UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

Reliability Standard for Transmission	)	
System Planned Performance for	)	**Docket No. RM15-11-000**
Geomagnetic Disturbance Events	)	

COMMENTS OF DAVID ROODMAN

Submitted to FERC on July 27, 2015

Pursuant to the Federal Energy Regulatory Commission's (FERC's) Notice of Proposed Rulemaking (NOPR) issued on May 14, 2015, I submit Comments on the FERC's proposals, which are to approve Reliability Standard TPL-007-1 (Transmission System Planned Performance for Geomagnetic Disturbance Events); to direct the North American Electric Reliability Corporation (NERC) to develop modifications thereof; and to direct NERC to submit a work plan, and subsequently one or more informational filings, that address specific geomagnetic disturbance (GMD)–related research areas.

1. About the submitter

I am trained as a mathematician and have 22 years of experience in evidence-based public policy analysis, mainly with Washington, DC, think tanks. I reside in Washington, DC. Since fall 2014 I have researched GMD risk for the San Francisco–based Open Philanthropy Project ("Open Phil"), first as a consultant and now as an employee. I recently wrote an in-depth report on GMD risk, which is included with this comment. Although Open Phil has supported my work, the views I express here are attributable to me alone.

Open Phil is administered by the 501(c)(3) organization GiveWell, which finds outstanding giving opportunities and publishes the full details of its analysis to help donors decide where to give. The primary funder of Open Phil has been the US foundation Good Ventures, which was created by Dustin Moskovitz (co-founder of Facebook and Asana) and Cari Tuna. Open Phil is also supported by Mike Krieger (co-founder of Instagram) and his fiancée Kaitlyn Trigger.

2. Overview

There is much to welcome in the NERC and FERC proposals. For the first time, entities responsible for the bulk power system would be obliged to seek and fix vulnerabilities to extreme geomagnetic disturbance.

Nevertheless, the proposals are fundamentally naïve, twice over. First, the proposals do not adequately confront the *deep uncertainty* of GMD risk—the enigmatic volatility of the sun, the fractal complexity of geomagnetic storms over time and space, the nonlinear behavior of bulk power systems. Best practice when planning in the face of deep uncertainty is to simulate many diverse scenarios.[1] As with any complex homeland security threat, a safety certification based on simulating one or two scenarios is not credible.

The degree of oversight looks similarly naive. It seems that grid operators would be subject to much more rigorous audit when reporting profits to shareholders than when reporting on vulnerability to a homeland security threat to the citizenry. Transformer makers may be contracted to determine the reliability of their own products, without third-party audit.

On both shortcomings, FERC's proposed revisions move in the right direction, asking for an additional scenario to be simulated, and increasing accountability by requiring not just mitigation plans, but deadlines for execution. Even so, the proposed regime would not befit the potential security threat.

FERC should require many more simulations, diverse in storm strength, spatial and temporal profile, power system load factor, etc. It should institutionalize *ongoing learning*, much as the National Transportation Safety Board continually improves knowledge of air safety risks through accident investigation. And FERC should institutionalize *independent oversight*, perhaps through a "red team," a device increasingly used by military and intelligence agencies to assure quality analysis of security threats. To echo a favorite motto of Ronald Reagan, FERC should "trust, but verify."

3. On the proposed assessment process

3.1. Praise for the assessment process

- **NERC's proposed reliability standard makes a big advance.** For the first time, entities responsible for the bulk power system would be obliged to review the vulnerability of their systems to GMD risk and draw up plans to rectify problems found; and would be required to do so regularly. The logical structure of the risk assessment process also makes broad sense, with sequenced simulations of power networks and transformers. The benchmark event looks intelligently derived.
- **FERC's proposed changes are welcome too.** These include:
    1. Expanding the simulation regime to two benchmark GMD events.
    2. Requiring additional data collection and research on geomagnetically induced currents (GICs), magnetic field disruptions, and the latitude–GMD intensity relationship.
    3. Requiring deadlines for implementation of Corrective Action Plans.

3.2. Criticism of the proposed assessment process

Each of the FERC-proposed modifications addresses a *symptom* of a deeper problem. And none of those deeper problems is addressed as well as it could or should be. Paralleling the above list, the deeper issues are:

- **The robustness of bulk power systems is best assessed via many scenarios, not one or two.** Power networks are complex dynamical systems capable of highly nonlinear, difficult-to-predict behavior. Complexity experts convey this idea by invoking the "butterfly effect," for the butterfly in Brazil that, with a flap of its wings, eventually brings tornadoes to Texas. (Perhaps power engineers

[1] Warren E. Walker, Robert J. Lempert, and Jan H. Kwakkel, "Deep Uncertainty." Public-access copy submitted with this comment, **which I urgently submit to the attention of FERC staff and commissioners**.

should call it the "squirrel effect.") When subtle changes can have such large consequences, the robustness of a system cannot be assessed by simulating a single scenario, or even two. Indeed, **reliance on a thin test suite can *increase* risk if it breeds a false sense of security**.

FERC notes the absence from NERC's proposed GMD benchmark event of spatially localized peaks, and proposes creation of a second scenario to model them. What is the logical basis for stopping there? The NERC event simplifies reality in other respects. It assumes that the field is spatially uniform in *direction* as well as intensity even though curled fields could increase forces on power line loops. It assumes perfect spatial correlation at each point in time. It focusses on *extremity* despite evidence that milder GMDs have damaged transformers.[2] It countenances a single storm even though high-speed coronal mass ejections often cluster over days. As with the neglect of spatially localized intensity peaks, it is hard to know *a priori* whether these simplifications matter greatly for grid response. Consistency and prudence call for more scenarios, not fewer.

FERC could expect dozens, even thousands of scenarios to be run, representing a diverse array of draws from the distribution of GMD events as measured in recent decades. Software could aggregate the results. The conceptual challenge for the modelers would be significant but tractable. In an era when chess computers can simulate millions of scenarios in seconds, running 1–2 GMD scenarios could look archaic—and lax, given the potential economic and humanitarian stakes.

- **NERC and FERC need to become "continual learners" on GMD.**
  FERC seeks further analysis of the latitude–GMD intensity relationship and additional data collection to expand the evidence base on GMDs and GICs. Improved knowledge should support improved GMD preparedness.

