Benchmark GMD – statistics, source spatial scales, latitude scaling and ground model dimensionality

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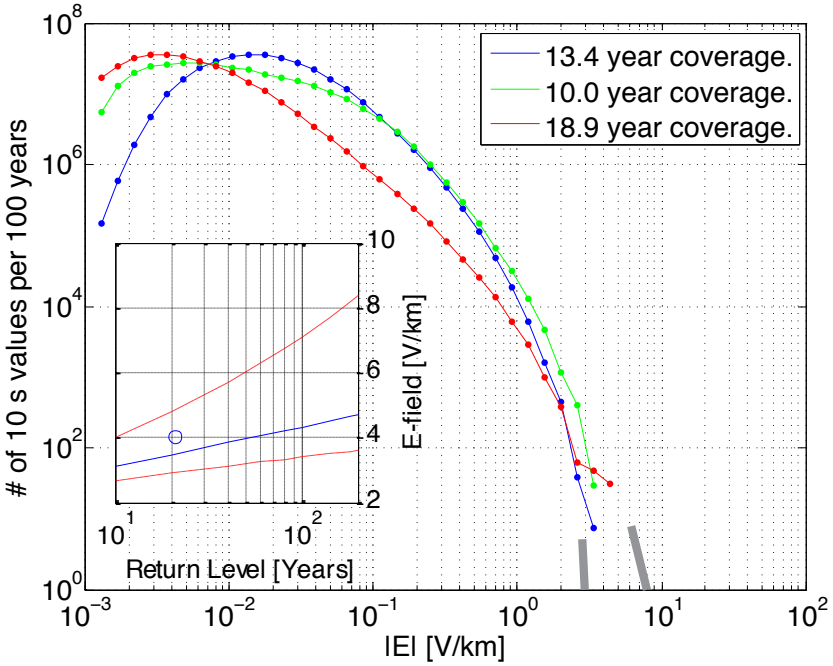
Statistics

- In the proposed Benchmark GMD, both visual extrapolation and rigorous extreme value analysis (peaks over threshold) were used to extrapolate the computed geoelectric fields to 1-in-100 year occurrences (*Pulkkinen et al.*, 2015).
  - The results from the two agree very well.
- In the extreme value analysis, both daily maxima and de-clustering were used to ensure statistical independence of the samples.
  - Also solar cycle modulation was taken into account.

