On the Little-Known Consequences of the 4 August 1972 Ultra-Fast Coronal Mass Ejecta: Facts, Commentary and Call to Action

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Abstract: Today the extreme space weather events of early August 1972 are discussed as benchmarks for Sun-Earth transit times of solar ejecta (14.6 hr) and for solar energetic particle fluxes (10 MeV ion flux > 70000 cm^{-2} s^{-1} sr^{-1}). Although the magnetic storm index, Dst, dipped to only -125 nT, the magnetopause was observed within 5.2 R_E and the plasmapause within 2 R_E. Widespread electric- and communication- grid disturbances plagued North America late on 4 August. There was an additional effect, long buried in the Vietnam War archives that adds credence to the severity of the storm impact: a nearly instantaneous, unintended detonation of dozens of sea mines south of Hai Phong, North Vietnam on 4 August 1972. The US Navy attributed the dramatic event to 'magnetic perturbations of solar storms.' Herein we discuss how such a finding is broadly consistent with terrestrial effects and technological impacts of the 4 August 1972 event and the propagation of major eruptive activity from the Sun to the Earth. We also provide insight into the solar, geophysical and military circumstances of this extraordinary situation. In our view this storm deserves a scientific revisit as a grand challenge for the space weather community, as it provides space-age terrestrial observations of what was likely a Carrington-class storm.

1. Circumstances and Consequences of the Early August 1972 Solar Storms

Flares and Ejecta. Between 2 and 4 August 1972 McMath Region (MR) 11976 (Fig. 1a) produced a series of brilliant flares, energetic particle enhancements and Earth-directed ejecta (note the terminology of the day was 'plasma driver'). The first two ejecta generated two impulses in the geomagnetic field and a magnetic storm shortly after 01 UT on 4 August. More importantly, they likely cleared the interplanetary (IP) path for the subsequent ultra-fast 4 August shock/IP coronal mass ejection (ICME) that reached Earth in record time—14.6 hr. The ICME has been linked to the H-α, Level-3 Brilliant flare that peaked at 0621 UT on 4 August (Srivastava, 1973; Cliver et al., 1990). Figure 1b shows the flare at 0648 UT. In concert, a 76000 sfu radio burst at 1 GHz peaked at 0636 UT (Bhonsle et al., 1976). At the other end of the solar spectrum, the SOLRAD-9 satellite X-ray detector saturated at what would be an X5.1 magnitude in the current NOAA solar X-ray classification (but clearly exceeded that level, see Dere et al. 1973, p 309). Dayside radio blackouts at Earth developed within minutes (Odinstova et al., 1973). X-ray emissions from the long duration flare remained above background for > 16 hrs. For the first time, a space-based detector observed gamma-rays during this solar flare (Chupp et al., 1973). Dodson and Hedeman (1973) rated the flare at Comprehensive Flare Index level 17—the highest level, and one assigned to only the most extreme and broad-spectrum flares.

The sequence of propagating structures produced one of the largest galactic cosmic ray dropouts (Forbush Decreases) of the space age (Pomerantz & Duggal, 1973). The ICME-associated shock (Fig. 1c) arrived at Earth at 2054 UT (e.g., Intrilligator, 1976). Vaisberg and Zastenker (1976)

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estimated the average transit speed as 2850 km/s, while Cliver et al. (1990) estimated it as ~ 2100 km/s. Freed and Russell (2013) reported the transit time was an outlier, even for the family of the extreme events they studied. We believe the extraordinary speed of this event had a direct bearing on the events we discuss below.

Energetic Particles. The chain of events led to extraordinary effects, including a solar energetic particle (SEP) event that punished spacecraft solar panels, satellite detectors and Earth's atmosphere. The solar particle flux observed at Earth, attributed to activity in MR 11976, began on August 2 after three brilliant flares in solar latitude-longitude region N12-N14 and E26-E34. These were: a 3N flare at 0316 UT (Hakura, 1976) and two rare white light flares at 1844 UT and 2058 UT, rated at 1B and 2B, respectively (Neidig and Cliver, 1983). The 19-80 MeV proton flux on NASA Interplanetary Monitoring Platforms (IMPs) IV and V started to increase at 0515 UT on 2 August (Van Hollenbeke et al., 1974).

