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On the Effective Height of Towers on Mountaintop from the Perspective of Lightning Attachment

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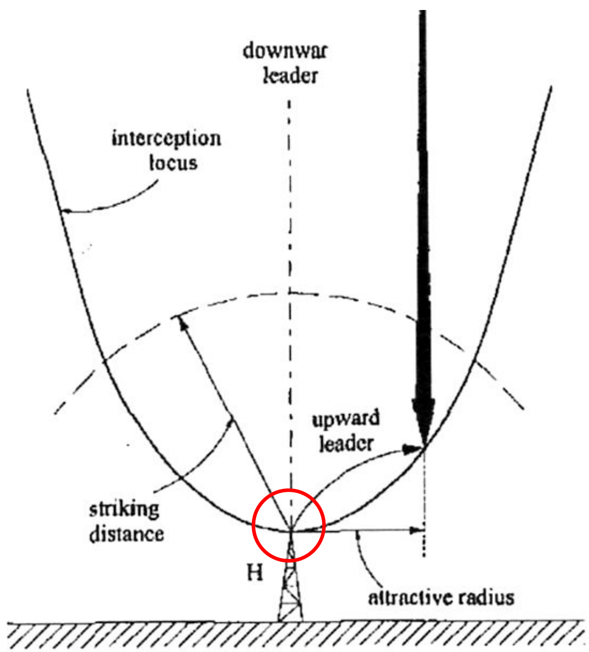
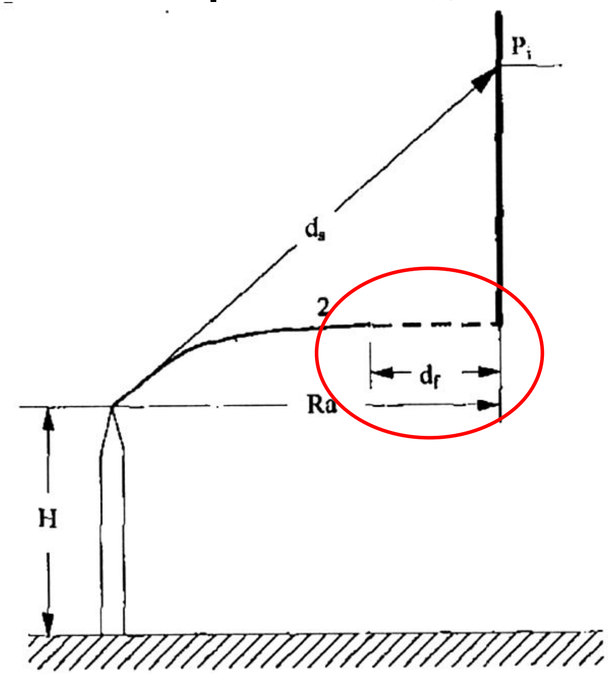
Lightning Attachment – 1

Events in lightning interception based on Leader progression models (Engineering models) by [Eriksson (1987), Dellera and Garbagnati (1989), Rizk (1990,1994)]

- **Downward leader – negative leader (with charge corresponding to prospective return stroke current)**
- **Striking distance (d_s) – distance between downward leader tip and structure tip at the time of upward leader inception.**
- **Upward leader – incepted upward leader propagates seeking tip of downward leader, velocity of two leaders could different or same?**
- **Final Jump – occurs if gradient between two leader tips is > 500kV/m**





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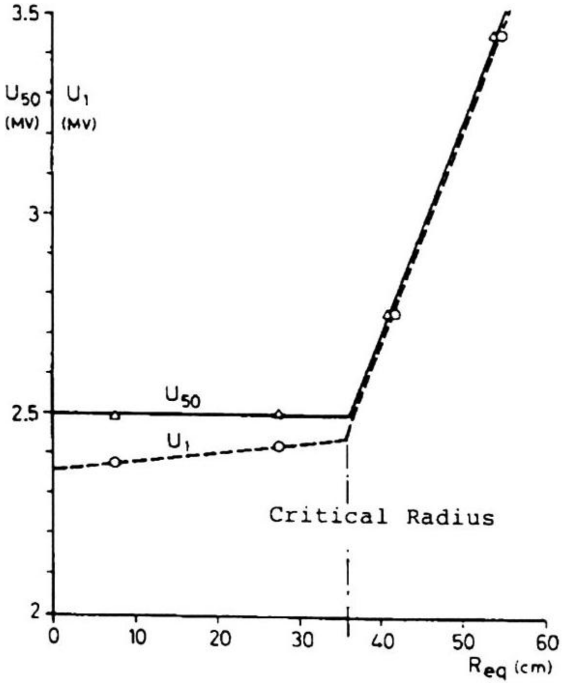
Lightning Attachment – 2

Upward leader inception – Critical radius concept (Leader Progression models) [Eriksson (1987), Dellera and Garbagnati (1989), Rizk (1990,1994)]

- It is difficult to apply physical models involving various nonlinear discharge mechanisms. Researchers thus adopted an engineering approach, i.e. it is enough to reasonably predict the instant of stable upward leader inception and propagation.
- For structures with slender tip the critical radius suggest that if the field at the surface of the sphere of critical radius placed at the structure tip due to any background electric field or downward leader exceeds or equals the corona inception field 30kV/cm then stable upward leader is incepted and is capable to propagate.
- The incepted upward leader and descending leader propagations are controlled by the field gradient between them (decided by voltage drop along the upward leader length and downward leader tips).



