'Real-time' Modelling of Electrostatic Fields within Dielectrics to Provide a Space Weather Risk Index for Internal Charging

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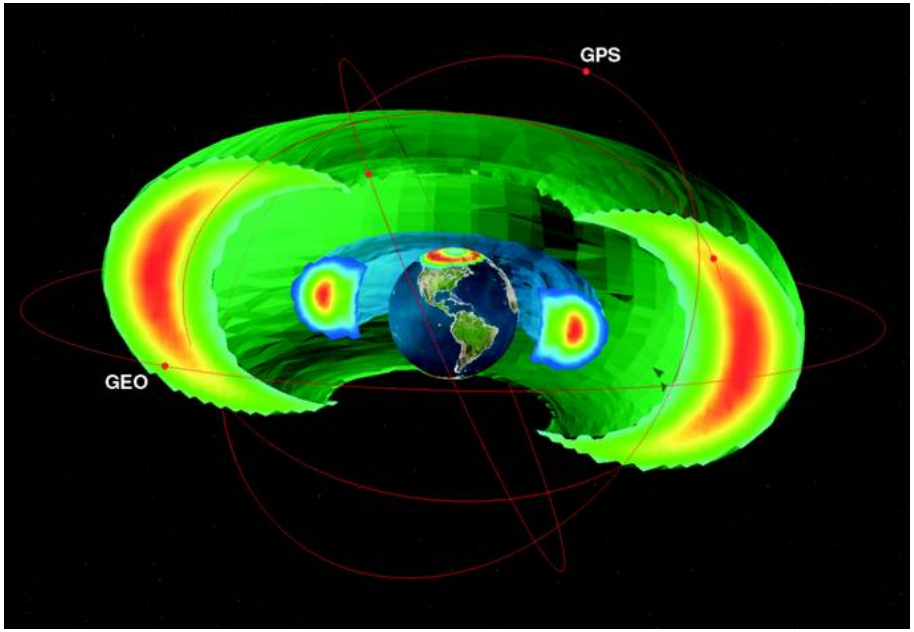
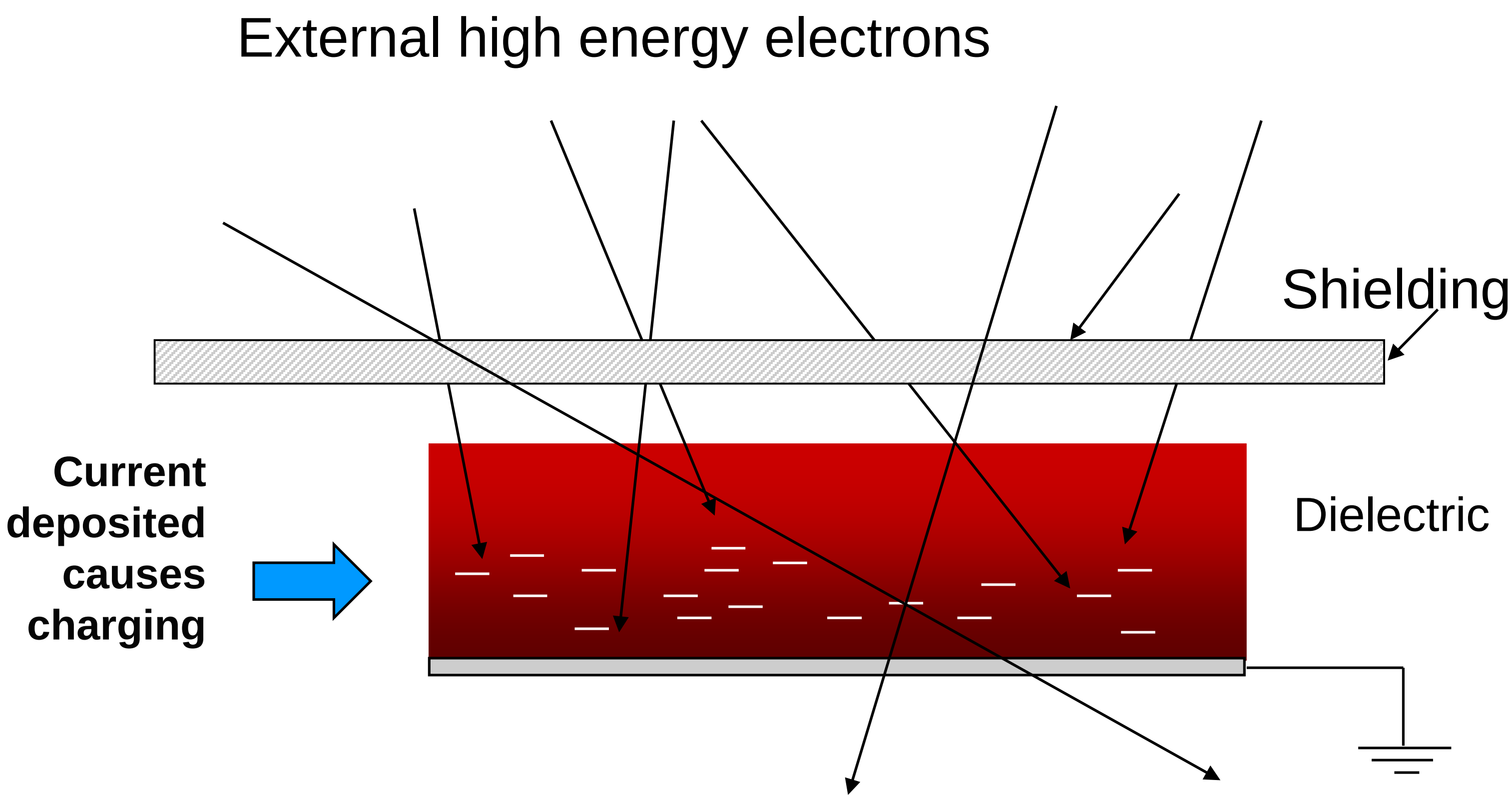


Image: NASA

Internal charging



- Internal electric field is the parameter which determines ESD events
- Dielectric breakdown typically at ~10^7 V/m
- Ideally would have observations of **electric fields** developed inside the dielectrics

