical operational context and the upcoming generation of high-performance computers;

to assess how best uncertainty information can be presented and communicated.

5.4.5. *Integrated soil-vegetation-atmosphere modelling and data assimilation*

The modelling of the soil-vegetation-atmosphere interface determines emissions and deposition of several atmospheric constituents. Parameterizations that represent the budgets of energy, water, carbon (including biogenic volatile organic compounds) as well as can consistently account for deposition of species are needed to improve the representation of surface fluxes of trace species. Research is needed:

- to develop surface models that can account accurately and dynamically for the sources and sinks of key trace gases;
- to improve methodologies to estimate deposition fluxes and associated uncertainties;
- to assess how satellite observations can help improve emission and deposition estimates.

5.4.6. *Monitoring and forecasting pollens*

Pollens affect the health of over 25% of the European population and this is understandably an area where CAMS is expected to deliver forecast products than can help patients and doctors decide upon the optimal taking of medication. However, pollen forecasting is still very challenging and research is needed:

- to develop accurate pollen source models for key allergenic species;
- to develop reliable and affordable monitoring methods that can be applied in real-time;
- to investigate how pollen allergenic potential evolves in time and as grains are transported in the atmosphere;
- to develop systems that not only forecast pollen grain counts but can take other parameters (air quality pollutants, temperature, humidity...) as well as patient-specific information to forecast symptoms.

5.4.7. *Improvement of secondary aerosols modelling*

Secondary aerosols are a major modelling challenge for completing the aerosol budget at global and regional scales and also for the health impacts of air quality (fine particulates). The modelling of the formation of secondary aerosols and it's interlinking with gas-phase chemistry remains a scientific challenge for air composition monitoring. Research is needed:

- to develop systematic methods to reduce the complex multiphase chemical reactions involving volatile organic compounds and other gases;

- to identify the major transformation processes and develop secondary aerosol schemes which are optimized for 3D models used in operational/time-critical conditions.

5.5. Climate Change Service

5.5.1. *Climate Prediction:*

During the two workshops that ECMWF has organised in the preparation for the C3S, it was clear that the user demand, across many sectors, for climate information at seasonal to decadal timescales "middle ground time scales", is very high. However, it was also considered that much research is still needed to develop services at these timescales, due to large scientific uncertainties. This is a typical case where H2020 should help by continuing funding R&I in this area (continuing and expanding SPECS), with the goal of filling the current gap in what C3S will deliver. Improvements of forecasts and projections for the 'middle ground' time ranges, where with 'middle grounds' we intend ranges up-to-40 years for which both initial conditions and external drivers should be one of the high level objectives of H2020 funding. Middle ground forecasts/projections can provide essential information to policy makers to develop adaptation and mitigation policies, and to the public and private sector to make optimal investments. They can provide extremely valuable inputs to the understanding of natural variability versus anthropogenic changes, and to assess the risk of abrupt, irreversible changes as opposed to gradual changes. Clearly, these forecasts/projects must be probabilistic, i.e. provide also uncertainty estimations (e.g. in the form of probabilities, or different possible scenarios). To ensure high quality initial fields for climate forecasts long term high climate-quality data are necessary enabling data assimilation for seasonal to decadal climate forecasts.

5.5.2. *Climate modelling at high resolution:*

Address the science underpinning of the production of climate projections, and in particular high resolution runs. The possibility to run these numerical integrations at 10 km or finer resolution is expected to be very important, since it will allow resolving more realistically a wide range of earth system processes relevant for these time-scales. The added value with respect to global climate projections arises especially at convection permitting resolution (below 3 km grid width). An additional benefit of this high model resolution is related to the assessment of the intensity and frequency of extreme events which become more realistic at that scale. Uncertainties associated with clouds and sea-ice in state-of-the-art climate and earth system models strongly contribute to the large spread in climate sensitivity estimates. In a 5-7 year perspective, high-resolution ensembles and process studies will significantly improve the representation of clouds and sea-ice and thus reduce the uncertainties in climate sensitivity, while the role of ice-sheets and permafrost may be significantly developed. At regional scale changes of the land use impact the local climate considerably. Therefore regional climate models need to be upgraded to be able to consider natural as well as anthropogenic land use changes in a similar way global climate models already do. CMIP6 activities are well underway, but some consider that the resolutions envisaged are not suitable to derive beneficial climate services. Additional effort (in coordination with WCRP) from H2020 is required. For evaluation and to assess the quality of the model simulations long term high quality data at very high resolution (in the order of the simulations' grid width) are mandatory.