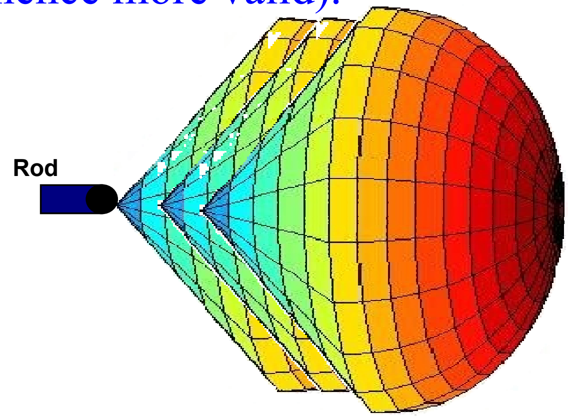
Lightning Attachment – 3

Recently a valid and simplified evaluation of the upward leader inception condition was proposed by (Becerra & Cooray, 2007), which is an advancement of existing leader progression model as it combines both physical and engineering approaches (hence more valid).

Background potential distribution

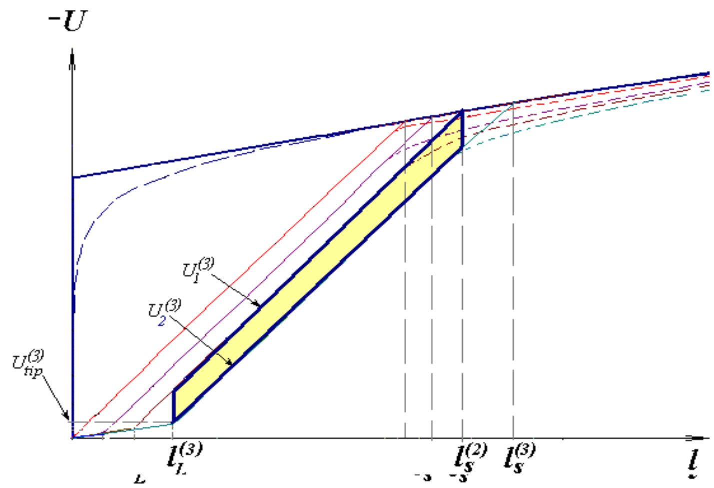
- *Corona charge calculation*

$$\Delta Q = k_Q \cdot \boxed{AreaUl}$$



Start Leader Advancement Analysis

- *Potential at the leader's tip (Rizk)*
- *Corona charge calculation*
- *Leader advancement distance*



Stable leader propagation??

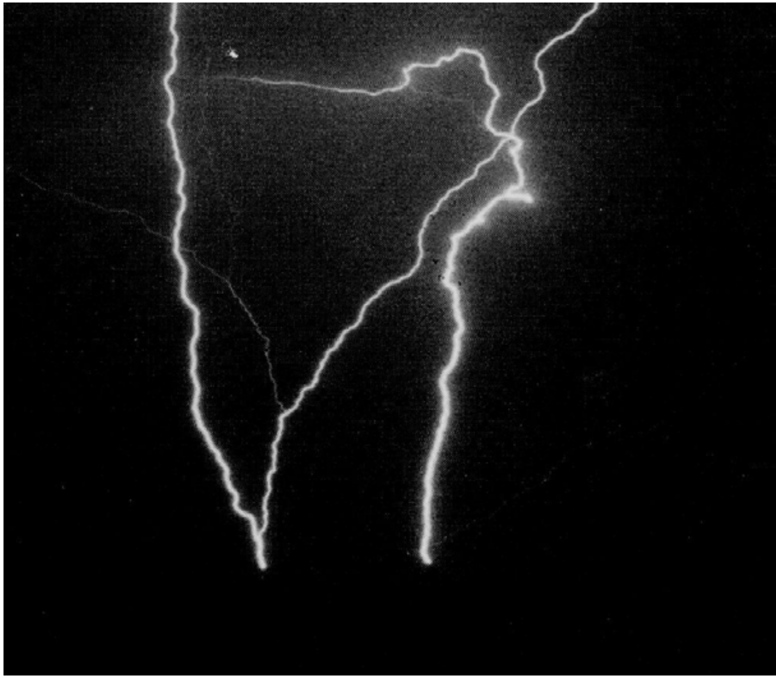
Lightning Attachment – 4

For towers with height > 250m (observations and calculations based on Leader progression models

