Disaster Risk Reduction – Availability of radio communications services at the time of space weather events

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Francois Lefeuvre[1] and Tullio Tanzi[2]

[1]LPC2E, 3A Av de la recherche scientifique, 45071 Orleans cedex 02, France

francois.lefeuvre@cnrs-orleans.fr

[2]Institut Mines-Telecom, Telecom ParisTech, LTCI CNRS. CS 50193, 06904 Sophia Antipolis cedex, France,

tullio.tanzi@telecom-paristech.fr

Abstract — Independently of the disasters observed on Earth, more than 600 space weather events are observed per solar cycle (11 years). When they occur during the response phase of a disaster (the first two weeks) they may seriously affect: satellite orientation, communication systems and navigation systems. Alert systems allow identifying in near real-time ($\Delta t \leq$ 15 minutes) corrupted or missing communications. For the sake of convenience the space weather events discussed here are mainly those generated by "geomagnetic storms" characterized by Kp or K indexes. Applications are made: (i) during the response phase of the 26th December 2004 earthquake and its subsequent tsunami, and (ii) for near real time observations.

. I. INTRODUCTION

In the 2013 Report of the United Nations Office for Disaster Reduction (UNISDR), drafted by the Scientific and Technical Advisory Group [1], a disaster risk reduction may be obtained "both by identifying and analysing the causal factors of disasters", and "by integrating science into both policy making and best practice for disaster management". However, disaster risk reduction also requires checking the availability of the different radio communications services at any time.

In the present paper, we will focus on the effects of space weather events on spatial radio communication systems. Space weather is the time varying environmental conditions within the solar system and especially the space surrounding the Earth. The space weather events are generated by the impact of the solar activity on the terrestrial environment, and more specifically by: "geomagnetic storms", "radio black outs" or "solar radiations"(see www.swpc.noaa.gov/NOAAscales/). One will mainly work here with the space weather events observed during "geomagnetic storms". They are characterized by measured values of the Kp index (see I.S.G.I. - International Service of Geomagnetic Indices), determined each 3 hours, and running from 0 (very quiet) to 9 (very disturbed). For the sake of convenience, those Kp values will run here from 5 (minor events) to 9 (extreme events).

During those "*geomagnetic storms",* radio propagation, radio navigation and spacecraft operations may be disturbed or disrupted on interval times running from a few minutes (minor and moderate events) to hours (strong and severe events) or even days (extreme events). Obviously, this may be at the origin of serious problems, in particular during the response phase of a disaster, i.e. during the first two weeks.

The object of the present paper is to point out risks of errors in alert systems during space weather events. The alert system considered here is the detection of a tsunami generated by an earthquake [2]. Surface boys detect water surface movements which are transmitted to satellites. However, errors in the spacecraft orientation and/or perturbations in the communication systems can corrupt the signal from the sensor to the control unit, and then prevent the disaster cell [3] to take the right decisions.

The plan of the paper is as follows. In section 2, the technique used for detecting a tsunami is recalled. Section 3 is dedicated to the detection of space weather events during the response phase of a disaster. Examples of applications are given in section 4. Section 5 concludes the paper.

II. Tsunami Warning and Mitigation for the Indian Ocean Region

The tsunami warning and mitigation programme for the Indian Ocean Region was decided in the wake of the 26th December 2004 earthquake and its subsequent tsunami which killed 230,000 people and caused widespread destruction. It is based on the deployment of DART (Deep-ocean Assessment and Reporting of Tsunamis) stations developed by PMEL (Pacific Marine Environmental Laboratory, http://nctr.pmel.noaa.gov/Dart/dart_ref.html). Early detection and real-time reporting of deep-ocean tsunamis was published by Bernard et al.[4]. A review of the past and future developments has been written by Bernard and Meinig [5].

