Improved model for correcting the ionospheric impact on bending angle in radio occultation measurements

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Background

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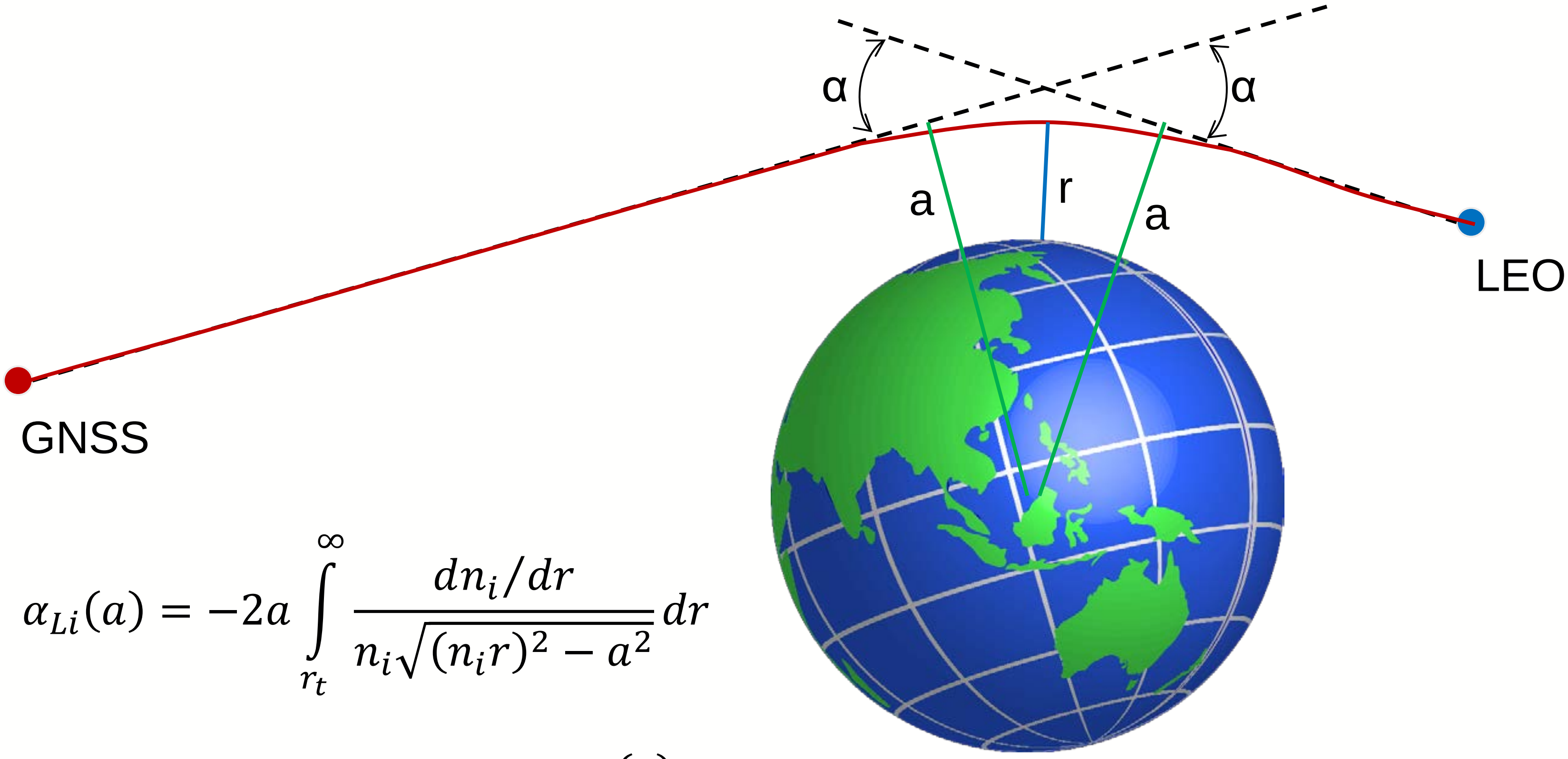
Radio Occultation



$$\alpha_{Li}(a) = -2a \int_{r_t}^{\infty} \frac{dn_i/dr}{n_i\sqrt{(n_i r)^2 - a^2}}\, dr$$

$$n_i \cong 1 + 10^{-6} N_n(r) - 40.3\,\frac{n_e(r)}{f_i^2}$$

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Standard ionospheric correction

- Neutral atmosphere bending angles are corrupted by the ionospheric bending
- Standard correction relies on dual frequency measurements
  - Described by Vorobev and Krasilnikova [1994]

$$\alpha_c(a) = \alpha_{L1}(a) + \frac{f_2^2}{f_1^2 - f_2^2}\left[\alpha_{L1}(a) - \alpha_{L2}(a)\right]$$

  - Approach is based on the standard parameters estimated by the retrieval system and does not require *a priori* information about the ionosphere
  - Downside is that a systematic bending angle error remains
    - Small, but bias important for climate studies
  - Can be shown to be a function of the electron density squared, integrated over the vertical profile

Modified correction

- Healy and Culverwell [2015] have proposed a modification to the standard ionospheric correction of the form:

$$\alpha_c(a) = \underbrace{\alpha_{L1}(a) + \frac{f_2^2}{f_1^2 - f_2^2}[\alpha_{L1}(a) - \alpha_{L2}(a)]}_{\text{Standard VK94 correction}} + \underbrace{\kappa(a)(\alpha_{L1}(a) - \alpha_{L2}(a))^2}_{\text{Residual error}}$$

Standard VK94 correction

Residual error

Modified correction

- Healy and Culverwell [2015] investigated the new correction term using analytic solutions to provide simple ionospheric profiles (i.e. Chapman)
- Danzer, Healy and Culverwell [2015] investigated using a ray trace
  - Limited success due to noisy results
- Both investigations concluded:
  - Residual error is approximately proportional to the TEC^2
  - κ is a weak function of impact parameter
    - In the range of 10 to 20 rad^{-1}

