eXtreme Space Weather Events: Probabilities and Uncertainties

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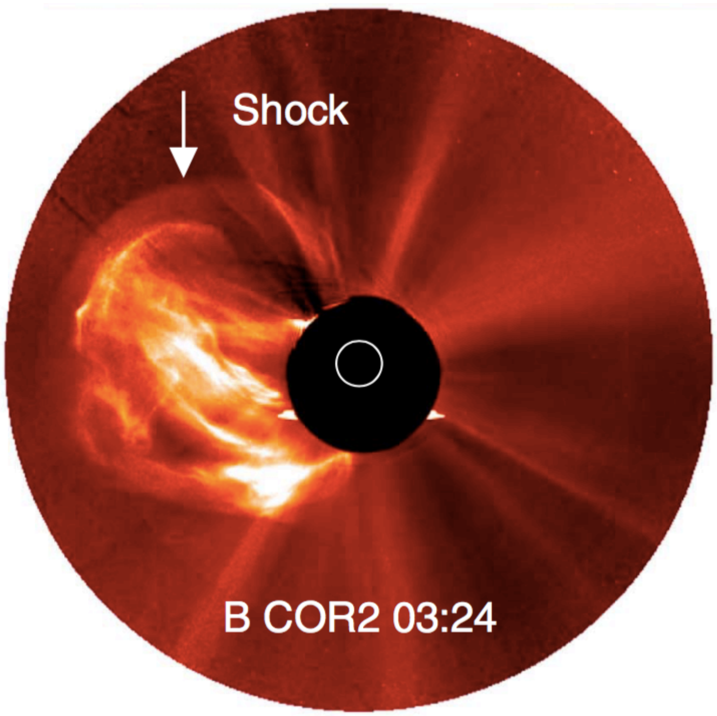
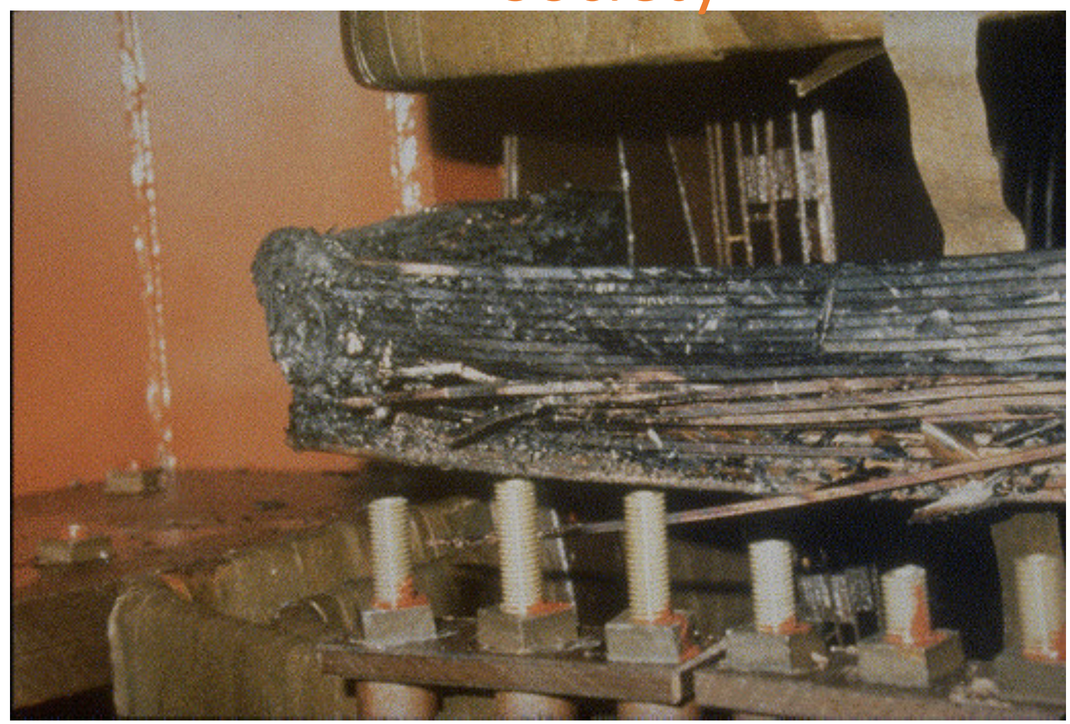
Why do we care about predicting **eXtreme** space weather events?

