## UK Space Environment Impacts Expert Group

# Comments on US Space Weather Benchmarks: Induced Geo-electric Fields and Ionospheric Disturbances

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## Introduction

This document consolidates comments from the UK Space Environment Impacts Expert Group (SEIEG, a group of independent UK space weather experts set up in 2010, with the encouragement of Cabinet Office, to provide advice to UK Government bodies seeking to mitigate the risks posed by space weather). It provides comments on the “Space Weather 1 Phase 1 Benchmarks” produced by the Space Weather Operations, Research, And Mitigation Subcommittee of the US National Science and Technology Council.

This document contains comments on the following aspects of the benchmarks and is as follows:

1. Induced Geo-electric Fields
2. Ionospheric Disturbances

## 1 Induced Geo-electric Fields

### 1.1 Overview

This benchmark is well-developed – an impressive piece of work. We note, in particular, that the EarthScope project is giving the US community an excellent database of ground impedance data that can be used to derive geoelectric fields from geomagnetic field variations (dB/dt) and that generally gives more accurate results than impedances estimated from ground conductivity models. This is an area where the US is truly world-leading. We hope that the UK will eventually adopt a similar approach, though we note that it will be more challenging to do such a task in our densely-populated island (and hence more electromagnetic noise from human activities).

In line with the other benchmarks, the US focus has been on extremes of the environment, i.e. the geoelectric field, and grid modelling has been left to industry. In contrast, in the UK, the scientific community has worked with industry to develop and validate grid models as well as environmental models. We would welcome opportunities to compare grid models as well as environmental models, and recognise that there are sensitivities concerning access to data on grid responses. We recommend the establishment of mechanisms to enable data access for trusted partners between the US and the UK.

### 1.2 Specific comments

1. The benchmark is quite specific to a particular frequency of source field oscillation, 240 sec, and also to the amplitude of wave packets of this period and of 10 minutes duration. In the GRL paper that accompanies the benchmark we see no sensitivity analysis provided. Is there a plan

to check whether this period/duration is appropriate? It will matter to industry, i.e. can the numbers be bigger and by how much?

2. The authors also fit a specific function (log-normal) to the data to get the 1:100 year extreme for E. Again there is no sensitivity analysis presented. Indeed there is a comment in their GRL paper about the log-normal function having a lighter tail compared to a power law and that therefore their estimates of 1:100 year extremes will be conservative (small). This is fair enough, but it would be useful to check this, with respect to other assumptions made about the fitting function.
3. Is there any plan to provide some additional sensitivity analysis to put a more comprehensive range of uncertainty around the numbers quoted as 1:100 year values?
4. We note that UK work to model geoelectric fields for 2003 showed values of 5 V/km in central Scotland. That level would seem to be regarded as 'big' in the US context, was well below the 1:100 year level in the UK (e.g. Thomson et al, 2011; Hapgood et al., 2016).

### 1.3 References

- Hapgood, M, et al., (2016). Summary of space weather worst-case environments. Revised edition. RAL technical report, RAL-TR-2016-006. http://purl.org/net/epubs/work/25015281.
- Thomson, A. W. P., Dawson, E. B., and Reay S. J., 2011. Quantifying extreme behavior in geomagnetic activity, Space Weather, 9, S10001, doi:10.1029/2011SW000696.

## 2 Ionospheric Disturbances

### 2.1 Overview

This section provides a review of ionospheric behaviour and its importance to a range of applications. It stresses the complexity of physics that makes this behaviour such fascinating science and long-standing intellectual challenge, and the requirement for better ionospheric datasets to underpin higher fidelity ionospheric models. We agree with this. But we are concerned by the failure to establish any benchmarks at all. Despite difficulty in the physics we should be trying to ask the questions that will be of interest to system operators – what are the most relevant aspects of the environmental parameters and temporal coverage? Obvious parameters to consider include F region critical frequency (foF2), total electron content (TEC) and scintillation measures such as $S_4$ and $S_\phi$. Although it's important to acknowledge the complex global morphology of the ionosphere, we should identify regions were some progress (even on a "best efforts" basis) is possible, and set benchmarks for those regions even if we can't do that globally. The UK studies (Cannon et al, 2013; Hapgood et al, 2016) have made progress using these approaches, even though they have necessarily had to make some (articulated) assumptions.

We recommend to consider the SEIEG report (Hapgood et al, 2016) as a starting point for benchmarks, in particular its identification of areas of interest for potential benchmarks; then engage with the rich community of expertise in this field in the US. We would welcome feedback on the SEIEG report as it will help us to clarify provenance and to fill gaps, making better documents on both sides. We believe that this technical area would gain significant benefit from a bilateral discussion/meeting.

## 2.2 Specific comments

1. In the ionosphere extreme low values (e.g. due to lack of solar activity) are perhaps as important as extreme high values. Low values of some ionospheric parameters may have important system impacts (most obviously that low foF2 may reduce capacity of HF communications), but may be badly handled in models. We need good models to deal with both high and low extremes of ionospheric parameters.
2. Lines 524-574. Given that geomagnetic storms drive much of the complexity of ionospheric behaviour, e.g. positive and negative phases in foF2 and TEC, this driver should perhaps be emphasised over the fairly simple ionospheric response to solar flares, i.e. put first in the order and more comprehensively explained, particularly in terms of variations mediated by thermospheric winds and composition. The traditional approach of starting with flare effects often distracts non-experts from many critical impacts on the ionosphere and on systems at risk. This is partially corrected by table 5. But maybe make this point from the start?
3. Given our growing understanding of prompt penetration electric fields from the solar wind and their impact on the ionosphere right down to the equator, it would be useful to include some discussion of their environmental and system impacts, e.g. that they can drive strong enhancements in TEC and foF2 and cause uplifts in the electron densityfollowing a southward turning of the interplanetary magnetic field. They also can result in mid-latitude scintillation events important for GNSS operations (note this is a different physics mechanism than the bubbles seen at low-latitudes).
4. Table 6. For protons the numbers appear to have been reversed; e.g. largest observed fluence is greater than Carrington?? Was the largest X-ray flare not November 2003 rather than October?

## 2.3 References

- Cannon, P, et al., (2013), Extreme space weather: impacts on engineered systems and infrastructure, Royal Academy of Engineering. http://www.raeng.org.uk/publications/reports/space-weather-full-report
- Hapgood, M, et al., (2016). Summary of space weather worst-case environments. Revised edition. RAL technical report, RAL-TR-2016-006. http://purl.org/net/epubs/work/25015281.