

# Effective Height of Towers on Mountain Tops in Lightning Incidence Studies: Sensitivity Analysis

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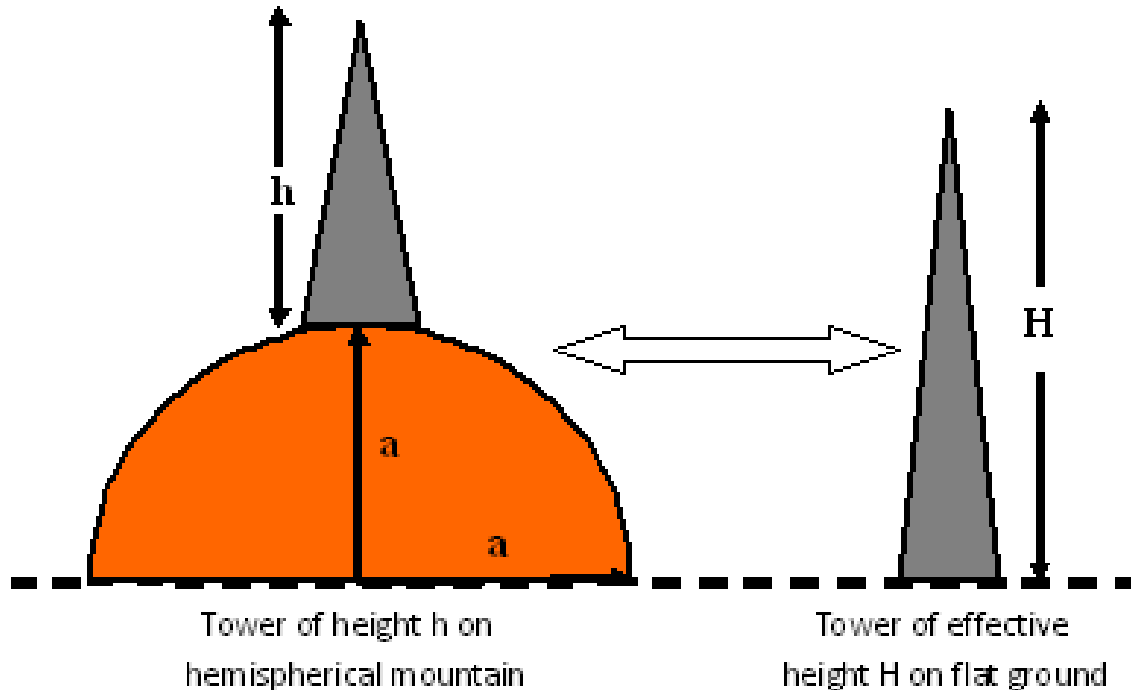
# Outline

- Introduction to Effective Height of Towers
- Rizk-Model Method & Results
- Sensitivity Analysis
- Discussion and Conclusions

# Introduction to Effective Height of Towers

- Usually the upward flashes can occur only when the tower height is exceeding **100 m** on the flat ground.
- However, if the tower is located on mountaintop, even the tower height **less than 100 m**, upward flashes can be triggered.
- So, an **effective height** for the tower held at mountaintop is introduced, it's **greater than the tower's physical height**.

# Definitions of Effective Height



The concept of effective height assuming a hemispherical mountain. The structure with height  $H$  on the flat ground will experience the same lightning incidence as the structure of height  $h$  on the mountain of height  $a$ .

# Estimations of Effective Height

- **Pierce**'s estimate was based on the observed higher lightning incidence to the mountaintop towers compared to similar towers on the flat ground.
- **Eriksson**'s approach is based on the observed percentage of the upward flashes ( $P_{u1}$  and  $P_{u2}$ ) initiated from towers of different height  $H_s$ .

$$P_{u1} = 68.2 \ln(H_s) - 315.5 \quad P_{u2} = 52.8 \ln(H_s) - 230$$

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# Rizk-Model Method

Rizk suggested two criteria for occurrence of upward flashes

$$\left\{ \begin{array}{l} U_i \geq U_{lc} + x_0 E_\infty \ln\left(\frac{E_i}{E_\infty}\right) \end{array} \right. \quad (1a)$$

$$\left\{ \begin{array}{l} E'_g \geq E_\infty \end{array} \right. \quad (1b)$$

$U_i$  is the ambient electric potential at the top of structure;

$x_0$  (5 m) is a leader length proportional to **the upward positive leader speed**;

$U_{lc}$  is the threshold for continuous leader inception potential;

**$E_\infty$  is the final quasi-stationary leader gradient (3 kv/m);**

**$E_i$  is the minimum positive streamer gradient (400 kv/m);**

$E'_g$  is the mean ambient electric field along the ascending leader path.

