Global Lightning Activity in Absolute Units from Multi-Station Schumann Resonance Observations

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Haystack Observatory
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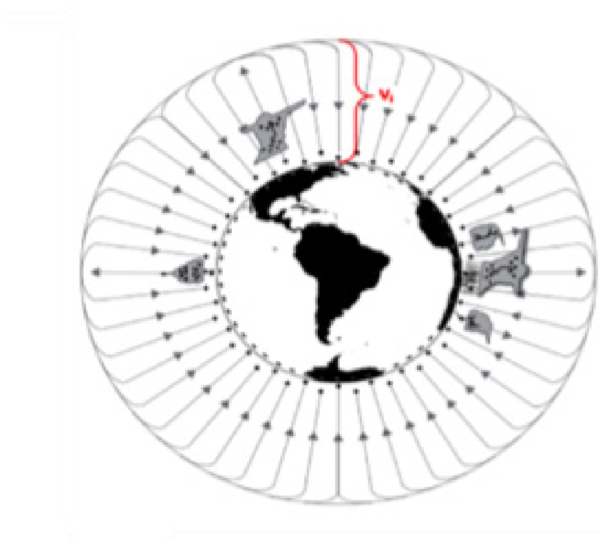
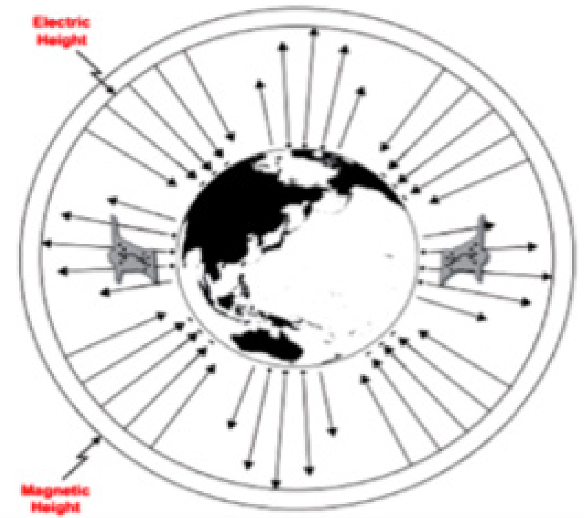
Two global circuits



Integrator of Electrified Weather



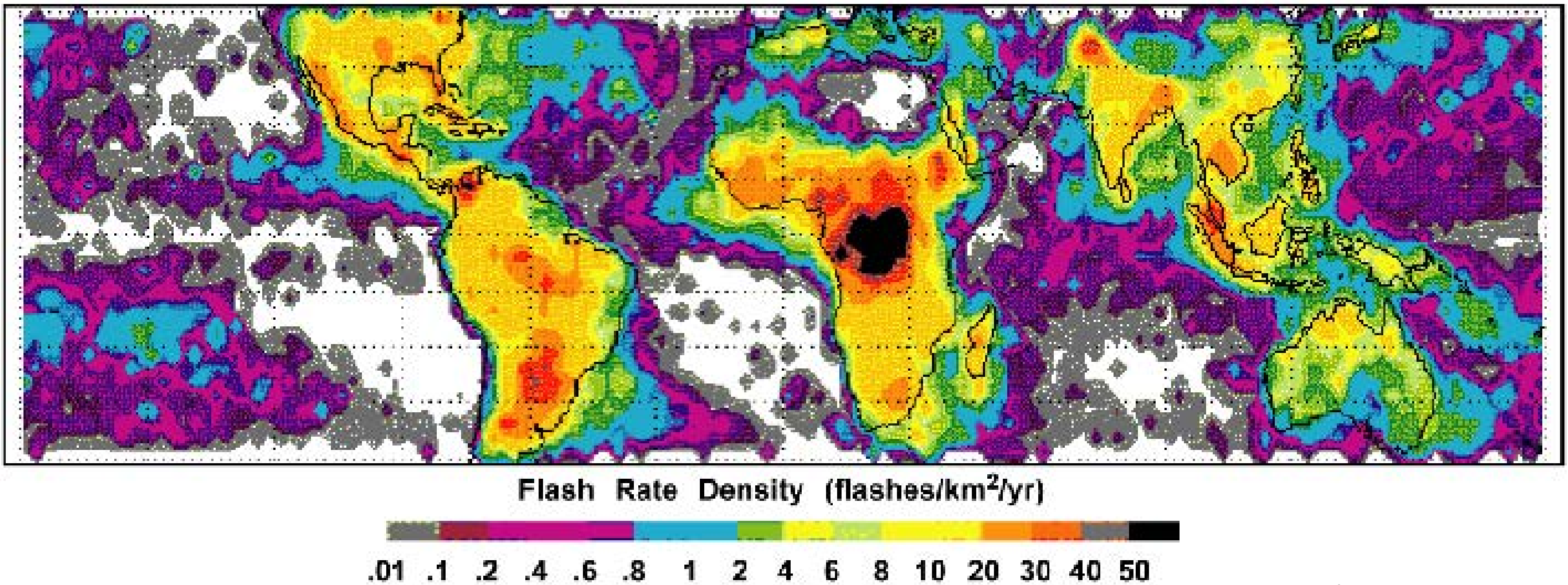
Integrator of Global Lightning

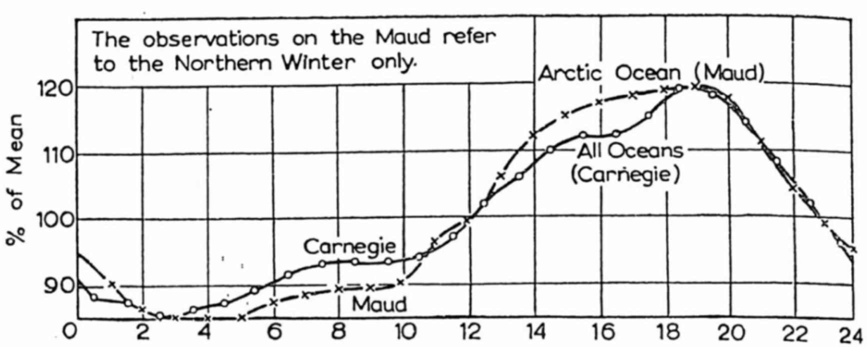
Why the interest in the two global circuits?

- Both global circuits provide natural and inexpensive frameworks for global climate change
- Lightning activity is sensitive to temperature so expect that the global circuit will be responsive to global temperature
- Schumann resonances provide a diagnostic for changes in the global C and D region ionosphere

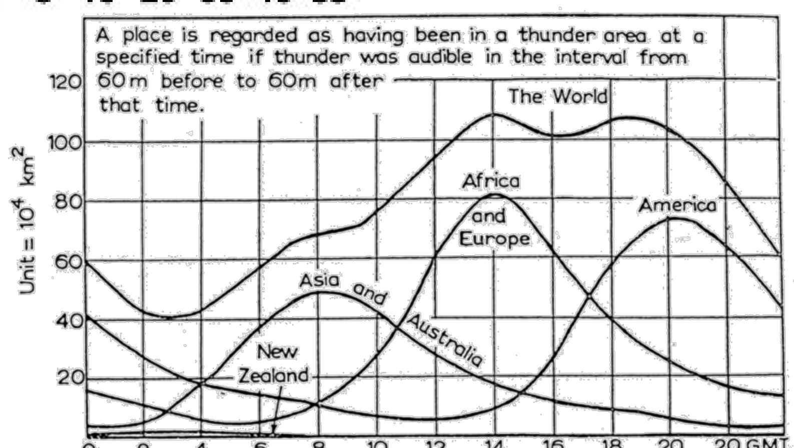
Diurnal Climatology of the DC Global Circuit

Lightning Flash Density





Carnegie Curve



Thunder Area

Motivation of study

- Overriding goal: measure the ‘Carnegie curve’ of global lightning activity on a daily basis
- For the DC global circuit, the daily Carnegie curve is ideally the record of ionospheric potential, with the fair-weather field as proxy
- For the AC global circuit, the Carnegie curve is the record of worldwide lightning activity in $Coul^2km^2/sec$