The proton flux on the IMP spacecrafts dramatically increased with the 4 August 2054 UT IP-shock arrival at Earth; the maximum particle flux was so intense that the particle detectors were saturated (see Van Hollenbeke et al., 1974; Kohl et al., 1973), resulting in uncertainty as to the actual magnitude of the particle increase. The flux peak also triggered the "event mode" data compression algorithm on the Vela neutron counter that was monitored in real time at Air Force Global Weather Central (AFGWC) for nuclear test ban verification. This situation was swiftly dealt with by AFGWC personnel monitoring the event (D. Smart, personal experience). These energetic proton fluxes produced a ground level event (Kodama et al., 1973). Levy et al. (1976) and Smart and Shea (1992) argued that IP medium-energy (seed) particles were accelerated between the 2 August IP structure(s) and the 4 August ultra-fast shock, thus producing a swarm of SEPs. The SEPs were so intense that the ongoing Forbush Decrease partially abated (See Fig. 3 of Pomerantz & Duggal, 1973). Rauschenbach (1980) showed an ~5% drop in solar cell power generation capability for the INTELSAT IV F-2 solar panel arrays during the 4 August SEP event; roughly equivalent to two years of magnetospheric trapped-radiation exposure to the panels. Shortly thereafter a Defense Communications Satellite Program II satellite suffered a mission-ending on-orbit power failure (Shea & Smart, 1998).

Lockwood & Hapgood (2007) note this as one of only a handful of events in the space age that would have posed an immediate threat to astronaut safety, had humans been in transit to the moon at the time. Reanalysis by Jiggens et al. (2014) suggests that the 10 MeV ion flux reached 70000 cm^{-2} s^{-1} sr^{-1}, thus bordering on a NOAA S5 event. The SEPs interacted with the Defense Meteorological Spacecraft Program (DMSP) satellite optical line scanner electronics, producing anomalous dots of light in the southern polar-cap imagery (A. Lee Snyder, personal communication). The energetic particle bombardment created a northern hemisphere polar ozone cavity—a 46% reduction at 50 km that recovered over several days. At ~39 km the ozone cavity persisted and circulated as a semi-rigid structure for more than 50 days (Reagan et al., 1981).

Geomagnetic Storm and Its Effects. At 2054 UT on 4 August the Guam observatory (0654 Local Time) reported an extraordinary 62-sec rise time for the sudden storm commencement (SSC) consistent with a 3080 km/s shock sweeping across the magnetosphere (Araki et al., 2004). The Boulder, CO USA magnetometer traces went off-scale and bright aurora appeared in the northern US. Another significant disturbance, a Sudden Impulse (SI) at 2238 UT, swept across pre-dawn, low-latitude India with amplitudes from 301 nT- 486 nT (Bhargava, 1973). The SI sent the magnetometer traces off scale at the near-noon Honolulu, HI observatory (Fig. 3, Matsushita, 1976). Within 15 minutes the first glow of what would become a "spectacular aurora," bright enough to cast shadows, appeared along the southern coast of the United Kingdom at ~54° MLAT (Taylor & Howarth, 1972). Within two hours commercial airline pilots reported aurora as far south as Bilboa, Spain at ~46° MLAT (McKinnon, 1972).

Between 2240-2310 UT the post-noon magnetopause compressed to within 5.2 R_E (Hoffman et al., 1975). Cahill and Skillman (1977) described numerous magnetopause crossings by satellites in the noon sector (Fig. 1d). Based on measurements from the Prognoz-1 spacecraft located within the morning-side magnetosheath, D'Uston et al. (1977) suggested that the solar wind dynamic pressure was 100 times its normal value. Figure 1c shows the hourly solar wind plasma values reconstructed from Prognoz, Prognoz-2 and HELIOS data (Vaisberg & Zastenker, 1976; Zastenker et al., 1978). Lockwood et al. (1975), Simnett (1976), Smith (1976), Venkatesan et al. (1975), Lanzerotti (1992) and Tsurutani et al. (1992) have offered data and insights related to the IP structures that likely passed Earth on 4-5 August 1972. All suggest a highly variable north-south interplanetary magnetic field (IMF) ahead of the main ejecta and a northward IMF at the ICME leading edge. Tsurutani et al. (1992) reasoned that the Dst intensity during early August 5 was due to sheath southward IMF while the subsequent leading ICME field was northward, resulting in quieting magnetic conditions in the subsequent interval. Some of these authors note signals of multiple tangential discontinuities indicative of interacting IMF structures ahead of the ICME. Medrano et al. (1975) reported an additional square-wave discontinuity passing Earth between 03-05 UT on 5 August.

