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Space Weather and Financial Systems: Findings and Outlook

An event co-organised by the European Commission's Joint Research Centre,
the UK Civil Contingencies Secretariat and
the NOAA Space Weather Prediction Centre
27 June, 2014, London, UK

Elisabeth Krausmann, Chris Felton, William Murtagh, Neil Mitchison, Stephan Lechner

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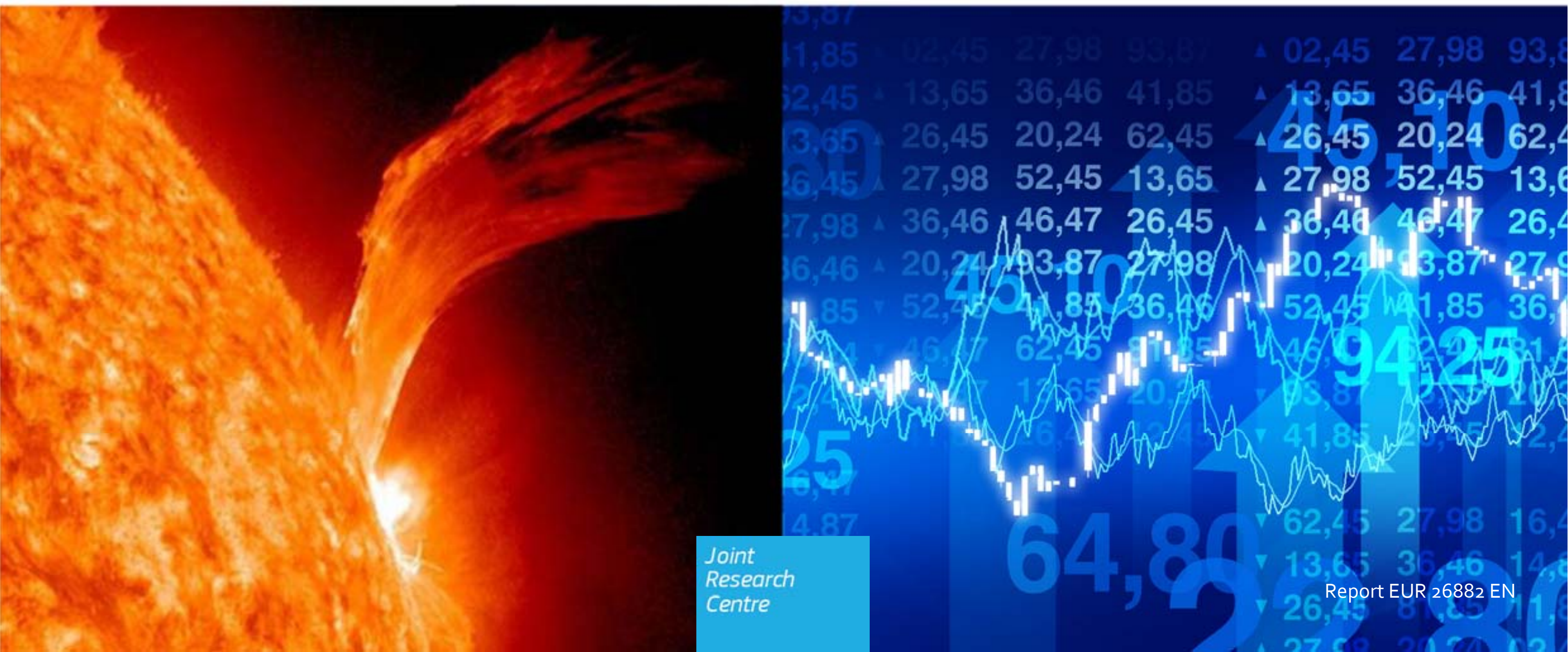