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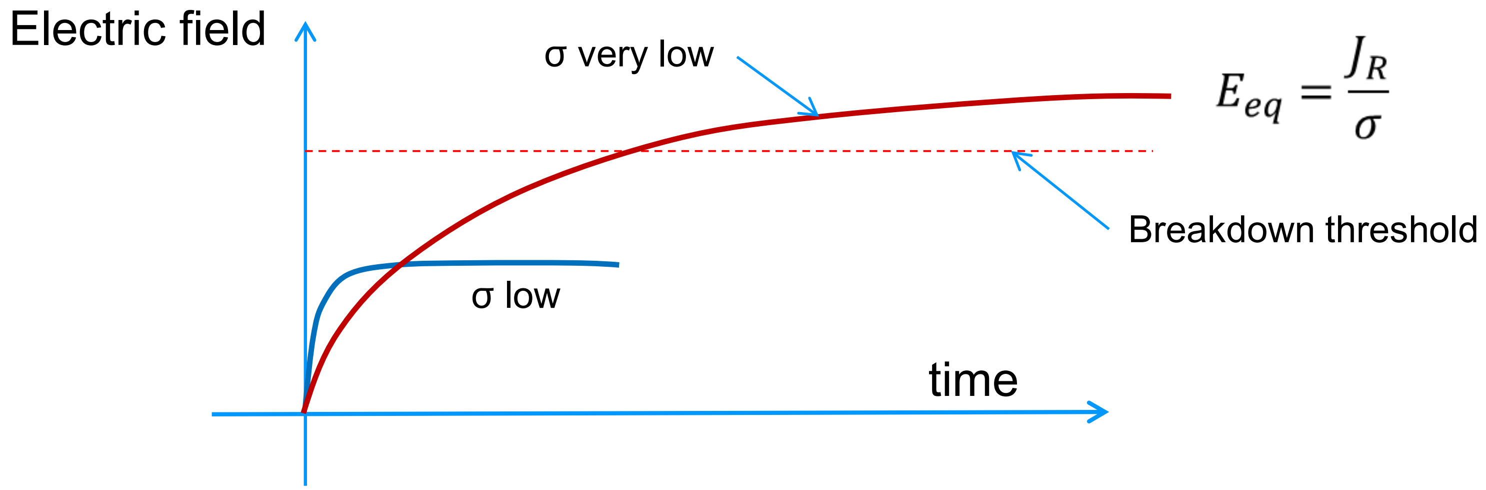
Internal charging curve

At a given depth and assuming non-varying conductivity:

$$E(t) = \frac{J_R}{\sigma}\left(1 - e^{-\frac{t}{\tau}}\right)$$

where $\tau = \frac{\varepsilon_0 \varepsilon_r}{\sigma}$



If σ is small (leading to large equilibrium E-fields) then time constant is long

Modelling electric field in dielectrics

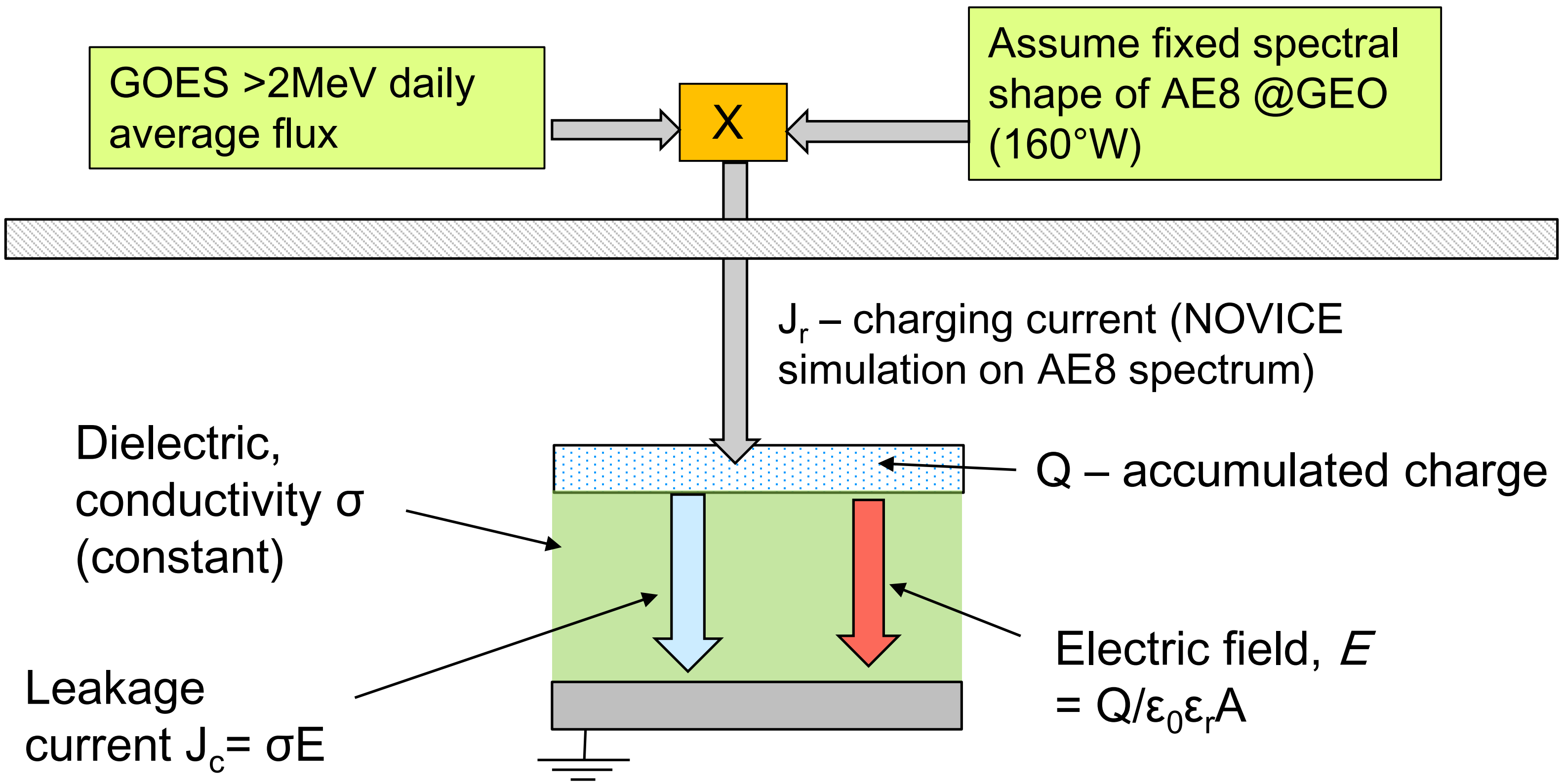
Mike Bodeau* examined charge/field build-up using a ‘leaky capacitor’ model

Used GOES record of energetic electron fluxes in GEO to create a 20 year history of electric field/charge density

For long time constant materials the 0.1pA cm^{2}’ charging current rule could be insufficient. Maybe be factor of ten lower for some materials.

*M Bodeau, High Energy Electron Climatology that Supports Deep Charging Risk Assessment in GEO, Proc. of 48th AIAA Aerospace Sciences Mtg, January 2010, Orlando, Florida.

