ADDRESSING EMERGENCY FLOOD MAPPING AND MONITORING OF INLAND WATER BODIES WITH SENTINEL 1-2. EXPECTATIVE AND PERSPECTIVES

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ABSTRACT

The importance of water resources and the escalating frequency and intensity of flood events around the world during the last decades, emphasize the necessity of their timely and cost-effective monitoring by Remote Sensing techniques. The purpose of this paper is to present the current capacity of Earth Observation in detecting and monitoring flooded areas and inland water bodies, by means of different sensors (SAR, optical/IR). This is achieved by using results and experience gained within the International Charter and SAFER GMESS, … , as well as from other relevant case studies such as ESA MOST Dragon project during the last decade and Take Five Experiment conducted by CNES-CESBIO. Based on this experience, the foreseen improvements that the Sentinel-1 and -2 missions will bring are presented, in the direction of meeting this new set of refined requirements, but also in the context of COPERNICUS. The user requirements for water resource and especially for flood monitoring are very high, with flash-floods being the most demanding case in terms of timely acquisitions of EO data. The Sentinels will be a milestone of the spatial and temporal improvements in Earth observation dedicated to risk management. While Sentinels will insure an efficient routine surveillance mission, VHR satellites like Pleiades will be tasked on demand over smaller high-risk areas.

1. INTRODUCTION

Passive and active spaceborne remote sensing instruments have been used for Earth Observation (EO) purposes for more than 30 years. The importance of water resources and the escalating frequency and intensity of flood events around the world during the last decades emphasize the necessity of their timely and cost-effective monitoring by Remote Sensing techniques, with no risk for human lives [1].

In the effort of satisfying this demand for several applications, the Sentinel satellites are part of EU & ESA's Copernicus, previously known as GMES (Global Monitoring for Environment and Security) initiative. The Sentinel missions shall also contribute to the Global Earth Observation System of Systems (GEOSS).

The purpose of this paper is to present the contribution of near-future missions and especially of Sentinel-1 (Synthetic Aperture Radar/SAR) and Sentinel-2 (Optical and Infrared/IR) data, in the direction of improving the current capacity of Earth Observation to detect and monitor flooded areas and inland water bodies.

Prior to presenting the foreseen improvements that the Sentinel missions will bring, the analysis of the recent experience and resulting requirements for flood/inland water monitoring with active and passive spaceborne instruments is due. This is carried out using results and experience gained within the "International Charter Space and major disaster'' and the former GMES ESA GSE (GMES Service Element) projects "RESPOND" and "RISK-EOS", the recent GMES "SAFER" project, as well as other relevant case studies of the last decade, such the Sino European "Dragon" project on flood plain monitoring in China [2-9].

2. STATE OF ART

Facing the problem of characterization of flooding events since the middle '80s, the potential of exploiting Earth Observation data for flood mapping is constantly increasing, providing the extent and much more rarely an indication of the depth of the water and/or of the flow pattern. These improvements of the capability of Earth Observation data are both in terms of revisit time and in the way of capturing an on-going event, but also in terms of spatial resolution allowing a finer recording of the event. In this context, a series of major steps have been reached, corresponding in fact to the launch of successive new generation satellites, both in optical and radar domain.

A trend under ongoing development is that for systematic flood mapping in a semi-automatic or manual process, using medium resolution data. Two ways are followed on each side of the Atlantic ocean; (i) a quasi systematic MODIS exploitation, at the Dartmouth Flood Observatory (DFO) [10] and (ii) the development of semi-automatic tools at the European Space Agency for the exploitation of Wide Swath Mode (WSM) and Image Mode Medium resolution (IMM) ENVISAT ASAR products, in preparation for the exploitation of future Sentinel data[11-12].

The launches of the new VHR SAR sensors, with Cosmo-Skymed constellation and TerraSAR-X in 2007

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can be considered as the latest step of this continual improvement of the EO capability for flood mapping, in parallel to the reinforcement of the optical Very High Resolution (VHR) resources [13-15]. Some additional milestones of VHR SAR achievements can be also associated with this later phase; the launch of ALOS platform carrying the PALSAR instrument in January 2006, that of Radarsat-2 in June 2006, as well as the reinforcement from middle 2000s of the Disaster Monitoring Constellation (DMC), ending with the recent launch of Deimos in 2009. In this context, the L-band ALOS\PALSAR sensor, heritage from the Japanese Earth Resources Satellite (JERS), has a particularly place, as this wavelength allows a better discrimination of flooded areas under canopies ([16-18] and taking into account that this sensor is one of the major resources of the Sentinel-Asia initiative [19]. An interest of these SAR sensors was their potential of regular acquisition on full polarimetric mode, leading available to investigate the effect variation of 192 water bodies extents on the polarimetric temporal signature. It has been has shown that Shannon Entropy parameter is a very promising descriptor to extract the limit and the evolution of the open water during the time [20-21]. An important result of this study was also to highlight the fact that this parameters appears to be both time invariant and incidence angle invariant.