# Rizk-Model Method

Where  $U_i$ ,  $U_{lc}$  are given by as follows:

$$U_i = E_g \cdot (h + a) \cdot \left[ 1 - \frac{a^3}{(h + a)^3} \right] \quad \text{For the hemisphere-shaped mountain}$$

$$U_{lc} = \frac{1556 \times 10^3}{1 + \frac{7.78}{R}} \quad R = \frac{2(h + a)}{\left[ 1 + \frac{2a(h + a)}{(h + a)^2 - a^2} - \frac{2a(h + a)}{(h + a)^2 + a^2} \right]}$$



After determine the  $E_g$  in Equation (1a), we get the effective height  $H$  :

$$H = \left( k_1 + k_2 E_g \right)^{-k_3} \quad K_1, K_2, K_3 \text{ are constant.}$$

# Results

Object and Location	Tower Height (m)	Mountain Height (m)	Effective Height (m)		
			Pierce Method	Eriksson Method	Rizk-mode Method
Two towers 400 m apart. Mount San Salvatore, Lugano, Switzerland	70	640	270	350	198
Two TV towers Sasso di Pale, near Foligno, central Italy and Monte Orsa, near Varese, northern Italy	40	990	NA	500	120
CSIR research mast, Pretoria, South Africa	60	80	NA	148	113
Peissenberg tower, Hoher Peissenberg, Munich, Germany	160	288	NA	NA	324
St. Chrischona tower, Basel, Switzerland	248	493	NA	NA	468
Cachimbo tower, Brazil	60	200	NA	NA	145
Gaisberg tower, Salzburg, Austria	100	800	1000	400 and 450 using (1) and (2), respectively	274

Rizk-model Method is **smaller** than Pierce and Eriksson Method.

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  - 1) Final quasi-stationary leader gradient.**
  - 2) Minimum positive streamer gradient.**
  - 3) Upward positive leader speed.**
  - 4) Mountain base radius.**
- Discussion and Conclusions