Joint Research Centre

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Abstract

Space weather can affect both ground-based and space-borne infrastructures, potentially resulting in failures or service disruptions across the globe and causing damage to equipment and systems. With society having become increasingly reliant on the services these infrastructures provide, a more thorough analysis of the risk due to extreme space weather is warranted. Most studies on the impact of space weather on infrastructures focus on the high-voltage power grid, aviation and communication. A less well-known area of potential vulnerability is the impact of space weather on the financial services sector. Elements of this sector's operations depend on accurate timing, a service which is increasingly provided by space based – and therefore space weather prone - technologies. The Global Navigation Satellite Systems (GNSS), for example, are commonly used for deriving time stamps for financial transactions. In order to address this topic, the Joint Research Centre of the European Commission, the UK Civil Contingencies Secretariat, and the US National Oceanic and Atmospheric Administration jointly organised the "Space weather and financial services" workshop in London on 27 June 2014. The half-day workshop was attended by 50 representatives of the financial service industry, insurance, European and US government agencies, regulators, academia and the European Commission. The objectives of the workshop were to discuss the potential impact of extreme space weather on financial services, in particular through the effect on timing systems of a loss of GNSS services, and to raise the awareness of this risk in the sector. This report presents the findings of this workshop.

Space Weather and Financial Systems: Findings and Outlook

An event co-organised by the European Commission's Joint Research Centre, the UK Civil Contingencies Secretariat and the NOAA Space Weather Prediction Centre

27 June 2014, London, United Kingdom

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Executive Summary

Space weather can affect both ground- and space-based infrastructures, potentially resulting in failures or service disruptions across the globe and causing damage to equipment and systems. With society having become increasingly reliant on the services these infrastructures provide, a more thorough analysis of the risk due to extreme space weather is warranted.

Most studies on the impact of space weather on infrastructures focus on the high-voltage power grid, aviation and communication. A less well-known area of potential vulnerability is the impact of space weather on the financial services sector. Elements of this sector's operations depend on accurate timing, a service which is increasingly provided by space-based – and therefore space-weather-prone – technologies. The Global Navigation Satellite Systems (GNSS), for example, are commonly used for deriving time stamps for financial transactions.

In order to address this topic, the Joint Research Centre of the European Commission, the UK Civil Contingencies Secretariat, and the US National Oceanic and Atmospheric Administration jointly organised the "Space weather and financial services" workshop in London on 27 June 2014. The half-day workshop was attended by 50 representatives of the financial service industry, insurance, European and US government agencies, regulators, academia and the European Commission. The objectives of the workshop were to discuss the potential impact of extreme space weather on financial services, in particular through the effect on timing systems of a loss of GNSS services, and to raise awareness of this risk in the sector.

The main workshop conclusions are:

- Space weather has a global footprint and can affect multiple infrastructures at the same time.
- The susceptibility of society to space weather is increasing due to its reliance on services provided by vulnerable infrastructures and interdependencies between infrastructures.
- Interdependencies between critical infrastructures need to be considered in the space-weather risk assessment. These interdependencies are complex and therefore not yet fully understood and routinely assessed.
- Elements of the financial sector's operations depend on accurate timing which is often provided by vulnerable space-borne infrastructures, such as GNSS.
- During extreme space weather the severe disruption or loss of GNSS services seems certain, although timing services are more resilient than those used for navigation. Other timing methods or holdover capability are therefore required, and alternative, fairly inexpensive, options exist.
- The vulnerability of the financial services sector internationally to extreme space weather appears to vary, and awareness among operators and regulators globally is currently limited.
- Resilience to space weather across the financial services sector needs to be built. This includes the identification of its vulnerabilities and any mitigation (including early-warning services) it needs to make the sector's activities more resilient.
- There are European and US space-weather forecasting capabilities to support early warning of governments and vulnerable industries.
- Multilateral and international collaboration for emergency-response planning is necessary to cope with extreme events.