- No downward leader
- Interception is only due to upward leaders – Upward_flash
- Depends on the field due to cloud charges alone
- E.g. CN tower in Canada and Empire State Building

For towers above mountains

- Interception is only due to upward leaders – Upward_flash
- Depends on the field due to cloud charges alone
- E.g. Berger's experimental tower in Switzerland



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Towers on mountaintop - 1

•For a structure on mountaintop, an effective height greater than the structure's physical height is assigned to the structure, to account for additional field distortion due to the presence of the mountain [Eriksson, Pierce, Rakov].

•Correlations are made with the structures on flat ground.

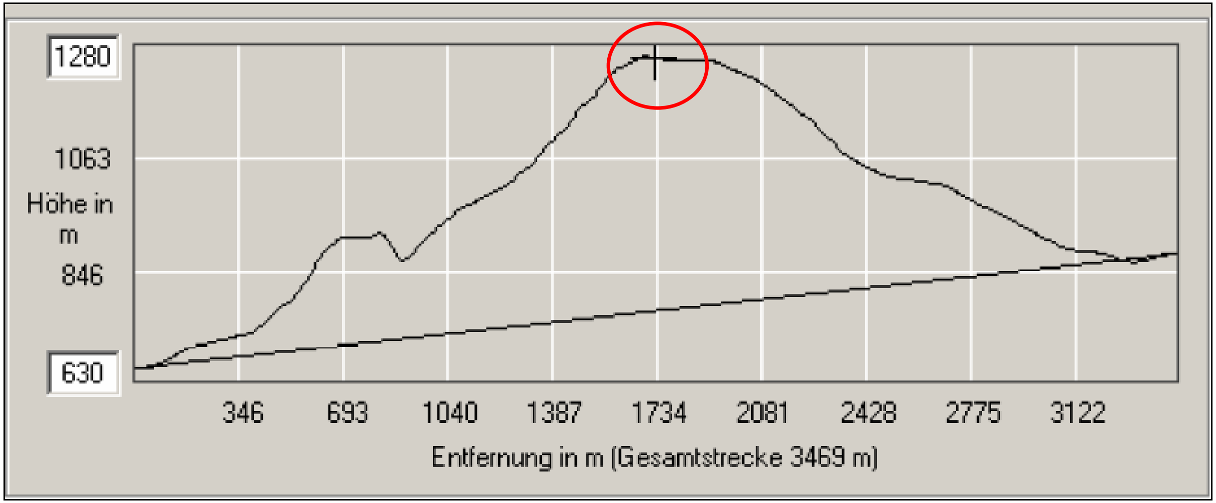
•If H* is the effective height of the tower whose physical height is H that is on the top of the mountain then;

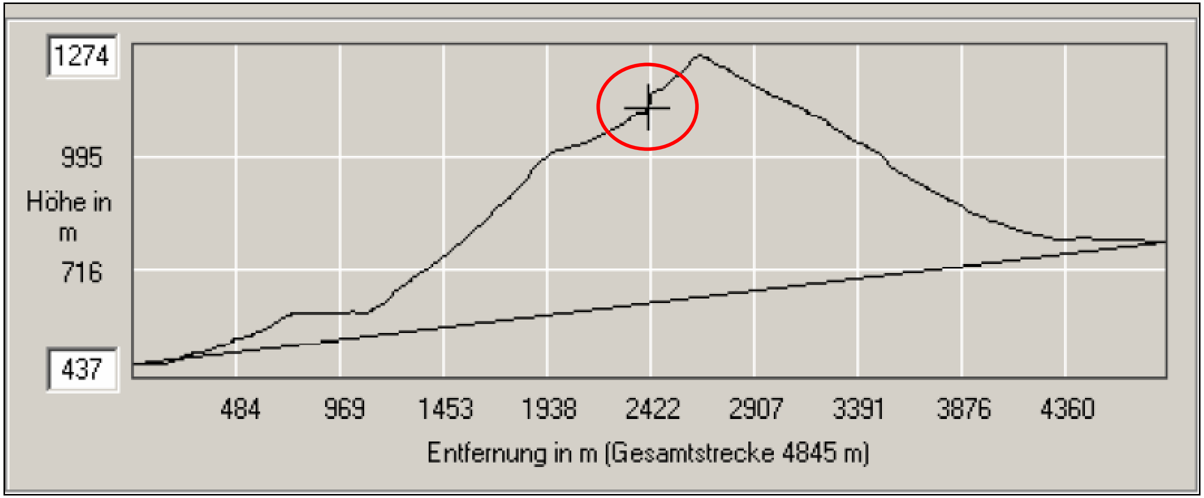
It is believed that a tower of height H on flat ground will have same number of upward flashes as that of the tower of height H on mountain top.*

