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DOCUMENT

Sentinel-2 Preparatory Symposium: session summaries

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1 INTRODUCTION

This document gathers the session summaries with seed questions, conclusions and recommendations of the Sentinel-2 preparatory symposium, hosted by the European Space Agency at ESRIN, Frascati, Italy, on 23-27 April 2012

The main objectives of the Sentinel-2 symposium were:

- to gather the future Sentinel-2 R&D user community;
- to present Sentinel-2 mission, algorithms and products;
- to bridge the gap between Science and Services;
- to provide a forum for international exchange on optical HR land applications;
- to provide a forum for ESA Principal investigators and scientists to present optical High Spatial Resolution projects results;
- to present large scale international initiatives on land cover, forestry and agriculture.

The symposium focussed on the following themes:

- Agriculture
- Forestry
- Land cover
- Other applications (inland and coastal water quality, glaciers monitoring, wetlands, floods monitoring , forest fires mapping, land degradation)
- Methods and tools

The web site of the symposium is available at http://www.s2symposium.org/

2 SYMPOSIUM PROGRAMME

The symposium has been organised along the following oral sessions:

Date	Session id	Sessions Title
Monday 23 April		Opening
	1.1	Services and Perspectives
	1.2	Glaciers, Wetlands, Floods, Fires and Land Degradation
	1.3	Coastal and Inland Water Quality
Tuesday 24 April	2	Agriculture
Wednesday 25 April	3	Land Cover
Thursday 26 April	4	Forestry
Friday 27 April	5.1	Methods and Tools
	5.2	Session Summaries
		Conclusion

complemented by two poster sessions:

- Tuesday 24 April: Agriculture, Cartography,
- Thursday 25 April: Land Cover, Forest, Methods and Tools

The symposium has been attended by a total of 338 participants originating from all 5 continents (see figure 1 for national distribution of the participants). The participants were well representing the scientific as well as the industrial EO community (the participant list is available on the symposium website). The European Commission participated to the symposium with a group of 9 experts with contributions to the opening session by the acting head of the GMES bureau (DG ENTR) as well as by JRC and EEA scientists during the further sessions.

72 oral presentations (12 keynote addresses and 60 thematic speeches) were given and 110 posters were presented. The symposium website www.s2symposium.org contains all oral presentations and most of the posters presented at the Sentinel-2 preparatory symposium.

3 SEED QUESTIONS

Twelve seed questions were addressed to all presenters and to the participants during the round table discussions:

#	Seed Question
1	Which new research is needed?
2	Which new retrieval techniques need to be developed?
3	Which development and demonstration activities are required?
4	Which new tools are needed?
5	Are there requirements for High Level Products beyond Level-1C?
6	Do you expect any difficulties related to the large volume of data, and how can these be mitigated?
7	What needs to be done to use Sentinel-2 in synergy with other satellite missions?
8	Which opportunities arise in using Sentinel-2 with the existing long time series of high resolution data (Landsat, SPOT, etc)?
9	What are the benefits of the improved revisiting capacity (5 days with 2 satellites)?
10	What are the benefits of the improved spectral information content (e.g. red edge)?
11	Are you planning to use Sentinel-2 for local, regional or global applications?
12	Are there any recommendations regarding the "ESA exploitation cycle"?

4 SYMPOSIUM CONCLUSIONS

4.1.1 Services and Perspectives

During the session "*services and perspectives*", a few important considerations were highlighted by the speakers and by the participants, in particular in relation to the Sentinel-2 data policy, to the scale of Sentinel-2 applications, to the volume of Sentinel-2 data and to the synergy with other missions.

Sentinel-2 data will be used for all scales of applications, from local to regional, national and even global scales. Many public policy areas will be served, especially multilateral environmental agreements (e.g. Rio conventions).

The advantages of free, full and open access to data was repeatedly demonstrated. A "free and open data" policy would be beneficial in many aspects:

- it will increase the number of users more than tenfold, thus assuring that more of the archive data (obtained at great public expense) is used;
- it will promote geographical spread of use (also facilitating access in developing countries);
- it will increase the number and nature of applications (trends, not just abrupt change);

The session also stressed that an open data policy must be accompanied by "ease of access and use". Sentinel-2 data will only be used if they are easy to find and easy to obtain. Easy data access will help guarantee users receive the data they need, where and when they need it, subject to successful completion of the mission ramp-up phase and availability of operational funding. Operational application (i.e. services) are impossible without trust in data availability and continuity.

It was also recommended, when keeping all Sentinel-2 data, to think pixels in addition to scenes since the handful of cloud free pixels at a particular location and at a particular time may will be crucial to many users. With the expected Sentinel-2 temporal revisiting capacity, it is essential to think "trends", it is also important to think "reduced uncertainty". The more complete a time series can be, the more reliable and pertinent will be the information obtained from the data.

It is expected that the Sentinel-2 large volume of data will cause some difficulties. This "data volume" challenge must be tackled adequately since it is already widely recognised that Sentinel-2 data will be used globally.