  But such a one-off expansion of knowledge and data collection would not be optimal. Especially if research is systematically supported, we can learn much more about GMDs, GICs, and how they affect power systems and transformers. And if we can, then, within reasonable bounds, we should. Independent, informed, empowered review of the technical standards should be institutionalized, perhaps also on a five-year cycle. If the 8 V/km and 75 amps/phase parameters are accepted today, research should be stimulated that could upend them tomorrow.

  Perhaps air safety provides a model. The National Transportation Safety Board continually improves knowledge of risks, by investigating accidents. The Federal Aviation Administration is empowered to revise rules in light of new evidence, through Airworthiness Directives. Where are these functions in the NERC proposal? Who will investigate and learn from transformer "crashes" and other emerging evidence?

  In addition to institutionalizing more review within its regulatory ambit, FERC should work to harvest the wisdom of the scientific "crowd," by pressing for transparency in the assessment process. Complete data and software used to develop the benchmark GMD events should be placed in the public domain. Absent countervailing security concerns, data on GICs and magnetic readings should also be publicly accessible. This will, at low cost, attract scientific interest and improve the state of knowledge.
- **With regard to the vulnerability assessment, FERC should "trust, but verify."**
  NERC proposes binding responsible entities to develop Corrective Action Plans but not to *implement* them within set deadlines. FERC has moved to correct this omission. But the omission is indicative of a larger and predictable tendency on NERC's part—to maximize its and the industry's autonomy—

[2] C.T. Gaunt and G. Coetzee, "Transformer failures in regions incorrectly considered to have low GIC-risk," presented at Power Tech 2007. Public-access copy submitted with this comment.

which FERC does not seem to otherwise counteract. As a result, key steps in the safety assessment could be shielded from the view of the public, or even of independent auditors.

Consider how the thermal impact assessments will be conducted. High-voltage transformers are diverse and complex. Who has the information needed to simulate them? Probably only the manufacturers, since some of the information is proprietary. So the Transmission Owners and Generator Owners may well contract with the transformer makers to fulfill requirement R6. When it comes to assessing the performance of their products, transformer manufactures are not disinterested parties. NERC proposes no oversight for them, nor any disclosure of their analyses.

I don't see a problem with that. Also, we should rely on GM's assurances about its ignition switches and Takata's about its airbags... Forgive the sarcasm. My purpose is not to impugn anyone's professionalism but to remind FERC why safety rules are often designed assuming the worst of people. Should the manufacturers or Transmission Owners or Generator Owners wish to list their shares on a public exchange, they are required to open their books to an independent auditor, in compliance with a rule designed to assure the smooth functioning of the financial system. Why should the standard be laxer when the concern is the smooth functioning of the power system, not to mention public safety?

FERC should prevent such unaccountability by creating a technical auditor with budget, staff, independence, expertise, and authority adequate to the task. Without such a function, the entire reliability standard will lack credibility.

One relevant model is the "red team," which has seen increasing use since 9/11 in defense and intelligence agencies, as a form of quality assurance for national security threat assessments. Geomagnetic storms indeed pose a complex threat to national security, though the adversary is not human but heliophysical. A Defense Science Board report explains that red teams can provide "wider and deeper understanding of potential adversary options and behavior that can expose potential vulnerabilities," "hedge against the social comfort of 'the accepted assumptions and the accepted solutions'…hedge against bias and conflict of interest," and "hedge against inexperience."[3] Among the "basic ingredients of a successful red teaming" is "top cover," meaning in the case at hand that a red team probably ought to be funded by and report to FERC, not NERC.

4. On the proposed benchmark GMD event

FERC will receive conflicting comments on the benchmark GMD event and the 75 amp/phase threshold for thermal modeling of transformers. For lack of adequate knowledge, I do not comment on the 75 amp/phase threshold. I do contend that NERC's 100-year benchmark GMD event is appropriately conservative in magnitude (except perhaps in the southernmost US) if unrealistic in some other respects.

4.1. Praise for the proposed benchmark GMD event

NERC's 100-year benchmark GMD event looks appropriately conservative in the specific sense that the 100-year electric field values, taken as large-area averages, appear representative for most of the US. The next three subsections explain why.

[3] Defense Science Board Task Force on the Role and Status of DoD Red Teaming Activities, Final report, September 2003. Copy submitted with this comment. This succinct report distills many useful lessons for successful red teaming.

4.1.1. Reinterpreting Kappenman/Metatech numbers

John Kappeneman has cited several historical statistics in order to motivate the possibility of more severe storms in the future. He has also used them to scale the 100-year benchmark GMD event in the Metatech report co-commissioned by FERC—the one that concludes that hundreds of high-voltage transformers are at risk.[4] These historical statistics may be invoked in criticizing the proposed benchmark event. Yet some reflect misunderstandings:

- **9.1 V/km was not measured over a long distance in Sweden in 1982.**
  The Metatech report cites an instance of 9.1 V/km in Sweden on "railroad communications circuits" in 1982, whose length is ~100 km.[5] However, the primary source, a magnetometer plot reproduced in an associated Kappenman article, reveals a length of 0.921 km.[6] Contemporaneous plots from ~28 km lines point to voltages peaking at 3–5 V/km.[7] The finding of a lower average voltage over a longer distance corroborates NERC's assertion that large-area averages experience lower peaks than small-area ones.
- **20 V/km was not measured in Sweden in 1921.**
  The Metatech 100-year GMD benchmark event has horizontal magnetic field changes of 4800 nanotesla per minute (nT/min) east of the Mississippi and 2400 nT/min to the west, the higher figure derived from a report of 20 V/km in Karlstad, Sweden, during the 1921 storm.[8] As I document in my recent report, submitted with this comment, the ultimate source of that number is a 1925 book by a Swedish telegraph engineer, David Stenquist.[9] He reports that the telegraph station in Karlstad caught fire during the 1921 storm while one in Ånge nearly did. At Karlstad, since copper, but not iron, wires melted, Stenquist inferred an incoming voltage of at least 6.3 V/km but less than 20 V/km, and settled on a central estimate of 10 V/km. "20 volts n'ont pas été dé-passés" (20 volts did not happen). Thus 10 V/km better represents the Karlstad incident, which in itself argues for halving the intensity of the Metatech benchmark GMD event.[10]