1-D leaky capacitor model



$$E(t+\Delta t) = E(t)\cdot e^{-\frac{\Delta t}{\tau}} + \frac{J_r}{\sigma}\left(1 - e^{-\frac{\Delta t}{\tau}}\right)$$

where $\tau = \dfrac{\varepsilon_0 \varepsilon_r}{\sigma}$

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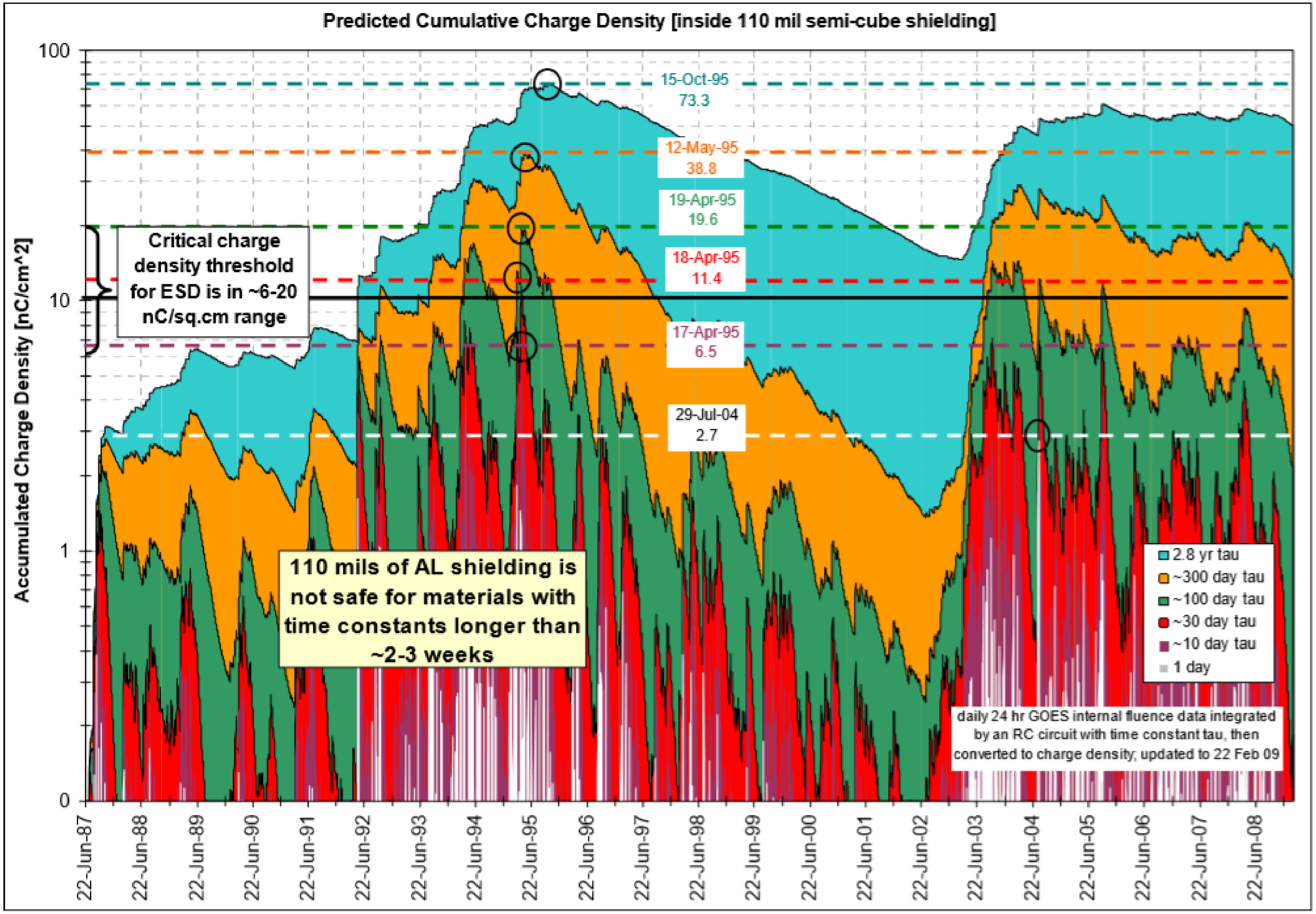
Figure 12. 110-mil Shielding is Unsafe for Materials with Long Decay Time Constant



*M Bodeau, High Energy Electron Climatology that Supports Deep Charging Risk Assessment in GEO, Proc. of 48th AIAA Aerospace Sciences Mtg, January 2010, Orlando, Florida.

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Drawbacks of the simple model

Fixed electron spectrum scaled by >2MeV flux

- AE8 is a static long term average spectrum whereas actual one is continually changing

Fixed bulk conductivity

- Radiation induced conductivity in dielectrics not accounted for
- Can time constants really be as long as weeks, months or years?

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New developments in this paper

Use in-flight measured deposited currents

- Instead of 2MeV flux + fixed spectrum + radiation transport calculation
- Directly acquired by the SURF instrument

Include radiation induced conductivity (RIC)

- important in many polymers

MEO orbit E-field modelling

- critical infrastructure located here (navigation satellites)
- significant internal charging threat
- this is where our measurements are from

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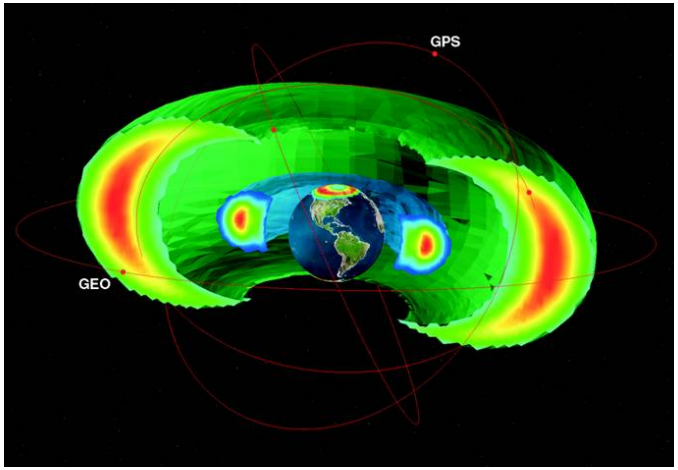
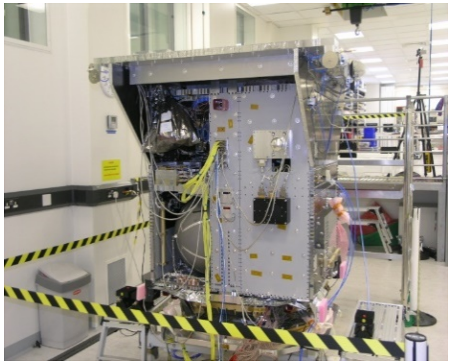
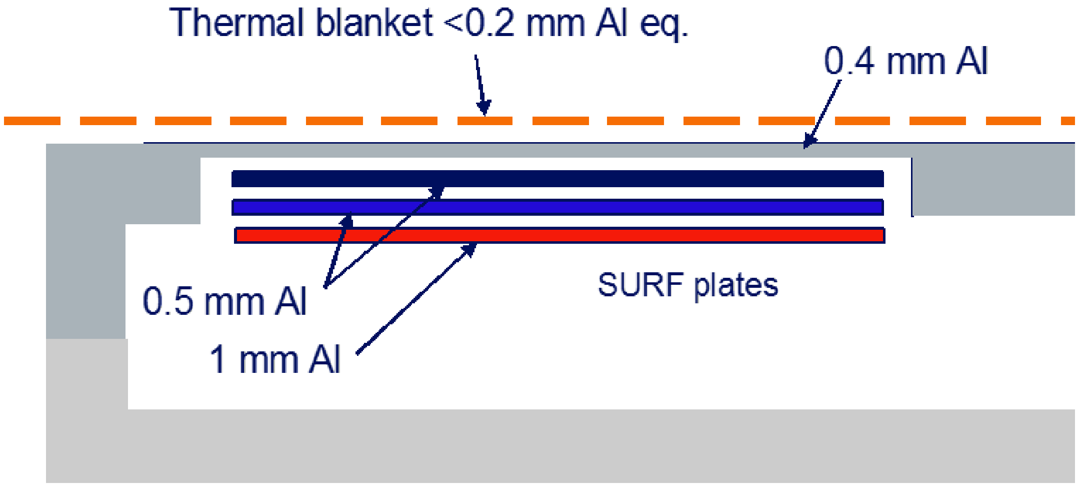
Internal charging current measurements

- December 2005 launch
- Orbit 23,260 km and 56 degrees inclination, 27 month lifetime
- Re-orbited by +300km in 2009
- Still collecting data.