The IP disturbances created geomagnetically induced currents (GIC) effects in North American power and communications lines. Albertson and Thorson (1974) listed numerous US and Canadian power companies that reported minor to severe power issues on 4-5 August 1972. According to Odenwald (2015) significant voltage swings and power disruptions were reported in northern tier US states. In Newfoundland, Canada, GICs activated protective relays many times on 4-5 August. The Manitoba Hydro Company recorded 120 MW drops in power supplied to Minnesota in only a few minutes. Anderson et al. (1974) reported an outage on the L4 American Telephone and Telegraph (AT&T) cable connecting the US states of Illinois and Iowa. The induced electric field of 7.0 V/km, which exceeded shutdown threshold for high current, accompanied magnetic field variations (dB/dt) of ~ 800 nT/min at 2240-2242 UT (the time of the L4 outage). In central and western Canada, Boteler and Jansen van Beek (1999) estimated that dB/dt exceeded ~2000 nT/min coincident with the SI.

On the other side of the world, coincident with the initial magnetopause compression at ~ 2240 UT, and roughly at dawn local time, there was > 160 nT/min positive magnetic perturbation (Fig. 1e) reported from the near-equatorial observatory at Manila, Philippines (Salcedo, 1973, p. 762). Simultaneously, a similar dB/dt perturbation was reported at Sao Jose dos Campos, Brazil (~12.6° S ML), by Sahai & Sales (1973). On-line images of the 4 August Kakioka, Japan magnetogram also show a mid-latitude pulse (http://www.kakioka-jma.go.jp). After 22 UT the AE index spiked to > 3000 nT (Fig. 1, Tsurutani et al. 1992) as the storm asymmetry index underwent severe variations (Kawasaki et al., 1973; Akasofu, 1974 and J. Love, personal communication). Giant magnetic pulsations rocked the magnetosphere. Odintsova et al. (1973) reported development of a nighttime mid-latitude E-layer on 4-5 August. Jachiaa and Slowey (1973) showed multi-altitude neutral density perturbations continuing into 5 August that equaled or exceeded those from the great storm of May 1967, during which half of the NORAD satellite-tracking catalogue had been reacquired (Knipp et al., 2016).

Hoffman et al. (1975) speculated that the sequence of strong cross-tail electric field and magnetopause compression allowed ring current particles that could have produced a more substantial Dst storm, to drift out the compressed/eroded dayside magnetopause. Lanzerotti (1992) argued that with the arrival of driver ejecta on 5 August, the IMF turned northward, thus cutting short the ring current development. Brace et al. (1974) reported the plasmapause to be at/inside $2R_E$. Grafe et al. (1979) indicated the energetic electrons invaded the radiation belt slot region, while Spjeldvik and Fritz [1981] reported orders of magnitude increases in the trapped energetic heavy ion population ($Z \geq 4$) within the radiation belts and slot region ($L \sim 2.5$-5) between 4 and 5 August. Auroral disturbances continued into 5 August with reports of intense midday red aurora in the dark southern hemisphere (Akasofu, 1974).

Naval Effects. Tucked away in the history of the Vietnam War is a likely associated effect of the extraordinary 4 August IP disturbance: The sudden detonation of a "large number" of US Navy magnetic-influence sea mines (designated as Destructors, DSTs) dropped into the coastal waters of North Vietnam only three months earlier (Greer, 1997). See Appendix for additional context. Tucker (2006) wrote that "…on 4 August (1972) TF-77 aircraft reported some two dozen explosions in a minefield near Hon La over a thirty-second time span...Ultimately the Navy concluded that the explosions had been caused by the magnetic perturbations of solar storms, the most intense in more than two decades."