  Nor is there evidence that even ~10 V/km occurred over a large area. Out of dozens of telegraph stations in Sweden, only two caught fire, or started to. Accepting that 10 V/km corresponds to about 2400 nT/min, it is worth noting that similar localized surges have been observed in the Nordic region in modern times, e.g., ~2700 nT between 23:59 and midnight on July 13, 1982 universal time at Lovoe, Sweden; ~2000 nT between 21:47 and 21:48 on March 13, 1989 at Brorfelde, Denmark. **So it is not obvious that the 1921 storm was more intense than modern ones.**

  Stenquist did gather proper current measurements from the telegraph network during the great

[4] John Kappenman, *Geomagnetic storms and their impacts on the U.S. power grid*, Meta-R-319, Metatech, January 2010.
[5] Ibid., p. 1-30; John Kappenman, "Great geomagnetic storms and extreme impulsive geomagnetic field disturbance events: An analysis of observational evidence including the great storm of May 1921," *Advances in Space Research* 38 (2006): 188–99.
[6] Kappenman, op. cit. note 5, p. 192.
[7] B. Artelius, "Jordemagnetiska störningar 82-07-13--14," memo, SJ (Swedish rail), courtesy of Sture Lindahl, Gothia Power, June 28, 2015. Submitted with this comment. All the cited figures appear at the bottom of the graphs on p. 3.
[8] This conversion from magnetic change in nT/min to electric field in V/km is consistent with that in the NERC proposed benchmark, for "shield" ground type.
[9] David Roodman, "The risk of geomagnetic storms to the grid: A preliminary review," GiveWell, July 2015. Submitted with this comment.
[10] David Stenquist, *Étude des Courants Telluriques*, R.W. Statlanders Boktryckeri, Stockholm, 1925, p. 54.

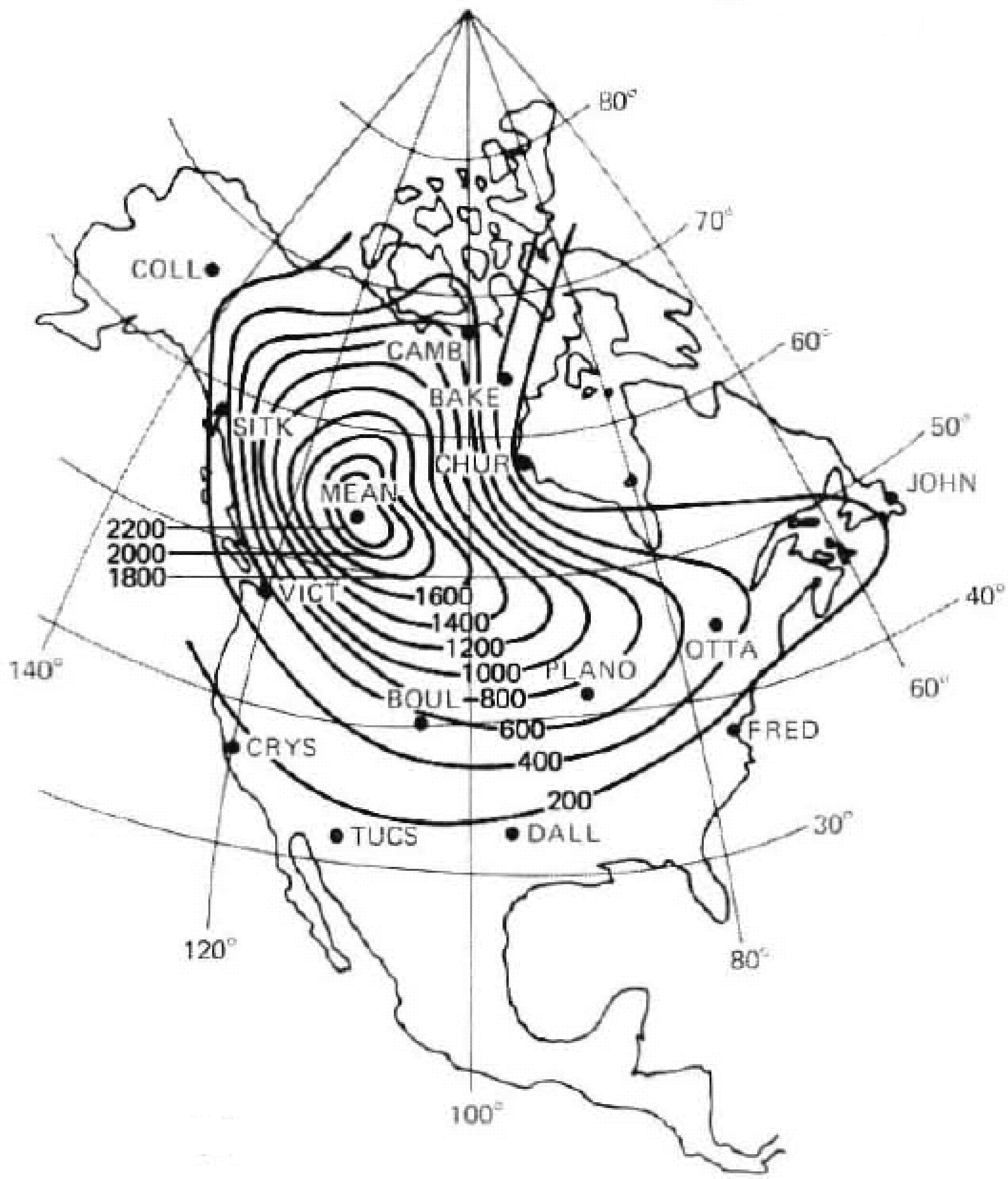
1909 and 1921 storms; from them he inferred long-distance voltages. In 1909, the highest reported was 1.94 V/km, on the 180 km telegraph line from Luleå (geomagnetic latitude 61.3°) to Gällivara (63.0°). The next-highest was 1.53 V/km on the 510 km line from Stockholm (55.3°) to Malmö (52.1°).[11] For 1921, the highest measurement provided by Stenquist is 0.584 V/km, over an unspecified distance.[12] None of these readings is even half as high as the corresponding NERC benchmark value, given local latitude and geology.[13]