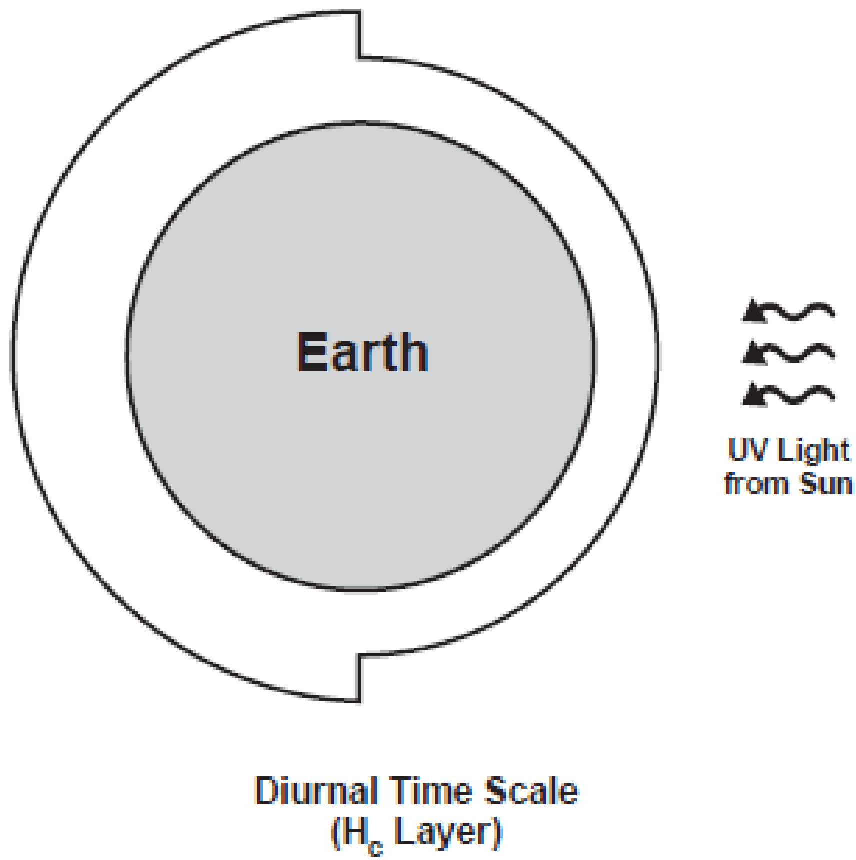
Normal Mode Equations: Exact solutions for a uniform Earth-ionosphere cavity in ELF range

$$E(\omega, \theta) = \frac{Ids \;\; v(v+1)}{4R^2 \varepsilon \omega h} \frac{p_v^0(-cos\theta)}{\sin(\pi v)}$$

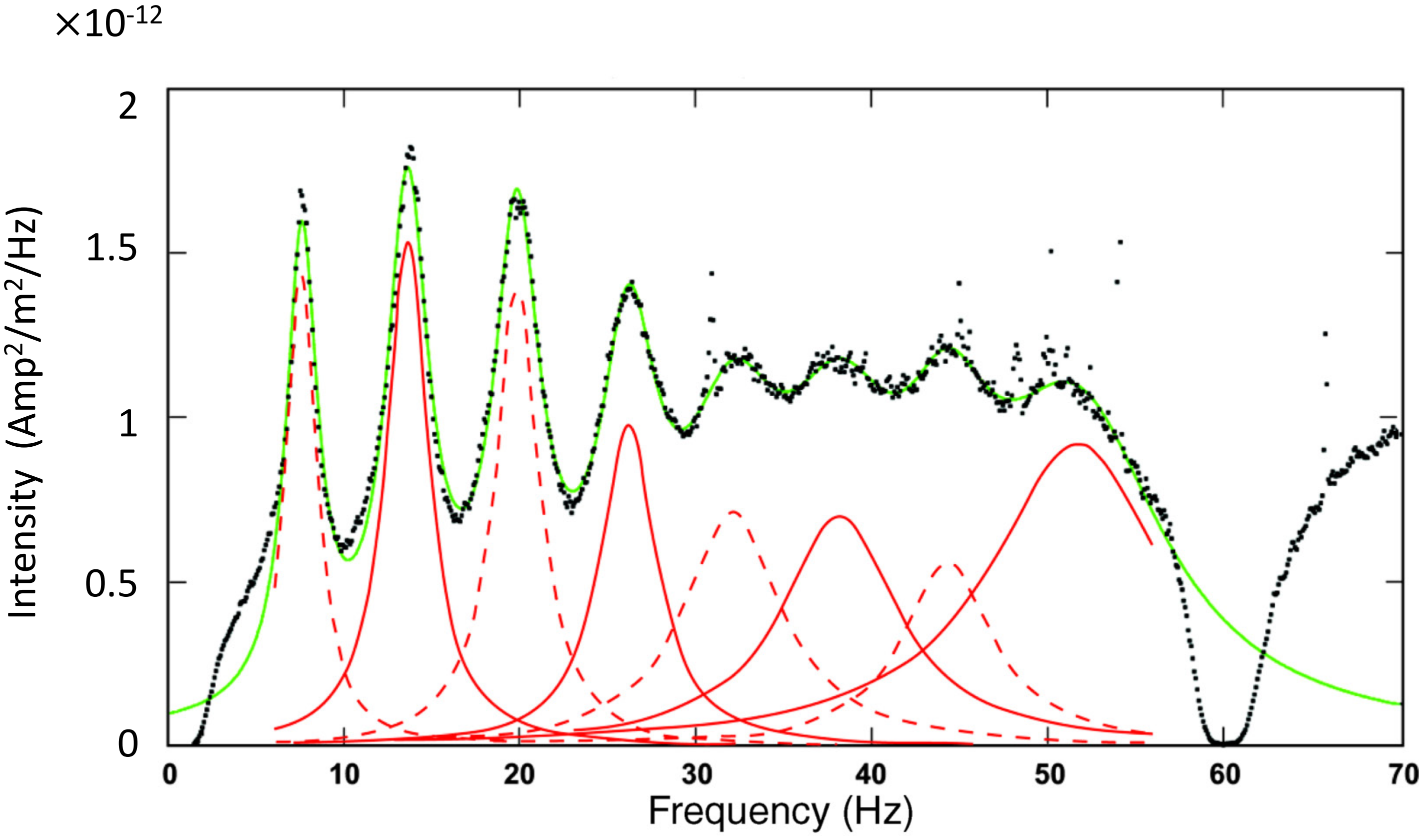
$$H(\omega, \theta) = \frac{-Ids}{4Rh} \frac{p_v^1(-cos\theta)}{\sin(\pi v)}$$

Wait (1960)

Day-night asymmetry of the Earth-ionosphere cavity



Lorentzian Fitting of Schumann Spectrum: Inputs for Inversion



Inversion of sensitivity matrix to estimate the lightning source

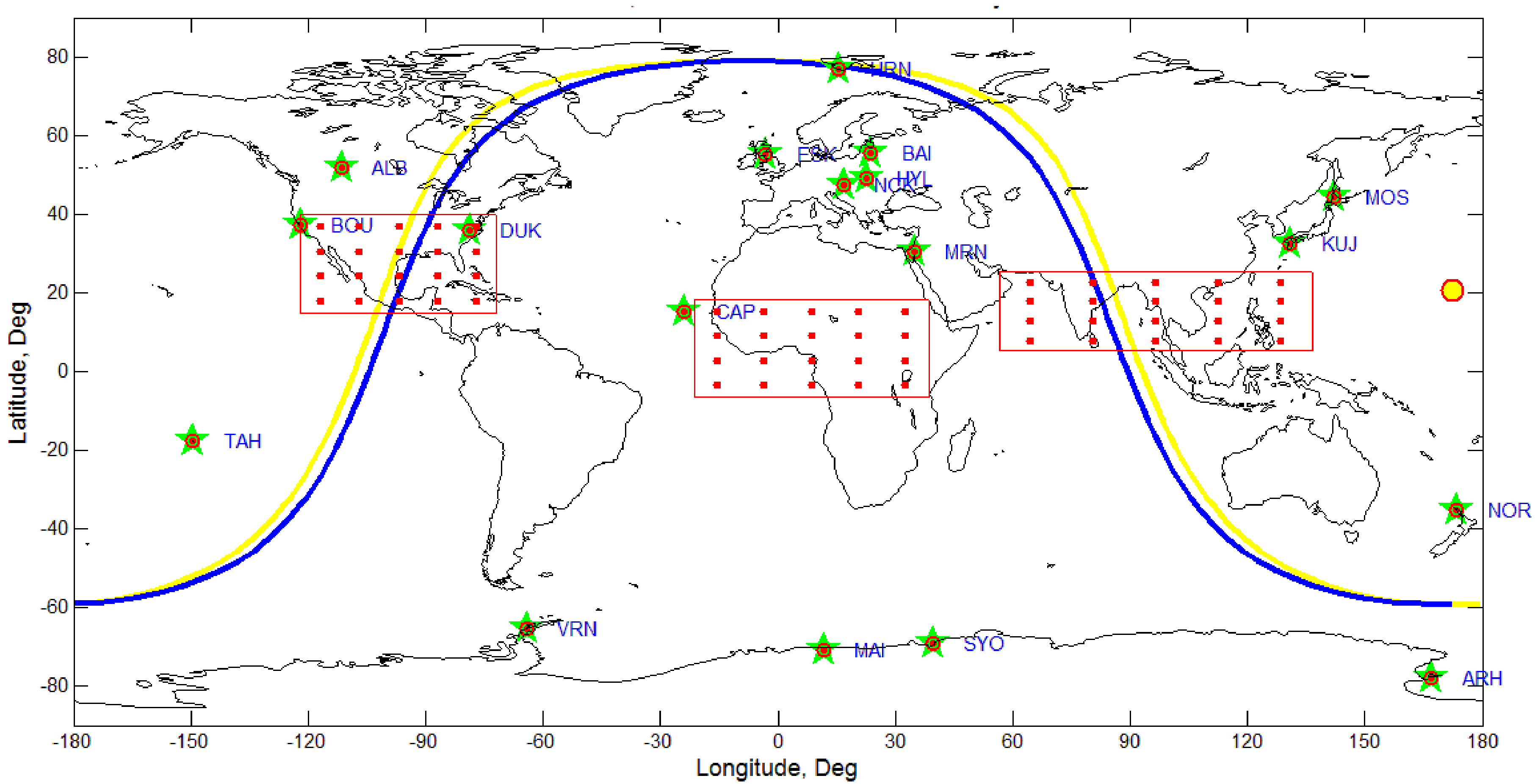
Sensitivity matrix — **Source information** ↓ — **Field information** ↓

$$\begin{bmatrix} \frac{\partial H_x^2}{\partial S} \mid S = S_i & \frac{\partial H_x^2}{\partial \theta} \mid \theta = \theta_i & \frac{\partial H_x^2}{\partial \varphi} \mid \varphi = \varphi_i \\ \frac{\partial H_y^2}{\partial S} \mid S = S_i & \frac{\partial H_y^2}{\partial \theta} \mid \theta = \theta_i & \frac{\partial H_y^2}{\partial \varphi} \mid \varphi = \varphi_i \\ \frac{\partial E_z^2}{\partial S} \mid S = S_i & \frac{\partial E_z^2}{\partial \theta} \mid \theta = \theta_i & \frac{\partial E_z^2}{\partial \varphi} \mid \varphi = \varphi_i \end{bmatrix} \begin{bmatrix} S_f - S_i \\ \theta_f - \theta_i \\ \varphi_f - \varphi_i \end{bmatrix} = \begin{bmatrix} H^2_{x[\text{model}]} - H^2_{x[\text{obs}]} \\ H^2_{y[\text{model}]} - H^2_{y[\text{obs}]} \\ E^2_{z[\text{model}]} - E^2_{z[\text{obs}]} \end{bmatrix}$$