Synergy with other satellite missions has been repeatedly stressed:

- synergy with Landsat 5-7, LDCM, SPOT, AVNIR, and RapidEye were mentioned but this list should not be considered exhaustive;
- Extensive opportunities will arise in using Sentinel-2 with the existing long time series of high resolution data (Landsat, SPOT, etc). It will allow Sentinel-2 applications to include a historical perspective;

- Alignment with Landsat was highlighted, including the ESA reprocessing of the European Landsat holdings, and copying this archive to the US central archive, thus providing another backup copy and assuring common processing;
- Cross calibration, and common processing standards, will help facilitate data fusion/combinations;
- Data fusion with SAR data (principally Sentinel 1 data) will provide extra information such as for agriculture monitoring, with post harvest stubble treatment being highlighted

Finally the session underlined that the impressive improved characteristics of Sentinel-2 (in spatial, temporal, -spectral and radiometric resolutions) together with the high value of the existing archive of high to moderate resolution optical data, will allow the long term tracking of human impacts and environmental response.

The session on " *Services and Perspectives*" formulated the following recommendations:

Id	Recommendations
1	Free and open data policy
2	Straightforward and efficient data access
3	Timely launch of Sentinel-2 B unit
4	Sentinel-2 Level 3 products
5	Sentinel-2 L1C simulated products
6	Inter-sensor calibrations
7	Sentinel-2 validation data sets
8	Time Series Analysis Methods

4.1.2 Glaciers, Wetlands, Floods, Fires and Land Degradation

This heterogeneous session addressed specific issues that should not been considered as secondary since it was stressed that Sentinel-2 application will be a key EO resource in a broad range of diverse applications.

High precision geometric correction will only be possible if a DEM of sufficient quality will be available:

- The orthorectificaiton errors can be substantial if Sentinel-2 L1C products are produced with a 90m SRTM DEM. For example 15m SRTM elevation errors will cause 3m horizontal error at swath edge. In rough topography where SRTM errors can be up to 100m (due to void fills), the Sentinel-2 horizontal errors can reach 20m.
- DEMs elevation errors north of 60-degrees north and south may be worse than noted above, as SRTM is not collected above these latitudes.
    - Note, the USGS has worked with individual nations (such as Canada) to obtain the "best available" DEM, used to augment the SRTM and other available sources. As a US government partner, the USGS likely also has access to the 30 m protected version of SRTM data. The possibility of sharing the USGS DEM that uses 30 m SRTM and individual nation augmented DEMs could be explored.
- For Glaciers monitoring, the use of out of date SRTM can have elevation errors in the range of 100 to 200m.
- The production of high precision measurement of terrain movements (landslides, seismic movements, slow glaciers, etc.) also requires high precision geometric correction

Due to the above reasons it is recommended to combine the best regional available DEM (such as SRTM, National DEMs, ref3D, Tandem- X) for Sentinel-2 orthorectification. Hence, the need for Sentinel-2 products without terrain correction. Sentinel-2 products at L1B processing level are without terrain correction. However for using the L1B product expert knowledge is required for the product in sensor geometry without band alignment.

Some applications, like glaciers monitoring in high topography, requires high accuracy during Sentinel-2 image-to-image registration. For these pixel-based change detection applications where an optimum co-registration is essential, the nominal 0.3 pixel geometry must be guaranteed and hence effects like jitter well under control.

The session also called for the development of easy-to-use and highly automatic tools to mosaic the Sentinel-2 L1C tiles over large Areas of Interest. Most of the Sentinel-2 users will have geographical areas that spread well over the 100x100 km2 tiles and will need to use some mosaicking tools to prepare the data before processing.

It was also recognised that time series analysis methods (being at pixel- and object-based) needs to be developed to exploit at best the uniquely dense and long Sentinel-2 time series.

Many applications, such as snow line feature extractions, will make use jointly of Sentinel 1 and Sentinel-2 data, to exploit at best high revisiting of both series of satellites when used together. The session exhorted the European Space Agency to launch some preparatory activities and develop some application tools that exploit jointly Sentinel 1 and Sentinel-2 data. A similar request was made for Sentinel-2 and Sentinel 3 (OLCI) retrieval tools.

The session on "*Glaciers, Wetlands, Floods, Fires and Land Degradation*" formulated the following recommendations:

Id	Recommendations
1	Free and open data policy
2	Straightforward and efficient data access
3	Timely launch of Sentinel-2 B unit
4	Sentinel-2 Level 3 products
5	Sentinel-2 L1C simulated products
6	Inter-sensor calibrations
7	Sentinel-2 validation data sets
8	Time Series Analysis Methods
9	Mosaicking Tools / Mosaic Products
12	Atmospheric correction tools
16	Combined S2-S1 demonstration/development activity
17	Combined S2-S3 demonstration /development activity
19	Use of "best available" Digital Elevation Models (DEM)
20	No-terrain corrected products
21	Sentinel-2 jitter control

4.1.3 Coastal and Inland Water Quality

The session on "*coastal and inland water quality*" addressed the potentialities of Sentinel 2 radiometry, and in particular its 10-60m imagery scale and 5 days revisiting scale, with its extended spectral range and better spectral resolution compared to existing comparable optical sensors, for the study of coastal and inland waters in relation to legal environmental regulations.