Being exploited more and more within an operational context, within initiatives such as those of the International Charter, as well as the Services and Applications For Emergency Response project of GMES (SAFER), service providers such as the Center for Satellite Based Crisis Information (ZKI), or SERTIT, bibliographic references on the exploitation of these VHR SAR and VHR optical data are decreasing [3-5]. Optical VHR data can be exploited both for mapping flood extent, as well as for characterizing the impact of the flood on the hydraulic equipments/structures of the affected river basin and/or on human stakes [23-25]. These VHR data allow the provision of new products, such as the relative water product for the Nargis flood event in 2008, which was based on the loss of linear structures, roads, dikes, rivers, field patterns and villages on Radarsat-2 ultra fine mode data . In the case of flash floods which are less extended and mostly characterized by mud deposit, river redrawing by strong but local modification of the embankments, as well as by trees falls, optical VHR data can provide very valuable information, thanks to their metric or sub-metric resolution. In addition, for the same event, using SAR or VHR SAR data, it would be possible to"capture" in fact mostly of the remaining small patches of water and not the associated damages and the mud deposits.

A last point to highlight from these 25 years of Earth Observation data exploitation for flood mapping is that the weather limitations, which would constrain the systematic choice to SAR data only, are no more applicable. Experience has shown that in a 220 lot of cases, even if the flood event occurs under bad meteorological conditions and associated cloud coverage, it is useful to trigger the acquisition of optical images to complement SAR data. It can be considered that in case of a flood, and much more in case of a flash flood, the meteorological conditions that caused the event are still present. Naturally, cloud coverage would affect the capability of optical data. Nevertheless, past experience indicates that such conditions are not so usual or that it is at least still possible to exploit parts of optical images. This is related to the fact that image acquisition is mostly done on demand mode and thus ordered data are acquired one to three days after the event, in the best case. At that time, especially for fast events, the image acquisition is often related to post-depression meteorological conditions, i.e. with a relative cloud-free sky.

It can still be said that the best image, either it an optical or a radar one, is the first received image allowing the derivation of a geospatial product describing the ongoing event. Its has to be kept in mind, that even if this first product could be relatively coarse, future acquisitions would allow to refine it, in order to satisfy the end users needs.

Additionally, during the last few years, there has been a great improvement in the fast dissemination of acquired images. Services and ground segment set up for Radarsat-2 or Cosmo-SkyMed for example, can deliver acquired images within 3 hours, whereas only medium resolution products, such as the WSM and IMM ASAR data from ENVISAT or the MERIS full or reduced resolution data, were rapidly accessible until recently, thanks to the ESA Rolling Archive services. Shortening the delay between acquisition and dissemination allows from one hand a better response to the end users request and on the other hand to integrate more and more data within the crisis period, allowing the updating of the first generated crisis product, if necessary.

There are still limitations in terms of accessing EO data in time after an event, but this is more linked with programming capabilities and data cost.

Thus, the experience and results discussed so far clearly demonstrate that despite the remarkable advances in Earth Observation in the last decades, there is still a lot of room for improvement, in the direction of meeting a new set of refined requirements for water resource and flood monitoring.

3. DERIVATION OD REQUIREMENS FOR FUTURE MISSIONS

From the gained experience, a few milestones can be drawn up. Concerning SAR data, HH polarisation and