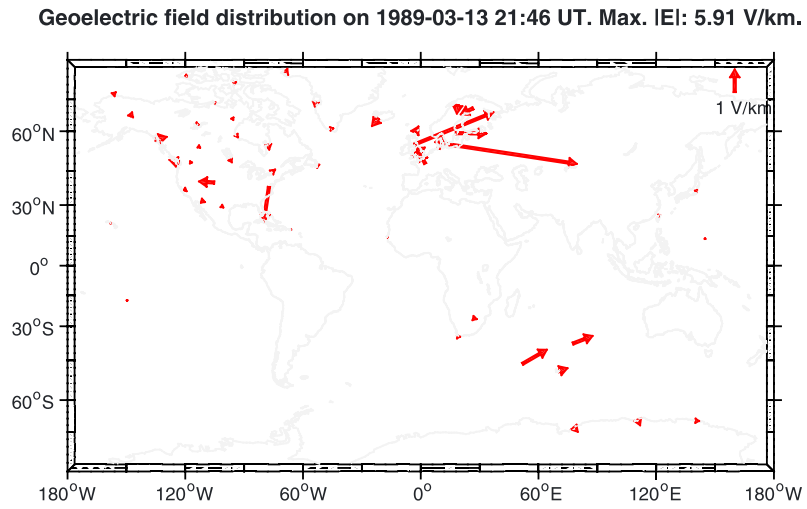


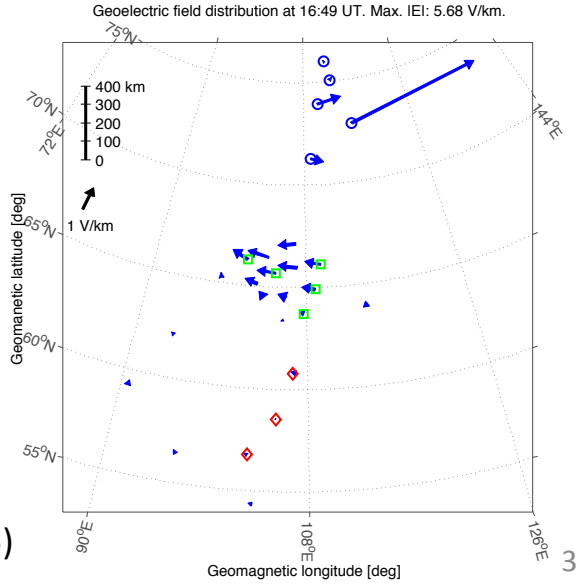
Pulkkinen et al. (2015)

Source spatial scales

Ngwira et al. (2015)

- Due to the complex source structure, the most extreme *dB/dt* and calculated geoelectric field enhancements are observed to often be spatiotemporally localized (*Pulkkinen et al.*, 2015; *Ngwira et al.*, 2015).
  - Consequently, it is not appropriate to apply single station extreme values over large areas.
- One needs to avoid bias caused by localized enhancements in wide-area extreme event analyses.
  - Spatial average can be used as a measure to characterize the field strength over wide areas.
  - Averaging is consistent with geomagnetically induced currents (GIC) being proportional to an integral operation of the geoelectric field.

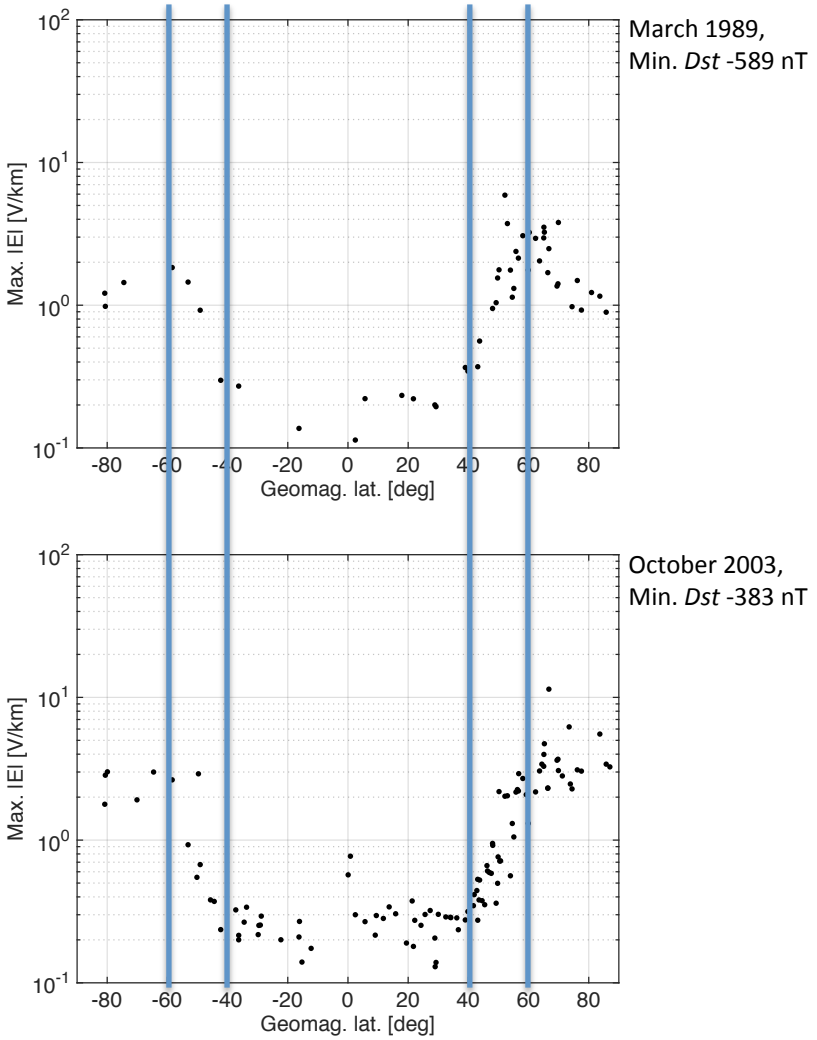




Pulkkinen et al. (2015)