5.5.3. *Climate and environmental observations*

It is necessary to better characterise atmospheric, marine, land and cryospheric observations that can be used to monitor the climate. This is in line with the research and development requirements identified by GCOS for data to meet the needs of the climate change community.

For the space based component these observations are not normally traceable to SI standards. This poses quite severe difficulties in the acceptance of results from satellite observations for climate studies, although with considerable effort and investment datasets of climate quality have been created. C3S (and CAMS) will not support, but benefit from these upstream efforts, and H2020 should play a role (together with Space Agencies such as ESA, EUMETSAT, with the Climate Change Initiative (CCI) and its proposed extension with new Essential Climate Variables (ECVs), and SAF initiatives respectively) in promoting and supporting the generation of climate quality Climate Data Records (CDRs). Sustained R&D funding is required to continually improve the CDRs in terms of accuracy, including error information, parameters derived as well as record length and spatial/temporal resolution. As the satellite based information will very rapidly grow in the next future, funding of R&D activities to extract climate relevant information and to extend the CDR length is required.

5.5.4. *C3S key data products*

C3S will benefit from the operational production of reanalyses at global and regional level. These reanalyses require sustained R&D funding to continually improve the products (projects such as ERA-CLIM-2 and UERRA). Research is required how best to derive information at the smaller scales, which are of high user interest. Best is meant in the sense of combined computational/storage cost and of scientific validity (both uncertainty reduction and proper uncertainty characterization). Research should include boundary and downscaling issues, optimization of ensembles methods, and post-processing. As earth systems become more complex (coupling atmosphere, ocean, land, carbon, etc.), an obvious need is to keep funding R&D in data assimilation for coupled models, to build on the current state of the art. Also R&D to improve the coupled models themselves is required (see points 1 and 2 above).

5.6. **Emergency Management Service (EMS)**

5.6.1. *"Operationability" of crowd sourcing for the EMS*

The goal is to combine mapping providers and crowd sourcing teams R&D efforts to create maps of the impact of a disaster in the first hours of the event, to be possibly integrated into the Copernicus EMS services, notably its Emergency Response, in order to better understand strength and weaknesses of the crowdsourcing approach, ways to integrate such sources into an operational effort, and address validation issues. Technical issues with access to data, sharing of data, and questions of credibility and verification need to be further addressed to finally enable operational service providers to effectively include social media/crowd-sourced material with the current sources of [satellite imagery](#), [in-situ data](#) and [aerial imagery](#). The challenge is to provide such combined mapping in a crisis/emergency event on a 24/7 basis to [civil protection authorities](#). The [possible extension of contributions to the Early Warning component](#) (e.g. floods, forest fires in EU) should particularly be investigated.

5.6.2. *Bringing satellite images closer to users*

With the introduction of publicly available image data (Landsat 8, Sentinel missions, MODIS etc.), there is a challenge of how to utilize them in emergency scenarios by large diversity of users. The effective access, data pre-processing, storage and the way of serving them to the large number of users (especially to those with limited knowledge of specialized tools and with limited internet connection) pose the main obstacle in their effective usage in emergency context. The ways how to ease access to those data and to ensure their easy interoperability has to be investigated and demonstrated.

5.6.3. *Large scale data assimilation of satellite data for improved disaster early warning and monitoring systems*

Unprecedented high resolution satellite data have become available through Copernicus in the last years and with the upcoming Sentinel missions the diversity, quality and resolution of these data will grow even further, opening new opportunities for improving numerical modelling in the context of disaster risk management. In addition, also the output of other Copernicus services, e.g. land monitoring or the marine service, are not yet fully exploited for disaster risk management and new applications can be envisaged. In particular, the necessity to develop better data assimilation methods for different applications has been identified already in other research topics of the COPERNICUS Services (see 5.1.2, 5.4.2 and 5.4.5). However, satellite data assimilation in real time early warning and monitoring systems requires specific attention to timeliness, reliability of the data acquisition as well as the assimilation algorithm, and computational cost. For example, assimilation of satellite soil moisture has shown to be potentially beneficial for flood and drought forecasting in small scale, offline case studies. Nevertheless, whether satellite soil moisture assimilation is useful at continental or global scale and whether it is computationally feasible in real time operations remains unknown. Similar problems exist for assimilation of other variables including exposure data into the disaster risk management chain. Hence, the goal of this research topic is to further improve data assimilation algorithms that can be used to enhance real time, large scale disaster early warning and monitoring systems for a variety of hazards, particularly those of the Copernicus EMS.