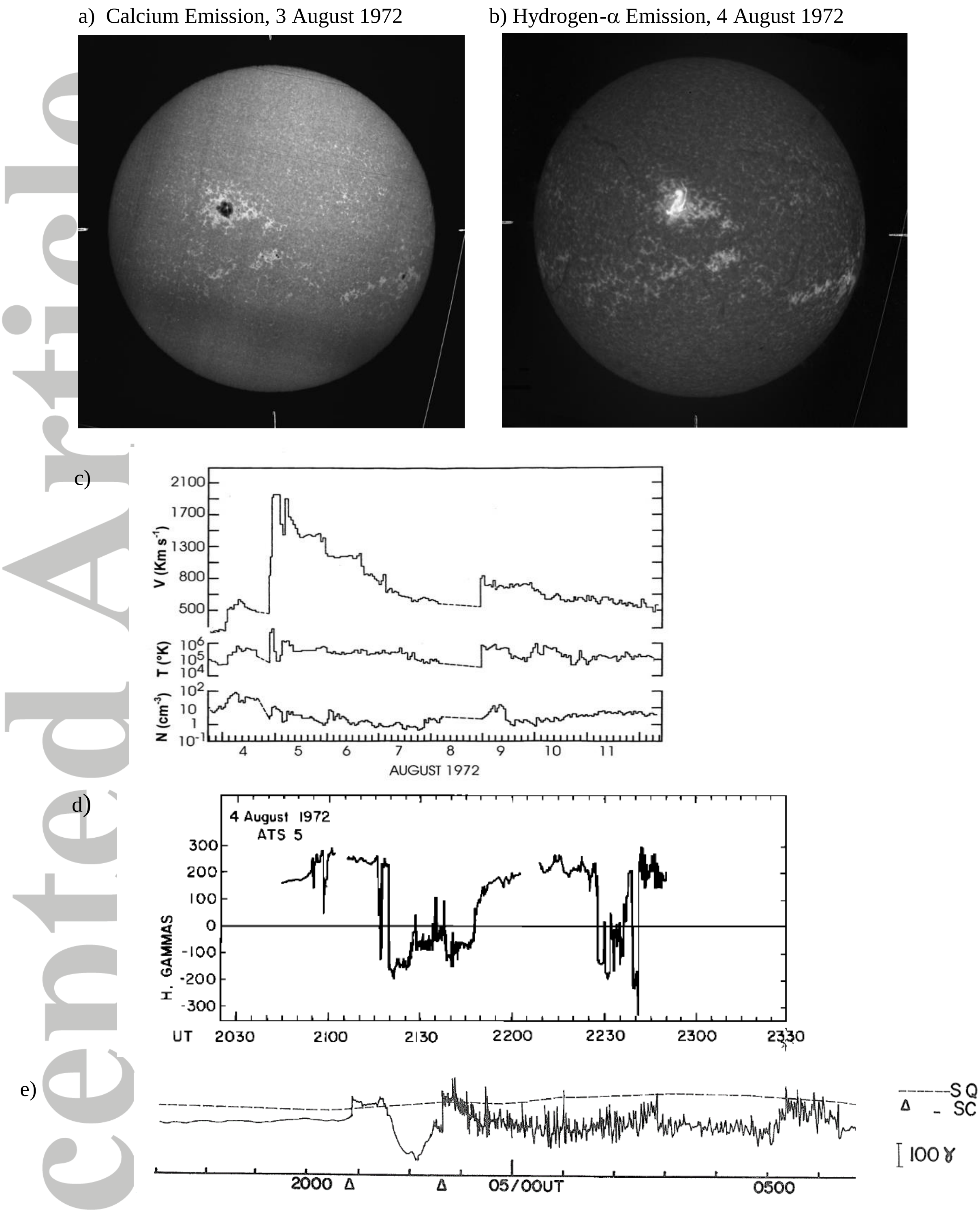

Figure 1 a) Calcium spectroheliogram of McMath Region 11976 on 3 August 1972; b) Hydrogen-α solar spectroheliogram of flaring region at 0648 UT on 4 August 1972. Copyright BASS2000, Paris Observatory, PSL. (Used with Permission). The east limb is at the left of both images; c) Hourly-average solar wind plasma data 4-11 August 1972; d) Magnetosheath magnetic measurements for 2120 and 2230 from ATS 5 geosynchronous spacecraft at 15 LT (Cahill & Skillman 1977); UT, e) Manila Observatory magnetic X component variations 4 Aug 17 UT-5 Aug 7 UT (Salcedo, 1973). The vertical jump at 2240 UT represents a 168 nT/min increase. After the second sudden commencement giant geomagnetic pulsations were present in the magnetosphere