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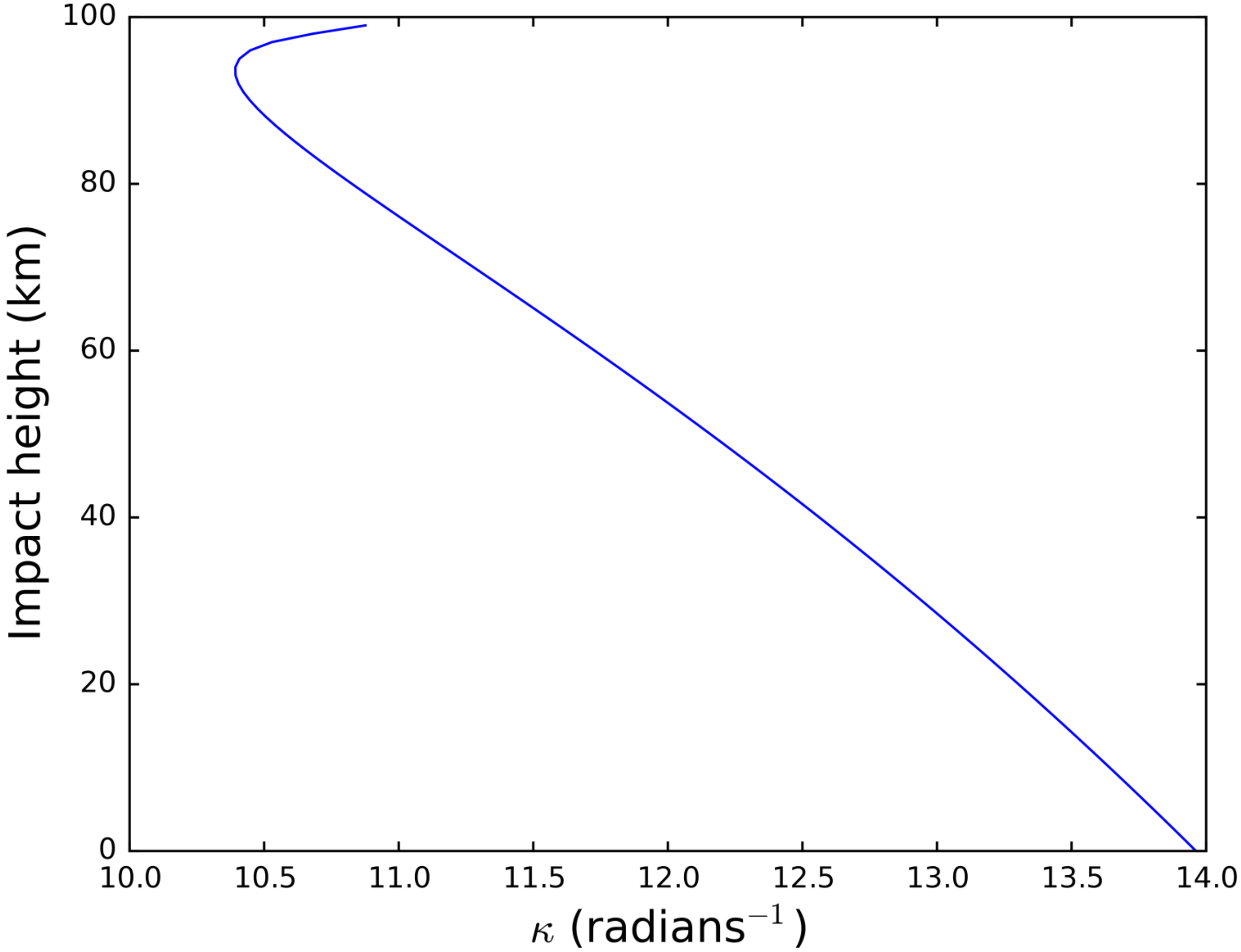
Investigation with NeQuick

Investigation with NeQuick

- An ionospheric model can be used to investigate the form of κ
- For this work NeQuick is used
  - “Version 3”
    - Tidied up D region
    - Hard limit of R12=150 / F10.7 = 193 removed
    - Day of month used to linearly interpolate between two monthly CCIR files
- Estimate bending angle using 1D observation operator for L1 and L2
- Form VK94 corrected bending angle (α_c)
- Since no neutral atmosphere any non-zero values of α_c are representative of the residual error

Example vertical profile of kappa



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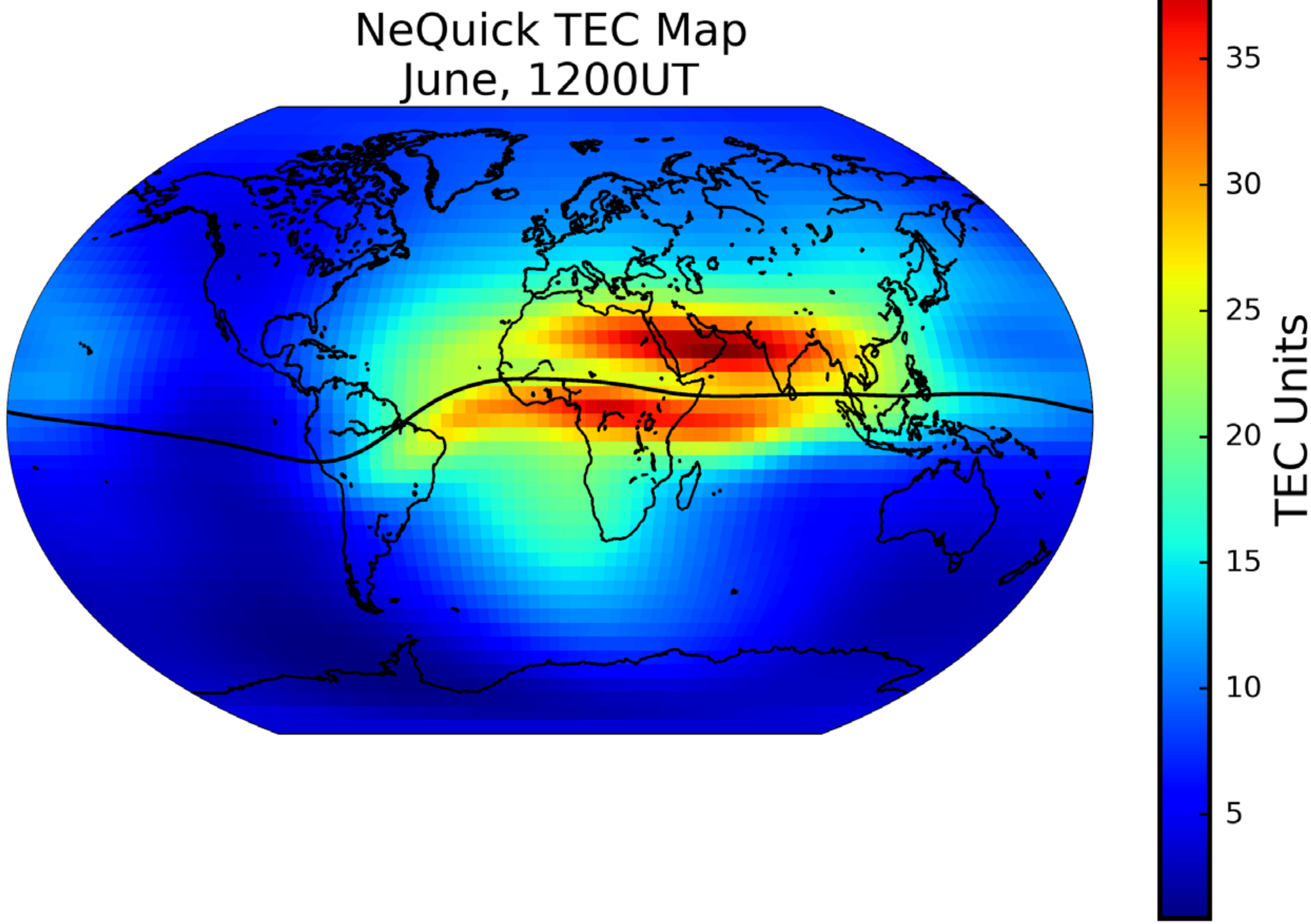
Example – June, f10.7=100