wide swath SAR data is requested. These SAR acquisitions have to be complemented by optical data having, if possible, a SWIR channel. Another very crucial element is the time delay between the event and the acquisition, which has to be as short as possible. To ensure the shortest delay as well as to be have the capacity to monitor the evolution of an event, daily revisit is requested (or even denser for flash-flood events or when important infrastructures are threatened). In this context, large swath acquisitions appear to be best suited for this batch in regards of most of the flood conditions.
Additionally, a strong recommendation over areas of important stakes (human and economical ones) is to exploit the synergy between large swath data having a good revisit but a relatively coarse resolution, and high to very high resolution EO data covering narrow areas, the latter being very useful for the analysis/characterization of floods affecting urban areas. Such approaches are already regularly realized in a crisis context [5]. This synergy between HR and VHR data will be soon reinforced, as Sentinels will be launched as the Pleiades HR system, first European VHR optical resource being in activity [26-27].
A last crucial point is that during a crisis, access to EO data has to be guaranteed. Conflicts between acquisitions requests have had a great influence on the actual capacity of ensuring regular monitoring in the past. This was well observed during the DRAGON I flood project, within which near 30 rapid mapping actions have been carried over a period of 4 years. The first years, data were acquired thanks to fast programming of requests [28]. Then, during the project's life, major changes occurred; EO resource was mostly ensured based on a pre-defined routine observation and NRT actions were then principally carried out thanks to fast access through the Rolling Archive service [29]. One other point to highlight is the actual accessibility to the satellite resources, to be opposed to the theoretical one, in case of a non-priority request; a point which is related to conflicts between requests, either commercial or scientific/research ones. The case of the 2010 flood event monitoring in China, involving loss of accessibility to EO resources, well illustrates these conflicts. In order to monitor floods over the Poyang lake region (Jiangxi province, PR China), a specific planning of acquisitions of ENVISAT ASAR WSM data was set up with the agreement and support of ENVISAT mission management. Twenty acquisitions were scheduled, covering mid July to end of September 2010. Finally, only a quarter of these scheduled data was acquired; most of the acquisitions failed due to conflicts between current instrument operations, i.e. commercial conflicts or too short time for satellite operations [30].
With respect to these two limiting points, in terms of potential obstacles in the fully operational exploitation of EO resources to catch and/or monitor an event, the systematic long-term acquisition plan for EO data over high-risk areas would ensure the monitoring these flood-prone areas. This is proposed for the Sentinels, keeping also in mind that, for matters of urgency, the system can be reprogrammed and also that Sentinels are only part of the available EO sensors suitable and being tasked for disaster management.
A summary of requirements for flood and water resource monitoring is provided in Table 1.

Table 1. Summary of proposed requirements for effective flood and water resource monitoring.

Parameter	Requirement
Spectral resolution	Microwave (SAR), Optical with Middle Infrared
Spatial resolution	Desirable: 10m Minimum: 75m
Temporal resolution	Desirable: 12-hourDaily (Monitor expansion/development of phenomena – Crisis/Alert) Minimum: Weekly (Identification of phenomena)
Imaged area	Max. swath (SAR): 400km
Acquisition delay	Desirable: < 6 hours – Near Real Time (Crisis/Alert) Minimum: 3 Days
Geographical coverage	From 66°N to 55°S
Programming	Continuous (systematic) acquisitions over high-risk areas

4. EXPEDCT IMPROVEMENTS FROM SENTINEL 1 and SENTINEL 2

ESA's Sentinels constitute the first series of operational satellites responding to the Earth Observation needs of the EU-ESA Copernicus (GMES) programme. From the five scheduled sentinel missions, the first two, will be launched in 2014 are tailored towards the needs of operational land monitoring and emergency services.

Since middle of the 2000s, ESA has been undertaking the development of a new European Radar Observatory (Sentinel-1), a near polar orbiting satellite system for the continuation of SAR operational applications. Sentinel-1 will ensure the continuity of SAR C-band missions, building upon ESA's and Canada's heritage with SAR systems on-board ERS-1, ERS-2, Envisat and Radarsat-1 and 2. This new SAR system consists of a C-band radar, mounted on-board two satellites, the first of which (Sentinel-1A), is envisaged to be launched during the first half of 2014, followed by the second satellite (Sentinel-1B). The SAR sensor on-board Sentinel-1 missions will have the following Operational Modes:

1. Stripmap Mode (SM) with 80 km swath and

5x5 m spatial resolution, for generally restricted use, mainly in cases of emergency.
2. Interferometric Wide swath Mode (IW) with 250 km swath and 5x20 m spatial resolution (in range and azimuth respectively), obtained through burst synchronisation; this will be the preferred mode over land areas
3. Extra-wide Swath Mode (EW) with 400 km swath and 25x40 m spatial resolution, mainly for sea-ocean applications

In terms of wavelength and geometry of acquisition, the two systems would be also very well suitable for flood mapping. For SAR data, an incidence angle greater than 25° and HH+HV polarisation mode are well adapted for water recognition and extraction [30-33].