The Chief of Naval Operations, Mine Warfare Project Office (CNO-MWPO, 1975) report notes that the Navy investigated all aspects of this event. After wide-spread inquiry and discussions with personnel from the National Academy of Science, the National Oceanographic and Atmospheric Administration (NOAA)-Boulder (B. Fraser, personal experience), various US Naval laboratories and the Naval Post Graduate School, the Navy determined that “anomalous signals from the solar system activity would be of sufficient length and intensity to have fired the DSTs…(and)… that a significant portion of all of the sensitive-setting DSTs could have been fired by the solar activity.” DST magneticlly-sensitive-influence mines would detonate when magnetic variations exceeded preset thresholds for one or more magnetic factors (e.g. amplitude, polarity, rate of change and /or gradient). The Navy was clear that the detonations observed by aircrews were on 4 August and that magnetic field variations were the cause. Although neither the exact time of the sea-mine detonations on 4 August nor the threshold for magnetic mine detonation are known to us, we suggest that one or more of the dB/dt spikes recorded after 2230 UT (Fig. 1e) caused the magnetic-influence-mine explosions reported at Hon La, North Vietnam (~9° Magnetic Latitude-ML). This is consistent with triggering information above. Figure 1e shows the horizontal component of dB/dt at Manila, Philippines. The sharp change, above the second triangle at ~2240 UT, is 168 nT/min. A similar range of dB/dt was recorded for an additional hour as giant magnetic pulsations permeated the magnetosphere (Salcedo, 1973).

Aerial inspections revealed additional evidence of detonations elsewhere along the coast. The wartime memoirs of a US Navy Mineman-Sailor, Chief Petty Officer Michael Gonzales, state: “During the first few weeks of August, a series of extremely strong solar flares caused a fluctuation of the magnetic fields, in and around, South East Asia. The resulting chain of events caused the premature detonation of over 4,000 magnetically sensitive DSTs (Destructor mines) …” (Gonzales, https://www.angelo.edu/content/files/21974-a). For the US Navy, dealing with the event was of “utmost priority.” (See Appendix). Hartmann and Truver (1991) note that “… the HaiPhong Destructor Field was actually swept by a solar magnetic storm in August of 1972.”

The storm spurred immediate and long-term actions**.** As noted in the CNO-MWPO report (1975), the US Navy fast-tracked replacement of the magnetic-influence-only mines with magneto/seismic mines. By 1 November 1972, AFGWC introduced a “fully automated, Vela satellite, proton event detection and warning system,” (Markus et al., 1987; D. Smart, personal experience). The DMSP program and data were declassified in December 1972, in part to encourage scientists to investigate storm time auroral imagery. In late October 1972, prior to the last Apollo moon landing, NASA held a workshop on space radiation (See footnote in Parsons and Townsend, 2000). No doubt this effort was to review NASA’s Radiation Plan for Apollo Missions, (See Lopez et al., 1969). AT&T re-engineered its communications lines for more robust worldwide communication. In subsequent years satellites have been hardened against radiation. Power grids have been fortified and refortified. Satellite drag continues to receive attention. Volumes of material have been published about the August 1972 storm(s), including a NOAA multi-volume review for the August storms (Lincoln & Leighton, 1972; Coffee, 1973) and a 1976 Special Collection in *Space Science Reviews* (Dryer, 1976).

Since 1972 there has been significant progress in understanding of CMEs and their role in geomagnetic storms. Tousey (1973) reported the first CME observed in late 1971 by NASA’s Orbiting Solar Observatory. Although not mentioned in the collected summaries of the August 1972 event, by the time of the *Space Science Review* Special Collection, Dryer et al. (1976) were estimating CME masses for this event. In the mid 1980’s CME-shock associations were established. By the mid-1990’s there was a general understanding of ICMEs as a prime agent for geomagnetic storms. The ideas of interacting and/or path clearing IP structures, seed particles for SEPs, and fast ICMEs as agents for extreme geomagnetic storms developed subsequently. Shock-sheath structures are now understood as potential sources of enhanced geospace disturbances. Howard (2006) provides a historical view of CME science.