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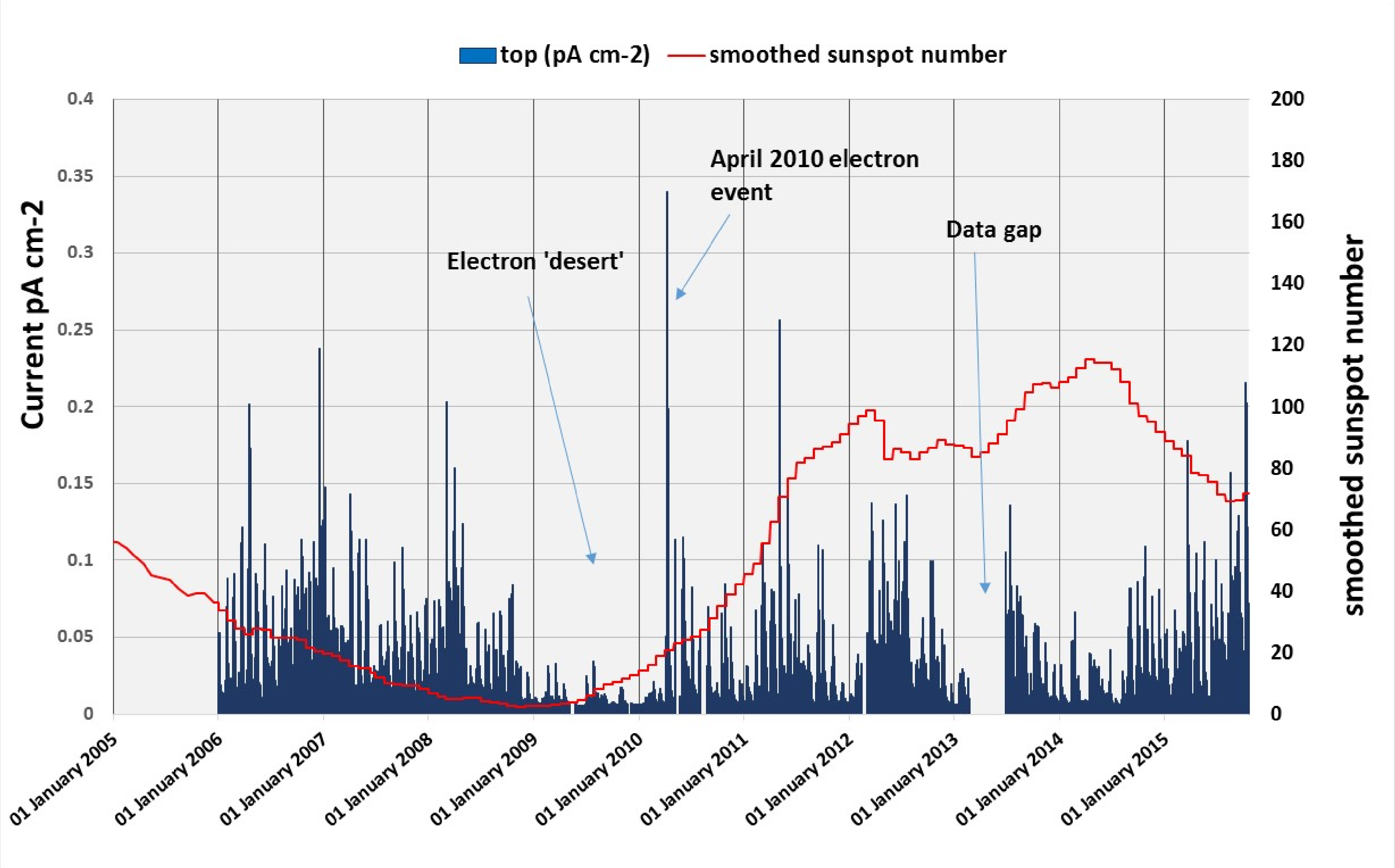
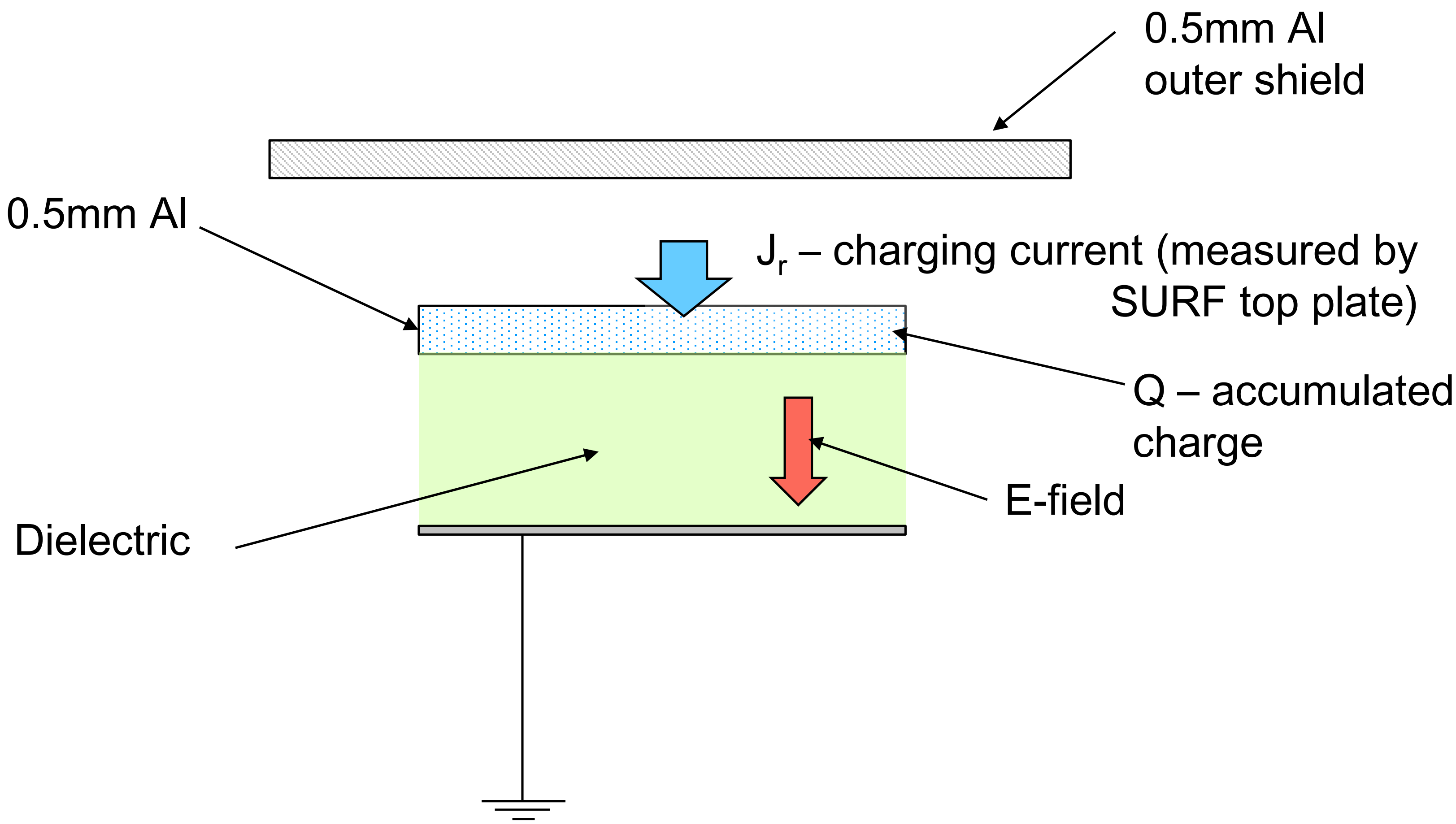
Top plate charging current (daily averages)