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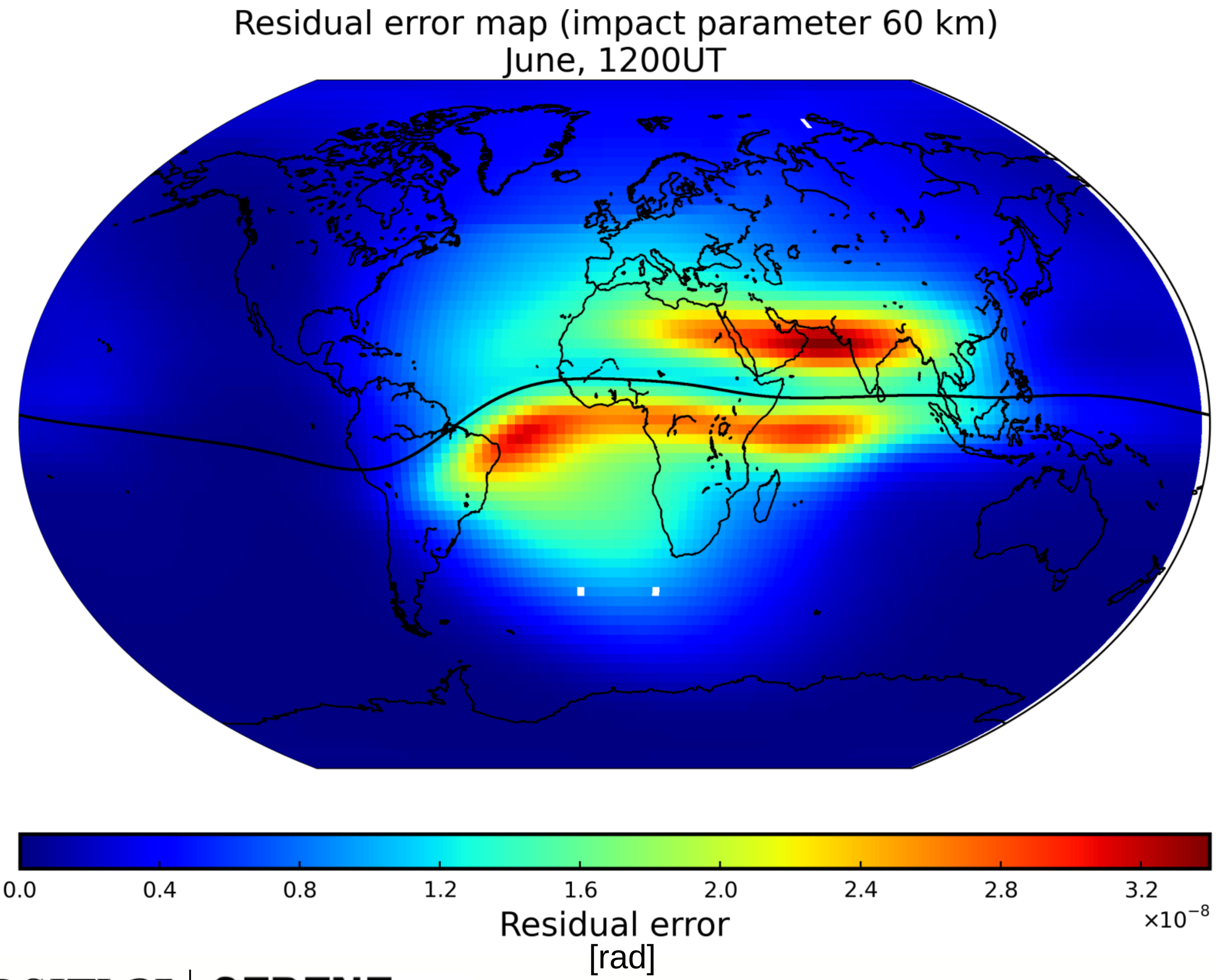