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1. Introduction

Solar activity shapes the space environment near the Earth and influences our planet's magnetosphere and upper atmosphere. This so-called space weather can affect both ground-based and space-borne infrastructures, potentially resulting in failures or service disruptions and causing damage to equipment and systems. With society becoming increasingly reliant on the services these infrastructures provide, a more thorough analysis of the risk resulting from extreme space weather is warranted.

Most studies on the impact of space weather on infrastructures focus on the high-voltage power grid - the backbone of modern society, aviation and communication. A potential area of concern that has been identified (e.g. RAE, 2013[1]) but is relatively less well known than for other sectors is the impact of space weather on the financial services sector. This sector depends on accurate timing, a service which is increasingly provided by space-weather-prone technologies. The Global Navigation Satellite Systems (GNSS), for example, are commonly used for deriving time stamps for financial transactions. Precision in timing is therefore critical, in particular for high-speed trading.

In order to address this topic, the Joint Research Centre (JRC) of the European Commission, the UK Civil Contingencies Secretariat (CCS), and the US National Oceanic and Atmospheric Administration (NOAA) jointly organised the "Space weather and financial services" workshop in London on 27 June 2014. The main aim of the event was to discuss the potential impact of extreme space weather on financial services, in particular through the effect on timing systems of a loss of GNSS services, and to raise the awareness of this risk in the financial sector. In addition, the workshop aimed to encourage the financial services industry to assess the space-weather risk to its systems in general, and to consider what mitigation measures might be needed.

The half-day workshop was attended by 50 representatives of the financial services industry (major European and non-European banks and industry bodies, the London Stock Exchange), insurance, European and US government agencies, regulators, academia and the European Commission. The main conclusions of the workshop are summarised in the following sections. The workshop programme and the list of participating institutions are provided in Annexes 1 and 2.

2. Space weather and its impacts

The first session of the workshop introduced the origin and characteristics of space weather, as well as its potential impacts on critical infrastructures. Three speakers from NOAA, the JRC, and CCS examined the problem from phenomenological, risk-assessment and emergency-planning perspectives.

Past space-weather-induced infrastructure damage and service outages, e.g. in 1989 or 2003, showed that the impact of space weather is global, and can affect multiple infrastructures simultaneously. The impact ranges from failure of GPS-based positioning or the rerouting of flights on polar routes to power outages and the loss of satellites. The potential for global impact is exacerbated by the increasing reliance of modern society on critical infrastructures. The GNSS, for instance, facilitate a wide range of commercial activities, such as aviation,

[1] Royal Academy of Engineering (2013) Extreme space weather: impacts on engineered systems and infrastructure, United Kingdom, ISBN 1-903496-95-0.

road and marine transport, precision agriculture, banking and the control of power grids. A loss of GNSS services would therefore be broadly disruptive.

There are three types of solar activity that can affect critical infrastructures: 1) Solar flares, which can trigger radio blackouts and disturb the GNSS network, radar, and ground- and space-based communications (including high-frequency communication); 2) solar radiation storms, which can affect satellite operations and aviation; and 3) the ejection of large quantities of magnetised solar plasma (so-called Coronal Mass Ejections or CMEs), which can cause geomagnetic storms on Earth. These storms have potentially significant consequences on satellite operations, aviation, power-grid operations, rail networks and GNSS. Fast CMEs with speeds of up to 3,000 km/s are of greatest concern and appear to occur every few years. Fortunately for human activities, most of them miss the Earth, or carry a magnetic field with a polarity that does not induce a geomagnetic storm. The predictability of space weather is still limited, and so is the early-warning lead time.