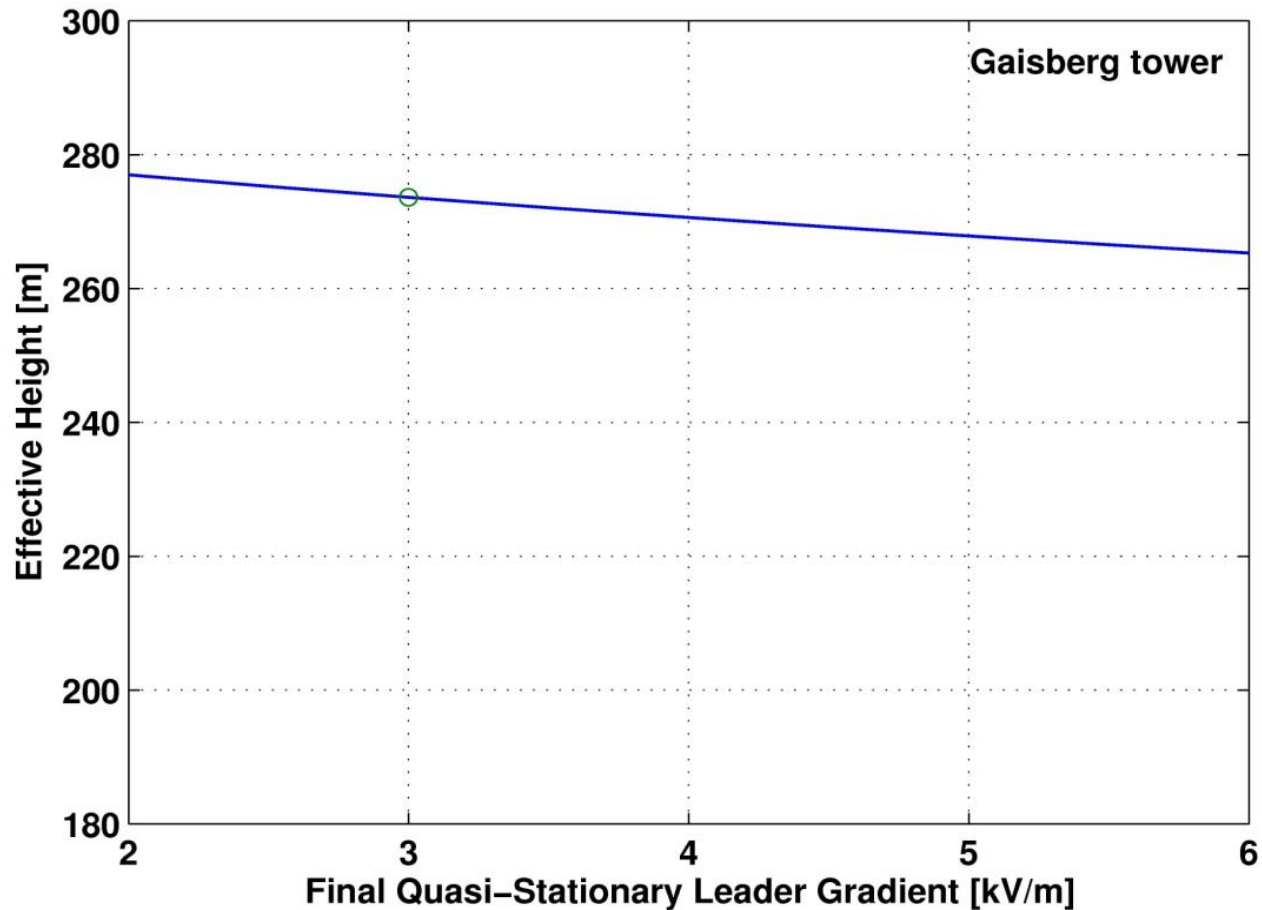
# Gaisberg tower



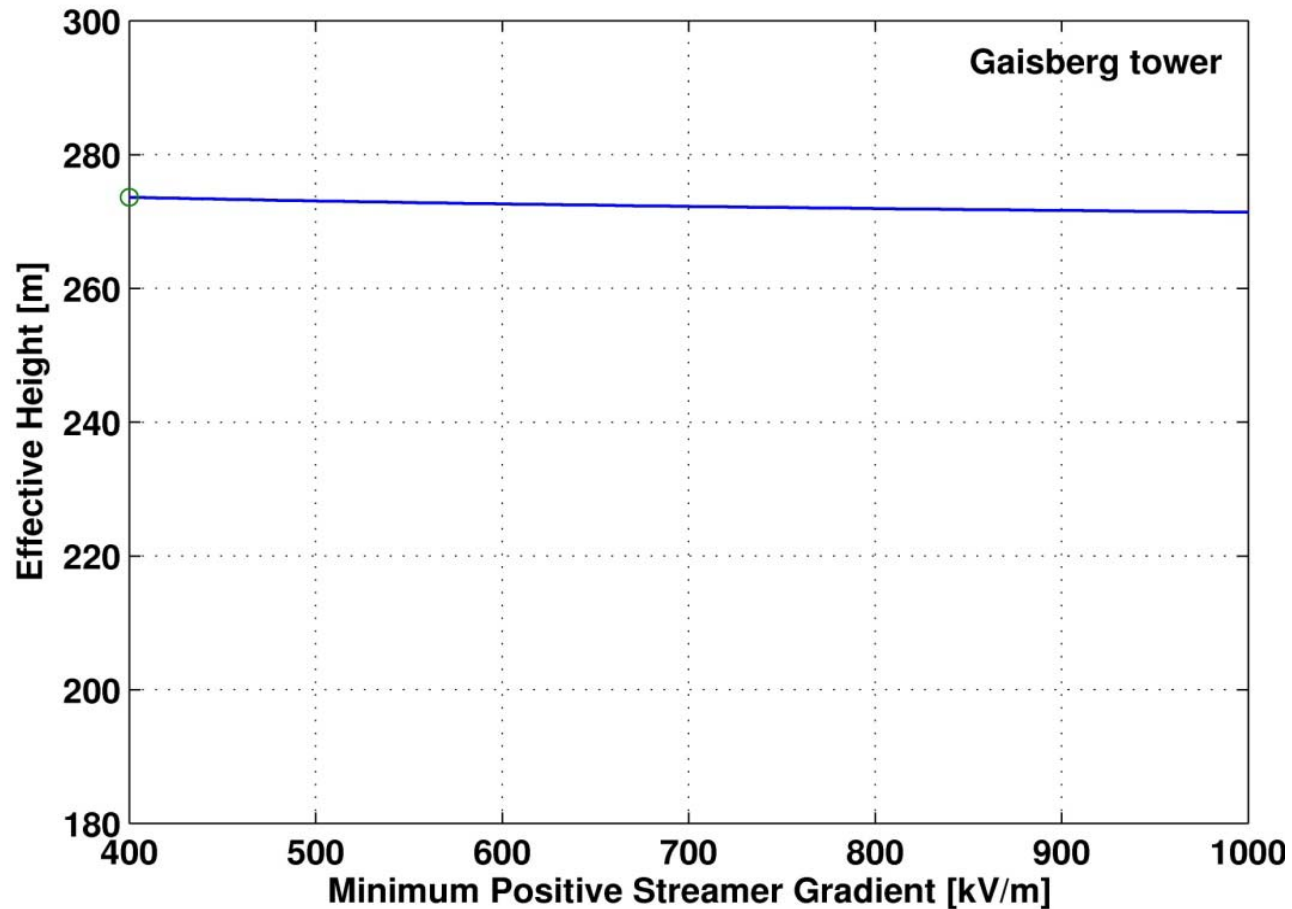
A 100 m tall radio tower located at Mt. Gaisberg (1287 m above sea level)