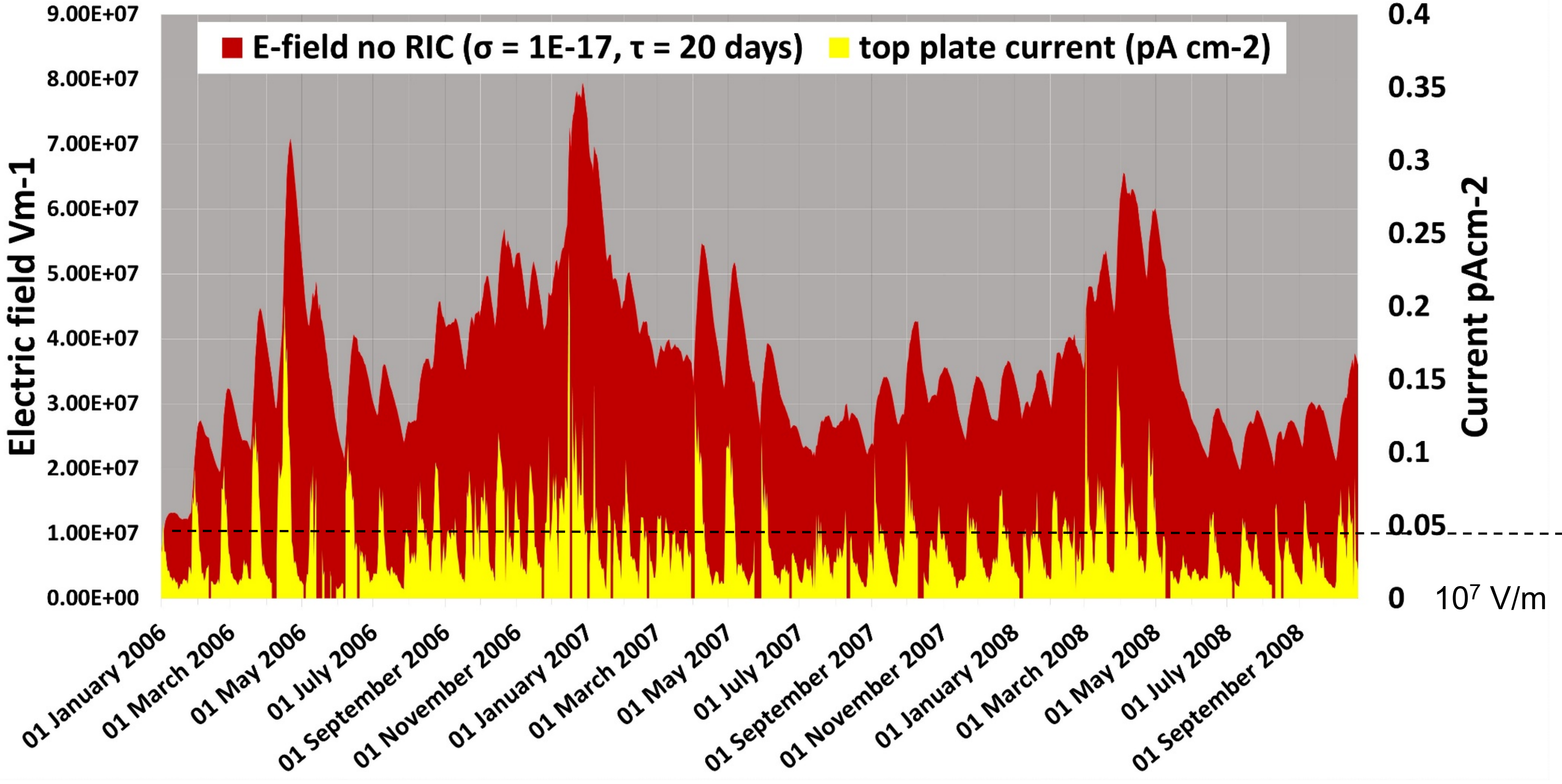


Leaky capacitor model



Dielectric internal field modelling (2006 – 2008)