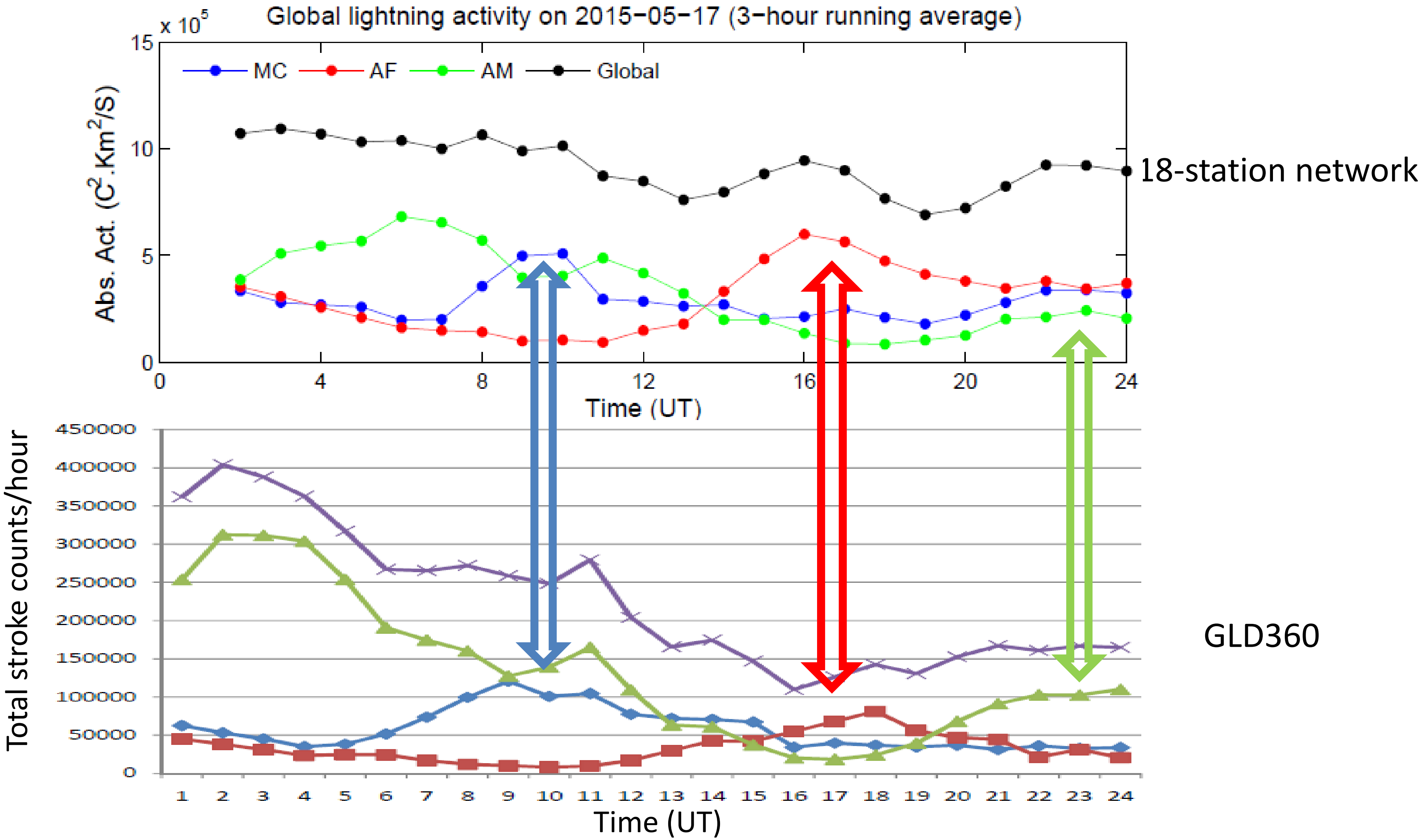
ELF stations and their operators: multi-station inversion (18 stations)

Station	Location	Operator(s)
Alberta	Canada	Mike Atkinson, Rollin McCraty
Arrival Heights	Antarctica	Robert Moore
Baisogala	Lithuania	Mike Atkinson, Rollin McCraty
Boulder Creek	California	Mike Atkinson, Rollin McCraty
Cape Verde	N. Atlantic Ocean	Joan Montanya
Duke	North Carolina	Steve Cummer
Eskdalemuir	Scotland	Ciaran Beggan
Hornsund	Spitzbergen	Mariusz Neska
Hylaty	Poland	Janusz Mlynarczyk
Kyushu	Japan	Mitsu Sato
Maitri	Antarctica	Ashwini Kumar
Mitzpe Ramon	Israel	Colin Price
Moshiri	Japan	Yasu Hobara
Nagycenk	Hungary	Gabriella Satori, Erno Pracser
Northland	New Zealand	Mike Atkinson, Rollin McCraty
Syowa	Antarctica	Mitsu Sato
Tahiti	S. Pacific Ocean	Pascal Ortega
Vernadsky	Antarctica	Alex Koloskov, Yuri Yampolski