The following challenges were highlighted by the "water quality" community:

- what opportunities will arise in introducing Sentinel-2 data in the existing long time series of medium-to-high resolution data (Landsat, SPOT, etc)?
- will there be any benefit from the improved revisiting capacity (5 days with the two Sentinel-2 satellites)?
- how can the improved spectral information content be efficiently used?
- is there any need for additional research expenditures on new retrieval techniques to ensure full exploitation of Sentinel-2 capabilities ?
- what type of application might be prototyped with the expected huge amount of Sentinel-2 data to fulfill laboratories' expectations but also to expand the remote sensing market ?

It was stressed that the combined use of medium and high resolution optical imageries, with new retrieval techniques, will offer new perspectives in coastal and inland water quality at continental, regional and local scales.

The session evidenced a broad range of potential use of Sentinel-2 data:

- implementation of **water quality regulations** derived from the EU directives: the Water Framework Directive (WFD), the Marine Strategy Framework Directive (MSFD), the Bathing Water Directive & the Birds/Habitats Directive.
- **extended mapping opportunities** such as topography and bathymetry, aquatic habitats & benthic classification, coral reefs, intertidal flats and estuarine areas, and inland waters, in particular for nature conservation, civil engineering, aquaculture, algal blooms.
- **support to modelling** (physical and biological)

Amongst the benefits that Sentinel-2 will offer in terms of water quality monitoring in inland and coastal waters, the session stressed the following main topics:

- Sentinel-2 will allow the mapping of small lakes;
- 10 m resolution is a suitable compromise for intertidal and supra-tidal vegetation mapping;
- Sentinel-2 is felt as one of the most suitable system for a systematic monitoring of coral reef for the next decades;

- The combined used of Sentinel-2 spatial resolution and Sentinel 3 spectral resolution will offer unprecedented water quality observing capabilities for coastal and inland waters.

The session on "C*oastal and Inland Water Quality*" formulated the following recommendations:

Id	Recommendations
1	Free and open data policy
2	Straightforward and efficient data access
3	Timely launch of Sentinel-2 B unit
4	Sentinel-2 Level 3 products
5	Sentinel-2 L1C simulated products
6	Inter-sensor calibrations
7	Sentinel-2 validation data sets
8	Time Series Analysis Methods
12	Atmospheric correction tools
17	Combined S2-S3 demonstration /development activity
22	Data Fusion algorithms
23	Observation Scenarios in coastal zones
24	Water Quality spatial variability at S-2 resolution
25	End-user S-2 needs for coastal/inland water quality
26	Dedicated algorithms for shallow water quality retrievals

4.1.4 Agriculture

The expectations from the *Agriculture* community toward the use of Sentinel-2 data are very high. Sentinel-2 is seen to be exceptionally well defined spectrally, spatially and temporally for agricultural applications. Two Sentinel-2 systems (with their combined 5 day revisiting mission characteristics) will likely meet most agricultural applications in both crop mapping and condition assessment. One Sentinel-2 system will likely need to operate in synergy with other missions for condition assessment but may be sufficient for crop area mapping.

The Agriculture session also stressed that institutional users will really only benefit from Sentinel-2 data if Level 3 products are widely and easily available, as they do not have their own capacity to process the high volume data provided by the mission.

A Sentinel-2 free and open data policy is fundamental to have success with all types of agricultural users and applications. Timely and easy data access is also seen of importance.

Potential uncertainties related to the broad exploitation of Sentinel-2 data for agricultural purposes might come from the limited performance of cloud masking in the absence of a S-2 thermal band and the need to combine spectral bands that are available at different spatial resolutions.

Many agricultural applications will be based on Near Real Time (1-3 days) access to information services that may be limited by the available internet bandwidth. For most of the NRT applications there is a need to consider data reduction strategies as Sentinel-2 dissemination bandwidth is seen as a limiting factor. For example, NRT end-users users might benefit from standardized high level data products that would reduce data volumes. NRT applications must be available to provide low data volume time series of Sentinel-2 L3 and higher level data, over some local areas.

It was emphasized that R&D activities are required to best adapt existing algorithms to Sentinel-2 and to determine appropriate data assimilation strategies. Amongst the research topics still to be studied, the following were evidenced:

- How to use process models and data assimilation techniques for higher level products?
- How to combine SWIR and Red Edge information?
- What are the most applicable spatial and temporal constraints for biophysical parameter retrieval?
- What will be the impact of BRDF? Will there be any need for BRDF corrections?

New Sentinel-2 methods need to be developed and evaluated considering the richness of the temporal and spatial information. In particular optimal atmospheric correction algorithms (including adjacency effect and bright targets) should be developed. The same considerations apply for S-2 image compositing, spatial downscaling/sharpening, adaptive machine learning, data assimilation, soil mapping, etc.

Tools will also be required to facilitate the extraction, compositing, and efficient processing of large S-2 time series, especially for Near Real Time (NRT) applications. Automated

parameter mapping approaches may facilitate the use of NRT Sentinel-2 data, in particular for precision farming applications.

The Sentinel-2 data user handbook that ESA is currently preparing is welcomed since it will largely facilitate system integration. However time series of Sentinel-2 prototyped data with correct format, data structure, complete metadata, the actual 10-20-60m spatial resolution (to well assess the scaling impact) and simulated data gaps (e.g. cloud coverage) are needed to be available prior to the launch.

Synergy with other optical and possibly radar sensors will be required for monitoring critical growth periods, especially when only one Sentinel-2 system is operating. This requires some interoperability at radiometric, formatting and algorithmic levels.