Towers on mountaintop - 2 [Rakov & Uman]

Object	Location	Height, m	Terrain	Effective height, m	Selected references
Empire State Building	New York City, USA	410	Flat	410	McEachron (1939, 1941), Hagenguth and Anderson (1952)
Two towers 400 m apart[a]	Monte San Salvatore, Lugano, Switzerland	70	Mountain 640 m above Lake Lugano, 912 m above sea level	270 (Pierce 1971), 350 (Eriksson 1978a)	Berger and Vogelsanger (1965, 1966, 1969), Berger (1967, 1972, 1977, 1978), Berger *et al.* (1975)
Ostankino TV tower	Moscow, Russia	540	Flat	540	Gorin *et al.* (1975; 1977), Gorin and Shkilev (1984)
Two TV towers[b]	Sasso di Pale, near Foligno, central Italy and Monte Orsa, near Varese, northern Italy	40	Mountains 980 and 993 m above sea level	500 (Eriksson 1978a)	Garbagnati and Lo Piparo (1970, 1973, 1982a, b), Garbagnati *et al.* (1974; 1975; 1978; 1981)
CSIR research mast	Pretoria, South Africa	60	Hill 80 m above surrounding terrain, 1400 m above sea level	148 (Eriksson 1978a)	Eriksson (1978a, 1982)
CN Tower	Toronto, Canada	553	Flat	553	Hussein *et al.* (1995), Janischewskyj *et al.* (1997)
Peissenberg tower	Hoher Peissenberg, Munich, Germany	160	Mountain about 288 m above surrounding terrain, 988 m above sea level[c]	Unknown	Beierl (1992), Fuchs *et al.* (1998)
St. Chrischona tower	Basel, Switzerland	248	Mountain 493 m above sea level	Unknown	Montandon (1992, 1995)
Cachimbo tower	Brazil	60	Mountain 200 m above surrounding terrain, 1600 m above sea level	Unknown	Lacerda *et al.* (1999)
Gaisberg tower	Salzburg, Austria	100	Mountain 1287 m above sea level	Unknown	Diendorfer *et al.* (2000)