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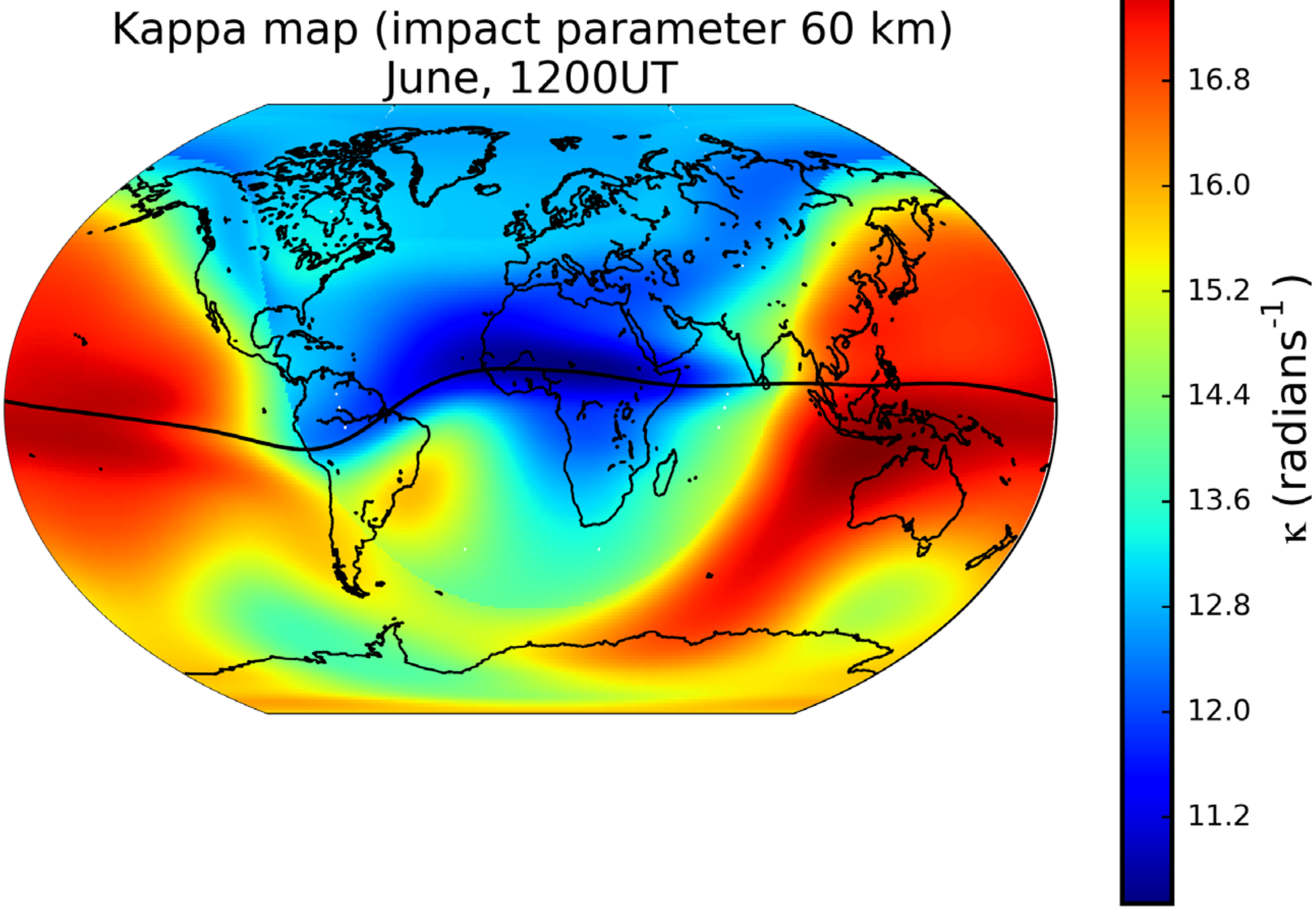
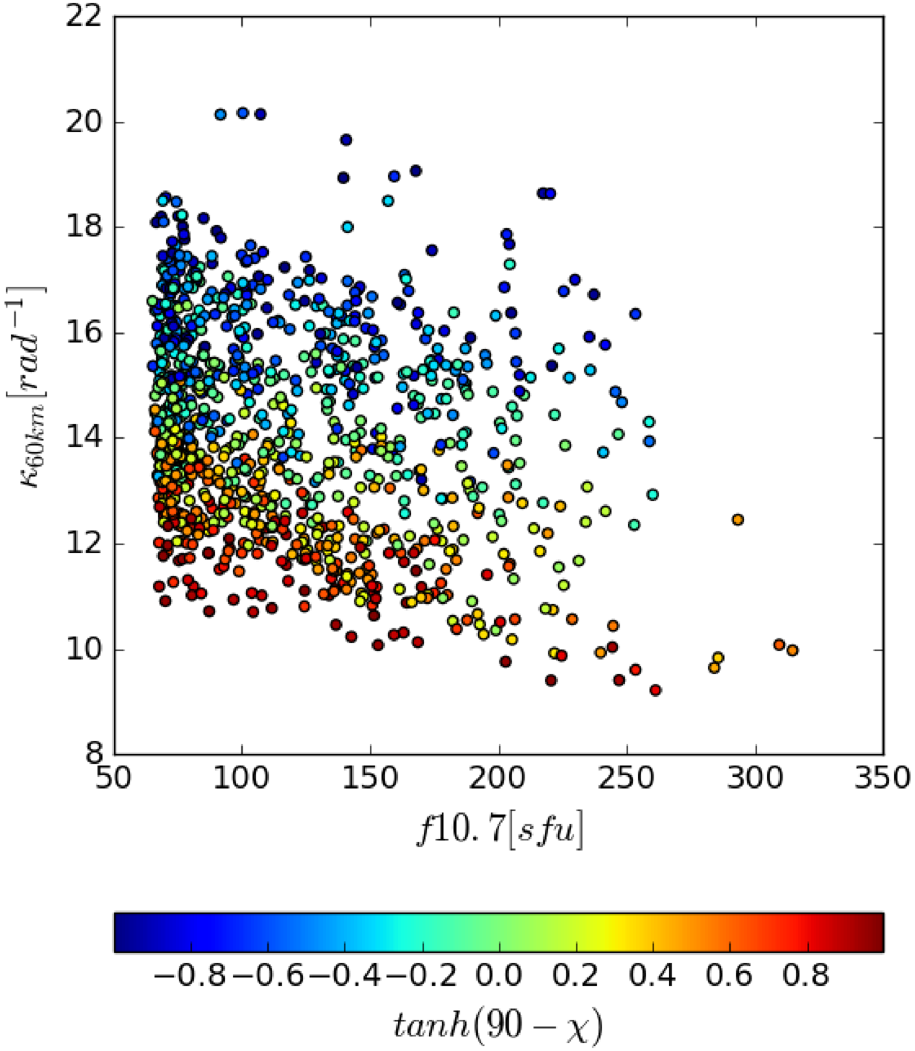
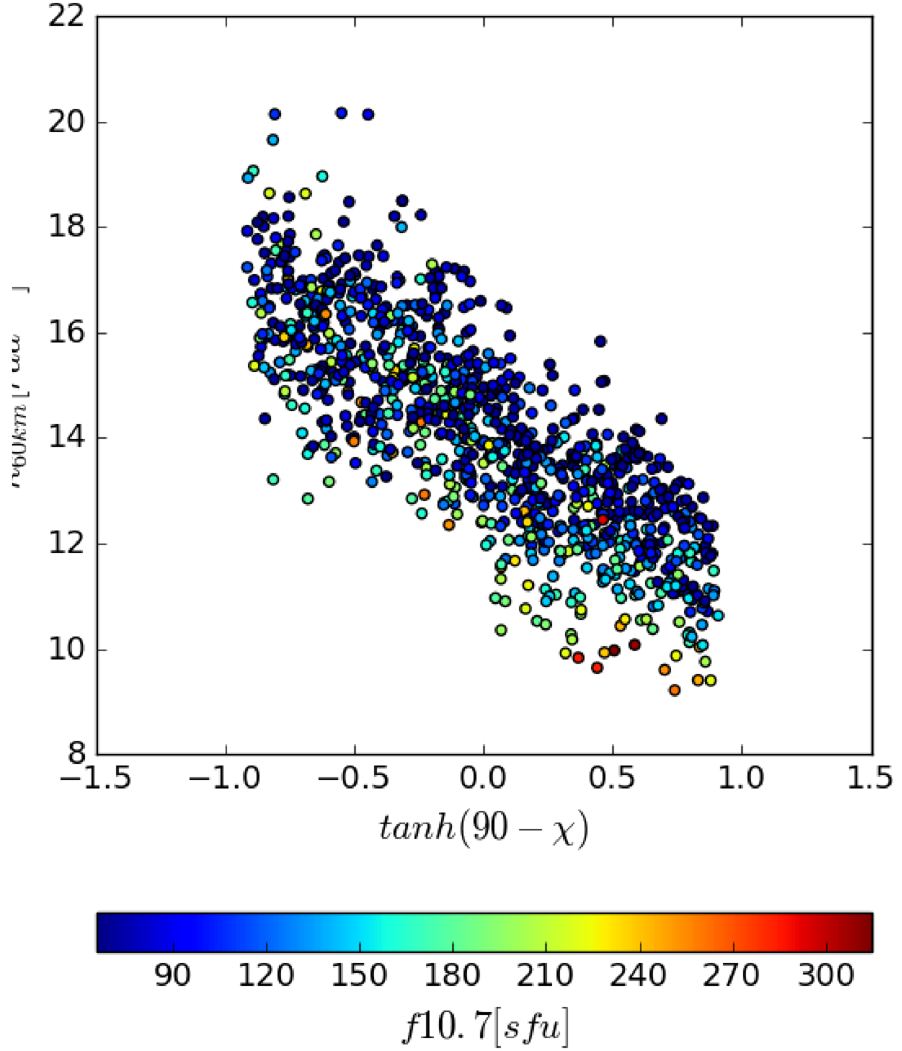


Simple kappa model

- Randomly select locations and time
  - 0 to 360° longitude
  - -80 to 80° latitude
  - 1960 to 2010
- Get f10.7 from database
- Calculate solar zenith angle
- Get L1 and L2 bending angles
- Get VK94 corrected bending angles
  - 1D approximation
- Estimate kappa