Science



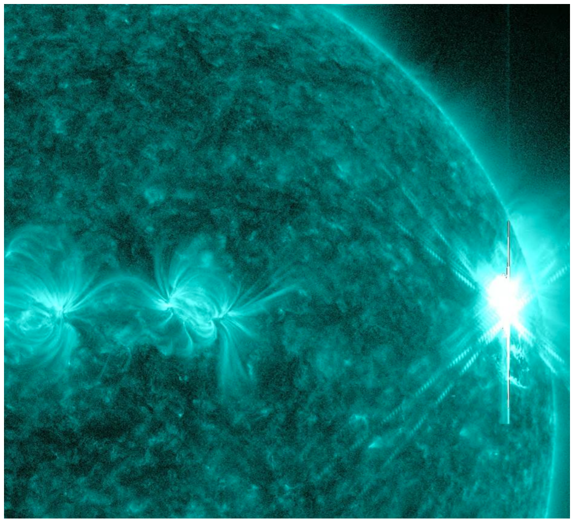
Society

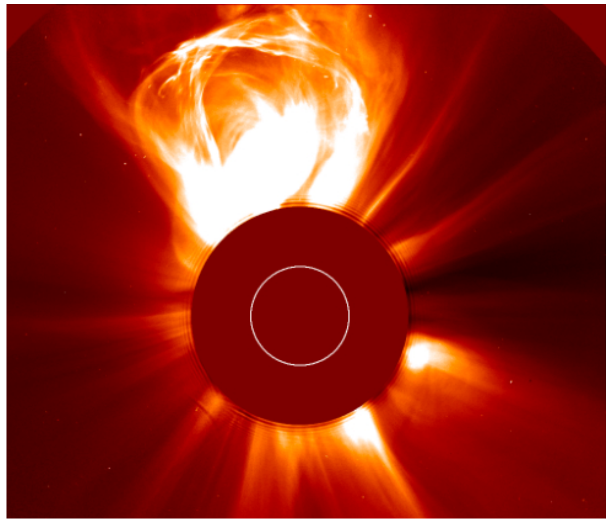


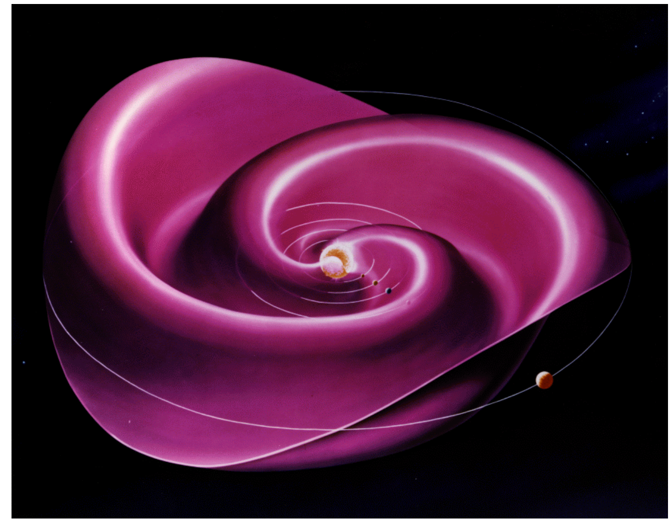
Motivation for these Studies

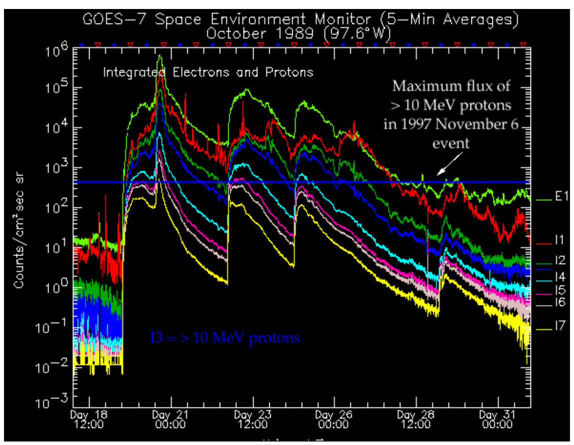
How likely is it that I’m going to witness a Carrington-like event - or worse - during my lifetime?

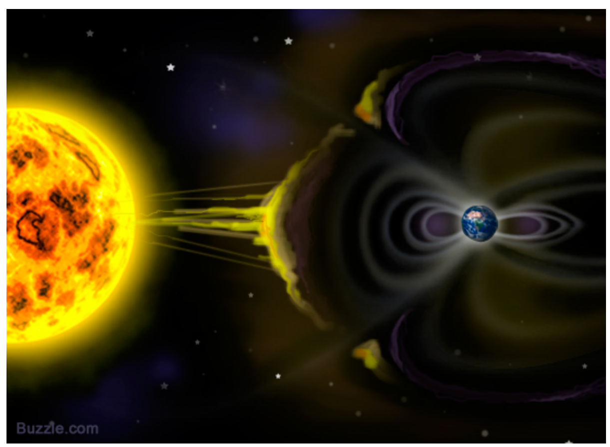
What IS an eXtreme space weather event?











A simple approach for estimating the likelihood of another Carrington Event: Time to Event

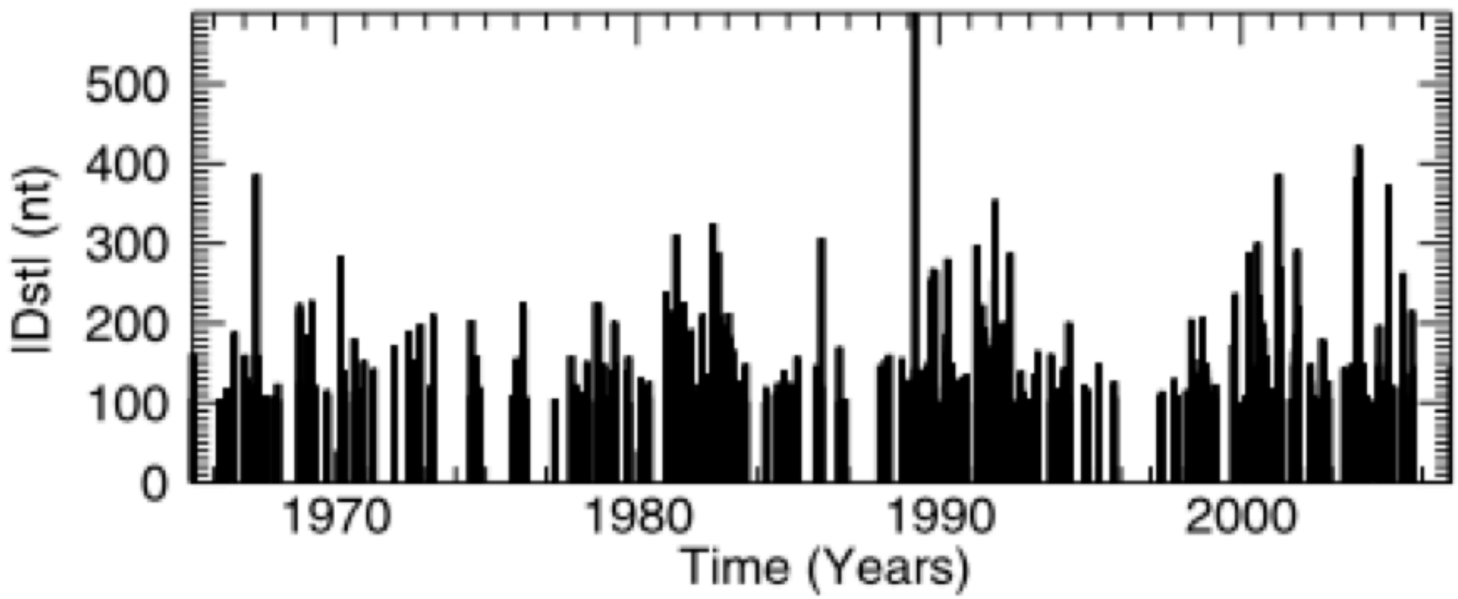
$$P(x) = \frac{1}{1 + \tau}$$

A simple approach for estimating the likelihood of another Carrington Event: Time to Event

$$P(x) = \frac{1}{1 + \tau}$$

- If τ = 100 years
  - P ≅ 9% per decade
- If τ = 153 years
  - P ≅ 6% per decade

Estimating the likelihood of another Carrington Event using the assumption of a power-law distribution



Riley (2012)

Estimating the likelihood of another Carrington Event using the assumption of quasi-power-law distribution

- Assumptions:
  - Power-law distribution
    - ➢No cut-off
  - Time stationarity
    - ➢No clustering
    - ➢No secular trends

$$p(x) = Cx^{-\alpha}$$

$$P(x \geq x_{crit}) = \int_{x_{crit}}^{\infty} p(x')dx'$$

$$P(x \geq x_{crit}) = \frac{C}{\alpha - 1} x_{crit}^{-\alpha+1}$$

$$\alpha - 1 = N \left[\sum_{i=1}^{N} \ln \frac{x_i}{x_{\min}} \right]^{-1}$$

$$P(x \geq x_{crit}, t = \Delta t) = 1 - e^{-N\frac{\Delta t}{\tau} P(x \geq x_{crit})}$$