0.5 mm Al shielding; 0.5mm Al-eq. thickness dielectric



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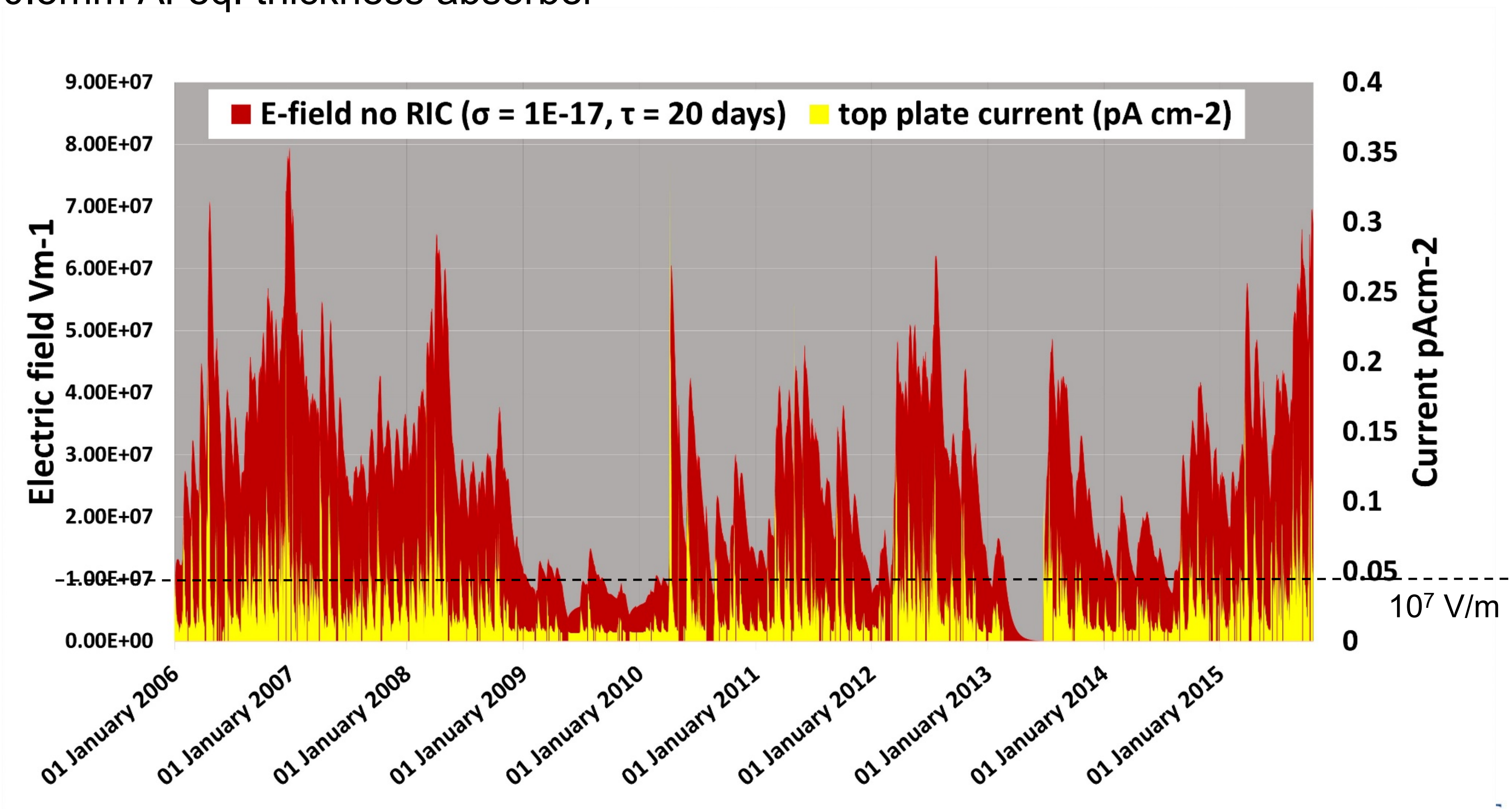
Dielectric internal field modelling (2006 - 2009)

0.5 mm Al shielding

0.5mm Al-eq. thickness absorber



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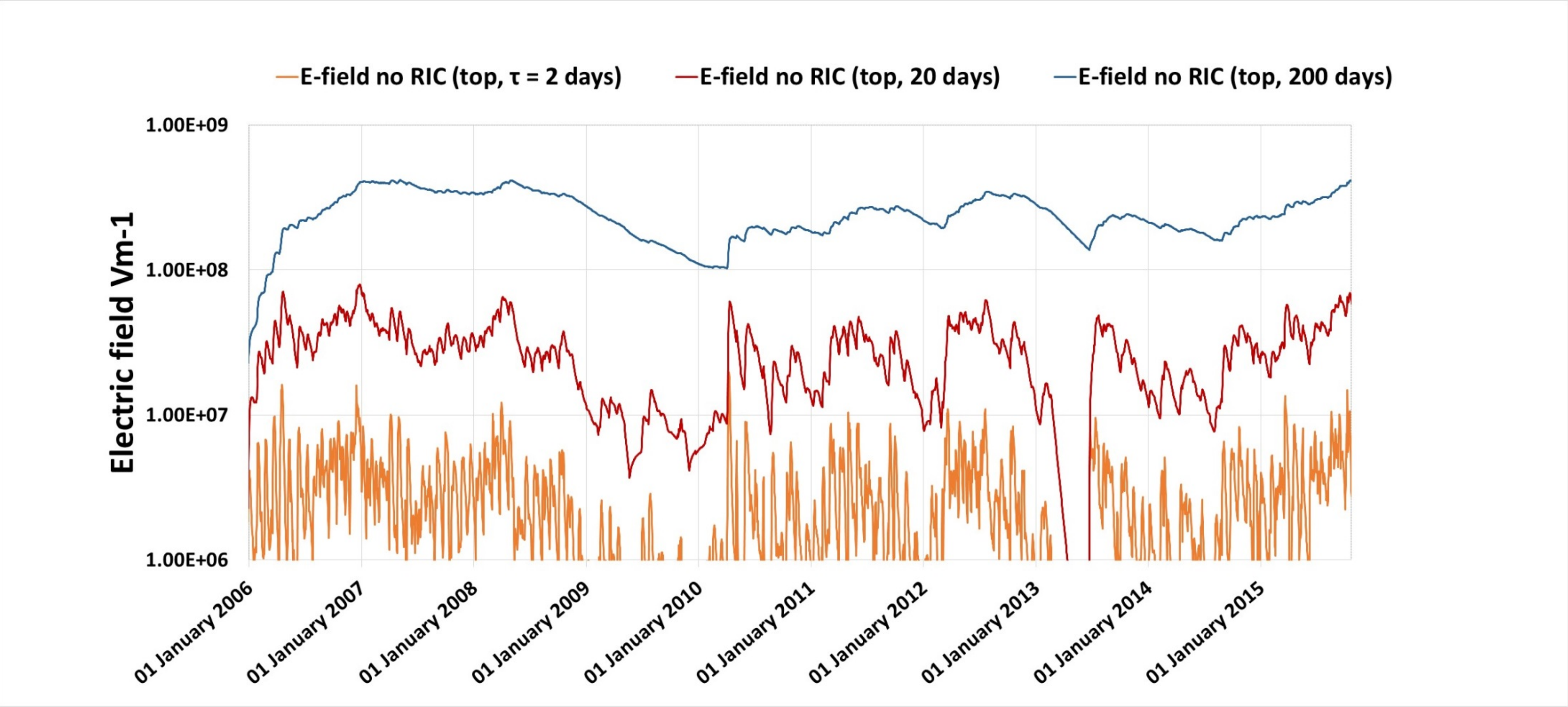
Electric fields (MEO, 0.5mm Al shield, 0.5mm Al-eq absorber, no RIC)

0.5 mm Al shielding; 0.5mm Al-eq. thickness absorber



Radiation induced conductivity (RIC)