Dependency of kappa on f10.7 and tanh(90-χ)





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Proposed model

$$\kappa = a + b(f10.7) + c\tanh\left(\frac{\pi/2 - \chi - d}{e}\right)$$

- fit (curve_fit from scipy.optimize)
  - a = 15.3
  - b = -1.02×10^{-2}
  - c = 2.51
  - d = 4.01×10^{-3}
  - e = -0.63

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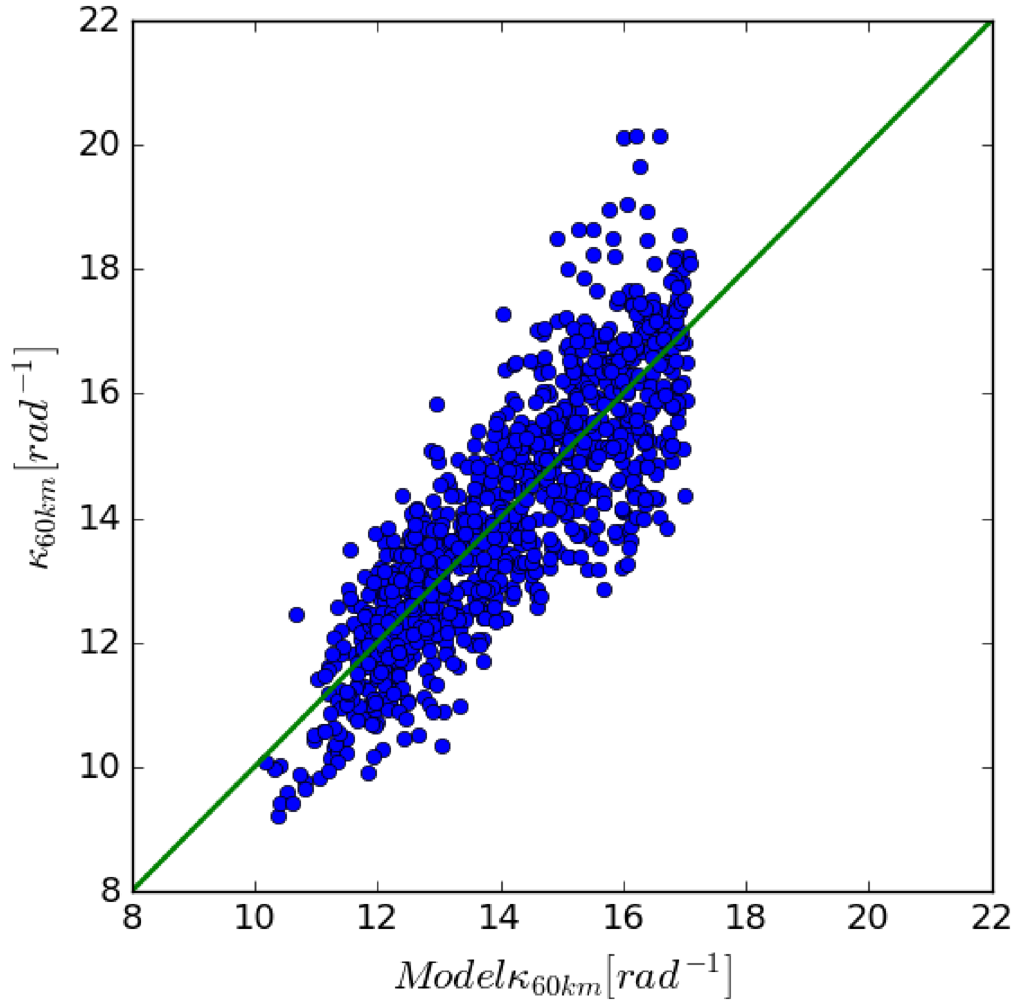

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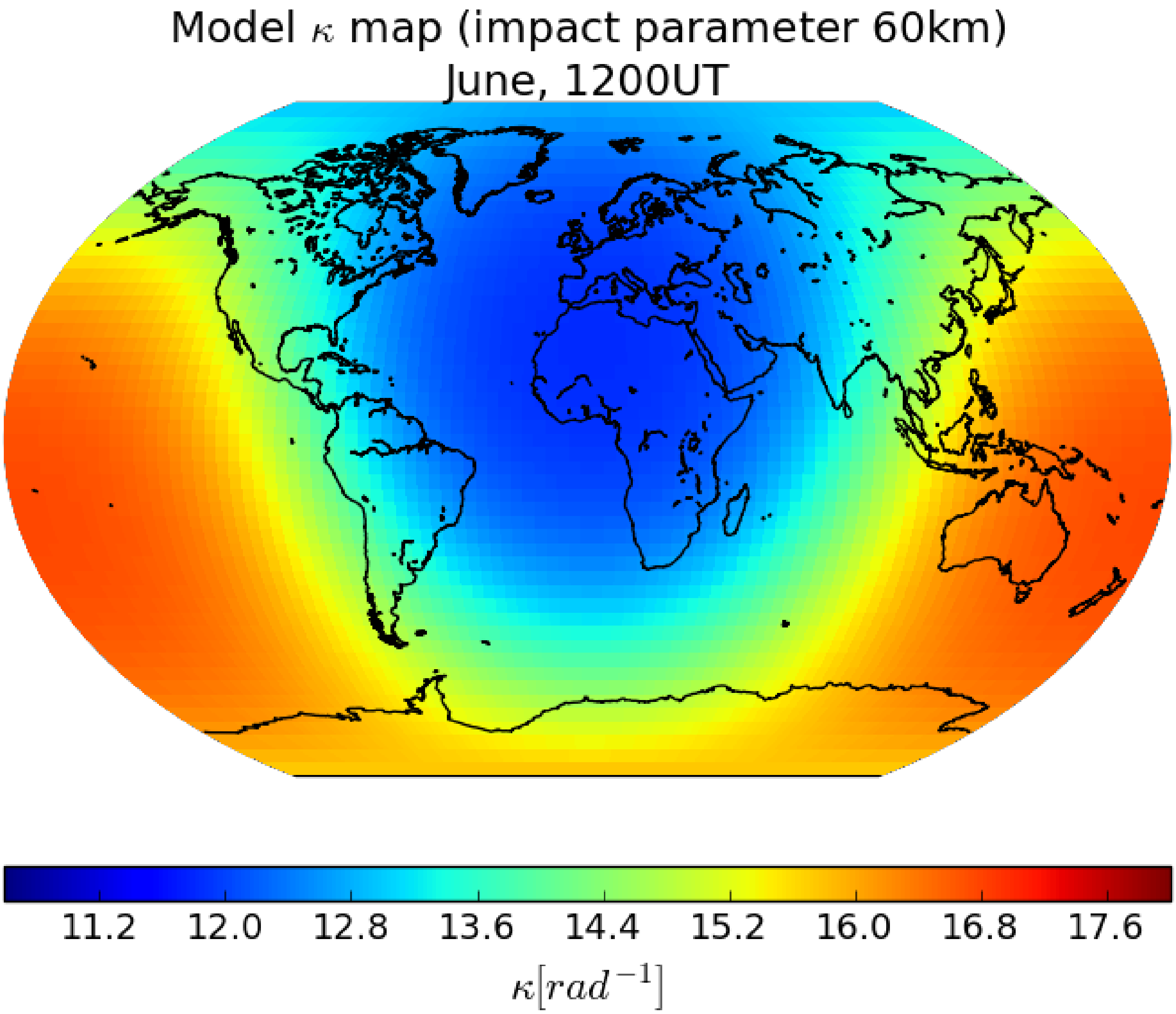