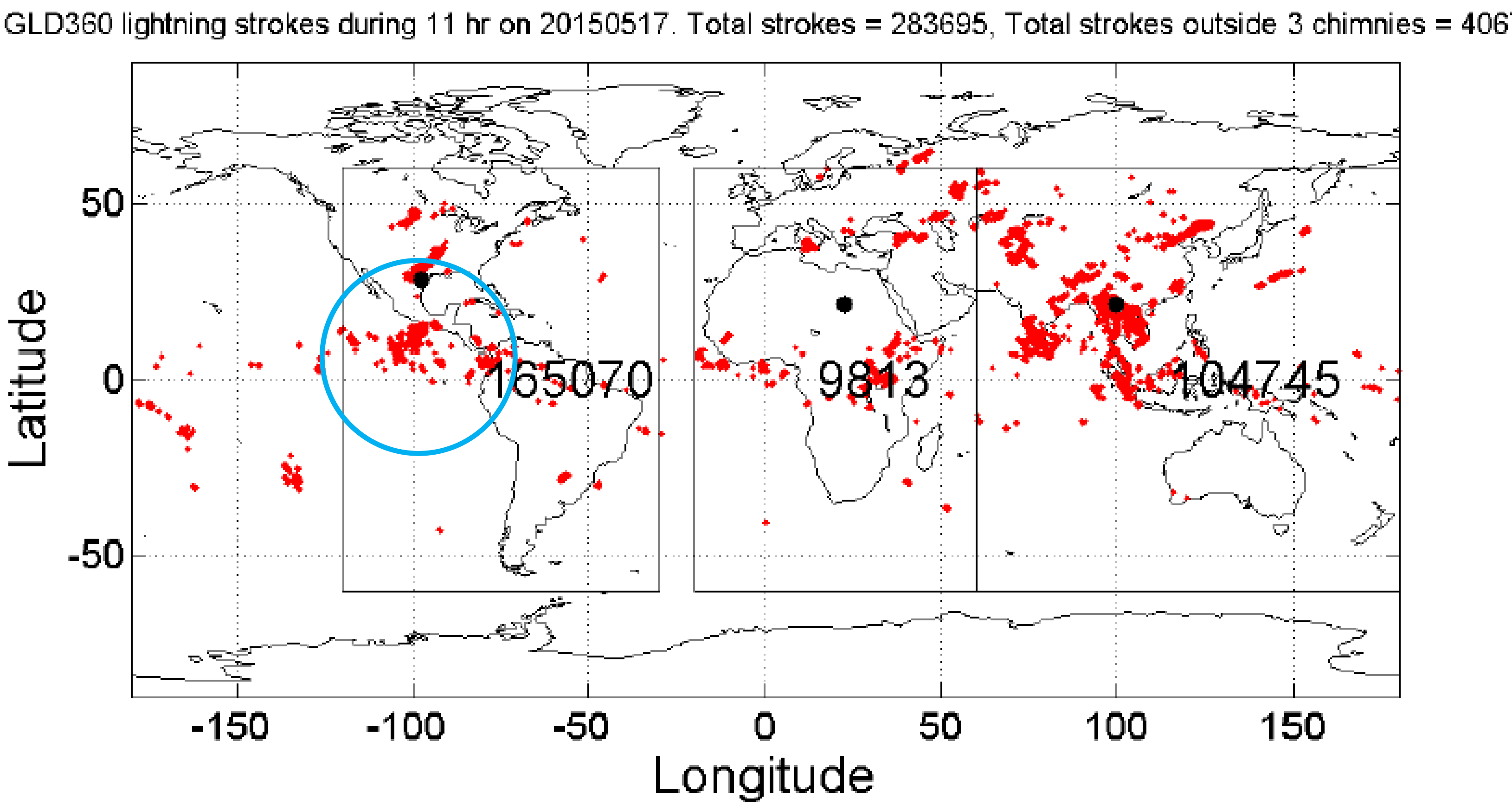
18-station network



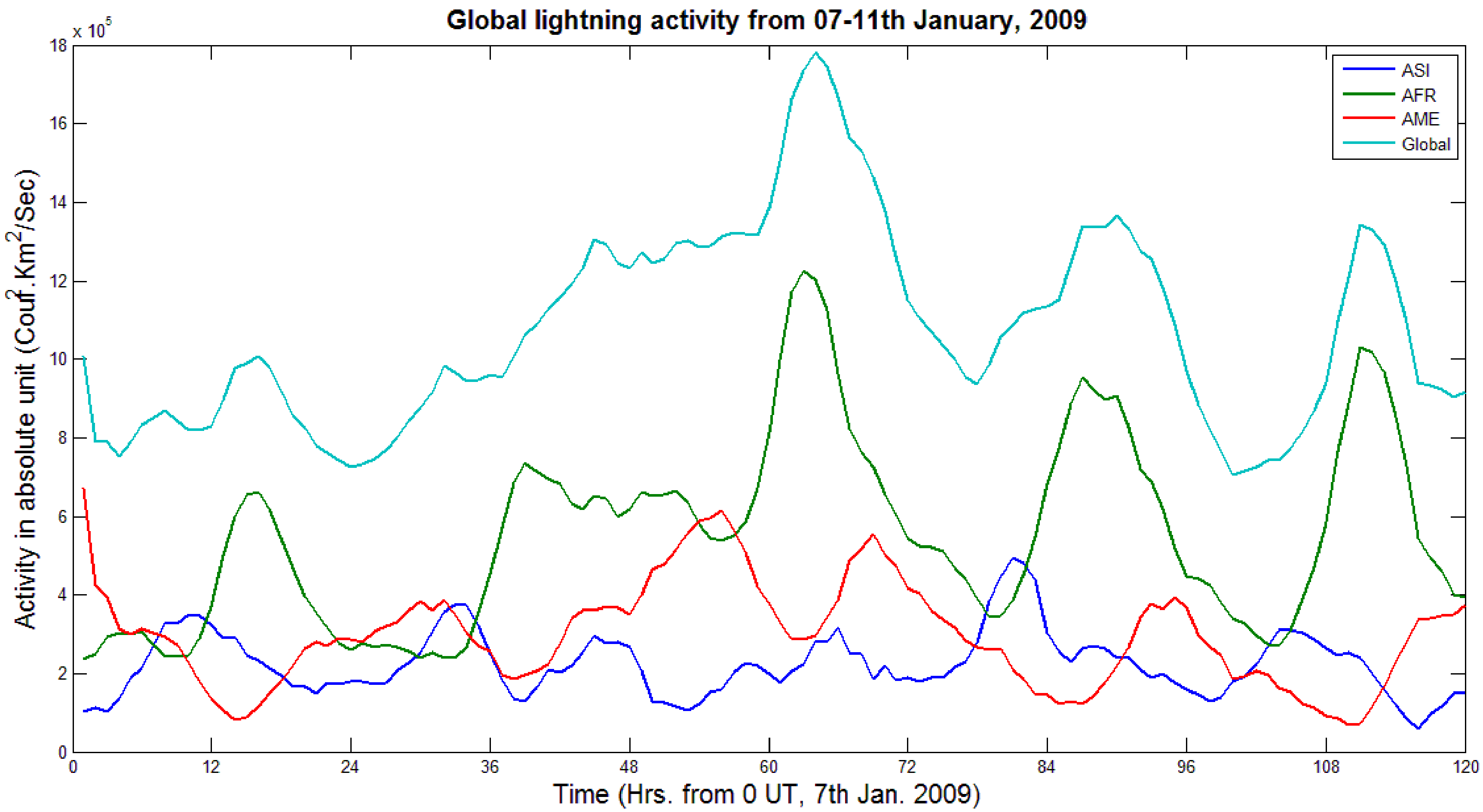
18-station inversion for May 17, 2015



Enhanced nocturnal activities over Eastern Pacific (11 UT, May 17, 2015)

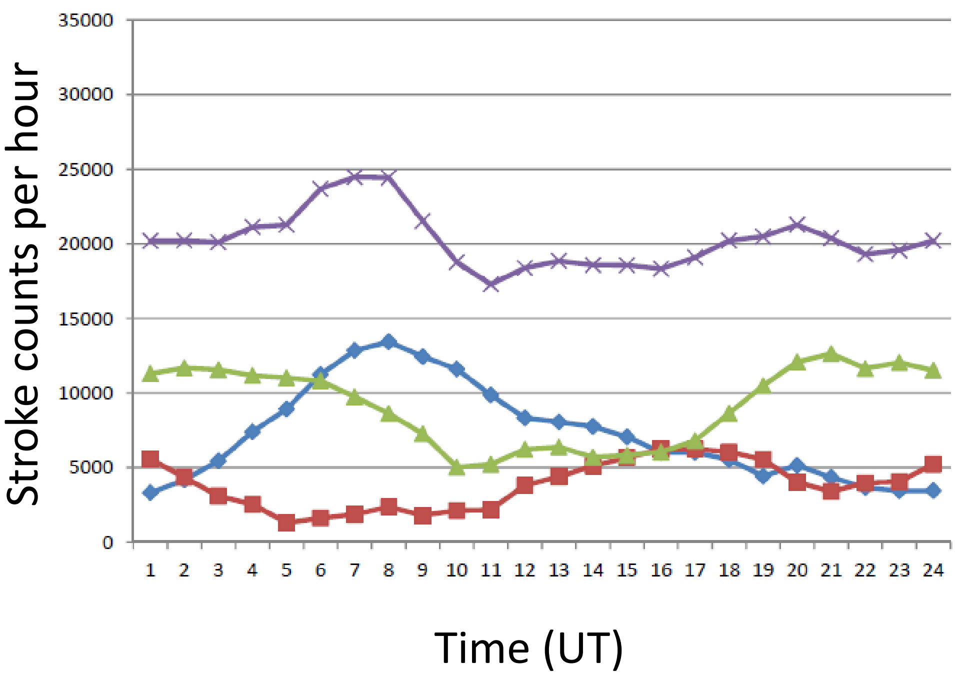


Five consecutive days of global inversion (January 7-11, 2009)