Validation datasets must be available to support the development of applications. Considering the importance of time series in agricultural monitoring, it is important to prepare some validation datasets that will allow the verification and testing of S-2 time series processing. The VENUS validation campaigns could be used for this purpose.

A performance assessment of the agricultural applications in relation to the instrument calibration (being optimal or threshold) and to the geometrical accuracy (considering different level of accuracy) should be performed. Such a sensitive analysis could help to assess if the processing solutions from both core ground segment and collaborative ground segment are satisfactory for agricultural applications.

The session on "*Agriculture*" formulated the following recommendations:

Id	Recommendations
1	Free and open data policy
2	Straightforward and efficient data access
3	Timely launch of Sentinel-2 B unit
4	Sentinel-2 Level 3 products
5	Sentinel-2 L1C simulated products
6	Inter-sensor calibrations
7	Sentinel-2 validation data sets
8	Time Series Analysis Methods
9	Mosaicking Tools / Mosaic Products
10	Compositing Tool / Composite Products
11	Downscaling / sharpening tools
12	Atmospheric correction tools
16	Combined S2-S1 demonstration/development activity
27	Sentinel-2 NRT applications

4.1.5 Land Cover

The session on "*Land Cover*" claimed that Sentinel-2 will bring a significant breakthrough by moving land cover applications at 10 to 30m spatial resolution from mapping to monitoring, from snapshot to time series data analysis, from image-based to pixel-based processing. The concept of "MERISize Sentinel-2 data" was even introduced. This implies that new development will be required to support S-2 pixel-based processing logic and mass processing of temporal series of imagery.

It was recalled that high quality data, freely available, ready to be used and easy to access are necessary. There is a need to remove the data preparation burden from the users in order for them to spend less time in preparing the data and more time in processing them. The access to Sentinel-2 data would also be facilitated if Sentinel-2 data products are also available in GIS compatible format such as GeoTiff format.

High quality data means that the quality of Sentinel-2 radiometry should be maintained through all processing and product stages. The Sentinel-2 exceptional radiometric, spectral, spatial and temporal specifications will enable to improve characterization of land cover, but the land cover community expectations can only be achieved if the quality of Sentinel-2 data are preserved through each stage of processing.

The complexity to process the expected vast amounts amount of data will be largely reduced if ready-to-use mosaics & composite products are available globally, in addition to the 100x100 km2 tiles:

- These mosaic & composite options in the Sentinel-2 L1C data delivery would complement perfectly the 100x100 km2 S-2 L1C tiles that are anyway necessary for many land cover applications.
- A global collection of S-2 composites and mosaic would ensure consistency and interoperability between all Sentinel-2 applications.
- Varieties of composite options should be offered such as monthly composites and annual composites.
- When building the S-2 mosaic products, a seamless "tile to mosaic" process should be developed.

The importance of having higher level S-2 data products (level 3 and above), widely and easily accessible, for all users, was evoked. This would promote comparability and consistency of value-added products amongst the land cover community.

A single portal that would work as the virtual repository of all collections of Sentinel-2 data, globally is highly desirable for the land cover community. This Sentinel-2 Portal should provide for easy access to all collections of S2 products by simple select, click and download functionalities. Batch access should also be enabled. The session strongly recommended the European Space Agency to drawn lesson learnt from the USGS experience with the opening of the Landsat archive, after 37 years of programme duration in which the US accumulated a huge data archive.

The importance of inter-sensor calibrations was recalled. This is essential for leveraging multi-sensor collections archives, across the Sentinel suite but also with other sensors.

The development of calibration / validation data sets are necessary (for example through JRC and GOFC-GOLD). This requires a proper analysis of scaling issues, considering the high S-2 spatial resolution, and hence the need for higher spatial resolution images that could be used as a global validation dataset.

The session also called for the development of "application enabling" tools such as

- high quality cloud / cloud shadow screening tools;
- high performance atmospheric correction tools.

In addition to the importance of having high quality "application enabling" tools, the availability of atmospheric corrected surface reflectance products (being part of the core or collaborative ground segments) would also facilitate the exploitation of Sentinel-2 products by the land cover community.

Considering the shortage and inadequacy of the proposed Digital Elevation Model (based upon available SRTM) at high/low latitudes and in rough topography, the session recommend to use the best DEM(s) available.

The importance of Sentinel-2 time series for the land cover applications has been strongly emphasised. There is a need to ensure linkages to the Landsat archive (e.g. making Landsat long-term archive becoming part of the Sentinel-2 archive) and to make LDCM and Sentinel-2 data interoperable. This would permit seamless integration with new collects and increase the temporal revisiting, particularly before the launch of the S-2 B unit. The session recommended USGS and ESA to develop common series of Landsat-S2 products.

Finally the land cover community stressed that the true value of Sentinel-2 will truley be realized with launch of its second unit, Sentinel-2B.

As a conclusion, the session on Land Cover urged the European Space Agency to take all necessary measures to ensure that all what is done now will create options and opportunities in the future, and that the Sentinel-2 gains and benefits will remain future proof.