There is increasing awareness of the threat of extreme space weather to infrastructures, which has led to the inclusion of worst-case scenarios in the national risk-assessment programmes of some countries (e.g. UK, Sweden, The Netherlands, Norway, USA). However, a quantitative risk assessment is rendered difficult by the fact that the frequency of extreme space-weather events is not precisely known. In the UK and USA, the occurrence probability of an extreme space-weather event is evaluated at 6-12 % in the next 10 years. With respect to impact, there are infrastructure sectors that have started looking into their vulnerability, e.g. the power grid, but interdependencies between infrastructures are not currently fully understood or assessed. Better understanding and routine assessment of interdependencies would help to improve resilience to possible cascading effects from this risk. This is compounded by the global footprint of extreme space weather, which challenges common business-continuity assumptions such as the replaceability of services and the continued availability of specialist knowledge, skills and equipment.

In response to the space-weather threat, the US government and regulatory bodies have set up working groups tasked with establishing standards and creating emergency-response plans to address space-weather-related issues more effectively. In the UK, the Civil Contingencies Secretariat is working with partners in Government, academia and industry to develop a national cross-cutting response plan to reflect the wide range of simultaneous impacts on critical infrastructures in case of extreme space weather. The reasonable worst-case baseline scenario is a Carrington-type solar storm[2] that would affect satellites, telecommunication, transport, and the power grid. While uncertainties remain, progress is being made to prepare for this threat. In this context, multilateral and international collaboration is deemed necessary, considering that national response capabilities could be overwhelmed by an extreme solar event affecting a large geographical area, and impacting on many different infrastructures.

The key messages from Session 1 are:

- Space weather has a global footprint and can affect multiple infrastructures at the same time.
- The susceptibility of society to space weather is increasing due to its reliance on services provided by vulnerable infrastructures and interdependencies between infrastructures.

[2] The Carrington event of 1859 is the largest solar storm recorded. It is believed that a similar solar storm occurring nowadays would cause significant and possibly long-lasting disruption to modern society (cf. National Research Council (2009) Severe Space Weather Events - Understanding Societal and Economic Impacts: A Workshop Report - Extended Summary, Washington, DC: The National Academies Press).

- Awareness of the space-weather threat is increasing and some countries have included it in their strategic national risk assessment.
- Interdependencies between critical infrastructures need to be considered in the space-weather risk assessment. These interdependencies are complex and therefore not always fully understood or routinely assessed.
- Emergency-response planning for extreme space-weather impact on society should consider the full range of potentially affected infrastructures.
- Multilateral and international collaboration for response planning is necessary to cope with extreme events that overwhelm national response capacities.

3. GNSS issues and what they mean for financial systems

In the second session, two speakers from the University of Bristol and the UK Financial Conduct Authority discussed the dependence of financial markets on accurate timing, and the UK regulatory requirements for ensuring resilience of the financial sector.

Timing is crucial in the financial sector, considering that exchange matching engines can operate at about one million transactions per second, and the same assets trade at multiple exchanges. Delayed or inaccurate time stamps affect the order of executed transactions and can therefore give a distorted picture of the current value of assets. Consequently, if timing is poor, the operator loses the overview of his or her current risk position. In such a situation, the prudent course of action would be to stop trading until reliable timing is re-established.

The fragility of the financial market and its dependence on accurate timing is illustrated by the Flash Crash on 6 May 2010. A combination of volatile market conditions, a sell algorithm gone awry that traded E-Mini S & P 500 contracts, and high-frequency trading triggered the crash. A contributing factor was the time delay in quotes from the New York Stock Exchange because of an exceptionally high trading volume on that day. Although delayed, these quotes were time-stamped as fresh, which created confusion as to the true current prices of stocks. As traders withdrew from the markets in the face of uncertainty, thereby removing liquidity, some shares plummeted to a price of 1 cent while others skyrocketed to astronomical levels. Prices started to recover only when an automatic stabiliser cut in and paused trading of the E-Mini S & P for five seconds to prevent further price declines. This example shows that there is also a risk resulting from poor knowledge of space weather amongst traders who could have an incentive to sell unnecessarily if a severe event was forecast and they based their actions upon extreme scenarios available on line.