Riley (2012)

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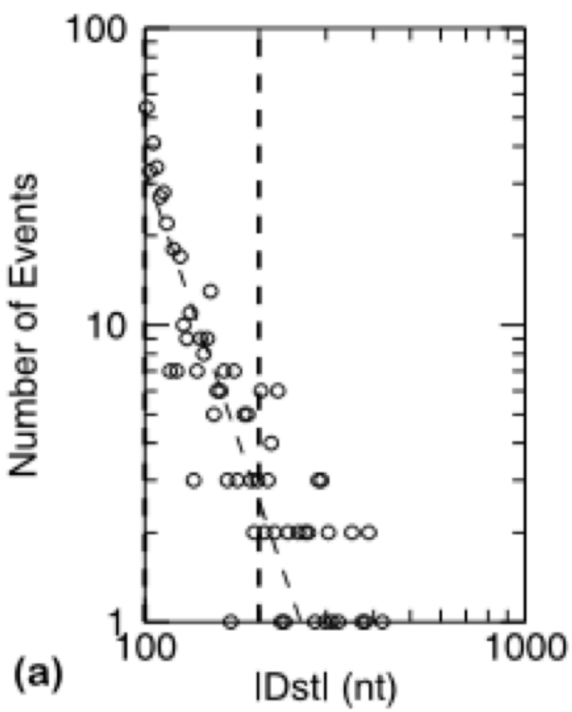

Riley (2012)

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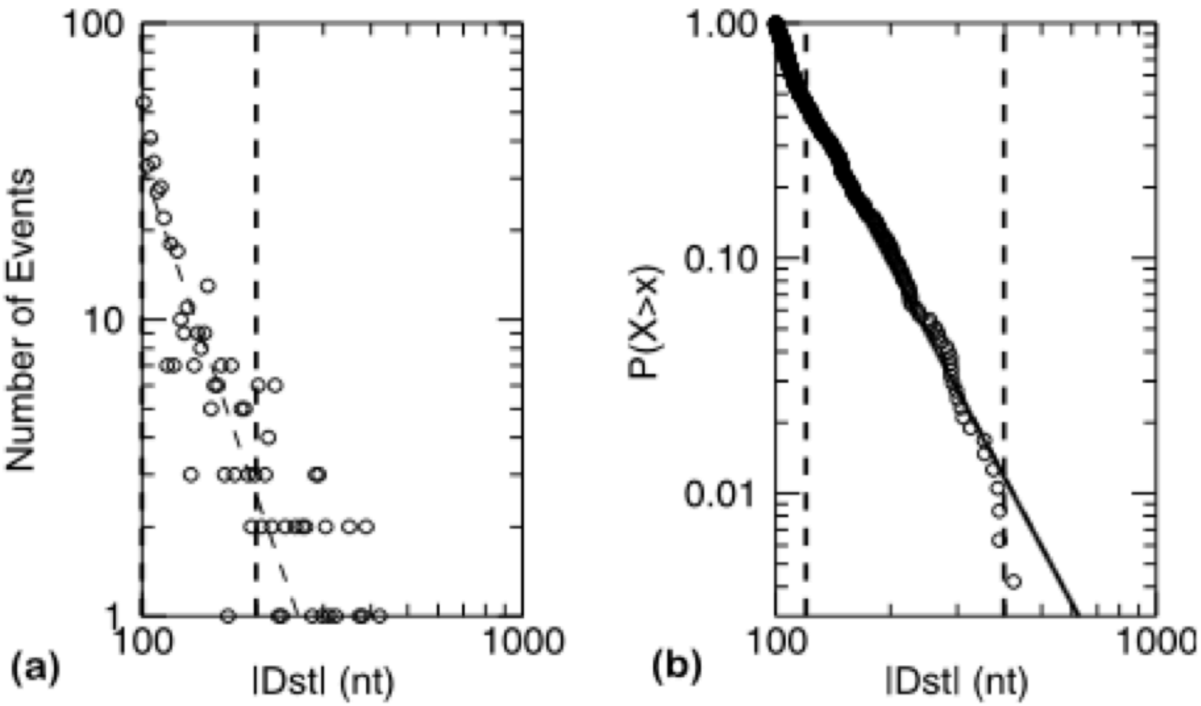
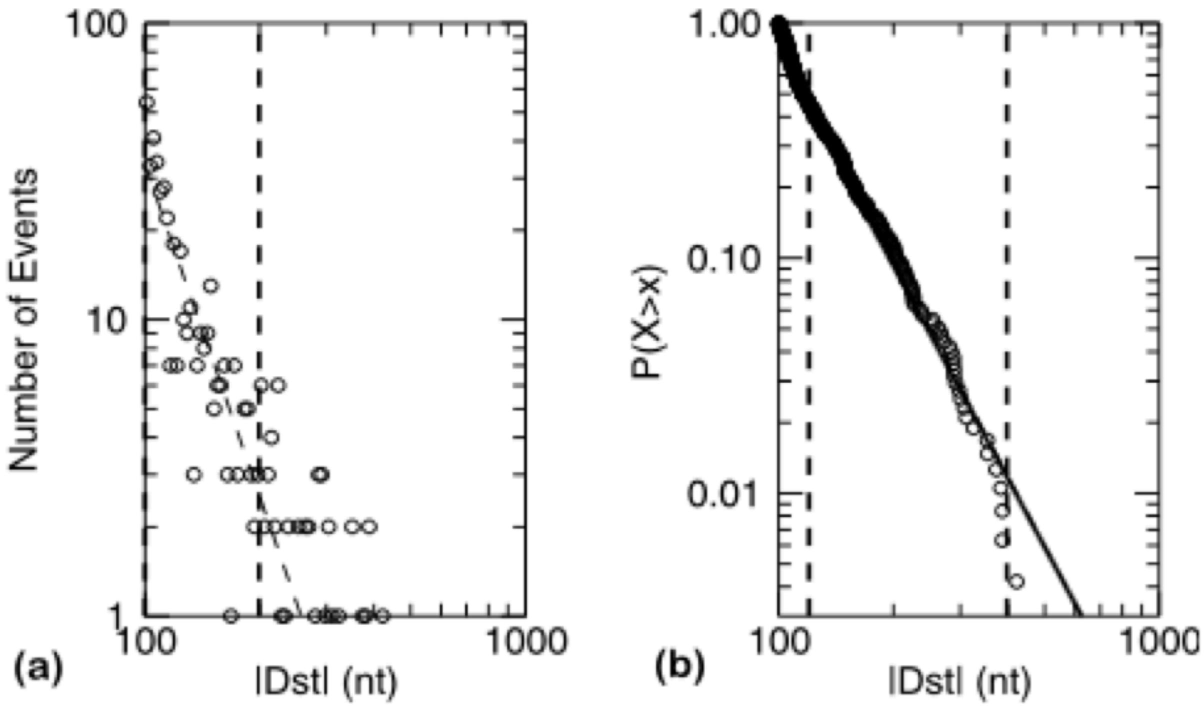