The session on "*Land Cover*" formulated the following recommendations:

Id	Recommendations
1	Free and open data policy
2	Straightforward and efficient data access
3	Timely launch of Sentinel-2 B unit
4	Sentinel-2 Level 3 products
5	Sentinel-2 L1C simulated products
6	Inter-sensor calibrations
7	Sentinel-2 validation data sets
8	Time Series Analysis Methods
9	Mosaicking Tools / Mosaic Products
10	Compositing Tool / Composite Products

12	Atmospheric correction tools
13	Sentinel-2 data formats
14	Surface Reflectance Products
15	Cloud / Cloud Shadow screening tools
18	Sentinel-2 – Landsat interoperability
19	Use of “best available” Digital Elevation Models (DEM)

4.1.6 Forestry

The expectations from the Forestry community regarding the value of Sentinel-2 are very high. Many types of forestry applications will be greatly enhanced with Sentinel-2, covering both existing applications (e.g. forest classification, forest change, biomass, wildfires, REDD+, etc.) and new applications (forest phenology, time series analysis). Many opportunities will also exist for synergy with other similar types of optical sensors functioning in the high to moderate resolutions such as Landsat TM/ETM, LDCM, SPOT 4/5, ALOS AVNIR-2, but also with low spatial resolution optical instruments such as Sentinel-3 OLCI, MERIS and MODIS and radar sensors in L-, C- and X-band. The use of Sentinel-2 with the existing long time series of high resolution data (principally Landsat and SPOT) will allow to extend the time periods of change detection. To use Sentinel-2 in synergy with other satellite missions, it is recommended to set up common data distribution systems, common geo-coding, common calibration activities.

The key observational benefits that will be offered with the launch of the Sentinel-2 series of satellites are all related to the exceptional combined improvements in temporal, spectral, radiometric and spatial resolutions.

- The temporal revisiting of the Sentinel-2 satellites (when both units will be operated together) will usher in new era for time series analysis at high/moderate resolutions. Monitoring global change at spatial scales that capture human activities will become a reality. The improved revisiting capacity (5 days with 2 satellites) will allow to reduce cloud contamination, utilize phenological stages in the data analysis, and will lead to improved consistency, accuracy, timeliness and thematic detail.
- The improved spectral information content (e.g. red edge) will improve forest species discrimination, assessment of forest degradation and biomass estimation.

The expected applications of Sentinel-2 will range from local forest resources management to global monitoring of forest change, vegetation dynamics and phenology.

The Forestry session expressed some caveats and warnings on issues that are of primary concerns for forestry applications:

- The Sentinel-2 data policy must be a real “free and open” data policy and the access to the Sentinel-2 data must be “seamless and effortless”.
- The processing of Sentinel-2 data must ensure compatibility with other sensors, in particular Landsat (TM, ETM and LDCM).
- The ability to employ the large Sentinel-2 archive and perform pertinent time series analysis requires a high quality pre-processing that identifies perfectly clouds and cloud shadows, and that produces the best surface reflectance products with cutting-edge atmospheric correction algorithms.

A few key R&D activities will be required on the data recipient side prior to the start of the mission, in terms of mass data management considering the impressive volume of Sentinel-2 data, in terms of pre-processing automation (e.g. cloud and cloud shadow screening, surface reflectance calibration, image compositing), in terms of automatic accuracy assessment of Sentinel-2 data products, in terms of automatic processing of

Sentinel-2 time series. New retrieval techniques will have to be developed for time series and change analysis.

The challenges in terms of mass data management can be mitigated with the use of cutting-edge and advanced technology in terms of parallel data processing, data browsing and data distribution (for fast downlink).

Some high quality "application enabling" tools should also be developed:

- for smooth data downloading similar to what is available for Landsat;
- to process Sentinel-2 time series in NRT (few days to one week);
- to use Sentinel-2 in synergy with historical data (e.g. Landsat)

The availability of real simulated Sentinel-2 data products is necessary well before the start of the mission. The simulation of the Sentinel-2 bands should be derived from hyperspectral data for its spectral content.

The forestry session recommended that the calibration and validation of Sentinel-2 time series products properly accounts for BRDF given the wide swath of Sentinel-2.

In terms of requirements for high level products beyond the Sentinel-2 L1C standard products, the forestry session listed the following products: surface reflectance, cloud-free composites, and cloud and cloud shadow masks

The session on "*Forestry*" formulated the following recommendations:

Id	Recommendations
1	Free and open data policy
2	Straightforward and efficient data access
3	Timely launch of Sentinel-2 B unit
4	Sentinel-2 Level 3 products
5	Sentinel-2 L1C simulated products
6	Inter-sensor calibrations
7	Sentinel-2 validation data sets
8	Time Series Analysis Methods
9	Mosaicking Tools / Mosaic Products
10	Compositing Tool / Composite Products
14	Surface Reflectance Products
15	Cloud / Cloud Shadow screening tools
18	Sentinel-2 – Landsat interoperability
19	Use of "best available" Digital Elevation Models (DEM)
27	Sentinel-2 NRT applications

4.1.7 Methods and Tools

The session "*Methods and Tools*" demonstrated that the European expertise, complemented by outside Europe know-how, is extremely high but that there is also a large duplication of efforts. It is required to streamline the efforts and coordinate better the development and exploitation of Sentinel-2 tools.

Most of the papers presented during the session dealt with orthorectification, cloud detection and atmospheric correction matters.