5.6.4. *Impact of human induced modifications of environment and structural developments in rivers on the forecasting of hydrological extremes*

Operational forecasting systems for floods and droughts often only partially include static and dynamic human modifications of the environment and river beds, e.g. through urbanisation, agriculture, transport, development of infrastructures, water management structures or any other relevant sectors. Mapping of such modifications including estimations of uncertainties through satellite or other remote sensing platforms, the modelling of their impacts and their assimilation in flood and drought forecasting systems is an emerging field of research. The goal of this research topic is to understand the spatio-temporal dynamics of changes in the environment and river beds relevant for the forecasting of floods and droughts on medium-seasonal scales and their wider impact on disaster impact modelling. This requires an explicit analysis of the sensitivity of flood and drought forecasting systems with respect to human induced modifications of environment and structural developments allowing establishing and ranking the importance of modifications. Furthermore, robust solutions which are fit for operational applications for the assimilation of such data into the models will be produced

5.6.5. *Methodologies for the assessment of vulnerability to natural hazards*

Several methodologies for the assessment of vulnerability have been developed over the past years. The shortcomings for an operational use, however, are (a) the diversity in the definition of vulnerability, (b) interoperability between scales, and (c) the incorporation of socio-economic, legal, cultural dimensions (primarily non-spatial data). One of the challenges is to meet the objectives of the Sendai Framework for Disaster Risk Reduction (2015-2030), which requires robust, multi-scale, interdisciplinary tools to assess, analyse, and monitor vulnerabilities to natural hazards compliant with international (e.g. UNISDR, IPCC) and European concepts (e.g. DG ECHO, DG RTD³) to feed into the evolution of the Risk & Recovery module of the Copernicus Emergency Management Service.

5.7. Security Service

Pre-operational activation of the security service during 2013-14 have shown the need to progress on detection capabilities, to better respond to the needs identified by users in the domains of (1) Support to EU External Actions, (2) Maritime Surveillance and (3) Border Surveillance.

5.7.1. *Automation of information extraction for large areas*

With the advent of new open data sources, in particular from Copernicus Sentinel 1 & 2 missions, huge amounts of data will become available on a daily basis that provide also information relevant for security applications. To fully exploit this information automated information extraction procedures need to be developed to be able to respond to crisis situations that affect entire countries or regions.

5.7.2. *Dissemination of EO based products*

Today's standard products in the operational and pre-operational Copernicus emergency and security services are printed and digital maps and to some extent layers that can be used for further analysis. However, as technology evolves new means of dissemination such as web services or smart phone applications may reach new user domains and eases the use of the information.

5.7.3. *Integration of EO derived information with other data sources*

Integrating environmental and socioeconomic indicators derived mainly from survey data and ancillary geospatial dataset combined with spatial modelling may provide new insights in security assessments for example in illicit crop monitoring the understanding of conflict induced land use changes (e.g. land abandonment, resource depletion around refugee/IDP camps).

The combination of EO derived damage information with social media and open source information may lead to a better understanding of the damage pattern in a conflict zone.

³ Risk Research ENSUREing to MOVE ahead. A cooperative paper based on the results of the projects ENSURE and MOVE (2013), bookshop.europa.eu/.../ensureing...move-ahead.../KI3212501EN

Combination of EO derived damage information with in-situ assessments based on UAV's for post crisis damage assessments for a better assessment of the damages.

5.7.4. Increased integration of multi-sensor and intelligence data for improving detection rates and identification of targets.

To achieve this increase in detection effectiveness, it is proposed to work towards a more integrated surveillance approach which will be able to make use of multiple sensors/assets but also intelligence sources. This will enable the optimum use of available assets not only for the detection and identification but also the eventual engagement with such targets of interest. Currently, the authorities possess a great number of different assets, sensors and intelligence sources. But these sources of information are usually used in a singular fashion. Ways of better integrating the different data and information would enable the closing of gaps in surveillance both in the terms of time and geographical-space. This would be done by optimising the positioning of in-situ assets near areas of high interest and the optimised use of EO space assets to fill identified surveillance gaps. In the short term, it is proposed to initiate work towards a more integrated surveillance, taking into account existing multiple sensors, platforms/assets and intelligence sources. This should include all relevant existing sensors including those providing ancillary data and space based sensors. Intelligence data such as that resulting from OSINT (Open Source Intelligence) but also from experts on the ground should also be integrated. In parallel to this first activity, further work could be initiated towards improved mission planning tools able to support end-users and decision makers on the how to optimise the use of assets based on the received data and intelligence sources. Additional work could be performed on the improvement of information tools used for the analysis but also visualisation of integrated data, including permeability maps. Finally, further work could be initiated towards the evaluation and integration of additional/future sensors, data and intelligence, not currently in use, including new platform concepts (e.g. space, UAVs, etc.).