- **A 1972 GMD was not "estimated to be at an intensity of ~2200 nT/min over extensive portions of North America."[14]**
  The cited source of that Metatech quote is the map reproduced below as Figure 1, which shows the change in magnetic field intensity during one minute on August 4, 1972.[15] The dots show the 14 geomagnetic observatories that provided the hard data in this map. The curved contours are interpolated estimates of the spatial distribution of the GMD in that minute. The map shows 2200 nT/min only at Meanook, Alberta, denoted by "MEAN." (Other stations include Dallas (DALL), Boulder (BOUL), Ottawa (OTTA), Fredericksburg (FRED), and Tucson (TUCS).) The second-highest reading appears to have been about 650 nT, at Cambridge Bay, above the Arctic Circle; and the third-highest about 575, at Boulder, Victoria, and Sitka. The spatial interpolations between the 14 readings are rough, reasonable guesses, which, even if correct, do not support the assertion of "~2200 nT/min over extensive portions of North America."

As just noted, the Metatech 100-year benchmark GMD event is scaled using a misconstrued report from Karlstad, Sweden, which was at 56° geomagnetic latitude. Aside from the jump from 2400 to 4800 nT/min when crossing the Mississippi from west to east, the Metatech event is uniform over a large area: a 5-degree band centered on 50° geomagnetic latitude, the latitude of Boulder. There is no recorded precedent for such intense magnetic fluctuations over such a large area at such a low latitude.

[11] Idem, *The Magnetic Storm of Sept. 25, 1909*, dissertation, University of Stockholm, 1941, p. 67, archive.org/details/magneticstormofs00stenrich.
[12] Idem, op. cit. note 10, p. 53.
[13] Using $0.001e^{0.115L}$ for the latitude multiplier, where L is the geomagnetic latitude, and 1.0 for the ground resistivity multiplier.
[14] Kappenman, op. cit. note 4, p. 3-5.
[15] C.W. Anderson, L.J. Lanzerotti, and C.G. MacLennan, "Outage of the L4 System and the Geomagnetic Disturbances of 4 August 1972," *Bell System Technical Journal* 53(9), November 1974, p. 1826.

Figure 1. Rate of change of magnetic field intensity over North America, 22:41–42 universal time, August 4, 1972

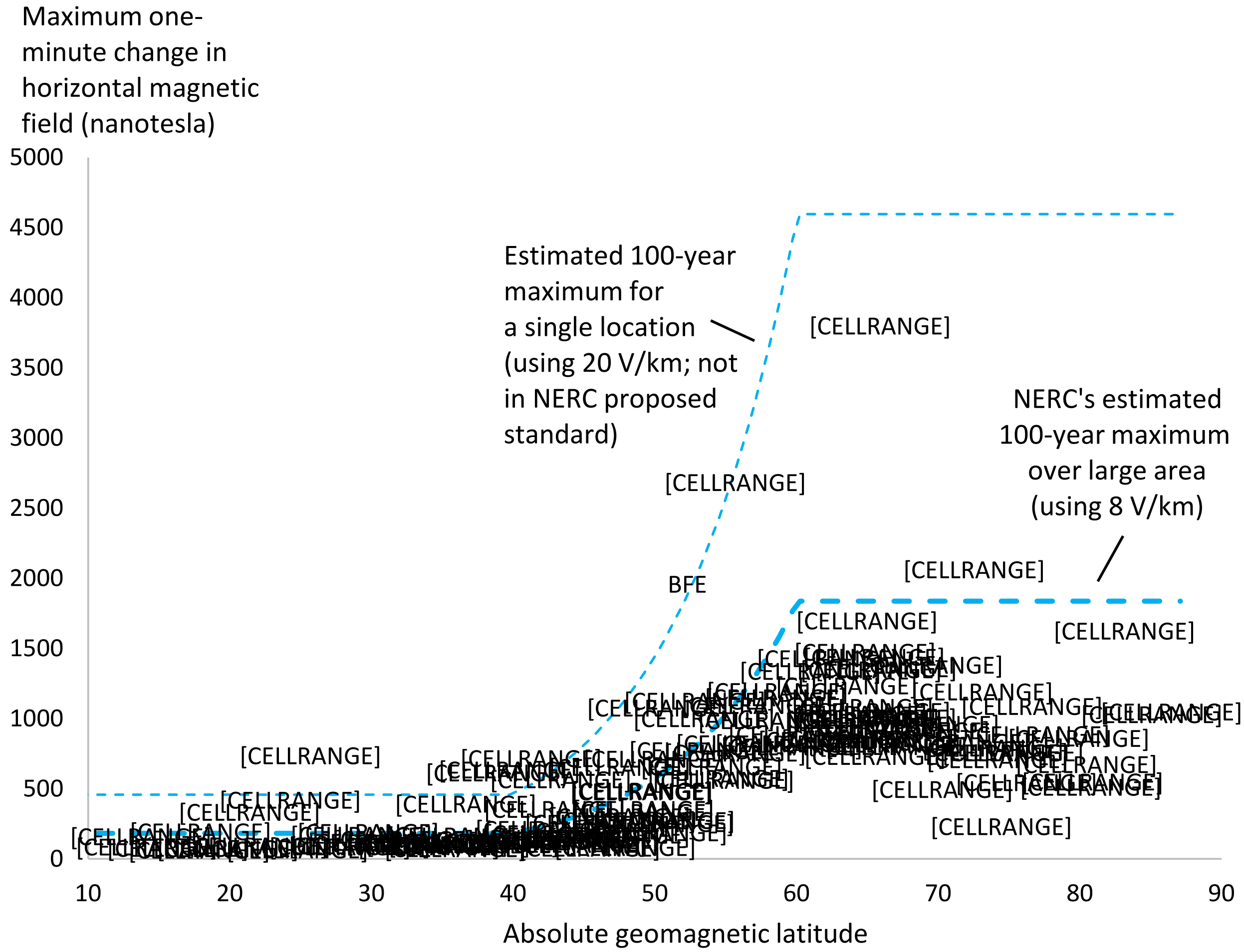


4.1.2. Comparing the NERC electric field ceilings to recent US history

In order to assess the conservatism of the 8 V/km parameter in the GMD benchmark event, as well as the multipliers applied thereto, Figure 2 plots the peak one-minute magnetic field change recorded at all magnetic observatories around the world for which I obtained data.[16]

[16] Data are one-minute cadence for July 1982, March 1989, November 2001, and October and November 2003. They are from the Spidr repository (spidr.ngdc.noaa.gov) and IMAGE network (www.ava.fmi.fi/image). Geomagnetic latitudes computed with VITMO (omniweb.gsfc.nasa.gov/vitmo/cgm_vitmo.html).