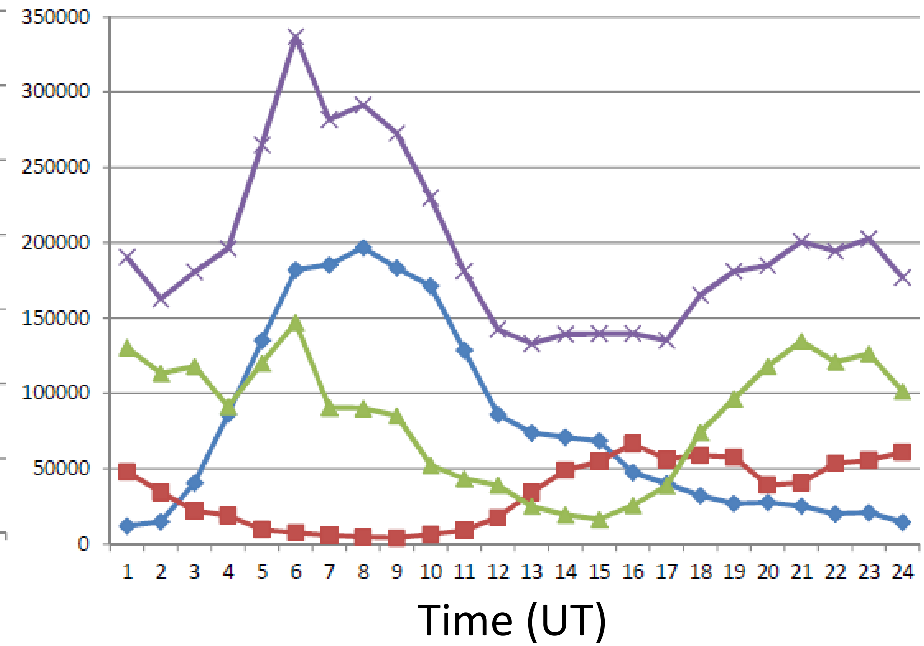


VLF network comparison on 19th January 2017

WWLLN



GLD360



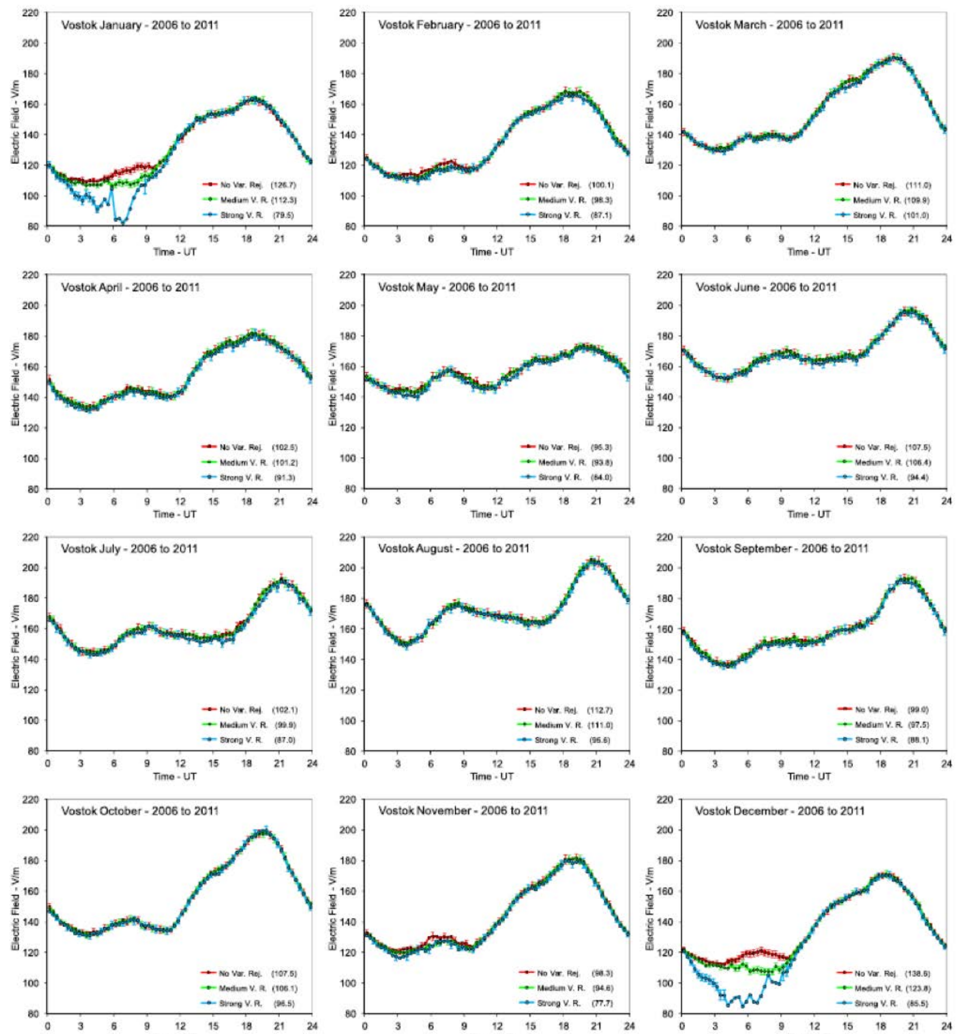
Conclusions

- Multi-station ELF methods show promise for continuous monitoring of global lightning in absolute units, with far fewer stations than are required for VLF analysis
- Nocturnal mesoscale convective activity, neglected in the classical analysis of the GEC, is a source of considerable day-to-day variability
- Recent availability of optical observations of lightning in geostationary orbit will enable new linkages between the DC and AC global circuits

Nighttime maximum in lightning activity

- The classical analysis of global thunderstorm activity (Brooks, 1925) overlooked the nighttime maximum in North America
- Accordingly, the classical analysis of the global electrical circuit (Whipple and Scrase, 1936) also leaves this out
- Prominent nighttime activity has been more recently documented by Wallace (1975) and Blakeslee et al. (2014)

Monthly climatology of diurnal variation of surface electric field at Vostok, Antarctica (Burns et al., 2017)



Lightning observations from geostationary orbit: New tools to study the global circuit

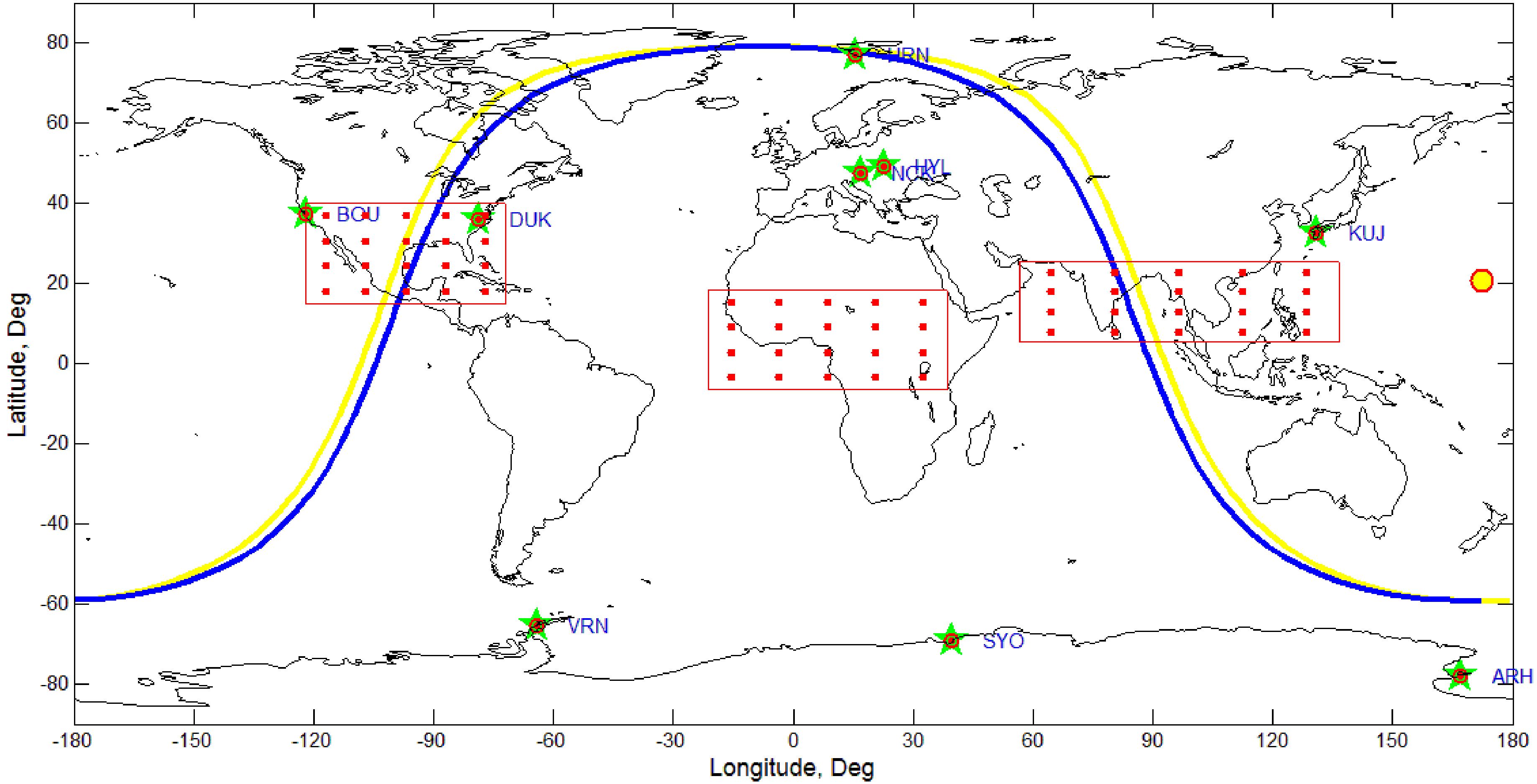
- China

Fengyun-4 satellite: Lightning Mapping Imager (LMI) Continuous access to the Asian chimney lightning