For orthorectification, Sentinel-2 will provide Level 1C products. There will be no need any more for orthorectification on the user side, provided that the L1C orthorectification be done with the most accurate DEM. This implies that the 90m SRTM be replaced by a DEM with improved accuracy, especially in difficult areas such as in high relief topography and in high latitudes where SRTM is known to perform poorly. A precise DEM is also needed in very flat areas: for runoff analyses in arid lands, and for flood studies.

Several methods exist and will be existing for cloud screening and atmospheric corrections:

- In relation to atmospheric correction, no Sentinel-2 L2A production is foreseen as part of the official ground segment but a toolbox for atmospheric correction will be available to the users. As a result of the strong interest in Sentinel-2 time series surface reflectance (and vegetation indices) are nevertheless required by most users. It is doubtful that an atmospheric correction and cloud screening toolbox will be sufficient for all users. If not part of the Sentinel-2 core ground segment, the production of L2A products should be the task of collaborative ground segments, and be accessible by all Sentinel-2 users. This requires the establishment of organizations/partnerships that save money, preserve diversity of approaches and deliver consistent products.
- Reliable and robust cloud screening methods applicable to S2 have been developed in the scientific community, which do not require thermal spectral bands.
- Reliable and robust atmospheric correction methods are also available

There is a need for validation and cross comparison exercises.

- Regarding cloud screening, it is recommended to build a cloud reference image set (100) at the beginning of Sentinel-2 mission.

Cross calibration and calibration monitoring are needed with sensors such as Sentinel 3, LDCM and SPOT. This implies:

- to agree on and share methods and databases;
- to coordinate cross calibration observations through CEOS;
- to address specific issues such as cross calibration with archived images (LandSat archive ranges from 1972).
- to use several cross calibration approaches (e.g. onboard calibration, desert sites, Rayleigh scattering, oceanic sites, etc.)

Some validation plans shall be established for the Sentinel-2 L2A reflectance products but also for higher level products such as LAI, fAPAR and Albedo.

The Sentinel-2 community should also establish some research priorities to further enhance the quality of the Sentinel-2 products, for example for mountain areas and water color studies, for slope/aspect, environment effects correction, cloud screening (especially haze, airplane trails), aerosol models.

The session on "*Methods and Tools*" formulated the following recommendations:

Id	Recommendations
1	Free and open data policy
2	Straightforward and efficient data access
3	Timely launch of Sentinel-2 B unit
4	Sentinel-2 Level 3 products
5	Sentinel-2 L1C simulated products
6	Inter-sensor calibrations
7	Sentinel-2 validation data sets
8	Time Series Analysis Methods
10	Compositing Tool / Composite Products
14	Surface Reflectance Products
15	Cloud / Cloud Shadow screening tools
18	Sentinel-2 – Landsat interoperability
19	Use of "best available" Digital Elevation Models (DEM)
28	Research priorities for Sentinel-2 methods and tools

Table 1

5 SYMPOSIUM RECOMMENDATIONS

Id	Sessions	Recommendations
1	all	**Free and open data policy** High quality data, freely available, ready to be used and easy to access is a prerequisite for an optimum exploitation of Sentinel-2 data. *The symposium participants repeatedly stressed the importance to have a real "free and open" data policy, applicable to users worldwide, with "easy to access" tools.*
2	all	**Straightforward and efficient data access** The Sentinel-2 open data policy must be accompanied by an "ease of access and use", also facilitating access in developing countries with low internet bandwidth. Easy data access will help guarantee users receive the data they need, where and when they need it. *There should be a single Sentinel-2 Portal that would work as the virtual repository of all Sentinel-2 data collections (including S-2 composites and mosaics). The Sentinel-2 Portal should support smooth data downloading similar to what is available for Landsat already today.*
3	all	**Timely launch of Sentinel-2 B unit** With its 5 day revisiting mission characteristics, two Sentinel-2 systems will likely meet most mapping and condition assessment applications One single Sentinel-2 satellite will not bring fully safe answers for most of the targeted domains of Sentinel-2 applications. The Sentinel-2 mission will really meet its objectives when the two satellite units (A and B) will be flying together. *It is strongly recommended to reduce as much as possible the time between both Sentinel-2 units will be fully operational.*
4	all	**Sentinel-2 Level 3 products** The exploitation of Sentinel 2 data will be facilitated if Level-3 products are widely available. The availability of high level data products would promote comparability and consistency of value-added products *It is recommended to extend the Sentinel-2 free and open data policy*

		as well as access to a series of level 3 products.
5	all	**Sentinel-2 L1C simulated products** Time series of Sentinel L1C 2 simulated products following specified format and data structure, including the complete metadata, the actual 10-20-60m spatial resolution (needed to well assess the scaling impact on S2 applications) and simulated data gaps (such as cloud coverage) are needed before launch to prepare Sentinel-2 exploitation. For the simulation of the spectral content of Sentinel-2 bands hyperspectral data sets should be considered (without limiting the frequency of the time series). *Sentinel-2 L1C simulated products and time series should be available well before the start of the mission.*
6	all	**Inter-sensor calibrations** Inter-sensor calibrations are essential for leveraging multi-sensor collections archives, across the Sentinel suite but also with other sensors. *Inter-sensor calibration campaigns should be organised, principally with the Sentinel 3 OLCI, LDCM and SPOT.*
7	all	**Sentinel-2 validation data sets** Validation datasets should be provided to application developers. A dataset focusing on time series should be considered. The calibration and validation of Sentinel-2 time series products must account for BRDF in wide swath Sentinel-2 data. *The production of a representative and useful Sentinel-2 validation data sets should be organized in time for the launch, in consultation with the main Sentinel-2 exploitation actors.*
8	all	**Time Series Analysis Methods** It is unanimously recognised that one of the major improvements Sentinel-2 (when the two S2 units will be operated together) will bring to the exploitation of High-Resolution optical satellite imagery is the uniquely dense and long Sentinel-2 time series. Despite the recently opening of the Landsat TM/ETM archive, the user community is not yet familiar with the processing of such long time series at this spatial resolution. Tools are required to facilitate an efficient processing of large time series (also in Near Real Time).