Sentinel-2 polar-orbiting satellites, tailored towards the needs of operational Copernicus land monitoring and emergency services, will provide systematic global acquisitions of high-resolution multispectral imagery, with a high revisit frequency. Sentinel-2 mission is designed to provide continuity of SPOT-5 and Landsat missions and thus guarantee the availability of data to service providers and users. Sentinel-2 satellites will routinely provide high resolution (10–20 m) optical images. Such resolution is of course very suitable to identification large wetlands and its water bodies but also for small remaining ones inside large agricultural fields (Fig.1).

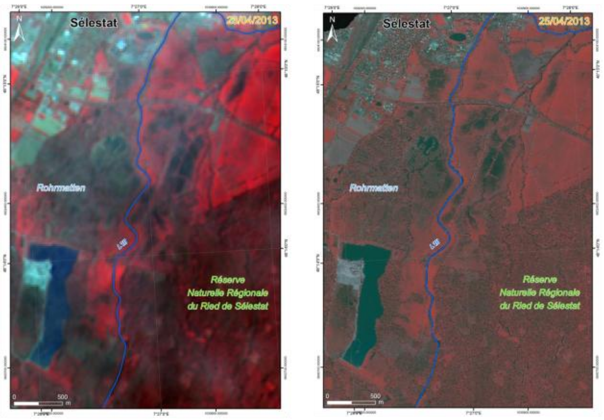

Figure 1: Comparison of wetlands viewed at 20 meters by SPOT4 acquired on the 23-04, and a 10 meter, Sentinel 2 simulation, deriving from a Pleiades HR XS data acquired on the 25-04-2013. ,

The first launch of Sentinel 2 (Sentinel-2A) is planned for the second half 2014. The orbit is Sun-synchronous at 786 km altitude (14+3/10 revolutions per day) with a 10:30 a.m. descending node. This local time was selected as the best compromise between minimising cloud cover and ensuring suitable Sun illumination. It is close to the Landsat local time and matches SPOT's, allowing the seamless combination of Sentinel-2 data with historical images to build long-term time series. The two satellites will work on opposite sides of the orbit [34].

The MultiSpectral Instrument (MSI) is planned to include 13 bands from blue to short wave infrared (SWIR) band, from 443 to 2190 nm providing high image quality across a wide field of view of 290 km and featuring 4 spectral bands at 10m, 6 bands at 20m and 3 bands at 60m spatial resolution.

The on-board presence of SWIR detectors is a real improvement of the actual systems, which all tend to renounce to the SWIR information, focussing on the very high resolution aspect (Fig. 2). As already mentioned, SWIR bands, alone or combined with visible, near infrared in a colour composite or in a ratio mode, can be very powerful to extract water bodies or to characterized wet soils, like after the passage of water [35-38].

Figure 2: Actual and future optical sensors more or less suitable for water surface mapping, ie covering or not the SWIR domain

With respect to the gained experience from 25 years of exploitation of a very large range EO data in NRT and for monitoring purposes, as previously presented, the two sentinel systems will provide a real improvement both in terms of capability of imaging a disaster event, like a flood, as well as in terms of providing valuable information from a thematic point of view.

The first very positive point of the Sentinel 1 and 2 constellations would guarantee, thanks to the selected orbits, the relative large swath and more importantly a predefined systematic acquisition scheme and maximum possible availability of images. These mutually exclusive modes, which are provided for continuity reasons (with respect to ERS & Envisat), would also fit very well with the accommodation of emerging user requirements, satisfying also tomorrow's requests by building up a consistent long-term archive.
Furthermore, the relative large swath of the both Sentinel systems, i.e. 250 km over lands for Sentinel-1

and 290 km for Sentinel-2 associated with high resolution, is a real improvement compared to Landsat or SPOT swaths (185 km and 120 km respectively). The availability of both satellites systems will also improve their revisit time capabilities.

In regards to recent rapid mapping activities, such as the June 2013 Germany and Central Europe case, the intake of the large swath is obvious. When during this action, 8 different scenes from various HR and THR optical SAR sensors have been exploited, plus a large part of the area was covered only by MR data, only in two descending pass, Sentinel 1 or 2 will covered such as large AOI (Fig. 4 and 5).