With its inherent dependence on time-stamping, the financial sector is vulnerable to all events that result in a loss of accurate timing, including extreme space weather through its impact on GNSS. Awareness of this vulnerability varies among financial operators, which has led to non-uniform levels of preparedness. Some exchanges have global high-precision networks with multiple atomic clocks as a backup; others use a GPS feed but have no fallback option in case the satellite signal is lost.

In the UK, regulators require financial market infrastructures to identify sources of operational risk and its likelihood, and to mitigate this risk to ensure high levels of resilience in case of major disruption. The obligation to identify threats and assess their impact also applies to external and unexpected hazards which could in principle include extreme space weather. The regulatory approach for risk mitigation is, therefore, generic. If new risk priorities are identified, the planning can be topped up.

According to UK regulatory requirements, risk reduction should be achieved by implementing appropriate systems, policies, procedures and controls that allow the identification, monitoring, and management of operational risks. This includes a business continuity plan (BCP), procedures for communicating and testing plans, and processes to facilitate management of change. These arrangements should enable financial infrastructures to function in case of disruption, to limit the losses caused, and to ensure timely recovery. How these requirements are implemented depends on an operator's business model and exposure. Major incidents involving financial infrastructures muse be reported to the respective regulators as soon as possible.

The key conclusions from Session 2 are:

- Accurate time stamps are necessary to determine the prices of assets. These time stamps are often derived from vulnerable space-borne infrastructures.
- In case of an event in which timing is lost, true prices cannot be established. This can cause or exacerbate market disruptions or crashes.
- In such a situation, it would be prudent to suspend trading until reliable timing can be re-established.
- Awareness of extreme space weather and the associated vulnerability of the financial sector appears to be limited across operators and regulators.
- Preparedness levels of financial operators to loss of GNSS services are not uniform.
- The UK regulatory framework for financial market infrastructures requires the identification of external and unforeseen threats, and an assessment of their potential impact. Extreme space weather should be included in the assessment.

4. Mitigation for loss of GNSS

In the third session, three speakers from the UK Met Office, the UK National Physical Laboratory, and the University of Bath provided an overview of mitigation options available in the case that GNSS services used for timing purposes are lost.

The UK Met Office has created its own 24/7 space-weather forecasting capability to support the industry and government in the UK. It has engaged in operational collaboration with the NOAA Space Weather Prediction Centre and the British Geological Survey and adds UK-centric advice and impact to daily space-weather forecasts. The Met Office's current capabilities include the provision of space-weather alerts and warnings (radio blackout alerts, geomagnetic watches, proton/electron flux warnings), technical guidance and plain-language forecasts. These products are currently available to restricted recipients only. They are the basis on which the Met Office teams prepare advice and guidance for external stakeholders and customers. Enhancements planned for the coming 12 months include the introduction of sector-specific web pages (e.g. for power-grid operators), information to the public, and the implementation of new models and model improvements (e.g. forecasts of solar energetic particle events, improved flare forecasts).

The UK National Physical Laboratory (NPL) is the home of the UK's timescale UTC (NPL) which is the national realisation of Coordinated Universal Time. The timing accuracy currently achieved is 2×10^{-16} which translates to an error of 1 second in 158 million years. Timing is used for a variety of actions in the financial sector, such as trading, instrumentation, forensics, and risk evaluation, as well as for regulatory purposes. In NPL's experience, awareness of the financial sector's dependence on timing is slowly increasing in the UK.

However, there is not much information available on how timing is implemented, and there is no common clock. As an alternative to timing via GNSS, the NPL offers a certified microsecond timing solution via optic fibre. This reduces the vulnerability to space weather, and also to jamming or spoofing. In addition, the NPL time signal is resilient owing to an atomic clock redundancy at the hub with a holdover capacity of over a month.