Riley (2012)

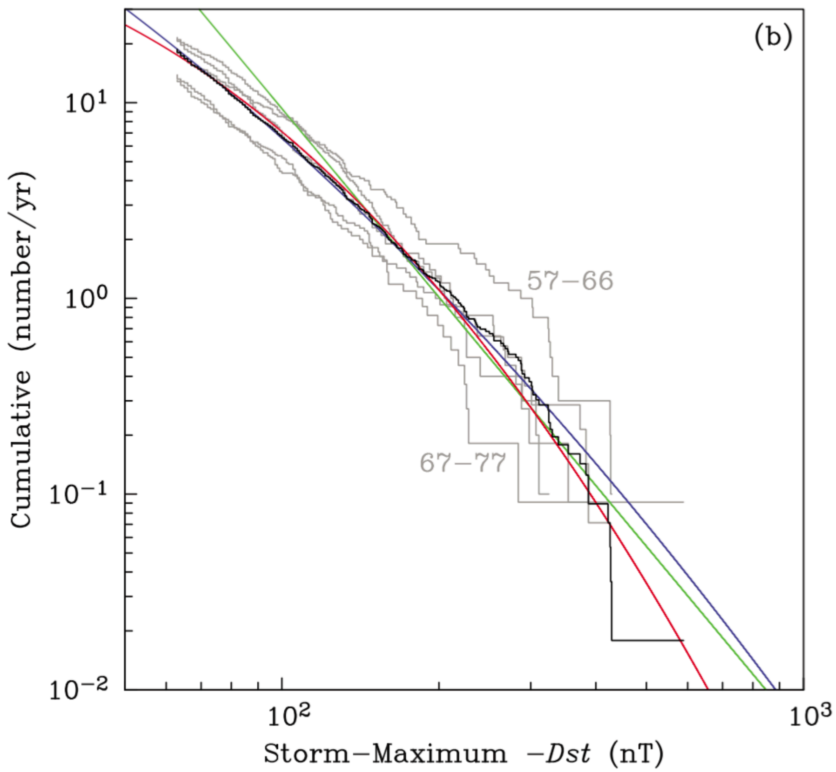
Estimating the likelihood of another Carrington Event using the assumption of quasi-power-law distribution



- For Dst < -850 nT:
  - 12% probability of occurrence over the next decade
- For Dst < -1700 nT:
  - 1.5% probability of occurrence over the next decade

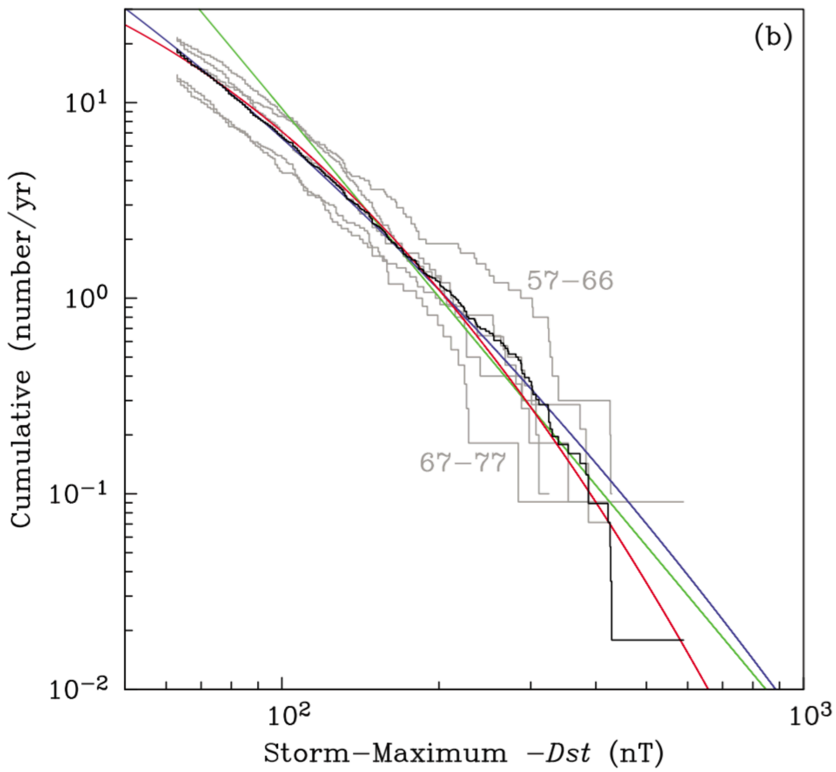
Riley (2012)

Do the data really follow a power-law?



Love, Rigler, Pulkkinen, and Riley (2015)

Do the data really follow a power-law?



Love, Rigler, Pulkkinen, and Riley (2015)

- Lognormal Occurrence rate for Carrington event:
  - 1.13 events per century
    - 95% CI [0.42, 2.41]
- Power-law Occurrence Rate:
  - 1.2 events per century