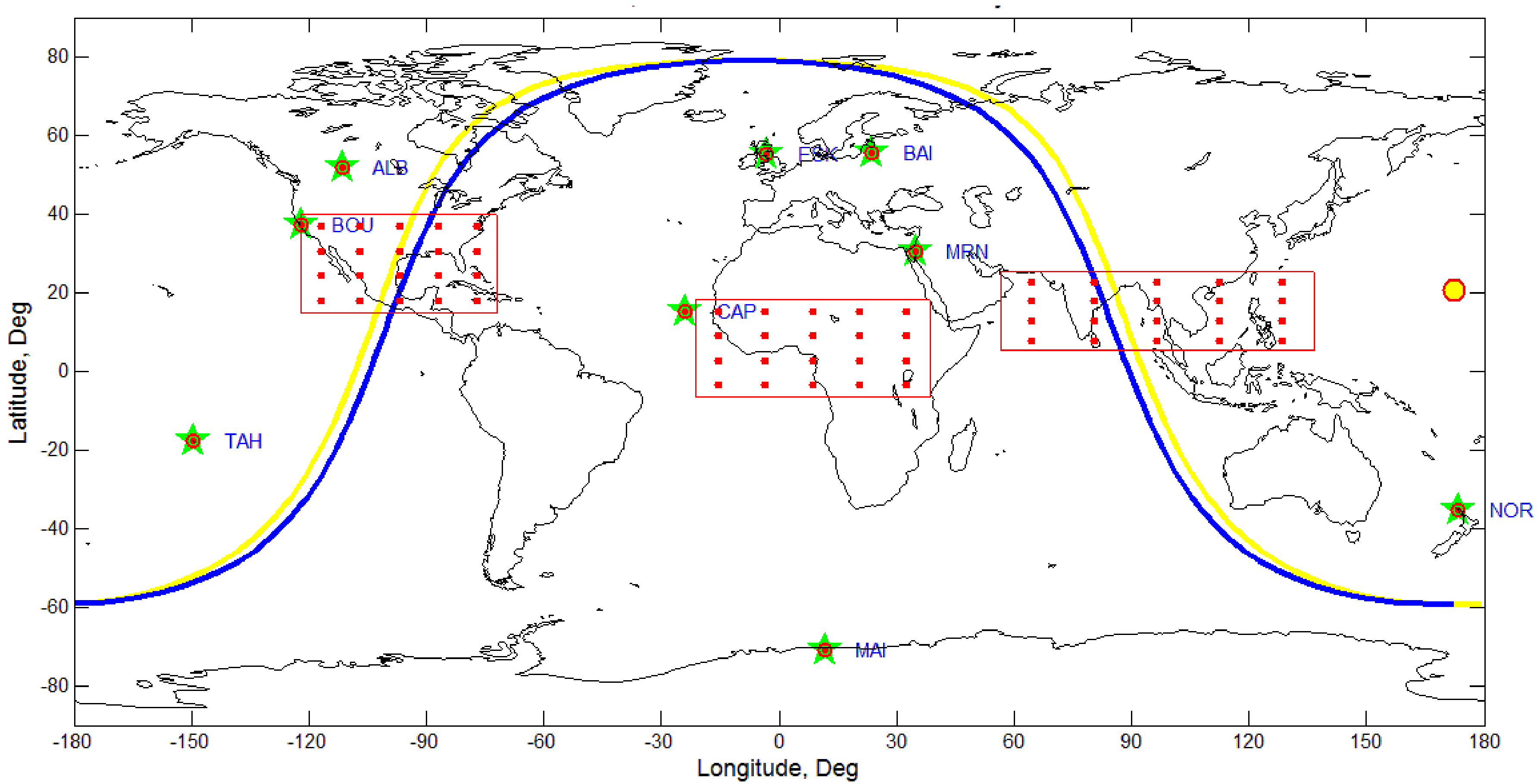
- United States

GOES-R satellite: Global Lightning Mapper (GLM) Continuous access to the American chimney lightning

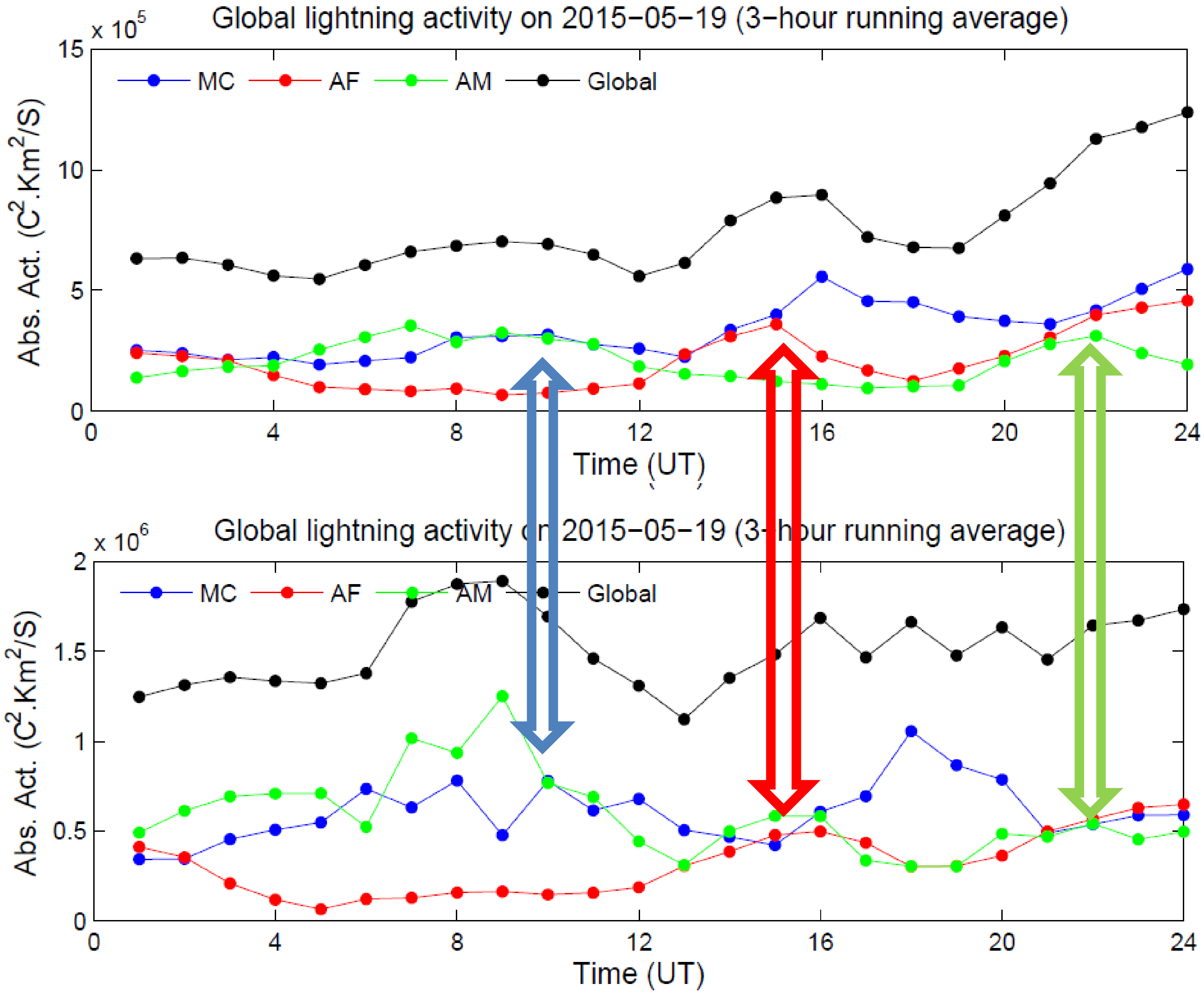
1st set of 9-station network



2nd set of 9-station network



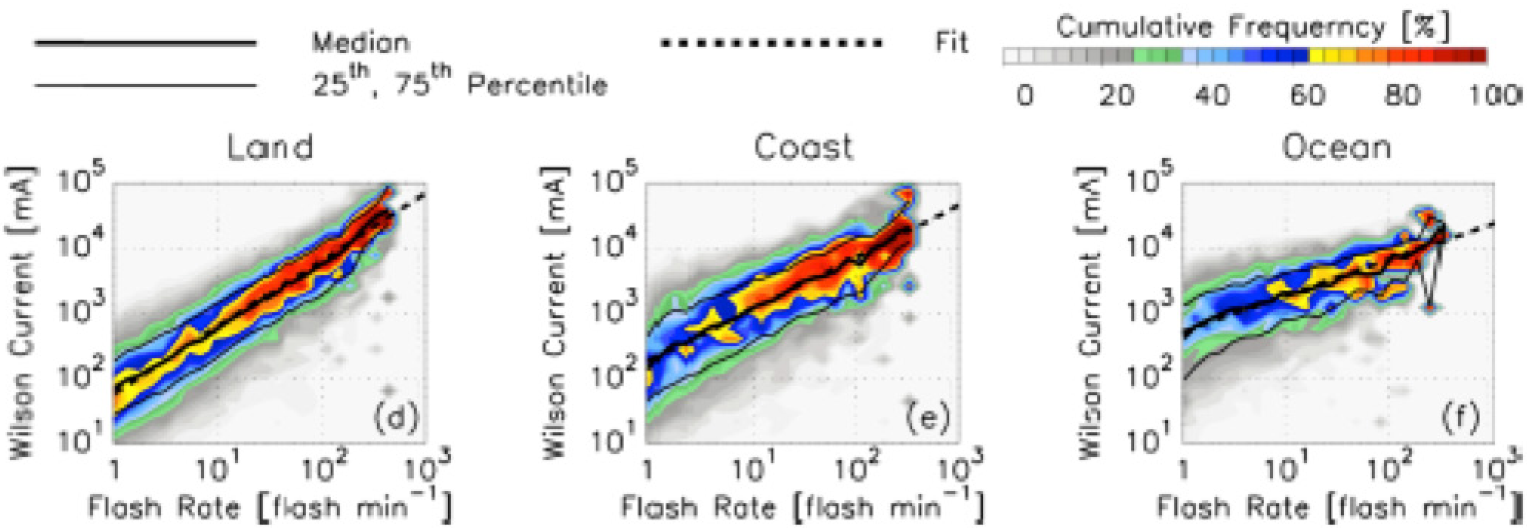
Holy Grail test: 2 network inversions for May 19, 2015