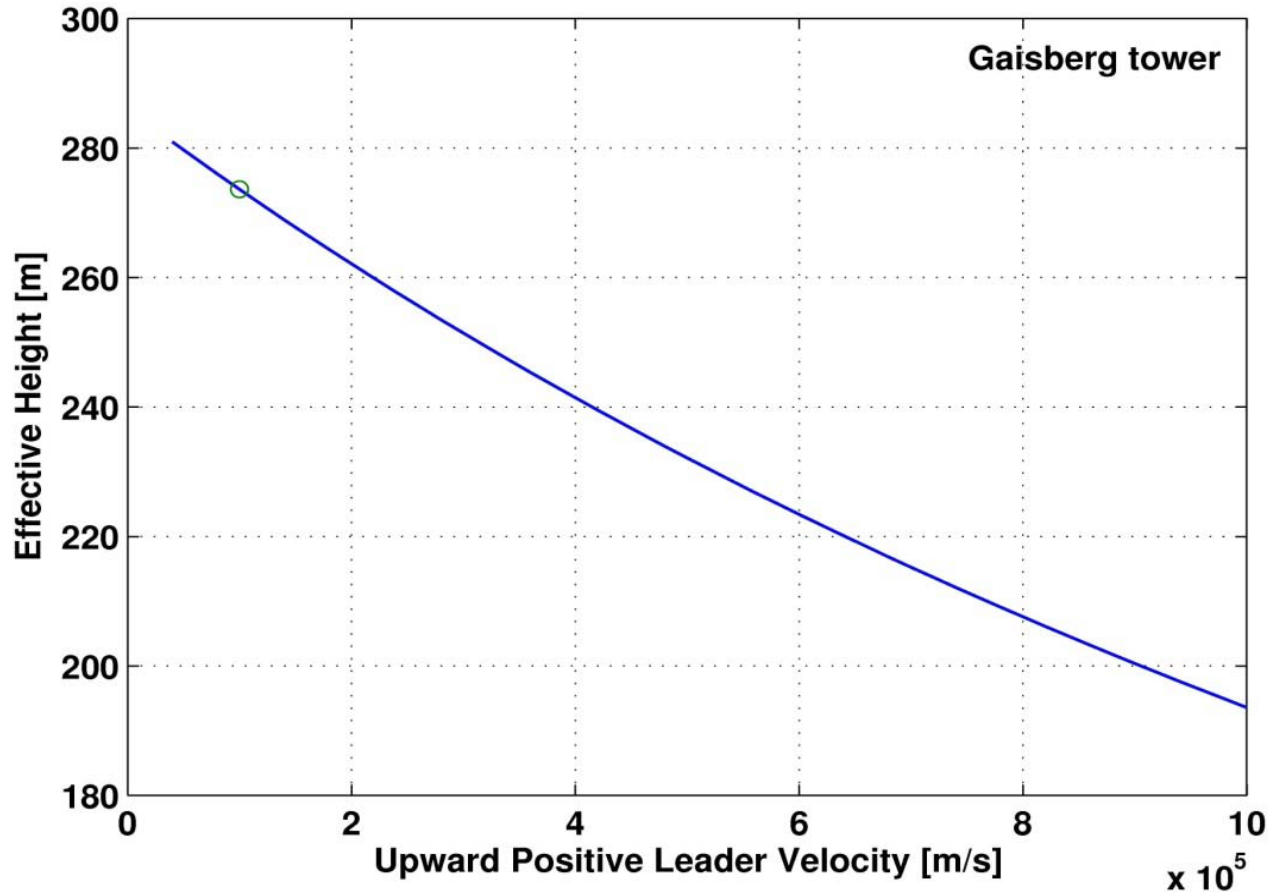
# Final Quasi-Stationary Leader Gradient