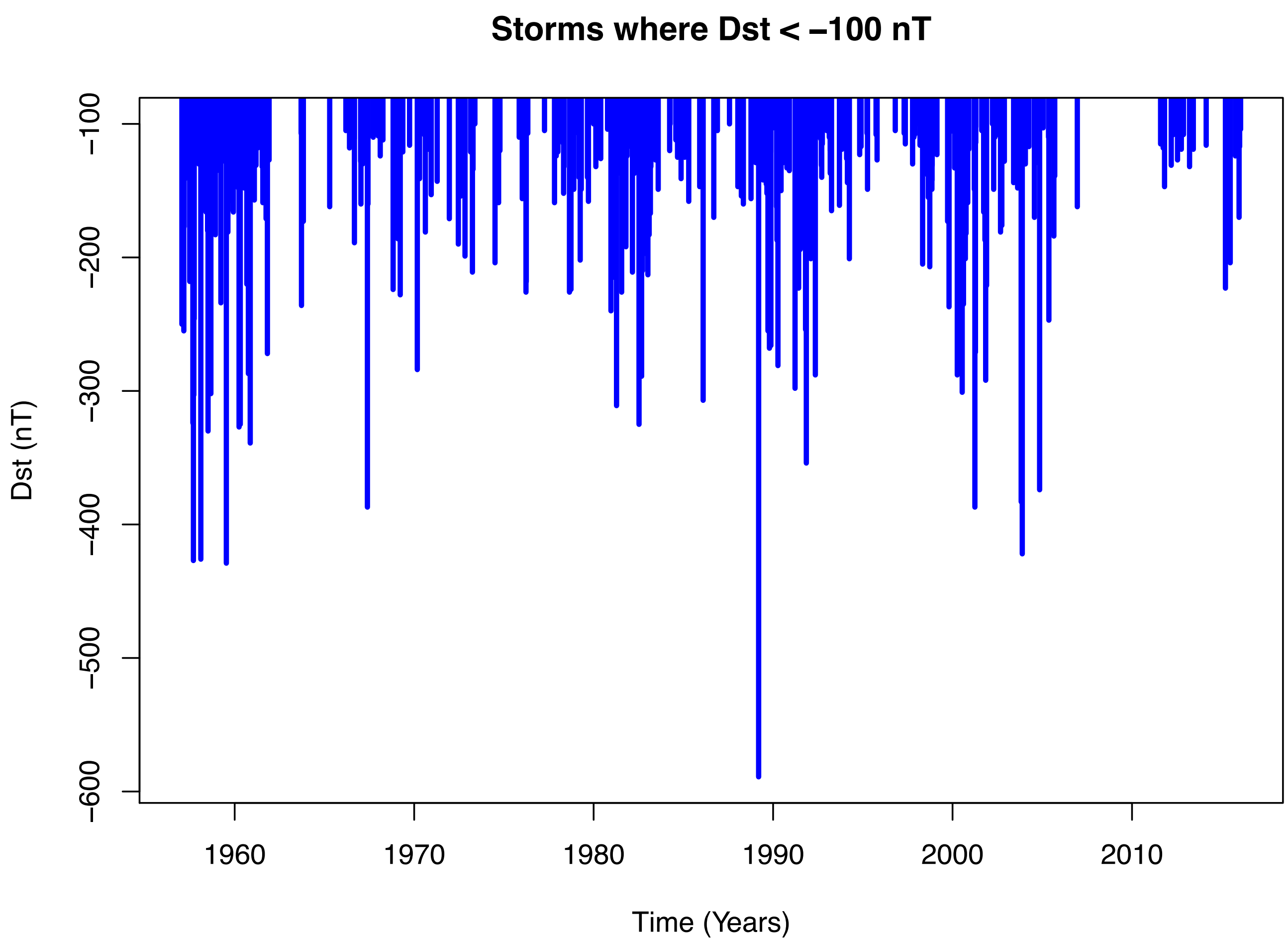
- The log-normal estimate is equivalent to a
  - 10.1% chance of occurrence over next decade
    - 95% CI [4.0, 19.4]
- The power-law estimate equates to a
  - 11% chance of occurrence over next decade

A General approach for estimating probabilities and uncertainties

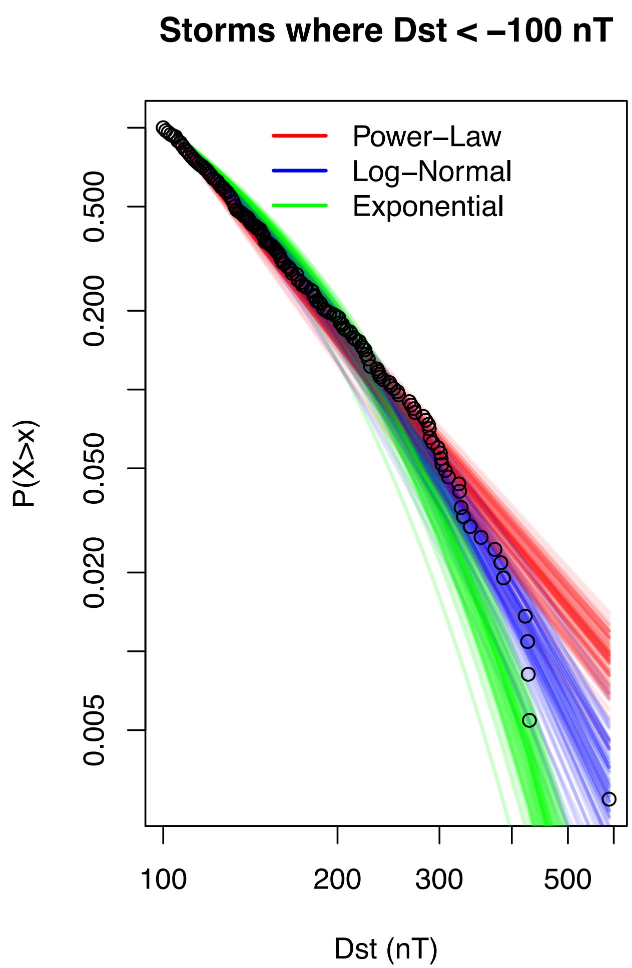
- Allow a variety of distributions
  1. Power-law
  2. Log-normal
  3. Exponential
- Provide robust procedures for estimating statistical model parameters
  1. KS Statistics – to estimate x_{min} and α
  2. Non-parametric bootstrapping – to estimate p-value for Power-law distribution and confidence intervals on forecast
  3. Kuong's test for model comparison – to reject one model over another

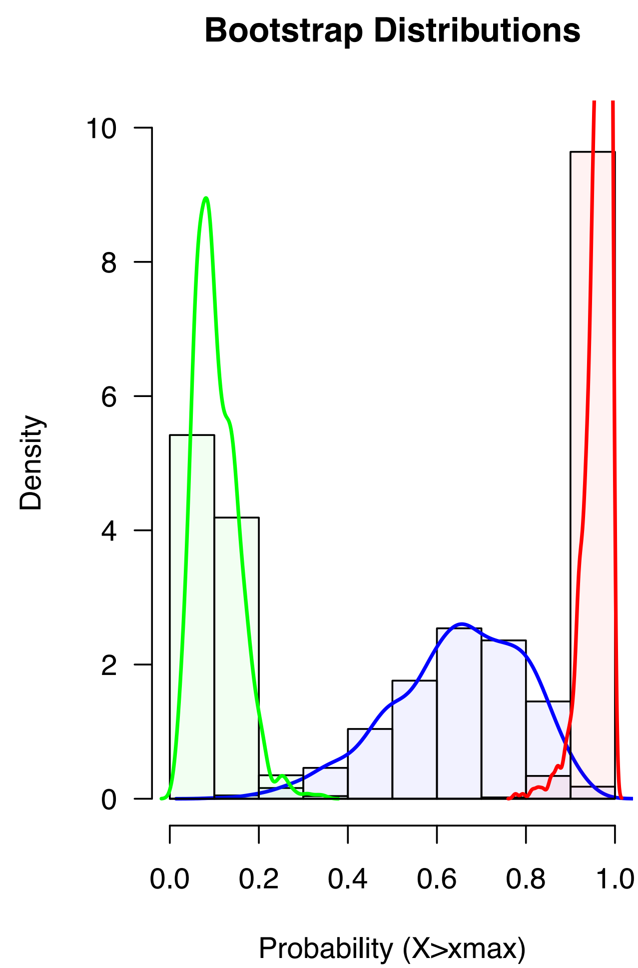
Riley (2016)