GNSS signals are weak, and are subject to interference from space weather. As a consequence, signal delays or fluctuations can result, with more or less significant impact on services using the GNSS for timing purposes. It is believed that signal delays caused by space-weather-triggered changes in the ionosphere could be mitigated for moderate space weather, such as the conditions during the Halloween Storm in October 2003. The use of multi-frequency receivers should be capable of largely eliminating the delay error in most cases owing to the frequency dependence of the signal delay. It is unclear, however, what would happen under conditions of extreme space weather. Signal-strength fluctuations due to ionospheric scintillation and the subsequent inability of the receiver to track the signal are more difficult to mitigate. In fact, under extreme space-weather conditions, the loss of GNSS services seems certain although timing services are more resilient than those for navigation as connection is needed with only one satellite rather than several. In this case, alternative, relatively inexpensive, timing methods or holdover capability is required. A possible mitigation option in case of GNSS-disciplined clocks would be the use of holdover oscillators that are disconnected from the satellite when a problem is detected. This requires timely and reliable early warning and a definition of the point in time at which the oscillator should disconnect. In addition, the oscillator quality significantly impacts the timing error.

The main outcomes from Session 3 are:

- There are European and US space-weather forecasting capabilities to support early warning of governments and vulnerable industries.
- The financial services sector needs to identify its vulnerabilities and the early-warning services it requires to render its activities more resilient.
- Under extreme space-weather conditions the loss of GNSS services seems certain, and alternative timing methods or holdover capability are required.
- Alternative timing options exist and they are not too costly.

5. Discussion

Following the introductory sessions on space weather, its potential impact on infrastructures, and consequence mitigation options, this session aimed at capturing first reactions and comments by the audience.

Awareness of the financial sector’s vulnerability to space weather appears to be limited. This concerns both the direct impact on the sector via its GNSS dependence and the indirect impact through space-weather effects in other critical infrastructures the sector relies on (e.g. power grid, communication, transport). In case of extreme space weather, the consequences might not be easily foreseeable due to the multiplicity of infrastructures and the simultaneous impact.

Concern was voiced with respect to regionalisation effects related to space weather, as areas in sunlight or around midnight would be affected more. With the financial market operating globally, serious repercussions on trading are possible due to timing errors, even if an operator’s own country or continent does not experience the space-weather event. These interdependencies need to be understood before evaluating the resilience of the financial sector to space-weather-induced critical-infrastructure disruptions.

There was agreement that the space-weather risk can in principle be mapped in the financial operators' Business Continuity Plan provided that sufficient information is available on the nature of the potential impact and its probabilities. However, there is a need to know if and how standard preparedness planning assumptions are challenged in case of extreme space weather. While there is some experience from other types of infrastructures to draw from, the current state of knowledge on space-weather impact on the financial sector is insufficient to make this determination. Targeted research efforts in collaboration with industry are required to shed light on this issue.

Mitigation options for timing errors are available and range from land-based time signals, cheaper oscillators up to very sophisticated holdover systems. In addition to significantly hardening the financial market to loss of GNSS services, any measure taken to mitigate against space weather could help to mitigate also against other risks, e.g. signal jamming of spoofing. The implementation of such measures has probably been hampered by a lack of awareness of the risk by operators and regulators.

Another issue raised was the availability of early warning tailored to the specific needs of the financial services sector in case of extreme space weather. Currently, no such warning mechanism is in place, in contrast to other types of infrastructures. Further study is required to define the events and threshold magnitudes that are severe enough to trigger a warning or an alarm, as well as the associated potential impacts on the financial market and a response framework. In the UK, the Met Office, the Civil Contingencies Secretariat and HMT would be involved in this task, which should be carried out in close collaboration with the financial sector in order to capture the industry's specific needs and requirements. In parallel, the existing communication mechanism and protocols should be enhanced that allow information to flow smoothly and effectively to and between the stakeholders in case of a major event.

There was a call for national coordination and guidance in the UK to address the financial sector's vulnerability to space weather. Since the industry operates globally, international coordination is also required to counteract regional space-weather effects.

