Guest Editorial: International Space Science Institute (ISSI) Workshop on Geohazards and Risks Studied from Earth Observations

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The Earth's environment and humankind have always suffered from natural hazards such as earthquakes, volcanic eruptions, tsunamis, occasional meteor impacts, wildfires and hydro-meteorological extremes (e.g., cyclones, floods, storm surges, landslides triggered by heavy rainfall or floods, heat waves and droughts). With the development of human societies, a new kind of hazards has appeared; these are referred to as man-made hazards. These new hazards include global warming and greenhouse gas emissions, air and water pollution, plastic wastes throughout the ecosystem and technological disasters such as oil spills, chemical or nuclear explosions (Alexander 2018). Among the man-made hazards, technological disasters may cause huge damages in terms of environmental degradation and human casualties, but due to their scarcity they are less susceptible to interact with natural hazards, as opposed to pollution and, above all, to greenhouse gas releases. Indeed, the development of anthropogenic hazards can enhance or interact with already existing natural risks, thus leading to more complex effects, which in turn are more difficult to predict. Hydro-meteorological hazards such as cyclones, storms, heat waves, floods and droughts are intensifying as time goes on and some of them are becoming more frequent (e.g., heat waves and floods) (Stocker et al. 2013; Yamazaki et al. 2018 and references therein), and increasing the vulnerability of populations. However, the societal and economic impacts of natural and man-made hazards will differ depending on the geographical region, southern countries paying generally a heavier price in terms of human casualties and goods lost (Hyndman and Hyndman 2016).

With the development of a large variety of advanced sensors aboard satellites and the growing amount of available data, space-based Earth Observations (EOs) are increasingly being used to better support disaster monitoring, mitigation, adaptation and risk

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management. The space-based observing systems have several advantages compared to in situ networks. Since they are not affected by the hazards occurring at the surface of the Earth, they collect consistent data over different spatiotemporal scales and give us access to dangerous and/or remote areas. The EO datasets provide human society with the benefits of a synoptic view of natural hazards and their associated risks.

The Copernicus Programme of the European Union now provides routine space-based and in situ observations of the Earth and the environment, in particular with the operational Sentinel missions developed and operated by the European Space Agency (ESA). These missions offer invaluable observations of natural and man-made hazards and disasters. The scientific community can then better understand the underlying processes and their complex interactions and further improve forecasts and projections. As the above-mentioned hazards cannot be treated in isolation, since several of them are interconnected (e.g., land use changes have an impact on hydrology and coastal zone dynamics; pollution affects fresh and coastal zone water quality, etc.), a Workshop entitled “Natural and man-made hazards monitoring by the Earth Observation missions: current status and scientific gaps” was held at the International Space Science Institute (ISSI) in Bern, Switzerland (from 15 to 18 April 2019), in order to facilitate cross-disciplinary discussions. The Workshop brought together scientists from different horizons working on different aspects of geohazards and their impacts on society and the environment. More specifically, the objectives of the Workshop consisted of:

- (1) Presenting the various natural and man-made hazards for which remote sensing data from the Copernicus Sentinels and other Earth Observation missions can be used in synergy, and with UAV (Unmanned Aerial Vehicles)-based and in situ data,
- (2) Discussing the interactions between different natural and man-made hazards,
- (3) Providing added-value information on the physical processes causing these phenomena, and
- (4) Addressing how the space-based data can be assimilated into predictive models in order to improve our forecasting abilities.

The first section of this Special Issue presents both the role and the benefits of EOs for hazards monitoring, post-disaster management and forecasting. The paper by Benveniste et al. (2020) provides an informative overview of European space missions that routinely monitor geohazards. The authors also describe relevant scientific and societal applications of the collected data and provide information on the downstream International Services such as the Copernicus ocean and land monitoring services that freely distribute remote sensing data products and information to a broad variety of users from scientists to managers and decision-makers.

With the increasing amount of EO data available and their improved coverage over large areas, Le Cozannet et al. (2020) investigate how space-based EOs best support disaster risk management. More precisely, they consider how and where EOs can be an asset for disaster prevention, preparedness and crisis management, as well as for post-crisis management. This article emphasizes the advantages of cross-disciplinary studies between the environmental and social sciences in order to improve disaster risk reduction. In the context of global warming, the monitoring of the evolution of key tipping points that will cascade global warming and other natural hazards, could benefit from the use of more EO datasets. Indeed, these datasets will stimulate the detection of early warning signals of such tipping elements. This is the issue discussed in the article by Swingedouw et al. (2020), whose

focus is on the overturning circulation of the Atlantic Ocean and on the subpolar gyre system, marine and terrestrial ecosystems, permafrost, and runaway melting of the Greenland and Antarctica ice sheets. The last article of this section on EOs reviews the use of UAVs deployed in the geohazards context (Antoine et al. 2020). The tremendous increase in the amount of UAV-based data available gives us access to very high-spatial resolution datasets which leads to the opening of new research areas. This article reviews the latest scientific and technical advances made in different domains such as mass movements of the Earth surface (e.g., landslides), volcanic eruptions, flood events and earthquakes. The benefits of combining EO datasets from space-borne sensors with UAVs' datasets in order to better monitor and forecast hazards are discussed.