Geomagnetic latitude scaling

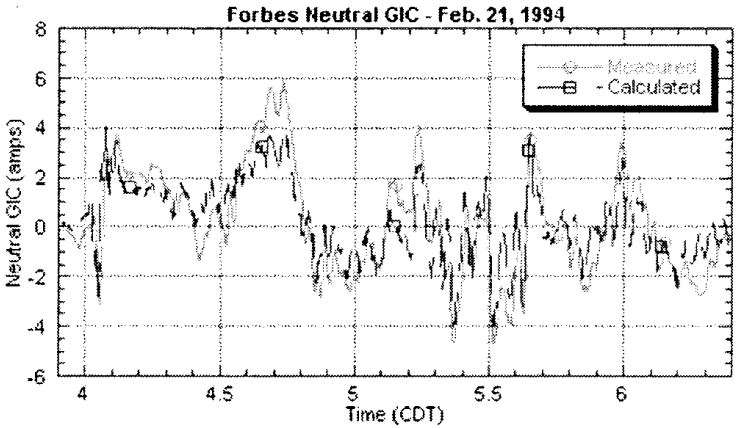
- While we know that auroral boundaries move during the storm times, we also observe saturation or stoppage of the expansion at peak times (*Thomson et al.*, 2011; *Pulkkinen et al.*, 2012; *Ngwira et al.*, 2013).
  - Saturation seen for all extreme storms since 1980s in both ground- and space-based data.
  - The boundary lies approximately between 40-60 degrees of geomagnetic latitude.
- Saturation of some of the key polar-auroral ionospheric parameters is a known characteristic of geospace (e.g., *Ridley*, 2005; *Xiong et al.*, 2014).
- Global observations are required to detect the boundary location at any given time.
  - One cannot determine the location from a single measurement.



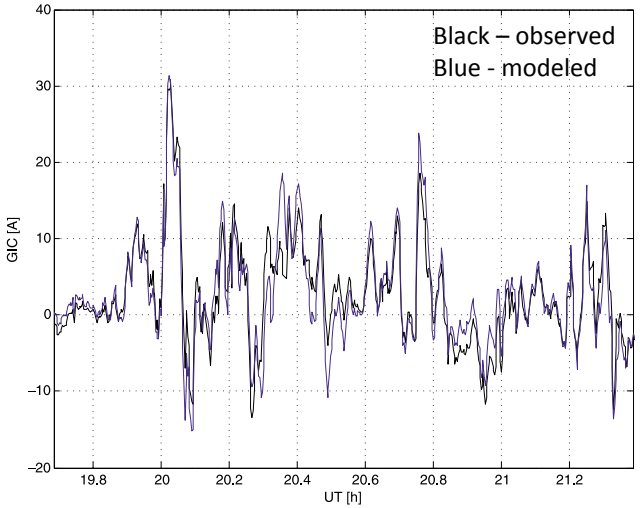
Pulkkinen et al. (2012)

Ground model dimensionality

- 1D – variations only as a function of depth. 2D – variations as a function of depth and single lateral dimension. 3D – variations in all directions.
- While approximate, 1D ground models have been the workhorse of GIC studies for decades across the globe (e.g., *Viljanen and Pirjola*, 1994, *Kappenman et al.*, 2000; *Boteler*, 2001; *Thomson et al.*, 2005; *Pulkkinen et al.*, 2007).
  - Demonstrated to work well in many situations if accurate *effective* 1D representation of the ground is available.
  - Well-suited also for hazard assessments.
- The science is advancing and full 3D modeling of both the source and the ground response (e.g., *Puthe et al.*, 2013; *Bendrosian and Love*, 2015) will be beneficial also for the future GIC science.



Time domain 1D by *Kappenman et al.* (2000)



Frequency domain 1D by *Pulkkinen et al.* (2007)

Bottom line

- The science is mature enough for us to take action now.
- The scientific research will go on and future observations, models and new understanding of the GIC physics will help to refine the assessments.
- Some of the key ongoing community-wide research activities with connection to GIC:
  - National Space Weather Strategy and Action Plan (*National Space Weather Strategy*, 2015).
  - NASA Living With a Star Institute GIC Working Group (*NASA LWS Institute*, 2015).
  - EarthScope (http://www.earthscope.org - project mapping the detailed geology of the US).

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