		It is important, prior to the start of the Sentinel-2 mission, to develop pixel- and object-based time series analysis methods for the different types of targeted Sentinel-2 applications.
9	[1.2] [2.] [3.] [4.]	**Mosaicking Tools / Mosaic Products** The Areas of Interest (AoI) of many applications will spread across many tiles and will be often much bigger than the 100 x 100 km2 tiles. *An easy to use, highly automatic tool is required for mosaicking the 100x100 km2 tiles over an AoI.* *It is also recommended to consult the Sentinel-2 user community (through user surveys) to determine what should be the capabilities of such a mosaicking tool (e.g. batch processing, band selection, choice of geographical coordinate systems)*
10	[2.] [3.] [4.] [5.1]	**Compositing Tool / Composite Products** The complexity to process huge amount of Sentinel-2 data will be reduced by ready-to-use composite products. *Most of the sessions called for the development of some compositing tools that would facilitate the extraction, compositing and processing of large time series of Sentinel-2 data at all scales (global, regional, national and sub-national) OR even for the worldwide availability of Sentinel-2 cloud free composite products.*
11	[2.]	**Downscaling / sharpening tools** Sentinel-2 data will be largely used concurrently with other satellite optical data featuring higher and lower spatial resolutions, such as LDCM, Sentinel 3 OLCI but also VHRO observations below 10m resolution. *Tools for synergy are required to e.g. downscale / sharpen Sentinel-2 data for a more effective use in combination with complementary sensors.*
12	[1.2] [1.3] [2.] [3.] [4.] [5.1]	**Atmospheric correction tools** All symposium sessions exhorted ESA to develop and evaluate Sentinel-2 atmospheric methods taking full benefit of the three 60m atmospheric correction bands and richness of its temporal information and the quality of the Sentinel radiometry. The atmospheric correction algorithms must take due considerations of the Sentinel-2 spatial resolution, of the adjacency effects and bright targets. These Tools and their parameters should be tested over hundreds of images in different conditions to ensure their robustness.

Appropriate and robust atmospheric correction tools should be part of a series of "S-2 application enabling" tools

13	[3.]	**Sentinel-2 data formats** Sentinel-2 data in a ready and easy to use format compatible with Geographical Information systems (GIS) is a necessity. *It is recommended that Sentinel-2 data products be also available in GIS compatible format such as GeoTIFF.*
14	[2.] [3.] [4.] [5.1]	**Surface Reflectance Products** In addition to the importance to have high quality "application enabling" tools, the availability of atmospheric corrected surface reflectance products (being part of the core or collaborative ground segments) would also facilitate the exploitation of Sentinel-2 products by the land cover community. A cloud mask products should be delivered along with surface reflectance product. *High quality Surface reflectance products should be part of the Sentinel-2 data products collection.*
15	[3.] [4.] [5.1]	**Cloud / Cloud Shadow screening tools** Many Sentinel-2 applications will require high quality cloud and cloud shadow masking, in particular because it is expected that pixel-based processing of Sentinel-2 data will be largely implemented. *Some reliable cloud/cloud screening tools should be available, taking full advantages of the long time series of Sentinel-2 data.* *The cloud masking tools should be part of a series of "S-2 application enabling" tools.*
16	[1.2] [2.]	**Combined S2-S1 demonstration/development activity** Many Sentinel-2 applications will be developed exploiting jointly Sentinel 1 and Sentinel-2 data, such as feature extractions from SAR and optical data for snow line retrievals, or agricultural monitoring during critical growth periods. *It is important to launch some preparatory activities to foster the development of S2-S1 joint application tools.*