2. Commentary: Benchmarking and a Grand Challenge

Benchmarking. Recent efforts at benchmarking space weather have placed a new emphasis on extreme events. As a magnetic storm, 4 August 1972 has been an enigma for such efforts. The event presented itself as a great solar storm with an extraordinary shock, but without a great geomagnetic storm (Tsurutani et al., 2003; Schmieder, 2018), as signaled by the Dst index and low-latitude aurora. The Dst index on August 5 reached the ‘intense’ category: -125 nT—a level attained on average three times per year (Loewe & Prölss, 1997). Along those lines, Gonzalez et al. (2011) called the 4-5 August 1972 event a 'failed Carrington type storm'. The United Kingdom's Royal Academy of Engineering report (2013) listed the storm as 'similar to the Carrington event', but a 'near miss.'

Based on the evidence presented in Section 1, we submit that the 4 August 1972 event was a Carrington-class storm. The transit time for this event was shorter than the Carrington event. Lin and Hudson (1976) estimated the August 1972 flare energy as commensurate with the Carrington flare. Kawasaki et al. (1973) showed an extraordinary Asymmetry (ASY) range of ~ 450 nT for the storm. They called it "one of the most complex ever recorded." (Affirmed by J. Love, personal communication, 2018). Bell et al. (1997) characterized the interval as a 'Superstorm'. Using data from Pioneer 10 Tsurutani et al. (2003) suggested a magnetic field strength at 1 AU ranging from 73 - 103 nT and an IP electric field > 200 mV/m. Li et al. (2006) estimated that a southward (rather than northward) IMF in the post-sheath magnetic cloud on 4-5 August 1972, would have produced a Dst approaching –1600 nT in the presence of a large density enhancement. Kozyra et al. (2013) noted that the fast and exceptional storm of 21 January 2005 shared some of the unusual solar wind features and magnetospheric behavior of the 4-5 August 1972 event. They suggested that solar filament material striking Earth's magnetosphere played a role in the severity of both storms.

Grand Challenge. In agreement with Lakhina et al. (2011), we see the August 1972 storm as part of a grand challenge to understand the scope, frequency and impacts of Carrington-class events (see references in Cliver and Dietrich, 2013; Ebihara et al., 2017, Kataoka et al., 2017, and Hayakawa et al., 2018, for possible additional events). Silverman and Cliver (2001) suggest the 14-15 May 1921 storm as a Carrington-class storm in the 20^{th} Century. Baker et al. (2013) held a similar opinion of the 23 July 2012 shock/ICME that hit STEREO A (but missed Earth) and the 4 August 1972 event. They stated that "…the event of 1859 joins the annals of modern powerful geomagnetic storms such as 4 August 1972 that have had severe impacts on power grids, satellites and communications systems…"

We now know that the 4 August 1972 event had significant civilian and military impacts. The event was likely associated with an ultra-fast IP structure that produced an extraordinary flux of SEPS and plowed into remnants of a previous ICME already in the vicinity of Earth. The complex interaction of the ultra-fast IP sheath-shock (and possibly solar filament material) with Earth's magnetic field appears as the primary suspect for the violent response at Earth's surface. Recently Saiz et al. (2015) and Cid et al. (2105) argued that high solar wind pressure and abrupt reversals of the IMF appear as the interplanetary trigger of sharp geomagnetic field perturbations in extreme storms. There is strong reason to believe these factors were present in the near-Earth IP medium after 2050 UT on 4 August 1972.

There would be much value in exercising current-epoch models to understand the sheath/shock aspects of 4-5 August 1972 storm. In particular, how did the following contribute to the effects observed in geospace?: 1) Sequential, multiple flares/shocks/ICMEs, and path-clearing behaviors for subsequent ultra-fast events; 2) Interaction of ultra-fast shocks, solar filament material and ICMEs that lead to extreme SEP events and severe magnetopause compression; 3) Pre-conditioning in the geospace system, especially in terms of ring current creation and neutral atmosphere heating; 4) The influence of compression and erosion of the magnetopause in regulating ring current formation; 5) The relative role of magnetopause and field aligned currents in producing low-latitude magnetic perturbations and extreme geomagnetic pulsations in the magnetosphere, and calculations of dB/dt at Earth's surface, particularly in the equatorial region. The space weather community would also benefit from: 1) Estimating the influence this type of storm might have on Global Navigation Satellite System services; 2) Determining if current upstream monitors would be able to produce and telemeter data through such a storm; and 3) Doing an in-depth comparison between this storm, which hit Earth, and the July 2012 event, which was well-measured by space-based instruments, but missed Earth.