Each DART station consists of a surface buoy and a seafloor BPR (Bottom Pressure Recording) package that detects pressure changes caused by tsunamis. The surface buoy receives transmitted information from the BPR via an acoustic link, then transmits data to a satellite, which relays the information to ground stations for immediate dissemination to: the NOAA's Tsunami Warning Centers, the NOAA's National Data Buoy Center and PMEL. As shown in Figure 1, the DART 2 system detects tsunami waves and communicates these to a surface buoy with satellite telecommunications capability.

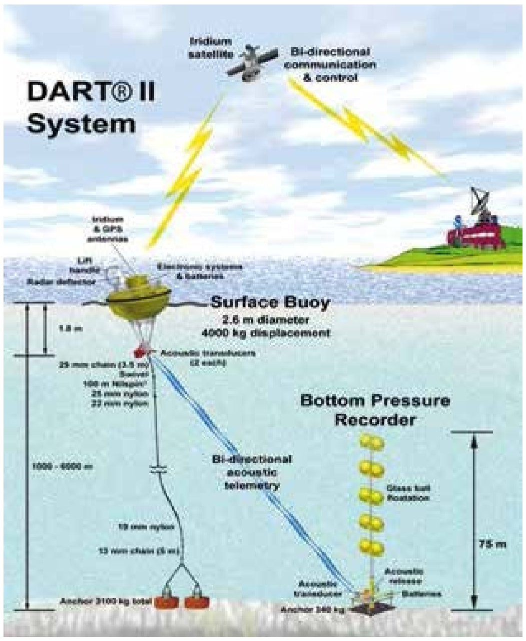

Fig. 1. DART II system

The 2013 UNISDR report notes initiatives taken from scientists and policymakers to form an international commitment to develop an Indian Ocean Tsunami Warning & Mitigation System (IOT WS)". That system is now fully operational, comprising a set of Regional Tsunami Service Providers (India, Australia, and Indonesia) issuing tsunami advisories to all National Tsunami Warning Centres of the Indian Ocean rim countries. Now, if gains in tsunami preparedness were demonstrated during the 12 April 2012 magnitude 8.5 earthquake offshore of northern Sumatra (Indonesia), the number of people who lost their life in the 2011 Tohoku tsunami (Japan) shown that the application of science and technology can save lives, but not always all of them. In addition, as it will be shown in section 3, space weather events may damage or even disrupt radio communications and radio navigations, which can make rescue much more difficult.

III. DETECTION OF SPACE WEATHER EVENTS DURING THE RESPONSE PHASE OF A DISASTER

Space weather events	Spacecraft operations	Radio propagation	Navigation
Extreme: Kp = 9 4 events per solar cycle (or 4 days per solar cycle)	May experience problems with orientation, uplink/downlink and tracking satellites	HF propagation may be impossible in many areas for one to 2 days	Satellite navigation may be degraded for days Low-frequency radio navigation can be out for hours
Severe: Kp= 8, 9- 100 events per solar cycle (or 60 days per solar cycle)	Corrections may be needed for orientation problems	HF radio propagation sporadic	Satellite navigation degraded for hours Low-frequency radio navigation disrupted
Strong: Kp=7 200 events per solar cycle (or 130 days per solar cycle)	Corrections may be needed for orientation problems (drag may increase on low-Earth orbit)	HR radio may be intermittent	Intermittent satellite navigation and low-frequency radio navigation may occur
Moderate: Kp =6 600 events per solar cycle (or 360 days per cycle)	Corrections may be needed for orientation problems (possible changes in drag affect orbit predictions).	HF radio propagation can fade at higher latitudes.	

Table 1. Space weather events generated by geomagnetic storms (condensed version of the NOAA Space weather scale)

According to the variety of communication problems potentially encountered during the response phase of a disaster (damage to ground-based communication links, poor communications between ground-based and satellite systems, etc.), one of the first priority is to check that all the communication services can work properly and that moderate to extreme space weather events don't pollute information to be distributed for search and rescue teams.

As recalled in section 1, the term "space weather" focuses on the impact of the solar activity on our terrestrial environment.