FIGURE 2. MAGNITUDE OF MAXIMUM MINUTE-TO-MINUTE CHANGE IN HORIZONTAL MAGNETIC FIELD, 121 GEOMAGNETIC OBSERVATORIES, ALL DATES WITH AVAILABLE DATA



Each three-letter code in the figure represents a geomagnetic observatory, such as OTT for Ottawa. Time coverage of the data varies by station, reaching back as far as 1982 for only a few. The lower blue contour shows the approximate peak rate of magnetic field change implied by the NERC benchmark event.[17] Most stations, especially at high latitudes, are beneath the line, as one would hope. But some stations have experienced higher peaks in just the last few decades than NERC's formulas imply should only happen once a century.

[17] The benchmark geomagnetic event is a scaled copy of the magnetic recordings at Ottawa for 30 hours on March 13–14, 1989. Comparison of the benchmark event to the 1-minute-cadence Ottawa data reveals a scale factor of about 3.305. Since Ottawa experienced a peak one-minute change of 556.25 nT, this implies a peak of 3.305 × 556.25 = 1838 nT/min magnetic change in the benchmark event, at its benchmark latitude of 60°. Implied maxima for lower latitudes are attained by multiplying by NERC's latitude adjustment factor, which is $0.001\ e^{0.115\ |\text{latitude}|}$ for absolute latitudes between 40 and 60, 0.1 below, and 1.0 above. NERC's plane-wave-based method for converting magnetic time series to electrical ones is more complicated than is implied by this calculation: the electrical field at a given moment depends on the history of magnetic changes, not the just the contemporaneous one, so the peak electric field (8 V/km) is not a function purely of the peak magnetic change, and the latter does not proxy perfectly for the former. But the method used here is in the spirit of the proposed NERC standard and should not introduce large errors.

Does this contradict the NERC benchmark? Not necessarily. For these spikes may only have occurred in isolated spots, not across the large areas that are NERC's concern. (Below, I return to whether NERC's interest in wide-area averages is too narrow.) And the data set covers many station-centuries (20 years for one station, plus 30 for another, etc.), so *some* readings above the line are expected.

For comparison, the figure includes a second blue contour calibrated not to 8 V/km in Québec, but 20 V/km, a figure whose provenance is noted in the NOPR. This line does *not* relate directly to the proposed standard and is drawn only for comparison. Just a few stations, in low-latitude areas, breach the line. **This does suggest that the proposed latitude multipliers for the southern United States are not leaving a large enough safety margin.** (BSL, a visible outlier at 40 degrees, is the Stennis Space Center in Louisiana.) But overall NERC's analytical frame does not strongly clash with the data.

In the same spirit, Table 1 estimates the strongest *electrical fields* induced by storms at North American magnetic observatories, and compares to the once-a-century values produced by NERC's formula for the peak field.[18] In all but one case, the peak field estimated to have occurred at a single observatory is comfortably below NERC's once-in-a-century maximum. The exception is BSL (Stennis Space Center), which appears to have experienced a field of 2.2 V/km in 2001, substantially exceeding NERC's ceiling of 1.3 V/km. This again suggests the need for refinement at low latitudes. **Or it may reflect the lack of adjustment for proximity to conductive salt water, since BSL is less than 15 miles from the coast.** But it is not a fatal blow to the overall approach, nor the anchoring in 8 V/km. We have no evidence that the 2.2 V/km occurred over a large area.

It is worth emphasizing that the way I have evaluated the NERC formula is statistically responsible in examining the *frequency* of violations of NERC's proposed once-a-century threshold. **Especially when many observatory-centuries of data are available, once a century does not mean never! Any commenter that cites isolated instances, such as at BSL, as invalidating the NERC benchmark on their own will not be reasoning properly about probabilities.** With enough data, even rare events become expected.

[18] Estimated peak electrical fields are computed as peak minute-to-minute horizontal field change divided by 1838 (see previous note) and multiplied by 8 V/km.

TABLE 1. NORTH AMERICA: ESTIMATED MAXIMUM MAGNITUDE OF GEOMAGNETICALLY INDUCED ELECTRICAL FIELD AND NERC BENCHMARK LEVEL

Code	Place	Magnetic latitude (degrees)	Earliest major storm in data	Ground resistivity multiplier	Latitude multiplier	NERC 100-year large-area maximum (V/km)	Estimated maximum electric field *experienced* (V/km)
DLR	Del Rio, TX	38.9	1989	0.28	0.10	2.9	0.7
TUC	Tucson, AZ	39.8	1989	0.22	0.10	3.6	0.6
BSL	Stennis Space Center, LA	41.3	1989	0.74	0.12	1.3	2.2
FRN	Fresno, CA	43.0	1989	0.62	0.14	1.8	0.9
FRD	Fredericksburg, VA	49.2	1989	0.81	0.28	2.8	1.6
STJ	St John's, Newfoundland	53.6	1982	0.79	0.48	4.8	3.3
VIC	Victoria, BC	53.8	1982	0.67	0.49	5.8	1.8
NEW	Newport, WA	54.9	1989	0.41	0.55	10.8	1.0
OTT	Ottawa	56.0	1982	1.00	0.62	5.0	3.1
SIT	Sitka, AK	59.7	1982	0.67	0.96	11.5	2.2
GLN	Glenlea, Manitoba	59.8	1982	0.96	0.97	8.1	3.5
MEA	Meanook, Alberta	62.1	1982	0.96	1.00	8.3	3.3
FCC	Fort Churchill, Manitoba	68.9	1982	0.96	1.00	8.3	3.6