17	[1.2] [1.3]	**Combined S2-S3 demonstration /development activity** Many Sentinel-2 applications will be developed exploiting jointly Sentinel-2 and Sentinel 3 data, such as for coastal/inland water quality. *It is important to launch some preparatory activities to foster the development of S2-S3 joint application tools.*
18	[2.] [3.] [4.] [5.1]	**Sentinel-2 – Landsat interoperability** The interoperability between Landsat data (TM, ETM and LDCM) and Sentinel-2 should be boosted enabling Landsat long-term archive to become part of the Sentinel-2 archive and increasing the S-2/Landsat temporal revisiting. *USGS and ESA should develop interoperable series of S-2/Landsat products. It is recommended to set up common data distribution system, common geo-coding, common calibration.*
19	[1.2] [3.] [4.] [5.1]	**Use of "best available" Digital Elevation Models (DEM)** Considering the shortage and inadequacy of the proposed Digital Elevation Model (SRTM) at high/low latitudes and in rough topography, it is recommended to use the best regional DEM available.
20	[1.2]	**No-terrain corrected products** The use of Sentinel-2 data in high topography as well as the production of high precision measurements of terrain movements (landslides, seismic movements, slow glaciers, etc.) requires high precision geometric correction, which will not be possible if Sentinel-2 products are contaminated by the L1C orthorectification. *It is therefore essential to have Sentinel-2 products without terrain corrections.*
21	[1.2]	**Sentinel-2 jitter control** For applications requiring high accuracy of image-to-image registration, the nominal 0.3 pixel geometric accuracy is essential. *It is recommended that effects like jitter be well under control to secure the nominal geometric accuracy.*
22	[1.3]	**Data Fusion algorithms** It is recognised that a multi-mission approach that fosters the synergetic use of Sentinel-2 data with lower resolution sensors (such

		as Sentinel 3) will bring unprecedented observation capabilities. In order to develop data fusion algorithms, it is important to understand well the instrument characterization (pre-launch, post-launch, matchups), to cross-compare sensors (for near identical bands) and to assess spatial resolution and spatial variability effects (such as the differences in radiometry for same targets with same observation conditions in time and spectral bands). *Preparatory activities for support development of data fusion algorithms are therefore necessary.*
23	[1.3]	**Observation Scenarios in coastal zones** Sentinel-2 is felt as one of the most suitable missions for systematic monitoring of coral reefs. The Sentinel-2 observation scenario and its related coastline delineations need to be well defined to allow a systematic monitoring of coral reefs at a global scale (also outside the 20 km zone off the coastline) and the observations of large intertidal zones. *An extended Sentinel-2 acquisition plan is recommended including main global coral reefs occurrence and large intertidal zones*
24	[1.3]	**Water Quality spatial variability at S-2 resolution** There is a need for a better understanding of the use of Sentinel-2 high resolution data in water quality monitoring of inland and coastal waters. Hence the necessity to study what is the spatial variability at Sentinel-2 spatial resolutions compared to other missions at lower and higher spatial scale, and what are the typical objects of interest detectable at these resolutions.
25	[1.3]	**End-user S-2 needs for coastal/inland water quality** There is a need to identify end-users (national agencies and commercial companies) who already use EO data for coastal/inland waters and habitat applications, and to record their needs (to decrease costs and/or improve performances). This means consulting FP-7 funded GMES R&D consortia, ESA-funded R&D consortia, national projects' consortia, EO servicing industry.
26	[1.3]	**Dedicated algorithms for shallow water quality retrievals** The development of Sentinel-2 algorithms should be driven by applications (such as small lakes, inter-tidal zones, coral reefs). A common necessity and general focus for coastal/inland water

		quality retrievals is the importance to have S-2 atmospheric correction algorithms and radiative transfer models that perform well in shallow waters.
27	[2.]	Sentinel-2 **NRT services**
	[4.]	Some of the Sentinel-2 agricultural applications will require near real time (NRT) (that is, max. 24h) access that might be limited due to data bandwidth restrictions. For some of these NRT applications there may be a need to consider data reduction strategies if available data dissemination bandwidths are restricted. *Sentinel-2 services must be available in Near Real Time, allowing the provision of time series of Sentinel-2 observations with reduced data volume over local areas.*
28	[5.1]	**Research priorities for Sentinel-2 methods and tools** *The Sentinel-2 community should establish some research priorities to further enhance the quality of the Sentinel-2 products, for example for slope/aspect, for water quality retrievals, for environment effects correction, for cloud screening (especially haze, airplane trails), for aerosol models, etc.*

6 CONCLUSIONS AND PERSPECTIVE

The Sentinel-2 mission has been more than welcomed by the participants to the symposium. With its exceptional revisiting of 5 days (with 2 satellites) and its spatial resolution of up to 10 meters, the Sentinel-2 mission is expected to largely satisfy the disparate user communities. The Sentinel-2 has been acclaimed to currently be the best designed and conceived operational mission for systematic land monitoring.

The Sentinel-2 operational scenario with its systematic acquisition and processing up to level 1C in less than 24 hours (in the worst case) is also very well appreciated.

Many of the speakers welcomed the red edge bands as well as the SWIR bands for several applications where most of the new exploitation development is needed.

A case to further optimize the mission operational scenario was brought by the coastal water and coral reef communities.

Some improvements in the used of DEM for orthorectification were suggested by the Glacier and alpine communities. The land cover and forestry communities also stressed the need for high quality elevation data to support orthorectification activities, including the need for revisiting of the source elevation data to be used, especially beyond north and south of 60-degrees latitude.

The unique revisit capacity of Sentinel-2 will require new methodology for time series analysis, which will have to be developed and become a new standard for High Resolution optical applications. The exploitation programs of the European Space Agency shall facilitate the development of these new time series analysis methods.

The 28 recommendations, derived from the inputs and discussion of the workshop, should be addressed by the European Space Agency, European Commission as well as national and international institutions working on preparing for the Sentinel-2 mission. The achieved progress on the recommendation should be reported on the next Sentinel-2 Symposium to be organized by ESA after the launch of the Sentinel-2 mission.

Summary of recommendations:

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