Gasiberg tower – 1: modelling attempts





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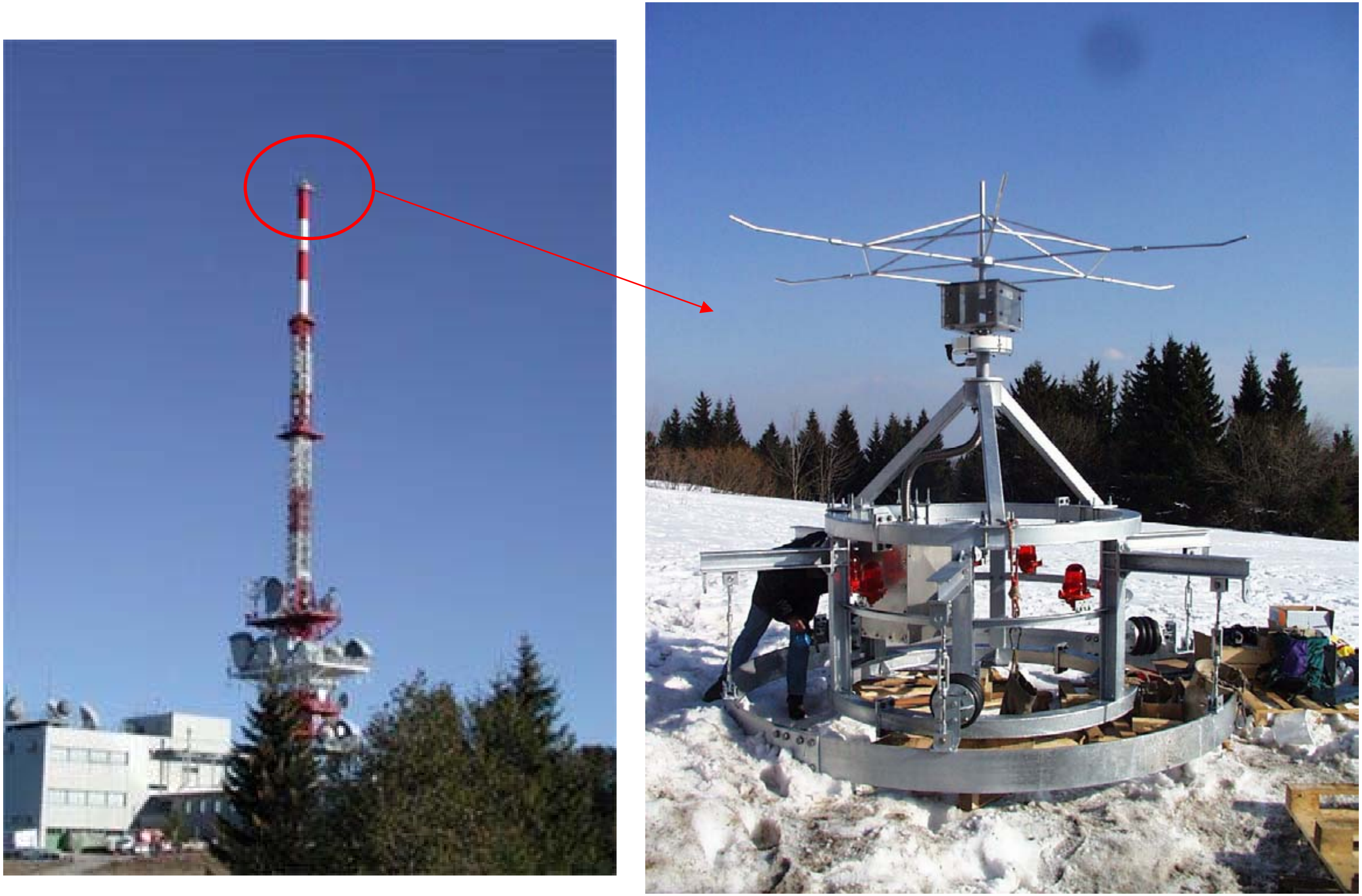
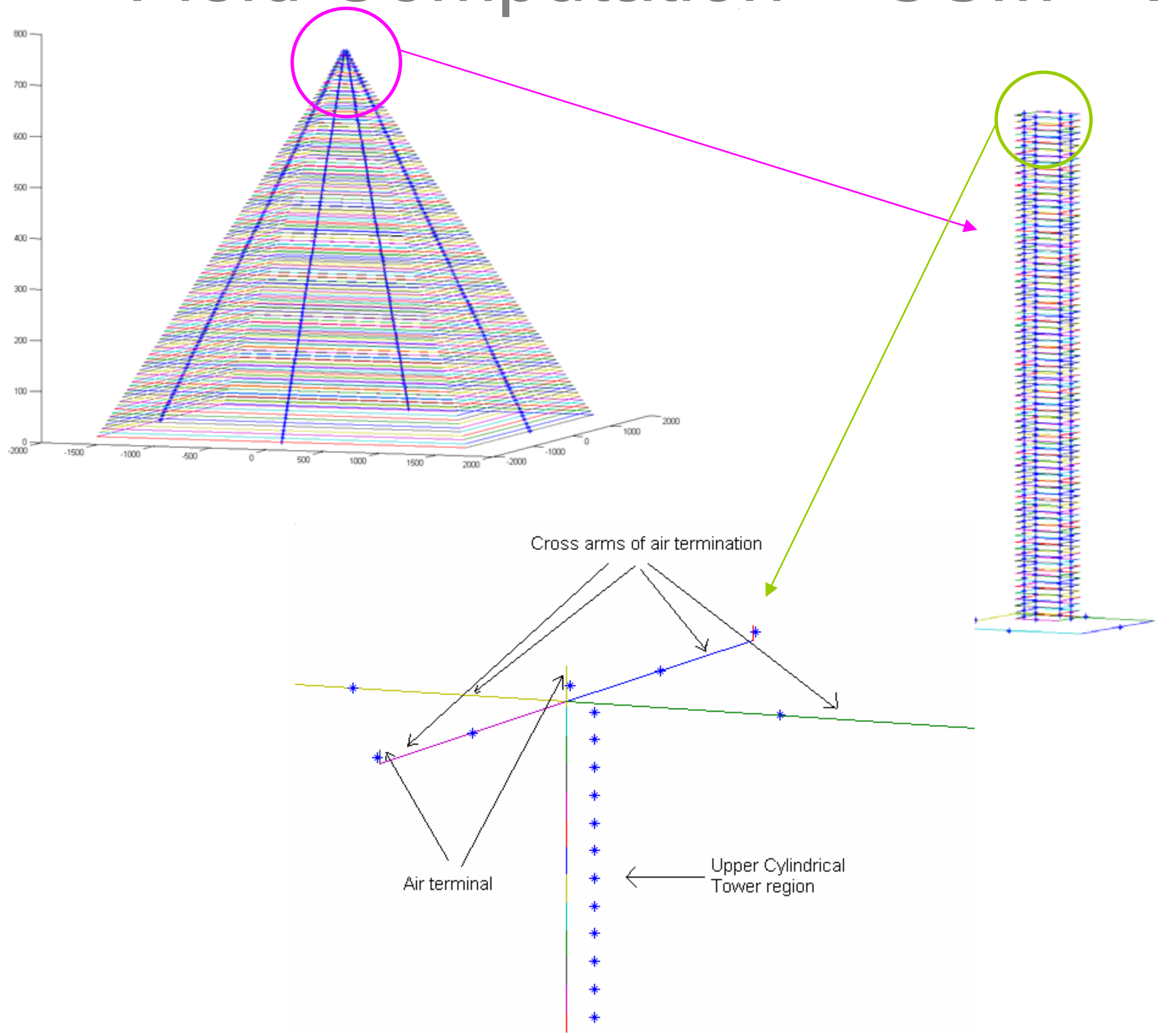
Gasiberg tower – 2: modelling attempts