4.1.3. Visualizing the spatial dimension

A contentious theme in the debate over the NERC benchmark GMD event relates to “hotspots,” or local peaks. Figure 3 and Figure 4 confirm their occurrence. Each plots the minute-cadence rate of magnetic field change over North America, at the two moments of peak activity at Ottawa in 1989, which figure in the NERC benchmark event. The latter, when Ottawa reached 556 nT/min, corresponds to when the benchmark event achieves 8 V/km. Again, each three-letter code represents an observatory, from THL (Thule) above the Arctic Circle to DLR (Del Rio, TX) in the south. And as in the 1972 map above, the contours are synthesized by a computer algorithm, anchored only by data from the observatories shown.[19] Lines of latitude and longitude are equally spaced, so the Canadian area is shown disproportionately large compared to the American. The graphs suggest that at the time of the Ottawa peaks, at 546 and 556 nT/min, the surrounding region was better characterized by 250–300 nT/min, a factor of 2 lower. This deflation roughly corresponds to the drop from 20 V/km for small areas to 8 V/km for wide.

[19] Plots are produced by Stata’s “twoway contour” command using thin-plate-spline interpolation. See stata.com/manuals13/g-2graphtwowaycontour.pdf.

FIGURE 3. CONTOUR PLOT OF MAGNITUDE OF HORIZONTAL MAGNETIC FIELD CHANGE, NORTH AMERICA, MARCH 13, 1989, 21:50–51 UT

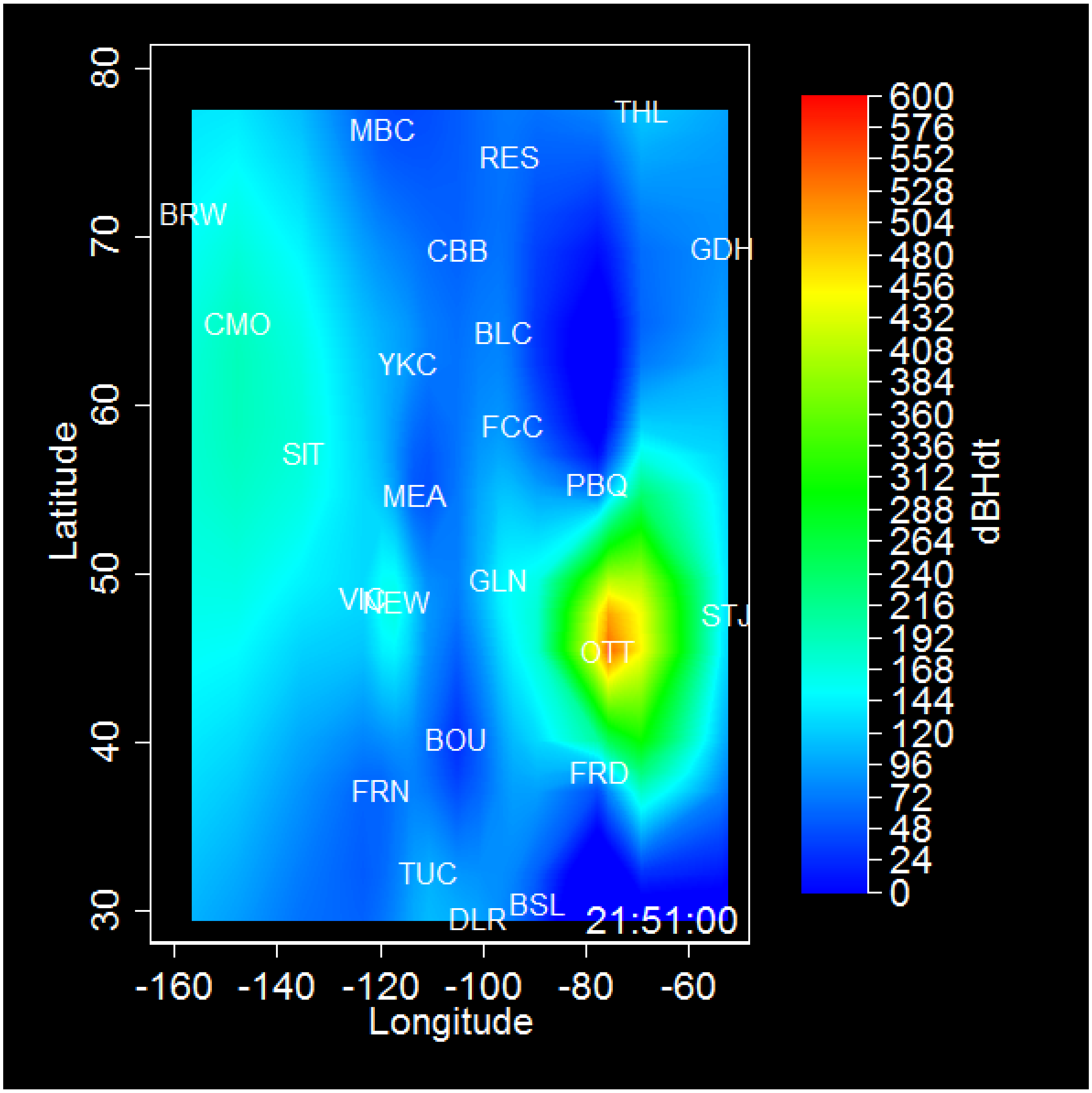
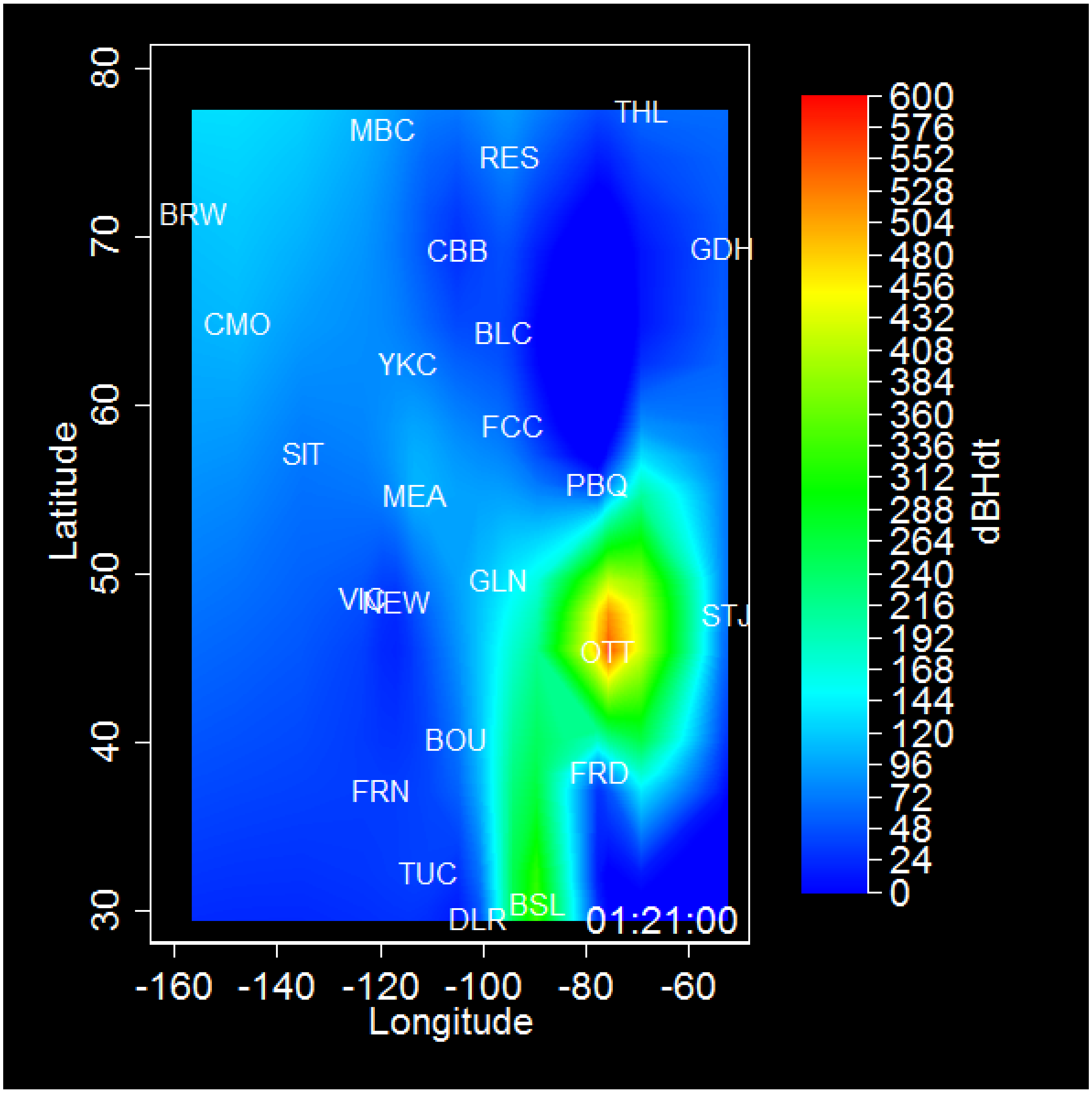