6. Conclusions

Extreme space weather would be a global event that could impact many different critical-infrastructure sectors with potential long-term service disruptions. In the past, space weather has already affected aviation, the power grid, and communication infrastructures on Earth or in orbit. It is clear that also the financial sector could be impacted, especially during extreme events, in particular through its dependence on GNSS services. As a first step towards reducing the risk to financial market infrastructures, awareness needs to be raised among the stakeholders. This should then permit members of the sector to assess their vulnerabilities to this risk. In order to support this process, the following questions need to be addressed:

- What is the vulnerability of the sector to a loss of GNSS services?
- What are the consequences of prolonged GNSS service disruption?
- Are there sufficient redundancies in the system to prevent or limit impacts, or are backup systems available?
- Are existing mitigation measures (both technical or organisational) sufficient under extreme space-weather conditions?
- If not, what new measures should be adopted?

- How might the impacts on other sectors, e.g. power and transport, affect operators' wider BCP planning?

Addressing these issues would enable an assessment by operators in the sector to evaluate if the benefits of implementing mitigation outweigh its costs.

With respect to early warning, financial operators need to specify what prediction capacity they need, both in terms of timeliness and warning contents. A further task is to develop an understanding in the industry of how to take advantage of early-warning information.

ANNEX 1: Agenda

Space Weather and Financial Services

FINAL PROGRAMME

Europe House, London

Friday 27 June 2014

09:00 - 09:15 Registration

09:15 - 09.45 **Opening – Building resilience to societal risks**
Stephan Lechner, Director, IPSC, Joint Research Centre
Philippa Makepeace, Deputy Director, UK Civil Contingencies Secretariat

Chair: Elisabeth Krausmann, JRC
09:45 - 10:15 **Space weather, what causes it, and how it is monitored**
Bill Murtagh, US NOAA
10:15 – 10:55 **The impacts of space weather**

- Space weather effects in an international context
  Neil Mitchison, JRC
- Severe space weather: the impact in the UK
  Chris Felton, UK CCS

Discussion

10:55- 11.15 Coffee break

Chair: Bill Murtagh, NOAA
11:15 - 12:05 **GNSS issues and what they mean for financial systems**

- Why timing matters in financial markets
  Philip Bond, University of Bristol
- Financial Sector Resilience
  Jagesh Thakkar, UK Financial Conduct Authority
  Discussion

Chair: Philippa Makepeace, CCS
12:05 - 12:55 **Mitigation for loss of GNSS**

- Provision of forecasts and alerts
  Mark Gibbs, UK Met Office
- Fibre optic link to UTC time signal
  Leon Lobo, National Physical Laboratory
- Holdover options for GNSS clocks
  Robert Watson, University of Bath
  Discussion

Chair: Neil Mitchison, JRC
12:55 – 13:30 **Final discussion, round up and next steps**

13:30 - 14:30 Networking buffet lunch

ANNEX 2: Participating institutions

Bacs Payment Scheme Ltd., UK
Bank of England
BNP Paribas
Civil Contingencies Secretariat, Cabinet Office, UK
Clearing House Automated Payment System (CHAPS), UK
City of London Corporation
Department for Business, Innovation and Skills, UK Government
Department for Environment, Food and Rural Affairs, UK Government
Department of Homeland Security, USA
Electric Infrastructure Security Council
European Commission, Joint Research Centre
Faster Payments Scheme Ltd., UK
Financial Conduct Authority, UK
Goldman Sachs
HSBC
HM Treasury, UK
JP Morgan
LCHClearnet
Lloyds Banking Group
Lloyd's of London
Man Group plc, UK
Met Office, UK
National Physical Laboratory, UK
NOAA, USA
Payments Council, UK
Satellite Applications Catapult, UK
Swedish Civil Contingencies Agency
UBS
University of Bath, UK
University of Bristol, UK
VocaLink Ltd., UK

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Serving society
Stimulating innovation
Supporting legislation

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