Basically, two types of events can be distinguished:

- the "geomagnetic storms", generated by a solar wind shock wave and/or cloud of magnetic field which interacts with the Earth's magnetic field [6] ,
- the "solar flares" or/and "CMEs" (Coronal Mass ejection), the solar flares reaching the Earth environment a day or two after the event [7] and the CMEs one to five days after leaving the sun [8].

The "geomagnetic storms" provide a global level of geomagnetic activity. Solar flares and CMEs generally influence local space weather. However large events may also generate global geomagnetic activity. A condensed version of the geomagnetic storm scale is given in Table 1.

IV EXAMPLES OF APPLICATION

There are two ways of identifying space weather events:

- a posteriori analysis from the Kp indexes, the present Kp indexes being delivered with a one month time delay,
- near real time observations of : (i) current conditions and (i) space weather events.

Examples of applications are given below.

IV.1 A posteriori analysis

A relevant example can be found in the response phase of the 26th December 2004 earthquake and its subsequent tsunami (see section 2). One notes that, from 26 December 2004 to 9 January 2005 (the two first weeks of the disaster):

- on January 2, from 15 to 18 UT, Kp = 6- (moderate space weather event): spacecraft operations may be required but radio propagation is not affected at latitudes considered here,
- on January 7, from 21 to 24 UT, Kp =8 (severe space weather event): spacecraft re-orientation are probably required, sporadic HF communications are over during ~3 hours, degradation of the navigation system are observed during the same time interval,
- on January 8, from 00 to 03 UT then 03 to 06 UT, Kp = 7- then 6^- (strong then moderate space weather events): spacecraft orientation, HF communications and navigation system are more or less affected.

In the time intervals listed above, data spacecraft orientation, HF communications and navigation system were affected, with the risk to transmit corrupted information from the satellites to the ground.

IV.2 Near real time detections

For "current conditions" and "space weather" events, we have considered here observations arbitrary made on 28 October 2014 at 09:00 UT (see Figure 2). However, we have taken into account observations made a few hours before.

<u>Current conditions</u>

Current conditions are derived from the NOAA "radio blackouts" scale. In the time period October 27 21-24 UT and October 28: 00-09 UT, one observes strong space weather events with:

- for HF radio : Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth.
- for navigation**:** Low-frequency navigation signals degraded for about an hour.

<u>Space weather events</u>

Space weather events are detected from the "geomagnetic storms" scale. Near real time detections are made at the NOAA Space Weather Prediction Center using data from 8 ground-based magnetometers (i.e. from a relatively weak number of instruments). The Estimated 3-hour Planetary Kp-index is derived at the NOAA Space Prediction Center. The chart is updated every 15 minutes at 1, 16, 31, and 46 minutes past the hour.

An example is given on Figure 2. The observations are made from October 22 - 00.00 UT up to October 28 - a few minutes below 09:00 UT (the UT time where the present paper is written). The K indices, slightly different from the Kp index are provided by the Fredericksburg (middle –latitude) and College (high – latitude) stations monitoring Earth's magnetic field. One notes:

- in the time period October 27 (21:00-24:00 UT) and October 28 (00:00–09:00 UT): (i) a wide area blackout of HF radio communication and the loss of radio contact for about an hour on sunlit side of Earth, (ii) low-frequency navigation signals degraded for about an hour.
- in the time period October 28 (12:00 – 18:00 UT), in one station only (the College station) K values of 5 then 6 (moderate space weather event). One cannot consider that we have a global level of geomagnetic activity. An analysis from the "radio black out" scale will probably be more adapted.

Clearly, as observed in the a posteriori analysis, in the time period analysed here, there a non negligeale risk: to miss communications or/and transmit corrupted information from the satellites to the ground.