Conclusions

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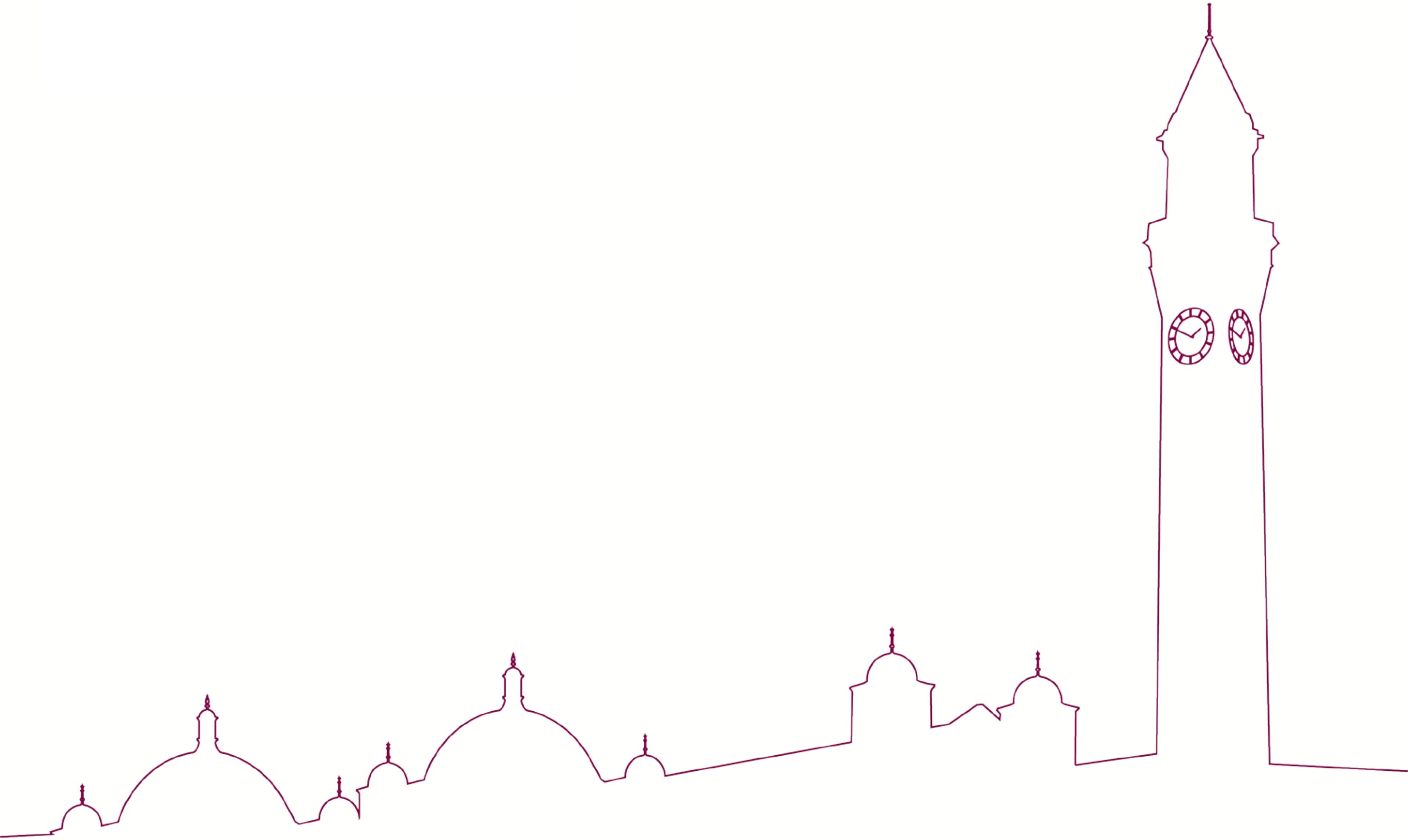
- A good model for the residual error in the ionospheric correction has the potential to improve stratospheric RO assimilation
  - Small error, but bias important for climate studies
- The spatial and temporal behaviour of kappa can be investigated using an ionospheric model
  - A simple model for kappa has been proposed
  - Usual RO assumptions apply
- Future work
  - Include height dependency in model
  - Testing
    - ray tracing
    - Other?



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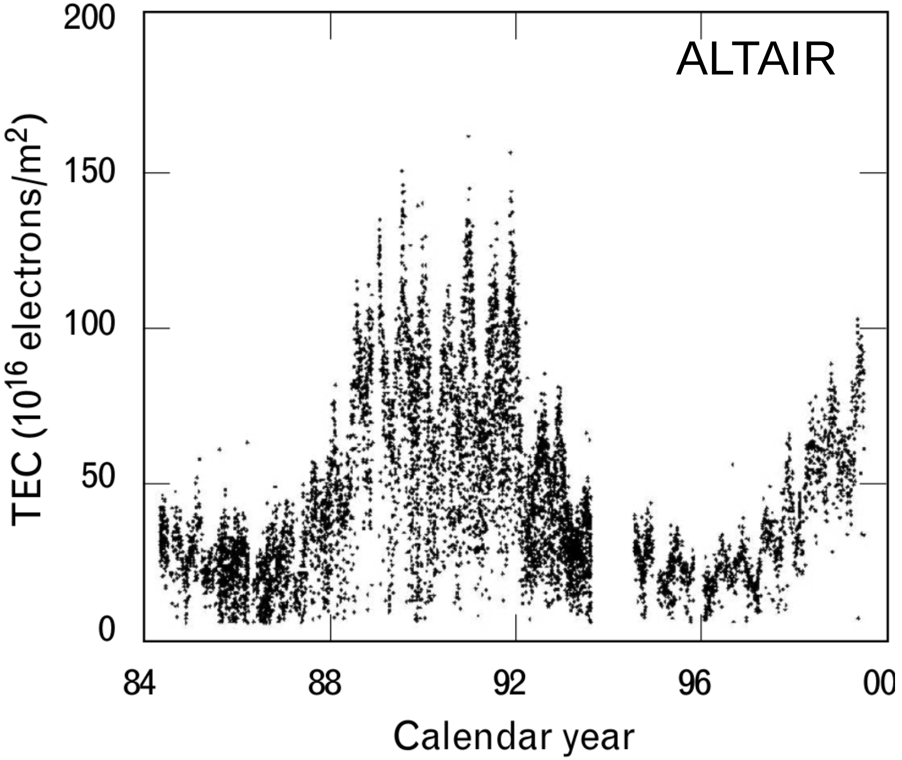
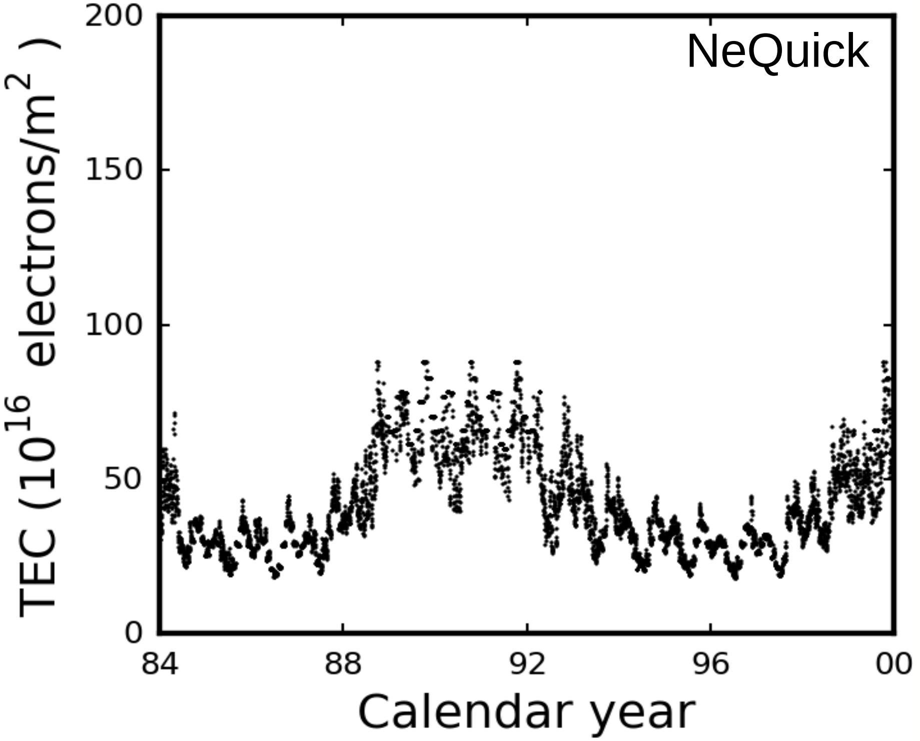
NeQuick f10.7 limit