The Disturbance Storm Time Index (*Dst*)

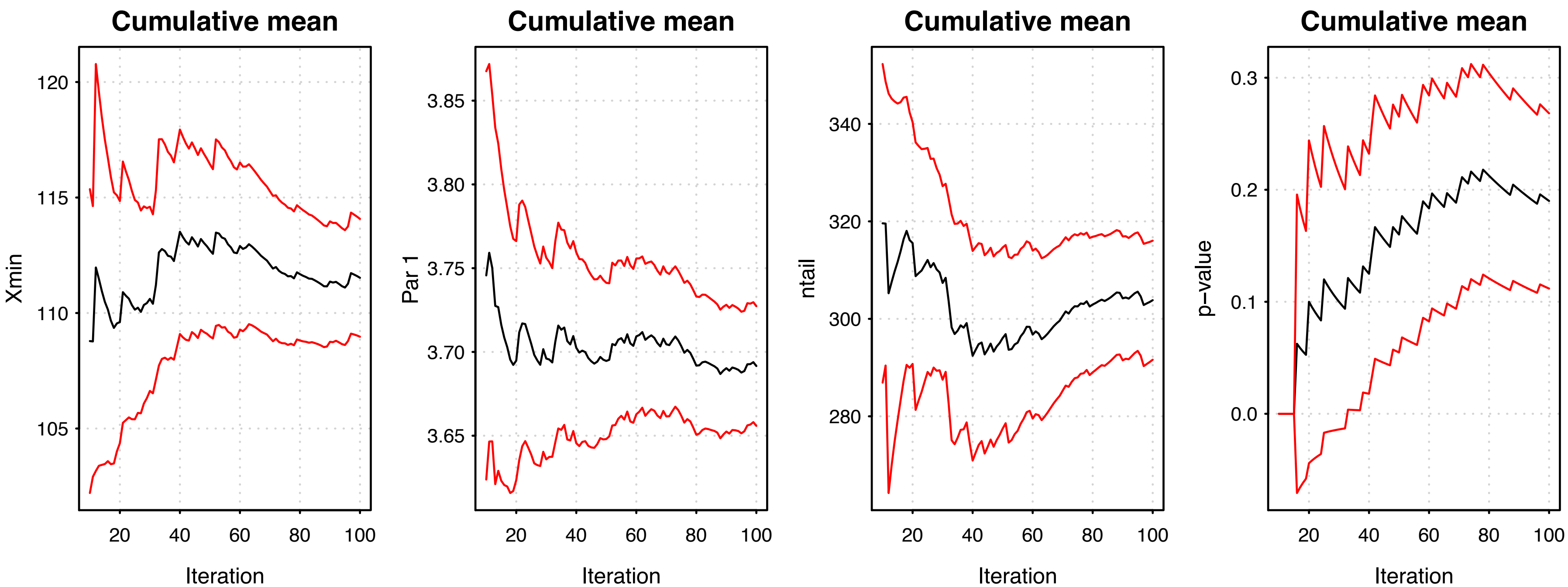


The Disturbance Storm Time Index (Dst)