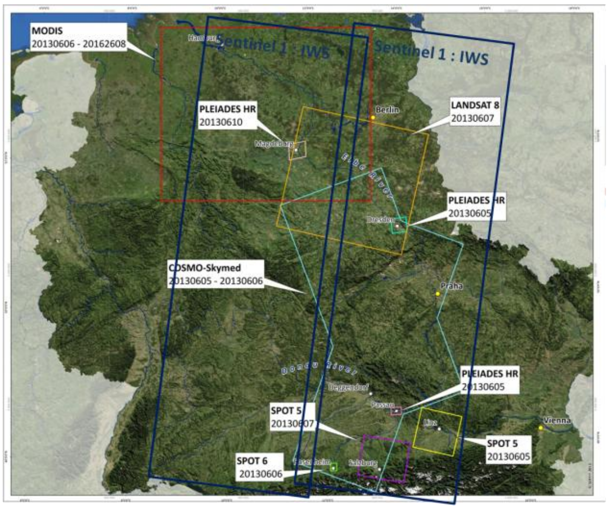

Figure 4: Sentinel 1's expect in term of swath coverage case of the IWS mode, ie the Sentinel 1 standard mode The back ground map correspond to the action carried within the Insurance EOMD action during the Germany flood in June 2013.

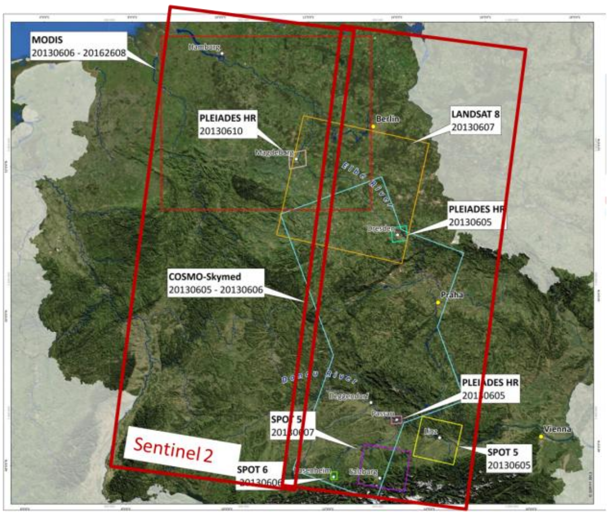

Figure 5: Sentinel 2's expect in term of swath coverage.

These points are relatively important, in terms of research perspectives applied to various research axes dealing with inland water bodies (Fig. 6). It is a unique opportunity to ensure and enrich the long-term monitoring of broad sensitive ecosystems, such as the ones previously mentioned.

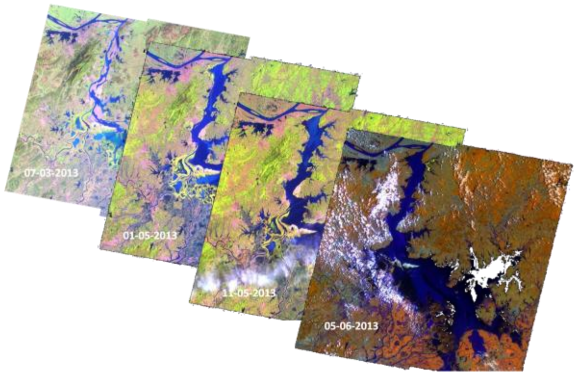

Figure 6: importance of continuous time series for the monitoring of inland water bodies. Example from the CNES Take Five Experiment over the Poyang Lake (PR China). Scale: 120 km by 120 km)

. Thanks to the long time series datasets, it will be possible to monitor environmental signal over decades, and this time both at high temporal and spatial resolution. Sentinel-1 and 2 will provide a unique source of information on the topics of water influence/relationship on landscape, having a strong dynamic aspect, with applications on water resource management, ecosystem understanding and prognosis of their evolution, on biodiversity management, as well as health-related applications such as malaria and bilharziosis.