From Hunt, S.M., S. Close, A. J. Coster, E. Stevens, L. M. Schuett, A. Vardaro, (2000), 12(1), Lincoln Laboratory Journal.

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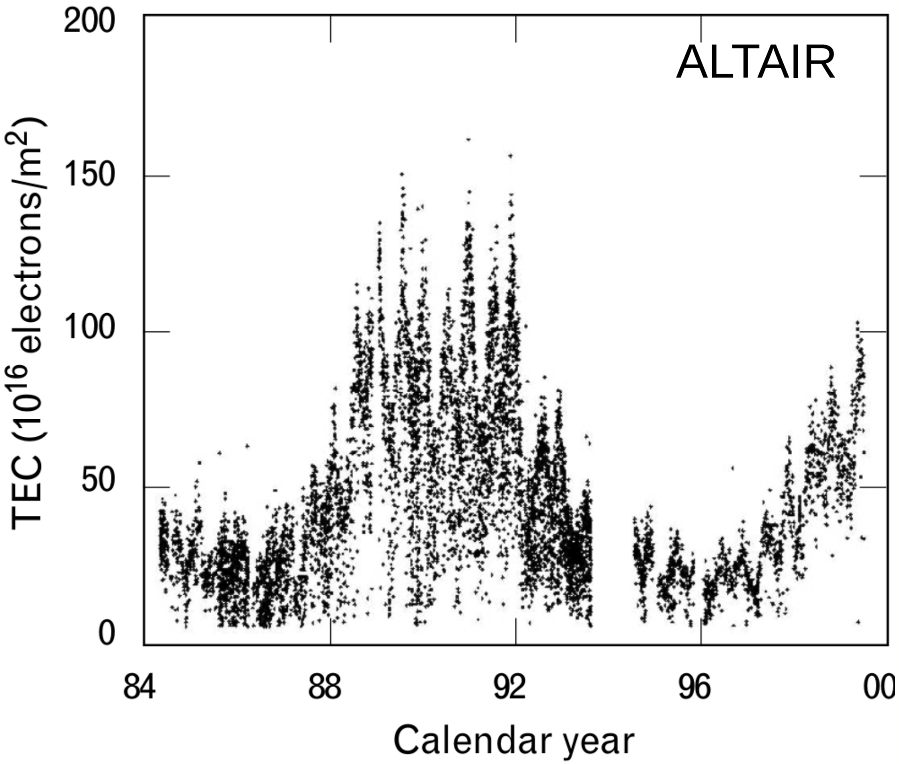