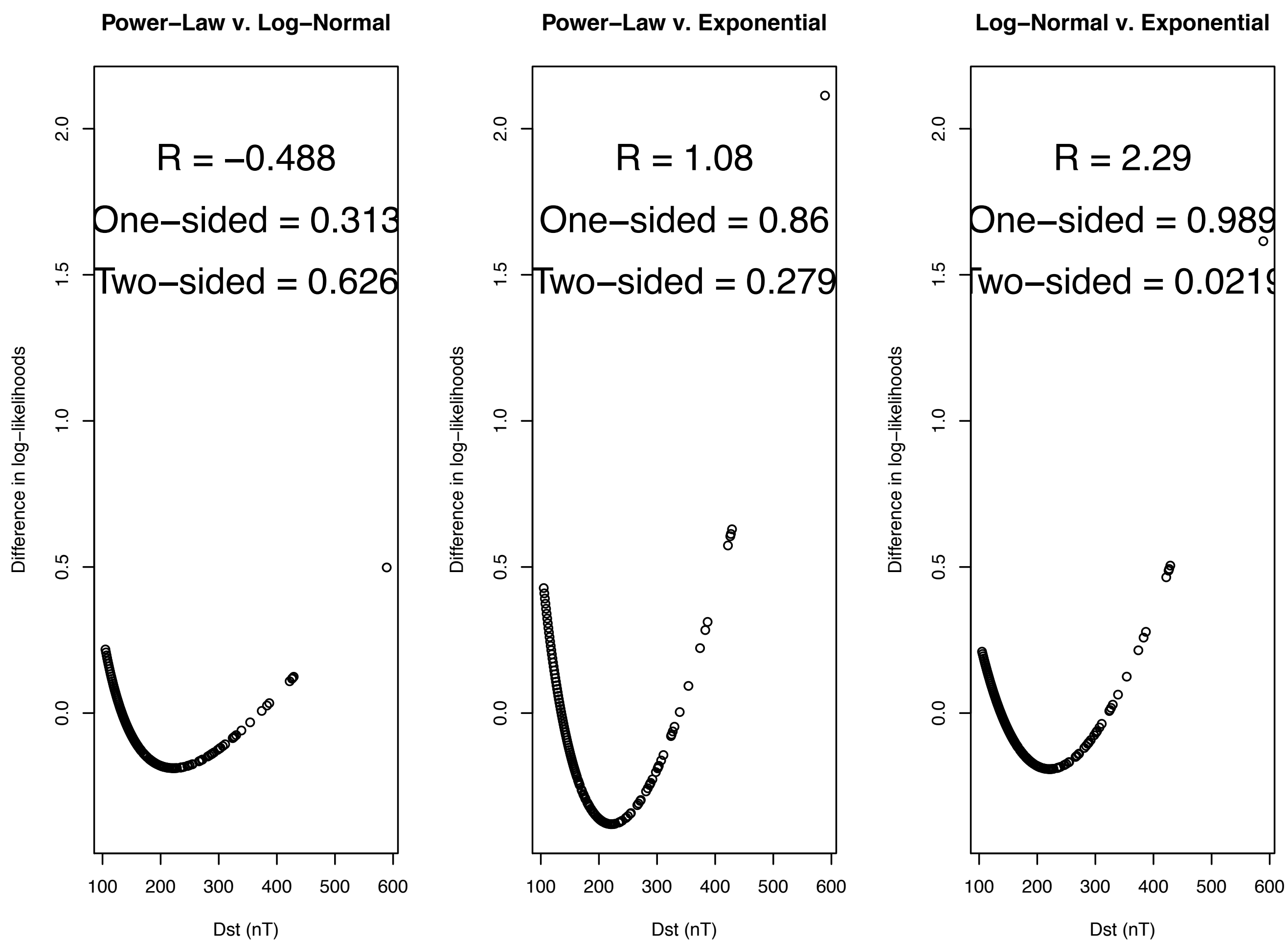




Dst Bootstrap Parameters for Power-Law Distribution



Kuong’s test for different distributions of *Dst*

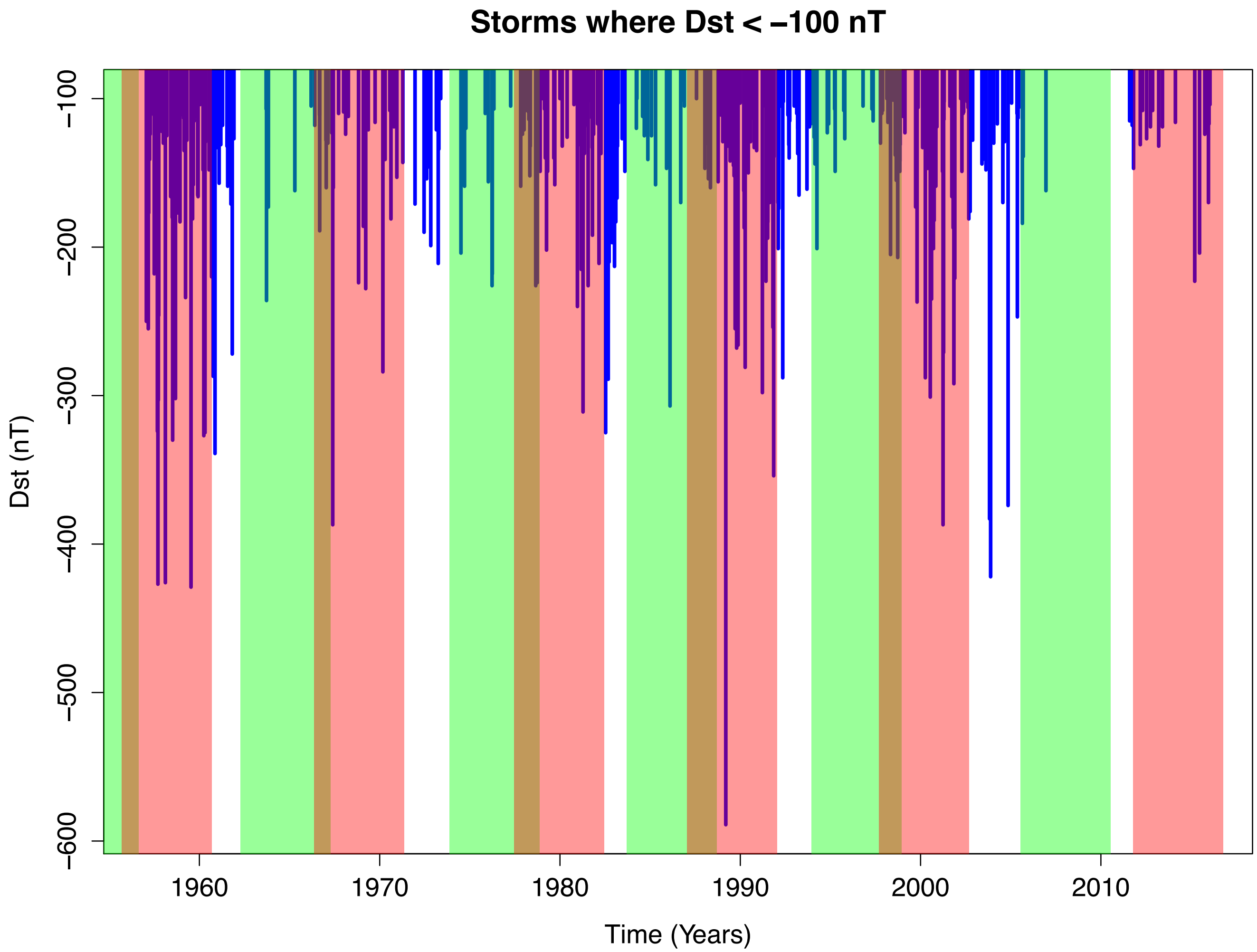


Best Estimates and confidence intervals for the probability of an extreme event (*Dst < -850 nT) over the next decade:*

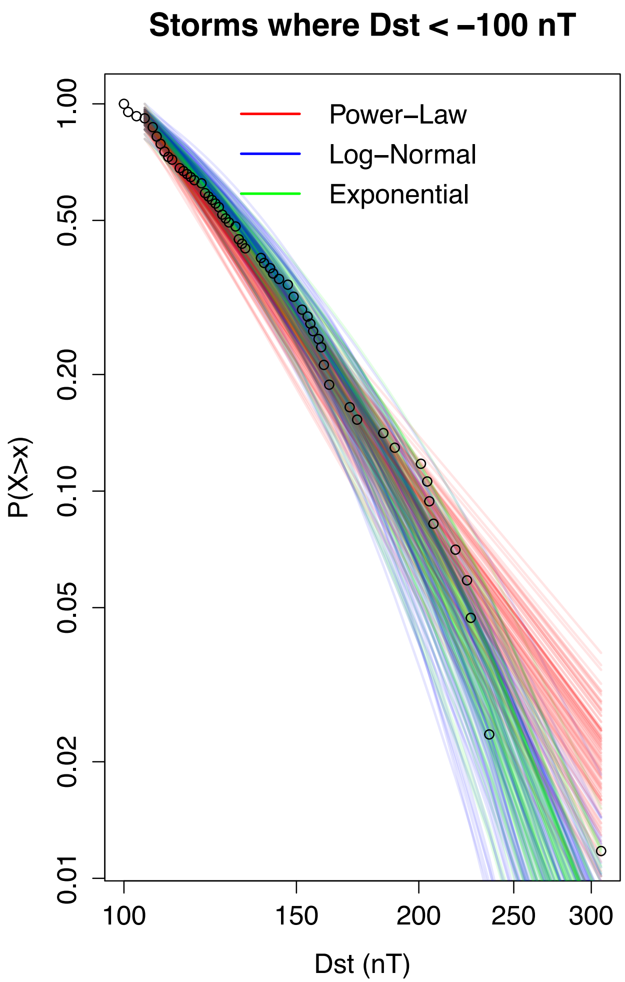
Distribution	Median (%)	2.5% (%)	97.5% (%)
Exponential	0.02	0.004	0.08
Log-Normal	3.0	0.6	9.0
Power-Law (‘64-’16)*	10.3	0.9	18.7
Power-Law (‘57-’16)**	20.3	12.5	30.1