The second section emphasizes the hazards that impact the Earth and its environment, such as fires, mass movements of the Earth, e.g., landslides, and earthquakes. As opposed to the number of flood and drought hazards which increased during the 1900s, fatality rates due to earthquakes remained relatively constant during the last century. In that context, Elliott (2020) proposes a review of how the assimilation of EO data into models helps to quantify the crustal deformation and associated risks during the seismic event and the subsequent longer-time scale inter-seismic deformation. Specific examples are presented in Elliott et al. (2020) to illustrate the use of EO, airborne and ground-based datasets to measure the deformation associated with the failure of the Earth's crust occurring at faults. This article also provides a study of the interest of EOs for smaller magnitude earthquakes that are associated with artificial water reservoirs.

Ground deformations also occur in other contexts such as coastal landslides, mountain debris flows, rockfalls and mudflows in periglacial environments. Due to their occurrence in such different environments, Lissak et al. (2020) present the main remote sensing tools currently being used for hazard mapping, for making inventories, and for monitoring surface deformations. They also focus on the assets becoming available for Earth mass redistribution studies and disaster risk prevention via multi-platform remote sensing using spaceborne, airborne and in situ datasets. Fires have an increasing impact on the natural environment and human and animal populations, as demonstrated by the recent disasters in Australia, Northern Europe and the West Coast of the USA. The article by Pettinari and Chuvieco (2020) describes the different causes of fires and their impacts on the environment. Due to the increased vulnerability of populations suffering from fires, EOs provide invaluable information with worldwide and frequent coverage which identifies the different factors triggering the fires and giving access to near real time information on them.

The last section of this Special Issue deals with some of the hazards that affect the hydrosphere (both continental and oceanic), the atmosphere and the upper atmosphere where space weather effects predominate. Recent advances on the monitoring of floods and droughts are rapidly progressing. This evolution is achieved because of moderate-to-low-resolution datasets obtained from the space gravimetry missions, GRACE and GRACE-FO, the SMOS and SMAP missions dedicated to measuring soil moisture, and the various nadir radar altimetry missions that measure surface water levels. Lopez et al. (2020) review the innovative applications of the datasets collected by these sensors, in particular to improve our understanding of the physical processes involved as well as the forecasting of floods and droughts. Due to their social, economic and environmental values to human society, coastal zones experience high stresses and suffer from higher vulnerability to different natural and anthropogenic hazards such as storm surges, marine heat waves, coastal flooding, sea level rise, erosion and shoreline retreat, acidification and destruction of ecosystems. In that context, Melet et al. (2020) investigate what are the benefits of EOs to monitor coastal hazards and their drivers via the development of monitoring

programs and early warning forecasting systems. One of the most massive natural hazards that also causes tremendous destruction in coastal areas is tsunamis. The major tsunamis that followed the Sumatra earthquake (in Indonesia, $M_w=9.1$) in 2004 and the Tohoku earthquake (in Japan, $M_w=9.1$) in 2011 have raised the public's awareness of this specific disaster. Hébert et al. (2020) prepared a review of the different challenges encountered in tsunami science and of how EO datasets improve the development of tsunami warning systems at the global scale. Another major anthropogenic hazard that impacts human health and the natural environment is pollution, in particular air and sea pollution. Viatte et al. (2020) review the benefits of EOs for monitoring different forms of pollution and discuss how their combination with in situ data increases our understanding of the complex interactions of all types of pollution within the biosphere. Finally, space weather hazards are also discussed in this Special Issue. Space weather deals with the complex interactions between the Sun, the solar wind and the Earth's magnetosphere, ionosphere and atmosphere. The manifestation of strong space weather events has a number of physical effects in the near-Earth environment: the acceleration of charged particles in space forming the Van Allen belts, extraordinary auroral displays in both polar regions, the intensification of electric currents in space and of induced currents on the ground, and global magnetic disturbances at the Earth's surface. In Mandeia and Chambodut (2020), the most recent developments in space-based measurements of the external and internal magnetic fields of the Earth and their interpretation are provided together with a discussion of related technological issues, such as the malfunctioning of satellites, impacts on radio communications and navigation systems, as well as impacts on electrical power distribution grid systems.

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