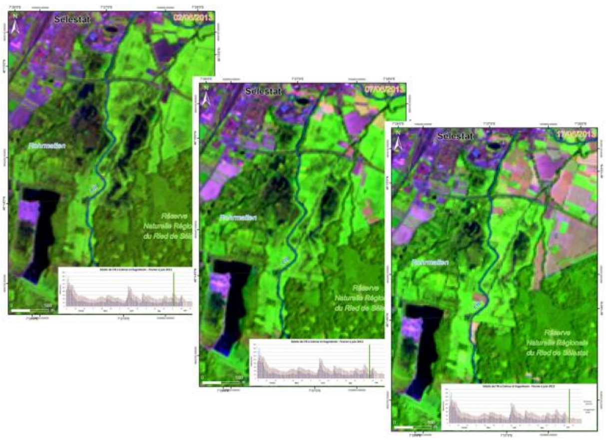

Figure 7: Take Five time series acquired over the Alsatian flood Plain, (France) on the 02-06; 07-06 & 17-06-2013 illustrating the potential of Sentinel 2 to monitor small inland water bodies. The draw off of the water induced a decrease of the water bodies size within grasslands

As already mentioned, thanks to the high resolution, up to 10 meters, such monitoring of water bodies , i.e/or wetlands complex will not be applicable only for large wide complex but also to small ones. It will be possible to catch the dynamic of tiny complex covering few hectares within large agricultural areas (Fig. 7).

A key point is the possibility or not to acquire in strip map mode. Indeed, thanks to a more resolute data, with a relative wide coverage, ie 80 km when actual SAR systems are limited to 40 km of swath, strip map mode would provide very valuable information both in a crisis and monitoring context. Taking into account a real case, five long strips would have been necessary to covered the affected area in Germany during the June 2013 floods (Fig. 8). In addition, as being in C band, data would be very low sensitivity to rain fall that can dramatically affect the X band data. Therefore acquire such data will involve to move from a long planned acquisition scheme in IW mode, to SM mode. By the way the question of exploiting the SM data, involves the motion of Sentinel 1 governance. Indeed. who will be in charge to receive, analyse and accept or reject an emergency request for a StripMap mode acquisition.

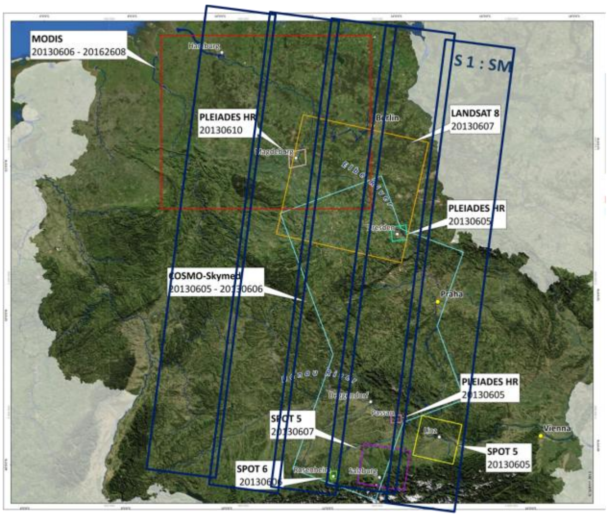

Figure 8: Sentinel 1's expect in term of swath coverage case of the strip map mode

For water bodies monitoring purpose, maybe, based on the gained experience after one year of acquisition or one year of exploiting the full systems, the predefined mode of acquisition, i.e. the Interferometric wide swath mode, of 250 km would be re-evaluated, in order to insure an optimal revisiting time over large inland water complexes, such as the Delta Interior of Niger and the Okavango in Africa, or the Yangtze medium basin and the Mekong complex, including the Tone Sap system, in Asia.

The last important point is the Sentinel ground segment capability. With the Rolling Archive facilities ESA has already a very interest tool, even if it is not so easy to manage, but an existing tools allow relative fast product dissemination for the Medium resolution products allowing relative fast product dissemination for the Medium resolution products (IMM, and WSM ASAR products; MERIS FR and RR products). It appears that the ground segment of the Sentinels will also be largely improved, with a NRT dissemination mode within 1 to 3 hours from observation in all cases, within 10 minutes from observation in special cases. With such ground system and dissemination procedures, near real processing of data will come more and closer to real time processing of data in a crisis context.

5. CONCLUSION

It is foreseen that the Sentinels will be able to meet some of these requirements or introduce improvements in this direction; larger swath, regular and shorter revisit time, systematic acquisition strategy over high-risk zones, fast data dissemination, along with the potential of synergistic use of Sentinel-1 and Sentinel-2 data. In this context, the Sentinels will be a milestone of the spatial and temporal improvements in Earth observation dedicated to risk management. While Sentinels will insure an efficient routine surveillance mission, VHR satellites like Pleiades will be tasked on demand over smaller high-risk areas.

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