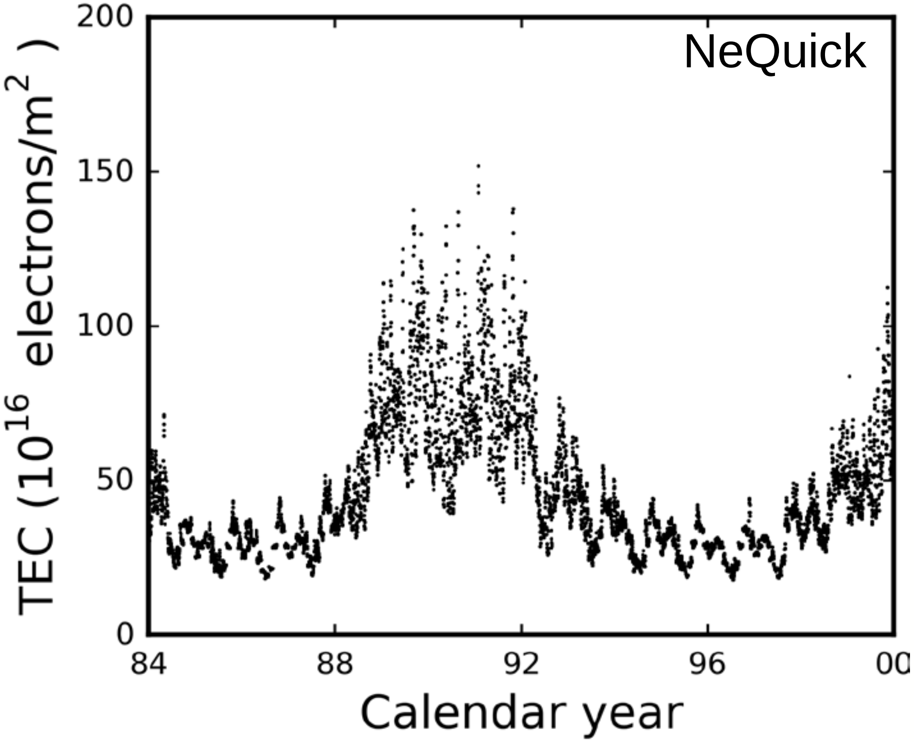

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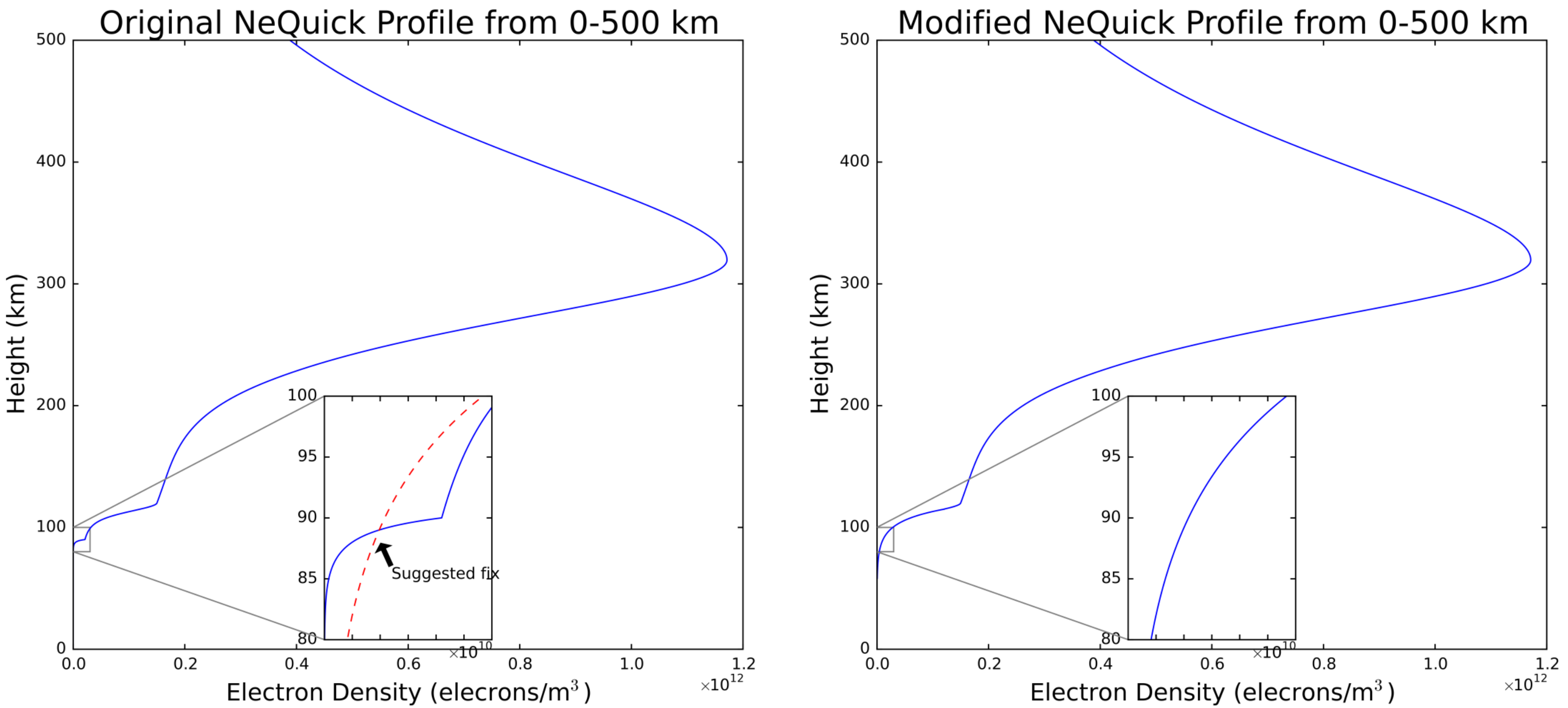
NeQuick D region



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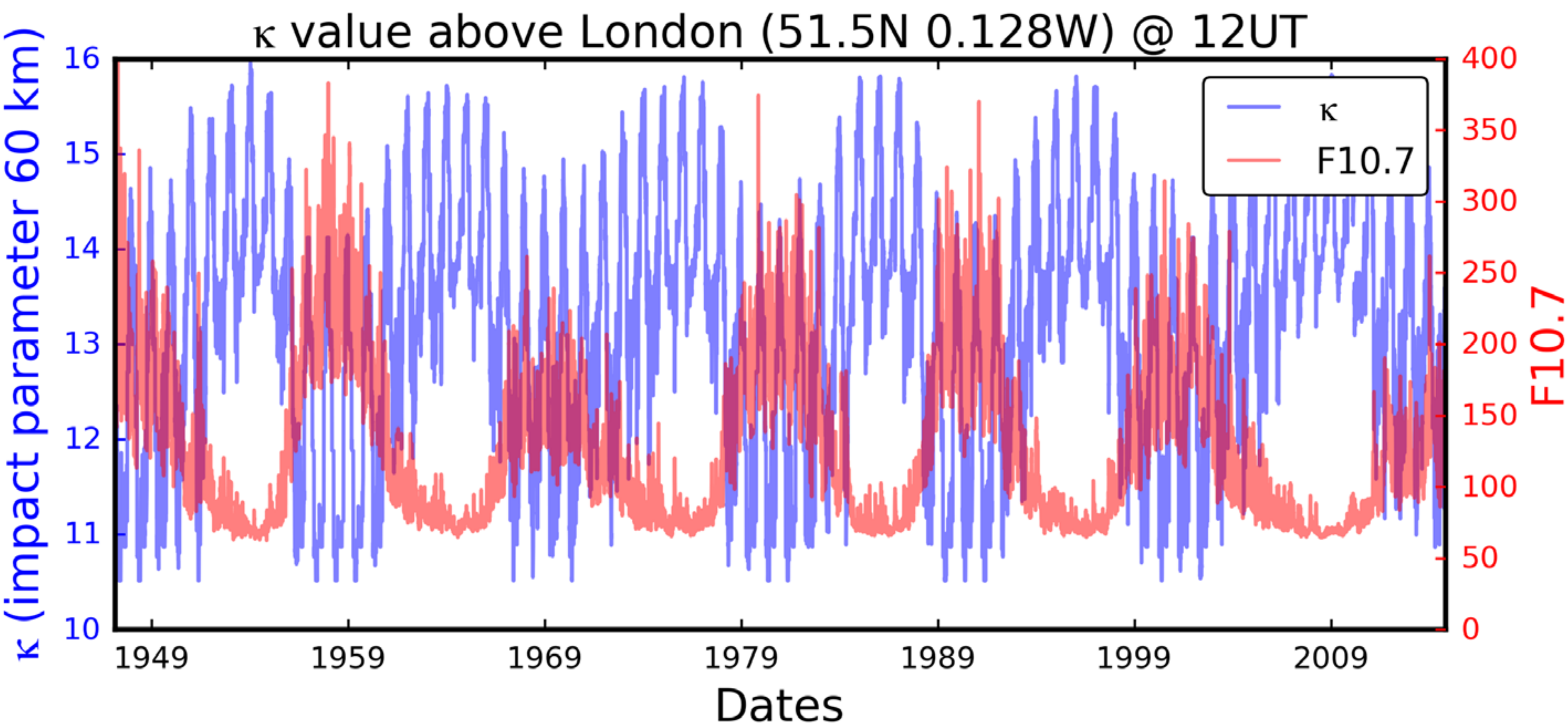

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