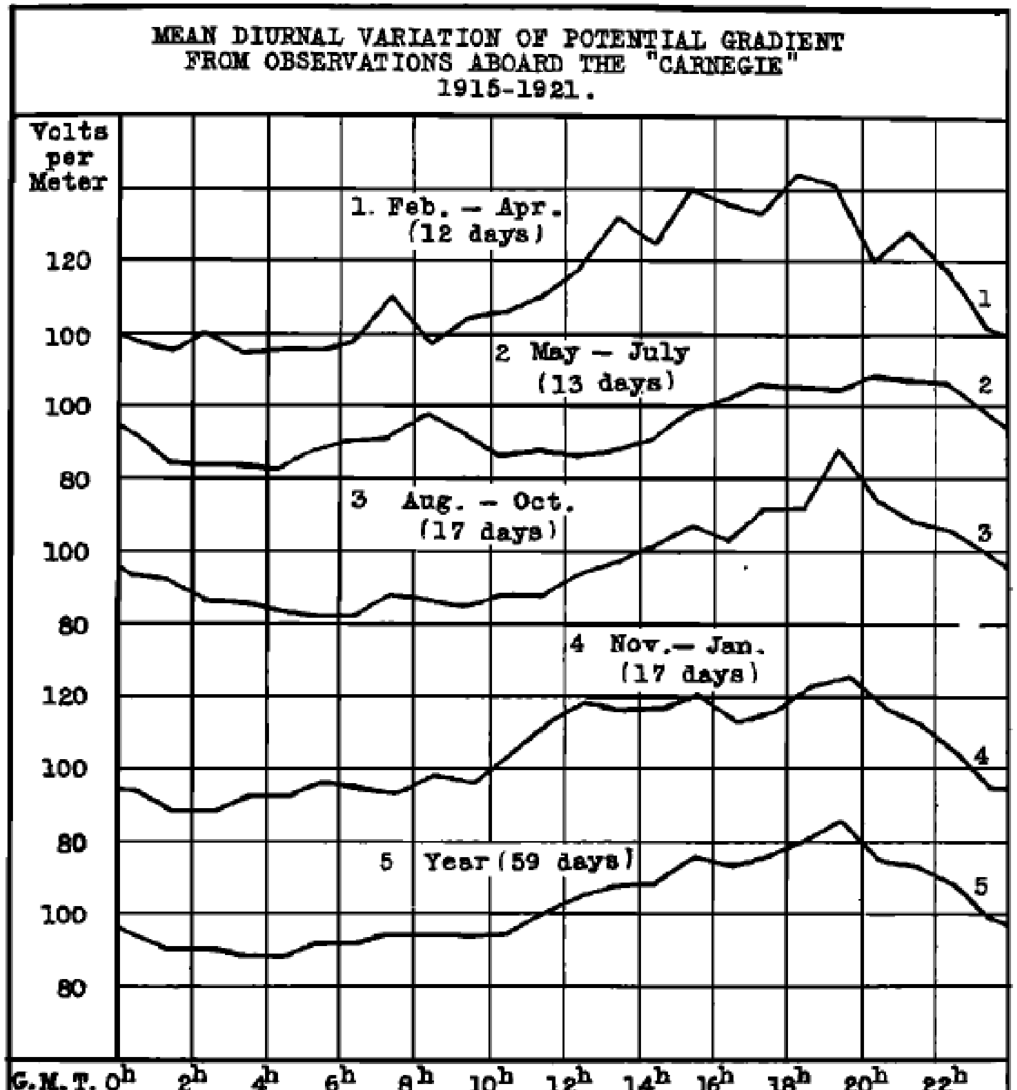
1st set of 9-stations

2nd set of 9-stations

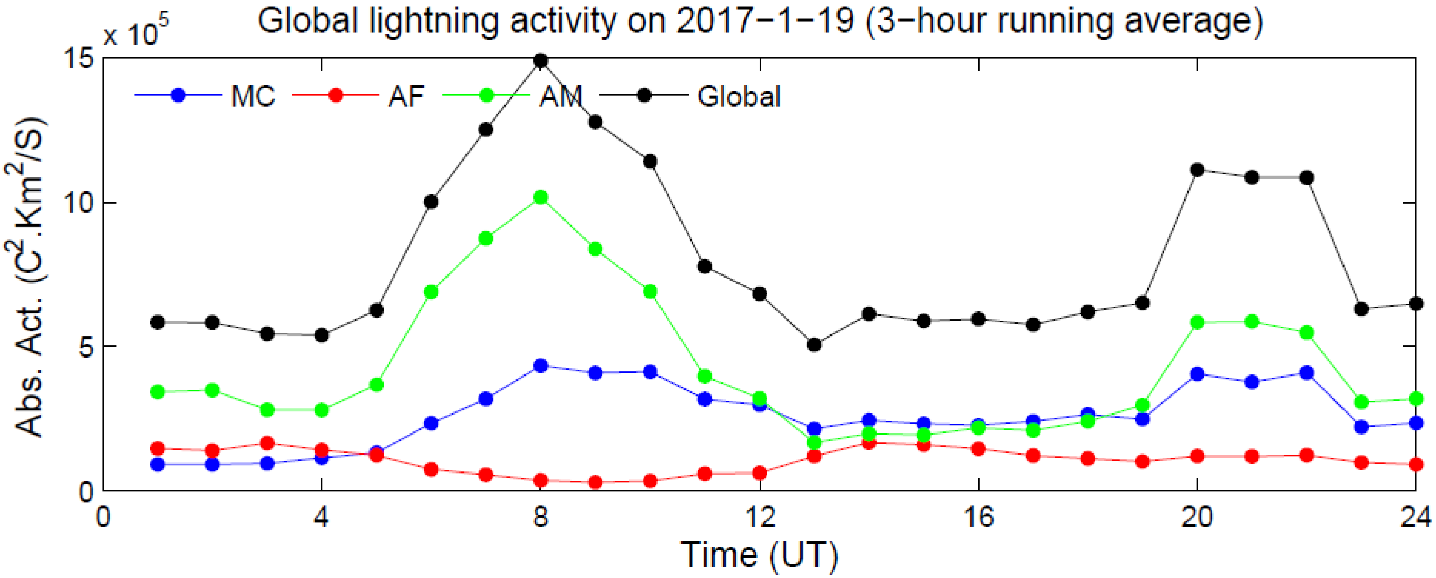
Proportionality of Wilson conduction current and storm flash rate (M. Peterson, pers. comm. 2017)



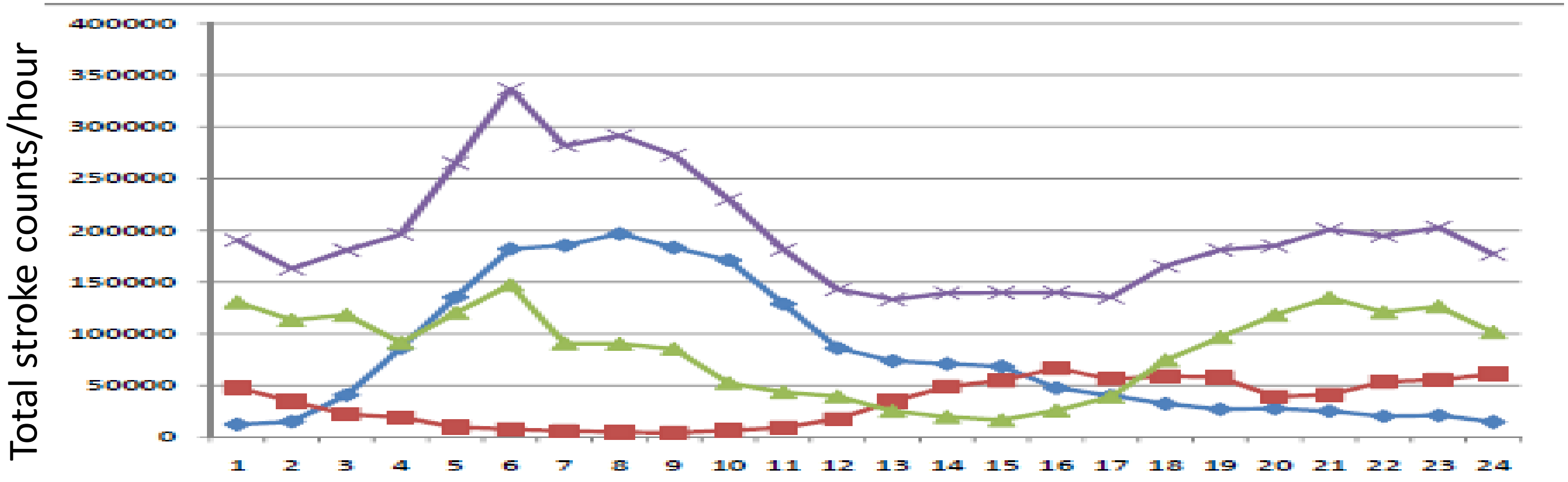
Diurnal variations of electric field (Mauchly 1923)