Ionising dose leads to generation of additional charge carriers

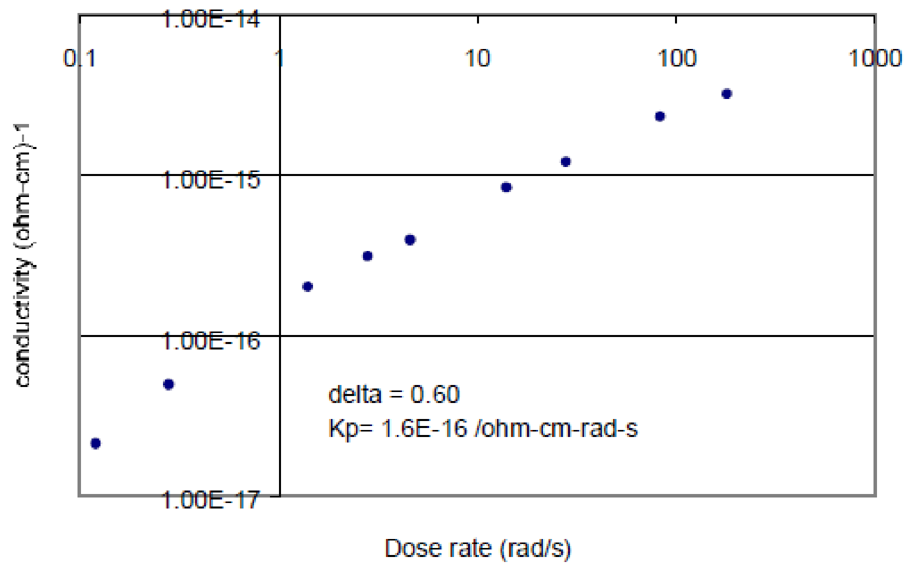
Can be due to primary particles or secondary (bremsstrahlung)

$$\sigma = \sigma_0 + k_p \dot{D}^{\Delta}$$

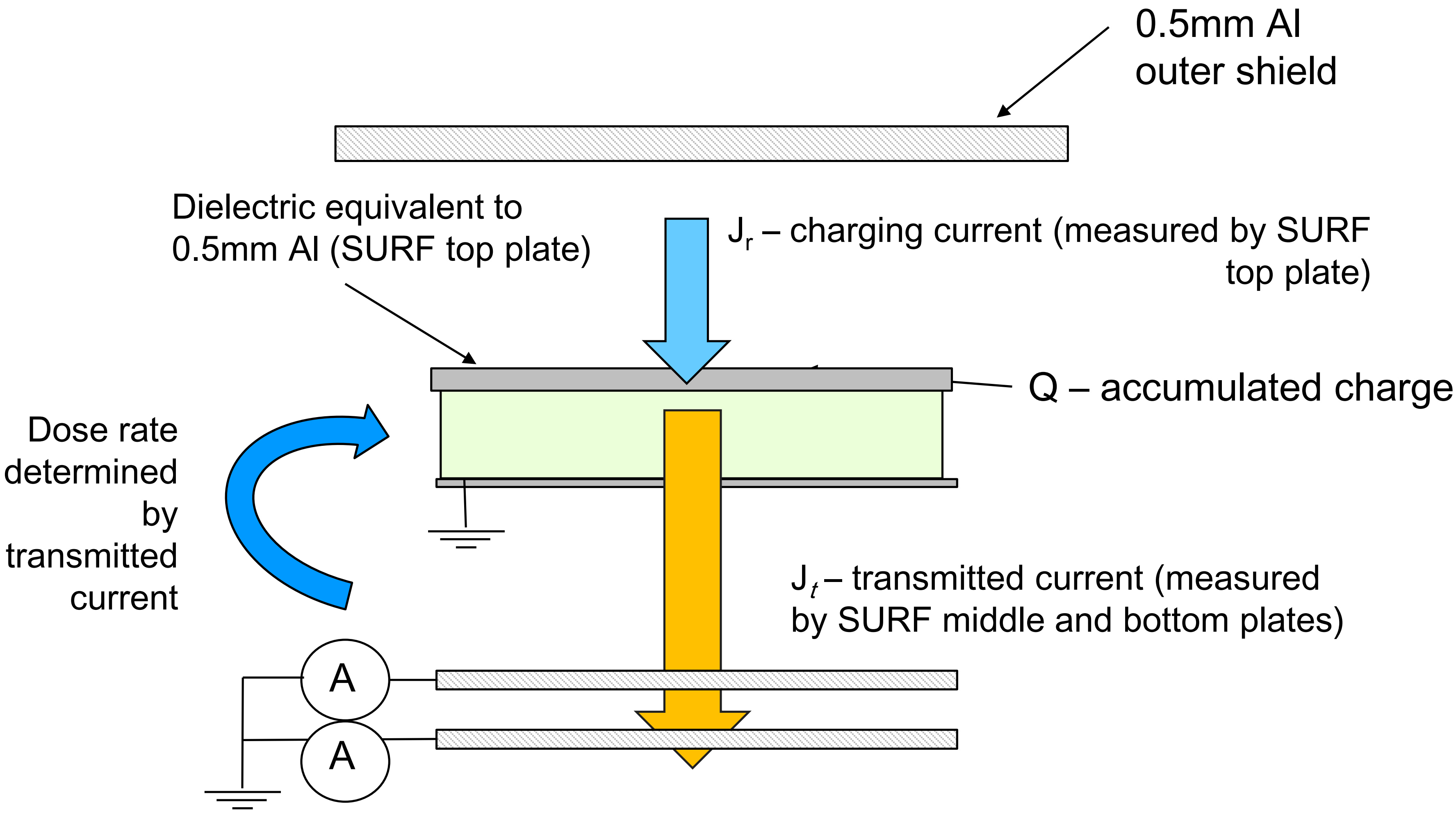
Where σ_0 is the dark conductivity ($\Omega^{-1}cm^{-1}$)

- k_p is the co-efficient of prompt RIC ($\Omega^{-1}cm^{-1}$ rad^{-1} s)
- $\dot{D}$ is ionising dose rate (rad s^{-1})
- Δ is a dimensionless material dependent exponent (Δ<1)