5.7.5. Improved and automated processes for EO-data supply.

The aim of this activity is to work towards a more automated approach in EO data and product acquisition, so that the full acquisition process is as transparent as possible to the end-user. This theme is linked primarily to space EO assets. To achieve this improved automation, it is proposed that more work is done in the short term on IT tools for improving existing space EO data and product acquisition processes but also the ingestion of such products. In the medium term, work will be needed on how to further improve all aspects of the EO data/product acquisition process. This should include an analysis of the technical/technological deficiencies that lead towards reduced responsiveness and delivery time. Topics to be addressed could include amongst other topics how to urgently and affordably program space assets for data/product acquisition, how to accelerate image/data processing or how to improve responsiveness and delivery time by improving the ground network segment. In parallel, two other elements would need to be addressed in the short to medium term in order to facilitate automation. These are standardisation within the process but also legal and contractual aspects that would increase the affordability of EO products. The outcomes of the different work-strands should then be combined in the medium to long term in order to work towards a fully automated approach in EO data and product acquisition.

5.8. Cross-cutting issues and priorities identified

5.8.1. Stimulating integration of EO data in business processes of Member States in the context of reporting requirements for specific EU legislation

EU legislation often includes targets and reporting requirements to which the MS need to respond. For example, Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment; Directive 2007/60/EC on the assessment and management of flood risk, Directive 2008/50/EC on ambient air quality and cleaner air for Europe.

The proposals should deal with specific examples of EU legislation that will demonstrate in a hands-on way (standardised workflow) how the existing reporting practices can easily include EO data/information for an improved result. Focus of the proposals should be to demonstrate the complementary value of EO data to facilitate and enhance comprehensive reporting (and decision making). Proposals can involve the (tailored) services of the downstream sector/users. The proposal should be able to demonstrate how the business processes are improved and the key benefits.

5.8.2. Stimulating wider use of EO data processing models

For each specific theme or sector, different EO data processing models and/or methods exist and are being exploited. Currently, the models are mostly known within specialised expert/thematic user communities, which hampers widespread knowledge, possible spill-over/innovative effects and possible wider use. Research should be undertaken to identify if and how the different EO data processing models/methods can be accessed and used, how and which quality and (open) standards requirements and assurance are being used. Research should also be undertaken to analyse if (a dedicated network of) points of access is needed and how it than could be organised.

5.8.3. Open dynamic Testportal/Testbed to test new EO products/information

The development of new EO products/information require a test phase during which elements like the quality, robustness, usefulness, multi-functional use, user-friendliness...are being assessed. The proposals should be able to develop an open portal that will facilitate the testing of new/innovative EO products and information pilots by other researchers, developers.... The expected impact is the development of enhanced, new and/or innovative EO products/information by giving access in their test phase; to create an open technical discussion platform and a technical think tank for solutions; to guarantee interaction between the expert-users and the EO user community in Europe.

5.8.4. Stimulating wider research of publication big, linked open Earth Observation data

Constantly increasing volumes of EO data are being produced (big data) and stored in different data silos which are not (yet) published as linked data. The publication of the content of these EO data silos in a format that allows for interlinking with semantic connections will make data more accessible to applications and helping developers integrate data into their applications. This will trigger business opportunities for companies that are operating along the value added chain of EO data and services, the so-

called downstream sector which can offer new added value and innovation. Research should be undertaken to develop

- rapid and standardised workflows to publish big EO data as Linked Open Data to ensure standardised products and hence better access, improved (real) knowledge;
- rapid and standardised workflows to publish added-value information from EO data and services as Linked Open Data to ensure standardised products and hence a better access, opportunities for improved, new added value services.

5.8.5. *Stimulating research development EO Body of Knowledge*

The Copernicus programme is estimated to have a significant positive impact on the job creation, especially in the sector where companies offer added value services on EO data (down-stream sector). At the same time, there is a growing need for people with adequate skills to answer to the actual EO data job requirements e.g. data cloud specialists, data visualizers.... The use of a commonly agreed ontology by both the job seekers and job suppliers will significantly improve the demand-offer matching process and this can be provided by setting up a dynamic e-EO Body of Knowledge. Research should be undertaken to develop an EO Body of Knowledge that will

- support companies to draft the job-profiles using the EO Body of Knowledge terminology and concepts
- enable job-seekers to use the EO Body of Knowledge to draw their curriculum vitae
- support academic institutions and/or vocational training institutions to better orientate their curriculum (courses and trainings) to answer to the (changing) needs of the job-market to deliver the rightly skilled people.