Some Preliminary Calculation attempts Field Computation – CSM – 2



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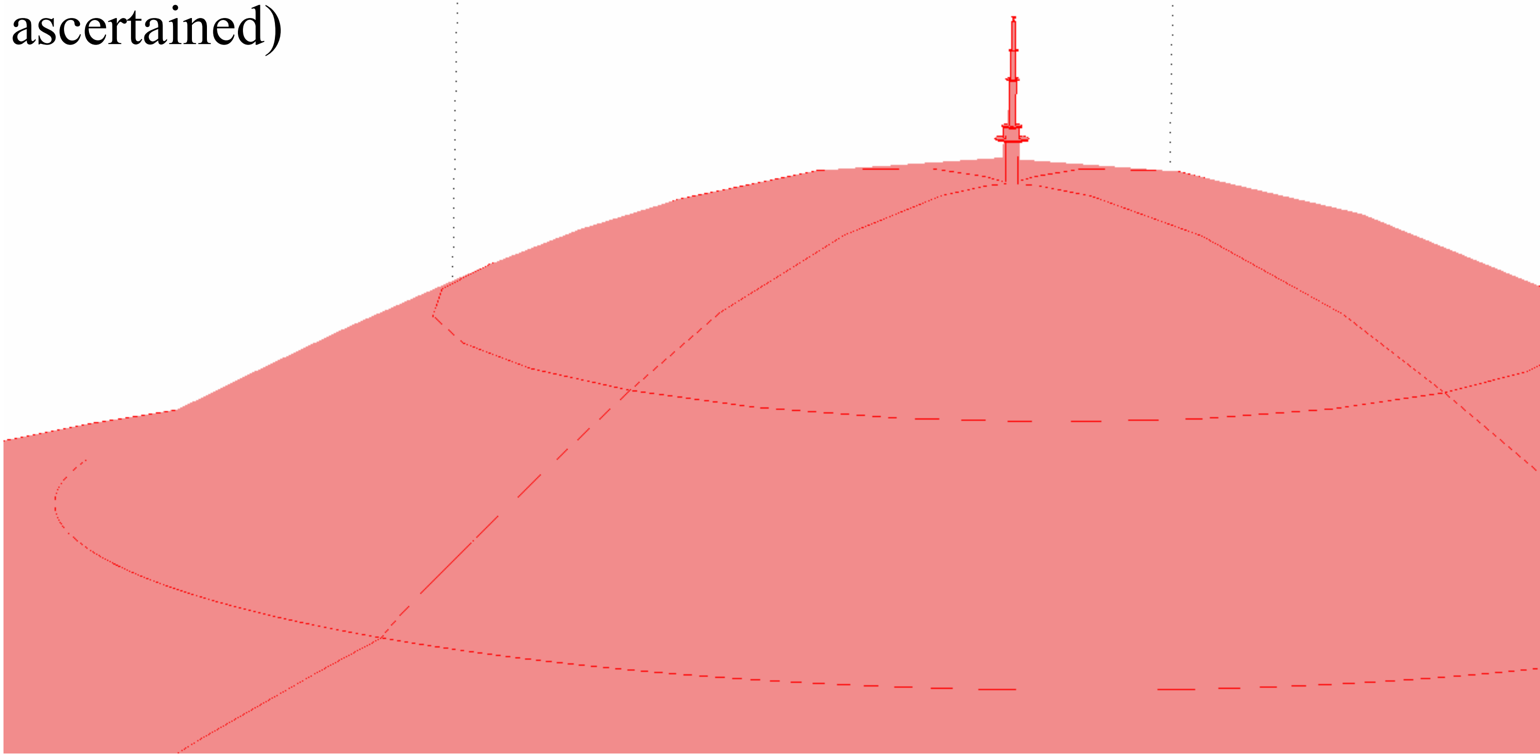
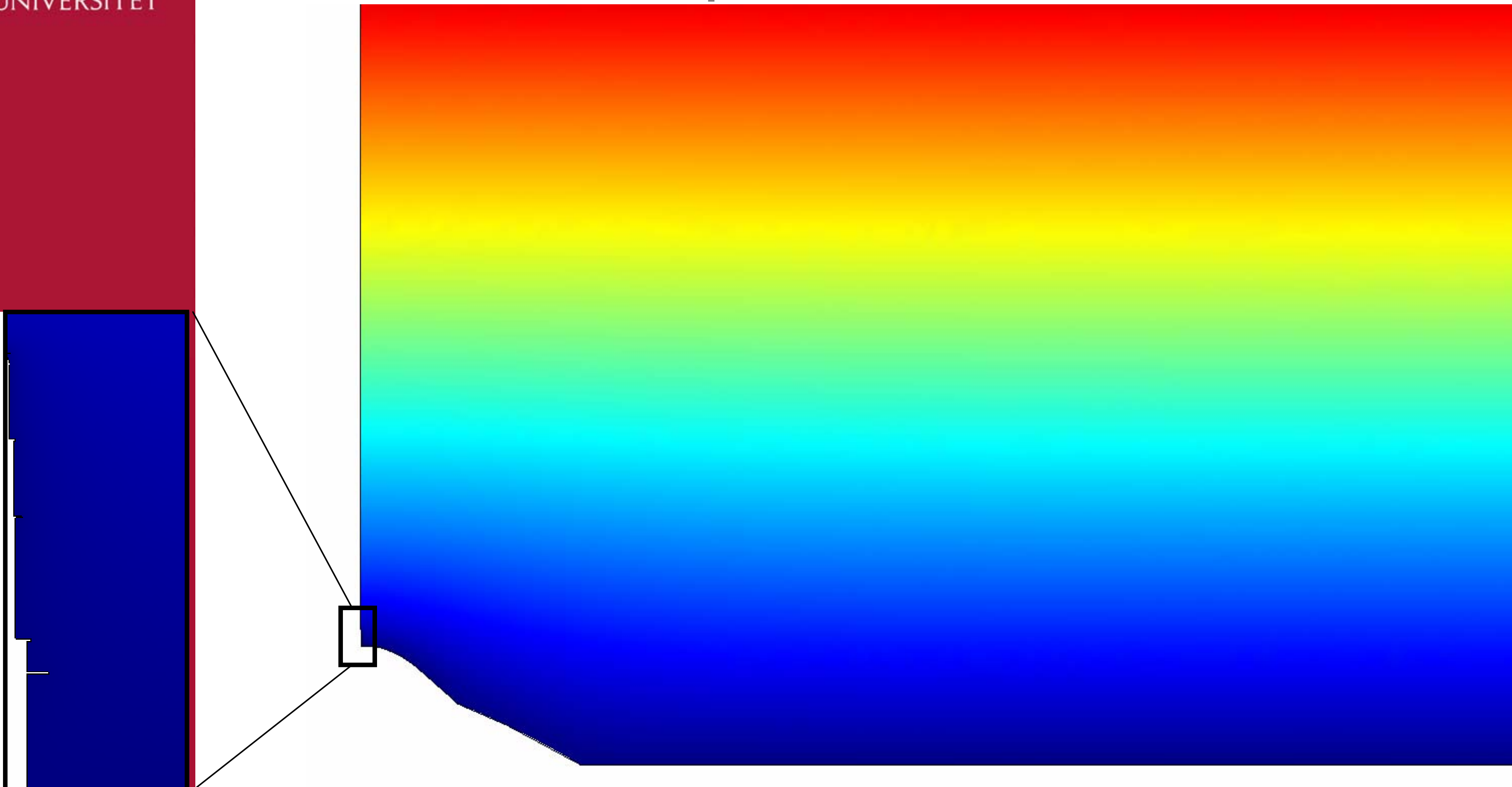
Some Preliminary Calculation attempts Field Computation – FEM – 3

To facilitate more accurate field calculations for the Becerra & Cooray model application, the mountain and tower are modelled in an FEM software immersed in a background electric field (and required leader inception and propagation conditions are ascertained)



Some Preliminary Calculation attempts Field Computation – FEM – 4



Background electric field distribution with tower and mountain (Becerra & Cooray model application).

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Assumptions in either modelling approaches

- The space charge effects neglected (wind), however these can be accounted in Becerra and Cooray model (JGR 2007).
- The effect of the cloud base on the upward leader inception conditions is negligible.
- The geometry of the mountain is “symmetric”.
- The source of background electric field is not considered except as a first approximation for the leader progression model a bipolar positive negative charge centres were assumed at different heights

Effective Height – Preliminary Calculations/Results - 1

Pierce's Method – Based on observed overall increase in lightning incidence to mountaintop towers to that of similar towers on flat ground.