FIGURE 4. CONTOUR PLOT OF MAGNITUDE OF HORIZONTAL MAGNETIC FIELD CHANGE, NORTH AMERICA, MARCH 14, 1989, 1:20–21 UT

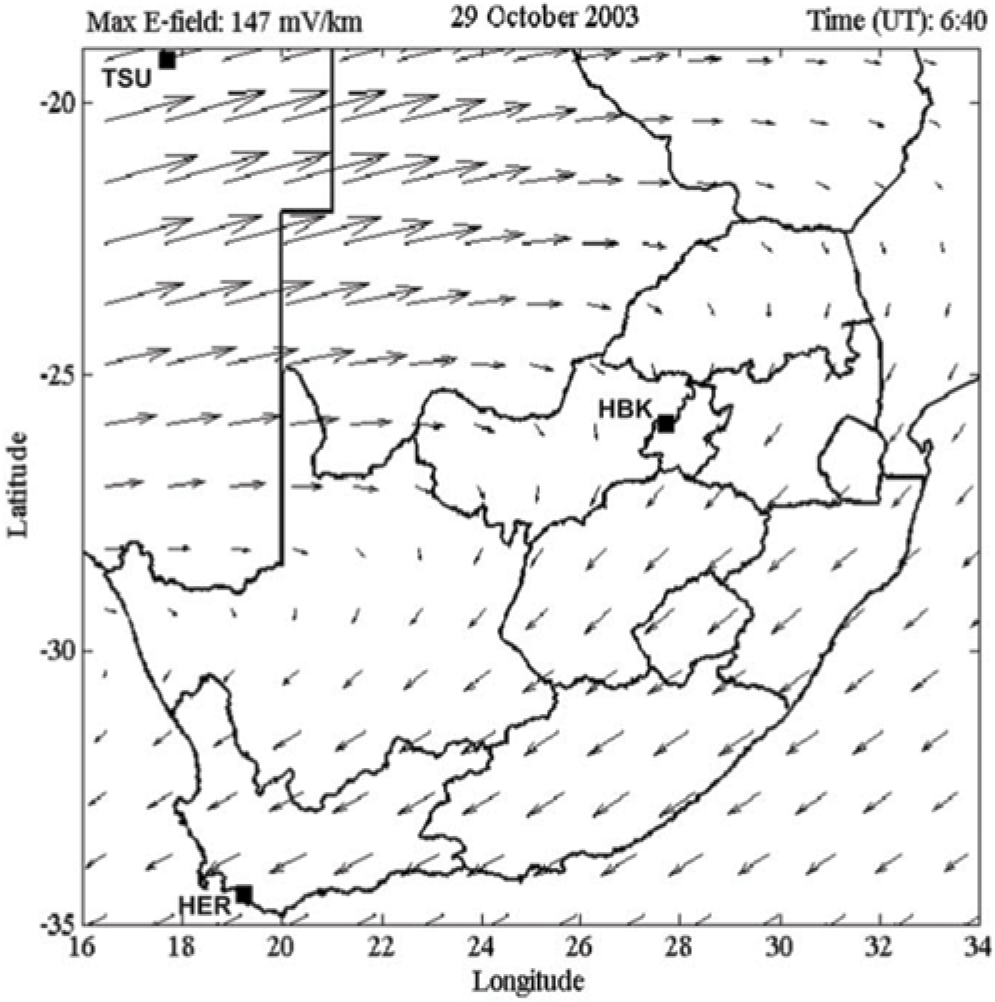


4.2. Criticism of the proposed benchmark GMD event

4.2.1. Real GMDs are not directionally uniform

The NERC 100-year benchmark GMD event assumes that the induced electrical field is spatially uniform at each moment. But as researchers in South Africa have shown, GMD disturbances are not necessarily uniform in direction. Figure 5 shows the inferred electric field across South Africa at one moment during the Halloween storm of 2003.[20]