Δ is typically in range 0.6 to 1.0

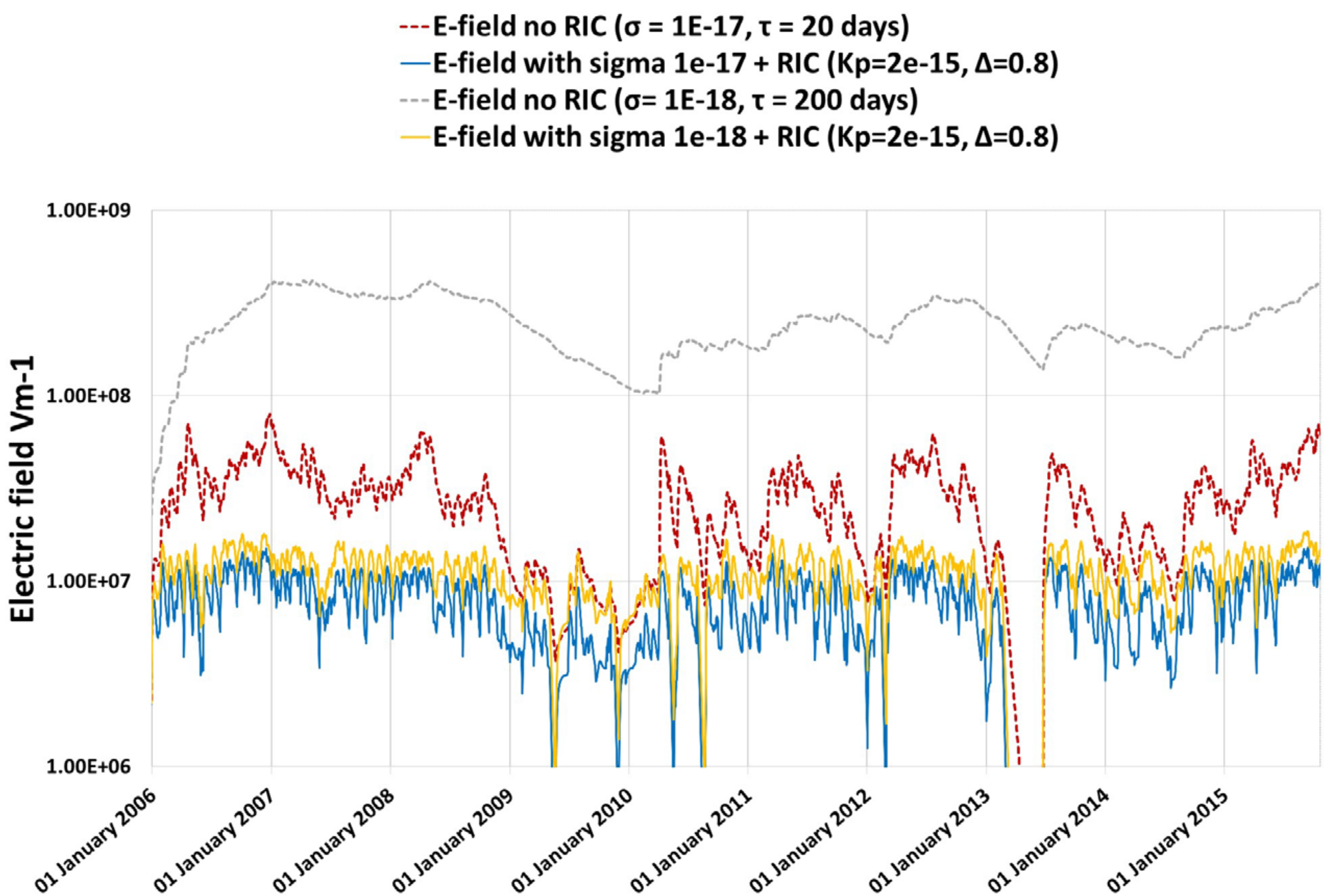


Leaky capacitor (with RIC added)

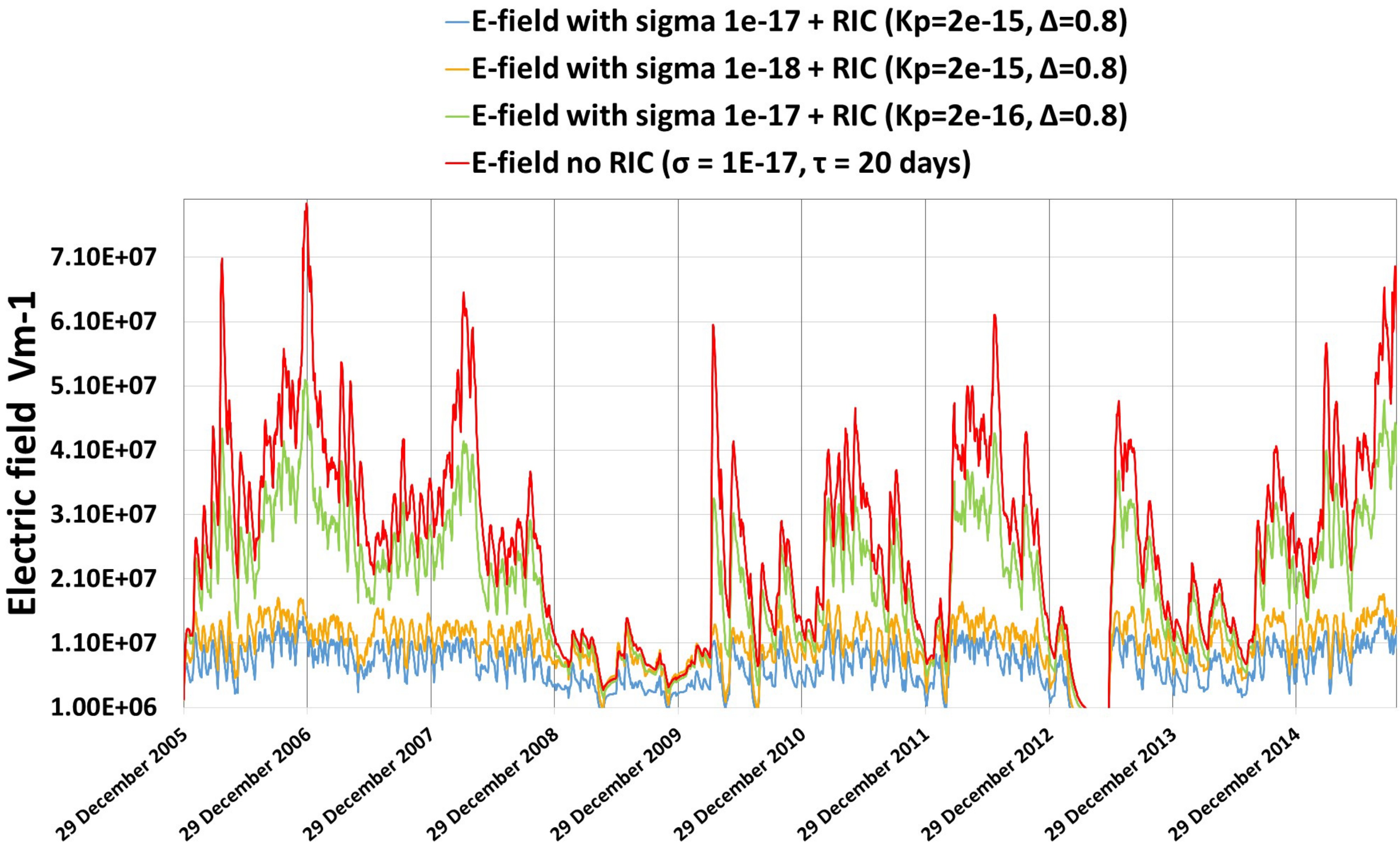


dD/dt [rad/s] = $1.92 \times 10^{11} J_t$ [A m^{-2}]

Effect of including RIC



Effect of changing conductivity parameters



Conclusions

Modelling of dielectric internal fields is assisted by using in-flight current measurements

Can take into account RIC: clearly important moderating factor on time constants and field strengths

Need better knowledge of RIC parameters

Need more in-flight charging current measurements

Can generate a space weather ESD threat ‘index’ – could be done in real time.

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