•For 90% - 95% Upward flashes the effective height of Gaisberg tower based on Pierce's method is about 1000m.

Eriksson's Method – Based on the observed percentage of the upward flashes initiated from towers on mountain tops.

$$\left.\begin{aligned} P_{u1} &= 68.2\ln(H_s) - 315.5 \\ P_{u2} &= 52.8\ln(H_s) - 230 \end{aligned}\right\}$$

$$(\textit{Observations of lightning incidence to tall towers})$$

•For 90% - 95% Upward flashes the effective height of Gaisberg tower based on Eriksson's method is about 380m – 410m (first equation) and 430m – 470m (second equation).

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Effective Height – Preliminary Calculations/Results - 2

Field method – leader progression model application based on critical radius concept

•Criterion for upward flash from the tower must be satisfied – field at the top of the sphere of critical radius of 37cm (sensitive to the value adopted) placed at the top of the tower air termination tips exceeds the corona inception (26 kV/cm) due to the cloud charges only.

•At the same time the final jump criterion also should be satisfied.

•Ambient ground field when both the conditions are satisfied is calculated using the cloud charges only (this is very crude approximation needs critical discussion and validations)

The effective height of Gaisberg Tower is 278m – 328m. The values are calculated for cloud height configuration; 1) Q- = 2.5km and Q+ = 7.5km 2) Q- = 5km and Q+ = 10km (needs sensitivity analysis). Note the final jump criterion was satisfied well before the upward leader inception criterion.

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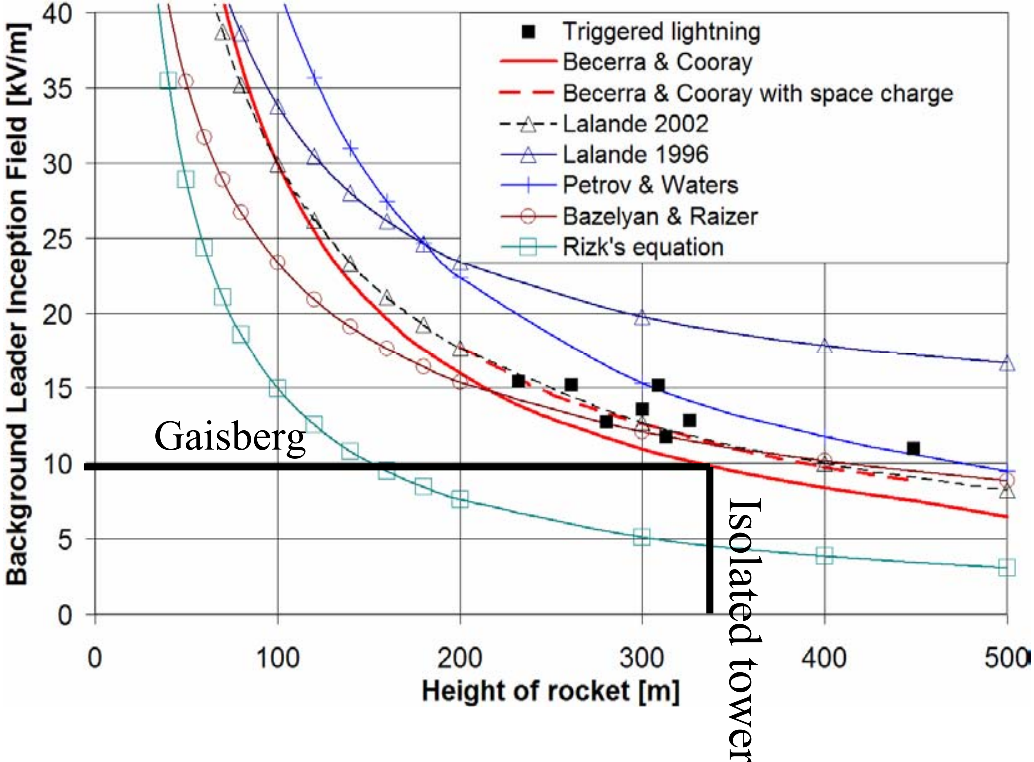
Effective Height – Preliminary Calculations/Results - 3

Applying the Becerra & Cooray model the effective height is about 325m (under ideal conditions) using also the computed leader stabilization fields for rocket-triggered lightning experiments.



Triggered Lightning Data from J. C. Willet, D. A. Davis, P. Laroche. Atmospheric research, Vol 51, 1999, pp. 189-219

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Conclusions:

- The Effective heights are found to be different for different definitions.
- The statistical methods of Pierce and Eriksson give different effective heights.
- A complete theoretical evaluation of the effective height would require the inclusion of site conditions such as wind, neutral aerosol concentration, proximity to the cloud base, distance to the cloud centre, etc, in the calculations.