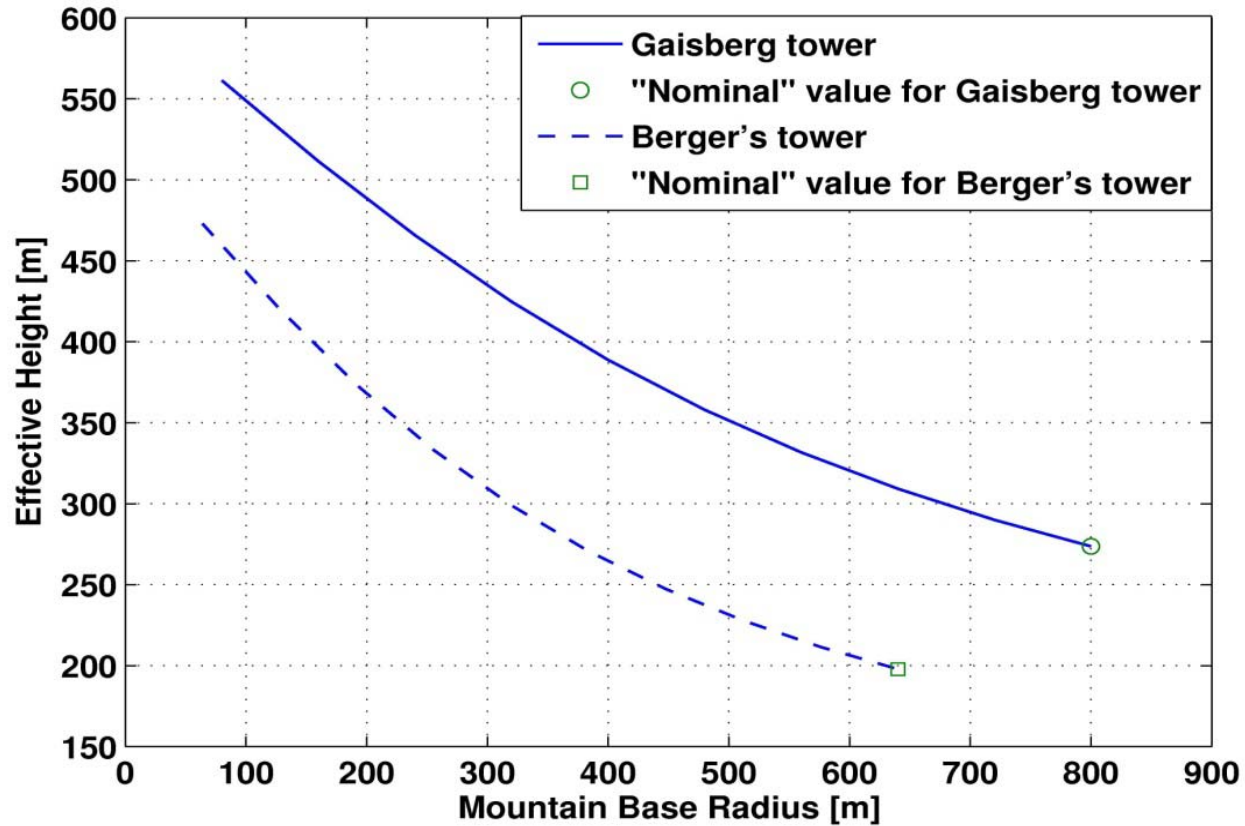
# Minimum positive streamer gradient



# Upward positive leader speed



# Mountain base radius



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# Discussion (1)

- The final quasi-stationary leader gradient  $E_{\infty}$  and the minimum positive streamer gradient  $E_i$ , having only a small effect (**less than 5%**) on effective height  $H$ .
- The variations of upward positive leader speed (proportional to  $X_0$ ) can cause up to **30%** uncertainty in effective height  $H$ .

# Discussion (2)

- Mountain base radius causes uncertainty depending on the ratio between the tower height  $h$  and mountain height  $a$ .
- When the ratio is less than 20%, the uncertainty in effective height  $H$  is large, from **105% to 322%**.
- In contrast, When the ratio is greater than 30%, the uncertainty in effective height  $H$  is small, from **20 to 65%**.

# Conclusions

- The effective height  $H$  depends primarily on the **structure height, mountain shape, and upward positive leader speed.**
- To estimate the effective height for towers for which no lightning incidence are available.
- And it can be used in designing lightning protection of communication/transmission line towers and masts on mountain tops.



Thank You !

Photo by Helin Zhou at Mt. Gaisberg

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