FIGURE 5. INFERRED GEOMAGNETICALLY INDUCED ELECTRIC FIELD OVER SOUTH AFRICA, OCTOBER 29, 2001, 6:40 UNIVERSAL TIME



(As in previous maps, the only real data behind this figure comes from measurements at the three observatories marked TSU, HBK, and HER. The rest is extrapolated. Probably the real field was more complex.)

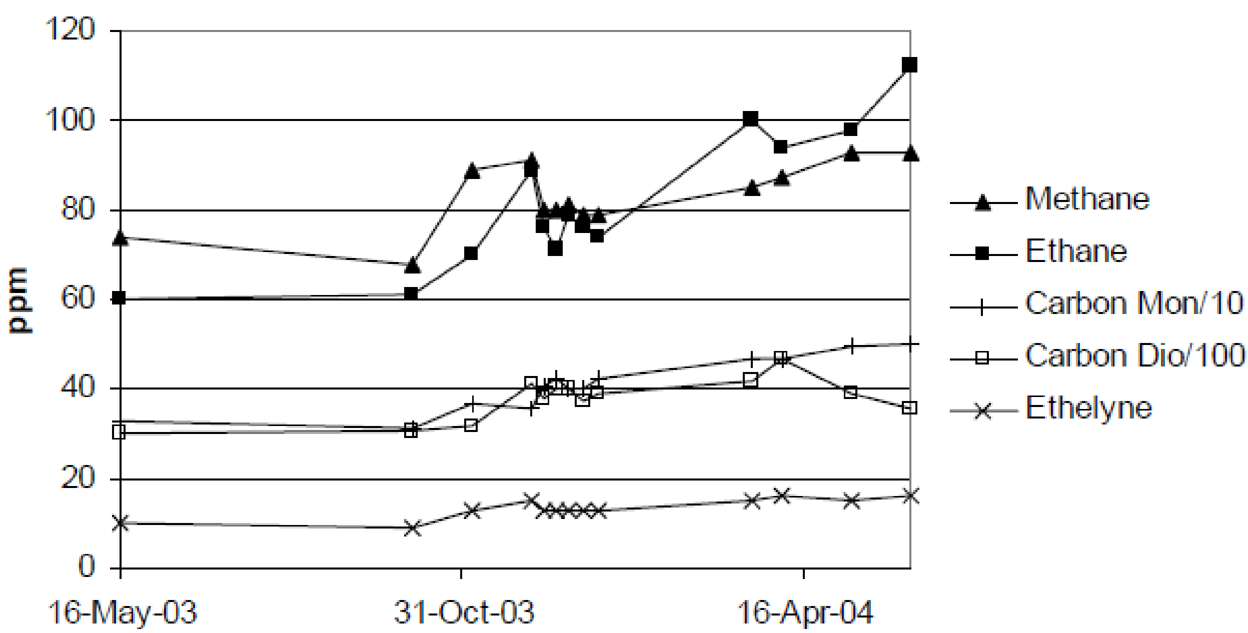
Lack of directional uniformity could matter for power network impacts. If a long-distance loop formed by some set of high-voltage power lines experienced, say, clockwise electrical forces all around its course—impossible if all the electrical force arrows point the same way, as the NERC GMD event assumes—the GICs might be much larger. As argued earlier, the reliability standard ought to require simulations that investigate such possibilities.

[20] E.H. Bernhardi, P.J. Cilliers, and C.T. Gaunt, "Improvement in the modelling of geomagnetically induced currents in southern Africa," *South Africa Journal of Science* 104, July/August 2008. Public-access copy submitted with this comment.

4.2.2. Milder GMDs damage transformers too

C.T. Gaunt and colleagues have documented how the storm depicted above disabled some eight transformers in South Africa, which is twice as close to the equator as Canada and Scandinavia and thus experienced much less magnetic disruption.[21] (The highest-latitude station in the map, HER, experienced a peak minute-to-minute horizontal magnetic change of just 66 nT/min, while HBK hit only 60 nT/min.) In all of the transformers, degradation began right after the storm and proceeded slowly, so that failure arrived in weeks or months rather than minutes. This suggests the existence in that context of a perverse "goldilocks" GIC magnitude: weak enough not to trigger protective shutdowns, strong enough to do disabling damage. As an example, Figure 6 shows how dissolved gas concentrations in the insulating oil of a transformer started rising after the Halloween 2003 storm, indicating steady breakdown of insulation. This transformer was still operating in August 2004, but others with similar plots had failed by then.

Figure 6. Concentrations of gases in insulating oil of a step-up transformer, Matimba power plant, South Africa, May 2003 – June 2004



Thus weaker storms could threaten bulk power system too. Again, it appears inconsistent and imprudent not to incorporate this important dimension of difference into the GMD event test suite.

5. Conclusion

The NERC and FERC proposals embody much path-breaking hard work. Nevertheless, FERC should not allow the structural emphasis on self-regulation in the US interstate power transmission to prevent a

[21] Gaunt and Coetzee, op. cit. note 2.

clear-eyed confrontation with a potentially serious homeland security threat. In setting final rules on both process and substance, FERC needs to recognize the deep uncertainty and complexity of the GMD threat, and respond accordingly. It should require a much larger array of events for simulation; public sharing of data and code where feasible; an auditing mechanism with as much independence and access to information as conventional financial auditor; and an ongoing process for incorporating new knowledge into standards.