As an important end note, this commentary is possible only because of the extraordinary data and report-archiving developed during the International Geophysical Year and carried on by a host of dedicated scientists at the World Data Centers, especially World Data Center A, Boulder, CO. It is likely that many of the records needed to reconstruct this event are not yet in accessible digital form. Therefore, as another aspect of the grand challenge, we encourage an all-out effort to make all relevant data part of a freely available archive.

Appendix. Historical Context

By 1972 US troops had been involved in the Vietnam War for seven years. The intense fighting had taken deep tolls on all sides. US President Nixon was finally convinced by naval advisors in the spring of 1972 that sea-mining of North Vietnam ports was a strategic necessity for reducing supply routes to North Vietnam and ending the conflict (Tucker, 2006, Chap 15). An intense mine-laying operation, 'Operation Pocket Money,' began on 9 May 1972, Vietnam time, in Haiphong harbor. Over the subsequent eight months more than 11,000 mines were dropped into the waters outside principal North Vietnamese ports (Campbell, 2015 p. 110). Such mines typically were timed to disarm (sterilize) themselves in about six months. They were actuated by pressure, acoustic and/or magnetic signatures of passing ships (Hartman and Truver, 1991). Magnetic-influence mines would detonate when magnetic variations exceeded preset thresholds for one or more magnetic factors (e.g. amplitude, polarity, rate of change and /or gradient).

In a 1997 Institute for Defense Analysis report, Vice Admiral (Ret.) Greer discussed the need for re-seeding and/or replacement of the self-sterilizing mines and noted that: "Also, a serious electromagnetic anomaly from a sunspot detonated a large number of mines." The wartime memoirs of a US Navy Mineman-sailor Chief Petty Officer Michael Gonzales, also report: "During the first few weeks of August, a series of extremely strong solar flares caused a fluctuation of the magnetic fields, in and around, South East Asia. The resulting chain of events caused the premature detonation of over 4,000 magnetically sensitive DSTs (Destructor mines), … Consequently, the task of re-seeding the depleted fields was an enormous evolution, which demanded immediate execution and was of the utmost priority. … I cannot emphasize the tremendous strain that it imposed on the Pacific fleet Minemen, aside from the vast war commitments that were already delegated to the U.S. Mines divisions at that time." (Gonzales, https://www.angelo.edu/content/files/21974-a).

There should be no doubt of the importance the US government attached to maintaining the mine fields. Numerous post-Vietnam War reports note that the interruption of goods and war materials into the ports eventually brought all sides to the Paris Peace Talks. A signed accord in late January 1973 contained a stipulation that the US would sweep the mines and (in return) North Vietnam would free prisoners of war. Operation 'End Sweep' involved considerable resources applied by the US minesweeping operations (Hartmann and Truver, 1991).

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Three main points:

The 4 August 1972 flare, shock and geomagnetic storm are components of a Carrington-class event

The event was associated with a nearly instantaneous, unintended detonation of dozens of sea mines near Hai Phong, North Vietnam

The entire series of events in August 1972 should be viewed as a grand challenge to current day space weather models

Figure Caption

Figure 1 a) Calcium spectroheliogram of McMath Region 11976 on 3 August 1972; b) Hydrogen-α solar spectroheliogram of flaring region at 0648 UT on 4 August 1972. Copyright BASS2000, Paris Observatory, PSL. (Used with Permission). The east limb is at the left of both images; c) Hourly-average solar wind plasma data 4-11 August 1972; d) Magnetosheath magnetic measurements for 2120 and 2230 from ATS 5 geosynchronous spacecraft at 15 LT (Cahill & Skillman 1977); UT, e) Manila Observatory magnetic X component variations 4 Aug 17 UT-5 Aug 7 UT (Salcedo, 1973). The vertical jump at 2240 UT represents a 168 nT/min increase. After the second sudden commencement giant geomagnetic pulsations were present in the magnetosphere