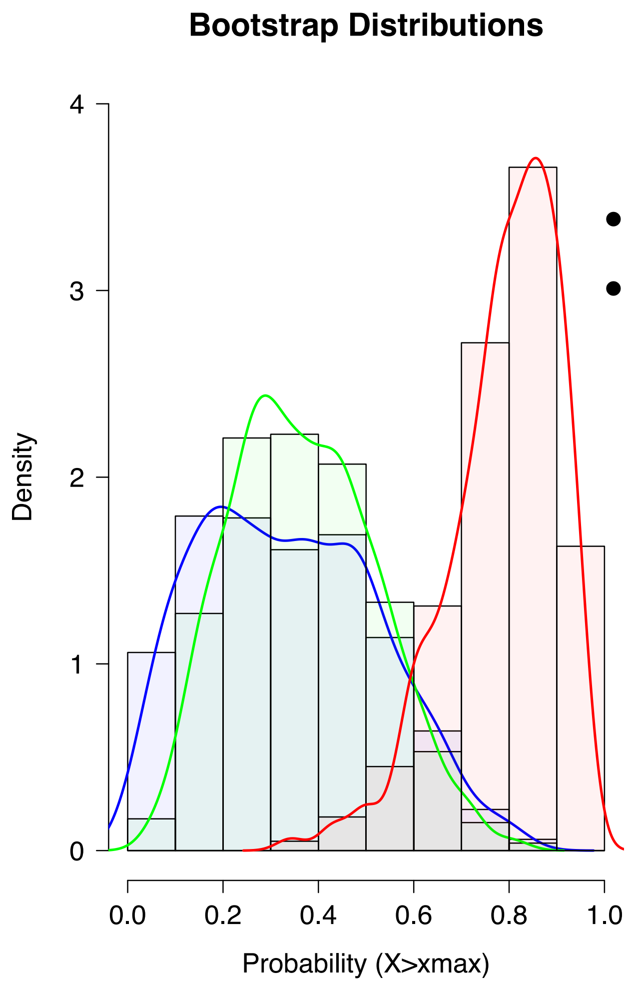
*NASA’s OMNI
*Kyoto / NOAA

Estimating probabilities for solar min and Solar Max Conditions



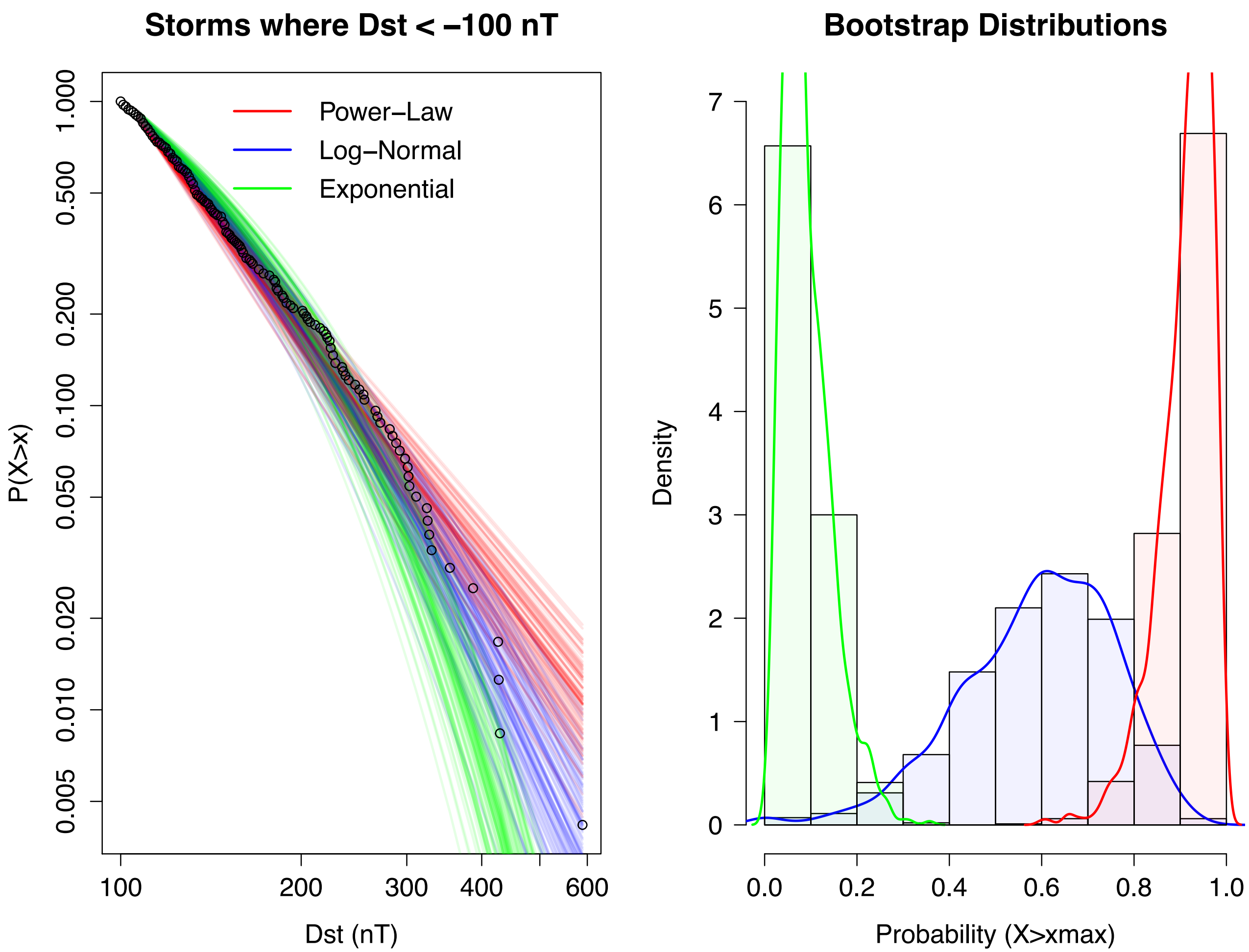
Dst Distributions and probabilities for Solar Minimum





- Dst < -850 nT
- Solar Minimum Conditions
  - 1.4% probability of occurrence over “next decade”

Dst Distributions and probabilities for Solar Maximum



- Dst < -850 nT
- Solar Max. Conditions
  - 28% probability of occurrence over "next decade"

Summary

The probability of another Carrington event depends on your definition of a "Carrington event" (Beauty **is** in the eye of the beholder)

Summary

- Estimates for a Carrington event range from 2.5% (SPEs, Dst with Log-Normal distribution) to 10.3% (Dst, Power-Law Distribution)
- Between solar minimum and solar maximum conditions, the probability varies from 1.5% to 28%.

Summary

The uncertainties in these estimates are substantial:

- For Dst < -850 nt, assuming a power-law distribution:
  - Prob./decade: 10.3%, 95%CI [0.9,18.7]

Summary

When communicating estimates, it is crucial to also communicate:

- Uncertainties associated with them, and
- Assumptions used to derive them

Summary

Applying the same techniques to other "catastrophe" scenarios would help policy makers to prioritize limited resources.