6-station inversion January 19, 2017



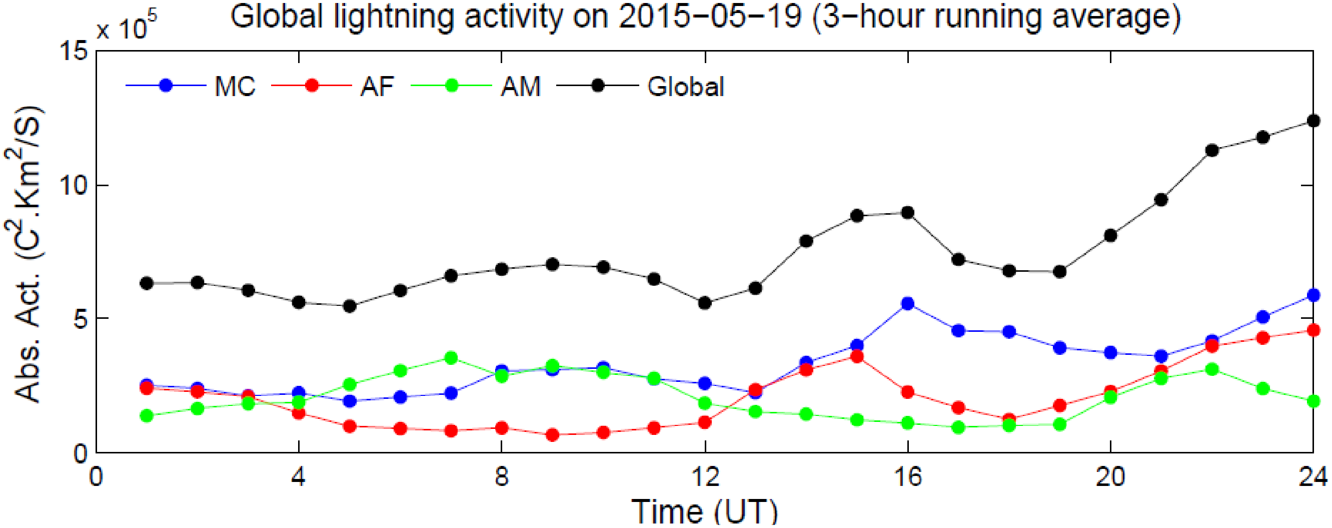
6-station network



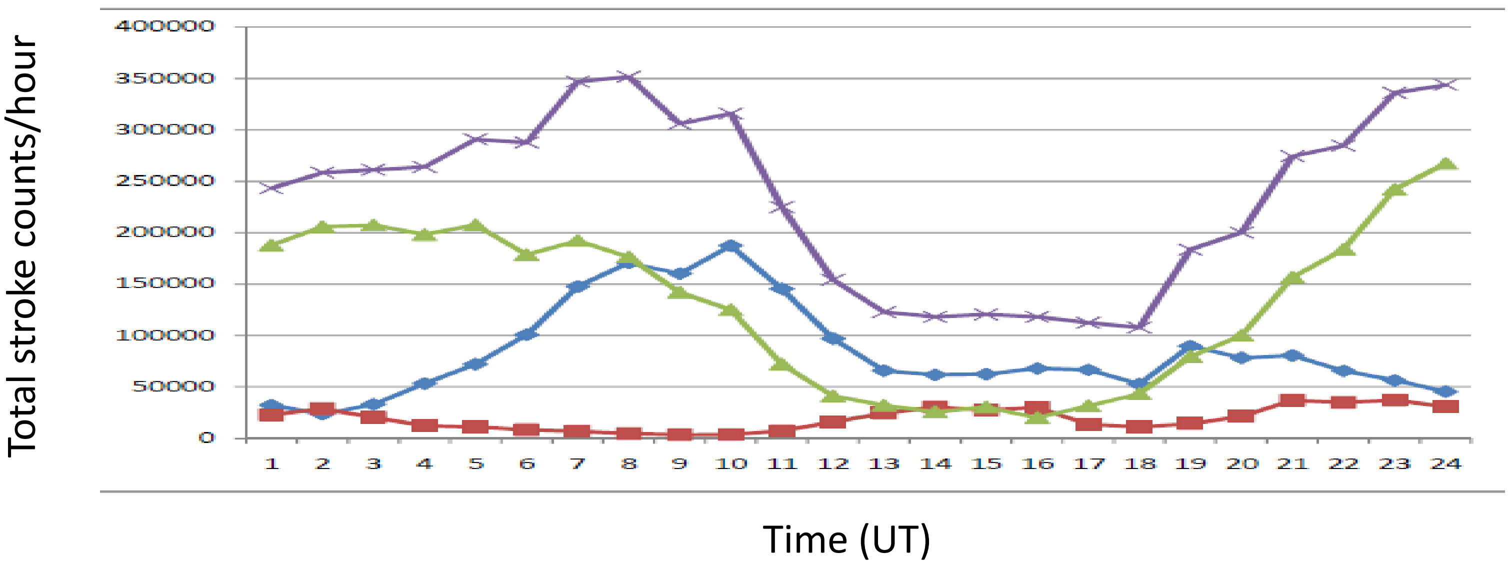
GLD360

Time (UT)

GLD360 comparison (May 19, 2015)

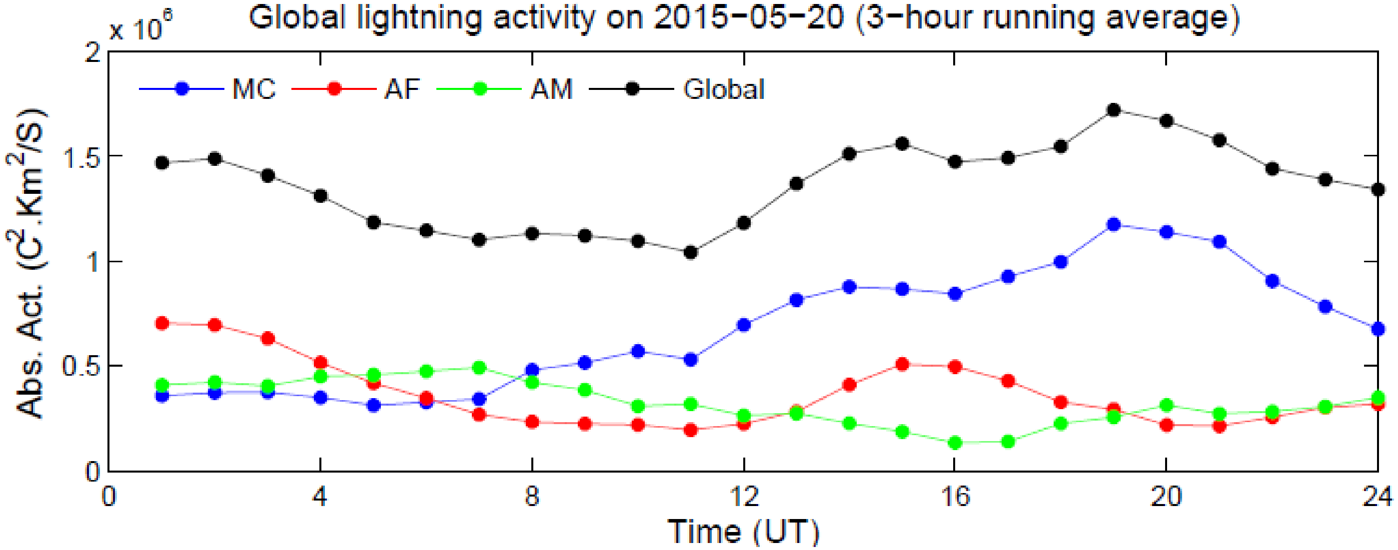


1st set of 9-stations

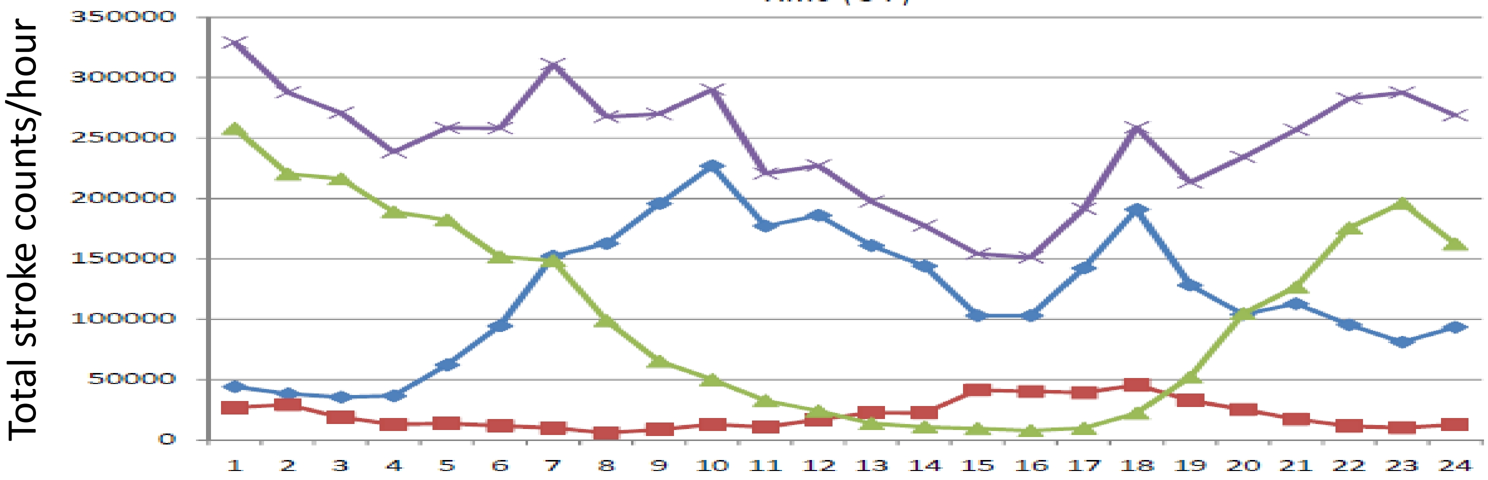


GLD360

18-station inversion May 20, 2015



18-station network



GLD360

Time (UT)

Current map of WWLLN receivers