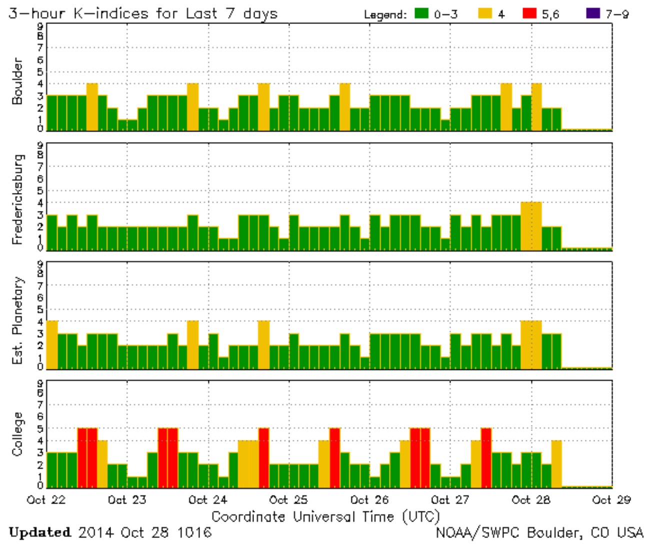

Fig. 2. Geomagnetic K-indices from. 2014 October 22 to October 29 (see text)

V. CONCLUSION

As recalled in [3], radio communications have three main functions: connecting the disaster cell, collecting and distributing observation data, then distributing display analysis and forecast provided by data processing centres. The object of the present paper was to contribute to the disaster risk reduction by showing how we could be more reactive to prevent errors or/and black outs in the accomplishment of those three functions during the response phase of a disaster, i.e. during the first two weeks.

The aspect we wanted first pointing point out was the ground-based satellite communications at the time of space weather events. In that respect, the use of the DART II system for "Tsunami Warning and Mitigation for the Indian Ocean Region" provided an excellent example of case study. As it is shown in several parts of the present paper, and in particular in section V, there are numerous space weather events observed during the response phase of disasters.

Our main conclusions are as follows:

- effects of space events on satellite orientation, communication systems and navigation systems, are pointed out, but except probably for the "Severe" and "Extreme " events, they are not easy to quantify,
- despite of the weak number of stations taken into account in the application part, near real time observations seem to be consistent with a posteriori analyses, which allows to control the functioning of the equipments in near real-time,
- even if all satellite observations are transmitted to the disaster cells then to the rescue teams, one must make sure that all the actors on the ground receive all information on the validity of the information transmitted during space weather events.

REFERENCES

[1] Using science for Disaster Risk Reduction, Report of the UNISDR Scientific and Technical Advisory Group – 2013.

[2] Case Study 1, Tsunami Warning and Mitigation for the Indian Ocean Region, Report of the UNISDR Scientific and Technical Advisory Group, pp. 14, 15, 2013

[3] François Lefeuvre and Tullio Joseph Tanzi, Radio Science's Contribution to Disaster Emergencies, The Radio Science Bulletin n° 348, March 2014.

[4] Bernard EN, González FI, Meinig C, Milburn HB, Early detection and real-time reporting of deep-ocean tsunamis. In: Proceedings of the International Tsunami Symposium 2001 (ITS 2001) (on CD-ROM), NTHMP Review Session, Seattle, WA, 7–10 August 2001.

[5] Bernard, E., and C. Meinig (2011): History and future of deep-ocean tsunami measurements. In Proceedings of Oceans' 11 MTS/IEEE, Kona, IEEE, Piscataway, NJ, 19–22 September 2011, No. 6106894, 7 pp.

[6] Gonzalez, W. D., J. A. Joselyn, Y. Kamide, H. W. Kroehl, G. Rostoker, B. T. Tsurutani, and V. M. Vasyliunas (1994), What is a Geomagnetic Storm?, J. Geophys. Res., 99(A4), 5771–5792

[7] Hugh Hudson, Kenneth Phillips, Amir Caspi et al., An Observational Overview of Solar Flares, Space Science Reviews, vol. 159, pp. 19-106; 09 September 2011, * or "Solar flares" – wikipedia.

[8] Christian, Eric R. (5 March 2012), Coronal Mass Ejections, Astronomical Society of the Pacific 66 (389): – 55–57, * NASA.gov. Retrieved 9 July 2013 – Wikipedia.